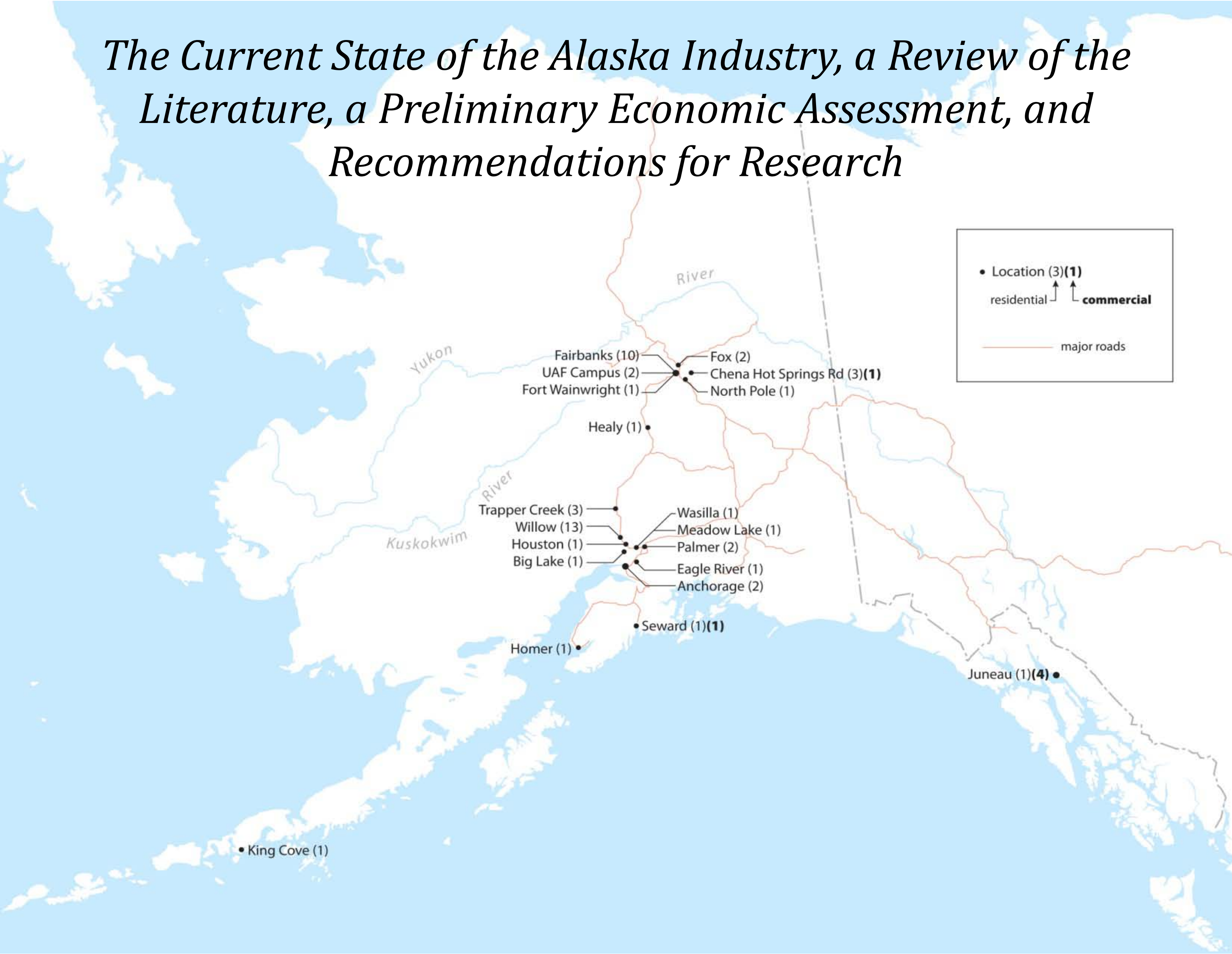
Ground-Source Heat Pumps in Cold Climates

The Current State of the Alaska Industry, a Review of the Literature, a Preliminary Economic Assessment, and Recommendations for Research



A report for the Denali Commission

Prepared by:
Alaska Center for Energy and Power
Cold Climate Housing Research Center

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May 31st, 2011
Final Draft

Prepared for the Denali Commission

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Acknowledgments

The Alaska Center for Energy and Power and the Cold Climate Housing Research Center would like to thank the Denali Commission for their support of this study, and their continued leadership in energy development across the state of Alaska.

In addition, the authors would like to thank the Alaska Energy Authority and the National Renewable Energy Laboratory for their partnership and contribution.

Finally, this report was made possible by input and contributions from individuals and organizations involved in ground-source heat pump installation around Alaska and in other cold climate regions. In particular, the authors wish to thank Andy Roe, Chuck Renfro, the Science Museum of Minnesota, and the Weidt Group for their contributions and professional expertise. Appendix B lists those interviewed for this report. Thank you to all involved for your time and information.

Executive Summary

While ground-source heat pump (GSHP) technology for space heating and cooling is well established, with widespread implementation across the U.S., information and experience specific to the practicality of using it in cold climates is limited. In Alaska, the use of GSHPs for residential and commercial space heating is uncommon, though several high-profile GSHP installations have occurred, which indicates a broader interest among homeowners, businesses, and government entities to explore this alternative space-heating method.

Within the U.S., the South has the highest percentage of GSHP installations (35%), followed by the Midwest (34%), the Northeast (20%), and the West (11%) (Lund, Gawell, Boyd, & Jennejohn, 2010). Ground-source heat pumps in the U.S. are typically sized for the cooling load (Navigant Consulting, Inc., 2009). This sizing is in contrast to GSHPs in Alaska and other northern areas, where the capacity of a GSHP is determined by the heating load of the building. Furthermore, in cold climates, it is probable that a GSHP will be used only for heating, unlike more moderate climates, where the ground is used for both heat extraction (space heating) and rejection (space cooling). This difference presents two disadvantages for GSHP efficiency in cold climates: heat is being extracted from relatively cold ground and is not being balanced by heat rejection used for space cooling.

Despite the relative novelty in Alaska, GSHPs are widely used in other cold climate regions in the world, as evidenced by their popularity in Scandinavian countries. In Sweden, 30% of the houses have GSHP systems (IEA, 2007). GSHPs in Sweden are typically designed to cover 90% of the annual heat energy demand, with an electric heating system as the backup heat source (Karlsson & Fahlen, 2003). In Norway, 15,000 GSHP systems have been installed, including 250 medium- and large-capacity nonresidential systems (Stene, Midttomme, Skarphagen, & Borgnes, 2008) and Finland has an estimated 46,000 units installed (Lund, Freeston, & Boyd, Direct Utilization of Geothermal Energy 2010 Worldwide Review, 2010). Heat pumps are widely used in Canada (Phetteplace, 2007), and in Europe, the market is growing (Rybach & Sanner, 2000).

The authors of this report—the Alaska Center for Energy and Power (ACEP) and the Cold Climate Housing Research Center (CCHRC)—have investigated and summarized information pertaining to the viability of GSHPs in cold climates in order to clarify the state of GSHP utilization in Alaska and provide a comprehensive resource of current knowledge for those interested in GSHP installations in cold climate regions such as Alaska.

Heat Pump Basics

A heat pump is a device that forces the movement of heat from a low-temperature medium to a higher-temperature medium. A GSHP transfers energy to and from a ground or water source to provide heating or cooling. In heating mode, the energy produced by this technology is considered partially renewable because solar and geothermal energy is mediated through the ground or water source. Depending on the generation source of electricity, the energy can be fully renewable.

A GSHP system is typically composed of a ground loop (tubing that passes through a ground or water source, transferring energy to circulating fluid), a heat pump (a mechanical system that allows for the extraction of energy from the ground-loop fluid), and a heat distribution system (the system that distributes heat throughout a conditioned space).

Left: Ground loops for installation at Weller School. Right: Heat pump units at the Juneau Airport.

A heat pump does not convert fuel to heat, but rather uses electricity to lift the temperature of its source (the fluid temperature from the ground loop) to a higher temperature used for space heating. For GSHPs in a heating mode, the most commonly used measure of efficiency is the coefficient of performance (COP). The COP is the ratio of heat output to work supplied to the system in the form of electricity.

$$COP = \frac{Quantity\ of\ Heat\ Delivered}{Energy\ Required\ by\ the\ Heat\ Pump}$$

For example, for electric resistance heating, the COP is 1.0, meaning that all of the electric energy is converted into heat. The energy required by a GSHP is also electrical, and includes the energy needed to run the compressor in the heat pump. Heat pumps have COPs higher than 1 because the energy delivered from a ground source is greater than the energy required to run the heat pump. A typical COP for a heat pump system is in the range of 2 to 4. This corresponds to an “efficiency” of 200-400%.

Cold Climate Considerations

One concern for locations with colder ground temperatures is that the low temperatures can lead to heat pumps operating at the bottom end of their designed operation ranges. An undersized ground loop could result in entering fluid temperatures that are too cold for the heat pump to operate efficiently and the heat pump will be unable to achieve the manufacturer COP.

Another consideration in cold climates is the potential creation of permafrost or seasonal frost due to thermal degradation caused by excessive heat extraction from the soil. There are concerns that the use of GSHPs in cold climates could lead to the creation of permafrost or seasonal ground freezing, which could cause heaving of utilities and structures near the ground loop, a reduction of COP over time, and other complications. Reports and journal articles address seasonal imbalances of heat extracted versus heat returned to the ground, and the possibility of soil freezing during the heating season. However, documented evidence of permanent soil degradation is scarce, and few long-term studies have been done to determine the effect of ground loops on the soil thermal regime.

The Alaska Industry

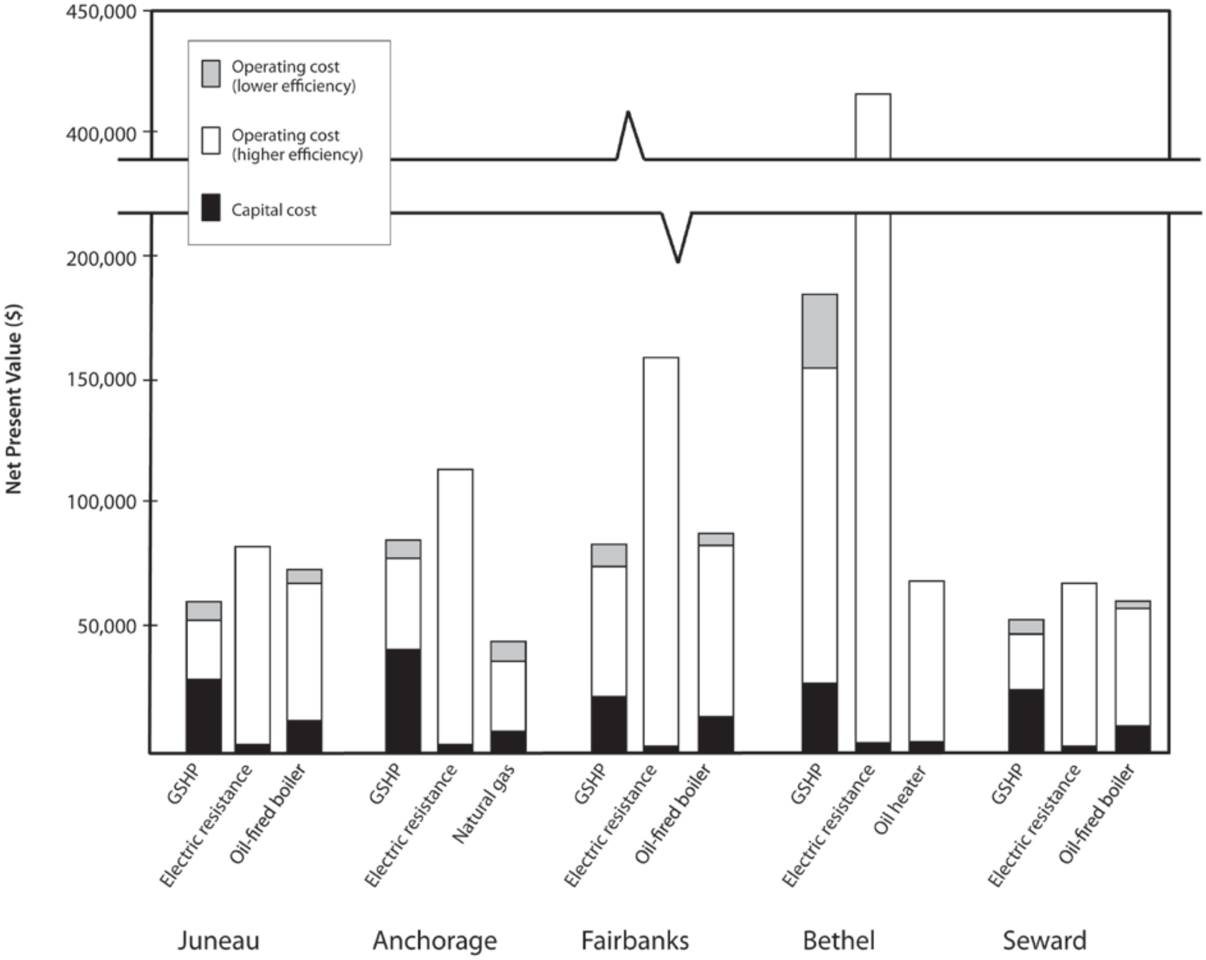
Alaska's GSHP industry is small, but recently has shown growth, with some prominent commercial installations in Juneau and several residential installations in Fairbanks. One large-profile commercial GSHP system has recently been installed at the Juneau Airport Terminal. In addition to the project's primary motivation, to reduce operating costs at the terminal, planners hope to increase public awareness of energy conservation and alternative energy (Fritz, 2008). This installation and other recent commercial installations are summarized in the report to provide examples of larger GSHP applications in Alaska.

Drilling to establish the vertical ground loops at the Juneau Dimond Park Aquatic Center

Residential GSHP owners interviewed for this report had installed a GSHP for a variety of reasons, but each homeowner reported that long-term cost savings was a strong motivation. Some homeowners found their systems to be low-maintenance, and more than one homeowner installed a GSHP in part because it is a partially renewable-energy technology. All of the residential GSHP owners interviewed reported satisfaction with their systems.

Preliminary Economic Assessment

Economic analyses were performed to compare the capital and energy costs of GSHPs with typical home-heating systems in five population centers in Alaska. The population centers examined include Juneau, Anchorage, Fairbanks, Bethel, and Seward. The net present value (NPV) of each system was calculated for each population center using the capital cost, annual energy, and maintenance costs over a 15-year period.



Results of the Economic Assessment

The capital cost of GSHP systems was higher than all other home-heating systems assessed for each population center. However, with the savings on annual heating energy costs, GSHP systems are the lowest-cost heating systems in Seward, Fairbanks, and Juneau. Homes in Seward, Fairbanks, and Juneau are primarily heated with heating oil. Ground-source heat pump systems use electricity to compress heat pulled from the ground and are fuel-efficient. For example, a GSHP system with a COP of 2.5 provides 2.5 kWh (kilowatt-hours) of heat for each kWh of electricity used by the pump. It is because of this fuel efficiency that homes using a GSHP for home heating can save on annual home-heating costs over fuel oil.

The GSHP system was unable to beat natural gas home heating in Anchorage because of the relatively low capital and energy costs of a natural gas home-heating system. The use of a GSHP system was also unable to beat a direct-vent laser stove, such as a Toyostove®, for home heating in Bethel. While the cost of heating oil is high in Bethel, the capital cost of a direct-vent laser stove is very low. Additionally, electricity in Bethel is expensive ($0.54 after the first 500 kWh each month).

Major Findings

A number of studies indicate that ground-source heat pumps (GSHPs) have been successful in cold climates. Based on this prior work, the range of COPs expected for professionally installed systems in Alaska is approximately 2.0 to 3.5 across a broad suite of locations, installers, heat sources, and heat pump manufacturers.

A number of studies discussed in the report addressed the issue of thermal imbalances that can be created in the soil because of a GSHP. While the long-term effects of GSHPs in soil with subfreezing temperatures is unknown (Bath, 2003), the concern of thermal degradation is site-specific. Whether ground temperatures can recover in the summer will depend on the region's climate, soil conditions at the site of the ground loop, and the sizing of the ground loop. In locations with low ground temperatures and a high annual heating demand, thermal imbalances are large concern.

Studies have identified barriers to growth of the GSHP market in the U.S. Barriers include high capital cost and lack of consumer knowledge and confidence in the technology (Hughes, 2008). Similarly, market diffusion is limited in Canada by factors such as high capital costs, nonstandardized systems, and actual performance that is less than promised (Hanova, Dowlatabadi, & Mueller, Ground Source Heat Pump Systems in Canada: Economics and GHG Reduction Potential, 2007). The GSHP market in Alaska faces these same problems.

In any part of the world, adequate design is necessary for GSHPs to meet performance expectations and have fewer maintenance issues. However, it is especially important in cold climates for the design of GSHP systems to match the parameters of the location. Poorly designed systems can result in a number of problems, such as decreasing COPs if the ground loop is undersized, because the soil cannot thermally recover (Cottrell, 2009). If the GSHP system is oversized, the capital costs will be higher than necessary, and excessive on-off cycling can stress the heat pump unit and reduce its operational efficiency. A common error in colder climates is to make the ground loop small and the heat pump large, which results in increased electrical use and decreased efficiency (Dr. John Straube, personal communication, November 11, 2010).

A lack of data on long-term GSHP applications in cold climates makes the decision to install one difficult. The longest study on using a GSHP in Alaska focuses on the ability of a GSHP to cool soil and maintain permafrost—not to heat a building (McFadden, 2000). Other studies note that longer monitoring projects are needed to determine under what circumstances a GSHP will cause thermal degradation and whether the COP can be maintained for several years (Mueller & Zarling, 1996; Nielson & Zarling, 1983).

Recommendations

The economic analysis of this report was conducted under the assumption of new construction, as opposed to retrofit, given the complexity of project-specific considerations and the need for accurate comparison. While this assumption served well for establishing preliminary economic considerations, investigating the economics of retrofitting a building with a GSHP system is critical for further understanding the feasibility of GSHPs in Alaska. Furthermore, the capital costs identified in the economic analysis were given as estimates by various installers from around Alaska. Due to the limited deployment of GSHP systems, some installers have little experience specific to GSHPs, which may be reflected in the given capital costs. It is recommended that these costs be carefully monitored, especially as more systems are installed and the experience of the industry grows, so that future analyses may offer refined numbers for economic comparison.

In 2008, the State of Alaska set a renewable energy generation target of 50% by 2025, and has since completed a guidance document to frame Alaska's energy future (AEA, 2009). Ground-source heat pump systems have several specific characteristics that make them an intriguing technology for consideration in meeting these targets; for example, they have efficiencies over 100%[1] and the ability to displace fossil fuel used for space heating, and they are either partially or fully renewable (depending on the generation source for electricity). It is recommended, therefore, that the state further investigate the role that GSHPs have in meeting renewable energy-generation targets, particularly with regard to public policy.

One finding from this report indicates that, in Alaska, GSHP systems are more viable where electricity costs are relatively low and heating costs are relatively high. Juneau, included in the economic analysis, displayed this relationship. These results can be roughly extrapolated to many other communities in Southeast Alaska that utilize hydropower. Not addressed are the potential ramifications of increased deployment of GSHP systems in these communities. Issues such as grid stability and capacity, supplemental or increased infrastructure costs, and relevant utility policy are examples of potential factors that need careful consideration to accurately assess the viability of GSHPs in a given community in Southeast Alaska. It is recommended, therefore, that potential GSHP-deployment stakeholders in relevant communities in Southeast Alaska carefully investigate integration ramifications of GSHPs if deployment of this technology is expected to grow.

While not considered in this report, air-source heat pumps (ASHPs) are attractive for moderate climates because they do not require ground coupling, substantially reducing capital costs and infrastructure complexities when compared with GSHPs. Recent technological advances may challenge the assumption that ASHP systems are not appropriate for cold climates (Roth, Dieckmann, & Brodrick, 2009), especially for locations like Southeast Alaska that have relatively mild temperatures for building heating load. Because several communities in Alaska that have a relatively mild climate also have relatively cheap electricity and expensive heating oil, a targeted analysis of ASHPs specific to these locations could help to determine whether ASHP systems represent a viable heating option.

There is insufficient clarity on the expected COP of cold climate GSHPs due to a lack of independently monitored GSHPs over periods greater than one to two years. A long-term monitoring period would last six to ten years. Further complicating the understanding of cold climate GSHP efficiency is a lack of standardization of the COP as an efficiency metric. Monitored GSHP systems should include documentation of the system configuration, measurement of COP, ground temperatures, climate data, temperature of the conditioned space, and electrical demand for heat pump components other than the compressor unit. Related to the recommendation for long-term monitoring of GSHP systems, research should address whether hybridization is necessary for cold climate applications of GSHPs. The installation of GSHP systems already suffers from high cost, which is increased with the inclusion of ancillary systems. Performance data should be collected on hybrid systems and compared to data on non-hybrid systems in similar locations.

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[1] Please see the discussion of coefficient of performance (COP) in the Heat Pump Technology Primer section of this report.

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List of Acronyms

ACEP	Alaska Center for Energy and Power
AEA	Alaska Energy Authority
AEL&P	Alaska Electric Light and Power Company
APA	Alaska Power Administration
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
Btu	British Thermal Unit
CCHRC	Cold Climate Housing Research Center
COP	Coefficient of Performance
DHW	Domestic Hot Water
DSM	Demand Side Management
EER	Energy Efficiency Rating
EWT	Entering Water Temperature
GHE	Ground Heat Exchanger
GHG	Greenhouse Gas
GSHP	Ground-Source Heat Pump
HVAC	Heating, Ventilation, and Air Conditioning
IGSHPA	International Ground Source Heat Pump Association
KWh	Kilowatt-hour
LWT	Leaving Water Temperature
MEA	Matanuska Electric Association
NPV	Net Present Value
NREL	National Renewable Energy Lab
PCE	Power Cost Equalization
PTF	Permafrost Technology Foundation
PV	Photovoltaic
REC	Rural Electric Cooperative
SCOP	System Coefficient of Performance
SEER	Seasonal Energy Efficiency Rating
SPF	Seasonal Performance Factor

Introduction

While the technology of ground-source heat pumps (GSHPs) is well established, with widespread implementation across the U.S. for space heating and cooling, information and experience specific to the practicality of using it in cold climates is limited. In Alaska, the use of GSHPs for residential and commercial space heating is uncommon, though several high-profile GSHP installations have occurred, which indicates a broader interest among homeowners, businesses, and government entities to explore this alternative space-heating method.

The authors of this report—the Alaska Center for Energy and Power (ACEP) and the Cold Climate Housing Research Center (CCHRC)—have investigated and summarized information pertaining to the viability of GSHPs in cold climates in order to clarify the state of GSHP utilization in Alaska and provide a comprehensive resource of current knowledge for those interested in GSHP installations in cold climate regions such as Alaska. The authors do not intend to promote or discourage GSHPs as a method of space heating, and this report does not provide site-specific or project-specific information useful in proposing, designing, or sizing a GSHP system. Homeowners and project managers interested in installing a GSHP should conduct additional technical and economic research in determining a system appropriate for their application.

In this report, "cold climate" is a climatic zone that annually has over 9,000 heating degree-days (HDD), as calculated from a base temperature of 65°F.[2] In approximate terms in North America, this area includes Alaska, Canada, and northern parts Midwest states. While portions of Southeast Alaska have fewer than 9,000 HDD, this report includes all of Alaska to provide statewide coverage.

This report is organized as follows:

Heat Pump Technology Primer is an introduction to GSHP systems, written for those with limited knowledge, both general and technical, about this technology. This section provides an overview of key concepts, a description of important system components, and an outline of commonly recognized advantages and disadvantages of GSHPs. Supplemental to the body of the report, this section is not required reading for those already familiar with GSHP systems.

Ground-Source Heat Pumps in Cold Climates, the body of this report, is divided into three subsections. The first subsection, **Cold Climate Considerations for GSHP Application**, seeks to examine those considerations for GSHP applications that are specific to Alaska as a cold climate region, and to examine relevant cold climate GSHP literature. The next subsection, **Current State of the Heat Pump Industry in Alaska**, serves to explore and define the state's current GSHP industry. The final subsection, **Preliminary Economic Analysis,** seeks to define and investigate, at a preliminary level, general economic factors and considerations for GSHP systems in Alaska. This subsection compares the net present value of hypothetical GSHP installations with more-common heating methods for five communities across Alaska.

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[2] For definition of heating degree-days, please see Footnote 10 within the section, Preliminary Economic Analysis.

The **Major Findings** section is a synthesis of significant findings and conclusions from the report. In **Recommendations**, the authors outline the remaining knowledge gaps and research needs to further advance the understanding of GSHP applications in cold climate regions.

To meet the goals of the report, the authors have conducted a comprehensive review of literature (Alaska, national, and international) and a lengthy series of interviews. The **Appendices** provide an inventory of residential and commercial-scale GSHP systems in Alaska, a list of those interviewed for this report, a detailed review of particularly relevant cold climate GSHP reports and studies, and an annotated bibliography of literature relevant to cold climate GSHPs.

For further information on this report, please visit www.uaf.edu/acep or www.cchrc.org, or contact:

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The Alaska Center for Energy and Power (ACEP) is an applied energy research program based at the University of Alaska. ACEP was formed in January, 2008 with the goal of meeting Alaska's unique energy research needs, and operates under a private sector business model within the University system. ACEP is a gateway for energy related activity at the University of Alaska. Working across campuses and pulling from the University's extensive resources and expertise, ACEP is interdisciplinary, needs-driven, and agile.

The Cold Climate Housing Research Center (CCHRC) is an industry-based, nonprofit corporation created to facilitate the development, use, and testing of energy-efficient, durable, healthy, and cost-effective building technologies for people living in circumpolar regions around the globe. Located in Fairbanks, Alaska, the Research Center was conceived and developed by members of the Alaska State Home Builders Association and represents more than 1,200 building industry firms and groups. Ninety percent of CCHRC's charter members are general contractors from across the state.

Heat Pump Technology Primer[3]

A heat pump is a device that forces the movement of heat from a low-temperature medium to a higher-temperature medium. A ground-source heat pump (GSHP) transfers energy to and from a ground or water source to provide heating or cooling. In heating mode, the energy produced by this technology is considered partially renewable because solar and geothermal energy is mediated through the ground or water source. Depending on the generation source of electricity, the energy can be fully renewable. The following provides a brief description of the operational process of heat pumps, GSHP components, and ground-loop configurations.

In the context of a cold climate, heat flows from a low-temperature source (approximately 32°–45°F), such as water or soil, to a lower-temperature refrigerant fluid via a ground heat exchanger (15°–30°F). This heat transfer causes the refrigerant to evaporate. The gaseous refrigerant is then compressed by the heat pump, forcing the temperature and pressure to increase to a useful range. The high-temperature gas passes through a condenser to transfer its heat to the heat distribution system. This heat extraction causes the refrigerant to return to a liquid. The refrigerant then passes through an expansion valve, where it is further cooled by depressurization, allowing the cycle to repeat (see Figure 1).

A common example of a heat pump is the residential refrigerator. The refrigerator moves heat inside the unit to the outside by the same process outlined above. In this instance, the interior space of the refrigerator is the heat source. This process can be scaled and configured to provide sufficient heating or cooling for a variety of applications, and may seem counterintuitive with GSHPs, since soil or water at a temperature below 32°F cannot provide useful energy or serve to heat a structure. However, material contains energy until it reaches absolute zero at -460°F, so for a given material at 32°F, energy can still be extracted if there is a sufficient temperature difference between the ground and the heat pump refrigerant.

The concept of a heat pump has been known since the 1850s, but it was 1940 before Robert Webber was credited with using the technology for heating a home with heat stored in the ground. The first commercial demonstration of a GSHP was in the Commonwealth Building in Portland, Oregon, in 1946 (Bloomquist, 1999). Heat pumps experienced a rise in popularity during the Arab oil embargo of the 1970s. The market then leveled off before expanding again in recent years. Annual worldwide growth rates for GSHP installations have exceeded 10% over the past 10 years (Le Feuvre & Kummert, 2008), and the industry’s support organizations, led by the International Ground-Source Heat Pump Association (IGSHPA) are mature and robust (Hughes, 2008). Currently, over 3 million GSHP units are installed worldwide in 43 countries. Of the total worldwide capacity, 37%are installed in the United States and Canada, 47% in Europe and 16% in Asia. (Lund, Freeston, & Boyd, Direct Utilization of Geothermal Energy 2010 Worldwide Review, 2010). Sweden leads Europe in number of GSHP installations, and markets in China, Japan, and South Korea represent the largest growth within Asia (Navigant Consulting, Inc., 2009).

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[3] Refer to the ASHRAE Handbook for HVAC Applications and Oklahoma State University (1997) for a more detailed description. Readers interested in recent technological improvements are referred to Spitler (2005), Chua, Chou, & Yang (2010), conference proceedings such as the Geothermal Resources Council (www.geothermal.org), and newsletters covering current research, such as the Heat Pump Centre Newsletter published by the International Energy Agency (www.iea.org).

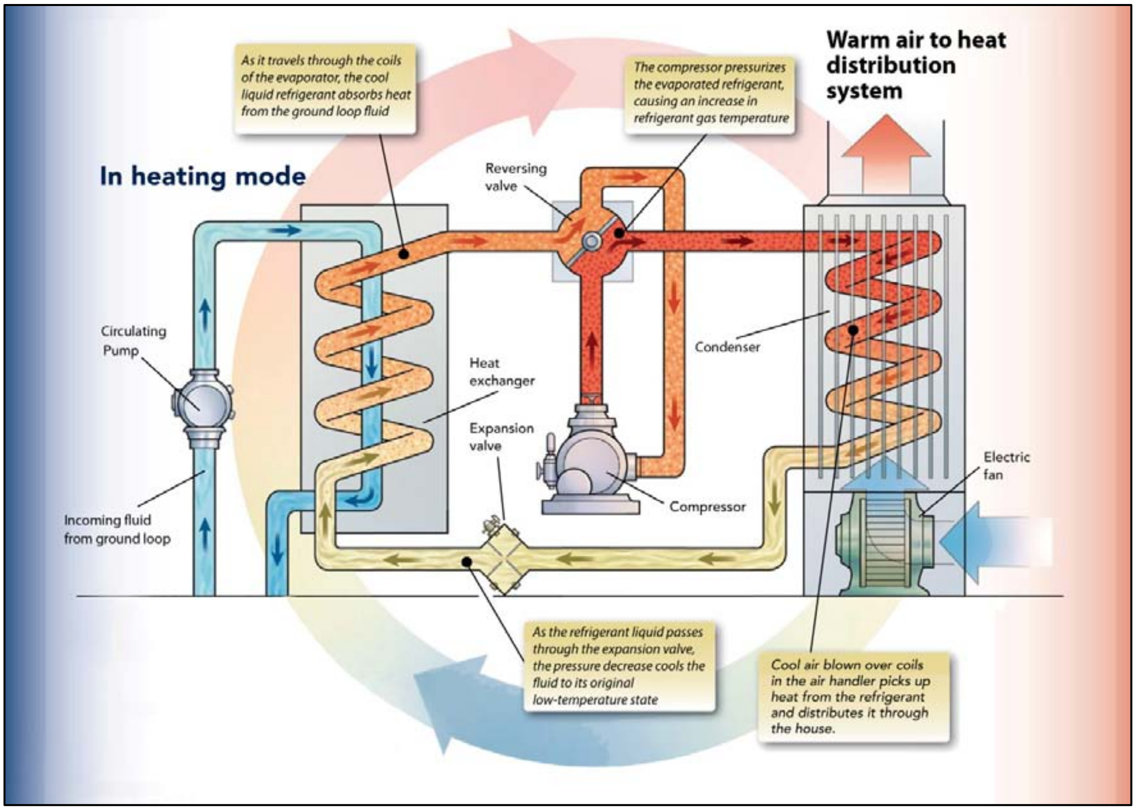

Figure 1: How a heat pump works (modified from Gibson, 2010)

Within the U.S., the South has the highest percentage of GSHP installations (35%), followed by the Midwest (34%), the Northeast (20%), and the West (11%) (Lund, Gawell, Boyd, & Jennejohn, 2010). Major GSHP manufacturers are located in the Midwest and South, and correspondingly, these regions have more personnel trained in GSHP installation and maintenance (Navigant Consulting, Inc., 2009). A look at Department of Defense (DoD) facility installations mirrors the installation percentages of the U.S. as a whole. Of the 264 projects representing 21,000 GSHP units in domestic DoD facilities, the majority are located in the Southeast and Midwest. No GSHP units are located in regions classified as very cold or subarctic (DoD, 2007).

Primary Heat Pump Components

As outlined above, a GSHP system is typically composed of a ground loop (tubing that passes through a ground or water source, transferring energy to circulating fluid), a heat pump (a mechanical system that allows for the extraction of energy from the ground-loop fluid), and a heat distribution system (the system that distributes heat throughout a conditioned space). Table 1 outlines the various components that are typical of a GSHP installation.

Table 1: GSHP system components

Main component	Sub component	Description
Ground loop	Tubing	Commonly a high-density polyethylene pipe, acts as a heat exchanger in the ground or water body.
	Working fluid	Water is mixed with either ethylene glycol, methyl alcohol, potassium acetate or other substances to lower the freezing temperature. This is the medium that transfers energy from the source to the heat pump. Open loop systems, especially in warmer climates, can use ground water directly.
	Pump	A circulating pump is used to move the working fluid through the ground loop and heat exchanger.
	Manifold	A plumbing connection where individual tubing loops are combined. This is useful in combination with valves to isolate loops.
Heat pump unit	Evaporator	The heat exchanger where working fluid from the ground loop passes its heat to the liquid refrigerant in the heat pump loop, evaporating it into a gas.
	Compressor	The compressor draws the refrigerant from the evaporator then compresses it. Compression adds energy to the refrigerant by raising the pressure and temperature to a desired level.
	Condenser	Heat exchange extracts the energy from the hot refrigerant to be used for heating, condensing the refrigerant gas back into a liquid.
	Expansion valve	This valve reduces the pressure and temperature of the refrigerant, returning it to its original state.
	Controls	Typically, the heat pump operation is centrally controlled and takes into account the ground-loop flow rate and room temperatures, among other variables.
	Desuperheater (optional)	This device extracts heat during the refrigerant cycle to produce domestic hot water (DWH).
Heat distribution	Hydronic	Fluid heated from the heat pump is circulated through a series of tubes embedded in flooring or panels and radiates the heat.
	Forced air	Air from the heat pump passes through ducts to rooms requiring heat.

Heat Sources

The source of heat for a heat pump depends on local resources and climatic conditions. Normally the choice is between air (air-source), water (water-source), and ground (ground-source). Some of the factors that need to be considered are the seasonal fluctuations in air temperatures, ground or water temperatures, ground thermal conductivity,[4] water table level, and installation costs.

Ground-Source and Water-Source

Ground and water sources can be considered a single category because their temperature ranges and heat collection methods are comparable: both pump fluid through a ground-loop heat exchanger.

There are several common configurations (see Figure 2), all of which fit two general categories:

- **Open-Loop**. Water from a surface water source (oceans, lakes, rivers) or groundwater is pumped through the heat exchanger and then discharged to the same or a different water body. Open-loop systems can be cheaper than closed-loop systems, because their installation involves less work; they also can have an efficiency that is comparable to or higher than a closed-loop system. However, local codes and regulations regarding groundwater discharge must be met. Consistency of the water supply in terms of quantity and quality are crucial to ensure uninterrupted heat pump operation and long service life (Siegenthaler, 2004). In cold climates, open-loop systems are further limited due to freezing temperatures that can make the source unavailable or cause pipes to freeze.

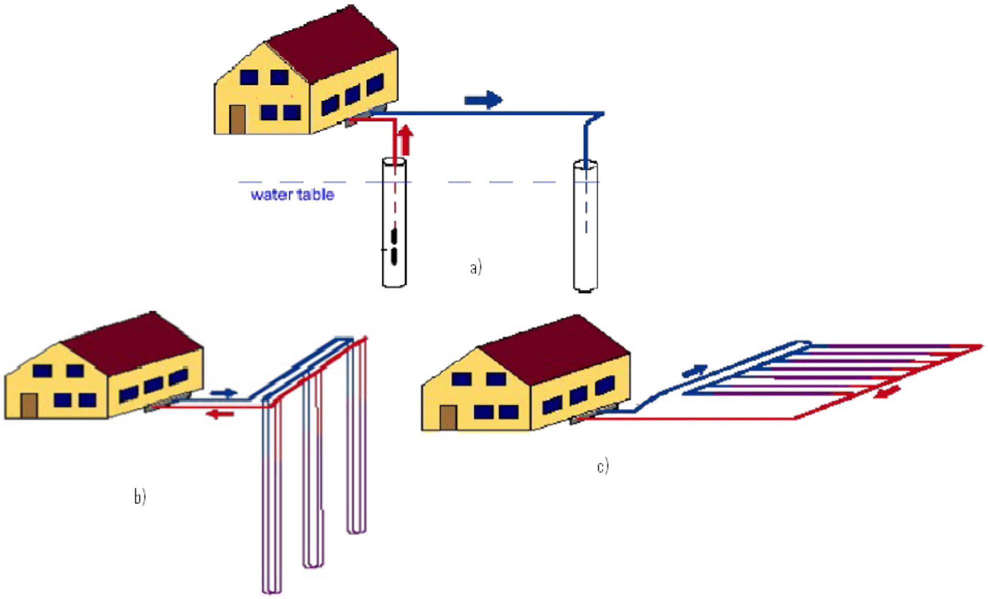

Figure 2: Ground-loop configurations: a) open-loop borehole, b) closed-loop vertical, c) closed-loop horizontal (Omer, 2006)

- **Closed-Loop**. A closed-loop system comprises a pipe loop located in the ground or a water body. Fluid with a low freezing temperature, such as a glycol-water solution, is circulated in this loop. Closed-loop systems are more expensive than open-loop systems because they require

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[4] The ability of a material to conduct heat.

expensive excavation or drilling; they are also more common due to the limitations of open-loop systems. Closed-loop systems reduce the risk of freeze-up and require virtually no routine maintenance. However, these loops are more susceptible to damage and have the potential to contaminate water bodies if they release fluid from the loop. To prevent fluid release, joints must be heat fused which adds to the capital cost. The length of pipe required is site-specific, and estimates range broadly from 400–600 feet of pipe per ton of heating capacity (NRC Office of Energy Efficiency, 2004) to 720–1040 feet per ton of heat pump capacity (Siegenthaler, 2004).

Several configurations are possible for closed-loop systems, the two most common being vertical borehole loops and horizontal loops. Horizontal ground loops are typically installed between 6 and 12 feet below the ground surface, depending on the local frost depth and the water table. The pipe can be laid in trenches or pits in a linear pattern, or coiled in “slinky” loops that create overlapping layers. Lake loops are cheaper to install and require shorter overall piping lengths, but they may require permits from regulatory agencies. In addition, care must be taken in shallow water to prevent boats and other watercraft from snagging and damaging the pipes.

In Alaska, closed ground loops that contain hazardous substances and open ground loops that displace water may be subject to restrictions by regulatory agencies such as the Department of Natural Resources and the Department of Environmental Conservation.

Air-Source

Air-source heat pump units are relatively simple, inexpensive, and easy to install. The heat pumps are located outside the building and use the air as a heat source. However, in cold climates, air-source heat pumps commonly have lower efficiencies than ground-source or water-source heat pumps because of low air temperatures during heating demand (Healy & Ugursal, 1997). In addition, their efficiency is reduced by some serious technical limitations, such as icing of the heat exchanger, which requires defrosting, and operation in snowy conditions. Due to these restrictions, air-source heat pumps are not considered in this report.

Hybrid Systems

Hybrid systems consist of a GSHP combined with another heat source or sink. In a hybrid system, both the ground loop and the other source are used for space conditioning, although not necessarily in equal proportions. For heating-dominated climates, ground loops can be combined with solar thermal collectors to form a hybrid system. The solar thermal contribution can be used for space heating or recharging of the ground-loop field. In cooling-dominated climates, a hybrid system often refers to a ground loop combined with a cooling tower or cooling pond for additional heat rejection.

Heat Distribution and Storage

In 2008, there were 23 heat pump manufacturers in the U.S. (Battocletti & Glassley, 2010). A wide range of heat pump units is available on the market, from small residential 3-ton systems to large 100-ton units.[5] Heat pumps generally accept a broad range of entering water temperatures (EWTs), from approximately 20°F to 120°F, and supply heat up to about 120°F. The units are designed for cooling or heating only, or are designed with both heating and cooling capacity.

Heat pumps are defined by their method of heat delivery:

- **Forced-air units**. A forced-air unit directly heats air to be distributed through ductwork. These systems can also be used for cooling if the heat pump is reversed for air-conditioning application.
- **Hydronic.** A GSHP application requires hydronic distribution to radiant floor or panel distribution, as it is impractical for heat pumps to produce high enough water temperatures for hydronic baseboard distribution. These units heat water in a number of applications. Radiant floor heating is the most common application, although these units also can be coupled with a fan coil for air conditioning or coupled with the domestic hot water (DHW) system.
- **Combination.** Combination units can produce hot water or air.

Desuperheaters

The output from the heat pump compressor can provide high-grade ("super") heat useful for DHW production. As such, a fraction of the heat generated for space conditioning can be diverted for providing hot water at temperatures around 160°F (Oklahoma State University, 1997). Depending on the design of the heat pump, the desuperheater can be used to provide supplemental or complete DHW demand. When the heat pump is in heating mode, the heat extracted by the desuperheater subtracts from the supply available for space heating. When in cooling mode, the desuperheater captures heat that would otherwise be rejected to the ground.

Storage Tanks

The addition of a water storage tank as part of a heat pump system can provide operational advantages. The heat pump is used to maintain the water storage tank within a given range of temperatures, and the heat distribution system runs off the water storage tank. The storage tank acts as a heat reservoir to buffer the heat pump from small and frequent space-heating demands, and the heat pump can then operate on longer runtimes with fewer on-off cycles (Siegenthaler, 2004). A water storage tank also can store heat for use during peak power periods, allowing the heat pump to run during off-peak hours. In some areas, heat pump owners can then qualify for discounted rates from utility companies.

Performance Measurements

A common measure of efficiency for combustion heaters, such as a furnace or boiler, is the annual fuel utilization efficiency (AFUE). The AFUE represents the average efficiency for a particular heating appliance over an entire heating season, and is a measure of the amount of heat delivered to a conditioned space relative to the amount of fuel delivered to the heating device. For example, a mid-efficiency natural gas furnace may have an AFUE of 80%, meaning that 20% of the heating potential of

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[5] The designed size of the system in tons (tonnage reflects how much energy the system is capable of transferring). 1 ton equals 12,000 British thermal units [BTUs] per hour.

the natural gas delivered to the furnace is lost due to inefficiencies in the heating system. Such inefficiencies can include cyclic operation, stack losses and standby losses. An electric resistance heater has an AFUE of 100%, as all of the supplied electricity to the unit is converted to heat.

The AFUE is not an appropriate measure of efficiency for a heat pump. A heat pump does not convert fuel to heat, but rather uses electricity to lift the temperature of its source (the fluid temperature from the ground loop) to a higher temperature used for space heating. For GSHPs in a heating mode, the most commonly used measure of efficiency is the coefficient of performance (COP). The COP is the ratio of heat output to work supplied to the system in the form of electricity.

$$COP = \frac{Quantity\ of\ Heat\ Delivered}{Energy\ Required\ by\ the\ Heat\ Pump}$$

For example, for electric resistance heating, the COP is 1: all of the electric energy is converted into heat. The energy required by a GSHP is also electrical, and includes the energy needed to run the compressor in the heat pump. Heat pumps have COPs higher than 1 because the energy delivered from a ground source is greater than the energy required to run the heat pump. A typical COP for a heat pump system is in the range of 2 to 4. This corresponds to an "efficiency" of 200-400%.

Often the system COP is reported as well, which is referred to as SCOP. SCOP takes into account all of the energy in the entire heating system and thus includes the energy required to run the circulating pumps and the heat delivery system. Because the SCOP includes all of the input energy to the system, it will be a lower value than COP. It is important to identify which components of the system are used when calculating the COP, because each system component decreases the COP.

The theoretical maximum COP is expressed in terms of the EWT from the ground loop and the output temperature to the heat delivery system. This "perfect" COP is referred to as the Carnot COP and will not actually be achieved. It is useful, however, because it indicates the upward bound of the possible COP from a given system. The EWT is the T_{cool} input to the heat pump and the output temperature is the T_{hot} that is used to heat the building. All temperatures must be expressed in Kelvin or Rankine units.

$$COP_{Carnot} = \frac{T_{hot}}{T_{hot} - T_{cool}}$$

The preceding equation shows that the Carnot COP is dependent on the difference between the EWT and the output temperature. The greater the difference between the two, or the further the heat pump must "lift" the EWT, the less efficient the heat pump will be. Manufacturer COPs generally list the EWT that was used when measuring the COP so that clients can compare this number with ground temperatures in their area. Generally for a GSHP used for heating, the EWT will be lower than the ground temperature, due to inefficiencies in heat transfer between the ground and the loop fluid. Thus, in the winter, the EWT can be lower than the ground temperature. Conversely, the EWT may be warmer than ground temperatures for cooling systems in the summer, depending on the quality of the ground loop installation.

The average COP over an entire heating season is known as the seasonal coefficient of performance. The seasonal COP is also referred to as the seasonal performance factor (SPF). This value takes into account the efficiency changes with source temperature as well as efficiency losses due to cycling. Thus, the SPF is the true measure of the annual efficiency of the system.

Commonly Recognized Advantages and Disadvantages of Heat Pumps

As with any heating system, GSHPs have a number of advantages and disadvantages for their users. The aspects discussed below are commonly recognized attributes for GSHPs, not specific to the cold climate context.

Technical

Efficiency. The most obvious advantages of GSHPs are their potential for superior efficiency and cost-effectiveness over conventional heating methods. For example, a heat pump with a COP greater than 1 will have a system efficiency greater than an electric resistance heating methods. In analyzing 184 case studies, Lienau, Boyd, and Rogers (1995) found that the average energy savings of GSHP systems ranges from 31% to 71% over heating and cooling systems that use natural gas, heating oil, electric resistance, or air source heat pumps in residential structures. However, 23% of those case studies that used natural gas or heating oil had annual operating costs lower than GSHP systems, demonstrating that energy cost savings are not guaranteed, but dependent on local fuel costs and availability. Similar energy-saving potential was found in 26 case studies of schools and 46 case studies of commercial buildings (Lienau, Boyd, & Rogers, 1995).–As energy prices continue to change, the energy savings potential of a GSHP system will be affected.

Demand Side Management. Local utilities throughout the U.S. have taken a keen interest in GSHP technology for its potential to reduce peak load demand, to obtain new customers where the original systems are based on oil or gas, or to reduce overall demand by replacing electric heating systems with more efficient GSHPs (Lienau, Boyd, & Rogers, 1995). This management method, referred to as Demand Side Management (DSM), is becoming more important as energy demands and costs of new power-generation capacity increase. Customers benefit from discounted electricity rates, ground-loop installation, and special financing (Lienau, Boyd, & Rogers, 1995).

A GSHP installation can reduce electrical demand when replacing an electric heating system. In replacing other types of heating systems, the GSHP increases electrical usage, but if the system incorporates a heat storage system, it can be used to reduce demand during times of peak electrical use. In these systems, the GSHP heats a storage tank during non-peak hours, then the storage tank is used to heat the building during high demand hours.

In the Lower 48, several rural electric cooperatives (RECs) have filed for loans from the federal government to provide GSHP infrastructure, such as the ground loop, to their customers. Customers are then charged a loop “tariff” with their electric bill to use the infrastructure. This construct was a recommendation of the Oak Ridge National Lab to streamline and deploy more REC programs in order to facilitate growth of the GSHP industry (Hughes, 2008). Rural electric cooperatives currently exist in 47 states, including Alaska.

This concept has been employed successfully in other locations. “Energy contracting” is used by Swiss public utilities. The utility company installs and maintains the GSHP and then sells the “heat” to homeowners at a contracted price (Curtis, Lund, Sanner, & Rybach, 2005). In Canada, utility models “lease” loop fields back to customers. In 2010, Roy Whiten, an HVAC engineer in Whitehorse, incorporated Greenheat, an alternative energy company, to help cover the capital cost of GSHPs for new homeowners who then pay a monthly fee.

Ground Loop Emplacement. A substantial limitation of GSHPs is the space needed for a horizontal ground loop. For example, a well-insulated 2000-square-foot home might need a 3-ton system with 1200 to 1800 feet of pipe (NRC Office of Energy Efficiency, 2004). Since this length of pipe is laid in trenches near the home, a substantial amount of land area is needed. Additionally, good access is needed for excavating equipment. These values are much larger for a commercial system. For instance, the new facilities hanger at the Juneau Airport (Appendix A) required a ground loop that covered an area of more than 216,000 square feet, which is larger than the area of four football fields. This ground-loop footprint can be reduced if vertical systems are installed. However, vertical systems present other problems, such as access of equipment and the availability of drilling rigs. Most residential systems documented in this report have horizontal ground loops, in part due to the high cost of drilling a vertical-loop system. In cold climates, for both horizontal and vertical systems, it is also necessary to install a sufficiently large ground loop to prevent large-scale thermal degradation (the lowering of temperatures from year to year) of the soil. An experienced designer and testing of local soil conditions ensure that the soil thermal regime will recover each year during the summer months.

Financial

High capital cost compared with conventional heating and cooling systems is a disadvantage of GSHPs. The higher cost is mainly due to the additional labor and material required to install the ground loop, which can result in a GSHP installation costs that are twice as much as a conventional system (Lienau, Boyd, & Rogers, 1995). In fact, one of the largest barriers to GSHP implementation is the capital cost (Hughes, 2008). These costs can be offset by state and federal rebates, as discussed in more detail in the Preliminary Economic Assessment.

While hampered by high initial costs, GSHP systems can provide savings over time by lower operating costs. As discussed previously, Lienau, Boyd, and Rogers (1995) found that the average annual savings of GSHP systems in residential case studies ranged from 18% to 54% over heating and cooling systems that use natural gas, heating oil, electric resistance, or air source heat pumps. Savings in operating costs for the school case studies ranged from 13% to 58%, and savings for the commercial building case studies ranged from 31% to 56% (Lienau, Boyd, & Rogers, 1995). Hanova and Dowlatabadi (2007) showed annual savings in Canada that average more than $1,500 over electric heating systems, and more than $1,600 over systems that use heating oil. Such financial savings are most dependent on relatively inexpensive electricity. Another factor relevant for determining financial savings is the building energy demand. Energy intensive buildings, such as those with a high number of annual operating hours, high ventilation rates, or high process loads, can generate greater energy savings to offset the capital cost.

Greenhouse Gas Emissions

Because GSHPs concentrate heat available within a ground source instead of burning fuel, they have the potential to reduce greenhouse gas (GHG) emissions. While a heat pump does not produce greenhouse gases itself, it uses electricity which may have produced greenhouse gases in its creation. Greenhouse gas emissions depend on the COP and the carbon dioxide (CO_2) intensity of the delivered electricity (Hanova & Dowlatabadi, Strategic GHG reduction through the use of ground source heat pump technology, 2007). Of particular importance is the ability of the particular region to support GSHPs without having to import electricity (Hanova, Dowlatabadi, & Mueller, Ground Source Heat Pump Systems in Canada: Economics and GHG Reduction Potential, 2007). Clean, inexpensive electricity, such as in the Pacific Northwest, which is powered by dams on the Columbia River, can make GSHPs attractive for a particular region (AEA, 2009). However, in other regions the situation is more complicated. A case study done in 2009 on five Canadian cities found that GSHPs actually increased GHG emissions in Calgary, and noted that one method of reducing GHG emissions in places without "clean" electricity is to combine the GSHP with photovoltaics (Kikuchi, Bristow, & Kennedy, 2009).

Other studies show a similar dependence on regional parameters. For instance, a study on the potential for CO_2 savings in different regions of Germany found that GHG emissions varied according to the electricity mix of the region (Blum, Campillo, Munch, & Kolbel, 2010). Ground-source heat pump deployment in the Yukon Territory of Canada has not been advised for implementation in the near future, as it could result in the use of backup generators due to the time of electricity demand versus hydroelectric generation capacity. Heating demand is highest in winter when the water available for hydroelectricity is at its lowest levels (Cottrell, 2009).

Because an increase in overall energy efficiency for providing space heating can have long-reaching benefits in the U.S., including energy security, economic growth, and a reduction in GHG emissions (APS, 2008), taking the time to assess whether widespread GSHPs for a region is worthwhile. Residential, commercial, and institutional buildings account for approximately 40% of primary energy consumption and carbon emissions in the U.S. (Navigant Consulting, Inc., 2009), and the building sector is growing faster than any other energy-use sector (Battocletti & Glassley, 2010). This potential applies to both businesses and individuals, because the U.S. market is divided roughly evenly between residential and commercial applications of GSHP technology (Navigant Consulting, Inc., 2009). An intergovernmental panel on climate change in 2007 identified the building sector as having both the highest GHG emissions and the best potential for emission reductions (Hughes, 2008).

Ground-Source Heat Pumps in Cold Climates

Cold Climate Considerations for GSHP Application

Ground-source heat pumps are widely used in cold climates, and are economically and technically feasible, as evidenced by their popularity in Scandinavian countries. In Sweden, 30% of the houses have GSHP systems (IEA, 2007). The majority of GSHPs in Sweden have vertical ground loops, and they are typically designed to cover 90% of the annual heat energy demand, with an electric heating system as the backup heat source (Karlsson & Fahlen, 2003). In Norway, 15,000 GSHP systems have been installed, including 250 medium- and large-capacity nonresidential systems (Stene, Midttomme, Skarphagen, & Borgnes, 2008) and Finland has an estimated 46,000 units installed (Lund, Freeston, & Boyd, Direct Utilization of Geothermal Energy 2010 Worldwide Review, 2010). Heat pumps are widely used in Canada (Phetteplace, 2007), and in Europe, the market is growing (Rybach & Sanner, 2000).

Ground-source heat pumps in the U.S. are typically sized for the cooling load (Navigant Consulting, Inc., 2009). This sizing is in contrast to GSHPs in Alaska and other northern areas, where the capacity of a GSHP is determined by the heating load of the building. Furthermore, in cold climates, it is probable that a GSHP will be used only for heating, unlike more moderate climates, where the ground is used for both heat extraction (space heating) and rejection (space cooling). This difference presents two disadvantages for GSHP efficiency in cold climates: heat is being extracted from relatively cold ground and is not being balanced by heat rejection used for space cooling.

Ground Temperature Considerations

One of the most important factors determining the efficiency of a heat pump is the difference between the EWT and the temperature of the heat delivered to the conditioned space. The EWT is related to the temperature of the ground in which the ground loop is placed. In the context of heating, therefore, a higher soil temperature will provide a higher EWT and more efficient GSHP operation. Figure 3 shows that the COP is proportional to the EWT.[6] On average, the range of ground temperatures in Alaska is substantially lower than in the contiguous U.S., which is one of the most significant differences in the application of GSHP systems in Alaska.

Also significant is how the heat is delivered to the conditioned space. Hydronic systems need different leaving water temperatures (LWT), depending on the type of flooring used in a building. For instance, compared with a wood or concrete floor, a carpeted floor will require a higher LWT from a heat pump to heat the space above it. Figure 3 illustrates this relationship by showing a range of LWT for the same heat pump. In each case, COP rises with a higher EWT. While data in Figure 3 are based on performance for a specific model and brand of heat pump, they are representative of the general trend that a higher EWT and a lower LWT result in a higher COP.

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[6] The data shown in Figure 3 were derived from the Engineering Specifications Manual for the ECONAR DualTEK GV37 through GV57 Series Models. ECONAR is a heat pump brand that has been manufactured in Minnesota for more than 25 years. The data are from performance measurements for the GV370 and GV371 Hydronic Heating Systems, with a flow through the ground loop of 8 GPM. The Engineering Specifications Manual is available for download on the ECONAR website (March 10, 2011).

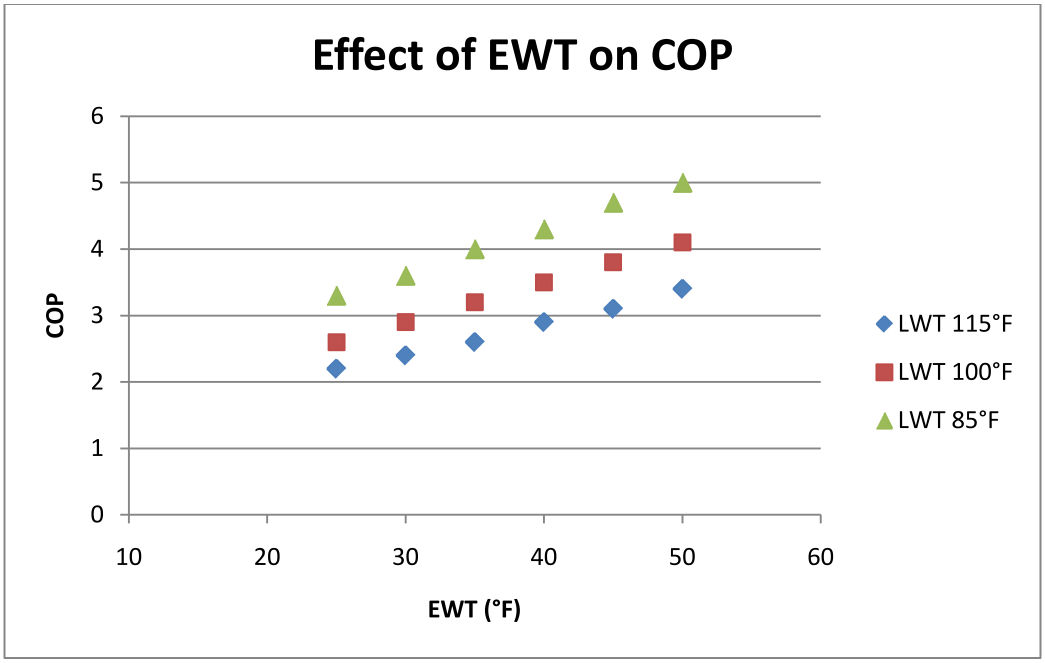

Figure 3: Effect of entering water temperature on COP

The limitations of GSHP efficiency in cold climates are evident when the graph in Figure 3 is compared with ground temperatures in cold climate regions. Figure 4 shows the dependence of soil temperature on ground depth and seasonal air temperatures using data from Ottawa, Canada. The EWT will depend on how deep the ground loop is buried. At a depth of 16 feet, the temperature does not vary significantly; however, most horizontal loops are not buried this deeply. At more-shallow depths, such as 7 feet, winter ground temperatures dip as low as 40°F. Such information is useful, as the ground-temperature profile of a site can be used to understand the approximate range of efficiencies possible for a GSHP system.

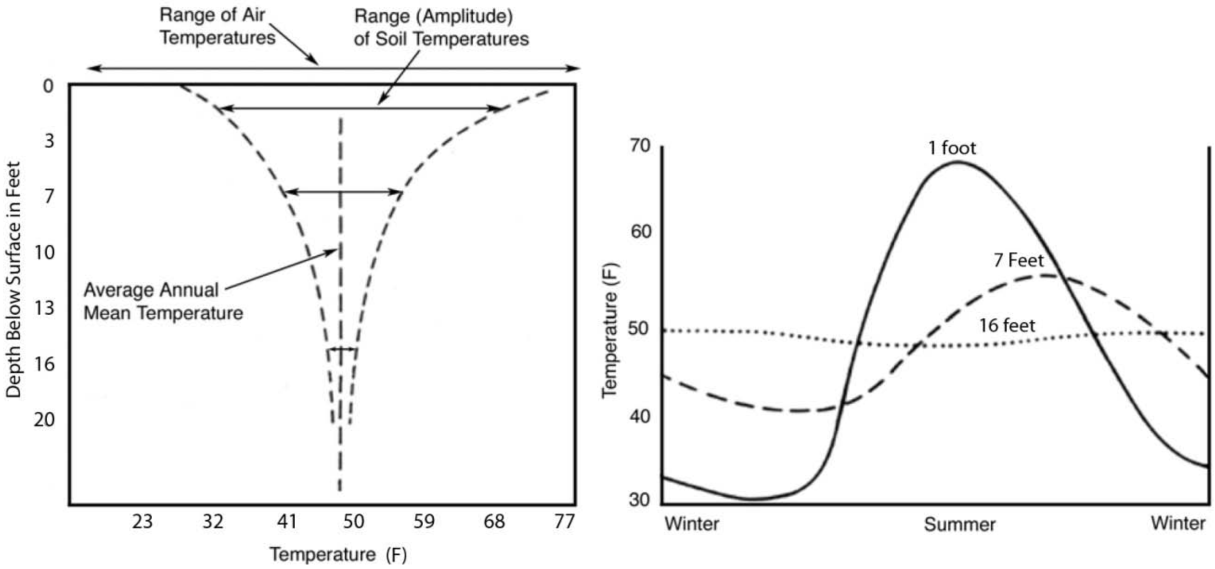

Figure 4: Depth dependence of ground temperatures (modified from Hanova & Dowlatabadi, 2007)

Ground temperature as a function of depth also varies for a given location in Alaska, with the largest temperature fluctuations occurring within the top few feet below the surface. Below the ground surface, ground temperature varies little throughout the year. Figure 5 illustrates this general behavior of temperature with ground depth, which is subject to variation due to influences such as solar exposure, soil type, soil moisture content, variation in the geothermal gradient, and anthropogenic disturbances. Installers consider many soil variables, including temperatures, to decide on an ideal ground-loop depth for a given location.

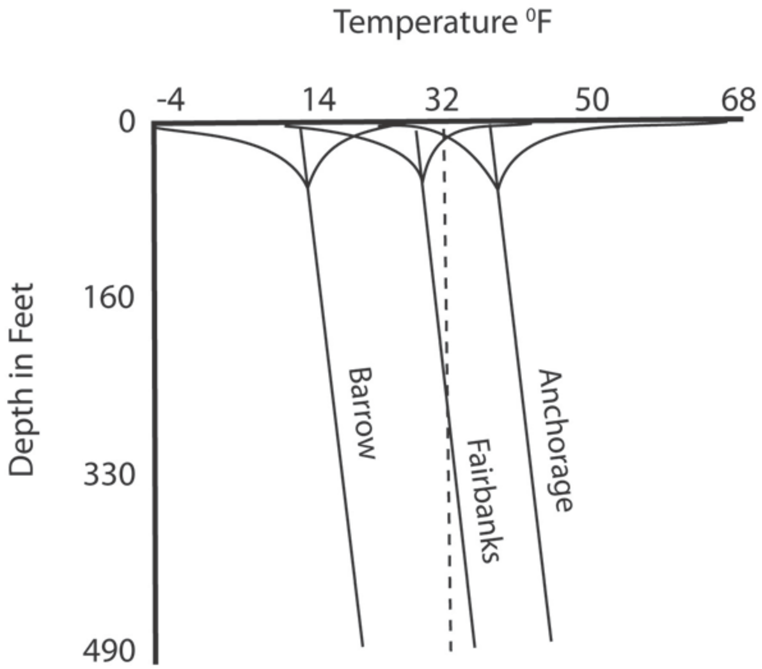

Figure 5: Soil temperatures in Alaska (modified from Rice, 1996)

One concern for locations with colder ground temperatures is that the low temperatures can lead to EWTs at the bottom end of many heat pump operational ranges. An undersized ground loop could result in EWTs that are too cold for the heat pump to operate efficiently and the heat pump will be unable to achieve the manufacturer COP.

Another consideration in cold climates is the potential creation of permafrost or seasonal frost due to thermal degradation caused by excessive heat extraction from the soil. There are concerns that the use of GSHPs in cold climates could lead to the creation of permafrost or seasonal ground freezing, which could cause heaving of utilities and structures near the ground loop, a reduction of COP over time, and other complications. Reports and journal articles address seasonal imbalances of heat extracted versus heat returned to the ground, and the possibility of soil freezing during the heating season. However, documented evidence of permanent soil degradation is scarce, and few long-term studies have been done to determine the effect of ground loops on the soil thermal regime.

One possibility in coastal cold climate locations is to install the ground loop in the ocean, and use the seawater as a heat source. Systems that use seawater as a heat source have been used successfully in Scandinavia (Underland, 2004) and in Juneau, Alaska (APA, 1984). There are new seawater heat pump systems in Southeast Alaska that are described in Appendix A.

Heat Distribution

Another aspect of an adequate design for cold climates is the heat delivery system. Hydronic heating by radiant flooring, which requires much lower output temperatures (120°–140°F) than baseboards (170°–190°F) is preferable for GSHP heating systems (Jacobsen, King, Eisenhauer, & Gibson, 1980). More recent hydronic systems use output temperatures as low as 90°F when the heating demand is low, and approximately 110 - 120°F for high heating demand. Radiant floors are used in both residential and commercial systems, although this type of system is more difficult and expensive to install when retrofitting a building. Many of the installers and industry professionals in Alaska have identified the advantage of having a lower output temperature and expressed their preference for radiant floor systems with GSHP installations. Similarly, an article on a commercial system in Montreal utilizes a radiant floor system as part of their GSHP heating system (Genest & Minea, 2006). As the largest factor in heat-pump energy use is design, a low-temperature radiant heating system can be very beneficial (Straube, 2009). In fact, Figure 3 supports this conclusion by showing that a higher LWT result in a lower COP, using data from Econar heat pumps.

Synthesis of Selected Cold Climate Literature

Seven academic studies on GSHPs in Alaska and several more on cold climate GSHPs in other locations have been published. These studies and others reviewed as part of this report provide insight on the performance of GSHPs in cold climates and the effect of GSHPs on the soil thermal regime. Summaries of the studies discussed in the following sections appear in Appendix C. Readers unfamiliar with the literature on Alaska and cold climate GSHPs are encouraged to refer to the article summaries as a background to the synthesis. An annotated bibliography of all reviewed articles is provided in Appendix D.

Alaska literature. Studies of GSHPs in Alaska span a broad range of locations, GSHP heat sources, and study methods. Some of the results from these studies are summarized in Table 2. Perhaps the most noteworthy finding from Table 2 is that few studies have been conducted. In addition, all of the studies analyze data from only a few heating systems. In the case of McFadden (2000) and Williams and Zarling (1994), only one heat pump is considered. Most of the studies are short-term, of less than two-year duration. The single long-term study, by McFadden in 2000, did not address the question of using a GSHP for space heating. Rather, the study considered the ability of the ground loop and a small heat pump to maintain the permafrost underneath a home foundation. The ground loop was located under the basement of the house, and removed the heat lost through the foundation that would have otherwise degraded the permafrost. This heat was used for space heating during the winter, and was rejected outside during the summer.

Table 2: Alaska study results

Study	Location	Duration	Heat Source	COP	Financial Analysis	Thermal Response of Soil	Maintenance Problems
Zarling (1976)	Fairbanks	-	Treated wastewater	3.7 (SPF)	Favorable	-	-
Jacobsen (1980)	Juneau	-	Water of variable source	2.25–2.5	Comparable to other systems	-	Possible with sea water
Nielsen & Zarling (1983)	Fairbanks	1½ years	Soil	2–3	-	Favorable	None
Juneau WSHP Program (1984)	Juneau	3 years	Sea water	2.53	Favorable	-	None
Williams & Zarling (1994)	Fairbanks	1 winter	Soil	2.0	Not favorable	More heat pipes needed if heat load increases	Few
Mueller & Zarling (1996)	Anchorage area	1 winter	Lake water and soil	2.16–3.89	-	Need longer study	None
McFadden (2000)	Fairbanks	15 years	Soil	-	-	Permafrost maintained	Several

Additional cold climate literature. Studies from cold climate regions other than Alaska complement the Alaska studies and provide more depth to the literature analysis. Four of these studies are monitoring ones that focus on the performance of a few GSHP systems. A few studies are represented in Table 3.

Table 3: Cold climate study results

Study	Location	Duration	Heat Source	COP	Financial Analysis	Thermal Response of Soil	Maintenance Problems
Phillips & Stanski (2003)	Winnipeg, Canada	1 year 4 months	Soil	2.6–2.8	Heat pump system would have a payback of 20 years	COP declined slightly during heating season	Yes, detected by the monitoring systems
Steinbock et al. (2007)	Minnesota	8 years	Soil	3.1	Favorable	Favorable	Few
Andrushuk & Merkel (2009)	Manitoba, Canada	1 year	Various	2.8	Favorable when compared with electric resistance heating	5 to 1 imbalance calculated of heat taken from soil to heat added to soil	Yes, detected by the monitoring systems
Bakirci (2010)	Erzurum, Turkey	1 winter	Soil	2.6	None	Favorable	None

These studies are valuable because they also provide COP measurements and report financial and technical considerations. In addition, because the study locations are not in Alaska, these studies provide a separate cold climate perspective that serves to strengthen the basis of trends across all studies. While the small number and broad range of Alaska and cold climate studies is not sufficient to draw any conclusions, the studies provide an initial view into a variety of aspects of heat pumps in cold climates.

Reported COPs and technical considerations. The reported COPs from six studies in Alaska all fall in the same general range of 2 to 3.89. As soil temperatures above 35°F exist in locations in Alaska (see Figure 5), GSHPs with a COP above 3 are possible (see Figure 3). The Alaska studies confirm that such systems exist. Additionally, three of the five monitoring studies in Alaska reported no maintenance problems, demonstrating that, in general, GSHPs require little maintenance (Bloomquist, 1999). This information is a first indication that GSHPs can function well in cold climates. Trends showing low maintenance and a COP of 2 to 3.8 are of particular interest, because the Alaska studies, while few, represent a broad range of heat sources and applications in three different locations across the state. The COPs reported by the additional cold climate studies fall within the range of the Alaska studies. In addition, two of these studies reported having few maintenance problems. More insight comes from Cane and Garnet (2000) and Lienau, Boyd, and Rogers (1995), as these studies are surveys of existing GSHP systems. Both studies identified GSHPs as needing less maintenance than other systems that were surveyed. While no average COPs are reported in Lienau, Boyd, and Rogers (1995) or Cane and Garnet (2000), the studies have value in establishing a database of systems that have been in operation for years with no noticeable decline in performance.

Financial Analysis. Financial analyses performed by authors of the Alaska studies were favorable in all but one case; the nonfavorable analysis was for a nontraditional ground loop. This finding agrees with the consensus that GSHPs can have a financial advantage over time when compared with conventional systems, even in colder climates. Steinbock (2007) and Andrushuk and Merkel (2009) reported a favorable financial analysis, and Lienau, Boyd, and Rogers (1995) reported a financial savings for GSHP owners when analyzed over a database of systems. The studies establish that, in some locations, a GSHP can compete with other heating systems.

Soil thermal response. There is inconclusive evidence of soil thermal response in the long term. As discussed previously, soil temperatures have a direct effect on the COP of a heat pump by ultimately determining the EWT. In cold climates, there are two main concerns, the first one being that the winter soil temperatures are too low in any given year to result in a high enough COP for the GSHP to be economically feasible. As numerous studies have shown, proper design and attention to soil properties can result in a COP in the range of 2–3.5, with the possibility of a higher COP. However, Mueller and Zarling (1996) and Williams and Zarling (1994) reported that soil froze during the heating season. While freezing soil does not necessarily constitute a problem if the ground is not part of a building foundation, the lower ground temperature will decrease the EWT and the COP of the heat pump. The second concern is more subtle: that the soil cannot maintain its average temperature over the long term if each year more heat is taken from the ground than is added back from the ground loop, solar heating, or groundwater. Andrushuk and Merkel (2009) calculated a 5-to-1 imbalance of heat removed from the ground to heat returned to the ground during summer. Over several years, this type of imbalance could result in lower soil temperatures and a decrease in heat pump performance. Other studies have indicated that ground temperatures could possibly recover, but more study is needed to produce definitive results (Nielson & Zarling, 1983). Additionally, no study has been made of long-term soil thermal response in the context of using a GSHP solely for space heating. McFadden (2000) is a long-term study, covering over ten years when taken together with its supplemental report, but this research focuses on the ability of the ground loop to maintain permafrost. Instanes and Instanes (2008) provide another example of using a GSHP to maintain permafrost, thus indicating that, as in McFadden (2000), the ground loop is effective at removing a significant amount of heat from the soil.

Hybrid systems. While a GSHP is ideal in areas that have balanced heating and cooling loads, because the amount of heat rejected to the ground in the summer is similar to the amount taken out in the winter, the situation is more complicated in heating- or cooling-dominated climates, where the yearly load on the ground is not balanced. Buildings in such climates may require a larger ground heat exchanger (GHE) than buildings with balanced heating and cooling loads, and this requirement increases capital costs and the area of land needed for the GHE (Yang, Cui, & Fang, 2010). A potential alternative to the traditional GSHP—that is, using a hybrid GSHP—has been identified in a number of studies. Hybrid cold climate GSHPs have supplemental heat absorbers, which in most cases are some type of solar collector connected in series or parallel to the ground loop by way of a water storage tank. The energy savings potential of a hybrid system in a heating- or cooling-dominated climate can be significant (Yang, Cui, & Fang, 2010).

Hybrid systems reduce the load on the ground loop, providing more heat during periods of high load and providing the potential to “store” heat in the ground during summer months. A history of studies done on hybrid GSHPs is provided by Shahed and Harrison (2010). Additionally, a Canadian study monitors and documents data on a hybrid residential system in Whitehorse, Yukon. Preliminary analysis shows that the system cost is comparable to heating with oil, and that the hybrid system provides adequate heat to the home (Lessoway Moir Partners, 2006). However, hybrid systems still require an external source of electricity to run the heat pump. Therefore they may still be an unattractive option in cold regions with high electricity rates, such as rural Alaska, because they will not be economic in comparison to other heating systems.

Current State of the Heat Pump Industry in Alaska

Alaska’s GSHP industry is small, but recently has shown growth, with some prominent commercial installations in Juneau and several residential installations in Fairbanks. One large-profile commercial GSHP system has recently been installed at the Juneau Airport Terminal. In addition to the project’s primary motivation, to reduce operating costs at the terminal, planners hope to increase public awareness of energy conservation and alternative energy (Fritz, 2008). This installation and other recent commercial installations are summarized below to provide examples of larger GSHP applications in Alaska.

Residential GSHP owners interviewed for this report had installed a GSHP for a variety of reasons, but each homeowner reported that long-term cost savings was a strong motivation. Some homeowners found their systems to be low-maintenance, and more than one homeowner installed a GSHP in part because it is a partially renewable-energy technology. All of the residential GSHP owners interviewed reported satisfaction with their systems.

Much of the information in this section is based on interviews with Alaska installers, residential and commercial GSHP owners in Alaska, and area sales representatives in the Northwest who represent various manufacturers. Appendix B contains a list of all of those interviewed for this report.

Installers

Nine installers in Alaska were identified and interviewed: two in Fairbanks, three in Anchorage, one in Willow, and three in Juneau. Many of these installers have certifications from heat pump manufacturers or the IGSHPA. Across Alaska, thirteen businesses are involved in heat pump installations. These businesses are located in Juneau, Fairbanks, Anchorage, the developed area of the Matanuska-Susitna Valley, Homer, and Sitka. However, the majority of installations were completed by only six or seven businesses. A number of heating, ventilation, and air conditioning (HVAC) companies have completed only one or two installations.

A few engineering firms have completed or are currently involved in commercial systems. These firms do not have extensive experience with GSHPs, especially since only seven commercial systems have been installed across the state. These projects were mostly completed with in-state contractors, except for the Juneau Airport and the Aquatic Center, which had boreholes drilled by a company out of Washington. However, a few design engineers in Alaska have the qualifications to undertake commercial projects.

Installers across Alaska have found that high capital cost is a large barrier for potential residential and commercial consumers. Each installer that was interviewed confirmed this problem, and several provided a number of anecdotes. Several installers have found that customers unfamiliar with the technology are unwilling to install a GSHP even after being informed, because of the high capital cost.

Manufacturers

While many manufacturers sell heat pumps for warmer climates that are designed for both heating and cooling purposes, some manufacturers make heating-only models, designed specifically for lower EWT. Companies generally advise customers living in cold climates to consult a sales representative who can provide them with recommendations on specific pumps that are appropriate for their area. Many companies provide installers with training and software to help design efficient systems. The majority of installed heat pumps in Alaska are WaterFurnace or ECONAR (see the GSHP inventory in Appendix A), reflecting installer preference. As no heat pump manufacturers are located in Alaska, installers and those performing maintenance must consider shipping times and costs for heat pumps and parts.

Qualifications and Training

Many installers and designers are trained by heat pump organizations such as IGSHPA and by the heat pump manufacturer. Some companies provide training and a support staff of engineers and designers that can be consulted when installing a system. Having IGSHPA training is becoming an industry standard. The IGSHPA provides a three-day training workshop, but the workshop is not offered in Alaska, because too few people are interested in completing the qualification due to lack of demand.[7] The IGSHPA workshops are run regularly in the contiguous U.S., and interested installers must travel to the closest location. One recently certified IGSHPA installer-trainer is located in Fairbanks. Although this

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[7] A list of training events is located at www.igshpa.okstate.edu.

individual does not presently offer certification courses, he plans to offer them in the future (Kirk Jackson, personal communication, December 21, 2010).

Drilling

No drilling companies in Alaska were identified that can drill boreholes cheaply enough to compete with horizontal systems. The high cost is due to a combination of ground conditions, limited competition, and available equipment. If the ground conditions allow slumping or heaving during drilling, well casing is needed to keep the borehole open during drilling to allow emplacement of the ground loop. This problem requires more materials and time during the drilling process. Drill rigs that bypass the need for casings by using drilling muds are available in the contiguous U.S., but this equipment is not commonly available in Alaska.

Drilling costs in Alaska are higher than drilling costs in the contiguous U.S., where there is more demand for heat pumps and more competition. In Juneau, rigs currently average around $20 per foot plus a mobilization fee, whereas drilling in the Seattle area can cost as little as $8 per foot (Doug Murray, personal communication, October 2010). Test holes and vertical boreholes for the Juneau Airport were drilled by rigs from Seattle. Catherine Fritz, the airport renovation project manager, said the decision was made to transport drill rigs to Juneau because the drilling company bid lower and had more experience (personal communication, October 4, 2010). In Anchorage, the cost of drilling ranges from $20 to $25 per foot. Alluvial gravel, which is predominant in Anchorage, is prone to slumping and requires casing for the borehole, adding approximately $19 per foot to the price (Ron Pichler, personal communication, October 2010).

Electrical Utilities

In 1996, Matanuska Electrical Association (MEA) contracted a research project (Mueller & Zarling, 1996) to obtain data for their customers on the reliability and economics of using GSHPs, but since this report MEA has taken no further action to investigate or promote the technology.

In Southcentral Alaska, the MEA has a program that offers off-peak rates to customers who qualify for them. Some GSHP systems located in the Matanuska-Susitna Valley operate on off-peak power, but MEA's program is expected to end in the near future because it has not had the desired effect of reducing peak power demand. Additionally, the program creates extra work for MEA (Eric Sanford, personal communication, November 2010).

Example Installations

Based on data obtained, at least 48 residential heat pump systems have been installed in Alaska. Most of the installations are in and around Fairbanks, Juneau, and Anchorage, and nearly all are closed horizontal ground-loop systems. Around ten commercial systems have been installed in Alaska, or are in the process of installation. Each of these installations is unique, encompassing ocean-source, vertical and horizontal ground loops, and wastewater as the heat source. A tabulated summary of each documented system is provided in Appendix A.

Preliminary Economic Analysis

Economic analyses were performed to compare the capital and energy costs of GSHPs with typical home-heating systems in five population centers in Alaska. The population centers examined include Juneau, Anchorage, Fairbanks, Bethel, and Seward. The net present value (NPV)[8] of each system was calculated for each population center using the capital cost, annual energy, and maintenance costs over a 15-year period. Capital cost estimates were obtained from system installers. Annual energy costs were estimated by using the average annual British thermal unit (Btu) per square foot used for heating the average-sized home and by using energy costs for each population center included in the analysis. Figure 6 displays the annual energy cost, capital cost, and NPV for each home-heating system assessed for a population center.

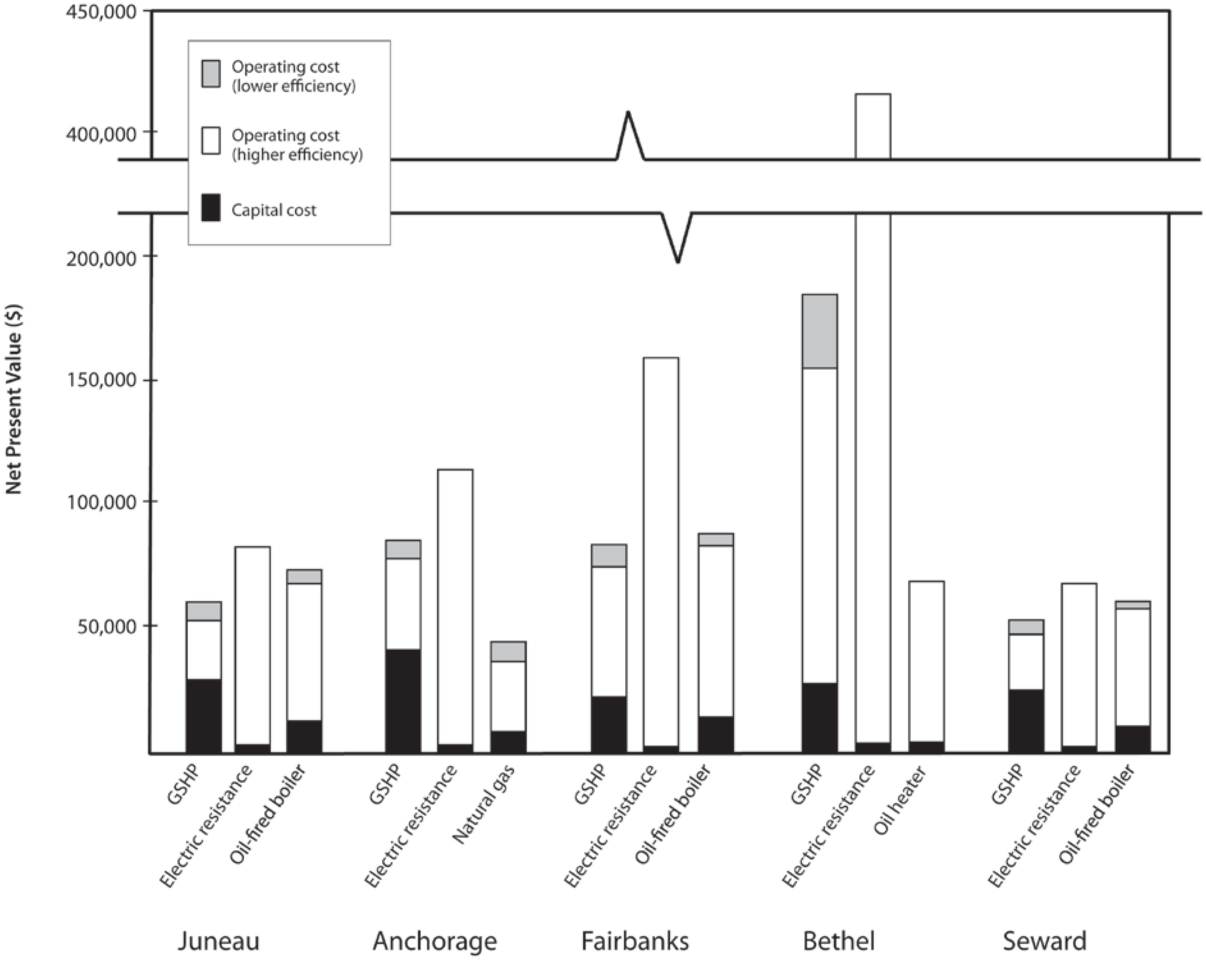

Figure 6: Results of the economic analysis

The capital cost of GSHP systems was higher than all other home-heating systems assessed for each population center. However, with the savings on annual heating energy costs, GSHP systems are the

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[8] NPV compares the value of a dollar today to the value of that same dollar in the future, taking inflation and returns into account. If the NPV of a prospective project is positive, it should be accepted. However, if NPV is negative, the project should probably be rejected, because cash flows will also be negative.

lowest-cost heating systems in Seward, Fairbanks, and Juneau. Homes in Seward, Fairbanks, and Juneau are primarily heated with heating oil. Ground-source heat pump systems use electricity to compress heat pulled from the ground and are fuel-efficient. For example, a GSHP system with a COP of 2.5 provides 2.5 kWh (kilowatt-hours) of heat for each kWh of electricity used by the pump. It is because of this fuel efficiency that homes using a GSHP for home heating can save on annual home-heating costs over fuel oil.

The GSHP system was unable to beat natural gas home heating in Anchorage because of the relatively low capital and energy costs of a natural gas home-heating system. The use of a GSHP system was also unable to beat a direct-vent laser stove, such as a Toyostove®, for home heating in Bethel. While the cost of heating oil is high in Bethel, the capital cost of a direct-vent laser stove is very low. Additionally, electricity in Bethel is expensive ($0.54 after the first 500 kWh each month).

Net Present Value Methodology

Through the literature review and interview process, it was determined that little comprehensive economic information is available for GSHP applications in Alaska. In general, the economic feasibility of a GSHP in a given area depends on capital costs and operating costs (Hanova & Dowlatabadi, Strategic GHG reduction through the use of ground source heat pump technology, 2007). The following section seeks to define and investigate, at a preliminary level, general economic factors and considerations for GSHP systems in Alaska. This task is accomplished through a NPV analysis of GSHP applications, as compared with alternative heating systems in representative communities across Alaska. All systems are assumed to have an expected useful life of 15 years, which is a conservative estimate for the portfolio of heating systems included in the analysis.

Given the complexity of project-specific considerations and the need for accurate comparison, this analysis assumes new building projects rather than retrofit installations. For similar reasons, residential-scale projects were investigated, rather than commercial-scale projects. Finally, horizontal ground-loop systems rather than vertical ground-loop systems were assumed, because the higher capital cost of vertical systems indicates that, in general, they are not economically feasible at the residential scale. This assumption seems to be supported by the installation database (Appendix A), which shows that most residential systems installed in Alaska utilize a horizontal ground loop,[9] and by interviews with Alaska GSHP installers.

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[9] The cost of the well field varies depending on the type of soil and whether a vertical or horizontal field is used. Vertical well fields appear to be more expensive than horizontal fields for residential systems. For example, an estimate from an Anchorage drilling company priced a vertical well field at $15–$40 per lineal foot for drilling, loop installation, and grouting. For a five-ton system, typically five 300-foot wells would be drilled, resulting in a cost of $22,500 to $60,000. Anchorage is built on an alluvial plain, characterized by anomalies such as sand, silt, and varying sizes of gravel. Drilling techniques depend upon the soil. Air, water, drilling mud, and steel casing are four techniques used for drilling in the Anchorage area. Air is the least expensive, followed by water, and then drilling mud. If air, water, or drilling mud is unable to keep a borehole open, then the most expensive method, steel casing, must be used. Estimates from contractors for excavation and installation of a horizontal well field for a five-ton GSHP system in Anchorage ranged from $8,100 to $15,500 by comparison.

Community Space Heating Use Profiles

To begin the NPV analysis, space heating energy use is defined for representative population centers across Alaska. The population centers examined include Juneau, Anchorage, Fairbanks (primary regions for current GSHP installations), Bethel (a representative rural hub community), and Seward (a representative community with comparatively low electricity costs to heating costs).

Table 4 displays space heating energy use by population center. Average annual Btu needed for space heating varies by population center because of differences in both heating degree-days and average home size. Bethel requires the most Btu per square foot for space heating. Homes in Anchorage require the most Btu for space heating annually, mostly because Anchorage homes are the largest in size of the sampled population centers. The calculations in this analysis are based on the average house size and average annual Btu for each population center (Information Insights, Inc., 2009).

Table 4: Space heating energy use by population center

Community	Average Home Size[10]	Annual Average Btu/ft^2	Average annual Btu	Heating degree days[11]
Juneau	1,730	75,818	131,165,140	8,897
Anchorage	2,074	87,894	182,292,156	10,570
Fairbanks	1,882	90,013	169,404,466	13,940
Bethel	1,554	91,486	142,169,244	12,769
Seward	1,730	75,818	131,165,140	9,007

Comparative Heating Systems Defined

In this section, performance and efficiency information is defined for comparing various heating systems. The heating systems included in the assessment are the GSHP, electric resistance baseboard heater, oil-fired boiler, and natural gas furnace.[12] We assumed that a single system serves a home's entire heating demand, not including domestic hot water heating. Supplementary heating systems were not included in the assessment.

Table 5 shows the heating fuel, heating value, and efficiency of the different systems. The efficiency of a GSHP is measured by its coefficient of performance (COP), which is a measure of heat delivered per hour, divided by the heat equivalent of electric energy input. Higher COPs indicate greater efficiency.

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[10] Data for average home size, average Btu/ft^2, and average annual Btu are from the Information Insights, Inc. 2009 Alaska Housing Assessment.

[11] Heating degree-days (HDD) is a measurement of heating demand for a climatic region, determined by the difference between 65°F and the average daily ambient temperature for a 24-hour period. Daily HDD values summed for a calendar year provide the annual HDD. HDD information is from the Information Insights, Inc. 2009 Alaska Housing Assessment (Information Insights, Inc., 2009), except for Bethel and Seward, for which information is from the UAF Geophysical Institute (Alaska Climate Research Center, 2001).

[12] GSHPs with horizontal ground loops were assessed for each population center, as was baseboard electric resistance heat. Oil-fired boilers were examined for Juneau, Fairbanks, and Seward. Oil-fired laser-vented heaters were assessed for Bethel. Oil-fired boilers were not assessed for Anchorage, because the availability of natural gas means people use natural gas furnaces instead of oil-fired boilers. Fuel oil is typically more expensive than natural gas on a Btu-equivalent basis. Anchorage was the only population center for which natural gas was examined, because it is the only population center in the study with a readily available supply of natural gas.

The efficiencies of other heating systems are measured by the U.S. Department of Energy's Annual Fuel Utilization Efficiency, (AFUE), which is calculated by the amount of heat delivered compared with the amount of fuel consumed by the system. Heating values were converted into kilowatt-hours (kWh) for ease of comparison between systems.

Table 5: Heating system comparison

	Heating Fuel	Heating Value	COP	AFUE
GSHP	Electricity	1 kWh/kWh	2.5–3.0	N/A
Electric Resistance	Electricity	1 kWh/kWh	N/A	99%
Oil-fired unit	Fuel oil	40.65 kWh/gal	N/A	80–90%
Natural gas furnace	Natural gas	30 kWh/CCF	N/A	78–97%

All energy cost estimates are based on the system efficiencies stated in Table 5. Systems with lower efficiencies will have higher annual heating costs. Of the systems compared in this analysis, GSHPs have the greatest efficiency, with an assumed COP of 2.5 to 3.0. Electric resistance heating is 99% efficient. The average natural-gas furnace efficiency is 78%, with high-efficiency units achieving efficiencies of 97%. Average oil-fired boilers have efficiencies of 80%, and high-efficiency units can have efficiencies up to 90%. The oil-fired laser vented heater system assessed for Bethel is assumed to have an efficiency of 87%.

Community Space Heating Cost Profiles

After defining space-heating use for each population center and the performance and efficiency characteristics of each heating system, resulting energy costs and fuel consumption were investigated. Table 6 compares system energy cost and fuel consumption by region. Unit cost is the price of the fuel per unit sold.[13] Actual cost is the unit price per kWh, adjusted for system efficiency. Fuel consumption is the amount of kWh the system requires for heating the average-sized home in the population center. Heating cost is the total annual fuel cost for the heating system at current energy prices.

Heating costs are displayed as a range of values.[14] The lower value represents annual system-heating cost with the higher efficiency. The higher value represents annual system-heating cost at the lower efficiency. For example, if heating cost is displayed at $1,500 to $1,800 annually for a natural gas system and natural gas systems are typically 79% to 97% efficient, then the $1,500 annual heating cost would result from a system that is 97% efficient and the $1,800 annual heating cost would result from a system that is 79% efficient.

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[13] All electricity prices came from local utilities except for Bethel. Bethel's electricity price came from the 2009 Power Cost Equalization Statistical Report. Fuel oil prices for 2010 through 2025 are from the Institute of Social and Economic Research Alaska Fuel Price Projections 2010-2030, July 2010 edition. The carbon cost factored into the prices was removed for this study.

[14] Heating costs were calculated by first converting the average annual Btu used for home heating for each population center to kWh. Then, the annual kWh for home heating was adjusted for system efficiency. For example, if a home required 10,000 kWh annually for home heating and its heating system had an efficiency of 50%, then the annual heating requirement for that home would be 20,000 kWh. Then, the efficiency-adjusted annual kWh for home heating was multiplied by the price of the system's fuel. For example, if a home required 20,000 kWh for home heating and the price of electricity was $0.10/kWh, then the energy cost of the system would be $2,000 annually. All fuel prices (including oil, natural gas, and electricity) were converted to cost per kWh to determine final heating costs.

In Juneau, an average-sized home (1,730 square feet) using a GSHP with a COP of 2.5 to 3.0 will have annual energy costs of $1,400 to $1,700 when electricity is $0.11 per kWh. Electric resistance heating for the same home will cost $4,300 when electricity is $0.11 per kWh. Heating the home with an oil-fired boiler would cost $3,300 to $3,700 annually when fuel oil is $3.13 per gallon. The system with the lowest energy cost is a GSHP with a COP of 2.5 to 3.0.

In Anchorage, an average-sized home (2,074 square feet) using a GSHP with a COP of 2.5 to 3.0 will have an annual heating cost of $2,000 to $2,400. The same home using electric resistance heat will have an annual heating cost of $5,900 when electricity costs $0.11 per kWh. Heating the home with natural gas will cost $1,500 to $1,800 annually when natural gas is $8.10 per MCF. In this scenario, natural gas is the lowest cost option.

Table 6: Comparison of energy cost and fuel consumption by population center

		GSHP	Electric Resistance	Oil-fired unit	Natural gas furnace
Juneau	Unit cost ($)	0.11/kWh	0.11/kWh	3.13/gal	N/A
	Actual cost ($/kWh)	0.037–0.044	0.11	0.09–0.10	N/A
	Fuel consumption (kWh)	12,800-15,400	38,800	42,700-48,000	N/A
	Heating cost ($)	1,400-1,700	4,300	3,300-3,700	N/A
Anchorage	Unit cost ($)	0.11/kWh	0.11/kWh	N/A	0.81/CCF
	Actual cost ($/kWh)	0.037–0.044	0.11	N/A	0.028–0.035
	Fuel consumption (kWh)	17,800-21,400	54,000	N/A	55,100-68,500
	Heating cost ($)	2,000-2,400	5,900	N/A	1,500-1,800
Fairbanks	Unit cost ($)	0.17/kWh	0.17/kWh	2.87/gal	N/A
	Actual cost ($/kWh)	0.06–0.07	0.17	0.08–0.09	N/A
	Fuel consumption (kWh)	16,500-19,900	50,100	55,200-62,000	N/A
	Heating cost ($)	2,800-3,400	8,500	3,900-4,400	N/A
Bethel	Unit cost ($)	0.15–0.54/kWh	0.15–0.54/kWh	3.45/gal	N/A
	Actual cost ($/kWh)	0.05–0.21	0.15–0.54	0.10	N/A
	Fuel consumption (kWh)	13,900-16,700	42,100	47,900	N/A
	Heating cost ($)	6,900-8,400	22,100	4,100	N/A
Seward	Unit cost ($)	0.09/kWh	0.09/kWh	2.60/gal	N/A
	Actual cost ($/kWh)	0.03–0.04	0.09	0.07–0.08	N/A
	Fuel consumption (kWh)	12,800-15,400	38,800	42,700-48,000	N/A
	Heating cost ($)	1,200-1,400	3,700	2,700-3,100	N/A

The average-sized home in Fairbanks (1,882 square feet) using a GSHP with a COP of 2.5 to 3.0 will have an annual energy cost of $2,800 to $3,400. The same home will incur an annual heating cost of $8,500 when electricity costs $0.17 per kWh. Heating the home with an oil-fired boiler will cost $3,900 to $4,400 when fuel oil is $2.87 per gallon. A GSHP has the lowest annual heating cost of the systems assessed for Fairbanks.

In Bethel the averaged-sized home (1,554 square feet), using a GSHP with a COP of 2.5 to 3.0, will have an annual heating cost $6,900 to $8,400.[15] Electric resistance heaters will cost $22,100 annually. An oil-fired laser vented heater will have an annual heating cost of $4,100. In Bethel, an oil-fired laser vented heater has the lowest heating cost.

In Seward, the average-sized home (1,730 square feet) using a GSHP with a COP of 2.5 to 3.0 will incur an annual heating cost of $1,200 to $1,400. Electric resistance heating will cost $3,700 annually when electricity costs $0.09/kWh. An oil-fired boiler will have an annual heating cost of $2,700 to $3,100 when fuel oil is $2.60 per gallon. In Seward, a GSHP has the lowest annual heating cost. In general, areas with low electricity prices, but high fuel oil prices are ideally suited for GSHPs.

Capital and Maintenance Cost Considerations

In addition to annual heating costs, total initial capital costs and annual maintenance costs of the various heating systems were defined. The Table 7 outlines the various system components that were included in capital costs for this analysis.

Table 7: System components included in capital cost

GSHP[16]	Electric Resistance	Oil-fired boiler	Oil-fired laser vented heater[17]	Natural gas furnace
GSHP unit In-floor radiant heating GHE piping Excavation for GHE GHE piping installation labor	Baseboard units Thermostat Labor	Oil-fired boiler Piping, tank, and stand Baseboard heating units Additional parts Labor	Oil-fired heater Oil tank and stand Parts Labor	Furnace Ductwork Thermostat Gas piping Labor

Note that all capital and maintenance cost estimates are from local system suppliers and installers. Because few residential GSHP systems have been installed in Alaska, the installation costs are less concrete than with more-traditional home-heating systems. The estimates given for installation cost varied greatly between installers, depending on whether the contractor owned excavation equipment and had plumbing expertise. As more systems are installed, installation costs will become more certain. The numbers used in this report are only estimates. Homeowners and project managers interested in installing a GSHP should research the energy and capital cost of a system appropriate for their

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[15] Electricity rates in Bethel are anomalous, because Bethel is the only Power Cost Equalization community in the analysis. Power Cost Equalization (PCE) is a state program that provides economic assistance to rural communities to reduce the cost of electricity. The first 500 kWh of residential usage is covered by PCE and cost $0.15 in Bethel during the 2009 fiscal year. Any usage beyond 500 kWh is not covered by PCE and cost $0.54/kWh in Bethel during the 2009 fiscal year. The average monthly home usage was 387/kWh. Therefore, the home-heating systems that use electricity as fuel (GSHP and electric resistance) can use 113 (500 kWh PCE eligible hours minus 387/kWh average monthly usage) hours per month at the lower $0.15/kWh PCE rate. Additional kWh beyond 500 kWh per month is not covered by PCE and cost $0.54/kWh.

[16] The estimate for Seward includes domestic water heating, and the in-floor radiant heating estimate for Juneau is an average of the other population centers.

[17] Estimate specific to Bethel.

application. Note also that the labor cost associated with system installation is included in the capital cost for this analysis.

Table 8 summarizes the assumed up-front capital costs and annual maintenance costs for the various heating systems in the representative communities.

Table 8: Capital and maintenance costs

	Heating System	Annual Maintenance Costs[18] ($/yr)	Total Capital Costs ($)
Bethel	Oil-fired laser vented heater	110	2,900
	Electric resistance	0	3,000
	GSHP	120	28,300
Fairbanks	Oil-fired boiler	250	13,800
	Electric resistance	0	3,700
	GSHP	120	23,500
Anchorage	Natural gas furnace	130	8,500
	Electric resistance	0	4,100
	GSHP	120	42,100
Juneau	Oil-fired boiler	181	13,000
	Electric resistance	0	3,300
	GSHP	110	29,300
Seward	Oil-fired boiler	175	12,500
	Electric resistance	0	3,300
	GSHP	120	27,000

Net Present Value Calculation

After determining the space-heating use profile for each representative community, the performance and efficiency information for each considered heat system, the resulting estimated energy cost information, and the associated capital and maintenance costs, the NPV for the various systems was determined. Table 9 shows the capital costs, energy costs, and NPV over a 15-year period using a 3% discount rate[19] for each system and escalating energy costs. The NPV shows how much a system will cost the owner over the 15-year life of the system. Capital cost, annual energy cost, and annual maintenance costs (also determined by estimates from local system suppliers and installers) are included in the NPV.

For the average-sized home in Juneau, electric resistance baseboard heaters have the lowest capital cost at $3,300, but electric resistance heaters have the highest annual heating energy cost at $4,300, which results in a NPV of $82,500 for electric resistance heating in Juneau over the 15-year period. An oil-fired boiler heating system for the same home has a capital cost of $13,000, an annual heating energy cost of $3,300 to $3,700, and a NPV of $68,200 to $74,800. A 4-ton GSHP system has a capital-

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[18] Maintenance cost for electric resistance heaters is assumed to be zero. The units are low cost and would likely be cheaper to replace than to repair.

[19] Three percent is the discount rate used by the Department of Energy for calculating the present value of energy costs.

cost quoted estimate of $29,300, an annual heating energy cost of $1,400 to $1,700, and a NPV of $56,300 to $61,500.

For the average-sized home in Anchorage, the capital cost of electric resistance baseboard heaters is $4,100, with an annual heating energy cost of $5,900 and a NPV of $114,100. A natural gas furnace for the same home has a capital cost of $8,500, with an annual heating energy cost of $1,500 to $1,800 and a NPV of $37,000 to $44,600. A 5-ton GSHP system for the home has a capital-cost quoted estimate of $42,100, with an annual heating energy cost $2,000 to $2,400 and a NPV of $79,100 to $86,400.

Table 9: Comparison of energy and capital costs and NPV for heating systems by population center

		GSHP	Electric resistance	Oil-fired boiler/[oil-fired laser vented heater[20]]	Natural Gas
Juneau	Capital Costs ($)	29,300	3,300	13,000	N/A
	Annual heating energy costs ($)	1,400–1,700	4,300	3,300–3,700	N/A
	Net present value ($)	56,300–61,500	82,500	68,200-74,800	N/A
Anchorage	Capital Costs ($)	42,100	4,100	N/A	8,500
	Annual heating energy costs ($)	2,000-2,400	5,900	N/A	1,500-1,800
	Net present value ($)	79,100-86,400	114,100	N/A	37,900-44,600
Fairbanks	Capital Costs ($)	23,500	3,700	13,800	N/A
	Annual heating energy costs ($)	2,800-3,400	8,500	3,900-4,400	N/A
	Net present value ($)	76,900-87,300	161,800	85,300-90,500	N/A
Bethel	Capital Costs ($)	28,300	3,000	2,900	N/A
	Annual heating energy costs ($)	6,900-8,400	22,100	4,100	N/A
	Net present value ($)	158,100-185,700	414,900	65,500	N/A
Seward	Capital Costs ($)	27,000	3,300	12,500	N/A
	Annual heating energy costs ($)	1,200-1,400	3,700	2,700-3,100	N/A
	Net present value ($)	50,500-55,000	71,100	57,000-62,200	N/A

For the average-sized home in Fairbanks, the capital cost of electric resistance baseboard heaters is $3,700, with an annual heating energy cost of $8,500 and a NPV of $161,800. An oil-fired boiler for the average-sized home has a capital cost of $13,800, with an annual heating energy cost of $3,900 to $4,100 and a NPV of $85,300 to $90,500. Installing a 5-ton GSHP system to heat the house has a capital-cost quoted estimate of $23,500, an annual heating energy cost of $2,800 to $3,400, and a NPV of $76,900 to $87,300.

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[20] Estimate specific to Bethel.

For the average-sized home in Bethel, the capital cost of installing an oil-fired laser vented oil heater is $2,900, with an annual heating energy cost of $4,100 and a NPV of $65,000. The capital cost of installing electric resistance baseboard heaters is $3,000, with an annual heating energy cost of $22,100 and a NPV of $414,900. Installing a 4-ton GSHP system for the same home has a capital-cost quoted estimate of $28,300, with an annual heating energy cost of $6,900 to $8,400 and a NPV of $158,100 to $185,700.

For the average-sized home in Seward, the capital cost of installing an oil-fired boiler is $12,500, with an annual heating energy cost of $2,700 to $3,100 and a NPV of $57,000 to $62,200. The capital cost of electric baseboard heaters is $3,300, with an annual heating energy cost of $3,700 and a NPV of $71,100. The capital-cost quoted estimate of a 5-ton GSHP system is $27,000, with an annual heating energy cost of $1,200 to $1,400 and a NPV of $50,500 to $55,000.

Fuel Price Sensitivity

As an additional analysis, escalating energy costs were considered to investigate the dynamics of changing energy costs and their potential effects on NPV. Electricity prices were increased by 5.4% annually, which is the average annual percentage change in Alaska residential electricity rates from 2003 to 2009.[21] The natural gas cost escalation assumed for Anchorage was 5.4%, to remain consistent with the annual electric price increase, as Anchorage's electricity prices are tied to the price of natural gas. All oil price projections are from the Institute of Social and Economic Research's Alaska Fuel Price Projections mid-case scenario for each population center. Kenai oil prices were used as a proxy for Seward, because Seward was not included in the Alaska Fuel Price Projections study. The annual oil price projection increases vary from year to year and, therefore, do not have a constant escalation factor.

Changing fuel prices over the system's useful life will affect the NPV of the system. Table 10 displays the Anchorage natural gas cost-escalation factor and its impact on the NPV of a natural gas furnace. In the analysis, it is assumed that natural gas prices will increase by 5.4% annually over the 15-year life of the system, resulting in a NPV of $37,900 to $44,600 for a natural gas furnace in an average-sized home in Anchorage. If an escalation factor of 10% is used for natural gas, the NPV of the system changes, ranging from $49,900 to $59,500. If an escalation factor of 3% is used for natural gas, the NPV changes, ranging from $33,400 to $39,000. A 7% variation in fuel cost escalation vastly impacts the NPV of the system.

Table 10: Anchorage natural gas cost escalation

Escalation factor	3%	5.4%	10%
Natural gas furnace NPV	33,400–39,000	37,900–44,600	49,900–59,500

Changing fuel oil prices alter the NPV of the oil-fired boiler system over the useful lifetime of the heating system. Table 11 shows the NPVs of oil-fired boiler systems in the four population centers for which they were assessed under the low, medium, and high fuel-cost projections from the Institute of Social and Economic Research's Alaska Fuel Price Projections.

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[21] Residential rates for 2003 are the earliest rates reported in the U.S. Department of Energy, Energy Information Administration's Electric Power Monthly.

Table 11: NPV of oil-fired boiler system under varying fuel oil escalation

	Juneau	Fairbanks	Bethel	Seward
Low case ($)	49,600-53,800	58,300-61,400	45,400	45,800-49,700
Medium case ($)	68,200-74,800	85,300-90,500	65,500	57,000-62,200
High case ($)	92,200-101,800	120,000-127,800	90,400	71,600-78,800

The price of electricity will affect the annual heating cost of systems that use electricity as their energy source. Changing the escalation factor will change the annual energy cost of the system and, therefore, the NPV of the heating system over the 15-year period. Table 12 shows the NPVs of electric resistance baseboard heaters and GSHP systems in the five population centers, under various annual electricity cost-escalation factors.

Table 12: NPV of electric heating systems under varying annual cost escalation factors

		3%	5.40%	10%
Juneau	Electric resistance ($)	69,600	82,500	116,900
	GSHP ($)	52,000-56,400	56,300-61,500	67,600-75,100
Anchorage	Electric resistance ($)	96,100	114,100	161,900
	GSHP ($)	73,200-79,300	79,100-86,400	94,900-105,300
Fairbanks	Electric resistance ($)	136,000	161,800	230,500
	GSHP ($)	68,400-77,100	76,900-87,300	99,600-114,500
Bethel	Electric resistance ($)	347,600	414,900	593,700
	GSHP ($)	137,000-160,200	158,100-185,700	213,900-253,600
Seward	Electric resistance ($)	60,000	71,100	100,600
	GSHP ($)	46,800-50,600	50,500-55,000	60,200-66,600

Government Incentives and Rebates

Finally, incentives and rebates available at the state and federal level for installation of GSHPs (listed in Table 13) were investigated to determine the potential impact on the overall NPV. These rebates can reduce the capital cost of a GSHP, making it more economically competitive with traditional home-heating systems.

Table 13: Government incentives and rebates

	State	Federal
Residential	• Home Energy Rebate Program • Second Mortgage Program for Energy Conservation	• Residential Renewable Energy Tax Credit
Commercial	• Renewable Energy Grant Program	• Modified Accelerated Cost-Recovery System • Business Energy Investment Tax Credit • USDA – Rural Energy for America Program Grant • USDA – Rural Energy for America Program Loan Guarantee

At the state level, the Home Energy Rebate Program and the Second Mortgage Program for Energy Conservation are available for residential installations from the Alaska Housing Finance Corporation. Also at the state level, the Alaska Energy Authority (AEA) offers the Renewable Energy Grant Program for commercial installations.

- The **Home Energy Rebate Program** is available to Alaska homeowners for owner-occupied properties. A rebate of up to $10,000 is available for energy efficiency improvements made by homeowners. An "as-is" energy rating must be performed before any improvements are made. Then, within 18 months of the original "as-is" rating, the homeowner must make efficiency improvements. A "post-improvement" energy rating must be conducted after the energy efficiency improvements are made. If the "post-improvement" rating shows an improvement of at least one step on the energy rating system, the homeowner qualifies for a rebate. Energy improvements range from one step to five steps, and the rebates range from $4,000 to $10,000. Rebates are only given for actual expenses incurred.

- The **Second Mortgage Plan for Energy Conservation** is available to homeowners for owner-occupied properties. First, an energy rating must be performed on the home. Then, the homeowner can select a GSHP as an energy upgrade. The system must be installed within 365 days of the loan closing. The maximum amount that can be borrowed is $30,000 for a length of 15 years. The current interest rate for the loan is 4.125%.

- In 2008, Alaska established the Renewable Energy Grant Fund from which the **Renewable Energy Grant Program** is funded. The program is administered by the Alaska Energy Authority. Funding is available to independent power producers, utilities, local governments, and tribal governments for studies and work related to the design and construction of eligible systems, including GSHPs. The AEA recommends projects to the legislature for funding, which is allocated in two rounds per fiscal year.

In addition to state-funded rebates and incentives, federal incentives are available for installation of a GSHP. For residential installations, the federal government offers the Residential Renewable Tax Credit. Federal incentives for commercial installations include the Modified Accelerated Cost-Recovery System, the Business Energy Investment Tax Credit, the U.S. Department of Agriculture (USDA) Rural Energy for America Program Grant, and the USDA Rural Energy for America Program Loan Guarantee.

- The **Modified Accelerated Cost-Recovery System** is a corporate depreciation incentive available for commercial and industrial installations of geothermal heat pumps. Since October 2008, investment in the geothermal heat pump can be recovered in depreciation over a period of five years.

- The **Business Energy Investment Tax Credit** allows a tax credit of 10% of total expenditures on geothermal heat pumps that were installed after October 3, 2008. Eligible sectors include utility, commercial, industrial, and agricultural. This tax credit expires December 31, 2016.

- The **USDA Rural Energy for America Program Grant** will cover 25% of the project cost for a geothermal heat pump. Eligible rural sectors include commercial, schools, local government, state government, tribal government, rural electric cooperative, agricultural, and public power entities. The program currently has funding through the 2012 fiscal year.

- The **USDA Rural Energy for America Program Loan Guarantee** is a federal loan program for rural commercial and agricultural sectors. The program is funded through the 2012 fiscal year. Under the loan guarantee, a business may secure a loan guarantee up to $25 million to pay for a GSHP. If a business is also using the USDA Rural Energy for America Program Grant, the grant and loan guarantee combined cannot exceed 75% of the total project cost.

- As of 2009, a 30% tax credit is available to a homeowner for the installation of a geothermal heat pump under the **Residential Renewable Tax Credit**. The system, which must be installed before December 31, 2016, must meet federal Energy Star Program requirements at the time of installation to qualify for the tax credit. This tax credit can greatly reduce the cost of installing a GSHP system.

For this analysis, performed on a residential scale, the Residential Renewable Tax Credit was included in the household NPV analysis. Technically, the NPV remains the same because the costs of implementing the technology are still incurred. However, the household economics change because a third party is absorbing part of the cost. Table 14 displays the capital cost and household net present value of the GSHP systems for each population center before and after the Residential Renewable Tax Credit.

Table 14: Capital cost and household economics before and after rebate

	Juneau	**Anchorage**	**Fairbanks**	**Bethel**	**Seward**
Before rebate					
Capital cost ($)	29,300	42,100	23,500	28,300	27,000
Household NPV ($)	56,300-61,500	79,100-86,400	76,900-87,300	158,100-185,700	50,500-55,000
After rebate					
Capital cost ($)	20,500	29,500	16,500	19,800	18,900
Household NPV ($)	47,800-53,000	66,900-74,100	70,100-80,500	149,800-177,500	42,600-47,100

After the 30% tax credit, the GSHP system remains the lowest cost home-heating option for Juneau, Fairbanks, and Seward. However, even with the 30% rebate, the GSHP system is still more expensive over a 15-year period than an oil-fired laser vented heater for home heating in Bethel or a natural gas furnace in Anchorage.

Major Findings

The following section represents a synthesis and discussion of the major findings from the literature review, interviews with heat pump professionals, and the preliminary economic assessment.

Technically and financially feasible cold climate GSHPs have been widely reported

A number of studies indicate that ground-source heat pumps (GSHPs) have been successful in cold climates. The literature review in Appendix C provides a number of examples of monitored systems that adequately met space-heating demand while saving costs over alternative heating systems. Based on this prior work, the range of coefficients of performance (COPs) expected for professionally installed systems in Alaska is approximately 2.0 to 3.5 across a broad suite of locations, installers, heat sources, and heat pump manufacturers.

Several buildings in other cold climate regions use GSHP systems. The Science House in Minnesota has successfully used a GSHP for space heating since 2003 (a description of the Science House can be found at www.smm.org). A “green” commercial building in Montreal has a GSHP with radiant floors (Genest & Minea, 2006). Two Canadian schools also use GSHPs in Quebec (Minea, 2006). An air base in Bodø, Norway, has used a seawater heat pump for twelve years to cover 40% to 60% of its heating load, with no reported problems (Underland, 2004). The Alaska Electric Light and Power Company (AEL&P) Building in Juneau has used a GSHP system for over sixteen years; few maintenance issues have been reported during that time.

The preliminary economic analysis for this report found that the net present value would be the lowest for a GSHP in three of the five Alaska population centers that were considered. In Fairbanks, Juneau, and Seward, operating costs for a GSHP were low enough to make it competitive with other heating systems. The preliminary economic analysis used recent and projected future fuel and electricity prices, and obtained installer estimates for capital costs of heating systems. Individuals considering installing a GSHP are encouraged to check current fuel prices, and consider their heating requirement as part of their own financial analysis. In Anchorage, natural gas had the lowest net present value, but use of a federal rebate to help with capital costs made GSHPs the more economical system. A GSHP was not economical in Bethel because of high electricity costs at that location. As the financial analysis is highly dependent on the cost of electricity, changes in electrical cost can dramatically impact the feasibility of a GSHP. Potential GSHP users should check current electrical rates in their location when performing their own financial analysis.

A Canadian study surveyed GSHP users and found that 95% would recommend systems to theirs (Hanova & Dowlatabadi, Strategic GHG reduction through the use of ground source heat pump technology, 2007). This sentiment was echoed by Alaska homeowners interviewed for this study. In two cases, people had chosen a GSHP after seeing the system of a friend or neighbor. All users were satisfied with their GSHPs, though some had suggestions for minor improvements based on their experience with the technology. While GSHP system owners and installers in Alaska are few, those that were interviewed believe that the technology could be successful in the state.

Therefore, despite the complications involved in ensuring that a GSHP system operates efficiently, a weight-of-evidence approach indicates that GSHPs are a viable heating system for cold climates. While some localities may have more cost-effective heating options, such as natural gas heating systems in Anchorage, GSHPs are cost competitive and may provide a viable option for residential and commercial buildings.

Thermal imbalances in the soil can be created by GSHPs in cold climates

A number of studies discussed in the literature review (Appendix C) addressed the issue of thermal imbalances that can be created in the soil because of a GSHP. One study used a numerical simulation to assess the effect of GSHPs on the soil temperature regime. A study in Sapporo, Japan, examined the potential of residential GSHPs with a horizontal ground heat exchanger, focusing on the thermal degradation of the ground. A computer simulation showed no change in the ground thermal regime after three years, low impact degradation after ten years, and no permafrost formation. Based on the relatively low thermal degradation, and a lower cost of heating and cooling the authors recommended horizontal GSHPs for residential use in the region of Japan near Sapporo. The study did not consider vertical loop GSHPs (Tarnawski, Leong, Momose, & Hamada, 2009).

Two studies have focused on the use of GSHPs to purposely cause thermal imbalance in the soil. In both studies, the ground heat exchanger was used to take a sufficient amount of heat from the soil in order to prevent the soil from warming. One study in Norway found that using GSHP technology in an on-grade foundation underneath a building to provide space heating, while maintaining the soil temperature and design value, was superior to the more common pile foundations used in Norway, and could be used in areas of permafrost (Instanes & Instanes, 2008). The other study, which assessed the potential for using a GHSP to maintain permafrost underneath the foundation of a house in Fairbanks, concluded that the heat removed from the ground could maintain the permafrost and stabilize the foundation (McFadden, 2000).

While the long-term effects of GSHPs in soil with subfreezing temperatures is unknown (Bath, 2003), the concern of thermal degradation is site-specific. For example, in many cases, thermal degradation around the ground-loop vicinity is not expected because of groundwater flow. This case was documented for a GSHP in a commercial building in Montreal (Genest & Minea, 2006). In addition, a ground temperature modeling study on the performance of vertical GSHPs in Switzerland found that, while a new thermal equilibrium forms in the soil, no thermal degradation occurs in the long term (Rybach & Hopkirk, 1994).

A ground loop must extract heat from the ground in order to heat a building. Whether ground temperatures can recover in the summer will depend on the region’s climate, soil conditions at the site of the ground loop, and the sizing of the ground loop. In locations with low ground temperatures and a high annual heating demand, thermal imbalances are large concern.

Hybrid technology may improve the performance of cold climate GSHPs

Research suggests that hybrid systems are best for climates that are strongly heating- or cooling-dominated (Yang, Zhou, Xu, & Zhang, 2010) and that hybridization is sometimes necessary for cost-effectiveness (DoD, 2007). As Alaska has a strongly heating-dominated climate, hybrid GSHPs have the potential to prevent thermal degradation of the soil over time, to maintain more efficient heat pump operation throughout the heating season, and to perform well over time. Most hybrid heating systems consist of a typical GSHP system that is augmented with a solar thermal system, used for supplementing the heat obtained from the ground loop in winter and for recharging the ground during summer. Such an innovative approach of using solar heat or waste heat to recharge the ground loop holds promise for using a GSHP in a cold climate (Straube, 2009).

A Tianjin, Chinese, study on a school heat pump showed that the COP can be improved by up to 0.25 with solar assistance to a single-source heat pump (Hu, Zhu, & Zhang, 2010). Another potential benefit of using artificial thermal recovery during the summer is that vertical boreholes can be located closer together if GSHPs become more popular in Europe (Rybach & Sanner, 2000), where the current market is heating-dominated (Sanner, Karytsas, Menarions, & Rybach, 2003). Solar collection systems can be used in locations where groundwater flow is insufficient to recharge vertical wells (Stene, Midttomme, Skarphagen, & Borgnes, 2008). Future research into new design methodologies will allow hybrid GSHP applications to grow (Spitler, 2005).

Hybrid systems are currently in use and being designed in cold climates. Weller Elementary School in Fairbanks has recently installed a hybrid GSHP for meeting a small portion of the school's heating demand, and the Cold Climate Housing Research Center has begun collecting ground temperature data on the area around the ground loop. The hybrid GSHP at Weller School will start operation in the winter of 2011-2012. A study in Yukon, Canada analyzed and archived performance data on a hybrid geothermal-solar residential heating system in Whitehorse. The solar panels were used to heat domestic hot water and to transfer excess heat to the ground in the summer. While the recommendations of the Yukon study include ground soil temperature and power consumption monitoring for one year for improved performance and savings, initial estimates show that use of the hybrid system during one year costs less than half the cost of heating the home with propane or oil for the same period (Lessoway Moir Partners, 2006).

It should be noted that while hybrid GSHPs may perform better than non-hybrid GSHP in heating-dominated climates, they are not necessarily significantly more economical. While it's probable that a hybrid GSHP will have a higher COP than a non-hybrid GSHP in the same location, hybrid systems will also presumably have higher capital costs. Whether the additional capital cost provides sufficient reductions in operating cost (by improving COP) to justify the system hybridization is a highly site specific consideration.

GSHP systems, given regional considerations, are economically viable heating systems

This report's economic analysis examined the net present value of GSHPs in five population centers in Alaska and found that, in spite of a higher capital cost, the net present value of using a GSHP is lower for Fairbanks, Seward, and Juneau when compared with other heating systems. These three locations rely primarily on oil-heating appliances, which cost more to operate and maintain than a GSHP. The differences between oil-fired systems and GSHPs in Seward and Juneau were particularly large, as electricity costs in those communities are substantially lower than in Fairbanks. This finding corresponds to previous studies that express the same idea: GSHPs are most viable in regions with an abundance of cheap electricity (AEA, 2009). In Anchorage, natural gas is more economically favorable than a GSHP, unless a rebate is used for part of the capital cost.

Previous studies have asserted that high installation costs and potentially high operating costs make GSHPs inappropriate for rural Alaska (AEA, 2009). The economic analysis for this report found that a GSHP is not an attractive heating option in Bethel. A direct vent laser stove, such as a Toyostove®, is the most economic heating system in Bethel, in terms of both capital and operating costs. A rebate did not substantially change the economics of installing of a GSHP in Bethel, as the very high electricity costs there do not allow the GSHP to be competitive with an oil-heating appliance.

Bethel, a rural hub community relying on high-cost diesel-generated electricity, was utilized in this report as a representative case for rural hub communities. The analysis of this report indicates that high electricity prices, in combination with high capital costs, make GSHPs an unviable option for Bethel. This result can be extrapolated to non-hub rural communities, although capital costs and electricity prices may increase. Ground-source heat pump systems are a highly unlikely alternative for rural communities relying on high-cost, diesel-generated electricity.

The lack of a developed heat pump market in Alaska is a barrier to GSHP implementation

Studies have identified barriers to growth of the GSHP market in the U.S. Barriers include high capital cost and lack of consumer knowledge and confidence in the technology (Hughes, 2008). Similarly, market diffusion is limited in Canada by factors such as high capital costs, nonstandardized systems, and actual performance that is less than promised (Hanova, Dowlatabadi, & Mueller, Ground Source Heat Pump Systems in Canada: Economics and GHG Reduction Potential, 2007). The GSHP market in Alaska faces these same problems.

The small Alaska market and, therefore, small number of installations can result in higher capital costs for customers. Less than eight HVAC businesses are involved in GSHP work, so there is less competition for customers. A few businesses focus substantial efforts toward GSHP installation, which results in limited bulk purchasing, less incentive toward promoting the technology, and decreased efficiency of installations due to lack of specialized employees. Some companies only install GSHPs as a side business, because they do not have enough GSHP customers for them to switch completely over to GSHP installation.

The high capital cost and few installations of GSHPs prevent a positive-feedback cycle, whereby the more installations that are completed, the more people understand the technology and recommend it to neighbors, which leads to more installations. Several professionals remarked that customers are skeptical about the idea of taking heat from ground that is “not hot,” which reflects a lack of understanding about the technology itself despite the widespread use of refrigeration. This lack of knowledge about GSHPs is one of the most serious limitations to market growth, because people are not willing to spend more money on a system with which they are unfamiliar and that has not been properly proven.

Furthermore, there is no current long-term energy plan in Alaska with the goal of maintaining an electricity supply at low inflation. This further reduces the incentive to make a large financial investment on a GSHP, which depends on electricity as an input. This is especially true for communities not tied to the railbelt grid in Alaska, as their electricity costs can be highly variable.

In addition, poorly designed systems can act to discourage GSHP technology (Dr. John Straube, personal communication, November 11, 2010). In many areas of Alaska, few systems have been installed (Appendix A contains an inventory of GSHP systems in Alaska). Fewer than ten commercial systems have been installed in the state. Thus, potential customers do not have a large database of example systems to consult when choosing their own heating system.

Design is paramount for meeting performance expectations

In any part of the world, adequate design is necessary for GSHPs to meet performance expectations and have fewer maintenance issues. However, it is especially important in cold climates for the design of

GSHP systems to match the parameters of the location. Poorly designed systems can result in a number of problems, such as decreasing COPs if the ground loop is undersized, because the soil cannot thermally recover (Cottrell, 2009). If the GSHP system is oversized, the capital costs will be higher than necessary, and excessive on-off cycling can stress the heat pump unit and reduce its operational efficiency.

We can define a good design as one that encompasses the building load, the building use, and the soil type. Additionally, the design must account for location specifics, such as how much solar radiation the ground loop will receive. Installers in Juneau stressed the importance of testing the soil at each GSHP location, as soil type in the Juneau area can change over a short distance. The soil type and presence of groundwater will affect the size of the ground loop. System designs are not standardized; thus having an experienced installer is invaluable. Most of the installers and industry professionals interviewed expressed the need for IGSHPA certification and manufacturer certification as the minimum requirements to be qualified to design and install successful GSHP systems. A number of tools are available to designers, such as software offered by heat pump manufacturers and soil thermal conductivity tests that can measure soil parameters at a given location.

A common error in colder climates is to make the ground loop small and the heat pump large, which results in increased electrical use and decreased efficiency (Dr. John Straube, personal communication, November 11, 2010). A Canadian desktop study confirms that the most common homeowner issues occur with poorly designed systems that result in thermal imbalance, where the soil cannot thermally recover, and low output temperature (Cottrell, 2009). As failed systems often receive more attention than successful ones, poor designs that result in long-term problems can make the technology unpopular. An appropriate design for a given location will result in a higher COP that is more sustainable over time.

The lack of long-term studies on cold climate GSHPs makes predicting their long-term performance difficult

A lack of data on long-term GSHP applications in cold climates makes the decision to install one difficult. The longest study on using a GSHP in Alaska focuses on the ability of a GSHP to cool soil and maintain permafrost—not to heat a building (McFadden, 2000). Other studies note that longer monitoring projects are needed to determine under what circumstances a GSHP will cause thermal degradation and whether the COP can be maintained for several years (Mueller & Zarling, 1996; Nielson & Zarling, 1983). The lack of long-term studies is not limited to Alaska. The U.S. Department of Defense recommends studying the long-term performance of heat pumps to facilitate growth of the GSHP industry, and identifies the need to assemble independent, statistically valid data on GSHP cost and benefits (DoD, 2007). A Manitoba study stated that long-term studies would be needed to assess that the COP can be sustained over the operating life of the heating system (Andrushuk & Merkel, 2009).

A few homeowners interviewed for this report have residential systems that have been in operation for more than ten years, with no noticeable decline in performance. However, no studies were found that addressed the economic benefits and heat pump performance over a period of several heating systems. This lack of data was a common complaint among installers, who need the information to promote the technology to customers and to help improve system design.

Recommendations

The following section represents the recommendations of the authors (in no particular order) in addressing knowledge gaps and research needs to further advance the understanding of ground-source heat pump (GSHP) application in cold climates, particularly in Alaska.

Focused Economic Analysis of GSHPs in Retrofit Construction

The economic analysis of this report was conducted under the assumption of new construction, as opposed to retrofit, given the complexity of project-specific considerations and the need for accurate comparison. While this assumption served well for establishing preliminary economic considerations, investigating the economics of retrofitting a building with a GSHP system is critical for further understanding the feasibility of GSHPs in Alaska. It is assumed, for instance, that capital and installation costs would be higher for retrofits, but this assumption merits investigation. How does this compare in the long term with upgrading the current heating system or overall building envelope? Certain government tax breaks and incentives, such as the Home Energy Rebate Program, target retrofit projects. How does this factor into the economics? Addressing these questions would help greatly in further assessing the feasibility of GSHPs in Alaska.

Increasing Certainty for Cost Estimation

The capital costs identified in the economic analysis of this report were given as estimates by various installers from around Alaska. Due to the limited deployment of GSHP systems, some installers have little experience specific to GSHPs, which may be reflected in the given capital costs. It is recommended that these costs be carefully monitored, especially as more systems are installed and the experience of the industry grows, so that future analyses may offer refined numbers for economic comparison. In addition, as a component of long-term project monitoring, operations and maintenance costs should be closely documented. This information is critical for an accurate understanding of the long-term costs associated with GSHP systems and for comparing GSHPs with alternative heating systems. Presently, limited data are available for residential or commercial-scale installations.

Role of GSHPs in State Renewable Energy Targets

In 2008, the State of Alaska set a renewable energy generation target of 50% by 2025, and has since completed a guidance document to frame Alaska's energy future (AEA, 2009). Ground-source heat pump systems have several specific characteristics that make them an intriguing technology for consideration in meeting these targets; for example, they have efficiencies over 100%[22] and the ability to displace fossil fuel used for space heating, and they are either partially or fully renewable (depending on the generation source for electricity). It is recommended, therefore, that the state further investigate the role that GSHPs have in meeting renewable energy-generation targets, particularly with regard to public policy.

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[22] Please see the discussion of coefficient of performance (COP) in the Heat Pump Technology Primer section of this report.

Implications of GSHP Deployment in Southeast Alaska

One finding from this report indicates that, in Alaska, GSHP systems are more viable where electricity costs are relatively low and heating costs are relatively high. Juneau, included in the economic analysis, displayed this relationship. These results can be roughly extrapolated to many other communities in Southeast Alaska that utilize hydropower to generate electricity and utilize fuel oil for heating purposes. Not addressed in this report are the potential ramifications of increased deployment of GSHP systems in these communities. Issues such as grid stability and capacity, supplemental or increased infrastructure costs, and relevant utility policy are examples of potential factors that need careful consideration to accurately assess the viability of GSHPs in a given community in Southeast Alaska. It is recommended, therefore, that potential GSHP-deployment stakeholders in relevant communities in Southeast Alaska carefully investigate integration ramifications of GSHPs if deployment of this technology is expected to grow.

Analysis of Air-Source Heat Pumps for Moderate Cold Climates

While not considered in this report, air-source heat pumps (ASHPs) are attractive for moderate climates because they do not require ground coupling, substantially reducing capital costs and infrastructure complexities when compared with GSHPs. Recent technological advances may challenge the assumption that ASHP systems are not appropriate for cold climates (Roth, Dieckmann, & Brodrick, 2009), especially for locations like Southeast Alaska that have relatively mild temperatures for building heating load. Roth, Dieckmann, and Brodrick (2009) estimate that the new ASHP designs could yield a slight savings over or have primary energy consumption similar to an oil-fired heating system for New York City, Chicago, and Minneapolis. Because several communities in Alaska that have a relatively mild climate also have relatively cheap electricity and expensive heating oil, a targeted analysis of ASHPs specific to these locations could help to determine whether ASHP systems represent a viable heating option.

Long-Term Cold Climate Efficiency and Thermal Degradation

There is insufficient clarity on the expected COP of cold climate GSHPs due to a lack of independently monitored GSHPs over periods greater than one to two years. A long-term monitoring period would last six to ten years. Is thermal degradation in a ground-loop field a long-term phenomenon not observable in the first several years of GSHP operation, or does this phenomenon result solely from improper system design? Can thermal degradation occur in ground-loop fields that contain flowing groundwater, or is this phenomenon confined to shallow loop fields above the water table?

Further complicating the understanding of cold climate GSHP efficiency is a lack of standardization of the COP as an efficiency metric. Monitored GSHP systems should include documentation of the system configuration, measurement of COP, ground temperatures, climate data, temperature of the conditioned space, and electrical demand for heat pump components other than the compressor unit. As a component of long-term project monitoring, operations and maintenance costs should be closely examined. This information is critical to an accurate understanding of the long-term costs associated with GSHP systems as compared with alternative heating systems.

While select GSHP installations merit monitoring to help elucidate these fundamental considerations, it is impractical to conduct detailed monitoring of a large sample size. Furthermore, it is anticipated that substantial variations in GSHP system performance will occur, depending on the ground source, climatic region, design goals, building use, and installation quality. To understand this variation, a long-term survey of GSHP installations across Alaska for basic operational metrics would help to establish performance expectations beyond a select few systems.

Investigation on the Necessity of GSHP Hybridization

Related to the recommendation for long-term monitoring of GSHP systems, research should address whether hybridization is necessary for cold climate applications of GSHPs. The installation of GSHP systems already suffers from high cost, which is increased with the inclusion of ancillary systems. In other words, do the extra capital costs for solar thermal systems, ground insulation, and other measures increase operating efficiency enough to warrant the expense? Performance data should be collected on hybrid systems and compared to data on non-hybrid systems in similar locations. In addition, ground temperatures should be monitored to discover if a hybrid system can prevent thermal degradation.

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Appendix A: Inventory of Alaska GSHP Installations

Tables A1 through A4 represent a comprehensive inventory of known residential and commercial-scale ground-source heat pump (GSHP) installations in Alaska. This information was collected through literature review, interviews, and survey methodology and is thus subject to the accuracy of the reporting entity. The inventory serves as a first-cut assessment of GSHP systems in Alaska, and is expected to increase in content and accuracy over time as more installations become known, more system information becomes available, and long-term instrumentation of systems occur. Due to project-specific information and complexity, the commercial-scale inventory is separated from the residential-scale inventory. An updated version of this database is on the ACEP website (www.uaf.edu/acep) and on the CCHRC website (www.cchrc.org).

Map of Alaska Residential and Commercial GSHP Systems

Figure A1 represents all residential and commercial-scale GSHP installations included in this inventory, depicted on a map of Alaska.

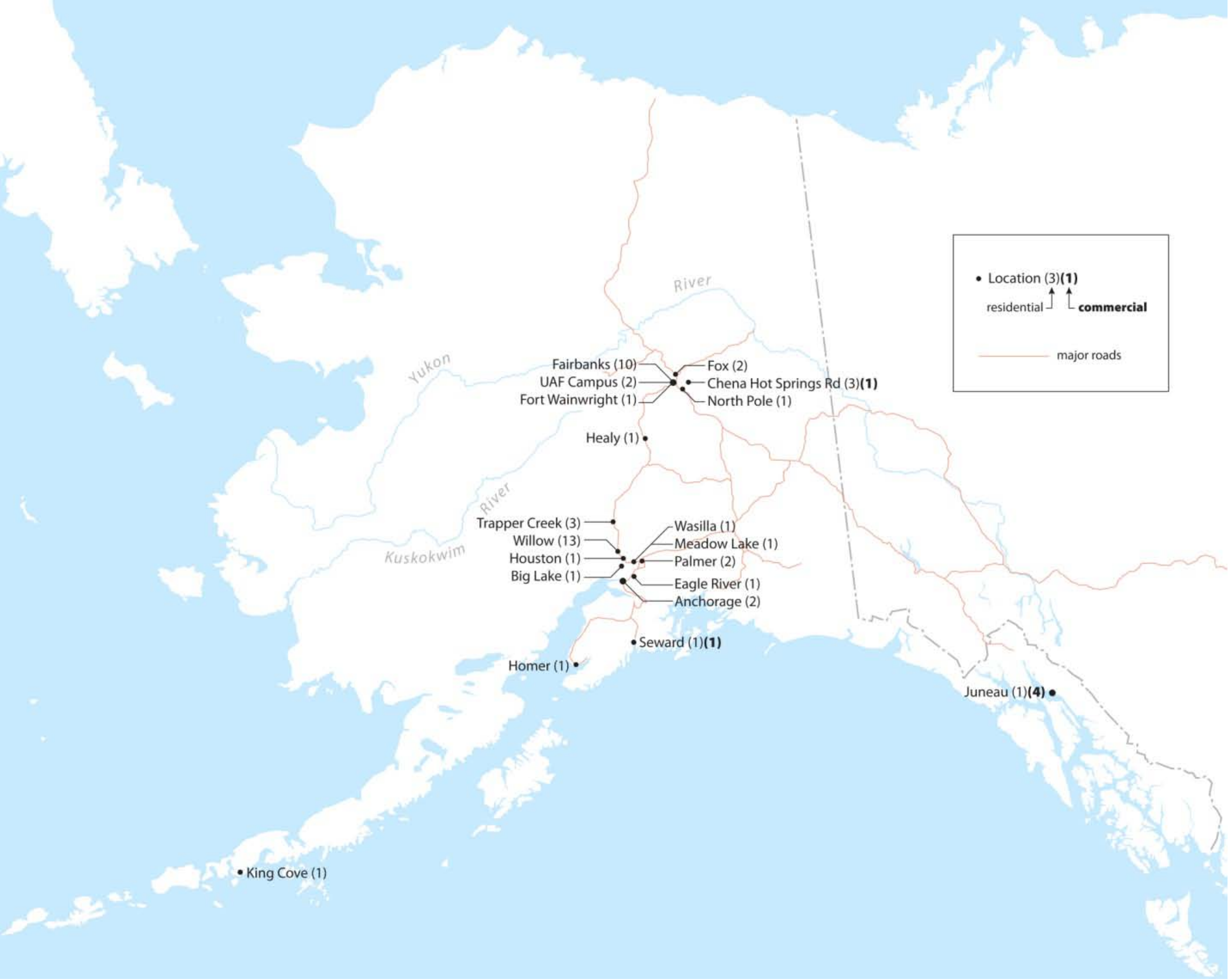

Figure A1: Previous and current ground-source heat pump systems of Alaska

Residential GSHP Inventory Categories

Reference Number	Randomly assigned installation identifier. Installations are listed in no particular order.
Location	General location of installation. In some cases, specific information is available upon request.
Application	Where/how the system is intended to be applied.
Space Area	Area heated by the heating system, in square feet.
Installation Date	If known, general date when system installation was finalized.
Involved Installer(s)	Identification of individuals or organizations that led or assisted in system installation.
Installation Type	The system is classified as either a new build (integrated with original home construction), or retrofit (integrated into the home-heating system after initial home construction).
Previous System	The primary heating source of the home prior to retrofit installation.
Manufacturer	The manufacturer of the installed heat pump.
Model	The specific manufacturer model of the installed heat pump.
Size	The designed size of the system in tons (tonnage reflects how much energy the system is capable of transferring. 1 ton equals 12,000 British thermal units [Btu] per hour).
Working Fluid	The working fluid that transfers heat from the source to the heat pump.
Flow	If available, flow rate of working fluid in gallons per minute.
Type	The system is classified as a horizontal or vertical system, with lake systems noted.
Sink	Identification of the heat source used by the ground loop.
Loop Type	The ground loop is classified as being open or closed.
Length	The overall length of the loop field, on the long axis, unless noted.
Material	Material of ground-loop piping: Polyethylene (PE), High Density Polyethylene (HDPE).
Depth	The average depth of the ground loop (horizontal) and the final depth of the well (vertical).
Pipe Size	Pipe diameter used for the ground loop, in inches.
Area/Number of Wells	The area of the horizontal ground loop, in square feet, or the number of wells used for a vertical system.
Soil Conditions	Report of the localized soil conditions where the ground loop is installed.
Heat Distribution	Indicates the general or specific type of heat distribution system within the home.
Desuperheater	The system is classified as either having a desuperheater (yes), or not having one (no).
COP	Reported coefficient of performance (COP).
EWT	Reported entering water temperature (EWT).
Notes	Other pertinent information available for the installation.

Commercial GSHP Inventory Categories

No. of units	Specific number of heat pumps used in the system.
Type of units	Specific type of heat pump used.
Manufacturer	The manufacturer of the installed heat pump.
System functions	Where/how the system is intended to be applied.
Loop configuration	The system is classified as a horizontal or vertical system, with open systems noted.
No. of wells	If known, the number of wells used for a vertical system.
Depth	The average depth of the ground loop (horizontal) and the final depth of the well (vertical).
No. of loop	If known, the amount of loops contained within the system.
EWT	Reported entering water temperature (EWT).
Flow	If available, flow rate of working fluid in gallons per minute.
Working Fluid	The working fluid that transfers heat from the source to the heat pump.

Alaska Residential GSHP Inventory

Table A1: Alaska residential GSHP inventory – Installation overview

Ref. #	Location	Application	Space Area	Installation Date	Involved Installer(s)
1	Eagle River	Home	1750 ft²	Jan-94	Water Heat Inc.
2.1	Palmer	Home	1700 ft²	Oct-92	Comfort Heat of Palmer
2.2	Palmer	Hot Water		Oct-92	Comfort Heat of Palmer
3	Meadow Lakes	Home	1600 ft²	Oct-93	Comfort Heat of Palmer
4	Trapper Creek	Home	1500 ft²	Oct-93	Water Heat Inc.
5	Trapper Creek	Home	2640 ft²	Aug-94	
6	Trapper Creek	Home	2640 ft²	Aug-94	
7	UAF Campus	Experimental	300 ft²	Aug-83	
8	UAF Campus	Experimental	300 ft²	Aug-83	
9	Willow	Home		May-08	Energy Efficiency Associates
10	Willow	Home		Oct-08	Energy Efficiency Associates
11	Willow	Home		Nov-08	Energy Efficiency Associates
12	Willow	Home/Hanger		Sep-08	Energy Efficiency Associates
13	Fairbanks	Home		Sep-09	Energy Efficiency Associates
14	Homer	Home		Aug-09	Energy Efficiency Associates
15	Willow	Home		Jul-09	Energy Efficiency Associates
16	Anchorage	Home		May-09	Energy Efficiency Associates
17	Houston	Home		Nov-09	Energy Efficiency Associates
18	Willow	Home	6000 ft²	Dec-09	Energy Efficiency Associates
19	Wasilla	Home		Sep-10	Energy Efficiency Associates
20	Anchorage	Home		In Process	Energy Efficiency Associates
21	Seward	Home		Oct-10	Energy Efficiency Associates
22	Willow	Home		Nov-10	Energy Efficiency Associates
23	Palmer	Home		Nov-10	Energy Efficiency Associates
24	King Cove	Home/Office		In Process	Energy Efficiency Associates
25	Fox	Home	3000 ft²	Oct-09	MCM Roe, Inc.
26	Fairbanks	Home	3500 ft²	Sep-08	MCM Roe, Inc.
27	Fox	Home	3000 ft²	Sep-08	Patrick Kohls
28	Fairbanks	Home	3400 ft²	Aug-09	MCM Roe, Inc.
29	North Pole	Home	4000 ft²	Aug-10	Darrel Bourne
30	Fort Wainwright	Home	2500 ft²	Aug-09	Trison - Oklahoma City, OK
31	Fairbanks	Home		Aug-09	Joe Brady
32	Chena Hot Springs Rd	Home	2000 ft²	2009	Jim Weidner
33	Chena Hot Springs Rd	Home	3000 ft²	2010	Patrick Kohls (ground loop) and Jim Weidner (heat pump)
34	Fairbanks	Home	2000 ft²		Bruce Dilbridge
35	Chena Hot Springs Rd	Heat make-up air, Weller School		Sep-10	MCM Roe, Inc.
36	Willow	Home	4000 ft²	Oct-08	Advanced Energy Systems
37	Willow	Home	4000 ft²	Sep-08	Advanced Energy Systems
38	Willow	Home	2800 ft²	Aug-08	Advanced Energy Systems
39	Willow	Home	4000 ft²	Aug-08	Advanced Energy Systems
40	Willow	Home	2800 ft²	Sep-08	Advanced Energy Systems
41	Willow	Home	2500 ft²	Jan-09	Advanced Energy Systems
42	Big Lake	Home	2500 ft²	Oct-09	Advanced Energy Systems
43	Juneau	Home		1996	
44	Fairbanks	Home			Joe Brady
45	Fairbanks	Home			Energy Efficiency Associates
46	Fairbanks	Home			
47	Fairbanks				
48	Fairbanks	Home		2009	Owner with help of Patrick Kohls

Table A2: Alaska residential GSHP inventory – Heat pump technical information

Ref. #	Installation Type	Previous System	Manufacturer	Model	Size	Working Fluid	Flow Rate
1			WaterFurnace	ATH045		Water/Methanol	
2.1			US Power	GSDX 04800	4 ton	HCFC-22	
2.2			US Power	GSDX 03000	2.5 ton	HCFC-22	
3			US Power	GSDX 04800	4 ton	HCFC-22	
4			WaterFurnace	WXW059	5 ton	Water/Methanol	
5			WaterFurnace	WXW059	5 ton	Water/Methanol	
6			WaterFurnace	WXW029	4 ton	Water/Methanol	
7			Cantherm Ltd.	DUO 500		R-22	
8			Command Aire	SWP-541		R-22	
9	Retrofit	Oil	WaterFurnace	EW 060	6 ton	Water/Methanol	
10	Retrofit	Oil	WaterFurnace	EW 060	6 ton	Water/Methanol	
11	Retrofit	Oil	WaterFurnace	EW 060	6 ton	Water/Methanol	
12	Retrofit	Oil	WaterFurnace	EW 060	6 ton	Water/Methanol	
13	Retrofit	Oil	WaterFurnace	EW 060	6 ton	Water/Methanol	
14	New		WaterFurnace	EW 042	4 ton	Water/Methanol	
15	Retrofit	Oil	WaterFurnace	EW060	6 ton	Water	
16	New		WaterFurnace	SDV064	6 ton	Water/Methanol	
17	New		WaterFurnace	EW060	6 ton	Water/Methanol	
18	Retrofit	Electric	WaterFurnace	EW042, SDV049	4 ton (x2)	Water/Methanol	
19	New		WaterFurnace	NSW050	5 ton	Water/Methanol	
20	Retrofit	Natural Gas	WaterFurnace	NSW060	6 ton	Water/Methanol	
21	Retrofit	Electric	WaterFurnace	NSW040	4 ton	Water/Methanol	
22	Retrofit	Oil	WaterFurnace	NSW060	6 ton	Water/Methanol	
23	Retrofit	Propane	WaterFurnace	NSW040 (x2)	4 ton (x2)	Water/Methanol	
24	New		WaterFurnace	NSW040	4 ton	Water/Methanol	
25	Retrofit	Oil	ECONAR	GW 880	8 ton	Methanol	
26	Retrofit	Oil	ECONAR	GW 110	10 ton	Methanol	
27	Retrofit	Oil	ECONAR	GW 880	8 ton	Methanol	
28	Retrofit	Oil					
29	New		ECONAR	GW 880	8 ton	Methanol	
30	Retrofit	Oil	ClimateMaster		6 ton		
31			ECONAR	GW 880	8 ton	Methanol	
32	Retrofit	Oil, Wood	ECONAR		5 ton		
33	Retrofit	Oil	ECONAR		8 ton	Methanol	50 gpm
34			WaterFurnace		5 ton		
35	Retrofit				5 ton	Methanol	
36	Retrofit	Oil	ECONAR	GW1100	10 ton	20% Methanol/Water	20 gpm
37	Retrofit	Oil	ECONAR	GW1100	10 ton	20% Methanol/Water	20 gpm
38	Retrofit	Oil	ECONAR	GW770	7 ton	20% Methanol/Water	18 gpm
39	Retrofit	Oil	ECONAR	GW1100	10 ton	20% Methanol/Water	20 gpm
40	Retrofit	Oil	ECONAR	GV780	7 ton	20% Methanol/Water	18 gpm
41	New		ECONAR	GV580	5 ton	20% Methanol/Water	13 gpm
42	New		ECONAR	GV580	5 ton	20% Methanol/Water	13 gpm
43	Retrofit		WaterFurnace	Hydronic			
44							
45	Retrofit						
46							
47							
48							

Table A3: Alaska residential GSHP inventory – Ground loop information

Ref. #	Type	Sink	Loop Type	Length	Material	Depth	Pipe Size	Area/# of Holes	Soil Conditions
1	Vertical	Ground	Closed	800 ft	PE	200 ft		4	
2.1	Horizontal	Ground	Closed		Copper	9 ft		1500 ft^2	
2.2	Horizontal	Ground	Closed		Copper	9 ft		375 ft^2	
3	Horizontal	Lake	Closed		Copper				
4	Horizontal	Lake	Closed	1500 ft	PE				
5	Horizontal	Ground	Closed	1000 ft		5 ft			
6	Horizontal	Lake	Closed	300 ft					
7	Horizontal	Ground	Closed	1000 ft	PE	3 ft			
8	Horizontal	Ground	Closed	1000 ft	PE	4 ft			
9	Horizontal	Ground	Closed	700 ft, 6 pipe trench	HDPE	7 ft	3/4		Damp Gravel
10	Horizontal	Ground	Closed	700 ft, 6 pipe trench	HDPE	7 ft	3/4		Damp Gravel
11	Horizontal	Ground	Closed	700 ft, 6 pipe trench	HDPE	7 ft	3/4		Damp Gravel
12	Horizontal	Ground	Closed	700 ft, 6 pipe trench	HDPE	5 ft	3/4		Wet Gravel
13	Horizontal	Ground	Closed	800 ft, 6 pipe trench	HDPE	7 ft	3/4		Damp Loam
14	Horizontal	Ground	Closed	500 ft, 6 pipe trench	HDPE	7 ft	3/4		Damp Gravel
15		Well	Open	180 ft	HDPE	7 ft	3/4		Water
16	Horizontal	Lake	Closed	300 ft (x12)	HDPE	8 ft	3/4		Water
17	Horizontal	Ground	Closed	700 ft, 6 pipe trench	HDPE	7 ft	3/4		Damp Gravel
18	Horizontal	Ground	Closed	800ft, 6 pipe trench	HDPE	7 ft	3/4		Damp Gravel
19	Horizontal	Ground	Closed	3600 ft	HDPE	7 ft	3/4		Damp Gravel
20	Horizontal	Ground	Closed		HDPE	7 ft	3/4		Damp Gravel
21	Horizontal	Ground	Closed	2400 ft, pit	HDPE	7 ft	3/4		Damp Gravel
22	Horizontal	Ground	Closed	700 ft, 6 pipe trench	HDPE	7 ft	3/4		Damp Gravel
23	Horizontal	Ground	Closed	800 ft, 6 pipe trench	HDPE	7 ft	3/4		Damp Gravel
24	Horizontal	Ground	Closed	600 ft, 6 pipe trench	HDPE	7 ft	3/4		Damp Soil
25	Horizontal	Ground	Closed	105 ft		9 ft	3/4	4600 ft^2	Fractured Schist
26	Horizontal	Lake	Closed	33 ft		12 ft	3/4	990 ft^2	
27	Horizontal	Ground	Closed	120 ft		9 ft	3/4	5000 ft^2	
28	Horizontal	Ground	Closed	100 ft		8 ft	3/4	4600 ft^2	Tanana Silt
29	Horizontal	Ground	Closed				3/4		Alluvial Gravel
30	Vertical	Ground	Closed			300 ft	1	3	Alluvial Gravel
31	Horizontal	Ground	Closed	100 ft (x10)		9 ft	3/4		
32	Horizontal	Ground	Closed	4000 ft	PE	6.5 ft	3/4	1440 ft^2	
33	Horizontal	Ground	Closed	8000 ft	PE	8 ft	3/4	2400 ft^2	
34	Horizontal	Ground	Closed				3/4		
35	Horizontal	Ground	Closed	105 ft (x6)		8 &12 ft	3/4	3570 ft^2	Fractured Schist
36	Horizontal	Ground	Closed	4000 ft	Trench	8 ft	3/4		Sand/Gravel/ Loam
37	Horizontal	Ground	Closed	4000 ft	Trench	8 ft	3/4		Sand/Gravel
38	Horizontal	Ground	Closed	2500 ft	Trench	8 ft	3/4		Sand/Gravel
39	Horizontal	Ground	Closed	4000 ft	Trench	8 ft	3/4		Loam/Gravel
40	Horizontal	Lake	Closed	1250 ft		12 ft	3/4		Water
41	Horizontal	Ground	Closed	3000 ft	Trench	8 ft	3/4		Sand/Gravel
42	Horizontal	Ground	Closed	3000 ft	Trench	8 ft	3/4		Sand/Gravel
43	Vertical	Ground/ Rock	Closed	720 ft	HDPE	90 ft		4	Rocky, no ground water
44					PE	200 ft		4	
45					Copper	9 ft		1500 ft^2	
46					Copper	9 ft		375 ft^2	
47					Copper				
48					PE				

Table A4: Alaska residential GSHP inventory – Other information

Ref. #	Heat Distribution	Desuperheater	COP	EWT	Notes
1	Forced air	Yes	3.37		"GSHP Monitoring" for MEA, by UAF
2.1	Forced air	No	3.89		"GSHP Monitoring" for MEA, by UAF
2.2	Radiant floor	Yes			"GSHP Monitoring" for MEA, by UAF
3	Forced air	No	3.98		"GSHP Monitoring" for MEA, by UAF
4	Radiant floor	Yes	2.95		"GSHP Monitoring" for MEA, by UAF
5	Radiant floor	No			"GSHP Monitoring" for MEA, by UAF
6	Radiant floor	Yes	3.03		"GSHP Monitoring" for MEA, by UAF
7	Radiant floor	No	2.3		"GSHP Demonstration" by UAF
8	Forced air	No	2.3		"GSHP Demonstration" by UAF
9	Radiant floor	Yes		32-40°F	
10	Radiant floor	Yes		32-40°F	
11	Radiant floor	Yes		32-40°F	
12	Radiant floor	Yes		32-40°F	
13	Radiant floor	Yes		32-40°F	
14	Radiant floor	Yes		32-40°F	
15	Radiant floor	Yes		32-40°F	
16	Radiant/warm air/AC	Yes		32-40°F	
17	Radiant floor	Yes		32-40°F	
18	Radiant/warm air/AC	Yes		32-40°F	
19	Radiant floor	Yes		32-40°F	
20	Radiant floor	Yes		32-40°F	
21	Radiant floor	Yes		32-40°F	
22	Radiant floor	Yes		32-40°F	
23	Radiant floor	Yes		32-40°F	
24	Radiant floor	No		32-40°F	
25	Radiant floor	No	3.4	34°F lowest recorded	COP measured 11/11/09
26	Radiant floor	Yes	3.0-3.3	33°F lowest recorded	Logged data available
27	Radiant floor	Yes		32°F lowest recorded	
28					Only loop field installed to date
29	Radiant floor				Forced air AC w/heat pump off
30	Radiant baseboard /slab	No		34°F	
31	Radiant floor				
32	Radiant floor	Yes		35°F	
33	Radiant floor	Yes			
34					
35	Forced air				
36	Radiant floor	Yes	3.5	29-42°F	
37	Radiant floor	Yes	3.5	29-43°F	
38	Radiant floor	Yes	3.5	29-44°F	
39	Radiant floor	Yes	3.5	29-45°F	
40	Forced air	Yes	3.7	45°F	
41	Forced air	Yes	3.7	29-45°F	
42	Forced air	Yes	3.7	29-45°F	
43	Radiant floor		2.2	30°F	
44					
45					
46					
47					
48					

Alaska Commercial GSHP Inventory

Juneau International Airport Terminal

The Juneau International Airport Terminal is undergoing a large renovation project to lower its operating costs by reducing electrical and heating demand. A large component of the renovations includes changing from heating oil to a GSHP system for the building's space heating and hot water needs. A motivating factor for this choice is the potential to reduce greenhouse gas emissions by removing the need for heating oil and using locally generated, renewable electricity (Fritz, 2008). While the expected maintenance costs for the GSHP system are higher than the costs for the former heating oil system, due to the need for additional maintenance personnel, overall operational costs are expected to decrease due to lower energy costs (Fritz, 2008). The estimated cost for the airport renovation project is over $50 million (Fritz, 2008). The new heating system is expected to save about $80,000 per year in operating costs, while avoiding the cost increases expected for heating oil prices (Catherine Fritz, personal communication, October 2010).

The Juneau airport terminal will include a large maintenance building to house emergency equipment and other operational equipment. At the time of writing this report, planners intend to heat the additional space with a GSHP system, using a horizontal-loop system located in an unused part of the airport grounds.

Technical specifications

No. of units	31	**Loop configuration**	Vertical and horizontal
Type of units	28 water-to-air 3 water-to-water	**No. of wells**	108
		Depth	350 feet
Manufacturer	Climate Master McQuay	**No. of loop**	3 (room for one more)
		EWT	39-45°F
System functions	Space heating/cooling, sidewalk ice melt, 7500 ft²	**Working Fluid**	Water and ethanol solution

Left: Drilling for ground loop at the Juneau Airport. Right: Water-to-water heat pumps.

Dimond Park Aquatic Center, Juneau

Construction of this new facility is presently nearing completion, including the commissioning of a GSHP system. This project is a unique application of GSHP, as there are no known reports of a GSHP system being used to heat a large body of water such as a pool (Doug Murray, personal communication, October 2010).

This project is closely related to the Juneau International Airport Terminal GSHP installation, as both projects, which are public facilities, were designed by the same people, obtained funds from the AEA, and had ground loops drilled by the same company.

Technical specifications

No. of units	1 water-to-water 7 water-to-air	**Loop configuration**	Vertical
		No. of wells	164
Manufacturer	Carrier Climate Master	**Depth**	350 feet
		No. of loops	5
System functions	Pool heating Space heating	**Working fluid**	Water/methanol solution

Above: Drilling at the Dimond Park Aquatic Center

AEL&P Offices, Juneau

The Alaska Electric Light and Power Company (AEL&P) installation is unique for Alaska applications of heat pump technology. This installation, completed over 16 years ago, has operated with relatively few problems since its commissioning. Only one heat pump unit and two compressors have required replacement. When this GSHP system was installed, no other successful commercial installation and relatively few residential systems existed. As an electric utility, AEL&P's motivation for installing the heat pumps was to promote the technology over electric resistance heating, as the latter requires too high an electrical load (Gayle Wood, personal communication, October 2010).

Technical specifications

No. of units	20 water-to-air 1 water-to-water	**Loop configuration**	Vertical
		No. of wells	Over 200
Manufacturer	Water Furnace	**Depth**	Unknown
System functions	Space heating (20 units), DHW (1 unit)	**No. of loops**	5
		Working fluid	Water/methanol solution

Left: Water-to-air heat pump units in the attic. Right: Circulating pumps.

NOAA Auke Bay Laboratories, Juneau

The NOAA Auke Bay Laboratories facility, which was commissioned in 2007, houses research laboratories and offices. Initially, the building used an oil-fired boiler for central heating, which, along with the ventilation system, was oversized and cost around $500,000 per year. As a federal government facility, the Auke Bay Labs were required to meet energy-reduction targets. This requirement was partially achieved by the installation of open-loop water-source heat pumps. Because the laboratory tanks require continuous cycling of seawater, drilling or additional pumping infrastructure to establish a ground loop was unnecessary; only the diversion of outgoing seawater through a heat exchanger (John Cooper, personal communication, October 2010).

Presently, two 90-ton heat pump units are being commissioned to serve as a test of this heating method. If successful, a third heat pump will be installed and possibly a large thermal storage tank. The new system will be monitored to evaluate the project's success. Expectations are that the heat pump system will significantly reduce operating costs of the facility. Because of the relatively low installation cost for the heat pump system, a short payback period is expected (John Cooper, personal communication, October 2010).

Technical specifications

No. of units	2	**Loop configuration**	Water-source
Type of units	Water-to-water		Open-loop
Manufacturer	Carrier	**Flow rate**	1,200 gal/min
System functions	Space heating, cooling	**Working Fluid**	Propylene glycol
		EWT	Approximately 45°F

Left: Water-to-water heat exchanger. Right: Seawater treatment pumps.

Alaska SeaLife Center, Seward

The Alaska SeaLife Center is installing two seawater heat pumps under the Emerging Energy Technology Grant program, funded by the Denali Commission and the State of Alaska Renewable Energy Fund program. The goal of the project is not only to increase the energy efficiency of the SeaLife Center, but also to evaluate the feasibility of alternate energy sources over conventional oil and electric heaters.

While heat pump technology has been successfully deployed in Europe, this innovative process of removing latent heat from seawater and using it to heat buildings is an emerging technology in Alaska. The seawater heat pump required for this process is not an "off the shelf" or conventional heat pump. While conventional heat pumps typically lift heat from 45–55°F water sources, seawater heat pumps lift heat from lower temperatures, requiring more innovative compressor technology.

The budget for this project, scheduled for completion by June 2011, is approximately $850,000. An initial feasibility study showed that two heat pump units could supply about 38% of the SeaLife Center's total heating load and have a payback period of 10 years (Andy Baker, personal communication, November 2010).

Technical specifications

No. of units	2	**Loop configuration**	Water-source
Type of units	Water-to-water		Open-loop
Manufacturer	Trane	**Flow rate**	700 gal/min
System functions	Space heating	**EWT**	37-52°F

Above: Heat pump units installed and ready for connections, 3-18-11

Weller Elementary School, Fairbanks

The Fairbanks North Star Borough School District is in the process of installing a residential-sized GSHP at Weller School as a test of technology. At Weller School, the heat pump will pre-heat supply air for the building ventilation system. The GSHP test system includes a solar thermal hybrid component that will help thermally recharge the GSHP ground-loop field. The CCHRC is monitoring the ground temperatures and GSHP COP as a research project. The School District is watching the project closely to see if the technology will be feasible for other schools in the district (Larry Morris, personal communication, January 25, 2011).

Technical specifications

No. of units	1	**Loop configuration**	Ground-source
Type of units	Water-to-air		Closed-loop
Manufacturer	Climate Master		
System functions	Ventilation supply air pre-heating	**Working Fluid**	40% ethylene glycol and 60% water

Left: Preparation of "slinky" ground loops. Right: Solar thermal collectors for hybrid GSHP.

Appendix B: List of Interviewees

As part of the research for this report, authors interviewed homeowners, industry professionals, and energy researchers. All these individuals contributed knowledge and perspectives to the report, and the list below reflects the variety of people involved in the cold climate GSHP market.

Name	Company	Location	Experience
Walter Adolphs	Advanced Energy Systems	Willow, Alaska	Adolphs is part-owner of Advanced Energy Systems. They have been involved in several GSHP installations. Adolphs also has a GSHP at his residence.
Gordon Bartel	BC Excavating, LLC	Anchorage, Alaska	BC Excavating, LLC is primarily an excavating company but they have been installing GSHP systems since 1992. Bartel is the president of the company.
Peter Bibb	AEL&P	Juneau, Alaska	Bibb was the head engineer for AEL&P during their GSHP installation and also has a GSHP in his home.
John Cooper	Auke Bay Labs	Juneau, Alaska	Cooper is the facility manager at Auke Bay Labs and is in charge of the heat pump they are installing.
Cathy Cottrell	Energy Solutions Centre	Whitehorse, Yukon Territory, Canada	Cottrell is a senior energy advisor with the Energy Solutions Centre of the Yukon Government Department of Energy, Mines and Resources.
John Dibble	Climate Master, Inc.	Sandpoint, Idaho	Dibble is the Western Regional Manager for the Western U.S. and Canada.
Sean Dillon	Water Furnace	Seattle, Washington	Dillon is the Western Regional manager for Water Furnace International.
Clint Elston	Equaris Corporation	Afton, Minnesota	Elston used a heat pump to heat his home in Healy, AK, for 13 years.
Dudley Field	Homeowner	Juneau	Field has installed heat pumps in his house and in his apartment/shop. The heat pump for his house has been in use for over 10 years.

Catherine Fritz	City of Juneau	Juneau, Alaska	Fritz is the architect and project manager for the Juneau airport renovation.
Pat Hamilton	Science Museum of Minnesota	St. Paul, Minnesota	Hamilton is the Director of Global Change Initiatives for the Science Museum. He was in charge of the design and construction of the Science House at the Science Museum of Minnesota.
Kirk Jackson	Fairbanks Plumbers and Pipefitters	Fairbanks, Alaska	Jackson is an IGSHPA installer trainer.
Patrick Kohls	Westwind Construction	Fairbanks, Alaska	Kohls is a contractor and has installed 5 heat pumps in the Fairbanks area. His own GSHP has been heating his home for 3 years.
Juergen Korn	Yukon Housing Corporation	Whitehorse, Yukon Territory, Canada	The Yukon Housing Corporation provides low interest loans to homeowners wishing to do repairs or retrofits.
Greg Lehmiller	Homeowner	North Pole, Alaska	Lehmiller installed a heat pump in his residence in May 2010 and is using it for both heating and cooling.
Larry Morris	Fairbanks North Star Borough School District	Fairbanks, Alaska	Morris is the facilities project manager for the Fairbanks North Star Borough School District.
Doug Murray	Murray and Associates, P.C.	Juneau, Alaska	Murray and Associates is an engineering firm that has experience with commercial and residential GSHP installations.
Hans Nielsen	University of Alaska	Fairbanks, Alaska	Dr. Nielsen participated in GSHP studies at UAF in the 1980s.
Rorik Peterson	University of Alaska	Fairbanks, Alaska	Dr. Peterson is a mechanical engineer who is currently researching the frost heave of soils.
Ron Pichler	Denali Drilling, Inc.	Anchorage, Alaska	Pichler is the president of Denali Drilling, which has been in business for over 40 years. They have been involved in installing vertical GSHP systems.
Jim Rehfeldt	Alaska Energy Engineering LLC	Juneau, Alaska	Rehfeldt has been involved in the design and installation of several commercial ground source and seawater heat pump systems in the Juneau area.

Chuck Renfro	Energy Efficiency Associates	Anchorage, Alaska	Renfro currently operates a business installing GSHPs. He is the former director of the Alaska Craftsman Home Program.
Andy Roe	MCM Roe, Inc.	Fairbanks, Alaska	Roe designs and installs GSHPs in Fairbanks.
Eric Sanford	MEA	Anchorage, Alaska	Sanford is the director of engineering at MEA.
Bill Semple	Canada Mortgage and Housing Corporation	Ottawa, Ontario, Canada	Semple is a senior researcher with CMHC. His work focuses on developing and promoting culturally appropriate super energy efficient housing in the North.
Aaron Sirois	PDC Inc. Engineers	Anchorage, Alaska	Sirois worked on the design of the Weller School heat pump in Fairbanks. It was PDC's first GSHP design.
Chad Spencer	Mike's Refrigeration and A/C Company	Juneau, Alaska	Spencer is the head technician who works with GSHP at Mike's Refrigeration. He has helped with the installation of over 30 GSHP systems.
John Straube	Building Science Consulting, Inc.	Waterloo, Ontario, Canada	Straube is a building science professor. His research focuses on sustainable buildings.
Darwin Thompson	Homeowner	Fairbanks, Alaska	Thompson installed a GSHP in his home during the summer and fall of 2010.
Jim Weidner	Homeowner	Fairbanks, Alaska	Weidner has been using a GSHP in his home for 2 years.
Roy Whiten	Green Heat	Whitehorse, Yukon Territory, Canada	Whiten is an HVAC contractor and Green Heat is an alternative energy company offering a utility based model to offset the consumer's initial capital cost.
Gayle Wood	AEL&P	Juneau, Alaska	Wood is the director of consumer affairs for AEL&P.
John Zarling	University of Alaska	Fairbanks	Dr. Zarling was the author of several heat pump studies in Alaska in the 1980s and 1990s.

Appendix C: Summaries of Selected Literature

A large range of literature was reviewed for this report, and short descriptions of each of these studies appear in the annotated bibliography (Appendix D). Some of the literature reviewed proved to be especially applicable to heat pump use in Alaska. These studies are summarized in the following sections. The first section, Alaska Studies, discusses the seven GSHP studies done in the state. The second section is a selection of cold climate literature, which serves to complement the Alaska studies while addressing GSHP in other cold climate locations.

Alaska Studies

Seven published academic studies on GSHP in Alaska document research done throughout the state over the past 35 years. These studies (see Table C1) range from calculations and assessments on feasibility (Zarling, 1976) to a long-term study on using heat pumps to stabilize a foundation (McFadden, 2000).

Table C1: Alaska GSHP studies

Year of Publication	Author	Location	Organization
1976	Zarling	Fairbanks	University of Alaska, Fairbanks
1980	Jacobsen, King, Eisenhauer and Gibson	Juneau	Alaska Power Administration
1983	Nielsen and Zarling	Fairbanks	University of Alaska, Fairbanks, Alaska Energy Center
1984	Juneau Water Source Heat Pump Program	Juneau	Alaska Power Administration
1994	Williams and Zarling	Fairbanks	Rural Electric Research Project
1995	Mueller and Zarling	Anchorage	Matanuska Electric Association
2000/2007	McFadden	Fairbanks	Permafrost Technology Foundation

The first two publications are theoretical studies on the feasibility of heat pumps in the authors' respective locations (Fairbanks and Juneau). In his report "Heat Pump Applications in Alaska," Zarling considers an air-to-air heat pump system for the average Fairbanks home and a water-to-air heat pump system installed at the Fairbanks wastewater treatment facility. The wastewater treatment plant used the treated water before discharge as a low-temperature heat source. Calculations showed that this heat-recovery system would achieve a two-year payback period with the predicted seasonal performance factor (SPF) of 3.7. The system had the added benefit of reducing ice fog in the winter, which was important because the wastewater treatment plant was located near the Fairbanks International Airport. The plant later had to shut down its heat pump because of corrosion in the evaporator that was caused by chlorine and sulfides in the effluent (Martel & Phetteplace, 1982), but

Zarling's study provided a first look at the feasibility of heat pumps in cold regions. Jacobsen et al. (1980) evaluated water-source heat pumps (WSHP) for residential, commercial, and industrial heating in Juneau for the Alaska Power Administration. The authors studied both the technical and economic aspects of WSHP viability by contacting manufacturers to identify price, specifications, and availability of WSHPs; conducting a literature review and interviewing experts on using seawater as a heat source; and considering four case studies that represented different areas in Juneau and applications of a WSHP. Selected details on these case studies are summarized in Table C2.

Table C2: Juneau case studies (Jacobsen, King, Eisenhauer, & Gibson, 1980)

Location	Mendenhall Valley Residence	Auke Bay Lab Filter Building	Juneau waterfront warehouse	Snettisham Salmon Hatchery
Outdoor design temperature (°F)	-15	-5	-5	-20
Indoor design temperature (°F)	70	60	60	45/70
Heat Source	Groundwater	Sea water	Sea water	Water from tailrace of hydroelectric project
Calculated COP (includes energy to pump water)	2.25	2.4	2.3	2.5
Anticipated Technical Problems	None	Possible fouling but sand filter already in place	Possible fouling but chlorinator would be used	None
Lowest levelized life cycle cost calculated (10 year period)	ASHP ($2283)	Oil furnace ($3208)	Oil furnace ($11,155)	Direct Electric Resistance ($9640)
Levelized life cycle cost (10 year period) for WSHP	$3092	$3254	$13,749	$10,516

For each case study, the heat load was calculated and the preliminary WSHP system was designed. Authors also calculated life cycle costs (installation, operation, and maintenance) for various heating systems for each case study, and accounted for the cost of projected inflation. The levelized cost (the present worth of the system over a period of interest) over a ten-year period was reported for ease of comparison. Of the case studies, the Mendenhall Valley Residence was a hypothetical residence that was taken to be typical of homes in the area. The Auke Bay and Juneau waterfront buildings were pre-existing, and the Snettisham Salmon Hatchery was being designed at the time of the report. Based on these case studies, the literature review, and manufacturer interviews, the study concludes that WSHPs are technically viable for the Juneau area, provided prospective water sources are evaluated on a case-by-case basis and life-cycle heating costs are comparable to those of other heating systems used in the area. The authors note that proper design of a WHSP system is paramount and that fossil fuel reduction is possible in the Juneau area; they conclude by stating that the results should be verified by a field demonstration.

The remaining reports are field demonstrations of heat pumps throughout the state. The first report, published in 1983, investigated the feasibility of GSHPs for home heating in Fairbanks. “Ground Source Heat Pump Demonstration,” authored by Nielsen and Zarling, discusses the results of using two commercially available heat pumps to heat a trailer located at the University of Alaska Fairbanks. Both heat pumps were connected to horizontal-loop heat exchangers buried at shallow depth (3 feet) in silt. The shallow depth was chosen on recommendation from AGA-Thermia, a Swedish heat pump manufacturer that recommended burying the pipes at shallow depths to allow quicker thermal recovery of the soil during summer. The heat pumps, installed in 1981, were in operation for 1½ years. The measured COPs ranged from 2–3 which was lower than expected and may have been due to warm air temperatures in the trailer, which were higher than a typical home because the two heat pumps were oversized for the trailer’s heat demand. The thermal response of soil was favorable: ground temperatures did not become as low as expected in the winter, and snow on the ground above the ground loops melted at the same time as snow on the ground not located near them.

The Juneau Water Source Heat Pump Program Final Report (APA, 1984) discusses two water-to-air residential heat pumps (Table C3) in a follow-up study to a prior study on ASHPs (APA, 1982).

Table C3: APA case studies (APA, 1984)

	Type	Heat Source	Installed in	Average COP	SPF
Residence 1	Water to air	Seawater	1981	2.53	2.20
Residence 2	Water to air	Seawater	1984	-	-

The first heat pump was installed prior to the study, and researchers monitored electrical use and heat output. The second heat pump was installed just prior to the study’s report, so its COP and SPF were not calculated. The report notes that while the installation costs are higher for a heat pump than for an electric heat or fuel oil system, the annual operating cost for the heat pump was lower than for the other systems (60% lower than electric heat and 45% lower than fuel oil). No maintenance problems were reported in the study.

The Matanuska Electric Association (MEA) also sponsored a study (Mueller & Zarling, 1996) to monitor heat pump performance in their service area near Anchorage. The MEA’s motivation was to inform customers about the reliability and economics of residential GSHPs. The sites included in the study, which are summarized in Table C4, were monitored during winter 1994–95.

Table C4: MEA case studies (Mueller & Zarling, 1996)

Location	Heat Source	Heat delivery	Annual COP	Annual COP (with desuperheater)
Trapper Creek	Soil	Radiant floor	2.44	3.03
Trapper Creek	Lake water	Radiant floor	2.16	2.95
Eagle River	Soil	Forced air	3.07	3.37
Palmer	Soil	Forced air	3.89	-
Wasilla	Lake water	Forced air	3.98	3.31

No effect on lake temperatures was observed on the sites that used lake water as a heat source. The soil froze at the three sites that used a ground loop in the soil, as indicated by temperature probes. The authors state that recovery would be necessary in the summer to maintain the observed COP, and a longer study is needed to study the long-term effect on the soil. No maintenance problems were reported. While the authors do not discuss the large range of COPs or any trends from their data, it should be noted that the study monitored existing systems in the MEA district to collect data for forming a general basis on which MEA could inform customers about the reliability of using a GSHP. Data were not collected on installers or home efficiency and insulation, and it cannot be assumed that these variables are constant for each location.

The remaining two studies discuss different applications of GSHPs. Williams and Zarling published "Thermosyphon-coupled Heat Pumps: Final Report" in 1994. In this study, they tested the new geothermal concept of using a heat pipe as the geothermal heat exchanger (GHE) so that only nontoxic fluids could be used. The heat pipe, which is a technology traditionally used to maintain permafrost, uses CO_2 to move heat from the ground to the surface. Researchers installed a GSHP fitted with heat pipes instead of a ground loop at a house 5 miles north of Fairbanks and monitored the system during winter 1993–94. Other than leaks in the heat pipe, the heat pump system, which provided back-up heat for the electric heating system, experienced few maintenance problems. The authors concluded that a COP of 2.0 could be expected for this system, but that a COP of 3.1 would be necessary for the GHSP to be as financially attractive as other heating methods. The heat pipe reliably provided a 30°F fluid temperature to the heat pump regardless of the outdoor air temperature. However, a numerical simulation showed that any further increase in the heating load would cause a growth in the area of frozen soil and necessitate either a longer heat pipe or additional heat pipes to prevent such a change.

The final study was published by the Permafrost Technology Foundation (PTF). In 1992, the PTF installed a heat pump with ground heat exchangers underneath a house located in Fairbanks in an attempt to maintain the thaw-unstable permafrost underlying the house. The primary function of this GSHP was to prevent the permafrost from thawing, although waste heat from this application was used as a supplementary heating system. In the summer, waste heat was diverted outside of the house. The house was re-leveled upon installation of the heat pump, and during the eight years of monitoring, the system lowered the soil temperature and prevented any large changes in elevation of the house foundation. The authors concluded that GSHP technology was "very promising" when used in this manner. A supplemental report was published in 2007. So much heat had been removed from the soil that frost heave had occurred since the 2000 study was published. Researchers installed zone-control valves to prevent the soil from becoming too cold, and concluded that, with diligent monitoring, a GSHP system is still a promising option for stabilizing a foundation located on permafrost by removing heat from the ground. Maintenance problems occurred during both phases of the study, including problems with the thermostat and leaks in the ground loop. The heat pump itself failed once, after eleven years of use.

Cold Climate Literature

Looking beyond the studies conducted in Alaska, several articles on GSHPs in cold climates throughout the world appear in the literature. Articles reviewed for this report appear in the annotated bibliography

(Appendix D). Note that these articles are limited to ones written in English. A selection of studies that complement Alaska studies is listed in Table C5 and discussed below.

Table C5: Cold climate studies

Year of Publication	Author	Location	Organization
1995	Lienau et al.	Contiguous U.S.	Oregon Institute of Technology
2000	Cane & Garnet	Cold Climates worldwide	CADDET
2003	Phillips & Stanski	Winnipeg, Canada	UNIES, Ltd.
2006	Lessoway Moir Partners	Yukon, Canada	Energy Solutions Centre
2008	Instanes & Instanes	Norway	
2007	Steinbock et al.	Minnesota	Science House
2009	Andrushuk & Merkel	Manitoba, Canada	Manitoba Hydro
2010	Bakirci	Erzurum, Turkey	Atatürk University

Studies by Lienau et al. (1995) and Cane and Garnet (2000), who surveyed existing GSHP systems, are included because of their depth. Lienau et al. (1995) synthesized existing monitoring data on heat pump performance, collecting information on 256 GSHP systems (residential, commercial, and schools) and 60 DSM electric utilities and RECs throughout the contiguous U.S. The study also monitored sites with conventional energy systems for comparison. While not all of these sites were located in cold climates, the study provides an introduction on GSHP performance expectations. The authors, who noted that it is very difficult to compare individual GSHP systems with each other, instead identified 31 variables that affect system performance, including climate, soil conditions, and equipment efficiency; gathered data on the basic parameters of each system; and then looked for patterns in the data. While readers should use caution in using these results to draw economic conclusions because of the large number of variables that affect each system, the authors did report trends identified from the case studies. They found that average annual energy savings of a residential GSHP ranged from 31% to 71%. For commercial GSHPs, the energy savings ranged from 40% to 72% when compared with the conventional systems from the survey. For residential systems, the mean payback was 6.8 years (Lienau, Boyd, & Rogers, 1995). The utilities and RECs identified several marketing techniques, primary market barriers, and common incentives offered to customers. While the study concludes that GSHPs are an effective means to reduce customer energy consumption and electric peak loads, the authors caution that GSHP performance is influenced by ground characteristics and climate, and encourage potential customers to perform their own economic analysis to ensure that they can recover capital cost in their region (Lienau, Boyd, & Rogers, 1995).

A second survey, Cane and Garnet (2000), considers commercial buildings in cold climates. Aimed at end-users and design professionals, the study presents readers with information on performance, economics, and environmental benefits of GSHPs in locations with a significant heating load. As design of the GSHP system is an important determinant of efficiency and dependent on many factors, the report includes detailed descriptions of 15 systems located in Canada, Norway, the United States, Japan, and The Netherlands. The systems represent a variety of energy sources that include both ground- and water-source heat pumps. From an analysis of these 15 demonstration systems, the authors establish a number of trends on GSHP use in a commercial setting. A number of advantages of GSHP installation are identified, including operating cost reduction, year-round heating and cooling, potential environmental benefits, architectural flexibility, and lower maintenance costs. In the U.S., the average annual energy use of the demonstration projects was 51% of the national average for commercial buildings, and the average payback period for the demonstration projects was 5.2 years (Cane & Garnet, 2000). While the report is a compilation of results from heat pump applications in locations with similar climatic conditions, the authors note that many region-specific factors should influence the decision to install a heat pump, such as local building codes, tax regimes, availability and price of heat pumps, and the regional price of energy.

Two of the articles are monitoring studies from Canada: Phillips and Stanski (2003) authored a study that monitored the use of GSHP in four energy-efficient residences in Winnipeg, Manitoba, and Andrushuk & Merkel (2009) monitored GSHPs of ten homes in the Manitoba province. Because about 200 units per year are installed in Manitoba, the Winnipeg study focused on their feasibility in the urban context of closely spaced houses (Phillips & Stanski, 2003). Vertical ground loops were installed because the four test houses were duplex units on small lots. The heat pumps were monitored from April 2002 to July 2003. The heating season system COPs were in the range of 2.6 to 2.8 when there were no problems, although the COP declined slightly over the course of the heating season. Equipment problems, lack of proper maintenance, and thermostat problems were found to reduce the COP; however, by monitoring the data, authors were alerted to the problems so could fix them promptly. Because of this experience, authors recommend proper maintenance and close monitoring of systems.

The Manitoba study monitored a larger number of homes with a variety of locations and heat pump designs. The ten homes were located throughout Manitoba, and included horizontal, vertical, open well, and lake loop systems. The average heating season system COP was 2.8, with the GSHP systems providing from 97% to 100% of the heating energy required by the homes. Andrushuk and Merkel (2009) discuss the thermal imbalance created in the ground. At 5 to 1 in favor of heat taken out during the winter to heat rejected to the ground loop in the summer, the authors note that this condition could result in a decline in performance. As all of the monitored homes had relatively new systems, between one and three years old, a longer monitoring study is needed to assess long-term performance (Andrushuk & Merkel, 2009). Conclusions of the study were that a GSHP produces significant energy savings in the Manitoba climate when compared with electric resistance heat, but the cooling savings were not significant when compared with central air conditioning (Andrushuk & Merkel, 2009).

The goal of the Science Museum of Minnesota in building the Science House was to create a net-zero energy building in a cold climate. Located in the Museum's outdoor science park, the Science House (1690 square feet) is home to the Museum's Teacher Resource Center. Science House employs passive solar heating, daylighting, roof-integrated photovoltaic (PV) panels, spray foam insulation, and a GSHP with a COP of 3.1 to meet its energy goals (Steinbock, Eijadi, & McDougall, 2007). Construction of Science House began in October 2002 and was finished in June 2003. Major interior remodeling was done in 2007 to accommodate the needs of the Teacher Resource Center. The GSHP heats the building in the winter and cools it in the summer, and has a desuperheater to supplement the DHW. An electric resistance heater provides back-up heating in case of failure of the GSHP. The heat pump unit has failed twice: in January 2004, it was under warranty and a faulty compressor was replaced; in December 2009, the Museum absorbed the cost of repair. Equipment failures and greatly increased building occupancy have resulted in the Science House missing its goal of operating as a zero-emissions building in recent years. Energy efforts are underway to trim electricity consumption by 10% in 2011, which if successful would bring energy production and consumption back into balance. Detailed monitoring of Science House's energy production and consumption has been ongoing since February 2004 and continues.

The data in Figure C1 are taken from the GSHP installed at the Science House, which is situated less than 500 feet from the Mississippi River. Daily minimum ground-loop exit temperatures as well as annual heating degree-days are plotted over a seven-year period. Temperatures in excess of about 60°F reflect periods when the heat pump is not operational, and should not be construed as an accurate measure of ground temperature. Of note, years with the lowest recorded exit temperatures tend to correspond with cooler years. Further, ground temperatures tend to increase in late winter and early spring prior to the seasonal switch to heat pump cooling. These two points indicate that no appreciable degradation of the ground temperature resource. Given the proximity to the Mississippi River, it is highly likely that the ground loops are situated in flowing groundwater. However, information on the area's hydrology is needed to confirm this speculation.

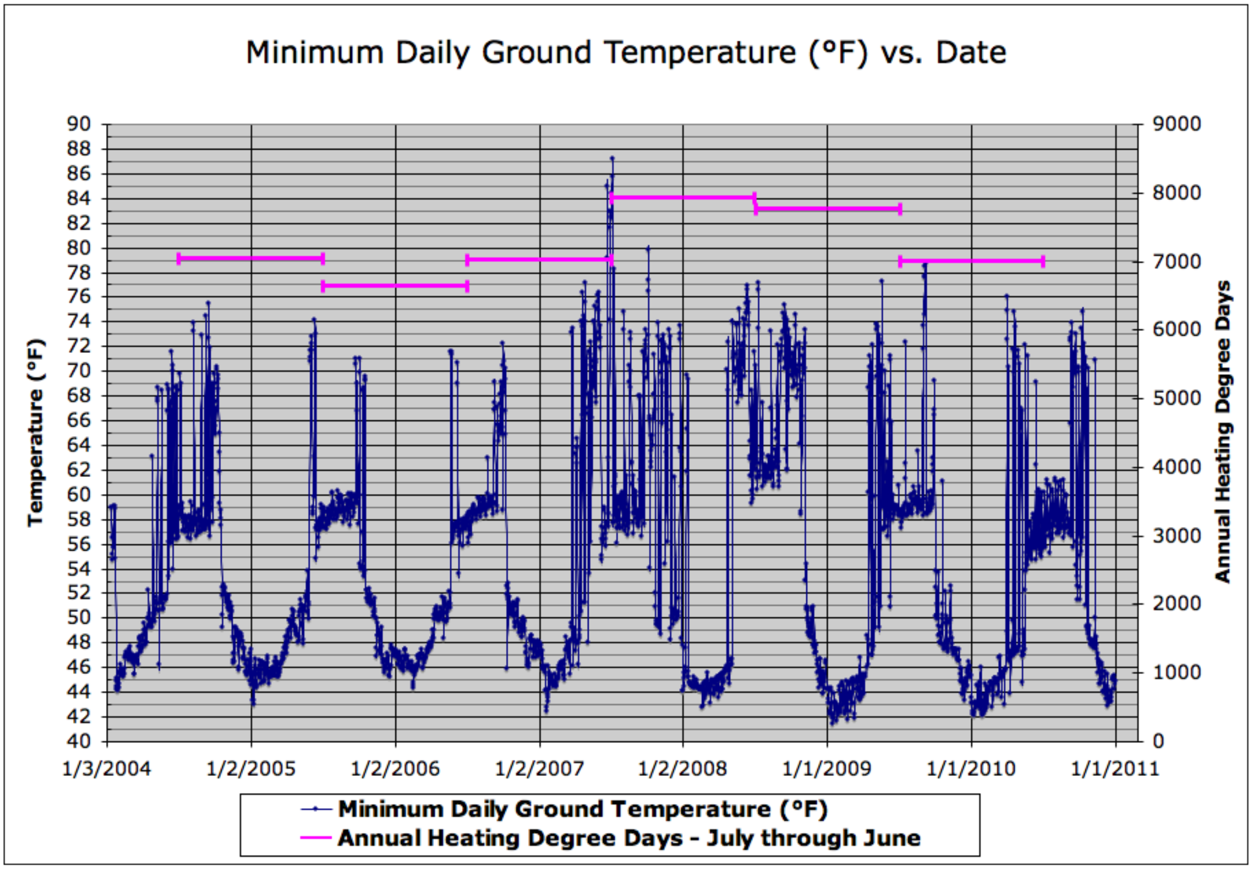

Figure C1: Science House Data

Bakirci (2010) provides another experimental study on a GSHP with a vertical ground loop located in Erzurum, Turkey, which has 8766 heating degree-days (in °F with a 65°F basis). Researchers monitored the performance of a GSHP with a vertical ground loop from October 2008 to May 2009 and found a system COP of 2.6 during the coldest months. The average system COP was 2.7 over the entire testing period. The authors speculated that poor design accounted for a low COP when compared with advertised COPs of 3 to 4; however, they did not observe a reduction in ground temperature over the course of the year and note that the system could be used for residential heating in the province.

Lessoway Moir Partners (2006) also monitored a hybrid system. The hybrid heating system, which is installed at a well-insulated 2700-square-foot house in Whitehorse, Yukon, consists of a geothermal loop, solar panels, a solar wall, and a heat-recovery ventilator. These multiple heat sources provide space heating and DHW to the house. Storage tanks are used to combine heat from each source and then connect it to the heat-distribution system. In summer, excess heat from the solar panels is transferred to the ground. Monitoring from December 2004 to July 2005 showed that the system provided ample heat, and the geothermal loop provided the majority of the heat needed for space heating during the winter. An initial economic analysis showed that the electrical cost of running the heating system was less than the cost of heating with oil. However, additional monitoring is needed to assess the costs of running the system and the ground loop's effect on soil temperatures.

Instanes and Instanes (2008) provide a feasibility study of another kind. In Svalbard, Norway, where the mean annual temperature is below 32°F, they describe the use of a GSHP as part of an on-grade foundation. This type of foundation provides an alternative to the pile foundations that are common in that region. It consists of insulation material under a concrete floor slab and a cooling system under the insulation to prevent thawing of underlying soil. A GSHP, which is used as the cooling system for the soil, transfers the heat removed from the soil to the house above for space heating. The authors identified several advantages to using a GSHP with the on-grade foundation system: the foundation can be used on permafrost or saline soils; any heat loss through the floor is regained by the GSHP; the floor can be located directly on the ground, which allows for higher foundation loads; water and sewage pipes can be buried; the "ground floor" can be warm; and foundation loads can be transferred to the embankment. The first building in Svalbard to use this technique was a storage building with high foundation loads. The foundation was installed in 1986. Since the study's publication, three more buildings have used the design. The authors conclude that on-grade foundations are an attractive alternative to pile foundations, from both a technical and economical standpoint (Instanes & Instanes, 2008).

Appendix D: Annotated Bibliography of Reviewed Articles

The following articles were reviewed as part of the research for this report. The list is representative of general literature on ground-source heat pumps (GSHPs), research studies on various aspects of heat pumps in cold climates, and national reports on energy policy. This list is not inclusive of all cold climate heat pump literature. However, it does provide the interested reader with a broad background on GSHPs in cold climates.

Heat Pump Technology and Applications

American Physical Society. (2008). Energy Future: Think Efficiency. American Physical Society, College Park, MD.

This report focuses on making major gains in energy efficiency in the transportation and building sectors. It suggests policies that the federal government could adopt and improvements in R&D.

CANMET. (2005). Ground *Source Heat Pump Project Analysis (Chapter).* CANMET Energy Technology Centre-Varennes, Canada.

This is an electronic textbook for installers who wish to use the RETScreen software to project energy savings and fit a GSHP system to their building or home. It contains an introductory chapter on how GSHPs access the heat stored in the ground throughout the year and use it to heat residential and commercial buildings. It describes the main components of heat pumps: and discusses markets for heat pumps and locations where many GSHPs are installed. It then reviews in detail how to use the RETScreen tool.

Chua,K., Chou, S., and Yang, W. (2010). Advances in heat pump systems: A review. *Applied Energy* **87**: 3611-3624.

The authors provide an update on recent developments in heat pump systems by reviewing various methods of enhancing performance of heat pumps, reviewing major hybrid heat pump systems, and presenting novel applications of heat pump systems in industry.

Department of Defense. (2007). *Ground Source Heat Pumps at Department of Defense Facilities: Report to* Congress. Office of the Secretary of Defense, United States. Washington, D.C.

The purpose of this report is to describe the types of DoD facilities where GSHPs have been used, assess applicability and cost-effectiveness of GSHP in different geographic areas of CONUS, assess the use of GSHPs for new construction and retrofits of DoD facilities and make recommendations for facilitating and encouraging increased use of GSHP systems in DoD facilities.

Geothermal Resources Council. (2010). Heat Pump/Direct Use. *GCR Transactions* **34**: 895-979. Sacramento.

This document contains summaries of the presentations at the 2010 Annual Meeting of GRC. Articles cover topics such as GSHP system descriptions and performance measurements, new technologies, new applications and current market analysis.

Hanova, J. and Dowlatabadi, H. (2007). Strategic GHG reduction through the use of ground source heat pump technology. *Environmental Research Letters* **2** 044001.

Authors studied the circumstances in which GSHP can achieve net emission reductions in order to explore GSHPs' potential to provide an alternative to conventional heating methods. Thus, they explored the availability of resources, the emission reduction potential and the economic feasibility of GSHP in different regions in Canada.

Hanova, J., Dowlatabadi, H., and Mueller, L. (2007). Ground Source Heat Pump Systems in Canada: Economics and GHG Reduction Potential. Resources for the Future Discussion Paper.

This paper is a regional analysis for the feasibility of GSHP in Canada. It contains emissions information for different areas, potential savings of GSHP, and the ability of each region to support GSHPs.

Hughes, P. (2008). *Geothermal (ground-source) Heat Pumps: Market Status, Barriers to Adoption and Actions to Overcome Barriers. Oak Ridge National Laboratory*. Oak Ridge, TN.

This report comments on the status of global GSHP markets, the status on the industry and technology in the United States, estimates the savings potential of GSHP and identifies both barriers to the application of GSHP and actions that accelerate market adoption. Researchers considered past studies, past programs to increase GSHP use and interviewed industry experts and researchers.

IEA. (various) Heat Pump Centre Newsletter. International Energy Agency.

The newsletters contain information on world heat pump news, articles on new technologies and applications of GSHP, event listings and educational materials.

IEA. (2007). *Renewables for Heating and Cooling*. Renewable Energy Technology Deployment and International Energy Agency. Paris.

The goal of this report is to emphasize the importance of renewable heating and cooling in reaching towards the renewable energy goals of energy security, climate change mitigation, reduced environmental impacts and cost-competitiveness. Thus, the report discusses the technologies, markets and policies of solar, bioenergy and geothermal technologies.

Lund, J. (1989). Geothermal Heat Pumps: Trends and Comparisons. *Geo-Heat Center Quarterly Bulletin*, **12**(1).

The author discusses the advantages and disadvantages of GSHP and compares earth and water GSHP and vertical and horizontal GSHP. He also does a cost comparison for different systems.

Navigant Consulting, Inc. (2009). *Ground-Source Heat Pumps: Overview of Market Status, Barriers to* Adoption *and Options from Overcoming Barriers.* U.S. Department of Energy. Washington, D.C.

This is a summary of the status of GSHP technology and the global market. It also contains estimates on the energy savings potential of GSHPs in the United States and a discussion of market barriers and the initiatives that could help to overcome them

NRC Office of Energy Efficiency. (2004). *Heating and Cooling with a Heat Pump*. Natural Resources Canada, Quebec, Canada.

This is a booklet produced by NRC in Quebec to provide general information about heat pumps to Canadians. They explain how heat pumps work, include a glossary of commonly encountered terms, and provide details on both ASHP and GSHP. Charts are

included that provide potential customers an estimate of the HSPF for different regions of Canada. They include a cost comparison of heat pumps and their payback period and FAQ section.

Omer, A. (2008). Ground-source heat pumps systems and applications. *Renewable and Sustainable Energy Reviews*, **12**, 344-371.

This literature-based review of GSHP technology covers earth-energy systems, heat pump efficiency, descriptions of different system types, environmental benefits, and the factors that can affect a GSHP's capability. It concludes with a look at the prospect of using GSHPs in the United Kingdom.

Phetteplace, G. (2007). Geothermal Heat Pumps. *Journal of Energy Engineering* **133**(1), 32-38.

This article explains types of heat pumps and discusses methods of ground coupling before looking at regional market penetration and the overall outlook for GSHP use.

Rafferty, K. (1995). A capital cost comparison of commercial ground-source heat pump systems. *ASHRAE Transactions*, **101**(2).

This is a cost comparison of hybrid, groundwater, and ground-coupled systems.

Roth, K., Dieckmann, J., and Brodrick, J. (2009) Heat Pumps for Cold Climates. *ASHRAE Journal*, **51**, 69-72.

This article discusses modifications that have been made to ASHP to improve their COPs in cold climates. These include sizing the ASHP for heating, using multiple compressors, increasing coil capacity, using alternative refrigerants, using mechanical liquid subcooling, optimizing coils for the heating load and using a GSHP instead. An economic analysis is also done.

Spitler, J.D. (2005) Ground-source Heat Pump System Research-Past, Present, and Future. *HVAC&R Research* **11**(2), 165-167.

This article reviews past research on GSHPs and looks to advances that can be expected in the future.

Straube, J. (2009). Ground Source Heat Pumps ("Geothermal") for Residential Heating and Cooling: Carbon Emissions and Efficiency. Building Science Digest 113.

This article summarizes heat pump technology and efficiency and then discusses how climate (both hot and cold) has an impact on efficiency. It also addresses carbon emissions and outlines the circumstances in which heat pumps would be ideal in the future.

Alaska Literature

Chandonnet, A. (2001). *Subterranean heat pumps gaining ground in Juneau*. Retrieved April 1, 2011 from http://juneauempire.com/stories/052701/lns_heating.html.

This article from Juneau newspaper The Juneau Empire discusses recent installations of heat pumps in the Juneau area, including both residential and commercial heat pumps.

Elston, C. (1988). Residential Heat Pump Demonstration Project. Human Endeavors. Healy, AK.

The business director and owner of Human Endeavors collaborated to build a house in Healy, AK, to serve as a live research testing, development, and marketing tool. This article reviews the technologies used in the house, including the GSHP.

Fritz, C. (2008). Ground Source Heat Pump Project Overview. Juneau International Airport.

This document describes the GSHP project at the Juneau Airport, which is part of the airport's overall renovation.

Jacobsen, King, Eisenhauer, and Gibson. (1980). *Evaluation of Water Source Heat Pumps for the Juneau, AK Area*. Alaska Power Administration. Juneau.

This report is an evaluation of WSHPs for residential, commercial, and industrial heating in the Juneau area. Researchers conducted a literature review, interviewed experts, contacted manufacturers, and analyzed four case studies to consider life cycle costs, technical viability, and the effect of WSHPs on fossil fuels and electric energy use.

Juneau Water Source Heat Pump Program Final Report. (1984). Alaska Power Administration.

This study reports on the results from monitoring 2 water-to-air residential heat pump systems in the Juneau area.

Lockard, D. (2009). *Geothermal Energy Technologies*. Chapter in: *Alaska Energy: A first step toward energy independence*. Alaska Energy Authority and Alaska Center for Energy and Power. Anchorage, AK.

Teams at AEA identified technology options and limitations for different resources found in Alaska. The section on heat pumps in this report provides an overview of the technology and discusses their suitability for different regions in Alaska.

McFadden, T. (2000). *Final Report on Foundation Stabilization using a Heat Pump Cooling System*. Permafrost Technology Foundation. Fairbanks, AK.

The PTF tested the possibility of protecting the permafrost underneath a house with a GSHP in order to first stabilize the foundation and then to heat the house. This report details the procedure of the experiment and the results. A supplemental report was published in 2007 after it was discovered that the heat pump was removing too much heat from the soil. Researchers installed zone control valves and reported on further results in the supplemental report.

Mueller, G. and Zarling, J. (1996). *Ground Source Heat Pump Monitoring: Final Report*. Matanuska Electric Association. Alaska.

Researchers installed instrumentation to monitor the performance of 5 heat pump systems in the MEA service area so that MEA could inform their customers on the reliability and economics of using GSHP. The report includes details on the performance of each heat pump and recommendations for further study.

Nielsen, H. and Zarling, J. (1983). *Ground Source Heat Pump Demonstration*. University of Alaska, Fairbanks. Fairbanks, AK.

Researchers at the University of Alaska investigated the feasibility of using heat extracted from the soil for home heating in Fairbanks by installing 2 commercially available ground coupled heat pump systems in a trailer on the campus. This report details the experiment, and contains information on the performance of the heat pumps and the thermal response of the soil.

Williams, R. and Zarling, J. (1994). *Thermosyphon-coupled Heat Pumps: Final Report*. Rural Electric Research Project 91-4. Washington, D.C.

Researchers adapted a technology used to sustain permafrost, heat pipes, to use in a heat pump and installed the system at a house 5 miles north of Fairbanks. They found that the heat pipes provided a reliable temperature but that numerical simulations predicted that an increase in the heat load would cause the area of frozen soil to increase.

Zarling, J. (1976). *Heat Pump Applications in Alaska.* Department of Mechanical Engineering, University of Alaska, Fairbanks, AK.

This paper describes an air-to-air heat pump system for the average Fairbanks home and a water to air heat pump system installed at the Fairbanks wastewater treatment facility. The latter uses the treated water before discharge as the low temperature heat source. This helps to eliminate ice fog and the system was paid back in 2 years. The economic analysis for the air-to-air heat pump is favorable.

Canada Literature

Andrushuk, R. and Merkel, P. (2009). Performance of Ground Source Heat Pumps in Manitoba. *Geoconnexion Magazine*, Spring/Summer 2009.

Manitoba Hydro is a utility company with a program to provide loans to homeowners for a GSHP, which has over 950 applicants. The purpose of this study, which monitored 10 residential GSHPs, is to investigate the energy savings from GSHPs so that Manitoba Hydro could better inform their customers about the expected performance of the technology. The study also looks at the thermal imbalance placed on the ground.
*The full report is Andrushuk, R. and Merkel, P. (2009). *Performance of Ground Source Heat Pumps in Manitoba*. Manitoba Hydro: Winnipeg.

Bath, A. (*2003*). *Yukon Groundwater and Ground Source Heat Potential Inventory*, Gartner Lee Limited, Whitehorse, Canada.

This document was written to provide developers, the government of Yukon and the public with information relevant to developing ground-source heat resources in the area. It is a preliminary assessment of the Yukon's groundwater resources and their potential for exploitation using GSHP technology.

Caneta *Research* Inc. (2002). *Investigation of a Ground-Source Heat Pump Retrofit to an Electrically Heated Multi-Family Building: Final Report*. CMHC-SCHL. CR File No. 6585-C108. Ontario.

Investigators researched the benefits of retrofitting electrically heated apartment buildings with GSHP. By conducting a search and review of available equipment and analyzing a building complex in Toronto, they concluded that though the technology was suitable, the capital cost is currently too large.

Cottrell, C. (*2009*). *Heat Pumps: A snapshot of the technology in cold climates: Desktop Study*. Energy Solutions Centre, Yukon Government, Canada.

The desktop study includes a technology overview, an overview of the context of heat pumps in the Yukon and a field study of 1 GSHP and 1 ASHP in the Whitehorse area. More field studies are planned for 2010. In addition, contributions and interviews were solicited from several experts and agencies who work with heat pumps in cold climates. Its purpose is to inform clients of the Energy Solutions Centre about the context of heat pumps in the Yukon.

Genest, F. and Minea, V. (2006) High-performance Retail Store with Integrated HVAC Systems. *ASHRAE Transactions*, **112**, 342-348.

This article provides details on a "green" commercial building in Montreal. Details on the GSHP of the building are provided.

Healy, P.F and Ugursal, V.I. (1997). Performance and Economic Feasibility of Ground Source Heat Pumps in Cold Climate. *International Journal of Energy Research*, **21**, 857-870.

The authors studied the effects of various system parameters on GSHP performance with a computer model and assessed the economic feasibility of using a GSHP in place of an ASHP or conventional heating system.

Kikuchi, E., Bristow, D., and Kennedy, C. (2009). Evaluation of region-specific residential energy systems for GHG reductions: Case studies in Canadian cities. *Energy policy*, **37**, 1257-1266.

This study investigates the energy use and GHG emissions associated with alternatives in residential energy systems. The technologies considered are GSHP, photovoltaics, energy efficient appliances and their combinations. They are considered in 5 different Canadian cities.

Lessoway Moir Partners. (2006). *Residential Hybrid Heating System: Final Report version 2.* Energy Solutions Centre, Yukon, Canada.

Information was collected, analyzed, and archived on the performance data of a hybrid geothermal-solar residential heating system in Whitehorse. Recommendations on how to better monitor the performance of the system are included in the report.

Minea, V. (2006). Ground-Source Heat Pumps Energy Efficiency for Two Canadian Schools. *ASHRAE Journal*, May 2006. 28-38.

This article provides details on the GSHPs installed at 2 schools in Quebec.

Phillips, B. and Stanski, D. (2003). Final Report on Residential Ground Source Heat Pumps on Urban Lots: Performance and Cost Effectiveness. UNIES Ltd. Winnipeg, CA

UNIES Ltd was contracted to monitor 4 heat pumps in operation in 4 low-income dwellings in Winnipeg. The study monitored temperatures, electricity, and flow rates for each GSHP and used this data to provide findings on performance, maintenance needs, and payback periods.

Shahed, A. and Harrison, S. (2010). Preliminary Review of Geothermal Solar Assisted Heat Pumps. Solar Calorimetry Laboratory. Kingston, CA.

This is a first review of work completed with regards to geothermal heat pumps and solar hybrid systems. It suggests guidance for future work focused on modeling and developing practical hybrid GSHP systems in Canada.

Literature from Other Cold Climate Locations

Badescu, V. (2007). Economic Aspects of using Ground Thermal Energy for Passive House Heating. *Renewable Energy*. **32**. 895-903.

This study investigated the economic aspects of various methods of using ground thermal energy for passive house heating. Theoretical models were used to simulate the heating system operation of a passive house and a reference heating system that did not use renewable energy.

Bakirci, K. (2010). Evaluation of the performance of a ground-source heat-pump system with series GHE in the cold climate region. *Energy*, **35**, 3088-3096.

Researchers evaluated the performance of a vertical GSHP at the University of Turkey in Erzurum. They report on the COP of the system and ground temperatures.

Bloomquist, R. (1999). Geothermal Heat Pumps: Four plus decades of experience. *Geo-Heat Centre Quarterly Bulletin*, **20**(4), 13-18.

This study consisted of 2 phases: 1) Look at systems in Washington state to obtain information on building size and use, type and size of GSHP and reasons for selecting a GSHP; 2) Look at systems in other parts of the country and to concentrate on operational, maintenance and reliability issues. Once systems were identified, researchers conducted interviews, visited sites and calculated maintenance costs.

Blum, P, Campillo, G., Munch, W. and Kolbel, T. (2010). CO_2 Savings of Ground Source Heat Pump Systems-A Regional Analysis. *Renewable Energy* **35**, 122-127.

Researchers determined the avoidance of additional CO_2 emissions due to the use of GSHP in comparison to conventional heating systems on a regional scale and to determine how much CO_2 can be saved by the application of GSHP in Germany.

Cane, D. and Garnet, J. (2000). *CADDET Analyses Series No. 27: Learning from experiences with commercial/institutional heat pump systems in cold climate*. Netherlands: Caddett, Sittard.

This study evaluated and compared operating experiences with heat pump systems in commercial buildings in cold climates in order to present the reader with information on heat pump systems' performance, economics, and environmental benefits. The intended audience is end-users and design professionals.

Esen, H., Inalli, M., and Esen, M. (2007). Numerical and experimental analysis of a horizontal ground-coupled heat pump system, *Building and Environment*, **42**, 1126-1134.

This study evaluates a heat pump system that is used to reduce the environmental impact of heating buildings. In addition, the study aims to model the temperature distribution in the ground around the horizontal ground loop.

Fujita, K., Iwamae, A., and Matsushita, T. (2008). *Experimental Study on Crawl-Space Heating with Thermal Storage* using *Heat Pump.* NSB 2008. Sweden.

The research team tested a heating system that used a heat pump to heat the crawl space in an experimental house in Osaka, Japan, for 10 days in 2006. This would then allow the house to be heated by the radiant floor. The paper discusses the feasibility of this system.

Hepbasli, A., Akdemir, O., and Hancioglu, E. (2003). Experimental study of a closed loop vertical ground source heat pump system. *Energy Conversion and Management*, **44**. 527-48.

This study is the first in Turkey at the university level of the performance of a vertical-loop GSHP. The paper provides details on the heating system used for the experiment and the results of monitoring the GSHP.

Hepbasli, A., Eltez, M., and Duran, H. (2001). Current Status and Future Directions of Geothermal Heat Pumps in Turkey. *GHC Bulletin*, **22**(1), 13-15.

This article is an overview of the developing GSHP market in Turkey. It reviews the installed heating systems, case studies, and research on development and standardization.

Ikeuchi, K., Takasugi, S., and Miyazaki, S. (2001). Hot Water Supply Test Using Geothermal Heat Pump Systems at Petropavlovsk-Kamchatshy, the capital of Kamchatka, Russia. GHC Bulletin,**22**(1), 9-12.

Researchers investigated the feasibility of geothermal heating in Kamchatka, Russia. This article discusses their experiment.

Instanes, B. and Instanes, A. (2008). *Foundation Design Using a Heat Pump Cooling System.* Ninth International Conference on Permafrost. U.S. Permafrost Association. Fairbanks, AK.

Authors present an alternative to pile foundations by introducing on-grade foundations that use a heat pump underneath the foundation to keep the soil at a design temperature. They discuss the foundation and its benefits.

Japan Metals and Chemicals Co., Ltd. (2004). *Fundamental Study on Introduction and Application of Geothermal Heat Pump Systems to District Heating in Irkutsk, Russian Federation*. Japan Metals and Chemicals Co.

This report discusses research on determining the feasibility of replacing existing heating systems in Irkutsk with GSHP to reduce GHG. The researchers examined existing data, studied the existing heating system, and conducted field surveys.

Karlsson, F., Axell, M., and Fahlen, P. (2003). *Heat Pumps in Sweden.* IEA HPP Annex 28.

Report contains a review of existing methods of measuring SPF and the requirements to receive quality markings from Nordic institutions. It also reviews which parameters should be measured in a system and what a system test should determine (heating-up time, stand-by power input, COP, etc.).

Lienau, P., Boyd, T., and Rogers, R. (1995). *Ground-Source Heat Pump Case Studies and Utility Programs*. Geoheat Center: Oregon Institute of Technology. Klamath Falls.

Information was collected for 256 case studies and 60 electric utilities and RECs. It was organized into a database and researchers looked for trends. The article discusses the economic and market trends that they found from looking at both GSHP and conventional systems.

Note: A shortened version of this article is Boyd, T. and Lienau, P. (1995). *Geothermal Heat Pump Performance*. Geoheat Center: Oregon Institute of Technology. Klamath Falls.

Lund, J., Sanner, B., Rybach, L., Curtis, R., and Hellström, G. (2004). Geothermal (Ground-Source) Heat Pumps: A World Overview. *GHC Bulletin*, **25**(3), 1-10.

The article reviews the state of heat pumps in the US, Europe overall, Germany, Switzerland, UK, and Sweden. Authors also mention recent technological developments, including TRT testing, better grouting materials, and heat pumps with increased supply temperatures.

Martel, C. and Phetteplace, G. (1982). *Evaluating the heat pump alternative for heating enclosed wastewater treatment facilities in cold regions*. U.S. Army Cold Regions Research and Engineering Laboratory. Hanover.

The authors present a 5-step process for evaluating the technical and economic feasibility of using heat pumps to recover heat from treatment plant effluent for engineers not familiar with the technology. The 5-step procedure was developed from site visits, technical reports, and HVAC manuals.

Rybach, L. and Hopkirk, R. (1994). Experience with Borehole Heat Exchangers in Switzerland. *GHC Bulletin*, **15**(3), 12-15.

Switzerland has the world's highest area density of BHEs. This article discusses theoretical and experimental studies that have been done to determine long-term performance.

Rybach, L. and Sanner, B. (2000). Ground Source Heat Pump Systems: The European Experience. *GHC Bulletin*, **21**(1), 16-26.

There are many vertical GSHPs in Central and Northern Europe. The authors discuss the GSHP market in different countries and the results of past R&D. They conclude that the European market is expected to grow.

Sanner, B., Karytsas, C., Menarions, D., and Rybach, L. (2003). Current status of ground source heat pumps and underground thermal energy storage in Europe. *Geothermics*, **32**, 579-588.

This article summarizes the status of Borehole Heat Exchangers (BHE) use with GSHP in Europe. The past 20 years of R&D on BHE has resulted in sound design and installation criteria and a concept of sustainability. The current market is also discussed.

Sector, P. (1977). *Demonstration of Building Heating with a Heat Pump Using Thermal Effluent*. U.S. Army Cold Regions Research and Engineering Laboratory. Hanover.

This report describes using a heat pump to provide energy-conservative and cost-effective space heating for an equipment storage and fabrication building. The building was operated as a thermal waste management project for CRREL

Shapiro, A. and Aldrich, R. (2008). Monitoring Data for Residential GSHP. *Energy Design Update* **28**(4), 11-13.

This study presents performance data on 4 residential systems located in Connecticut and Vermont.

Steinbock, J., Eijadi, D., and McDougall, T. (2007). Net Zero Energy Building Case Study: Science House. *ASHRAE Transactions*, **113**, 26-35.

This article describes the Science House, a net-zero building at the Science Museum of Minnesota. It uses passive solar design, daylighting, a GSHP, and photovoltaic panels to achieve its net-zero energy goal.

Stene, J., Midttomme, K., Skarphagen, H., and Borgnes, B. (2008). *Design and Operation of Ground Source Heat Pump Systems for Heating and Cooling of non-residential Buildings*. 9th International IEA Heat Pump Conference, Zürich.

Authors discuss the main characteristics of GSHP systems for heating and cooling of non-residential systems in Norway and provide information on groundwater temperatures, design problems, borehole heat exchangers and TRT and case studies.

Takasugi, S., Tsukashi, A., Takashi, O., and Hanano, M. (2001). Feasibility Study on the Utilization of Geothermal Heat Pump(GHP) Systems in Japan. *GHC Bulletin*, **22**(1), 3-8.

The authors investigated the different aspects of using geothermal resources with respect to cost, technology, and measures affecting acceptance of GHP systems. They then apply this information to GSHP market in Japan.

Tarnawski, V., Leong, W., Momose, T., and Hamada, Y. (2009). Analysis of ground source heat pumps with horizontal ground heat exchangers for northern Japan. *Renewable Energy*. **34**. 127-134.

This study examines the potential use of GSHP with horizontal GHE for residential space heating and cooling in northern Japan. Authors wished to specifically focus on the possible issues of degradation of ground thermal and moisture storage capacity, and the low conductivity of volcanic soils.

Trillat-Berdal, V., Souryri, B., and Achard, G. (2007). Coupling of geothermal heat pumps with thermal solar collectors. *Applied Thermal Engineering* **27**, 1750-1755.

The GEOSOL process couples a GSHP with thermal solar collectors for the purpose of preheating DHW, heating the dwelling, and thermal recharge of the soil. The process offers an alternative technical solution that reduces operating costs compared to fossil fuel heating systems. The article covers the experimental and theoretical testing of the system.

Underland, H. (2004). On top of the world: Arctic Air Base warmed with heat pump technology. *GHC Bulletin*, **25**(3), 20-24.

This article discusses the WSHP that has been used at an air base in Norway for 12 years and discusses a few other high latitude heat pumps located in Norway.

Yang, H., Cui, P., and Fang, Z. (2010). Vertical-borehole ground-coupled heat pumps: A review of models and systems. Applied Energy **87**, 16-27.

This is a literature review of research and development of vertical borehole GCHP technology used for air-conditioning. It also considers hybrid technology for heating and cooling dominated climates.

Yang, W., Zhou, J., Xu, W., and Zhang, G. (2010). Current status of ground-source heat pumps in China. *Energy Policy*, **38**, 323-332.

This article summarizes Chinese research and application of GSHP. It analyzes GSHP policy and includes suggestions for overcoming potential obstacles.

Wang, W., Ma, Z., Jiang, Y., Xu, S., and Yang, Z. (2005). Field test investigation of a double-stage coupled heat pump heating system for cold regions. *International Journal of Refrigeration* **28**, 672-679.

Researchers report on improving the working condition and heating performance of an ASHP in a cold environment by coupling an ASHP to a WSHP.