Research Briefing:


Project Introduction

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; however, several recent high-profile installations indicate that there is 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, and 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, whereas in more moderate climates 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 it 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). Ground-source heat pumps 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, Axell, and Fahlen, 2003). In Norway, 15,000 GSHP systems have been installed, including 250 medium- and large-capacity nonresidential systems (Stene, Midttomme, Skarphagen, and Borgnes, 2008), and Finland has an estimated 46,000 units installed (Lund, Freeston, and Boyd, 2010). Heat pumps are widely used in Canada (Phetteplace, 2007), and in Europe, the market is growing (Rybach and Sanner, 2000).

The authors of this report 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.
Cold Climate Considerations

One of the most important factors determining the efficiency of a heat pump is the difference between the entering water temperature (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. 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.

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’s coefficient of performance (COP).

There are concerns that the use of GSHPs in cold climates could result in thermal degradation caused by excessive heat extraction from the soil and lead to the creation of permafrost and/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.

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. 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 instead of fuel oil for heating can save on annual home-heating costs.

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).
Other Major Findings

Ground-source heat pumps have been successful in cold climates.
Based on 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.

Thermal imbalances caused by GSHPs depend on the specific location.
Other sources 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 a major concern.

Barriers to growth are consistent with other areas.
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, and Mueller, 2007). The GSHP market in Alaska faces these same problems.

Proper design and installation are critical to performance.
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. For example, if the ground loop is undersized, COPs will decrease 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).

More long-term data is necessary.
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 on heating 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 and Zarling, 1996; Nielson and Zarling, 1983).

The Alaska Industry
Alaska’s GSHP industry is small, but has recently 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 International Airport terminal. In addition to reducing operating costs at the terminal, the project’s primary motivation, 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. 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.