Cold Climate Ground Source Heat Pump Demonstration: Energy Efficient Space Heating for Alaska

AEA Emerging Energy Technology Grant Fund Application AEA-12-047

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Total Project Cost: $143,778
Grant Funds Requested: $119,467
Match Committed: $24,311

Previous project/application title and/or number for grants from the Renewable Energy Fund or Denali Commission Emerging Energy Technology Grant program: N/A

Previous Project title(s) for abstracts submitted to the Emerging Energy Technology Fund: N/A

1. Project Summary

a. **Project Description:** The Cold Climate Housing Research Center (CCHRC) in partnership with the Alaska Center for Energy and Power (ACEP) recently documented potential energy savings for several communities in Alaska by the use of ground source heat pumps (GSHP) for space heating, as well as the current knowledge gaps that would impede implementation (2011). In light of this potential, CCHRC proposes to work with its project partners to test and demonstrate the potential for GSHPs to expand the range of efficient space heating options for Alaskans. This need is particularly strong in areas of the state that rely on heating oil for their primary heating needs. If proven to be efficient and reliable in long-term operation, a properly designed and installed GSHP could provide significant cost savings for residential and commercial consumers in many regions of Alaska.

CCHRC will install the GSHP system in its Research and Testing Facility (RTF) in Fairbanks, located on University of Alaska Fairbanks land. The GSHP will displace an oil-fired boiler that currently heats the eastern half of the RTF. Testing this emerging technology at the RTF will provide a controlled research setting and high-visibility environment for the demonstration, both of which are identified as important to overcoming implementation barriers.

Because GSHPs extract geothermal energy instead of burning fuel to generate heat, site-specific considerations are critical in ensuring reliable and efficient heat pump operation. The land around CCHRC formerly had permafrost to the surface, but changes in surface conditions have altered the ground thermal regime. The ground is currently thawed to a depth of approximately 25 feet, which provides a narrow band for optimizing a ground loop between the zone of seasonal frost and the underlying permafrost. These are challenging conditions for the operation of a heat pump system and will provide a rigorous testing environment for using GSHPs in Alaska. Lessons learned during the design, installation and maintenance of a GSHP installed at CCHRC will provide valuable insight into the potential of GSHPs in Alaska and the optimal design for cold climates.

b. **Project Eligibility**: This project will test the application of a GSHP in a challenging sub-arctic climate to determine whether current heat pump technology designed for cold climates is capable of reliably providing space heating at an efficiency that makes them economical.

While other heat pump systems have been installed in Alaska, the long-term efficiency of GSHP systems has not been rigorously and independently evaluated. All GSHP projects with published monitoring data in Alaska documented initial performance conditions, and the studied installations are either no longer in operation or no longer undergoing monitoring. Lack of long-term GSHP performance evaluation has also been noted in Canada, and Alaskan GSHP installers have noted the lack of long-term performance data as a hindrance to adoption of the energy technology within Alaska (Andrushuk, 2009 and CCHRC, 2011). Corresponding to this level of development, CCHRC considers GSHPs in a cold climate such as Alaska currently to be at a Technology Readiness Level (TRL) of 8. Pending successful operation by the end of the project in 2015, the energy technology could advance to TRL 9.

c. **Project Innovation:** GSHPs have the potential to provide attractive energy savings for space heating of buildings in regions where heating oil is the primary heating fuel and electricity is not prohibitively expensive (CCHRC, 2011). At locations where electric resistance methods are used for space heating, GSHPs provide the opportunity to substantially reduce operating costs and increase electricity supply by reducing demand. Demand is reduced because GSHPs use one unit of electricity to move several units of geothermal energy, whereas electric resistance heating requires substantially more electricity to produce the same amount of heat.

d. **Priority:** This project will be led by CCHRC, a 501(c)(3) non-profit research center based in Fairbanks, in partnership with MCM Roe, a Fairbanks-based company specializing in geothermal heating, and the University of Alaska Fairbanks (UAF). CCHRC will be providing matching funds of $17,500, while MCM Roe will be providing matching funds of $6,811. CCHRC will work with UAF during this project to benefit from its expertise in permafrost science. Ronald Daanen, PhD, will be a key project partner in the design of the ground loop field and analysis of the subsurface monitoring data.
The Fairbanks North Star Borough School District is a research partner with CCHRC on other projects, and has expressed interest in using GSHPs for School District buildings pending sufficient confidence in the technology that could be provided by this project. This will enable testing of GSHPs in the northernmost area of Alaska where the technology is expected to be functional, which will help provide the market with confidence in applying the systems in virtually all other locations south of Fairbanks.

2. **Technology Validation and Research Methodology**

a. **Objectives:** The objectives for installing and monitoring a GSHP at CCHRC's facility are to:

1. Determine if stable, long-term performance of a GSHP is possible in a severe cold climate.
2. Evaluate if thermal degradation of the ground loop field is a fundamental challenge.
3. Determine optimal surface treatments to maximize energy capture in the ground.
4. Determine whether GSHPs consume more primary energy and emit more greenhouse gases relative to conventional heating systems.
5. Demonstrate the viability of a GSHP at its most northern (coldest) limit of operation.

b. **Methodology**: The performance of the GSHP will be evaluated by measuring the coefficient of performance (COP), which is the ratio of heat output to work supplied to the system from electricity. Monitoring COP over the duration of a heating season will allow for determination of the seasonal COP (i.e. seasonal performance factor or SPF), which is a more complete description of the annual efficiency of the system. While not directly comparable, the SPF is the closest efficiency metric to Annual Fuel Utilization Efficiency (AFUE) for gas and oil-fired heating systems. The COP of the heat pump within a heating season and across multiple heating seasons will be tracked to determine if there are changes from the initial state over time.
Closely connected to heat pump efficiency is the thermal regime of the ground in which the ground loop exchanger is installed. To evaluate the potential for declining ground temperatures due to heat extraction, CCHRC will monitor ground temperatures at various depths around the ground loop system. Permafrost monitoring boreholes at UAF will also be available for comparison. This information will be used to establish the initial ground temperatures, monitor for seasonal changes attributable to heat extraction, and determine the trajectory of long-term changes in the thermal regime after multiple years of heat extraction.

The optimization of ground heat collection is a combination of summer heating collection and winter cooling reduction. During the summer the ground surface needs solar exposure, which can be optimized through elimination of shade. During the winter it is important that heat is kept from escaping. In this project, CCHRC will consider multiple ground treatments to optimize performance, such as grass cutting, dark gravel placement, shallow greenhouse beds and ground irrigation.

Beyond the potential for energy savings for an individual building, a key consideration in evaluating heat pump performance is determining whether it provides a net benefit when considering primary energy consumption and greenhouse gas emissions associated with electricity generation. By understanding the long-term efficiency GSHPs, a comparison of GSHPs to conventional heating methods (e.g. heating oil) can be conducted via a life cycle cost analysis.

3. Summary of Project Schedule and Summary of Project Budget

a. **Pre-deployment:** In this project phase, CCHRC will work with its project partners to establish the heat pump system design and plan for data acquisition and monitoring. To account for site-specific subsurface conditions, an in-situ thermal response test will be performed following ASHRAE recommended procedures (ASHRAE, 2007). This allows for determination of the area averaged thermal conductivity and diffusivity, which are key design parameters and will allow for accurate numerical simulation of the system over time. This will take place as soon as possible upon the grant award, with an estimated completion date of September 7, 2012. The total estimated cost for this project phase is $25,688, of which $20,688 would be grant funds and $5,000 matching funds.

b. **Deployment and Research:** Immediately after completion of pre-deployment planning, CCHRC will initiate the ground loop installation. The ground loop installation will be complete by September 21, 2012. The heat pump installation in CCHRC's mechanical room will follow and will be completed by October 5, 2012. Sensors that are integral to the plumbing will be installed concurrently with the heat pump; completion of the data acquisition system will soon follow. Allowing for troubleshooting of any components will allow for completion of the monitoring system by October 31, 2012. This will be the beginning of the monitoring period that will extend to the end of winter 2014/2015. CCHRC plans to monitor the GSHP for several years beyond this period, but has only included the project costs through mid 2015. The total estimated cost for this project phase is $86,733, of which $72,422 would be grant funds and $14,311 matching funds.

c. **Post-deployment:** After three winters of heat pump operation, CCHRC and its project partners will prepare a report that documents the final system design, findings and analysis on system performance and of ground temperatures with respect to the ground loop, an account of the heat pump system operating costs, and a life cycle cost analysis for the GSHP in comparison to other conventional heating options. Assuming that the end of the monitoring period is late March 2015, CCHRC will provide a rough draft of the report by June 1, 2015 and a final report four weeks after any review and commentary by the grantor. The total estimated cost for this project phase is $31,357, of which $26,357 would be grant funds and $5,000 matching funds.

4. Project Team Qualifications

Robbin Garber-Slaght (CCHRC), EIT, will have overall responsibility for the project. Ms. Garber-Slaght will coordinate the design and installation of the heat pump systems performed by MCM Roe, and will lead the design and implementation of the monitoring equipment. She will also be responsible for creating or overseeing the creation of a monitoring plan, sensor programming, data standards, and other technical project needs. Ms. Garber-Slaght is a mechanical engineer currently in charge of numerous monitoring projects, including a hybrid heat pump-solar thermal installation at Weller Elementary School. Nathan Wiltse, MSc, will perform the life cycle cost analysis. Other technical project staff from CCHRC will include Colin Craven, MSc; Bruno Grunau, PE; Vanessa Spencer, MSc.

Andy Roe, owner of MCM Roe, will be the GSHP system designer and installer. Mr. Roe is an International Ground Source Heat Pump Association certified installer and is in the process of becoming a certified designer. Mr. Roe is a civil engineer that has designed and installed several heat pump systems. He will complete the ground loop system installation after design adjustments and will be responsible for retrofitting the heat pump to the existing hydronic system at CCHRC's facility.

Ronald Daanen, PhD, a research associate at the Water and Environmental Research Center at the University of Alaska Fairbanks, will assist in the characterization of the subsurface thermal regime for optimizing the ground loop placement and the subsequent assessment of the subsurface monitoring data during GSHP operation. This characterization will include participation in the initial ground work for an in-situ thermal response test, finalization of the ground loop design, and analysis and simulation of the ground temperature data. Dr. Daanen earned his PhD in Water Resource Science from the University of Minnesota in 2004 and has since been conducting research on the dynamics of permafrost and coupled mass and heat transport in frozen ground at UAF.

5. Discussion of Commercialization of Funded Technology

GSHPs are already a widely adopted technology in the lower 48 states, where approximately 50,000 GSHP systems are installed each year (US DOE, 2011). However, GSHP adoption in cold climates like Alaska is very limited, partially because long-term performance in cold climates is not sufficiently understood. If proven successful and economically competitive, it is expected that manufacturers and installers will have a stronger case for offering GSHPs to homeowners and commercial building facility managers.

Potential consumers of GSHPs in Alaska will be residential and commercial buildings located in areas with high heating fuel costs and relatively inexpensive electricity (Lockard, 2009). This includes Alaskans along the railbelt and those who live in Southeast. GSHPs can be installed with new construction or retrofitted into a building with compatible heat distribution systems. An economic analysis performed in a recent report by ACEP and CCHRC found GSHPs to be economically advantageous in Fairbanks, Seward and Juneau (CCHRC, 2011). However, this analysis assumed an efficiency of heat pump operation substantially less than documented for some heat pump installations in the Interior and Southcentral. Further confidence in the long-term efficiency of GSHP systems in Alaska could allow for less conservative economic assessments and less risk for people interested in implementing this emerging energy technology.

6. Signed Applicant Certification

By signature on this application, I certify that we are complying and will comply with the amount of matching funds being offered.

References

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