Baby, It's Cold Outside: Lessons Learned From Geothermal Heat Pump Installations in the United States

Dr. Katherine Johnson[1]

[1] Johnson Consulting Group, Frederick, MD USA
kjohnson@johnsonconsults.com

Abstract. Geothermal heat pumps (GHP) are an energy efficient technology that continues to gain traction as a viable heating and cooling system in the United States and around the world. Although this is a proven technology that has been in use since the 1940s, installation rates still lag behind its full market potential. GHPs continue to garner interest, however, and several high-profile installations include Buckingham Palace, the U.S. Embassy in Seoul, South Korea, and 2008 Summer Olympics venues in Beijing, China.

Even though GHPs have been around for decades, this technology still faces numerous challenges, including high first costs, low awareness and the need to develop a sustainable contractor infrastructure.

Interest in this technology is increasing in cold climate locations as well. This presentation will summarize some of the lessons learned from geothermal heat pump installations in US cold climates and identify some of the winning strategies utilities and energy organizations are using to promote this technology to residential and commercial and industrial customers. Specifically, this paper highlights several successful strategies that have been used to increase GHP installations across the United States.

Keywords: Geothermal Heat Pumps, Installations, United States.

1 The Promise of Geothermal Heat Pumps

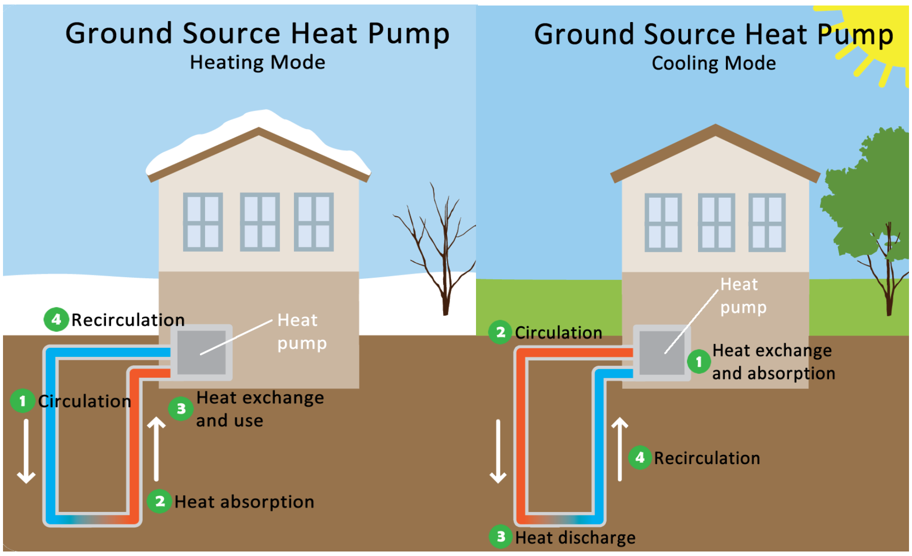
Geothermal heat pumps (GHP) are an energy efficient technology that continues to gain traction as a viable heating and cooling system in the United States and around the world. Although this is a proven technology that has been in use since the 1940s, installation rates still lag behind its full market potential. GHPs continue to garner interest, however, and several high-profile installations include Buckingham Palace, the U.S. Embassy in Seoul, South Korea, and 2008 Summer Olympics venues in Beijing, China.

One continuing challenge for the GHP industry is the multitude of names by which this technology is referred. GHPS are also called ground source heat pumps, earth source/earth coupled heat pumps, geothermal heating and cooling systems, direct exchange, ―geo, and other names. This paper will refer to the technology as geothermal heat pumps, or GHPs.

This paper highlights the critical marketing approaches that have been successful in encouraging energy organizations to promote this heating and cooling solution to residential customers across North America. This paper's conclusions and recommendations are based on an in-depth literature review of GHP installations across North America, focusing on cold climate locations. The results from this literature review were further supplemented with information provided through interviews with GHP manufacturers, trade associations, and electric utilities. Therefore, the focus of this paper is to highlight the successful strategies that energy organizations are using to demonstrate the success of GHP installations in cold climate locations.

1.1 An Energy Efficient Technology

While the name may change, the technology is essentially the same. The GHP system will use approximately 50 percent less energy than conventional systems by tapping the solar energy stored in the ground. Every geothermal heat pump system consists of three major elements: a geothermal heat pump to move heat between the building and the fluid in the earth connection, an earth connection for transferring heat between its fluid and the earth, and a distribution subsystem for delivering heating or cooling to the building. To heat a building, the heat is extracted from the fluid in the earth connection by the geothermal heat pump and distributed through a system of air ducts. Cooler air from the building is returned to the geothermal heat pump, where it cools the fluid flowing to the earth connection. The fluid is warmed again as it flows through the earth connection. The process is reversed to cool the building (Johnson 2013, a, pp. 2-3).

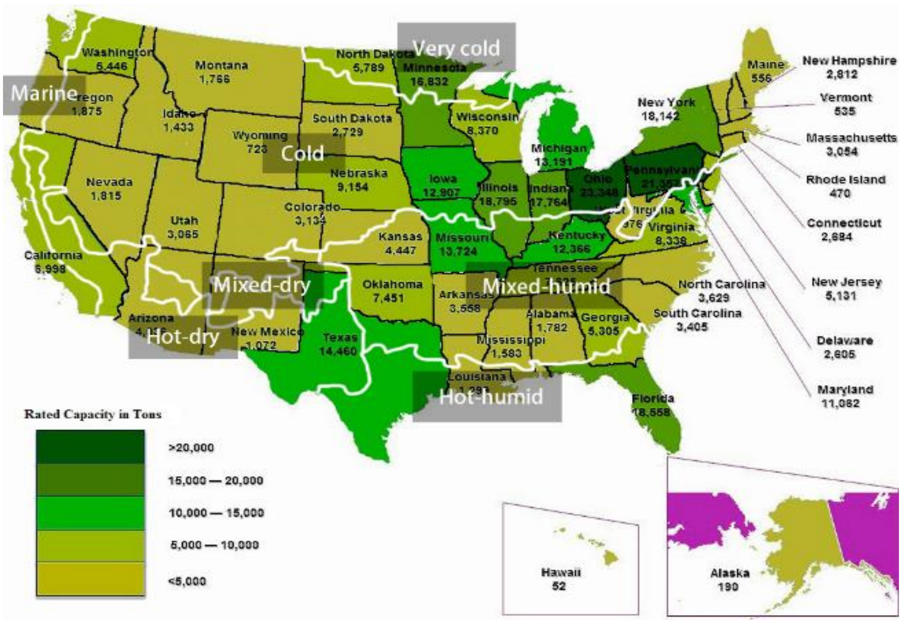


Source: Graphics courtesy of EPA

Fig. 1. Heating and Cooling Systems in Heating and Cooling Mode

Most GHP systems installed in the United States are installed with closed-loop heat exchangers using high-density polyethylene (HDPE) pipe buried in the earth in either a vertical or horizontal configuration. (Liu 2010, p. 3).

The Department of Energy's Guide to Geothermal Heat Pump further points out that these systems work in any climate as the Figure 2 illustrates. The map below also shows a higher concentration of GHP applications in states that have cold climates and high population densities (Muller 2017, p. 1.)



Source: Department of Energy 2017[1]

Fig. 2. Distribution of GHP unit shipments in the United States in 2009

GHP installations are also growing in popularity in Canada. According to the most recently available data, Ontario represents nearly two-thirds of the GHPs installed in Canada in 2010, with more than 7,000 GHP installations. Of note, most of these installations are for C&I locations, with most installations concentrated in mid-rise and high-rise buildings (Hamilton 2012, p. 2).

1.2 Typical Costs for GHPs

One of the major drawbacks to this system is its high initial cost; A GHP system can cost between $3,500-$7,500 (US) for the unit; the more expensive models may include options such as a two-stage compressor or a hot water heater. Drilling for the loop field

[1] Note: the number below each state name indicates the total capacity of GHP shipment in 2009 in the particular state; the white lines indicate climate zones).

and installation costs can bring total installation costs to $10,000-$25,000 or more, depending on depth of pipes, type of equipment and soil conditions. The total GHP installation may cost between $12,000 to $15,000 with most installations averaging $13,400. Although the average GHP system costs two to three times the price of a standard air source heat pump (ASHP), the higher up-front costs are more than offset by the significant energy savings. The internal system lasts approximately 25 years while the external loop may last as long as 50 years (Pike Research 2011). However, a recent study of residential GHP installations in Fairbanks Alaska area generally cost between $20,000 and $35,000 in total to install (Garber-Slaght & Stevens, 2014).

1.3 Energy Savings from GHPs

Despite the high initial costs, GHPs are significantly more energy-efficient than even ASHPs because they take advantage of the relatively consistent ground temperatures, which are far more uniform than air temperatures. GHPs offer utilities a way to improve load factor while lowering total energy consumption by promoting a viable and proven “green technology.” Even in the current environment of inexpensive natural gas, GHPs provide utilities and their customers a long-term hedge against fossil fuel prices and possible carbon caps or taxes.

However, the customers are the ones who truly benefit from the significant energy saving compared to more standard options. For example, GHPs can reduce energy consumption by approximately 25 to 50 percent compared to ASHPs. Geothermal heat pumps reach high efficiencies (300%-600%) on the coldest of winter nights. Table 1 provides a comparison of GHPs to other standard residential heating, cooling, air conditioning and ventilation (HVAC) systems.

Table 1. Comparison of Efficiencies and Installed Costs for Typical Residential HVAC Systems

Technology	Rated Cooling Efficiencies	Rated Heating Efficiencies	Typical Installed Cost
Gas-Fired Furnace	--	Typical:80% AFUE; 780 kWh/yr. ENERGY STAR®: 90% AFUE; 500 kWh/yr 2007 Best Available: 96% AFUE; 275 kWh/yr	$24.00/kBtuh $32.70/kBtuh $44.00/kBtuh
Oil-Fired Furnace	--	Typical:81% AFUE; 850 kWh/yr ENERGY STAR ® 83% AFUE; 800 kWh/yr 2007 Best Available:95% AFUE; 650 kWh/yr	$23.80/kBtuh $26.20/kBtuh $50.50/kBtuh
Central A/C (Air Source)	Typical:13 SEER ENERGY STAR®:14 SEER Best Available:21 SEER	--	$814/ton $886/ton $1,714/ton
Central Heat Pump (Air Source)	Typical:13 SEER ENERGY STAR®:14 SEER Best Available:17 SEER	Typical:7.7 HSPF ENERGY STAR®:8.2 HSPF 2007 Best Available: 0.6 HSPFb	$1450/ton $1570/ton $2300/ton
Geothermal Heat Pump	Typical:16 EER ENERGY STAR®:14.1 EER Best Available:30 EER	Typical:3.4 COP ENERGY STAR®:3.3 COP Best Available:4.8 COP	$3,000/ton $2,830/ton $5,250/ton

Source: GSHP Report, Navigant Consulting 2009, p. 33

These savings are even more apparent for installations located in extreme cold climates, such as the North Pole in Alaska. This $20,000 installation, paid by Habitat for Humanity, reduced heating bills from $985 to $467 during the winter months Combining the energy savings with tax credits and rebates reduced the initial cost to $14,000. However, the investment will pay back in about 18 months due the high costs of heating oil in Alaska (Andrews 2016 p. 1).

2 Challenges Facing the GHP Market

Though the United States was the world leader in GHP technology and still has the largest installed base of GHP systems—approximately 600,000 units in 2005 (Liu 2010, p. v)—the GHP market share in the United States is much smaller than in some European counties. A 2005 review of the global market status of GHP systems estimated that Sweden, Denmark, Switzerland, and some other countries ranked higher on a per capita basis (Liu 2010, p. v.) than the United States.

Even though GHPs have been around for decades, this technology still faces numerous challenges, including high first costs, low awareness and the need to develop a sustainable contractor infrastructure. Only about 600,000 GHP units have been installed in the United States (Meyers et al 2011, p. iii). Given the 127.8 million households in the United States, even if all 600,000 GHP units were installed in residential buildings, they would account for only slightly less than 0.5 percent of the entire U.S. housing stock (Liu 2010, p. 6)

The major barriers preventing rapid growth of GHP applications have been identified as a lack of knowledge in this technology, limited infrastructure to support these installations and high initial cost to customers (Hughes 2008). These barriers are discussed next.

Lack of Contractor Knowledge: The lack of contractor knowledge about GHPs remains one of the biggest barriers to GHP installations gaining traction in cold climate locations such as Alaska. This is especially concerning given that GHPs are widely used in other cold climate regions in the world, as evidenced by their popularity in Scandinavian countries, Canada and Northern Europe (Meyers et al., 2011, p. iii).

Installations have been lagging in Alaska because the technology is simply not well-understood. First, there are concerns about proper sizing of the GHPs. In cold climates, GHPs are sized differently than in other regions. Typically, GHPs in the U.S. are sized for the cooling load (Navigant Consulting, Inc., 2009). However, in Alaska and northern areas, unit sizing is based on the heating load of the building. Furthermore, in cold climates, GHP 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 GHP efficiency in cold climates: heat is being extracted from relatively cold ground and is not being balanced by heat rejection used for space cooling (Meyer et al 2011, p. vii).

A related concern in 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 (Brown 2015, p. 1; Meyer et al., 2011, p. vii).

Another consideration for cold climate installations 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 GHPs in cold climates could lead to the creation of permafrost or seasonal ground freezing, which could damage to nearby structures, a reduction of COP over time, and other complications. However, the extent of this degradation is unknown (Meyers et al., 2011, p. vii).

Lack of Infrastructure: GHPs are complicated installations, requiring expertise from contractors in three separate areas: HVAC sizing, knowledge of soil conditions for drilling and excavation, and designing the loop field. Since contractors are really expert in all three areas, a successful GHP program requires on-going training and coordination among these three diverse groups of trade allies. another critical element of the GHP market is the cost of components required to install and operate a GHP. These systems also come in a variety of configurations including: closed loop and open loop, horizontal and vertical-bore loop fields (Hughes 2008, pp. 12-13). However, each of these components require access to specialized equipment such as back-hoes and drilling rigs, in addition to standard HVAC and duct sealing equipment and supplies.

High First Costs: While GHP systems save on energy costs, the high installation cost is still a major barrier to widespread adoption. A GHP system can cost between $3,500-$7,500 (US) for the unit; the more expensive models may include options such as a two-stage compressor or a hot water heater.

Drilling for the loop field and installation costs can bring total installation costs to $10,000-$25,000 or more, depending on depth of pipes, type of equipment and soil conditions. The total GHP installation may cost between $12,000 to $15,000 with most installations averaging $13,400 These increased costs are driven by the cost of the unit itself, the ground loop and the air or fluid distribution system. In fact, if ductwork is needed then the price to install a GHP rises $6,000-$8,000 depending upon the size of the installed system (Liu, p.4). So a customer purchasing a GHP for a home not only pays a $4,000-$6,000 premium for the equipment, but could also pay another $6,000-$8,000 premium for the duct work. The total installed costs of GHPs are also significantly higher compared to the installation costs for conventional systems, such as ASHPs or natural gas furnaces with central air conditioning. Conservatively, GHP owners may have to spend twice as much to install this system.

Initial cost and long payback periods may also limit GHP system acceptance in many markets. Currently in commercial markets, GHPs are primarily limited to institutional customers (e.g., federal, state, and local governments and K–12 schools) that take the lifecycle view. In residential markets, GHPs are limited to a small subset of newly constructed homes that the builder plans to occupy—and thus wants to equip with the best available system—and to home retrofits in which the owner plans to occupy the premises long enough to justify the investment. In all of these cases, the building owner must have the financial wherewithal to use his or her own credit to finance the system (Liu 2010, p. 8).

Despite these barriers, GHPs are proving themselves as viable technology, even in the most extreme climates. Specifically, there has been an increase in GHP installations in a number of cold climate locations throughout the United States and Canada as described next.

3 Strategies to Encourage GHP Installations

Currently, most GHP installations tend to be concentrated in those parts of the United States that have developed a strong contractor base that provides both knowledge and the infrastructure required to support GHPs; financing solutions to reduce the higher first cost barrier; and enthusiastic contractors, customers, and energy utilities to promote GHPs to residential and commercial and industrial customers. These strategies, especially those applicable to cold climate locations, are discussed next.

Increase Contractor Knowledge: The most successful GHP programs are those in which trade allies and utilities work closely together. For example, when Iowa-based Muscatine Power & Water (MP&W) wanted to develop a GHP program, the staff looked for guidance from the local trade allies affiliated with the Iowa Heat Pump Association. With this support, the utility was able to develop a network of geothermal experts, such the Iowa Heat Pump Contractors Association and the International Ground Source Heat Pump Association, that helped to reach out educate other contractors in its service territory (Johnson 2010, p. 47).

Another Midwestern utility, Otter Tail Power, also forged deep relationships with its contractor network which led to an increased education among both contractors, as well as architects and engineers, about GHP capabilities. Otter Tail has subsequently developed a group of installation contractors and drillers that are experienced in geothermal systems (Johnson 2010, p. 53).

Otter Tail's strong contractor network has also led to GHP installations in a hundreds of Midwestern communities. For example, De Smet, South Dakota, population 1,100, has GHP installations in several offices, two churches, a school, and a bank (Johnson 2010, p. 54).

This contractor expertise has also spilled over to neighboring North Dakota which reported an increase of GHP installations by 26 percent. According to the most recent information available, GHP installations have increased from 897 installations to 1,135 from 2010 to 2011. Dickinson has 12 commercial installations (Baumgarten 2010).

Contractor relationships have also been an essential ingredient to the success of Yellowstone Valley Electric Cooperative, located in Montana. This rural electric cooperative has fostered relationships with three separate dealers, thereby offering customers a true competitive choice among geothermal systems. It also has a strong relationship with one of the largest drillers in the United States. This strategy of friendly competition benefits everyone — especially the customer (Johnson 2010, pp. 67-69).

Specialized contractor expertise also led to a decrease in GHP engineering services. A Colorado school district was able to reduce the "risk premium" associated with installing a new GHP system by relying on established and proven engineering models thus "right sizing" the GHP installation from the beginning (Johnson 2013 b, p. 2).

The Habitat for Humanity GHP installation was championed by an Alaskan builder who had previously installed GHPs in Fairbanks, with good results. He advocated for the GHP installation because "You can pretty much do GHPs anywhere." (Andrews 2016, p. 1).

Build Support from the Ground Up: Another strategy is to install GHPs in high profile locations. This approach has been especially successful in Alaska as there has been some prominent commercial installations in Juneau and several residential installations in Fairbanks. One large-profile commercial GHP system was installed at the Juneau Airport Terminal. The planners hope this installation will increase public awareness of energy conservation and alternative energy (Meyer et al., 2011, p. v). This tactic also seems to be paying off as there has been an increase in residential GHP installations near the North Pole (Habitat for Humanity 2013).

Another successful strategy, used by several energy organizations and contractors across the United States. involves installing GHPs at utility headquarters and in employees' homes (Johnson 2010, p. 24). This strategy has been used effectively at a number of utilities including the headquarters buildings Palmetto Electric and Yellowstone Valley have also installed GHPs at their headquarters buildings. Similarly, First Energy often holds its dealer training seminars at Richard Stockton College, home to one of the largest GHP installations in the world. This technique demonstrates the utility's belief in the system, and reinforces the versatility and overall superiority of GHPs to potential customers (Johnson 2010, p. 25).

South Dakota has also been able to create a market for GHPs by targeting a building unique to the landscape in this far Northern climate- farm shops A farm shop serves as a central location for equipment maintenance, fabrication and service; parts and tool storage; and often has an adjoining office. The shop also provides a place where farmers can service, assemble, repair, adjust and modify equipment, and keep tools in one location for field and farmstead operations (Atkinson 2013, p. 1).

Another technique is to foster a geo culture, or creating a sense of pride in ownership among geothermal customers. This is an effective way to build word-of-mouth among potential customers and leads to further installations and a broadening of the geo-mindset. This strategy has been most effectively demonstrated in several utility strategies such as hosting GHP owner dinners in rural electric Colorado and offering tours and demonstrations at utility locations (Johnson 2010, p. 24).

Target "Patient" Customers: GHP installations have also been popular in military installations and public schools because these organizations can take the long-term view in terms of calculating payback. Rather than relying on the traditional payback methods, institutional decision-makers, such as governments, use life cycle costing-which includes both the up-front investment as well as the annual maintenance and operating costs. While GHPs are more expensive initially, their reduced operating and maintenance costs means they are often the most cost-effective heating and cooling option in the long run markets (Liu 2010, p. 8).

The Colorado Springs District 11 relied on life cycle costing to justify installing GHPs in three of its new public schools. As a result of installing these units, the district is able to meet its overall energy savings goal of 25 KBTU/per square foot per year (Johnson 2013, a, pp. 2-3). A preliminary energy analysis of billing records indicates that the school is on track to use 25 KBTUS/sq. ft. annually.

Other Colorado school districts have also invested in GHPs due to the significant energy savings. The Poudre School District is monitoring the performance its new Kinard Junior High School. Comparisons with another school have shown that the energy savings is significantly less than Preston Junior High School, which relies on conventional HVAC systems. As Table 2 shows, Kinard's total energy costs, which include both natural gas and electricity, is 65 cents per square foot less compared to Preston. This represents an annual savings of 75 percent (Johnson 2013 b, p. 2).

Table 2. Comparison between Preston and Kinard Junior High Schools

School	Total Square Footage	Energy Cost kBTU/sq.ft.
Preston Junior High School	125,000	87 cents
Kinard Junior High School	113,000	22 cents

Offer Financing Solutions: Several organizations around the United States, including utilities and non-profit groups, have created a variety of financing strategies designed to make GHP systems even more affordable for residential customers. These approaches include creating a "green bank" through Michigan Saves, a non-profit organization funded by the rate payers. As of July 2017, the organization has provided more than $6.8 million in financing 359 GHP systems. The estimated lifetime savings for these systems will be 11,845,804 kWh (Geo Industry News 2017).

Other organizations are even more committed to promoting GHPs by investing in the equipment initially and leasing the system back to the customers. Corn Belt Energy, a rural electric cooperative in Illinois, offers customers loop-leases to buy-down the cost of the GHP loop. This program, patterned after successful loop-leasing programs in Colorado and Kansas, was launched in late 2015. Through the program, the utility invests in long-term capital intensive assets – geothermal loop – which reduces the high-cost associated with geothermal heat pumps (Johnson, Volker et al 2015, p.6; Johnson 2016).

A builder in Ontario has also found a unique solution to reduce the high first costs for commercial installations. This developer is capitalizing on the long-term financial and environmental benefits of GHPs. In 2011, the building code in Ontario required that buildings be 25 percent more efficient, which promoted interest in GHP installations. Developers are now playing the role of energy supplier by installing the GHP system and selling the resulting heat or cool air to the building owner or tenant under fixed-priced, long-term contracts (Hamilton 2012, p. 3).

4 Conclusions

This paper identified the following best practices to help encourage and support GHPs by incorporating the following strategies:

- **Increase Contractor Knowledge:** The most successful GHP programs are those in which trade allies and utilities work closely together.
- **Build Support from the Ground Up:** Another strategy is to install GHPs in high profile locations.
- **Target "Patient" Customers:** GHP installations have also been popular in military installations and public schools because these organizations can take the long-term view in terms of calculating payback.
- **Offer Financing Solutions:** Several organizations around the United States, including utilities and non profit groups, have created a variety of financing strategies designed to make GHP systems even more affordable for both residential and C&I customers.

GHPs are truly a "clean and green" technology that offers significant benefits to customers, energy organizations, trade allies, and the planet. But, barriers to market adoption and widespread acceptance, especially in the US, still remain. This paper has identified some of the more innovative approaches have been used to encourage installations across all climate zones—even the coldest ones.

References

1. Johnson, K. (2013) Case Study: Colorado Governor's Office*: "Space Age Technology at Christa McAuliffe Elementary School*," March 17. (Johnson 2013 a). U.S. Environmental Protection Agency https://www.epa.gov/rhc/geothermal-heating-and-cooling-technologies <Accessed 10-19-2017>
2. Liu, X. (2010). "*Assessment of National Benefits from Retrofitting Existing Single-Family Homes with Ground Source Heat Pump Systems,"* Final Report, Oak Ridge National Laboratory, Energy Transportation and Science Division, United States Department of Energy. August.
3. Pike Research (2011). *"Geothermal Heat Pumps and Direct Use Report-Executive Summary"* Published 3Q.
4. Garber-Slaght, R. & Stevens, V. (2014). Ground source heat pumps in interior Alaska; lessons learned from installed systems. Retrieved from http://cchrc.org/ground-source-heat-pumps-interior-alaska
5. Muller, M. 2017 U "*5 Things You Should Know about Geothermal Heat Pumps,"* Office of Energy Efficiency & Renewable Energy, U.S. Department of Energy, August 1.

6. Hamilton, T. 2012. *"Ontario Leads Canada with Installation of Geothermal Heat Pump or "Geo-Exchange" Systems, but Residential Lags Commercial Market,"* Clean Break Canada, February 20. http://www.cleanbreak.ca/2012/02/20/ontario-leads-canada-with-installation-of-geothermal-heat-pump-or-geo-exchange-systems-but-residential-lags-commercial-market/<Accessed 10-11-2017>
7. Navigant (2009). "*Ground-Source Heat Pumps: Overview of Market Status, Barriers to Adoption, and Options for Overcoming Barriers,"* Final Report, U.S. Department of Energy, Energy Efficiency and Renewable Energy, Geothermal Technologies Program.
8. Andrews, L. 2016. *"Habitat for Humanity's geothermal home is paying off,"* Alaska Dispatch News https://www.adn.com/energy/article/habitat-humanitys-geothermal-home-paying/2013/07/22/ <Accessed 10-19-2017>
9. Meyer, J. Pride, D., O'Toole, J. Craven, C. & Spenser, V. (2011). *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,* May 31.
10. Hughes, P. (2008) "*Geothermal (Ground-Source) Heat Pumps: Market Status, Barriers to Adoption, and Actions to Overcome Barriers*," Oak Ridge National Laboratory, ORNL/TM-2008, December.
11. Brown, J. (2015) *"Do Geothermal Heat Pumps Work in Cold Climates*?" http://www.nordicghp.com/2015/03/do-geothermal-heat-pumps-work-in-cold-climates/ <Accessed 8-28-2017>
12. Johnson, K. (2010). Geo Heat Pumps: Leading Energy Utility Programs-Fifth Edition
13. Baumgarten, A. (2011). *Geothermal expansion: North Dakota sees 26 percent increase in installation,* McClatchy-Tribune Regional News, The Dickinson Press, North Dakota. No Date. http://www.northeastgeo.com/index.cfm/geo-talk/geothermal-expansion-north-dakota-sees-26-percent-increase-in-installation/ <Accessed 8-28-2017>>.
14. Johnson, K. (2013). Case Study: Colorado Governor's Office: *"Kinard Junior High School, Fort Collins, CO installed by Poudre School District,"* March. (Johnson 2013 b)
15. Atkinson, W. (2013). "Geothermal in the Dakotas," May 19. http://digital.bnpmedia.com/publication/?i=141319&article_id=1279916&view=articleBrowser&ver=html5#{"issue_id":141319,"view":"articleBrowser","article_id":"1279916"} <Accessed 8-28-2017>
16. Geo Industry News (2017) "*Michigan Program Promotes Geo,"* Volume 4, Number 8.
17. Johnson, K. Volker, M. Bhedwar, C. & Ambach, G. (2015) "*Digging Deeper for Energy Savings: A Look at Successful On-Bill Financing Program Designs,"* Journal of Energy Challenges and Mechanics, Conference Proceedings, June.
18. Johnson, K. (2016). "*Utility Strategies to Put a Geothermal Heat Pump in Everyone's Backyard,"* Association of Energy Services Professional Summer Conference, August 17.