Residential Ground-Source Heat Pumps

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Summary

Definition	Residential heat pumps that use the ground or groundwater instead of air as the heat source and sink					
Basecase	3-ton central air-source heat pump (ASHP) with electric water heating					
New Measure:	3-ton closed-loop ground-source heat pump (GSHP) with desuperheater	Percent Savings	2020 Savings TBtu (Source)	2020 Cost of Saved Energy	Success Rating (1-5)
		22%	205	$0.12/kWh	3

Background and Description

Ground-source heat pumps are commonly referred to as geothermal heat pumps or "GeoExchange" (GX). The technology has been in residential use for decades, but the estimated market share is less than 2%. Three heat exchanger types predominate for residential classes. "Closed" or "**ground loop**" heat pumps circulate water or water and antifreeze through high density polyethylene pipes laid out horizontally several feet below the ground, or installed vertically in boreholes that are back-filled with an impermeable grout to prevent groundwater contamination. Depending on the thermal properties of the ground, closed loop heat exchangers will typically require 200' to 300' of borehole per ton of load. "Open" or "**groundwater**" systems draw water via a well from a below-surface aquifer. Good practice requires the groundwater to be returned unaltered to the same aquifer. In both closed and open systems, fluid circulates through the unit's heat exchanger at 2–3 gallons per minute for each ton (12,000 Btuh) of heat capacity. The third category, "**direct exchange**" (DGX), circulates refrigerant in copper pipes through the ground. Although technically attractive, these systems have a small market share.

Most residential GSHPs enclose all components in a single box installed inside the house. This makes it feasible to integrate water heating, in two different ways. "Full condensing" units assign the total capacity of the compressor when required. These systems offer output comparable to a fossil fuel water heater, with water heating electricity use to be about 1/3 as great as with a resistive water heater. These are typically high-end products. ACEEE believes that a majority of all residential heat pumps are sold with desuperheaters that provide auxiliary water heating capability. The desuperheater is a small heat exchanger between the compressor and the primary condenser. It "steals" a little heat from the hot, high-pressure vapor to heat water, using a loop between the heat pump and a storage water heater. In the summer, this improves performance, but it is a small additional load in winter. A desuperheater system costs several hundred dollars, and the desuperheater is expected to offset about half of the annual electricity that would otherwise be consumed by a resistance water heater. The principal drawback of the desuperheater approach is that it only heats water when the unit is operating to provide space heating or cooling.

Historically, it has been difficult to compare performance of ground-source equipment to air-source heat pumps or furnaces. More common technologies, including both ASHPs and fossil fuel furnaces, are rated with seasonal efficiency metrics. In contrast, GSHPs are measured by steady state performance, that is, how efficiently they run while operating. Both approaches are technically valid, but comparisons have been very difficult. As of 2007, a new software package is nearing completion that will allow site-specific conversion of GSHP metrics (EER, COP) into air-source metrics (SEER, HSPF). This will allow direct comparison of life-cycle costs of ground-source and other residential HVAC options.

Data Summary

Basecase: 3-ton central air-source heat pump with electric water heating
New Measure: 3-ton closed-loop ground-source heat pump with desuperheater

Application and Status			
Market Sector(s)	**Application(s)**	**End Use(s)**	**Fuel Type(s)**
Residential	Retrofit New Construction	Heating Air Conditioning Water Heating	Electricity
Market Segment	**National/Regional**	**Region(s)**	**State(s)**
Single Family Multi-family< 4 unit	Regional	Midwest	
Current Status	**Date of Commercialization**	***Notes***	
Commercialized	1980	Approximate	
Market Players/Manufacturers	**Life**		
- ClimateMaster - Florida heat pump - WaterFurnace - Trane	**18.4 years**	For heat pump component. Ground loop lasts >50 years	

Basecase Information			***Notes (Source)***
Efficiency	7.7 13 0.91	HSPF SEER EF	 (electric water heater)
Electric Use	10,138	kWh/yr	Average HVAC + water heating use in Midwest
Summer Peak Demand	3.2	kW	
Winter Peak Demand	10	kW	
Gas/Fuel Use		MMBtu/yr	
New Measure Information			***Notes (Source)***
Efficiency	3.3 14.1	COP EER	Heating Cooling
Electric Use	7,890	kWh/yr	Average HVAC + water heating use in Midwest
Summer Peak Demand	2.95	kW	
Winter Peak Demand	3.9	kW	
Gas/Fuel Use		MMBtu/yr	
Savings Information			***Notes (Source)***
Electric Savings	2,248	kWh/yr	
Summer Peak Demand Savings	0.3	kW	
Winter Peak Demand Savings	6.1	kW	
Gas/Fuel Savings		MMBtu/yr	
Percent Savings	22	%	21% HVAC savings; 25% water heating savings
Feasible Applications (%)	15	%	50% households with electric heat (29% total)
Industrial Savings Potential (>25%)	NO		
2020 Savings Potential	**19,682**	**GWH**	
2020 Savings Potential (Source)	**205**	**TBtu**	
Cost of Saved Energy	**$0.12**	**$/Kwh**	
Cost Information			***Notes (Source)***
Incremental Cost	$3,400	2006 $	
Other Costs / (Savings)	$0	$/yr	

Success Factors			
Market Barriers	**Non-Energy Benefits**	**Current Promotional Activity**	**Next Steps**
- High first cost - Weak design and installation infrastructure - No economies of scale - Consumer awareness	- Greater comfort - Very low environmental impact	- Manufacturer marketing and advertising - Utility and public benefit programs - Standards	- Strategic marketing - Market aggregation - Incentives
Priority (1-5)	**Likelihood of Success (1-5)**	**Success Rationale**	
2	3	First cost is a major barrier, but large niche markets such as “green” consumers can help drive up economies of scale.	
Data Quality Assessment (A-D)	**Data Explanation**		
B	Qualitative analysis based on authors’ experience in the industry. Retail prices relatively uncertain.		

Current Status of Measure

In general, ground-source heat pump technology is mature. Industry sources estimate that about 1.1 million units have been installed. Manufacturers report that early installations of each type have operated successfully for decades. Based on discussion with manufacturers and others, we believe that four manufacturers dominate the market, but another 10–15 are active in various niches, regions, or nationally. Some major brands sell GSHPs made by others under their own brands, rather than designing and manufacturing for the relatively small market themselves.

In addition to efforts by manufacturers, the Federal Energy Management Program (FEMP) and ASHRAE have supported the industry with recommendations and publications. ENERGY STAR criteria are published and widely used.

Jurisdictions and utilities in 30 states offer direct incentives for residential GSHP installation in the form of utility rebates, sales tax exemptions, and personal tax credits, and as a part of a home energy loan. In Canada, the federal government now offers a $3,500 grant to encourage the retrofit of geothermal heat pumps in existing homes under the ecoENERGY retrofit program. In the United States, a federal tax credit of up to $300 is offered through 2007.

Savings Potential and Cost-Effectiveness

At a cost of roughly $0.12/kWh avoided, residential ground-source heat pumps look cost-effective where utility rates are high, but compared to the current average cost of residential electricity, the cost of a GSHP is about 60% higher. As electricity rates rise, time-of-day rate or demand charges become more common, and as the cost of GSHP systems comes down, the economics will become more favorable.

However, open loop systems can be very cost-effective in rural regions where potable water is provided by individual water wells. If the well has adequate supply for the heat pump (which requires 2–3 gpm/ton), and if a high-quality, relatively shallow aquifer can be accessed, the cost of installing the ground loop can be radically reduced. However, well drilling may cost $20/ft, so the incremental cost of the return well is high if the aquifer is deep, or where the primary well is not also the potable water supply.

Costs would also be much lower for installations staged for entire subdivisions. However, it is not often in a builder’s interest to offer such features, which would still be more expensive up front.

Market Barriers

The high first cost of GSHPs is the principal barrier to greater use in the residential sector. The equipment cost is about 10% more than comparable air-source heat pumps, but the ground loop and its auxilaries costs in the range of $1,000/ton for individual residential applications. In part, this is a result of market immaturity: few contractors have a great deal of experience with installing either vertical or horizontal heat exchangers. In fact, finding a high-quality contractor can be more of a barrier than cost in many regions. The lack of infrastructure for manufacturing, design and installation results in small economies of scale and keeps consumer awareness low.

Because of the technology’s weak footing, GSHPs are highly subject to market conditions. High and/or escalating utility rates cause spikes in interest in GSHPs among consumers, and number of installations increase. Conversely, market share for GSHPs would be threatened by declining utility costs (reduce incentive to invest); large improvements in air-source heat pumps (much lower resistive heat requirements, leading to much lower bills); or measures that greatly reduce loads (such as smaller houses, better ductwork, etc., so that energy bills are less critical for household economics).

Another barrier is that ground loop and water well regulations vary greatly among states (Den Braven 1998). This hampers contractors who attempt to do business in multiple states, and tends to keep installation costs relatively high in many areas. It remains to be seen whether technical advances, such as low-permeability, high thermal conductivity grouting materials for completing boreholes will increase regulatory confidence and support more commonality among regulations.

One variable that may positively change the market dynamics for GSHPs is the currently very high price of copper (>$3.50 per lb for futures). Increasingly, outdoor condensing units are being destroyed and the copper stolen for scrap. Ground-source systems generally have no exterior equipment, and thus have much less exposure to this problem. The reduced operating risks may be important in the commercial sector, and for housing authorities and other public agencies.

Next Steps

Ground-source heat pumps of all types are positioned as premium systems, and now marketed to those for whom first cost is not the principal concern. We believe that the industry would do well to focus on expanding niches such as "green" consumers and those for whom low, less volatile energy bills are highly important (such as fixed-income sectors). Even for these groups, long-term financing or lease arrangements may be important program opportunities. Market aggregation may be very important, since installation costs go down when many ground-source heat exchangers are installed nearly simultaneously, as for a subdivision under construction, or residences of a military base or public housing authority. It would be important for federal agencies to work together to stimulate uptake, as for housing complexes.

Key Assumptions Used in Analysis

Our base system is a 2006 minimum legal split system air-source heat pump (13 SEER, 7.7 HSPF). For several reasons, including the increases in equipment prices due to extraordinary metal price increases, we believe that the market share of ENERGY STAR air-source equipment (14 SEER, 8.2 HSPF) is small, so the base unit is more appropriate. Because desuperheater or full condensing water heating is very rare with ASHPs, we assume resistive water heating. In contrast, we use an ENERGY STAR closed-loop ground-source system (14.1 EER, 3.3 COP), with desuperheater. These seem to represent common, mainstream, products today. We assume Midwestern climate conditions.

Average Price of Electricity	$0.083/kWh
Percent New Res. Construction in 2020 (EIA 2006)	14.8%
Average Price of Natural Gas	$10.16/MMBtu
Projected 2020 End Use Electricity Consumption (EIA 2006)	0.39 quads
Real Discount Rate	4.53%
Projected 2020 End Use Gas Consumption (EIA 2006)	1.25 quads
Heat Rate	10.42 kBtu/kWh

References

Den Braven, K.R. 1998. "Antifreeze Acceptability for Ground-Coupled Heat Pump Ground Loops in the United States." *ASHRAE Transactions*, 104(1): 938–943. ASHRAE, Atlanta, GA. www.ashrae.org

[EIA] Energy Information Administration. 2006. *The 2006 Annual Energy Outlook.* Washington, D.C.: U.S. Department of Energy.