Efficiency With Short Payback Periods

Residential GSHPs

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Ground source heat pumps (GSHPs, also called geothermal heat pumps) provide an alternative to more conventional HVAC systems for residential and commercial buildings. In this article, we will explore residential GSHPs. In 2010, residential buildings consumed 22.05 quads of primary energy (26.5% was consumed by space heating and 15.8% by space cooling).[1] According to the 2009 Residential Energy Consumption Survey (RECS), space heating is provided by three main energy sources: natural gas, electricity, and fuel oil.

Table 1 gives the distribution of these energy sources across the U.S. *Table 2* provides a breakdown by U.S. census regions. Natural gas and electricity are the top two fuel sources. Of the homes using electricity, a little over 25% use air-source heat pumps, and the majority of these users are concentrated in the South. Similarly, out of all of the homes with air conditioning, the majority are in the South and the majority of heat pump users are also found in the South.[2]

Ground source heat pumps are not a new technology. They have been in use since the 1970s. However, GSHP units continue to increase in efficiency due to advances in HVAC system components.

Overview of Technology

A GSHP is comprised of three main elements: the ground loop heat exchanger, the refrigerant loop (heat pump), and the air-handling unit (AHU) or the heat exchanger between the refrigerant and the heating system supply water. Hydronic GSHP configurations use the latter configuration.[3]

A GSHP operates by using the earth for the external reservoir, rejecting heat to the earth in the cooling mode, and taking heat from the earth in the heating mode.

Around 47% of the Sun's heat energy is absorbed by the ground. Unlike the fluctuations seen in the air temperature, the earth, below a certain depth (greater than 6 ft [1.8 m], typically, with stable temperatures after 30 ft [9 m]), remains at a constant temperature. On average, the temperature below 30 ft (9 m) is 55°F (13°C) in the U.S. This temperature varies regionally, generally being a few degrees cooler in the north and a few degrees warmer in the South.[3]

The energy savings of GSHPs are primarily attributable to the stability and moderation of the ground temperature.

In the heating mode, a water glycol mixture circulating in the ground loop absorbs heat from the ground. It then transfers this heat to the heat pump's refrigerant loop, vaporizing refrigerant, which is subsequently compressed, increasing its temperature and its ability to transfer heat to the home. For cooling, the process is reversed.

Overall, one unit of energy from the grid is converted into 4–6 units of heating or cooling energy output; about 3–5 units of energy are supplied from the ground.[3]

There are two halves to a GSHP, the underground heat transfer loop and the above-ground heat transfer system and HVAC components. The above-ground components are the same as those found in conventional HVAC systems. Advancements made in compressor, AHU, and motor drive technology have been carried over to the GSHP. The key and unique technology to the GSHP is its ground loop. This loop can be configured as open or closed. Closed-loop systems can be configured either vertically or horizontally.[3,4]

Open-loop systems are the oldest type. They account for at most 20% of the US market. Groundwater is the ground source heat carrier. It directly enters the groundwater heat exchanger of the heat pump and after transferring heat to or from the working fluid is discharged to a well or surface body of water. This type of loop requires proximity to a supply of pure ground water. Open-loop systems are sometimes prohibited due to municipal regulations protecting groundwater.

Closed-loop systems circulate water or a water glycol mixture through a buried heat exchanger loop in contact with the earth. Vertical loops or boreholes require holes up to 300 ft (91 m) deep per ton of capacity required. This can add up to 600 ft (183 m) of piping.

Multiples of these loops can be arranged in either series or parallel. Series loops require larger piping and are lim-

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ited in capacity by pipe frictional losses. Parallel loops can use smaller piping and have larger capacities than series systems.[3,4]

When there is space, horizontal loops are easier and less expensive to install than drilling vertical boreholes. The ground loop is installed in trenches that are approximately 6 ft (1.8 m) deep, or below the frost line. These loops require considerable space, up to 3500 ft^2 (325 m^2) per ton. The loop can be configured with series flow through only one or multiple layers of pipe, or parallel flow through many layers of pipe in the same trench. The latter reduces the trench length but increases its depth.[3,4]

Horizontal systems can also have a "slinky" piping loop installed. A slinky piping loop consists of many loops of flexible plastic pipe spread out along the length of the trench. This type of loop increases the amount of pipe per length of the hole or trench due to its shape.

		U.S. Totals
Total Homes (Millions)		113.6
	Percentage Using Space Heating Equipment	96.9%
	Percentage as Using Main Fuel	
	Natural Gas	50.5%
	Electricity	34.7%
	Heat Pump	8.9%
	Fuel Oil	6.3%
	Other Fuel	8.5%

Table 1: Space heating fuel use by fuel type in the U.S. in 2010.[2]

		Northeast	Midwest	South	West
Total Homes		18.3%	22.8%	37.1%	21.8%
	Using Space Heating Equipment	100.0%	99.6%	97.6%	90.3%
	Percentage as Using Main Fuel				
	Natural Gas	51.9%	69.4%	32.6%	60.7%
	Electricity	11.5%	17.8%	58.9%	31.3%
	Heat Pump	1.9%	2.3%	18.2%	5.8%
	Fuel Oil	27.4%	1.9%	1.5%	0.4%

Table 2: Space heating fuel use by fuel type and by region in the U.S. In 2010.[2]

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Technology	Cooling Efficiency	Heating Efficiency	Installed Cost
GSHP	Typical: 16 EER 2007 Best: 30 EER	Typical: 3.4 COP 2007 Best: 5.0 COP	$3,000/ton $5,250/ton
ASHP	Typical: 13 SEER 2007 Best: 17 SEER	Typical: 7.7 HSPF 2007 Best: 10.6 HSPF	$1,450/ton $2,300/ton

Table 3: Installation cost of GSHP.[4]

Table 3 summarizes typical installed costs for GSHPs and air source heat pumps (ASHPs) at typical and best efficiency levels. The ground loop accounts for the bulk of the cost (30% to 35%) of installing a GSHP.

GSHPs are about twice as expensive to install as ASHPs and more than three times as expensive as gas or oil fired furnaces and conventional air conditioners.[4]

Energy Savings

Ground source heat pumps, unlike air source heat pumps, have the benefit that the ground, which is used as the thermal reservoir, maintains an almost constant, and moderate, temperature year round. Air, which acts as a thermal reservoir for ASHPs, fluctuates in temperature seasonally. Ground source heat pumps can consume up to 50% less energy than conventional HVAC equipment.[6] If the installed base of heating and cooling equipment were to be replaced by ground source heat pumps, energy would be saved.

Installed Base	Savings (Quads)
ASHP	0.5
Natural Gas Furnace + AC	2.1
Fuel Oil Furnace + AC	0.3
Propane Furnace + AC	0.2
Total	**3.1**

Table 4: Maximum potential annual primary energy savings for heating and cooling if the installed base equipment were replaced by GSHPs.[4]

Table 4 represents the savings if GSHPs replaced the entire installed base technologies listed. Ground source heat pumps provide significant primary energy savings relative to both air source heat pumps and gas fired furnaces.

Table 5 outlines the potential savings, and highlights the consistency of savings achievable regardless of region; this consistency is a result of the stability of ground temperature.

vs.	ASHP	Gas-Fired Furnace
GSHP		
Northeast	35% to 40%	30%
Midwest	40% to 50%	30%
South	~ 30%	30%
West	30% to 35%	30%
High-Efficiency GSHP		
Northeast	55% to 60%	55%
Midwest	60% to 70%	55%
South	>50%	55%
West	50% to 60%	55%

Table 5: Annual space conditioning primary energy savings.[4]

Market

Globally, heat pumps are becoming a larger portion of the installed base, with growth rates greater than 10% over the last decade. This growth is primarily found in Europe and North American markets. The global installed GSHP capacity is 15,400 MW (52.5 billion Btu/h); North America accounts for 56% of this, Europe 39%. The 2006 U.S. installed base comprised almost one million units, with yearly sales of more than 60,000 units. The highest average SEER rating was 19.3, and the highest average COP was 4.4.[4] Shipments of GSHP exceeded 100,000 units in 2009.[7] The majority of GSHP shipments are for residential end use.[4]

Though a growing presence in the market, GSHPs face many residential market barriers including ground loop design complexity and cost and overall system cost, longer payback relative to ASHPs, and space limitations. As mentioned earlier, the ground loop is the most expensive part of the system, and the hardest to design. Each ground loop must be site-specifically designed due to site plan variations and geological variations, which can be found on the neighborhood level. This high cost and complexity is a deterrent to residential application. Additionally, significant space is required for the ground loop, which often makes GSHP applications impractical in dense urban areas.

Increased R&D efforts, variable electric rates, and/or carbon taxing could help to reduce the cost of GSHP and increase the incentive for increased installation. *Table 6* summarizes typical simple payback periods for residential GSHPs relative to other technologies.[4]

Payback periods for GSHPs can be as low as 4–8 years compared to fuel-oil furnaces and a traditional air conditioner system. However, fuel-oil, as shown in *Table 1*, is limited in use to the Northeast, whereas GSHPs are predominantly used in the South. Payback for GSHPs in the South can be as low as 10 years, or, more likely, 15 years. Means to reduce the cost of ground loop installation and increased incentives could lead to increased market growth.

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Baseline Technology	ASHP	High-Efficiency ASHP	NG Furnace + AC
Northeast & Midwest			
ASHP	–	10 Years	
GSHP	5-10 Years	–	10 Years
High-Efficiency GSHP	–	10-20 Years	
South			
ASHP	–	10-15 Years	
GSHP	>20 Years	–	10 Years*
High-Efficiency GSHP	–	>30 Years	

*Some Southern regions have a 15-year payback period.[4]

Table 6: Payback relative to installed technology.[4]

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