How to Buy an Energy-Efficient Ground-Source Heat Pump

Energy Efficiency and Renewable Energy
Federal Energy Management Program

Why Agencies Should Buy Efficient Products

- *Executive Order 13123 and FAR section 23.704 direct agencies to purchase products in the upper 25% of energy efficiency, including all models that qualify for the EPA/DOE* ENERGY STAR® *product labeling program.*
- *Agencies that use these guidelines to buy efficient products can realize substantial operating cost savings and help prevent pollution.*
- *As the world's largest consumer, the federal government can help "pull" the entire U.S. market towards greater energy efficiency, while saving taxpayer dollars.*

Efficiency Recommendation

Product Type	*Recommended*		*Best Available*[a]	
	EER	*COP*	*EER*	*COP*
Closed Loop	*14.1 or more*	*3.3 or more*	*25.8*	*4.9*
Open Loop[b]	*16.2 or more*	*3.6 or more*	*31.1*	*5.5*

a) The best available COP and best available EER for the open loop system apply to different models.

b) Open loop heat pumps, as opposed to closed loop models, utilize "once-through" water from a well, lake, or stream.

Definitions

EER *(Energy Efficiency Ratio) is the cooling capacity (in Btu/hour) of the unit divided by its electrical input (in watts) at standard (ARI/ISO 13256-1) conditions of 77°F entering water for closed loop models and 59°F entering water for open loop systems.* ***COP*** *(Coefficient of Performance) is the heating capacity (in Btu/hour) of the unit divided by its electrical input (also in Btu/h) at standard (ARI/ISO 13256-1) conditions of 32°F entering water for closed loop models and 50°F entering water for open loop equipment.*

What is a Ground-Source Heat Pump?

Ground-source heat pump is the name for a broad category of space conditioning systems that employ a geothermal resource – the ground, groundwater, or surface water – as both a heat source and sink. GSHPs use a reversible refrigeration cycle to provide either heating or cooling.

GSHPs operate in much the same manner as air-source heat pumps. Both use a compressor to move refrigerant around a closed loop, transferring heat between an indoor coil and another coil where heat is absorbed or rejected. As the name implies, an air-source heat pump (ASHP) uses outside air, flowing over its outdoor coil, as the heat source and sink. The main drawback of ASHPs is that their performance depends on ambient air temperature, which can vary by as much as 100° F over a year. Both the capacity (i.e., the ability to produce heating and cooling) and efficiency of an ASHP are significantly reduced at the extreme temperatures experienced in summer and winter.

Definition

A heat sink is a body of air or liquid to which heat can be transferred.

A GSHP, on the other hand, uses a geothermal resource as its heat source and sink: the earth itself, a body of surface water, or water from a subsurface aquifer. Unlike ambient air, the temperature of the earth, beginning just five to ten feet below the surface, is relatively constant, and provides a

For More Information:

- DOE's Federal Energy Management Program (FEMP) Help Desk and World Wide Web site have up-to-date information on energy-efficient federal procurement, including the latest versions of these recommendations.
Phone: (800) 363-3732
www.eren.doe.gov/femp/procurement
- FEMP provides a number of technical and procurement resources related to GSHPs through its "Geothermal Heat Pump Technical Resources" Web site.
www.eren.doe.gov/femp/financing/ghpresources.html
- Environmental Protection Agency has ENERGY STAR® ground-source heat pump listings.
Phone: (888) 782-7937
www.energystar.gov/products
- International Ground Source Heat Pump Association (IGSHPA) publishes *Ground-source Heat Pumps: The Introductory Guide* and *Closed Loop/ground-source Heat Pump Systems: Design and Installation Standard*. IGSHPA also runs a certification program for ground-source heat pump installers.
Phone: (800) 626-4747
www.igshpa.okstate.edu
- American Society of Heating, Refrigerating, and Air-conditioning Engineers publishes several manuals and reports related to GSHPs, including *Design of Geothermal Systems for Commercial and Institutional Buildings*, which offers design and evaluation guidelines for GSHPs in commercial buildings.
Phone: (800) 527-4723
www.ashrae.org/BOOK/bookshop.htm
- Geothermal Heat Pump Consortium has educational material, financing information, and case studies on GSHPs.
Phone: (888) 255-4436
www.geoexchange.org
- Oak Ridge and Lawrence Berkeley National Laboratories provided supporting analysis for this recommendation.
Phone: (865) 574-2694

much better heat source and sink for a heat pump. The same is true of water from subsurface aquifers, as well as water from surface bodies at only slightly greater depths. The geothermal resource is generally cooler than outdoor air in the summer and warmer in the winter. For this reason, GSHPs are more efficient than air-source heat pumps.

When to Choose a Ground-Source Heat Pump

The technical feasibility of GSHPs depends on the availability of geothermal resources and the specifics of the application. Given an ample supply of ground water (and an acceptable means of disposing of it), an open-loop system may be a viable option. Such systems usually include a plate heat exchanger to transfer heat between the ground water and a common water loop inside the building; zone heat pumps exchange heat with the common loop. Surface water from lakes and streams can also be used in an open loop system, but applications are usually limited to warmer climates, or to cooling-only applications in colder climates.

In closed-loop designs, the earth itself can be used as the heat source and sink by way of vertical or horizontal ground-coupled heat exchangers. Most large systems use vertical heat exchangers, which consist of polyethylene u-tube pipes in deep (typically 150-250 feet) boreholes. Horizontal loops require more land area, but are usually less costly to install, depending on the types of soil and rock formations encountered at the site. Closed loops can also be located in lakes, ponds and other bodies of surface water.

There are various types of GSHP systems. Hybrid systems using several different geothermal resources, or a combination of a geothermal resource with outdoor air (i.e., a cooling tower), are another technology option. Hybrid approaches are particularly effective where cooling needs are significantly larger than heating needs. Where local geology permits, the "standing column well" is another option. In this variation of an open-loop system, one or more deep vertical wells is drilled. Water is drawn from the bottom of a standing column and returned to the top. During periods of peak heating and cooling, the system can bleed a portion of the return water rather than reinjecting it all, causing water inflow to the column from the surrounding aquifer. The bleed cycle cools the column during heat rejection, heats it during heat extraction, and reduces the required bore depth.

The installed cost of GSHP systems can be somewhat higher than that of conventional space conditioning equipment, but this depends on a number of factors, including the particular geothermal resource to be used, and whether the project involves new construction or renovation of an existing facility. For new commercial applications, the installation cost of a well-designed GSHP system is competitive with the cost of most conventional alternatives. However, even in applications where GSHPs have higher first costs, their life cycle cost is usually lower than other alternatives, given their substantially lower energy and maintenance costs. (see "Cost-Effectiveness Example," below).

How to Select Energy-Efficient GSHPs

When selecting ground-source heat pumps, choose models that qualify for the ENERGY STAR® label, all of which meet this Recommendation (see p. 1). Alternatively, specify a COP and EER that meet the recommended levels. Since GSHPs are an inherently efficient technology, the FEMP and ENERGY STAR® efficiency thresholds include the great majority of models for sale. However, models with efficiencies that substantially exceed these levels are widely available. The most efficient models, though, generally involve dual-speed compressor systems and increased heat exchange area, and thus cost significantly more.

Design and Sizing

A proper assessment of the building's peak heating and cooling loads is critical to the design of a GSHP system. As with all heating and cooling equipment, oversizing of GSHPs, besides raising purchase cost, will result in decreased energy efficiency, poorer humidity control, and shorter product life, all due to excessive on-off cycling.

Accurate knowledge of the properties of the geothermal resource is also crucial in the design of a GSHP system. For ground-coupled systems, important parameters include the thermal conductivity and temperature stability of the soil formation. In larger installations, these properties are often measured directly in short-term tests at one or more locations on the site. Because ground heat exchangers represent a significant portion of the cost of these types of systems, it is important to size ground loops accurately. Software tools for ground loop sizing are available from a number of vendors.

The design of groundwater systems depends on several properties of the water source, including temperature, well flow rates, and water quality. Surface water systems, whether open- or closed-loop, depend on the temperature profile of the surface water body (through all seasons, as this may vary significantly).

Financing GSHPs

Since GSHPs may be more costly to purchase than more conventional systems, direct procurement may be problematic. FEMP has a variety of programs that allow federal facilities to leverage available resources with private financing to fund energy conservation measures, including GSHPs. In an energy savings performance contract (ESPC), equipment is purchased and installed by an energy services company (ESCO), which then receives payments based on energy cost savings. FEMP makes it easy for federal facilities to enter into ESPCs with pre-selected ESCOs for installation of GSHPs. GSHP projects can also be readily developed and financed with local utilities in some areas. For more information on these contracts, visit the FEMP Web site or call the FEMP Help Desk (see "For More Information").

GSHP Cost-Effectiveness Example
(25,000 sq. ft. office building, Washington, DC)

Performance	Air-source Heat Pump	Gas furnace, Air-source AC	Recommended Level GSHP	Best Available GSHP
Heating/Cooling Efficiency	10.1 EER / 2.7 COP[a]	10.3 EER / 90% AFUE	14.1 EER / 3.3 COP	25.8 EER / 4.9 COP
Annual Cooling Energy Use	41,100 kWh	40,300 kWh	31,200 kWh	22,200 kWh
Annual Heating Energy Use	31,300 kWh	1,970 therms	12,000 kWh	11,400 kWh
Annual Energy Cost	$4,350	$3,200	$2,600	$2,050
Lifetime Energy Cost	$43,000	$32,000	$26,000	$20,000
Lifetime Energy Cost Savings	–	**$11,000**	**$17,000**	**$23,000**

a) The modeled 2.7 COP heating efficiency of the air-source heat pump is halfway between the cold weather (17°F) and standard, mild weather (47°F) rating conditions of a new high-efficiency (FEMP-recommended) model. Similarly, the modeled cooling efficiencies of the air-source heat pump, gas furnace, and air-source air conditioner all represent models that just meet the FEMP-recommended levels.

Definition

Lifetime Energy Cost is the sum of the discounted (present) value of annual energy costs based on average usage and assumed equipment life of 15 years. (GSHPs generally last longer than this, but 15 years is used since this is the expected life of the air-source equipment.) The assumed electricity and gas prices are 6¢/kWh and 40¢/therm. Future energy price trends and a discount rate of 3.3% are based on federal guidelines (effective from April, 2001 to March, 2002).

Cost-Effectiveness Assumptions

This example uses a well-known energy simulation program, DOE2, to model the four scenarios. Annual energy use is based on average heating and cooling load conditions in Washington, DC, where cooling predominates in commercial buildings. Calculations are based on a prototype 25,000 sq. ft. two-story building whose envelope parameters and lighting density just meet the requirements of ASHRAE Standard 90.1-99. The modeled building's window coverage is 40% of the gross wall area. Occupant density is one person per 200 square feet.

To properly evaluate different alternatives, a thorough modeling analysis such as this one using DOE2 is recommended. To compare systems with different purchase and annual energy costs (as estimated from DOE2, for example), FEMP's "Building Life-Cycle Cost" (BLCC) software is recommended (see "For More Information").

Metric Conversions

1 Ton = 12,000 Btu/h
1,000 Btu/h = 293 watts
*°F = (1.8 * °C) + 32*
1 Foot = 30.5 cm

Using the Cost-Effectiveness Table

In the example shown above, a GSHP with an EER of 14.1 and a 3.3 COP is cost-effective relative to the modeled air-source heat pump system if its installed purchase price is no more than $17,000 higher. The same GSHP is cost-effective relative to the modeled 10.3 EER air conditioner / 90% AFUE gas furnace combination if the price is not more than $6,000 higher ($32,000 – $26,000). The Best Available model, with an EER of 25.8 and a COP of 4.9, is cost-effective if its price is no more than $23,000 above the price of the air-source heat pump system.

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Case Study: Fort Polk's Conversion to GSHPs

At Fort Polk, Louisiana, the space conditioning systems of 4,000 military family housing units, occupying 5.6 million square feet were converted from air-source heat pumps (or, in some cases, central air / gas furnace combinations) to GSHPs with the help of an energy savings performance contract (ESPC).

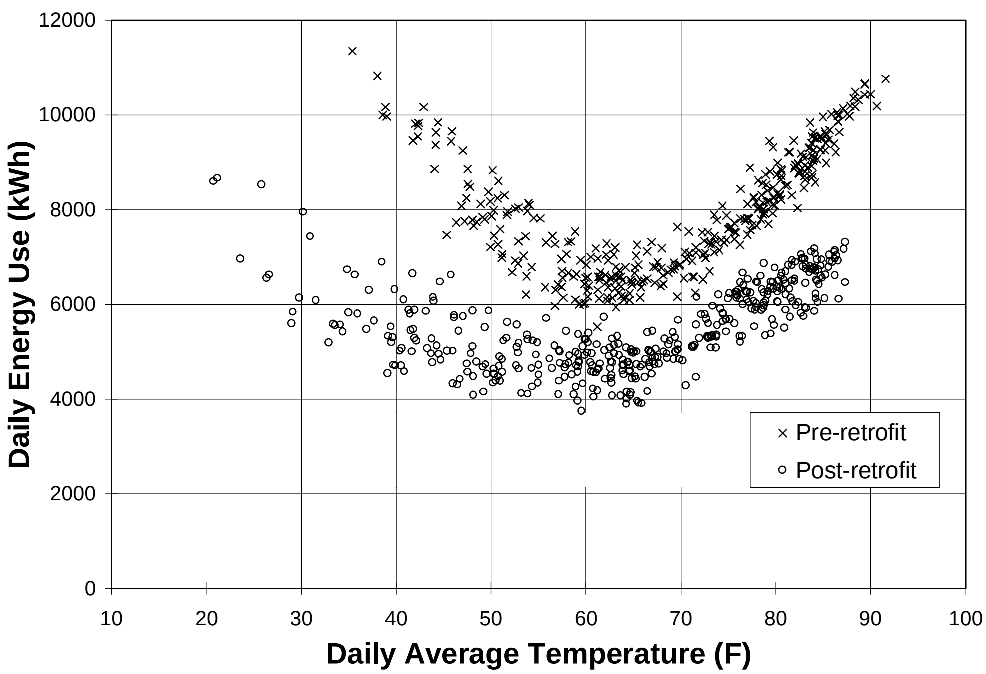
A total of 6,600 tons of cooling was installed to supply the 4,000 units. Approximately 75% of the new GSHPs included hot gas desuperheaters to supplement domestic hot water heating. As is common with major retrofit projects, other efficiency measures, such as compact fluorescent lamps (CFLs), low-flow shower heads, and attic insulation, were installed along with the GSHPs. Including all these measures, the total cost of the project came to approximately $19 million.

Definition

A desuperheater is a type of heat exchange coil at the outlet of an air-conditioning compressor that permits the transfer of heat to service hot water. Desuperheaters provide substantial water heating savings when air conditioning is occurring, since heat normally transferred to the ground can be utilized for water heating.

An independent evaluation revealed that the project resulted in a 25.6 million kWh, or 33%, savings in electricity for a typical meteorological year. Peak electrical demand was also reduced, by over 6.5 MW, or 43% of the peak demand. Natural gas savings average 260,000 therms per year. In addition, the ESPC allowed the Army to effectively cap its future maintenance costs for heating, ventilation, and air conditioning in family housing at about 77% of the pre-retrofit levels.

The total value of all energy and maintenance savings is approximately $3 million per year, part of which is paid to the energy service company that financed and installed the retrofit equipment.



Each data point represents the electric usage of 200 homes (one electrical feeder) on a given day.