Pergamon

Renewable Energy, Vol. 10, No. 2/3, pp. 481–488, 1997

0960–1481/97 $15.00 + 0.00

PII: S0960–1481(96)00107–3

GEOTHERMAL HEAT PUMPS: AN INCREASINGLY SUCCESSFUL TECHNOLOGY

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ABSTRACT

Geothermal heat pumps use the earth as a source of and sink for thermal energy used and given off by structures to be space conditioned. Closed and open loops of polyethylene pipe are placed into the ground or into surface waters to effect heat exchange with the earth. The space conditioning that results has significant benefits to the end user, to utility companies and to the local and national economies. Increased emphasis on education and technical awareness, decreasing first costs of installations and the availability of economic assistance to prospective geothermal heat pump system purchasers have led to impressive recent acceptance and market penetration.

KEYWORDS

Geothermal heat pumps, loop configurations, closed loops, open loops, heat pump benefits, market penetration, heat pump financing.

INTRODUCTION

Geothermal Heat Pump (GHP) systems utilize the earth or bodies of water as both a source of and a sink for the energy needed to heat and cool buildings and to heat water. Thermal energy is transferred between the earth and the GHP by fluids (often anti-freeze solutions) that circulate within "loop fields" comprising polyethylene pipes emplaced in vertical boreholes, horizontal trenches or in surface water bodies. Within the GHP, thermal energy is exchanged with a benign refrigerant (commonly HCFC-22) which then circulates past fan coils or through radiating tubes to give off or absorb heat at strategically designed locations within the building. In some less common types of installations, the heat pump refrigerant is circulated directly through a loopfield. Domestic hot water can be heated by a GHP either as a byproduct of the space heating or cooling processes or alternatively, "on-demand", in which case the entire output of the heat pump can be dedicated to the task.

TYPICAL GHP LOOP CONFIGURATIONS

Closed Loops

In a typical closed loop system, water or a water and antifreeze solution is circulated in a continuous buried pipe. The diameter and length of the pipe depends on the amount of heating or cooling required for adequate space conditioning and on the ground temperature, the degree of ground moisture, the thermal conductivity of the ground and the basic design of the system.

The buried pipe is normally a high density polyethylene. Subsurface pipe sections are connected using a heat fusing technique that results in a joint that is stronger than the original pipe. Prior to final burial of the loops, the pipes are purged to remove debris, flushed to remove air bubbles and pressure tested to preclude leaks. Proper design and installation is critical to the achievement of optimum system performance. Installation standards have been set by the International Ground Source Heat Pump Association (IGSHPA). This organization, together with some equipment manufacturers and a few other recognized authorities conduct training and certification of industry professionals.

Though seasonal variations of the ground temperature do occur, state-of-the-art geothermal heat pumps can still function efficiently. Because optimum conditions for energy extraction can occur when the ground around a loop freezes, antifreeze solutions are used to permits achievement of these high efficiencies while still protecting the loops and other equipment. Many antifreeze types are available. The antifreeze parameters of primary concern are toxicity, viscosity and cost. Among the acceptable antifreezes are propylene glycol, potassium acetate, methanol, denatured ethanol and inorganic salts such as calcium chloride. Ethylene glycol is not allowed in many parts of the U.S., but it is commonly used in other heat pump-rich countries such as Switzerland and Germany.

Horizontal Closed Loops - These systems are most often used for small installations were space is not at a premium. Pipes are buried in trenches dug about 5 feet deep with a backhoe or a chain excavator. As many as six pipes can be buried in one trench, with about a foot separating the pipes and trenches typically being twelve to fifteen feet apart. The "Slinky™", a loop comprising overlapping coils of pipe, can be used to maximize the number of feet of pipe buried per foot of trench, but Slinkys™ require more feet of pipe per ton of thermal energy needed than do conventional horizontal systems. Recent advances in drilling techniques have allowed the drilling of subhorizontal holes through which pipes can be pulled. This method is gaining popularity because it allows loopfields to be constructed under existing structures and because it minimizes disturbance of the ground surface.

The most important aspect of horizontal loop systems is their burial. Great care must be taken to obtain close contact with all of the pipe and the backfill materials. To ensure this, techniques have evolved that utilize 1) high pressure water to create slurries that are washed into place around the pipes and 2) "flowable backfills" composed of water, cement, flyash and sand having high thermal conductivities and which readily flow into place around the pipes. In some dry-ground situations, installers emplace "drip lines" through which water leaks so as to increase the soil moisture and the degree of heat exchange possible.

Vertical Closed Loops - At small sites where the soil layer is thin and for most commercial and school installations, vertical closed loop systems are preferred. The depths of the boreholes ranges between 100 and 400 feet. Depending on the soil, rock and groundwater conditions, from 130 to 300 feet of loop may be required per ton of heat exchange. At most vertical installation sites, many holes are drilled and the loops emplaced in the holes are then joined in parallel or series-in-parallel configurations.

Hole diameters range from 4 to 6 inches. Drilling costs range from $2.00 per foot in easy drilling environments where there are many installers seeking work to $7.00 per foot or more in places where the bedrock is hard and little drilling competition exists.

As is true for the horizontal systems, boreholes must be carefully backfilled or grouted to ensure optimum heat exchange and also to preclude contamination of aquifers by cross flow.

Surface Water Closed Loops - At sites where there is a body of surface water that is deep enough and which has significant flow, closed loops of pipe can be positioned on the bottom. The circulating fluids effect excellent heat exchange with the surrounding water while limiting the need for excavation to that required on dry land to bury the pipes leading to and from the water body. These systems are inexpensive to install, efficient and have no documented deleterious effects on aquatic ecosystems.

Open Loops

Open loop systems are very simple. Water is pumped out of a well, a surface water body or even a municipal water system component, passed through the heat pump heat exchanger and then discharged back into the source. Typical pumping rates are only 2-3 gallons per minute and, since water temperatures remain relatively constant year-round, these systems are favored in places where their use is allowed.

Overall, open loop systems are most inexpensive and efficient, however their use can lead to a need for frequent cleaning of the heat exchanger, addition of chemical inhibitors to prevent fouling of loops by organic matter and identification/permitting of a suitable discharge site.

Standing Column Wells

Standing Column Wells (SCWs) are used primarily in those parts of the country where bedrock and the ground water table are near the ground surface. SCWs can be up to 1500 feet deep and have diameters of 6-8 inches. The latter size is mandated by the need to position a pump downhole while still allowing room for water to circulate past the pump.

SCWs operate by pumping water from near the bottom of the well through the heat pump and then returning the water to the top of the well. The temperature of the heated or cooled return water is moderated by the temperature of the large volume of water in the SCW. When the temperature of the SCW water gets undesirably high or low, a small amount of water can be "bled" from the well. This allows ground water at the ambient temperature to enter the well and return the well water temperature to the prescribed range. When an SCW is used to provide potable water, as is often the case, "bleeding" is rarely needed.

Because SCWs are usually drilled in hard rock, their cost per foot is greater than that of vertical closed loop wells (~$10-12.00 per foot vs. $2-7.00+ per foot). However, because SCWs have heat exchange capabilities that are 3 to 4 times better than those of the vertical closed loop wells, (as little as 100 feet of well per ton of heat exchange), the cost per ton of SCWs is very competitive.

BENEFITS OF GHP USE

Consumer Benefits

Lower operating costs - Because of the high Seasonal Performance Factors (SPFs) of the modern GHP (the ration of annual energy demand to annual energy input), a consumer will find that energy bills using fossil energy sources can be reduced by 45% or more. Accordingly, the cost of installing a GHP system can be recovered in 2 to 3 years for a 33-50% return on investment. In the case of commercial consumers, such savings reduce overhead and prices charged customers thus making the business more competitive.

No outdoor unit - Since the well field is buried and the heat pump is indoors, GHP systems do not have an ugly, noisy, emissions-prone, vandal-attracting outdoor unit used by other HVAC systems.

Higher reliability and longer unit life - GHPs work indoors without burning fuels. They therefore avoid weathering and fouling associated with other systems. Also, because the GHPs are manufactured by well established leaders in the field, they are highly reliable and have very low maintenance costs.

Comfort - GHPs provide consumers with high comfort levels including humidity control. In addition, by using multiple heat pumps, temperatures can be regulated on a zone by zone basis. For these reasons, the great majority of GHP users have expressed total satisfaction with their systems and a willingness to recommend use of a GHP to others.

Utility Benefits

Customer satisfaction and business stability - Because customers who install GHPs often do so upon the recommendation of the local utility, they often express their satisfaction to the utility and tend to remain loyal customers for long periods of time.

Flatter power load profile - GHP use tends to even out the demand for energy on both seasonal and annual bases. This means that a utility needs less peaking power and, in the long run, that expenditures for building new capacity can be delayed thus maintaining low power prices for all consumers and greater profits for shareholders.

Benefits to Local and National Economies

Increased employment - As the demand for GHPs increases, there has been a growing market for skilled drillers, installers and system operators and maintainers. These small to medium sized businesses contribute to local and regional economic improvements.

New equipment sales - As the GHP industry grows, the demand for drilling and excavation machinery increases. Since most of this equipment is manufactured in the U.S., the GHP industry-related sales contribute significantly to both local and national economies.

Improved balance of trade - Statistics confirm that the adoption of GHP systems results in a decrease in the use of fossil fuels, some of which are imported. Also, because the U.S. is a world leader in GHP equipment manufacture and in development of innovative technology, a significant opportunity has been created for export of high quality goods and services. Both of these trends help improve the national balance of trade; the former by reducing imports and the latter by increasing exports.

Increased competitiveness - The adoption of GHP systems leads to money savings for residential, commercial and institutional end users. These savings contribute to reduced overhead, increased business efficiency, the ability to lower prices to customers and advantages in the marketplace.

THE KEYS TO SUCCESSFUL GHP MARKET PENETRATION

The simplicity, economic benefits and energy efficiency of geothermal heat pumps has led to significant increases in market penetration over the last few years. In the US, there is now a concentrated effort underway to effect a ten-fold increase in the number of GHP units sold annually from about 40,000 to 400,000 by the year 2000.

There are three key activities being used by the GHP industry, many US utilities and their allies to accomplish this objective:

1. Education and technology awareness,
2. First cost reduction
3. Financial assistance to prospective end users

Education and technology awareness - The GHP industry is well past "ground zero" with regard to the status of education and technology awareness in the northeastern, mid-Atlantic, central and the southern parts of the country. The GHP message is now being aggressively spread to the west via work being led by the International Ground Source Heat Pump Association (IGSHPA), the Geothermal Heat Pump Consortium (GHPC) and most of the GHP manufacturers.

IGSHPA has, since the 1980's, been promoting GHPs by conducting courses for installers, training more educators and distributing informative literature. The GHPC has recently announced funding for establishment of additional training centers and the manufacturers are expanding and upgrading their training facilities.

This education is being focused on architects, HVAC contractors, utilities, environmental groups, state and local regulators and prospective governmental, institutional, commercial and residential end-users. Experience has shown that once managers in these fields develop confidence in the technology, they are anxious to specify and/or approve its use. As a result, the technology rapidly gains acceptance.

First cost reduction - In addition to the education of the groups listed above, it has been found to be important to lower the first cost of GHP system installation as much as possible. This is being done through the development of more efficient drilling, loop installation and grouting techniques and by encouragement of competition among installers. The former is happening as installers dedicated entirely to GHP work discover innovative ways to work more efficiently and the latter is happening thanks to the training programs alluded to above. As the industry matures, declining costs can be credited with the increasing degree of acceptance of the technology.

Financial assistance to prospective end users - The final key to market penetration of GHPs is the provision of financing and of incentives to end users. Financing can take the form of standard loans, of loans with shared savings provided, leases and end-use pricing.

In a standard loan, the end-user borrows the money for the system purchase and pays all O&M costs. With shared savings, the end-user borrows money and then pays a fixed monthly fee to a financial operator who is responsible for all O&M. In a lease, the costs of the equipment and maintenance is covered by the lease payment while the end-user pays all operating costs. Finally, in end-use pricing, the total cost of equipment plus O&M is covered in one monthly payment.

Incentives, commonly provided by utilities, comprise the second important financial incentive. These usually take the form of initial cost reductions, interest rate reductions and per-ton rebates to the customer.

SUMMARY

Geothermal heat pump systems can be installed in closed and open loop configurations that include vertical, horizontal, and surface water closed loops and standing column/water well open loops. The use of any of these systems has many benefits that accrue to end users, to utilities, and to local and national economies. There are three keys to the successful market penetration of GHPs that has occurred since the 1980s: Education and increase of technology awareness, first cost reduction and provision of financial assistance to end-users. The combination of a simple, efficient technology coupled with a growing awareness of benefits, a rapidly developing infrastructure and attractive paybacks has resulted in successful proliferation of geothermal heat pumps.

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