3-1987

Earth-Coupled Heat Pump Systems--Selection, Design & Performance

Larry W. Turner
University of Kentucky

Donald G. Colliver
University of Kentucky, dcolliver@uky.edu

W. E. Murphy
University of Kentucky

AEES-38

Earth-Coupled Heat Pump Systems – Selection, Design & Performance

University of Kentucky
College of Agriculture
Cooperative Extension Service
Department of Agricultural Engineering

L. W. Turner, D.G. Colliver and W.E. Murphy

Rising energy costs have caused many people to look for more efficient ways to heat and cool their homes. One of the most energy-efficient systems to come along in recent years is the earth-coupled heat pump. Pioneered at the University of Kentucky in the 1950s, the earth-coupled system relies on the thermal capacity of water to transfer heat, whereas a conventional heat pump relies on outside air. In an earth-coupled system, a water-source heat pump is connected (or "coupled") to pipes in the ground or in wells for the source of heat in winter and cool air in the summer. In this way, heating or cooling energy is transferred by water through the system.

Prompted by the energy crisis of the 1970s, many Kentuckians have installed earth-coupled systems. Sadly, not everyone has realized the energy savings they had hoped for because of a poorly designed system not suited to their home heating and cooling needs. However, when installed properly, an earth-coupled heat pump system offers a high-efficiency alternative to the more common air-source heat pump. This publication is about the operation and design of the earth-coupled heat pump system as compared to air-to-air systems. It will help you, as a homebuyer or builder, recognize the characteristics of a well designed system.

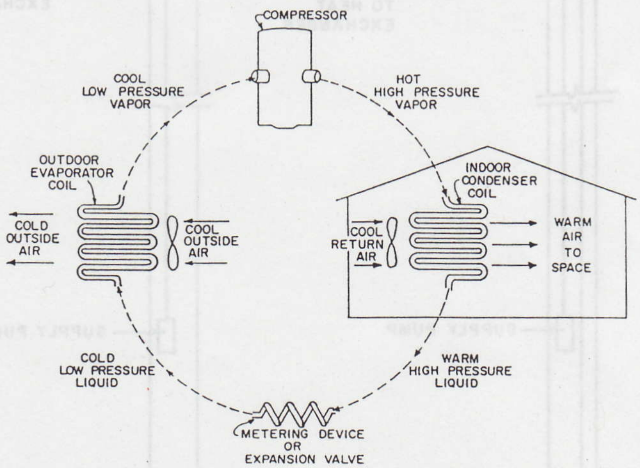
Overview of Systems

Earth-coupled heat pump systems operate on the same basic principles as air-source systems. Each extracts heat using some type of heat exchanger. The heat is then transferred by a refrigeration system to another heat exchanger, which delivers the heat. Figure 1 shows the typical wintertime air-to-air cycle of operation in which heat is extracted from outside air and delivered to the interior heated space by passing air over a finned-coil (auto-radiator-type) heat exchanger.

Figure 2 illustrates the operation cycle of earth-coupled heat pump systems. Instead of an air-type heat exchanger, the outdoor coil is replaced by a water-type heat exchanger (tube-in-tube or shell and tube). This exchanger picks up heat from water warmed by the earth. This can be done by circulating water in coils of plastic pipe buried in the soil or by drawing water directly from a well, pond or lake.

There are two types of earth coupled systems, open and closed-loop.

FIGURE 1. Heat pump cycle for heating, for an air-to-air heat pump system.



Published by the Cooperative Extension Service in cooperation with the Kentucky Department of Energy as a part of the Kentucky Energy Conservation Program.

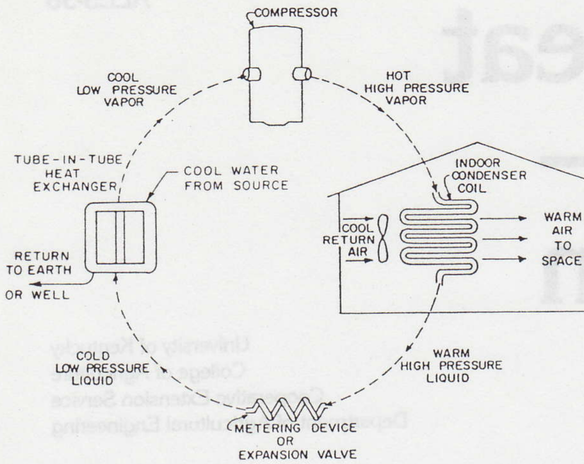


FIGURE 2. Heat pump cycle for heating, for an earth-coupled heat pump system.

Open Systems

Open earth-coupled systems are those in which the water loop is open during some portion of the circulation cycle. This includes systems where: a) water is recirculated in a single well, b) a supply and a return well are used, or c) a single supply well is used in conjunction with open discharge (see Figure 3). In any of these systems, the quality and quantity of available water are important design considerations. Quality is important because open systems expose equipment to a continuous source of oxygen and minerals. Therefore, steps must be taken to prevent corrosion and remove deposits in the water-type heat exchanger.

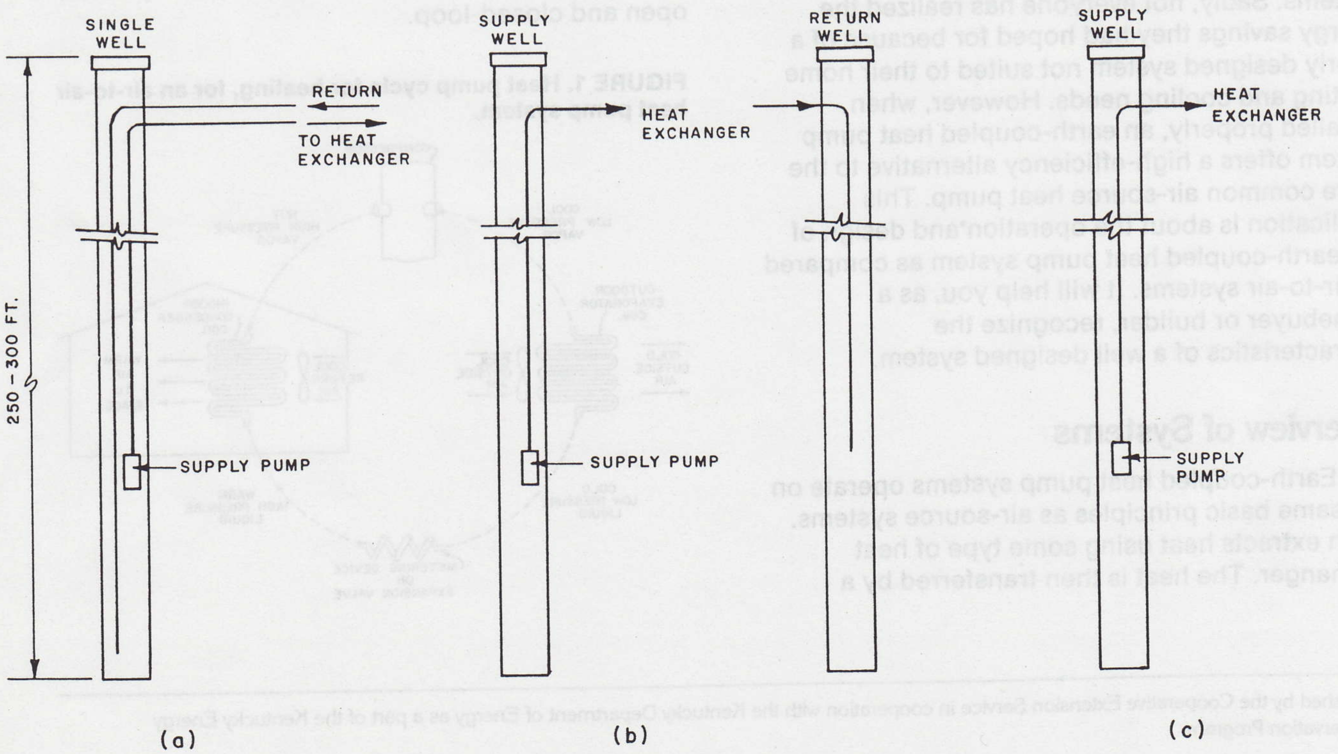
Quantity of water is important because most water-source heat pumps specify a flow rate of three to five gallons per minute per ton of capacity. Assuming 10 gallons per minute for a two-ton unit, this would require 7200 gallons in a 12-hour day of operation or 1.8 million gallons for a 3000-hour operation year. Therefore, both abundant supply and efficient disposal of water are very important in open systems.

Closed-Loop Systems

Closed-loop systems are those which use water flowing through a buried pipe to transfer the heat. Water is recirculated through a sealed loop of pipe and picks up or releases heat depending upon the season. By recirculating the water through the system, it is not discharged or wasted.

There are two main types of closed-loop systems: vertical and horizontal. The vertical system calls for drilling a 250- to 300-foot hole and placing a pipe loop within an outer casing (Figure 4). For the horizontal loop system, pipe usually is

FIGURE 3. Open earth-coupled heat pump installations: a) single well, recirculating, b) two-well system, c) single well, open discharge.



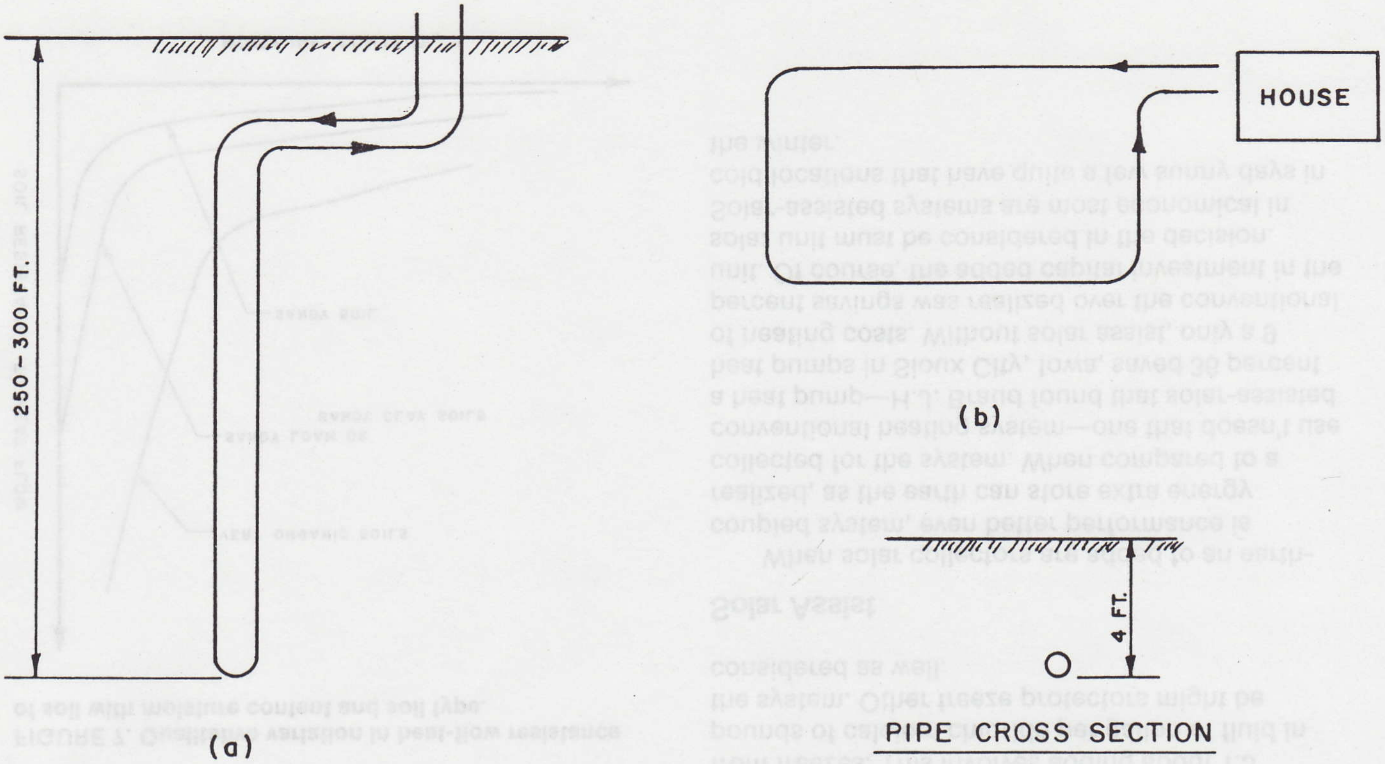


FIGURE 4. Closed-loop earth-coupled heat pump installations: a) vertical loop, b) horizontal loop.

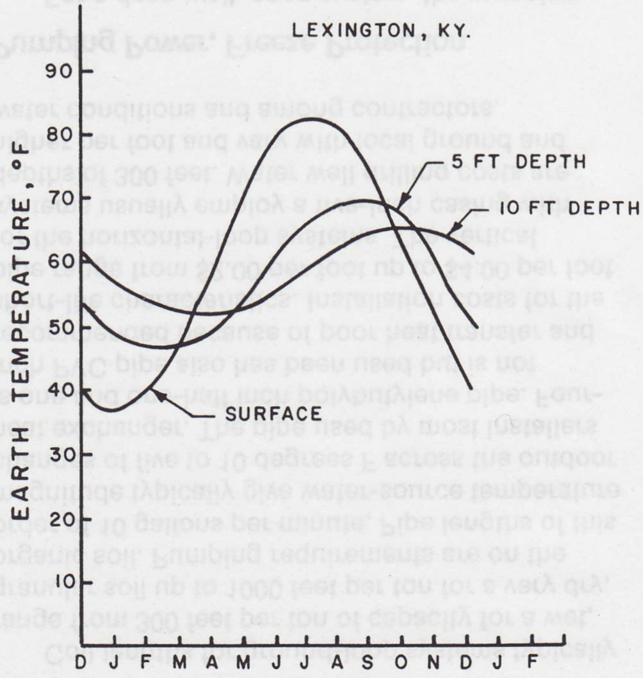
laid in a four-foot-deep trench. The length of pipe required varies between 300 to 800 feet per ton of capacity, depending upon depth, climate, soil type and drainage. Water flow rates are the same for closed-loop heat pump systems as for open systems.

Source Temperatures

The advantages of using the nearly constant temperature of well water as opposed to air as a heat source include improved efficiency gained from a more favorable source temperature during each season and the greater thermal capacity of water as compared to air. The temperature of well water in most locations is fairly constant at depths of 50 feet or below. For Lexington, Kentucky, this value is 58 degrees F. In comparison, West Lafayette, Indiana, has a value of 54 degrees F and Gainesville, Florida, has a value of 74 degrees F.

Horizontal earth-coupled ground loops also offer the same advantages as systems using well water, although ground temperature varies more with season (Figure 5). In Lexington, for example, the monthly average temperature of the ground surface varies from 36 degrees F up to 83 degrees F. However, at a depth of five feet, the ground temperature varies only from about 47 degrees F up to 69 degrees F. Such limited variation provides an advantage for the earth-coupled unit as opposed to using air to supply or discard heat.

FIGURE 5. Average monthly temperature variation for a particular soil in Lexington, KY.



Performance of Earth-Coupled Systems

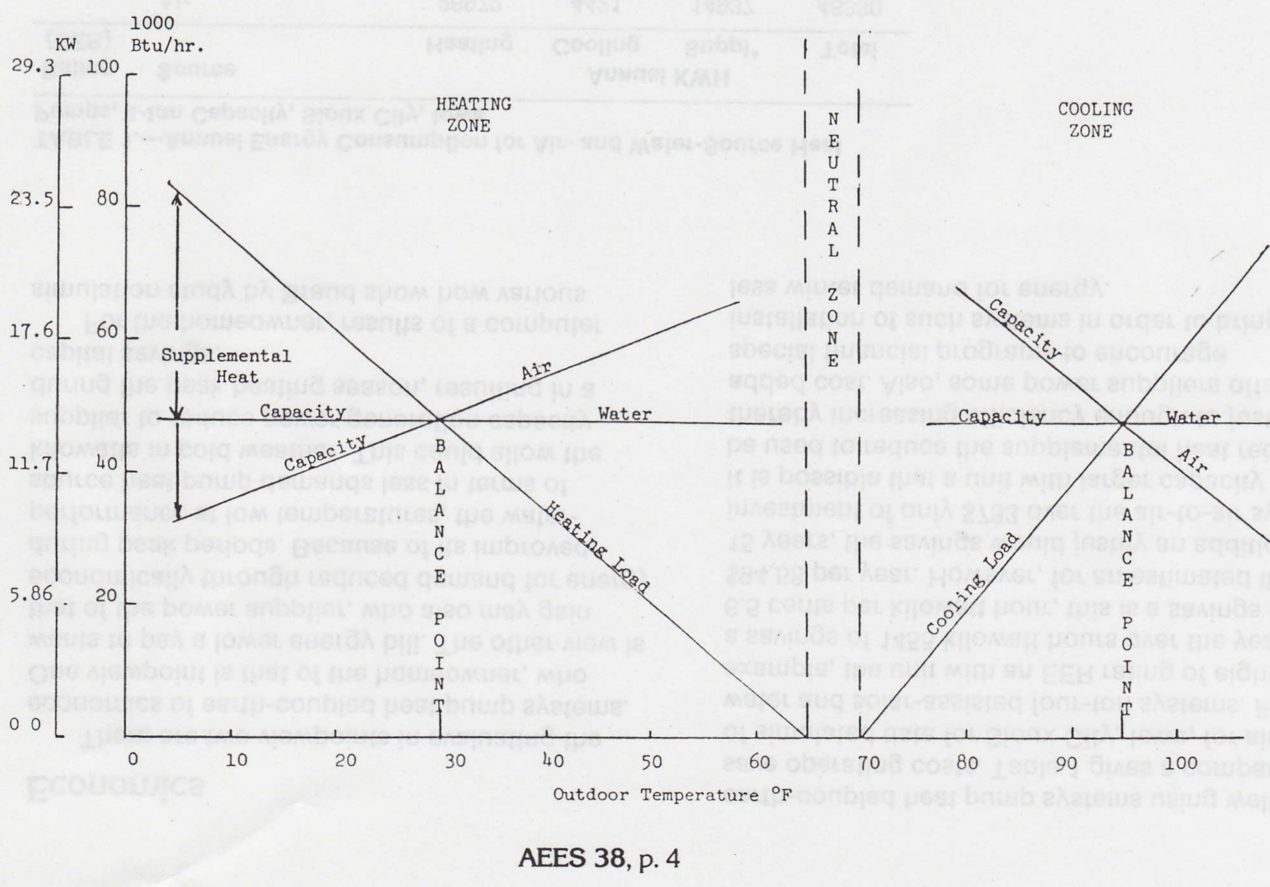
For a constant water-source temperature of around 52 degrees F, an earth-coupled system has a seasonal performance factor (SPF) of 3. This means it supplies an average of about three times as much heat energy as an electric resistance heating system, such as an electric baseboard unit, for every kilowatt hour of electricity purchased. In comparison, most air-source heat pump systems have SPF values of 1.25 to 2.0, that is, they generate 1.25 to 2.0 times more heat for every kilowatt hour of input than an electric resistance heating system. Operating the water-source unit is therefore more economical than an air-source heat pump, as long as the system is properly sized. The water-source unit should be large enough to eliminate the need for supplemental, back-up heat to achieve comfortable temperatures, except when it is very cold outdoors.

One important aspect to consider in comparing air-source to earth-coupled systems is the fact that the heating or cooling capacity of an air system changes with outdoor temperature. However, when a well is the water source, the capacity of an earth-coupled system is nearly constant. Figure 6 illustrates this principle. If both systems are balanced to meet the heating load at a certain outdoor air temperature, then at air temperatures above the balance point the capacity of the air-source heat pump increases while the water-source heat pump's capacity is constant. This shows one of the major disadvantages of an air-source system: it must be sized to meet the heating load at low outdoor air temperatures, even though it has a higher capacity at higher temperatures. Therefore, a larger capacity compressor is required than is the case with earth-coupled systems.

Heat pumps are rated at different temperatures, depending upon the source. In the heating mode, the water-source heat pumps of an earth-coupled system are rated at 50 degrees F entering water temperature. Because air temperature varies much more than water temperature, air-source units are rated at two air-source temperatures: 47 degrees F, and an "application" rating at 17 degrees F, a temperature representative of typical cold-weather operation.

In the cooling mode, water-source earth-coupled units are tested at 70 degrees F entering temperature while air units are tested at 95

Figure 6. Heating and cooling load lines for a four-ton (48,000 BTU/hr.) load at balance point temperature of 30 degrees F heating and 95 degrees F cooling. (Braud, 1979.)



degrees F. Note that water-source ratings do not include the electricity needed to pump water. Some engineers estimate this input as 10 kilowatts per million BTU's delivered for an open system. This would serve to reduce the performance rating slightly. Performance curves sometimes are available from the manufacturer, to enable your particular source temperature to be used in designing the system. A standard method of rating all heat pumps, both air-source and water-source, has been developed by the Air-Conditioning and Refrigeration Institute.

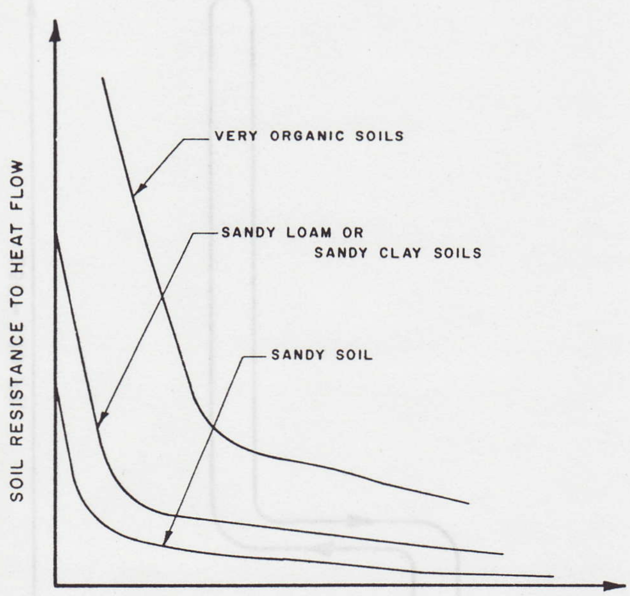
System Design

The key to designing a workable earth-coupled heat pump system is proper sizing and installation of the well or ground coil. This depends upon climate, soil properties, water quality and quantity, and heating capacity. Important considerations also include pumping power required, freeze protection and the possibility of adding a solar collector.

Soil Properties

The most important factors with regard to soil properties are moisture content and dry density. Figure 7 indicates the variation of soils in their resistance to heat flow. For example, for a dry, organic soil, the pipe length required to pick up sufficient heat may be two to three times the length required for a wet, granular soil.

FIGURE 7. Qualitative variation in heat-flow resistance of soil with moisture content and soil type.



Coil or Well Design

Coil lengths for ground-loop systems typically range from 300 feet per ton of capacity for a wet, granular soil up to 1000 feet per ton for a very dry, organic soil. Pumping requirements are on the order of 10 gallons per minute. Pipe lengths of this magnitude typically give water-source temperature changes of five to 10 degrees F across the outdoor heat exchanger. The pipe used by most installers is one and one-half inch polybutylene pipe. Four-inch PVC pipe also has been used but is not recommended because of poor heat transfer and short-life characteristics. Installation costs for the pipe range from $2.00 per foot up to $4.00 per foot for the horizontal-loop systems. The vertical systems usually employ a five-inch casing with depths of 300 feet. Water well drilling costs are higher per foot and vary with local ground and water conditions and among contractors.

Pumping Power, Freeze Protection

For a deep-well, open system, the pumping power required is approximately seven to 10 kilowatt hours per million BTU. Typically the pumping power for a horizontal closed-loop system will be less than that of a deep-well, open system because there is no elevation to pump against. Only the pipe's friction must be overcome. To function properly, the pump must be designed to handle the pressure drop anticipated for the system.

A closed-loop system should be protected from freezes. This involves adding about 1.5 pounds of calcium chloride per gallon of fluid in the system. Other freeze protectors might be considered as well.

Solar Assist

When solar collectors are added to an earth-coupled system, even better performance is realized, as the earth can store extra energy collected for the system. When compared to a conventional heating system—one that doesn't use a heat pump—H.J. Braud found that solar-assisted heat pumps in Sioux City, Iowa, saved 36 percent of heating costs. Without solar assist, only a 9 percent savings was realized over the conventional unit. Of course, the added capital investment in the solar unit must be considered in the decision. Solar-assisted systems are most economical in cold locations that have quite a few sunny days in the winter.

Economics

There are two viewpoints in evaluating the economics of earth-coupled heat pump systems. One viewpoint is that of the homeowner, who wants to pay a lower energy bill. The other view is that of the power supplier, who also may gain economically through reduced demand for energy during peak periods. Because of its improved performance at low temperatures, the water-source heat pump demands less in terms of kilowatts in cold weather. This could allow the supplier to reduce power generation capacity during the peak heating season, resulting in a capital savings.

For the homeowner, results of a computer simulation study by Braud show how various earth-coupled heat pump systems using well water save operating costs. Table 1 gives a comparison of simulated data for Sioux City, Iowa, for air, well water and solar-assisted four-ton systems. For example, the unit with an EER rating of eight gave a savings of 1455 kilowatt hours over the year. At 6.5 cents per kilowatt hour, this is a savings of $94.58 per year. However, for an estimated life of 15 years, the savings would justify an additional investment of only $733 over the air-to-air system. It is possible that a unit with larger capacity could be used to reduce the supplemental heat required, thereby increasing efficiency enough to justify the added cost. Also, some power suppliers offer special financial programs to encourage installation of such systems in order to bring about less winter demand for energy.

TABLE 1.—Annual Energy Consumption for Air- and Water-Source Heat Pumps, 4-ton Capacity, Sioux City, Iowa

Rating	Source	Annual KWH			
(EER)		Heating	Cooling	Suppl*	Total
	Air	26972	4421	14937	46330
7	Well Water (52°F)	25646	3999	13713	43358
	Solar + Well Water	22302	3999	2478	28779
	Air	21475	3913	14937	40325
8	Well Water (52°F)	21518	3639	13713	38870
	Solar + Well Water	19516	3639	2478	25633
	Air	17871	3512	14937	36320
9	Well Water (52°F)	18621	3342	13713	35676
	Solar + Well Water	17390	3342	2478	23210
	Air	17293	3184	14937	35414
10	Well Water (52°F)	18142	3093	13713	34948
	Solar + Well Water	17024	3093	2478	22595

*Supplemental

Summary

Earth-coupled heat pump systems offer a high-efficiency alternative to the conventional air-to-air heat pump system. They also require a large initial investment, as much as $1,500 to $2,000 more than an air-to-air system. To make this investment worthwhile, a properly designed system is imperative. For this reason, only a qualified contractor who has received adequate training should install it. This professional will be aware of the many factors discussed here that must be considered in order to obtain the full benefit of an earth-coupled heat pump system.

Reference

Braud, H. J. 1979. Water source heat pumps for agricultural applications. American Society of Agricultural Engineers Paper No. 79-4562.

For more detailed information:

"Design/Data Manual for Closed-Looped, Ground-Coupled Heat Pump Systems," American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., Atlanta, Ga., 1985.

Issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Charles E. Barnhart, Director of Cooperative Extension Service, University of Kentucky College of Agriculture, Lexington, and Kentucky State University, Frankfort.

1M—3-87