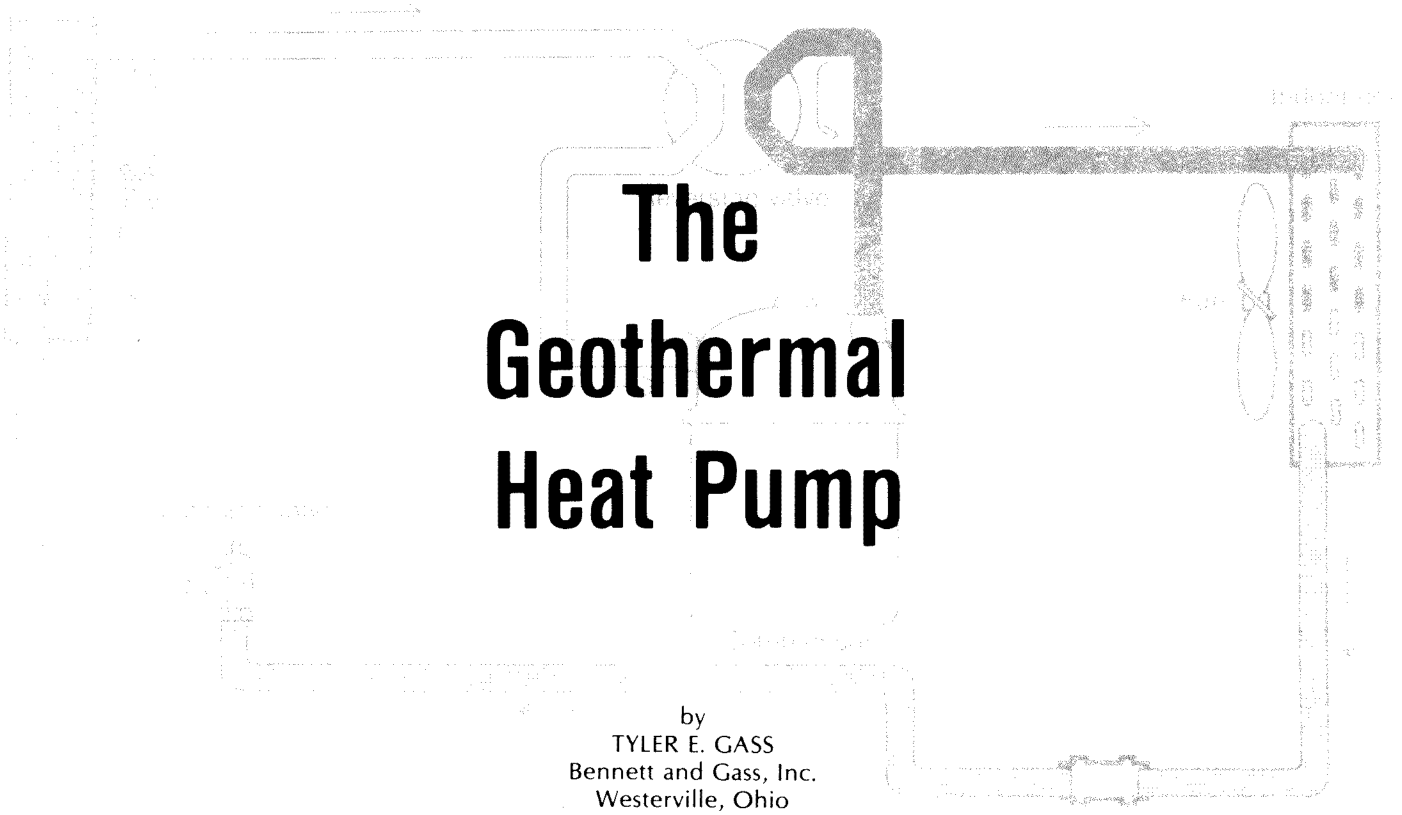
Editor's Note: The Geothermal Resources Council is keenly interested in the utilization of geothermal ground-water heat pumps for large industrial applications. We are publishing the following feature articles as an expression of this interest and hope to be able to publish many more in future issues. In addition, the Council's Education Committee has tentatively planned a workshop on industrial heat pumps to be presented during the GRC Annual Meeting, 23-27 October 1983, in Portland, Oregon. The Council's aim is to provide those who are involved in the research, design, manufacture, sales, and installation of industrial heat pumps with a place in ongoing GRC activities, as well as to offer them membership in an organization that understands and will accommodate their specific needs.

If you are interested in industrial heat pumps; in future GRC programs in this area; in the Portland, Oregon workshop; or in publishing an article on the subject in the BULLETIN, *please contact David Anderson at the Council office, 1-916/758-2360.*



The Geothermal Heat Pump

by
TYLER E. GASS
Bennett and Gass, Inc.
Westerville, Ohio

Few people today question the feasibility of using steam or high-temperature fluids contained in the earth to generate electricity for industrial processing or for heating buildings. This resource—known as geothermal energy—is typically associated with places such as The Geysers, Yellowstone, and Iceland.

Unfortunately, most of the world's population has overlooked the potential of a readily accessible source of geothermal energy lying just beneath our feet. Ground water ranging in temperature from only 38° to 140°F can supply a considerable amount of heat energy when coupled with a geothermal or ground-water heat pump. In the United States, geothermal heat pumps have been marketed for over thirty years as a means of providing space heating and cooling.

The U.S. Department of Energy has recognized the potential applications for low-temperature geothermal resources and has actively undertaken research and demonstration projects to evaluate the performance and cost-effectiveness of geothermal heat pumps.

The Geothermal Resource and Energy Committee (E-45) of the American Society of Testing and Materials (ASTM) established a special task group to prepare standards for the installation and application of geothermal heat-pump systems. ASTM E-45 has also proposed a definition for geothermal energy to cover the use of earth temperatures as low as 38°F.

Geothermal heat pumps currently are responsible for providing less than five percent of the heating and cooling requirements of the United States. However, during the past seven years their use and popularity has dramatically increased. To understand the cause of this sudden interest in the geothermal heat pump, we must examine the method of its operation as well as its performance characteristics.

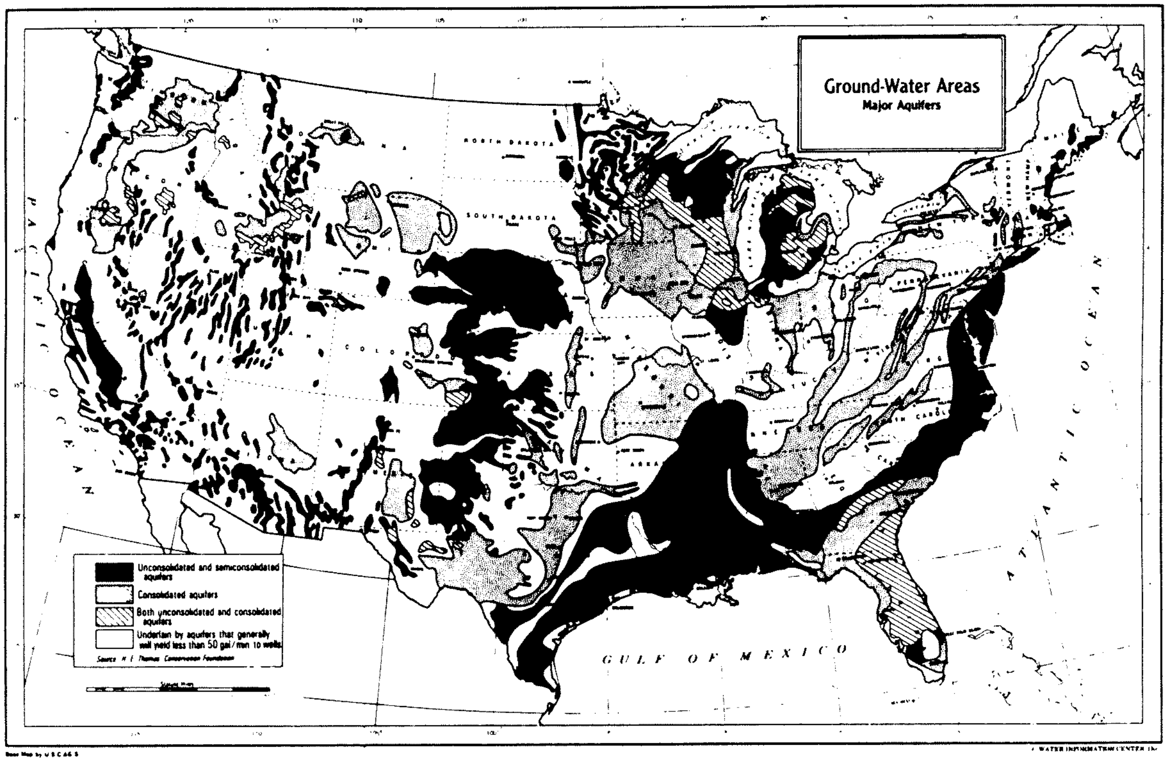


Figure 1. Ground-water areas: major aquifers.

Low-Temperature Geothermal Energy: Ground Water

Beneath the surface of the earth are vast reservoirs of ground water stored in formations called aquifers. Figure 1 depicts the major aquifer systems in the United States. This underground water, utilized essentially as a source of municipal, domestic, and industrial water supply, is now being considered by many energy experts as one of the United States' most promising energy resources. The National Water Well Association estimates that beneath approximately 80 percent of our country there are adequate supplies of ground water for residential and commercial applications of geothermal heat-pump systems.

To understand how ground water can be used as a source of energy, we must first be familiar with water's unique characteristics. Few substances known to man exhibit the physical and chemical properties that make water both essential to life and a potential source of energy.

Heat is energy, and water in its liquid state stores energy in the form of heat. The quantity of heat required to increase the temperature of a unit weight of any substance one degree centigrade is known as that substance's specific heat. Water, which has been taken as the standard substance for defining the unit of heat quantity, has with few exceptions the highest specific heat of all compound substances. In fact, few substances have a specific heat half as great as water.

The following example can be utilized to demonstrate why water is a source of energy:

At 32°F the specific heat of lead is 0.03; of water it is approximately 1.0. If the same quantity of heat, say 1 Btu (British thermal unit), is put into a pound of lead and a pound of water (both at 32°F), the temperature of the lead will be raised more than thirty degrees and that of water one degree. In other words, with the same temperature input, we can store thirty times as much heat in a pound of water as in a pound of lead. Thus, water has an enormous potential to absorb and store heat. Furthermore, at some later date, we can get back thirty times as much heat from the pound of water by letting it cool one degree. Since heat is energy, the higher the water temperature, the greater the amount of energy it has stored.

Ground water is more than a subsurface reservoir or domestic, municipal, agricultural, and industrial water supply: it is also a subsurface reservoir of heat energy.

With this understanding of the potential of ground water as an energy source, let us turn to the heat pump and discuss how it utilizes this stored energy.

The Geothermal Heat Pump

"Heat pump" is the name generally applied to a year-round air-conditioning system in which refrigeration equipment is employed to supply useful heat to a space during the heating cycle and to extract unwanted heat from the space during the cooling cycle. The advantage of the geothermal heat-pump system lies in its ability to extract available heat energy from ground water (the heat source) when heating is required, or to reject heat to ground water (the heat sink) when cooling is required.

Figure 2 is a schematic diagram of a geothermal heat-pump system operating during a heating cycle. Valve 1 directs a hot (180°F) gaseous refrigerant (i.e., Freon) from the compressor to a refrigerant heat-exchanger coil. The usable heat is removed by the refrigerant passing through a radiator in a ventilation system (air handler). As the temperature is lowered, the gaseous refrigerant is cooled and it condenses to a liquid. The liquid refrigerant then travels through an expansion device where the pressure and temperature of the Freon are reduced as it partially vaporizes. The Freon is then returned to the ground water-to-refrigerant heat exchanger where heat is to be extracted from the water. The liquid refrigerant absorbs the heat from the water and evaporates. The cycle is then repeated.

During the cooling cycle (Figure 3), the position of Valve 1 is reversed. Hot air blowing over the air-to-refrigerant heat exchanger coil gives up heat to the liquid refrigerant causing it to evaporate. The cooled air then passes through the ducts of the ventilation system. The gaseous refrigerant is directed by Valve 1 into the compressor and is then pumped to the water-to-refrigerant heat exchanger. The refrigerant gives up heat to the water and condenses. The water is warmed and is subsequently discharged into a well, sewer line, holding tank, or stream. The liquid refrigerant returns to the air-to-refrigerant heat-exchanger coil to extract more heat from the air and continue the cooling cycle.

Another type of geothermal heat-pump system relies on either vertical or horizontal coils buried beneath the ground. A fluid such as water, water propylene glycol mixture, brine, etc. can be circulated through the coil and heat can be transferred between the fluid and the surrounding earth. Better

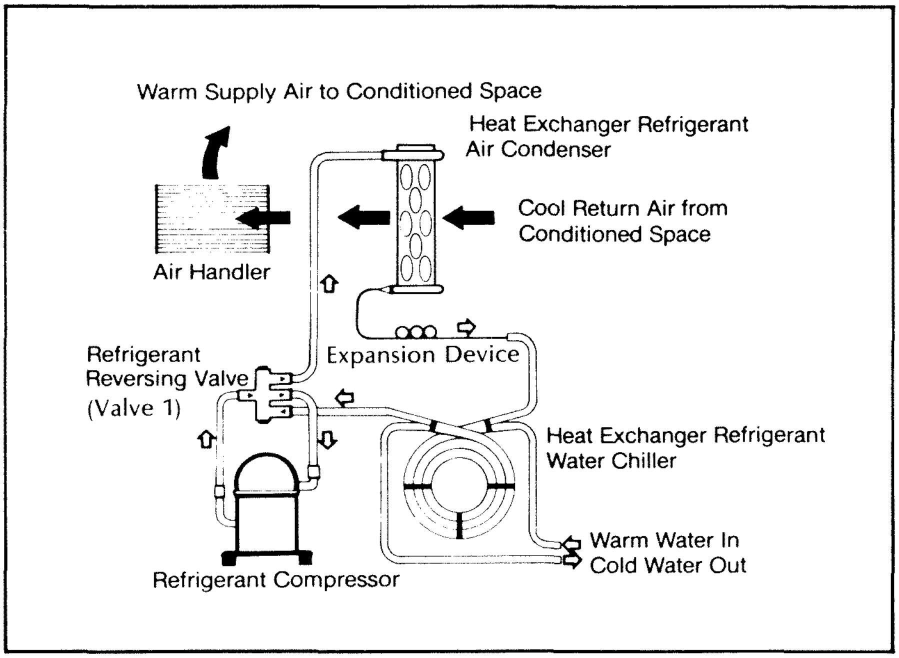


Figure 2. Heating mode operation.

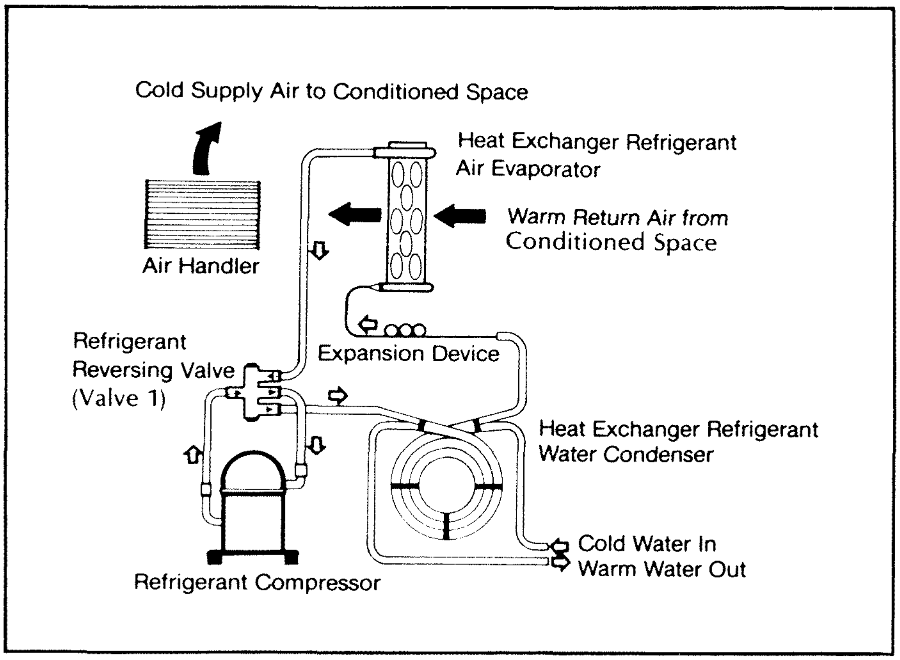


Figure 3. Cooling mode operation.

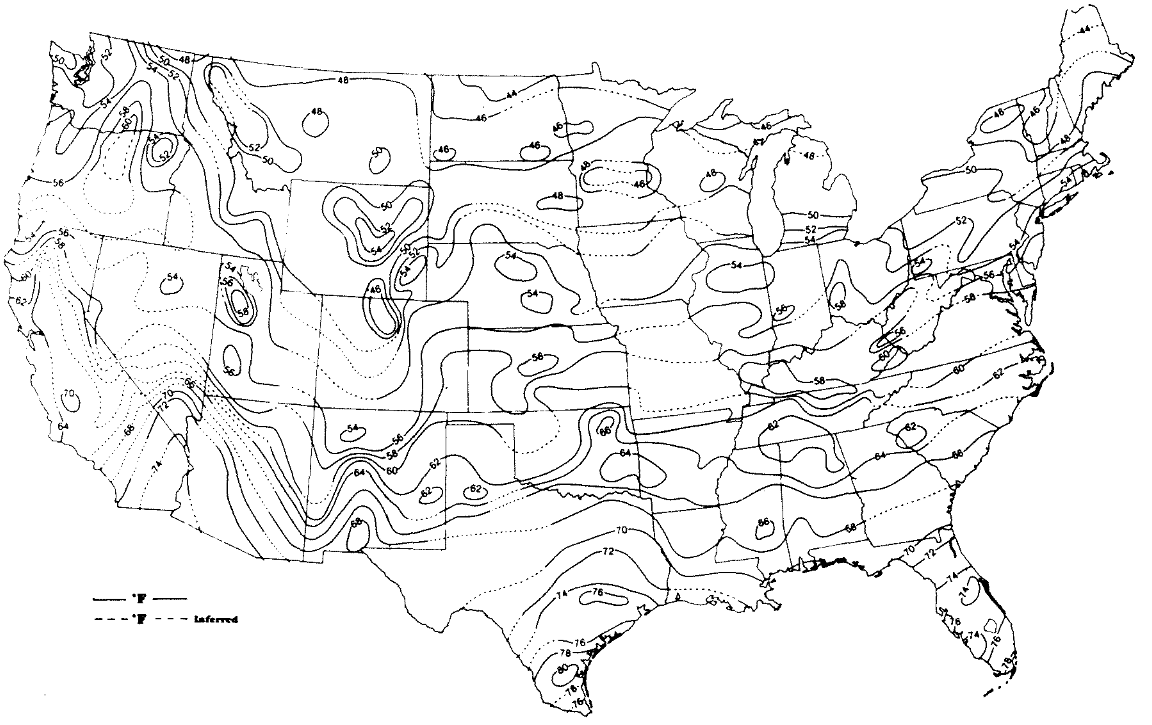


Figure 4. Ground-water temperatures in wells ranging from 50' to 150' in depth.

performance is achieved if all or part of the coil lies in contact with ground water, which enables better ground-to-coil heat exchange.

Geothermal heat-pump systems can use water rather than air for supplying heat or extracting heat from interior spaces. Such systems frequently make use of radiators or fan-coils, and temperature-conditioned water carries heat to or from the parts of the structure to be heated or cooled.

There are two reasons that ground water is the ideal energy source for heat-pump operation in the United States. First, the temperature of shallow ground water (with the exception of in Alaska) ranges from about 40°F along our northern boundary to about 80°F in southern Florida (Figure 4). These temperatures fall within a geothermal heat pump's efficient operating limits. Second, unlike air or surface water, the temperature of ground water varies little, if at all, regardless of surface temperature extremes. Therefore, when utilized in conjunction with a heat-pump system for interior building temperature control, the ambient thermal characteristics of underground water in the United States make it an ideal source of energy.

The use of geothermal heat-pump systems is not new. In fact, heat-pump systems have been in operation for as long as thirty years. In most situations, considerable energy savings have been reported by users of geothermal heat pumps as compared to the energy requirements of other forms of interior-space temperature control.

In all but the warmest geographical areas, most of the energy savings engendered by a heat pump take place in the winter when it provides more Btu's of heat than the Btu equivalent amount of kilowatts consumed. This ratio of output to input is called the Coefficient of Performance (COP).

A 2,000-sq-ft single-family dwelling requires a heating system with a capacity of 30,000 Btu's/hr. Operating this system 50 percent of the time to maintain an inside temperature of 68°F while the outside temperature is 20°F calls for 108 kw/day. Under the same operating conditions, an average 30,000 Btu/hr geothermal heat-pump unit utilizing a water temperature of 45°F would require less than 30 kw/day.

The difference results because energy in the form of heat is being extracted from the ground water at no cost, with the exception of the negligible cost of pumping the 10 gallons of water per minute required by the system. This cost will vary depending on the design of the well and the depth to water; however, it is insignificant under normal conditions when compared to the cost of electrical resistance heating. At a daily use of 30 kw's of energy into this heat-pump system, it would deliver 3.6 times the equivalent Btu's per hour. This means the geothermal heat-pump system described above operates at a COP of 3.6. This includes the cost of pumping the well.

Battelle Memorial Institute of Columbus, Ohio has installed a heat pump utilizing 54°F ground water for heating and cooling four of its buildings. The buildings' air-conditioning engineer reports that the system has an operational COP of 5.

If the heat pump and the knowledge of its application to ground-water energy have been available for thirty years, why has it not gained nationwide recognition? Widespread use of heat-pump systems has been stifled by a number of factors, including lack of general knowledge, unwarranted assumptions, and underdeveloped technology. Recent developments, however, have resulted in a significant increase in interest in the use of ground-water-source heat pumps.

In the past, heat-pump manufacturers hesitated to design and build heat-pump systems that could utilize ground water with a temperature of less than 60°F due to the extra cost involved in running the heavy-duty pumps and compressors. This problem restricted the use of geothermal heat pumps predominantly to the southern third of the continental United States. In recent years, manufacturers have found that they can produce the equipment required for lower water temperatures without significantly raising the cost of the heat-pump system. Today geothermal heat pumps are operating along the northern tier of the United States, utilizing ground water with temperatures as low as 40°F.

Formerly, the availability of cheap energy discouraged contractors from installing high-capital-cost heat-pump systems. This attitude has dramatically changed since the OPEC oil embargo and the natural gas crisis during the "Winter of '77." Skyrocketing energy costs in the wake of these two events have caused Americans to be more aware of the fact that our fossil fuel supplies are severely limited.

At current prices, a home or building owner can have his heat-pump investment returned in four to eight years. This return on investment will be reduced even more as the cost of heating and cooling with conventional fuels continues to rise.

Factors such as depth and temperature of ground water, type of building, amount of insulation, and climate variations will have an effect on the operating cost and energy utilized by a ground-water-source system. However, in a typical building, the use of a geothermal heat pump can result in 25 percent reduction of energy utilization for cooling and over 50 percent reduction of energy utilization for heating.

In the past, most manufacturers incorrectly believed that geothermal heat pumps would never become practical for large-scale production because of inadequate ground-water supplies. Manufacturers now realize that in most parts of the nation, adequate ground-water yields are available to operate residential and small commercial building heat-pump units. The system will be economically unfeasible only when extremely large and/or deep wells are required and the costs of the drilling, completion, and pumping of the water are high.

Although many of the drawbacks of the use of geothermal heat pumps have been eliminated, some limitations still exist:

1. The potential environmental consequences of the utilization of ground water for heat exchange must be carefully examined. Current designs call for withdrawal and injection of all water used. There is no consumptive use and no consequently appreciable effect on the water table. However, if the system is designed so that spent water is discharged into sewers or streams, recharge may be reduced or eliminated, resulting in the lowering of the water table under certain hydrologic conditions.

2. There is also the potential risk of changing the ambient temperature of the aquifer. This problem could occur in extremely hot or extremely cold environments where increased ground-water withdrawal may be required to meet heat-exchange demands. In temperate climates, thermal pollution is minimal due to the balancing effect of recharging the aquifer with warmer water in the summer and cooler water in the winter. In areas like the Gulf Coast region, where air conditioning is required nearly three-fourths of the year, there exists a definite possibility of increasing aquifer temperature.

This is more pronounced in areas where aquifer permeability is low because movement of water away from the wellbore is much slower.

3. Ground-water quality may also affect the use of geothermal heat pumps. Minor amounts of dissolved iron or calcium carbonate, suspended solids, or even low pH can result in scaling or corrosion of heat-pump piping and heat exchangers. Some manufacturers have designed their systems to reduce the effects of poor water quality. A manufacturer in Florida reports that his heat-pump units can be operated with saline water. Other manufacturers' specifications require some water conditioning before the ground water enters their units.

The minor limitations of geothermal heat-pump utilization are overshadowed by its advantages:

1. The versatility of the geothermal heat pump adds new dimensions to interior-temperature control of domestic and commercial buildings. The heat-pump system allows for the heating and simultaneous cooling of different rooms in the same building.

2. Water warmed or cooled can be stored in different aquifers or in different parts of the same aquifer. When heating becomes necessary, the well that has been recharged with warm water becomes the supply well, pumping water with a higher temperature than the surrounding aquifer to provide more efficient heating. During the cooling cycle, the well which had been recharged with cool water (the by-product of heating) becomes the supply well to assist cooling efficiency.

Conclusions

As oil, gas, and electricity prices continue to escalate, the applications of geothermal heat pumps will expand. Jay Lehr, Executive Director of the National Water Well Association, predicts that 20 percent of all buildings in the United States will utilize geothermal heat pumps by the turn of the century. At the present time, there is already a wide range of geothermal heat-pump applications. A number of greenhouse users in the Midwest are using geothermal heat pumps for space heating and heating of plant beds. An egg farm in Ohio uses geothermal heat pumps for heating incubators and cooling eggs, and the discharge water is used for washing eggs and cleaning the facilities.

In years to come, there will be increasing use of geothermal heat pumps for industrial applications. The 1980's will see a growing awareness of the use and practicality of geothermal heat-pump technology. Geothermal heat pumps may not solve all our energy problems, but their use may represent a major portion of our energy mix, bringing us closer to energy independence. ψ