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GROUND-WATER HEAT PUMPS: AN EXAMINATION OF HYDROGEOLOGIC, ENVIRONMENTAL, LEGAL, AND ECONOMIC FACTORS AFFECTING THEIR USE

Executive Summary

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November 12, 1980

Work Performed Under Contract No. AC01-78CS20060

National Water Well Association
Worthington, Ohio

U. S. DEPARTMENT OF ENERGY

Division of Industrial Energy Conservation

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EXECUTIVE SUMMARY

Ground water is attractive as a potential low-temperature energy source in residential and commercial space-conditioning applications. When used in conjunction with a heat pump, ground water can serve as both a heat source (for heating) and a heat sink (for cooling). The temperature of the ground water varies little, if at all, on a seasonal basis, regardless of the temperature extremes on the surface. Thus, it is warmer than the outside air in winter and cooler in summer. Since heat pump capacity and efficiency vary significantly with the heat source/sink temperature (or temperature difference between the source/sink and the conditioned space), a ground water-source heat pump system should, in principle, offer considerable advantages over the more widely used air-source heat pump system.

However, the use of ground water (well water) is not without potential technical problems or economic and institutional constraints. First, is the well cost and the availability of an adequate supply of suitable quality well water. Second, the removal of significant quantities of well water without suitable recharge may deplete the underground aquifer. Also, plans to reinject or return the water underground may be precluded by legal restrictions. And if permitted, it could entail additional costs for the disposal well. Special provisions to prevent thermal alteration of the underground source may be required. This study was designed to answer these and other questions related to:

- ground-water quality and availability
- potential environmental effects
- legal restrictions
- energy use and economics of ground-water heat pump use

SCOPE OF STUDY

In more detailed terms, the study project included three main elements, or tasks, as follows:

Task 1. Collection of Hydrogeologic and Climatologic Data - This task involved assessing the availability and characteristics of ground water supplies throughout the United States for use with ground water-source heat pumps. This assessment was made on a state-by-state basis and included evaluation maps for each state. Water quality was considered, as it affects the performance and life-expectancy of the water-to-refrigerant heat exchanger and, in extreme cases, the technical viability of the ground-water heat pump option. Depth-to-water and ground-water temperature were considered, as they affect the operational efficiency of the heat pump system. Data regarding ground water availability were considered, as a minimum water flow rate is necessary for proper operation of a ground-water heat pump. Weather data for each of nine test cities were acquired for use in the Task 2 analysis (for heating and cooling load calculations and source temperatures for the conventional air-to-air heat pump).

Task 2. Economic and Energy Analysis of Ground-Water Source Heat Pumps - Using information and data collected in Task 1, together with manufacturers' performance data on water-source heat pump performance, a comparative analysis of the energy consumption and owning and operating cost of ground-water heat pumps was undertaken. The analysis was based on an hour-by-hour computer simulation of the performance of the ground-water heat pump and more conventional heating/cooling systems in a typical single-family residence in nine cities representative of the various geographic and climatic regions. The conventional systems were electric resistance heating with electric air conditioning, fossil-fueled (oil and gas) furnaces in combination with electric air conditioning, and the air-to-air heat pump. The results of this analysis include seasonal performance factors, equipment costs, operating costs, simple payback, and total life cycle costs.

Task 3. Environmental and Legal Consequences of Using Ground Water as an Energy Source - This task involved evaluating the environmental problems that can potentially result from expanded use of ground-water source heat pumps and conducting a survey of Federal, state, and local regulations that might affect the potential use of ground-water heat pumps. In examining the potential environmental impact, consideration was given to thermal alteration of ground-water temperatures, ground-water chemistry aspects, alternative methods of disposal, methods of of recharge (if used), and varied hydrologic conditions which limit discharge options to be considered. The environmental parameters that influence the feasibility of ground-water heat pump use were also examined for each of the nine test cities (in Task 2) to illustrate technical problems and favorable potential on a case study basis. To evaluate the potential legal problems involving ground-water use and water quality control, a state-by-state review was conducted of water use restrictions, well construction standards, and waste disposal regulation. Major Federal programs on waste water disposal were analyzed. Examples of pertinent local county and municipal regulations were also examined for their potential impact on ground-water heat pump use.

A major contribution of this study is the economic evaluation which compares the initial purchase/installation and operating costs of ground-water heat pumps to conventional space-conditioning systems. However, it must be recognized that the energy use and economics are evaluated only for residential size units and only for an individual end-user. This is a significant limitation. Economics would probably be more favorable for applications other than single-family residences requiring their own supply wells, pump/piping systems, and discharge provisions. Applications in the commercial building sector or possibly "community wells" serving several residences are potentially more cost-effective than the single-family residence application.

On the other hand, the information and data developed to characterize ground water as an energy resource and to define the legal and environmental problems associated with its use seem to be more broadly applicable to all ground-water heat pump systems, regardless of size or configuration.

The applicability of ground-water heat pumps is determined by hydrogeologic, economic, legal, and environmental factors. The results of this study will, therefore, be useful in identifying those areas in each state where ground-water heat pumps may be capable of supplying a portion of residential space-conditioning. Examination of these data, supplemented by appropriate site specific analysis, should enable planners, developers, and/or utility companies to assess the feasibility of using or promoting ground-water heat pumps in a specific area. In addition, manufacturers and distributors of ground-water heat pumps may use this information to plan market strategies in select areas. However, detailed site-specific analyses of all relevant factors should be conducted prior to any large-scale implementation. The hydrogeologic data shown on the state maps in Appendix D are locally variable. The maps are meant to indicate major trends only. These maps should not be used for design criteria or for determining the suitability of a particular site.

CONCLUSIONS

The major conclusions reached during the course of this study involved both the subjective results from the Task 1 and Task 3 data collection and assessment activities and the more quantitative results from the Task 2 energy use and economic analyses. These conclusions are given in summary form below, and the results are presented and discussed in more detail in subsequent sections of this Executive Summary report.

1. Results of computer simulations indicate that in nine test cities, reflecting a variety of climatological conditions, the ground-water heat pump uses less energy and operates at higher efficiencies than conventional heating/cooling equipment.

   - Simulations indicate that the ground-water heat pump uses from 20 to 60 percent less energy for heating than the air-source heat pump.

   - If the energy required for both heating and cooling is taken into account, the ground-water heat pump uses from 10 to 60 percent less energy than the air-source heat pump.

2. The economics of owning and operating a ground-water heat pump depends on consideration of the alternate heating/cooling system choices and on well cost options included in the ground-water heat pump system. The following can be concluded:

   - Based on U.S. Department of Energy projections of energy costs, a gas heating/electric cooling system is the most economically attractive of current system choices in most parts of the United States.

- The ground-water heat pump system, with no well costs included, has an economic advantage over all other systems evaluated (including conventional air-source heat pump systems, electric heating/electric cooling systems, and oil heating/electric cooling systems) in eight of the nine test cities (Houston, Texas is the exception).

- With the cost of an injection well included, payback of incremental first costs for installation of a ground-water heat pump system is usually achieved within a 20-year life cycle period. The shortest payback periods are indicated for northern climate installations. Using the air-source heat pump or the electric heating/electric cooling system as the alternate choice, payback periods range from 4 to more than 20 years and from 1.5 to 17 years, respectively. Using the oil heating/electric cooling system as the alternate, payback period ranges from 1 to more than 20 years.

- With the cost of both a supply and injection well included, the ground-water heat pump generally does not achieve payback within a 20-year life cycle period when compared to alternative systems.

It is recognized that in some areas, shallow, small-diameter wells can be used for both supply and injection wells at substantially lower costs than those used in this study. These circumstances are considered atypical and were not evaluated.

3. Water use and discharge methods are important in the consideration of ground-water heat pump installations. Improper design may lead to a decrease in system performance or environmental problems or both.

   - Ground-water depletion and local lowering of water tables should be avoided. Thus, in most areas recharge to the subsurface (usually via injection wells) is recommended.

4. Corrosion and incrustation of the water-side heat exchanger are potential problems under certain water quality conditions. Corrosion appears to be a greater potential problem than incrustation.

5. County and municipal controls on well construction and water use are often stricter than state or Federal regulations. These rules represent the most significant restrictions on ground-water heat pump development in some areas.

In general, recharge using an injection well is the preferred method of water discharge. However, due to regulations at the state and/or local level(s) of government and to geologic influences, alternative methods (e.g., leach fields, dry wells, discharge to surface water bodies) could be investigated.

The review of existing legislation affecting ground-water heat pump development presented in this report can represent only a "snapshot in time" of relevant Federal and state laws. It is recognized that these laws are in a state of flux and will undoubtedly change in the future to accommodate further market development. Federal regulations pertaining to ground-water quality will not pose a serious impediment to ground-water heat pump use. Permit requirements for water use and waste water disposal will be the primary method of ground-water heat pump control at the state level. Most state permit requirements will not severely restrict heat pump use, although large-scale heat pump development may be subject to stringent rules in some areas.

It can be concluded from this study that ground-water heat pumps are an economically feasible and environmentally sound alternative to conventional heating/cooling systems. Monitored installations where meaningful data can be accumulated are needed to substantiate this. Energy requirements under recorded climatologic conditions and a quantification of environmental impact would be helpful to further investigate the market potential of these devices.

GROUND-WATER RESOURCES IN THE U.S.

Water temperatures in shallow wells not affected by geothermal activities in the conterminous United States range from approximately 44°F in the north-central regions to near 80°F in southern Texas and Florida (Figure 1). This range is within the minimum and maximum entering water temperature requirements of currently marketed ground-water heat pumps. There are vast reservoirs of underground water in the U.S., and they contain large quantities of useful heat energy. Figure 2 shows the types and locations of these aquifers. Every aquifer will yield water; in general, aquifers composed of unconsolidated or semiconsolidated clastic materials (i.e., sands and gravels) are more productive and reliable sources of ground water than are aquifers composed of consolidated materials such as limestones, shales, and sandstones. Dense rocks such as granites, schists, and slates contain water in interconnected fractures and generally do not yield large supplies of water to individual wells.

State-by-state maps of major aquifers and of ground-water chemistry characteristics, including a description and evaluation of select hydrogeologic parameters, can be found in Appendix D.

WATER-SOURCE HEAT PUMP EQUIPMENT

Most water-to-air heat pumps currently available commercially appear to have been developed for use in commercial building applications. The technology is similar to that of air-to-air systems, except that the outdoor fan-coil unit is replaced by a coiled, coaxial water-to-refrigerant heat exchanger. Such systems are typically designed to operate with a water source/sink temperature in the range of 60°F to 90°F. That is, where heating is needed, 60°F to 90°F water is used as the heat source; if cooling is required, the same water loop serves as the heat sink. With the

Figure 1

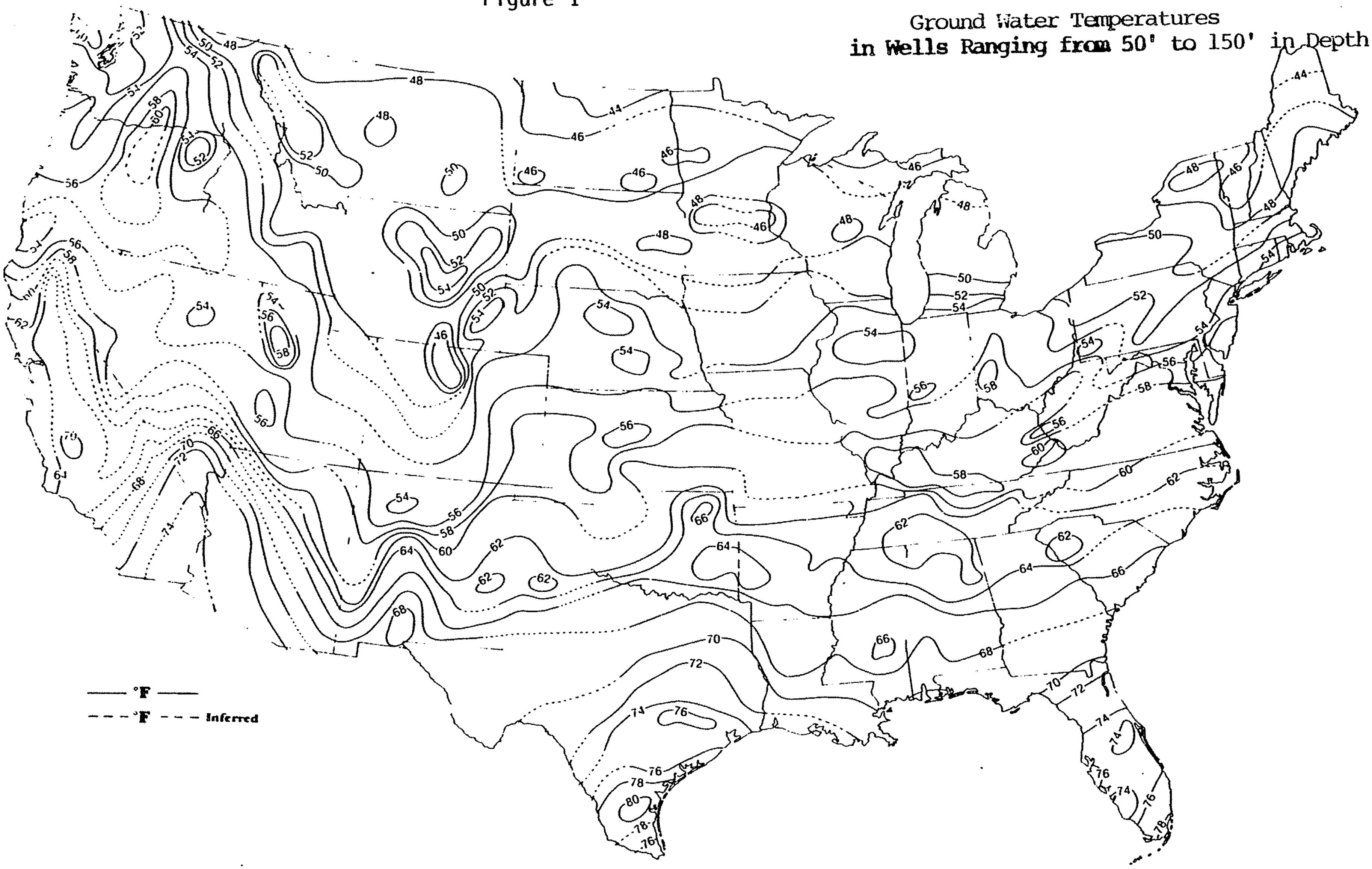
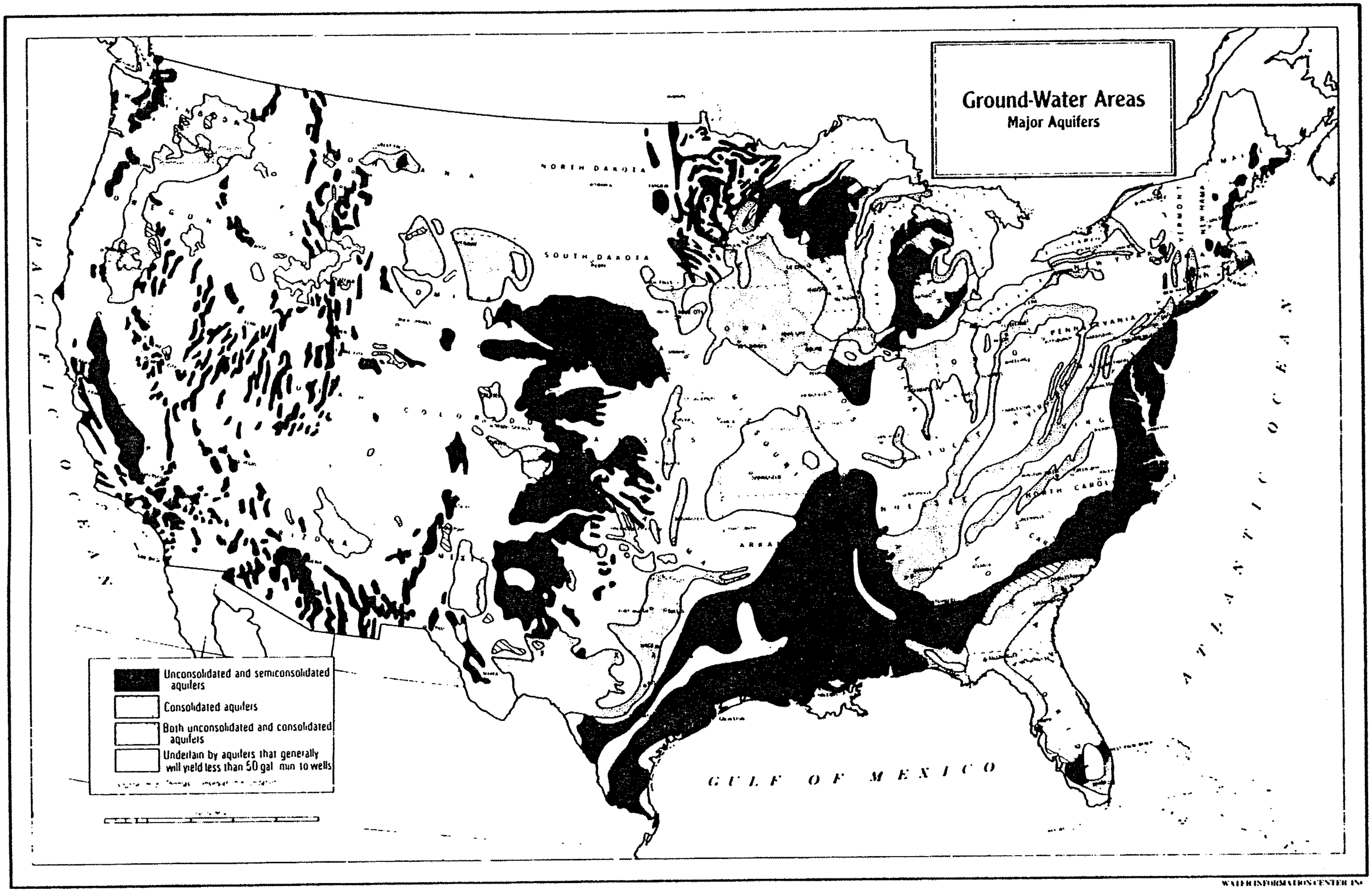

Ground Water Temperatures
in Wells Ranging from 50' to 150' in Depth
°F
°F Inferred

Figure 2


Ground-Water Areas
Major Aquifers
Unconsolidated and semiconsolidated aquifers
Consolidated aquifers
Both unconsolidated and consolidated aquifers
Underlain by aquifers that generally will yield less than 50 gal min to wells
NORTH DAKOTA
SOUTH DAKOTA
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO

addition of a boiler and cooling tower to the water loop, the net heating or cooling requirements can be met while the individual water-to-air heat pumps provide zoned heating or cooling, whichever is required.

Most such heat pumps apparently have been designed for low equipment cost. Rated heating COPs with a 60°F water source are generally no better than those of high-efficiency air-source systems at 47°F. These systems may not be suitable for use with cooler ground-water sources, which may be as low as 45°F. However, with proper controls and component matching, water-source heat pumps can be used with 45°F sources. In addition, a number of such smaller specialty manufacturers and at least one major manufacturer have announced new water-source heat pump models featuring substantially improved efficiency at ground water temperatures (45°F-60°F). Also, optional cupro-nickel alloy heat exchangers are available for service where ground-water chemistry conditions warrant.

Ground-water heat pumps offer the potential advantages of almost constant capacity and higher seasonal COPs, compared to air-to-air units employing similar technology. Reliability of the refrigerant system should be superior because of the narrower range of operating conditions and the elimination of frosting. However, the water system may require some maintenance above that required for air-to-air units.

Figure 3 is a schematic diagram of a ground-water heat pump operating during a heating cycle. The refrigerant reversing valve directs a gaseous refrigerant from the compressor to a heat exchanger coil. Heat is removed by air passing over the coil, and the gaseous refrigerant is cooled and condensed to a liquid. The liquid refrigerant then travels through the expansion device to a second heat exchanger where heat is extracted from the ground water. The liquid refrigerant absorbs the heat and evaporates, and the cycle begins again.

During the cooling cycle (Figure 4), the position of the refrigerant reversing valve is reversed. Hot air blowing over the air-to-refrigerant heat exchanger coil gives up heat to the liquid refrigerant, causing it to evaporate. Cool air then passes out the ventilation duct of the system. The gaseous refrigerant is directed by the refrigerant reversing valve into the compressor and is then pumped to the water-to-refrigerant heat exchanger. The refrigerant gives up heat to the water and condenses. After the water is warmed it is subsequently discharged. In the last step, the liquid refrigerant passes through the expansion device and returns to the air-to-refrigerant heat exchanger coil to extract more heat from the air and continue the cooling cycle.

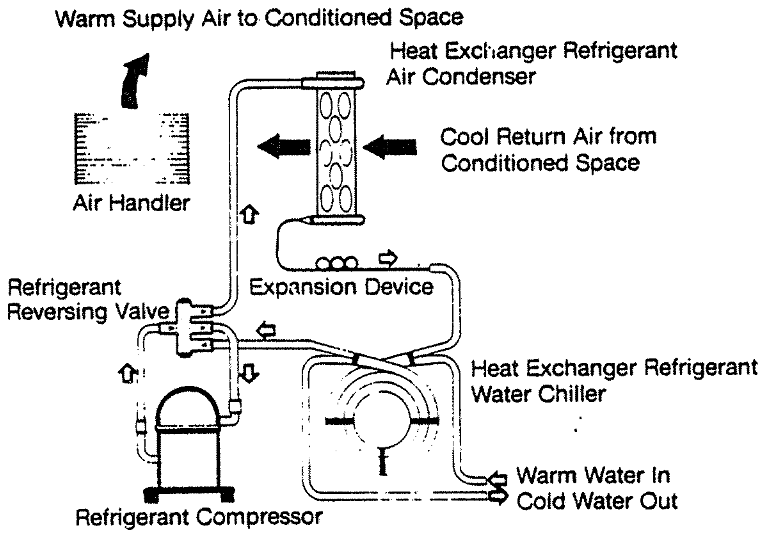


Fig. 3 Heating mode operation

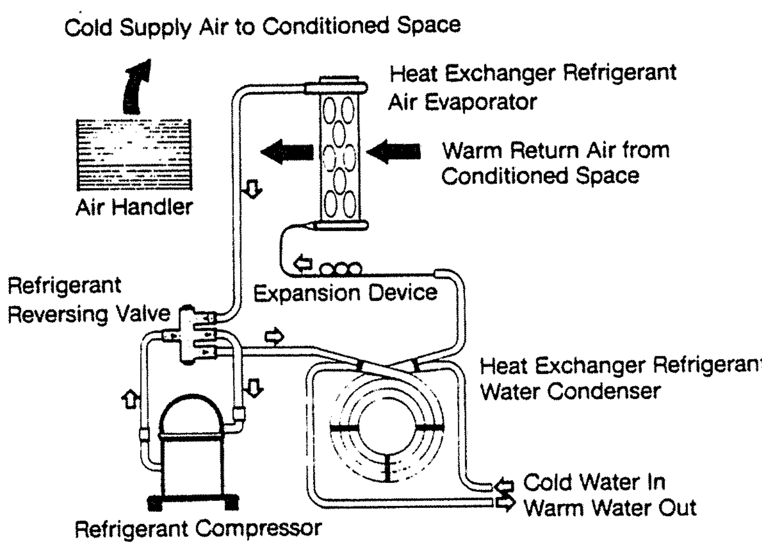


Fig. 4 Cooling mode operation

ENERGY USE COMPARISONS

A measure of efficiency of the heat pump is the seasonal performance factor (SPF). For heating mode operation, the number is defined by:

$$(SPF)_H = \frac{\text{Quantity of heat energy delivered}}{\text{Quantity of energy supplied to operate device}}$$

For cooling mode operation, the SPF is defined by:

$$(SPF)_C = \frac{\text{Quantity of heat energy removed}}{\text{Quantity of energy supplied to operate device}}$$

The SPF of the heat pump varies according to the heating/cooling load, heat pump capacity/sizing, heat source/sink temperature, flow rate, and the design and operational characteristics of the particular heat pump equipment used.

Computer-simulated SPF values for residential air-source and ground-water heat pumps in nine different test cities, representing various climatological conditions in the U.S., are shown in Table 1. Included are the SPF values for a heat-only ground-water heat pump sized to design heating load. Cooling, in that case, is accomplished by direct heat exchange with ground water.

The annual coefficient of performance (ACOP) can be used to compare the performance of various heating/cooling equipment combinations. This measure of operational efficiency is defined as:

$$ACOP = \frac{\text{Annual heating and cooling requirement}}{\text{Total annual energy used for heating and cooling}}$$

Figure 5 graphically shows the relationship of the ACOP to the ratio of annual heating load to total load (Q_H/Q_T). An electric air conditioner is included in the electric/electric system, while both heat pumps provide cooling as described previously. It is evident that as the value of Q_H/Q_T increases, the performance of the air-source heat pump and the electric/electric system decreases while the performance of the ground-water heat pump remains relatively stable.

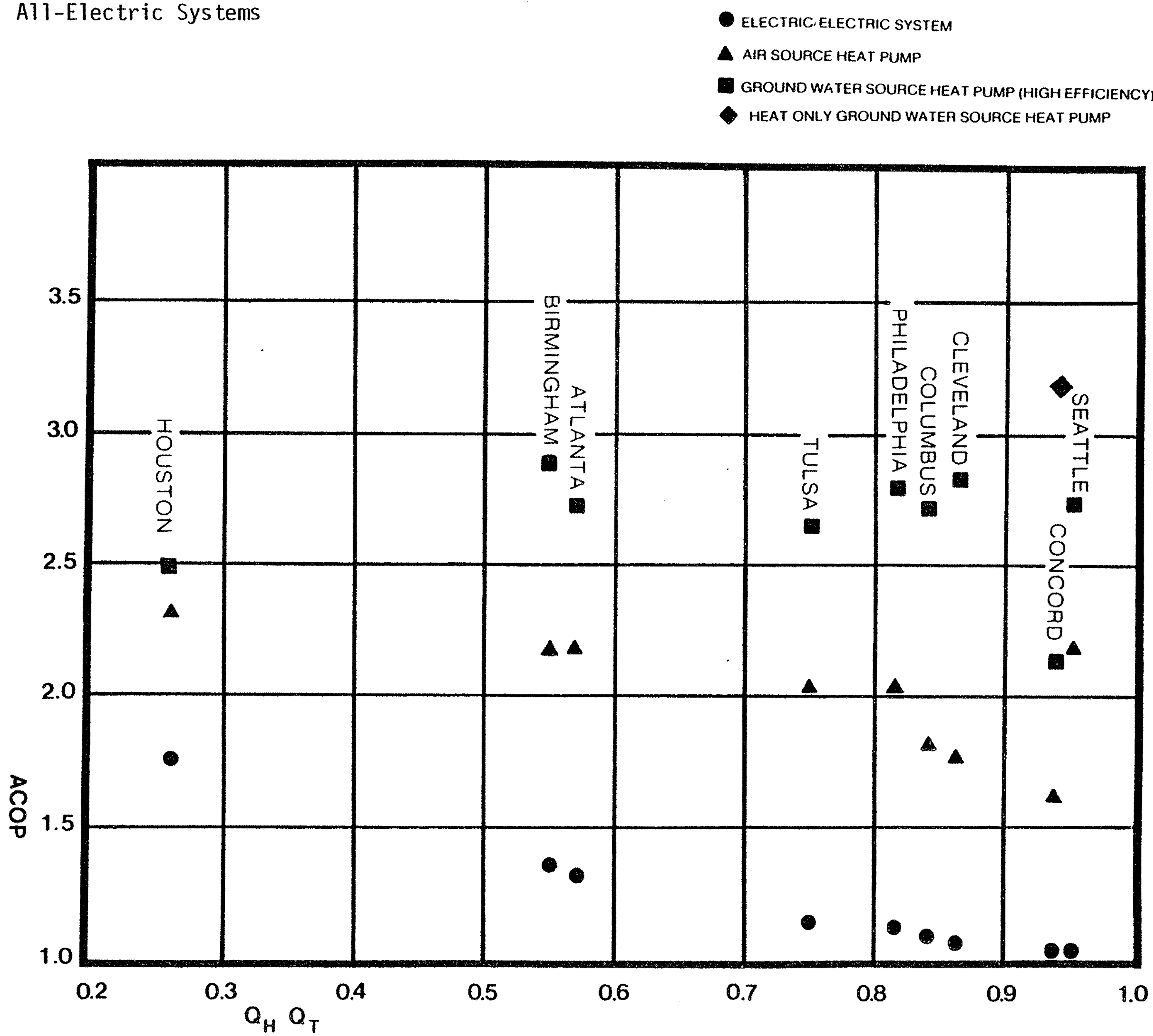
The lowest efficiency rating (ACOP = 2.2) was obtained in the Concord, New Hampshire test city where the annual heating load constitutes 94 percent of the total load. In the Concord test city, 10 percent of the total annual energy consumed by the ground-water heat pump was used for supplemental electric strip heat while the air-source heat pump required 40 percent for the same purpose. The simulation of a heat-only ground-water heat pump and direct heat-exchange cooling (with ground water) resulted in a 30 percent reduction in energy requirements compared to the reversible-cycle model. This is a result of sizing to full heating design load rather than cooling load. Using this strategy, the use of supplemental electric strip heat is substantially reduced or eliminated.

TABLE 1

HEAT PUMP SEASONAL PERFORMANCE FACTORS

CITY	HEATING AIR-SOURCE	HEATING WATER-SOURCE	COOLING AIR-SOURCE	COOLING WATER-SOURCE
Atlanta	2.10	2.67	2.30	2.83
Birmingham	2.04	2.84	2.28	2.99
Cleveland	1.74	2.81	2.31	2.90
Columbus	1.75	2.48	2.29	2.80
Concord	1.58	2.14	2.30	2.33
Heat-Only w/ Direct Cooling		3.05		10.87
Houston	2.24	2.74	2.31	2.43
Philadelphia	1.96	2.77	2.29	2.91
Seattle	2.17	2.72	2.29	3.06
Tulsa	1.94	2.70	2.26	2.48

Fig. 5
ACOP vs QH/QT for
All-Electric Systems



Otherwise, the highest efficiency rating (ACOP = 2.9), utilizing heat pump operation for both heating and cooling and conventional cooling load sizing methods, was obtained under conditions in which the annual heating load was approximately one-half the total annual load (Birmingham, Alabama). Under these conditions, the ground-water heat pump required 50 percent less energy than an electric heating/electric cooling system and 25 percent less than an air-source heat pump. The lowest efficiency rating vis-a-vis the air-source heat pump was obtained under conditions in which the annual heating load was approximately one-fourth the total load (Houston, Texas). Under these conditions, the ground-water heat pump used only 8 percent less than the air-source heat pump. The ACOP value for the ground-water heat pump in Houston is 2.5.

ECONOMICS OF GROUND-WATER HEAT PUMPS

The initial cost of a ground-water heat pump and its annual operating cost must be evaluated for an accurate economic picture. Table 2 compares ranges of installed costs for the ground-water heat pump and other conventional heating/cooling systems. Computer simulations indicate that the ground-water heat pump is not economically attractive when compared to a gas/electric system at the Department of Energy's current projected natural gas prices. (Deregulation and resulting increases in the price of natural gas could change this conclusion.) That cost model (gas/electric system) is therefore not included in this summary discussion of life-cycle cost comparisons and payback.

With the cost of an injection well included in the ground-water heat pump cost, the system is generally more expensive to install, but the benefits of lower annual operating costs make it economically competitive. The ground-water heat pump system, including both supply and injection well costs, is generally not economically viable.

Table 3 shows present worth of total life-cycle costs for two ground-water heat pump cost models (no well or injection well costs included) and conventional heating/cooling systems. These costs include installed, operation and maintenance, and fuel costs for a projected 20-year life cycle period. Using a 2 percent real discount rate, simulated total life-cycle costs for the ground-water heat pump ranged from $8,900 (Seattle) to $20,500 (Concord). This cost included the initial expense of an injection well in the ground-water heat pump system. This model was taken to be typical (or at least desirable) in most installations. (It is recognized that, in some areas, shallow, small-diameter wells can be used for both supply and injection wells at a substantially lower cost than those presented here. These circumstances are considered atypical and were not included in this work.) As a comparison, the air-source heat pump showed a total life cycle cost of $7,600 in Seattle and $24,100 in Concord. Costs for the electric heating/electric cooling system for the same cities were $11,800 and $35,300, respectively. The heat-only heat pump with direct cooling in the Concord test city showed a total cost of $17,400, substantially less than any other system.

TABLE 2

Installed Costs of Heating/Cooling Equipment

	*Ground-Water Heat Pump	*Air-Source Heat Pump	Oil/Electric System	Electric/Electric System
HEATING	$1300-2100	$2300-3200	$ 1300	$ 600- 700
COOLING			$1600-1900	$1600-1900
DUCTWORK	$ 800-1000	$ 800-1000	$ 800-1000	$ 800-1000
FLUE			$ 400	
PLUMBING/WIRING	$ 400- 500	$ 100	$ 200	$ 100
TOTAL	$2500-3600	$3200-4300	$4300-4800	$3100-3700
With Injection Well	$3900-6100			
With Supply and Injection Wells	$6000-9300			

*Since the heat pump provides both heating and cooling, the costs are not separated as they are for the other systems.

Table 3

Present Worth of Total Life Cycle Costs (1979 Dollars x 10^{-3})

City	Electric/ Electric	Air-Source Heat Pump	Oil/ Electric	GWHP* (0 Wells)	GWHP* (1 Well)
Atlanta	$13.7	$9.9	$13.6	$7.8	$9.5
Birmingham	13.3	9.8	13.3	7.8	9.5
Cleveland	25.1	16.9	19.2	12.0	13.7
**Columbus d = 2%	23.0	15.6	17.8	11.6	13.3
**Columbus d = 10%	13.3	9.6	11.1	7.5	9.1
Concord	35.3	24.1	21.1		
Reversible-cycle				18.6	20.5
Heat-only w/Direct Cooling				15.5	17.4
Houston	13.5	11.3	13.4	10.2	13.1
Philadelphia	21.3	13.9	17.4	10.9	12.8
Seattle	11.8	7.6	15.9	6.8	8.9
Tulsa	19.5	13.9	15.7	10.7	13.1

* Ground-water heat pump

** The Columbus, Ohio test city was used to test the sensitivity of Life Cycle Costs to changes in the real discount rate (d).

Table 3 also shows the effect on present worth values when a 10 percent real discount rate is applied in the cost model, using the Columbus test city as an example.

Payback periods of incremental costs resulting from the installation of the ground-water heat pump system (including no wells, injection well only, and supply and injection wells) rather than conventional systems are shown in Tables 4 and 5.

Table 4 shows payback periods using the electric heating/electric cooling system or the air-source heat pump as the alternative choice. With no well costs included in the ground-water heat pump system, the installed cost of that system is usually less than that of the alternatives. Thus, there is no payback period. Inclusion of the injection well cost in the ground-water heat pump model results in payback periods ranging from 1.5 to 17 years for the electric heating/electric cooling system comparison and from 4 years to more than 20 years (the life cycle period used in the study) for the air-source heat pump comparison. With both supply and injection well costs included in the cost model, payback period ranges from 4 years to more than 20 years and is more than 10 years for most of the test cities using the electric heating/electric cooling system as the alternative. Payback is rarely achieved within the life-cycle study period using this cost model and the air-source heat pump for the comparison.

Table 5 shows payback periods using the oil heating/electric cooling as the alternative choice. For all but one test city, the oil heating/electric cooling system costs more to install than the ground-water heat pump if no well costs are included. For that circumstance, a payback period is not defined. If the injection well cost is included in the ground-water heat pump system cost, payback period ranges from less than 1 year to more than 20 years relative to the oil heating/electric cooling system. Payback of incremental costs with both wells included in the cost model is achieved in less than 15 years in only three test cities.

ENVIRONMENTAL AND WATER QUALITY ASPECTS

Temperature changes in the vicinity of the recharge well will usually result from injection of the heat pump discharge water. If the discharge water from the heat pump is recharged to the supply aquifer, proper well spacing must be maintained to avoid thermal interference of supply and recharge waters. This "short circuiting" is not a significant detrimental environmental impact, but could lower the operating efficiency of the ground-water heat pump. If the discharge water is recharged to an aquifer other than the supply aquifer and the two aquifers are separated by a thickness of low-permeability material, thermal interference should be minimal or non-existent. Supply and recharge aquifers must be chemically compatible to assure that mixing of the two water types does not result in precipitation of salts or hydroxides from solution, which might lead to eventual "plugging" of the aquifer surrounding the recharge well.

Table 4

Simple Payback Period (years)

Ground-Water Heat Pump System

vs.

All-Electric Systems

CITY	WITH NO WELLS		WITH INJECTION WELL		WITH SUPPLY & INJECTION WELLS	
	Elec. Htg./ Elec. Clg.	Air-Source Heat Pump	Elec. Htg./ Elec. Clg.	Air-Source Heat Pump	Elec. Htg./ Elec. Clg.	Air-Source Heat Pump
Atlanta	*	*	3.1	11.9	11.0	>20
Birmingham	*	*	4.4	14.3	12.7	>20
Cleveland	*	*	2.0	5.2	5.2	15.7
Columbus	<0.1	*	2.6	7.3	6.2	20.0
Concord						
Reversible-cycle	*	*	1.5	4.4	3.7	12.5
Heat-Only w/Direct Cooling	0.7	1.2	2.1	4.3	3.8	8.6
Houston	*	*	17.2	>20	>20	>20
Philadelphia	*	*	2.7	10.2	6.9	>20
Seattle	*	*	7.4	>20	>20	>20
Tulsa	*	*	4.4	11.3	11.0	>20

* Payback period is undefined (Ground-Water Heat Pump system costs less to install and operate)

† Payback period is undefined (Ground-Water Heat Pump system costs more to install and/or operate)

Table 5

Simple Payback Period (years)

Ground-Water Heat Pump System

vs.

Oil Heating/Electric Cooling System

CITY	WITH NO WELLS	WITH INJECTION WELL	WITH SUPPLY & INJECTION WELLS
Atlanta	*	*	13.1
Birmingham	*	*	16.3
Cleveland	*	*	14.4
Columbus	*	1.1	>20
Concord			
Reversible-cycle	†	†	†
Heat-Only w/Direct Cooling	*	19.9	>20
Houston	*	>20	>20
Philadelphia	*	0.3	>20
Seattle	*	0.6	9.5
Tulsa	*	4.7	>20

* Payback period is undefined (Ground-Water Heat Pump system costs less to install and operate)

† Payback period is undefined (Ground-Water Heat Pump system costs more to install and/or operate)

Corrosion of the water-side heat exchanger is inhibited by the formation of an oxide or hydroxide film. Any ground-water constituent that prevents the formation of this film or removes it will cause degradation of the metal. Hydrogen sulfide (H_2S) is the most common corrosive agent with the water-side heat exchangers. Although the cupro-nickel alloy (No. 706) heat exchanger is more resistant than the copper variety to mechanical erosion and corrosion by brackish waters, neither metal shows acceptable resistance to dissolved hydrogen sulfide. Concentrations as little as 0.5 parts per million are known to cause corrosion of the metals. Chemical incrustation has not been a significant problem in existing installations. Analytical techniques are available to predict the tendency of a water sample to corrode or scale. Biological incrustation (fouling), if encountered, is likely to be a problem throughout the entire domestic water supply system. If bacterial infestation and subsequent blockage of the heat exchanger is a chronic problem, water treatment before passage through the heat exchanger would be required. Due to the large volumes of water used, this would substantially increase system operating costs.

Environmental impacts associated with the usage of ground-water heat pumps are minimal or non-existent when the properties of the hydrologic system are evaluated and taken into consideration. However, in areas where well yields are low, consumptive use of ground water due to overpumping can lead to water depletion in the aquifer. In environmentally sensitive ground-water regions, careful planning is required in order to minimize environmental impacts.

Whenever possible, the consumptive use of ground water for heat pump applications should be avoided. The problems associated with widespread, high density use of this method are usually too numerous to warrant its use.

A possible alternative to consumptive use is the implementation of earth-coupled well systems. These closed-loop units do not withdraw water from the well avoiding problems of aquifer depletion.

Some problems are associated with the non-consumptive use of ground-water supplies. The most serious of these is the thermal alteration of the aquifer system. However, the environmental effects of thermal alteration are minimal. The greatest effect will be in the performance of the heat pump system. Management of the heat balance within an aquifer is essential in urban areas where heat transfers between several users may have to be coordinated. Spacing of private domestic wells is likely to depend on property boundaries rather than the hydrologic characteristics of the aquifer under development. Random installation of ground-water heat pumps could lead to thermal interference through improper well spacing. Efficiency of the heat pump system would be considerably reduced where a sufficient amount of interfer :e exists.

Through careful planning and analysis of the aquifer prior to housing construction, it is possible to avoid the problem of well interference. Production and injection wells can be spaced for optimum dissipation of thermal energy within the aquifer. Well spacing should be based on the heating and cooling loads for the proposed number of residential units to be built at a given location, as well as the hydrologic properties of the aquifer to ensure the efficient utilization of ground water for the operation of ground-water heat pumps. A computer model is currently being developed at the University of Missouri for NWWA under U.S. EPA Grant #R806 465-01-1. This model will be validated with experimental data obtained from a test installation and will be used to predict thermal alteration under varied hydrogeologic conditions. The information can then be used to plan optimum spacing of production and injection wells. The projected completion date for this work is July 1981.

In a single aquifer system, both the production and injection wells utilize the same aquifer. This may limit the number of heat pumps in a given area. A greater volume of the aquifer is needed for thermal reconditioning of the injected water as it is transmitted from the injection well to the production well.

A dual aquifer system enhances the feasibility of operating a greater number of heat pumps in a smaller area. This type of system can operate effectively only where there exist two or more aquifers of sufficient capacity and chemical compatibility. In addition, care must be taken so that the quality of the water in the supply aquifer is at least as good as that in the recharge aquifer.

REGULATORY RESTRICTIONS

Federal, state, and local regulations impose restrictions and mandate various requirements for well construction, ground-water use and quality, and effluent disposal, but they will not significantly obstruct the implementation of ground-water heat pump technology.

The Safe Drinking Water Act was enacted to insure that public water systems are adequately supervised by the states. This act requires the EPA to adopt regulations for state underground injection programs. Heat pumps which use a reinjection system or discharge water in a manner which could affect drinking water supplies may be subject to regulations as a Class V well discharge system. States are required to participate in inventory and impact assessment of all Class V wells. This may include heat pump reinjection wells, depending upon the state's interpretation of the Act.

At the state level, well construction requirements may be numerous or nonexistent. Concern here is more a matter of cost than of limitation; the expense involved in meeting such requirements can rule out the feasibility of heat pump utilization. Where water-use restraints exist, usually in the form of permit requirements, they are not serious deterrents to heat pump use. The disposal of effluent to a recharge well is uncontrolled in some states and prohibited in others. Where this disposal method is forbidden, heat pump viability may suffer. Alternative disposal methods are available, however, and are generally subject to less regulation than are recharge wells. Since other disposal methods, such as discharge to land,

Table 6

Summary of Ground Water Heat Pump Water Use and Effluent Disposal Regulations by State*

State	Water Use	To Recharge Well	To Surface Water	To Land	To Septic Tank	To Sewer
Alabama	No permit needed to use water for H-P under domestic category	Notification and perhaps a permit needed from Water Improvement Commission	Theoretically covered by NPDES-however this system is usually not equipped to consider small domestic use so in most cases could just discharge w/o a permit	Not a problem if discharge to land owned by H-P user	A loophole in regulations--this type of discharge is allowed if tank is big enough and far enough from well	Would probably be allowed almost anywhere--although in many areas would be cost-prohibitive
Alaska	No problem to obtain water rights	No mechanism to require a permit or to prevent this type of injection well	1	2	3	4
Arizona	Falls into domestic category--permit needed	Discharge is prohibited to any well that penetrates water-bearing strata	1	2	3	4
Arkansas	No permit needed for water use of this type	Apparently no program exists to control recharge wells of this type	1	2	3	4
California	32 counties out of 58 total require permits for all wells--no real problems	Waste disposal under control of Water Quality Control Board, which does not regulate H-P return wells at this time	1	2	3	4
Colorado	Permit needed for all wells	Permit required for recharge	1	2	3	4
Connecticut	No permit needed--falls into private domestic well category	Permit is required from Department of Environmental Protection for all types of discharge				
Delaware	Well construction permit required	Strict rules exist regarding reinjection --however, would probably be able to get a permit for a H-P return well	1	2	3	4
Florida	A permit would be required for this volume of water use--but not a serious problem in most parts of state	A permit would be required for a disposal well of this type--not a serious problem to obtain	1	2	3	4
Georgia	No permit needed for use under 100,000 gpd (378,500 l/day)	Reinjection of cooling water is only type allowed in state. No permit is required for this	1	2	3	4
Hawaii	Classified as a domestic well --no problem to obtain water use	A regulation exists that requires permission for disposal wells and wastewater disposal --however, not enforced at present	1	2	3	4

1, 2, 3, and 4 regulations pertaining to this type of discharge are similar to those in Alabama

*Small scale domestic heat pump utilization only

Idaho	No permit needed for a domestic use except in critical ground-water area--need a permit for any use over 13,000 gpd (49,205 l/day)	Theoretically required to obtain permit for any type of disposal or injection well but permit mechanism does not exist at present	No problem except in critical ground-water areas where recharge back to the aquifers would be required			
Illinois	Domestic use classification--no permit needed	Under control of the state EPA which at present has no mechanism to regulate wells of this type	1	2	3	4
Indiana	Domestic use--no permit needed	Conventional and cooling water recharge wells not regulated--though Stream Control Board has theoretical authority	Board of Health permit, no special problem to obtain	2	3	4
Iowa	No permit needed for domestic use	No permit needed for discharge of this type	1	2	3	4
Kansas	A water appropriation permit would be needed	A permit would be required but not a problem--mostly for record-keeping purposes	1	2	3	4
Kentucky	Private use--no permit required	No permit required	1	2	3	4
Louisiana	No permit required	Might eventually need a permit from Department of environmental Control but no official policy at present	1	2	3	4
Maine	No permit needed for this type of water use	At the present time no underground injection of any type is allowed in this state	1	2	3	4
Maryland	A permit is needed for use of this type	A permit is required for discharge into surface or underground waters of the state		2	3	4
Massachusetts	No permit needed for this type of water use	Permit would be needed from Division of Water Pollution Control to discharge heated or cooled water		2	3	4
Michigan	No permit needed for this type of water use	Discharge permit required from Water Resources Commission for all units with heat exchange capacity greater than 120,000 BTU per hour (35,172 W). Permit also required for any unit using chemical additives.				
Minnesota	No permit required	Reinjection of this type is generally prohibited but could apply for a variance permit.	1	2	3	4
Mississippi	No permit required	No permit needed	1	2	3	4
Missouri	No permit needed	No permit required for small-scale domestic use	1	2	3	4
Montana	Certificate of water right is needed--no serious problem to obtain	Permit would theoretically be needed--but no mechanism is set up to issue them at this time	1	2	3	4

Nebraska	No permit needed	No regulations exist to cover a permit process	1	2	3	4
Nevada	Permit would be required	Regulations exist and a permit would be required for this type of injection	1	2	3	4
New Hampshire	No permit needed	Permit theoretically required but at this time notification would suffice	1	2	3	4
New Jersey	No permit needed	No permit required	1	2	3	4
New Mexico	Permit needed for use of this magnitude	Notification and a simple permit required	1	2	3	4
New York	No permit needed	No permit needed to cover this type of discharge	1	2	3	4
North Carolina	No permit required	Permit needed--at present time this disposal method is discouraged	1	2	3	4
North Dakota	Standard appropriation permit needed	No policy exists to cover this type of discharge	1	2	3	4
Ohio	No permit needed for domestic use	A permit is needed for all types of well injection	1	2	3	4
Oklahoma	No permit needed for domestic use	Discharge into water-bearing strata prohibited under law--but Water Resources Board won't enforce it if no necessary	1	2	3	4
Oregon	Less than 15,000 gpd (56,775 l/day)--no permit required	Return water must be reinjected into the same formation	1	2	3	4
Pennsylvania	No permit needed	A simple permit might be required (just notification) but no specific regulations	1	2	3	4
Rhode Island	No permit needed	Recharge wells not required to obtain permit	Rhode Island Pollution Discharge Elimination System may require a simple permit	2	3	4
South Carolina	No permit needed	No regulations exist at this time	1	2	3	4
South Dakota	No permit needed	No program to regulate this type of well exists at this time	1	2	3	4
Tennessee	No permit needed for water use under 50,000 gpd (189,250 l/day)	Permit would be required from Department of Health--no special problem to obtain		2	3	4

Texas	No permit needed for water use	Permit granting procedures do not exist for recharge wells--no permit needed	1	2	3	4
Utah	Permit needed for use of any type	No permit program exists for this type of reinjection --no permit needed	1	2	3	4
Vermont	No permit needed	Permit theoretically needed	1	2	3	4
Virginia	No permit needed	Non-injection of waste water is a policy in the state at present--would be a complicated permitting procedure for H-P return well	1	2	3	4
Washington	Permit needed for use over 5,000 gpd (18,925 l/day)	Necessary to obtain a discharge permit from the Department of Ecology		2	3	4
West Virginia	No permit needed	No real policy exists requiring permits at this time	1	2	3	4
Wisconsin	No permit needed	No reinjecting allowed in state	1	2	3	4
Wyoming	No permit needed	The method of disposal would have to be indicated on the use permit but otherwise no special requirement for any type of discharge				

surface water, septic tank, or sewer, are usually possible, state limitations on recharge wells should not hinder heat pump utilization. Table 6 shows existing water use and effluent regulations pertaining to ground-water heat pump use for each state.

Some local controls on well construction, ground-water use and quality, and waste disposal may adversely affect heat pump utilization. Most local regulations, however, will not seriously impede widespread development of this alternative energy source.

Most regulations and restrictions enacted at the Federal, state, and local levels will not present serious obstacles. Knowledge of their existence and their legal implications is vital to the implementation of ground-water heat pump technology.

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