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# HEAT PUMPS
# PRIMER FOR USE WITH LOW TEMPERATURE GEOTHERMAL RESOURCES

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November 16, 1977

EG&G Idaho, Inc.

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# HEAT PUMPS - PRIMER FOR USE WITH LOW TEMPERATURE GEOTHERMAL RESOURCES

## INTRODUCTION

This report focuses on utilizing heat pumps to obtain heat energy from low temperature geothermal resources. The principles of heat pumps will be examined to explore applications in residential and commercial heat requirements. The report also provides discussions concerning availability and costs. The report is intended to serve as a primer and user document for the reader with little or no background in heat pump technology.

### A. Principles of Heat Pumps

Since temperature is a measure of the heat energy possessed by geothermal water, a low temperature geothermal resource would contain less heat energy than a higher temperature resource. If a bottle of geothermal water is placed in an ambient temperature room, heat energy would be transferred to the room air. Heat transfer would continue until the water temperature comes to equilibrium with the temperature of the room. However, it is not economically sound to attempt to cool the geothermal water to room temperature in an operating system. Transfer of heat from the geothermal water to the room is accomplished by heat exchanger equipment. Tube-in-shell heat exchangers, finned tube radiators and heating coils are examples of conventional heat exchange equipment for transferring heat from a geothermal resource (thereby lowering the temperature of the resource) to a residential or commercial living space requiring heat.

Figure 1 shows the approximate temperature reduction that should be expected with economically-sized conventional heat exchange equipment, depending upon resource temperature.

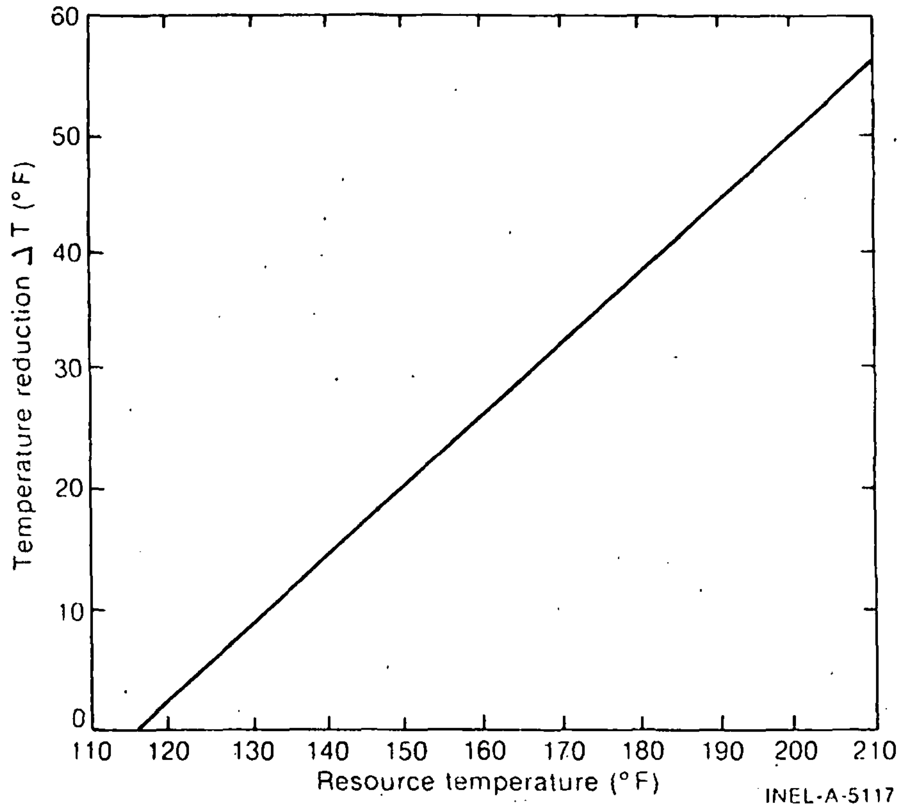


FIGURE 1

Nominal Temperature Reduction Using Conventional Heat Exchange Equipment in a Room at 70°F

Figure 1 is a representation of the simplified formula:

$$\Delta T = (0.6 \times \text{resource temperature } ^\circ F) - 70^\circ F$$

This simplified formula states that a heat exchanger with inlet fluid temperature of 118°F will essentially transfer no heat to the 70°F room, and will experience only 60% of the maximum possible drop for temperatures above 118°F. Though admittedly an oversimplification, the formula represents a useful rule-of-thumb.

The rate that heat (H) can be extracted from geothermal water is given by the formula:

$$H = 500\ (\Delta T)\ (Q)$$

where

$H$ = heat rate in Btu/hr

$\Delta T$ = temperature reduction from Figure 1

$Q$ = flow rate (gallons/minute)

(the number 500 is an approximation of the hourly heat content for each gallon of water reduced one degree Fahrenheit in temperature)

Figure 1 assumes that conventional methods of extracting heat become impractical and uneconomic when the geothermal water is below 120°F ($\Delta T \sim 0$), although the geothermal water still contains heat energy. The 120°F is not an absolute limit, but is based on typical conditions in which the heating air should be at least 100°F and a driving force of 20°F is needed to transfer heat across the heat exchanger. Therefore, alternate methods must be employed to extract heat from low temperature sources, e.g., heat pumps as discussed in this report.

In a residential forced air heating system, hot air in the temperature range of 100°F - 140°F from heating systems is added to the room air to maintain the desired indoor temperature. Absorbing heat from a low temperature geothermal source of 60°F - 90°F and transferring heat to provide 100°F - 140°F air temperatures might seem impossible when the principle of heat flow from high to low temperature is considered. However, as the name heat pump implies, heat pumps are to transfer heat or pump heat from a low temperature to a higher temperature medium. The principle is identical to the operation of a refrigerator, where heat is removed (pumped) from the colder interior of the refrigerator and given off to the surrounding room air. A second fluid is used inside the "heat pump machine," to absorb heat from the geothermal water and transfer this heat to a surrounding space. This secondary fluid is the key to the ability of a heat pump to transfer heat from low temperature sources, and to understand this transfer, some elementary principles of thermodynamics must be considered.

The secondary or working fluid is called a refrigerant, freon 12 and freon 22 being the most commonly used. When heat is absorbed by a refrigerant, it undergoes a change of state from a liquid to a gas, much the same as water changes to steam when heated. This change occurs at a constant temperature (the boiling point). The refrigerant will give off heat in the reverse process as it changes from a gas back to a liquid state. If a warm refrigerant while in a gas state is brought into a cool room, the refrigerant will cool and condense, transferring heat and raising the temperature of the room.

Pressure is another thermodynamic property important to understanding the operation of a heat pump. A change in pressure of a refrigerant can lower or raise the boiling temperature. For example, high pressure in a household pressure cooker allows the temperature of water to exceed 212°F without boiling. (Water boils at 212°F at sea level atmospheric pressure.) Likewise, water will boil at only 198°F at Pike's Peak, Colorado where the atmospheric pressure is below normal. By manipulating the pressure, the refrigerant under reduced pressure can absorb heat from a low temperature source and change to a gas, and at a high pressure, the heat of the refrigerant can be given to a higher temperature substance while changing back to a liquid. Thus, a heat pump refrigerant can absorb heat and become vaporized from a low temperature geothermal source and transfer this heat to the higher temperature room air by condensing to a liquid.

A schematic diagram, Figure 2, illustrates these processes with the various stages numbered and described as follows:

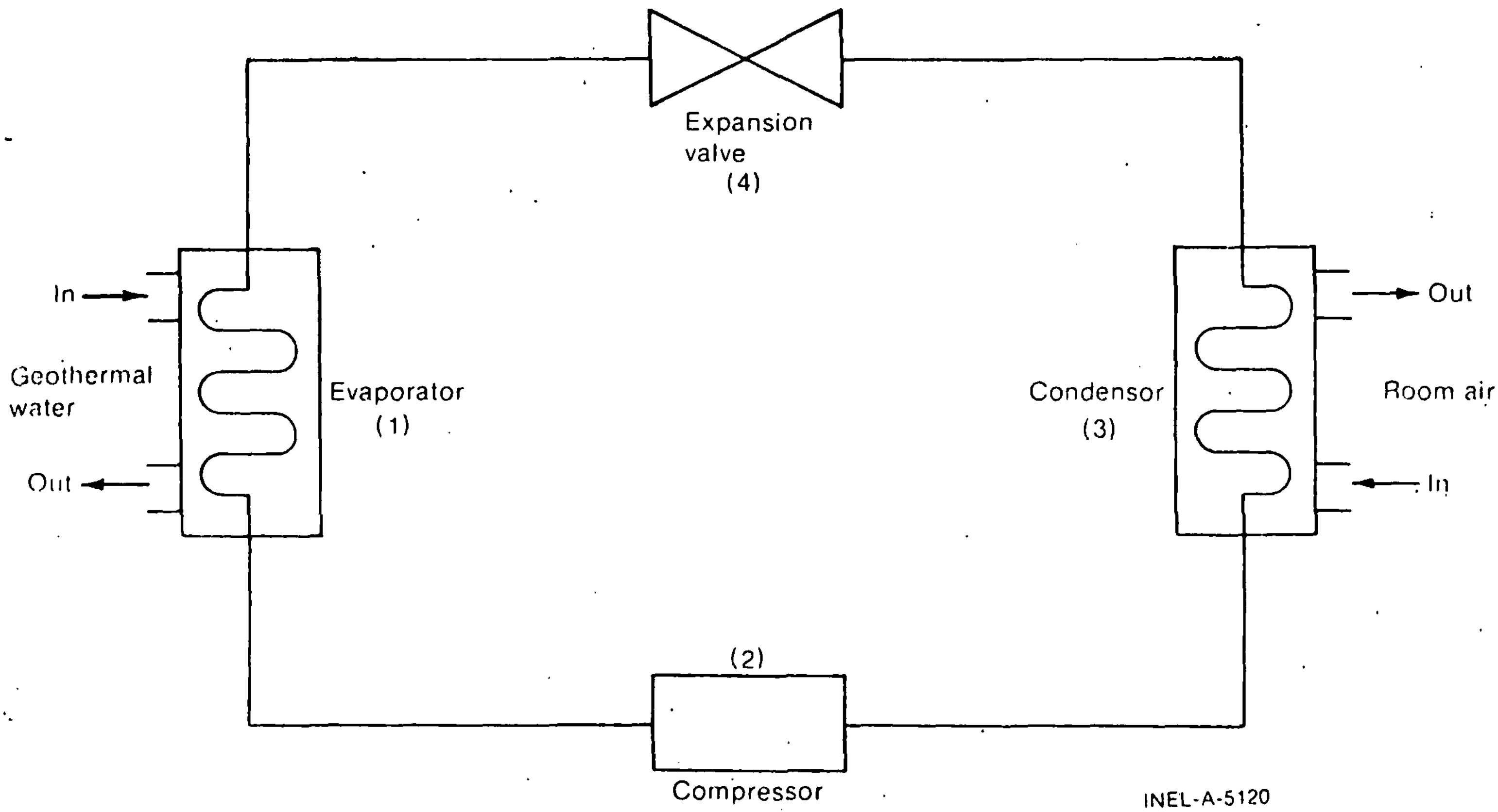


FIGURE 2.
Heat Pump Schematic

1. The refrigerant enters the evaporator at low temperature and pressure as a liquid. In the evaporator, low temperature geothermal water transfers heat to the refrigerant which becomes vaporized. The refrigerant is capable of vaporizing at this low temperature because of the low pressure.

2. The refrigerant enters the compressor as a gas at low temperature and pressure. As a result of compression, the refrigerant leaves at high temperature and pressure.

3. The refrigerant enters the condensor as a gas at high temperature and pressure. Heat is given up to the room as the refrigerant condenses to a liquid at high pressure. The refrigerant is capable of condensing at high temperatures because of the high pressure.

4. The refrigerant enters the expansion valve as a liquid at high pressure and low temperature. As the pressure is reduced, its boiling point decreases and part of the refrigerant is vaporized, cooling the remaining liquid.

The process is continued as heat is removed from the low temperature geothermal water and transferred to the higher temperature room air. Return air ducts collect cool room air while supply air ducts provide the heated air to the room in much the same manner as a conventional forced air heating system only in the heat pump case, the condenser coil replaces the fire box. Geothermal water from a spring or well is piped to the evaporator. The cooler geothermal water leaving the evaporator is then discharged. The heat pump schematic in Figure 2 is termed a water-to-air heat pump as it uses water as the heat source and air as the delivery medium. Some companies who manufacture water/air heat pumps are listed in Appendix A.

A requirement for a heat pump is electrical energy to circulate and compress the refrigerant. But for each electrical energy unit used, 2, 3, or more equivalent units of heat energy are transferred from the source. The efficiency of the heat pump is the ratio of these two energies and is called the coefficient of performance (COP). It is given by the formula:

$$COP = \frac{\text{quantity of heat energy delivered}}{\text{quantity of energy supplied to operate the device}}$$

A hydraulic analogy of COP is shown in Figure 3.

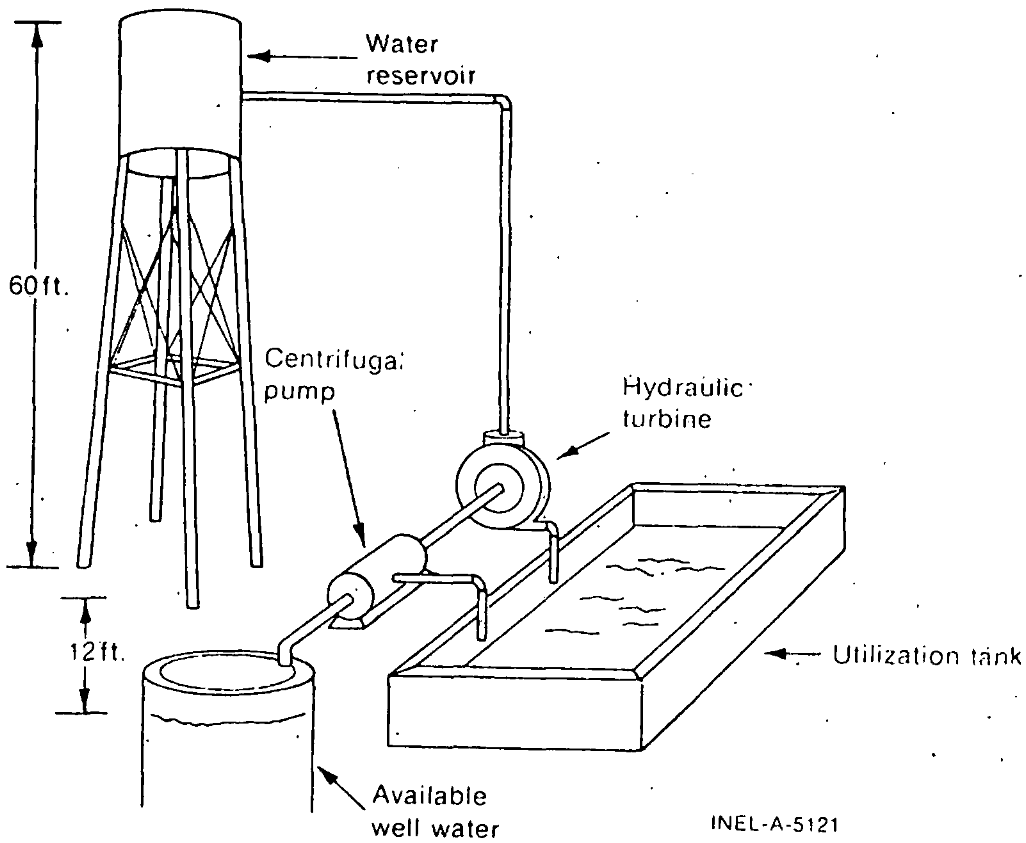


FIGURE 3
Hydraulic Analogy of COP

Water is collected in a storage tank 60 feet above ground. Piping is connected from this storage tank to a utilization tank at ground level. Another source of water from a tank or well is located 12 feet below ground level and connected such that it can also be pumped into the utilization tank.

Suppose that one gallon of water from the storage tank was released directly into the utilization tank without going through the hydraulic turbine. The work that this gallon of water is capable of doing by dropping 60 feet has been lost and only one gallon is available at the utilization tank. If another gallon of water is released from the storage tank and run through the hydraulic turbine, the centrifugal pump will raise water from the well. If the centrifugal pump is 100%

efficient, one gallon dropped 60 feet will raise five gallons 12 feet and thus a total of six gallons will now be available in the utilization tank. Actually, the pump will not be 100% efficient so something slightly less than five gallons would be transferred.

The heat pump works in much the same way. Electrical energy is used to compress a refrigerant which has absorbed heat from a low temperature air or water source and then transfers this heat to the utilization area. In the process 2-4 kwhr of equivalent heat energy are delivered for each kwhr supplied. With an apparent efficiency greater than 100%, the heat pump uses electricity to operate a device which absorbs heat from the geothermal water and delivers it at a higher temperature to the user. (Note that the geothermal water is assumed to be a "free" source. Likewise, electrical fans and pumps for circulating room air and geothermal water have not been taken into account in this energy balance. The requirements are usually small compared to the energy needed to operate the heat pump motor.) The formula for COP, then, is not a mere summation as it only calculates how much more energy is obtainable for each energy unit consumed.

If the condensor and evaporator are interchanged, the heat pump is capable of air conditioning. In this case, the temperature of the geothermal water would increase. Switching of two-way valves allows this interchange in current heat pump models. Using outdoor cooler air during summer use would be more sensible by conventional air conditioners (also a heat pump).

Example: A geothermal spring has a temperature of 90°F. A heat pump manufacturer states that his heat pump will use 10 gallons/minute with a COP of 2.5 and 10.55 kw electrical input.

a. How much heat is delivered?
b. How much heat is removed from the geothermal water? and
c. What is the exit temperature of the geothermal water?

a. Heat delivered

$$\text{COP} = \frac{\text{heat delivered}}{\text{heat supplied}}$$

$$2.5 = \frac{\text{heat delivered}}{10.55\ \text{kw} \times \frac{3413\ \text{Btu/hr}}{\text{kw}}} \qquad (1\text{kw} = 3413\ \text{Btu/hr})$$

$$\therefore \text{heat delivered} = 2.5 \times 10.55\ \text{kw} \times \frac{3413\ \text{Btu/hr}}{\text{kw}}$$

$$= \underline{\underline{90{,}000\ \text{Btu/hr}}}$$

b. Heat from geothermal water

The electrical input is 10.55 kw which equals 36,000 Btu/hr ($10.55\ \text{kw} \times \frac{3413\ \text{Btu/hr}}{\text{kw}}$). The heat from the geothermal water is equal to the difference between heat delivered and heat supplied.

heat delivered - heat supplied = geothermal heat removed

90,000 Btu/hr - 36,000 Btu/hr = <u>54,000 Btu/hr</u>

c. Exit temperature of geothermal water

$$54{,}000\ \text{Btu/hr} = 500 \times 10\ \frac{\text{gallons}}{\text{minute}} \times \Delta T$$

$$\Delta T = 10.8°\text{F}$$

If the geothermal spring water was 90°F and 10.8°F were removed, then the final temperature is:

$$90°\text{F} - 10.8°\text{F} = \underline{\underline{79.2°\text{F}}}$$

As noted earlier, conventional heat exchange equipment are dependent upon the source temperature. (See Figure 1.) The heat pump has a varying coefficient of performance (COP) depending upon the source temperature (Figure 4).

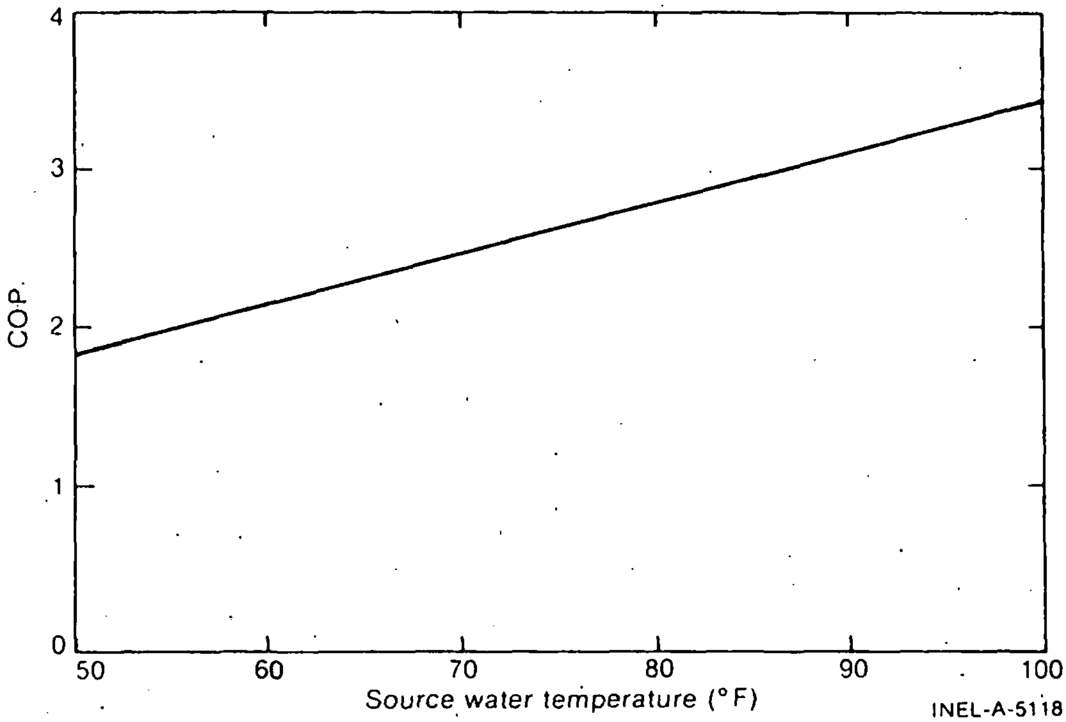


FIGURE 4

Typical Conventional Water-to-Air Heat Pump Performance Curve

The coefficient of performance is dependent upon the source temperature flow rate and particular heat pump used. The temperature dependence is a function of the thermodynamic properties of the refrigerant used. The temperature and pressure characteristics of freon are such that Figure 4 is valid for most heat pump models.

An understanding of home heat losses is helpful in calculating residential heat requirements. If the desired indoor temperature is 65°F, then heating requirement calculations would be based on the severity and duration of outdoor temperatures below 65°F.* For any particular

* 65°F is usually taken as the base for heat loss calculations from a building. The difference between 65°F and the normal 68°F to 70°F thermostat setting is accounted for by various intrinsic sources--body heat, electric lights, etc.

day, each outdoor temperature degree below 65°F is called a heating Degree Day.* Heating Degree Days (DD) are normally calculated on a monthly or annual basis.

Example: The average temperature for February in City A was 40°F; how many heating Degree Days were there in that month?

$$DD = \frac{\text{days}}{\text{month}} (65°F - t_o)$$

$t_o$ = average monthly temperature

$$DD = 28 (65°F - 40°F)$$

$$= 700 \text{ heating Degree Days}$$

The annual heating requirements and maximum hourly heat load for a typical well-insulated, modern 1800 square foot house can be estimated by the formula:

Maximum hourly heat load = $500 (t_i - t_m)$ Btu/hr

$t_i$ = desired indoor temperature

$t_m$ = minimum outside design temperature

Annual heating requirement = 12,000 x DD/yr*

* Degree Days per year for a specific area (state) can be obtained by ordering the July "Climatological Data" publication for that area from: Environmental Data Service
National Oceanic & Atmospheric Administration
National Climate Center
Asheville, NC 28801

Example: An average-sized home in City A has 7000 DD/yr and an outdoor design temperature of -15°F. a. What is the maximum hourly heat load, b. What is the seasonal heat load, and c. What is the annual cost of supplying this heat for:

i. an oil furnace, oil = 38¢/gallon, 145,000 Btu/gallon and 75% efficient

ii. an electric furnace, electricity = \$0.017/kwhr, 3413 Btu/kwhr and 100% efficient

iii. a heat pump, electricty = \$0.017/kwhr, 3413 Btu/kwhr and COP of 3.

a. maximum hourly heat load $= 500\ (t_i - t_m)$ Btu/hr

$= 500$ (65°F - [-15°F]) Btu/hr

= <u>40,000 Btu/hr</u>

b. seasonal heat load = 12,000 x DD/yr

= 12,000 x 7000 DD/yr

= <u>84,000,000 Btu/yr</u>

c. oil cost $= \dfrac{84{,}000{,}000 \text{ Btu/yr}}{145{,}000 \text{ Btu/gallon} \times 0.75}$ = 772 gallons x 38¢/gallon = \$293/yr

electric resistance heating $= \dfrac{84{,}000{,}000 \text{ Btu/yr}}{3413 \text{ Btu/kwhr} \times 1.0} = 24{,}619 \text{ kwhr} \times \dfrac{\$0.017}{\text{kwhr}} = \$418/\text{yr}$

heat pump $= \dfrac{84{,}000{,}000 \text{ Btu/yr}}{3413 \text{ Btu/kwhr} \times 3.0} = 8206 \text{ Kwhr} \times \dfrac{\$0.017}{\text{kwhr}} = \$140/\text{yr}$

Because of its somewhat complex machinery, the cost of the heat pump normally will be greater than the first costs for conventional heating equipment. When operating costs, maintenance, life expectancy of equipment as well as first costs are compared, however, the economics of the heat pump still looks more favorable. Figure 5 shows average first costs for capital equipment of heating systems.

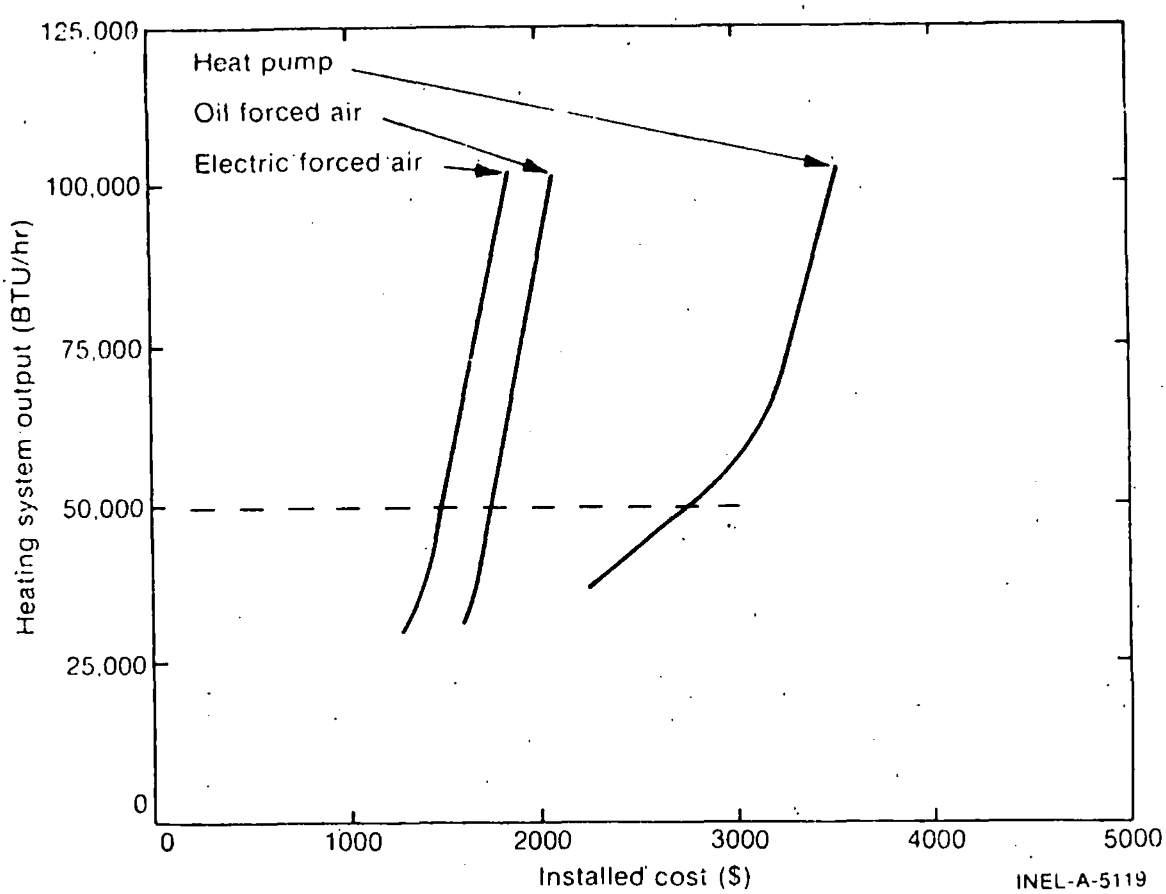


FIGURE 5

First Cost for Residential Sized Heat Pumps

For the example of heating costs noted above, a 40,000 Btu/hr system was calculated. Oversizing this by 25% to ensure adequate operation would result in a 50,000 Btu/hr system costing $1500 (electric forced air, $1750 (oil forced air) and $2800 (heat pump). The conservatively estimated life expectancy of these systems is 13 years, 19 years and 20 years, respectively. These costs amortized over the system's life expectancy and using 9% interest on straight line depreciation represent an annual cost of $196 (electric forced air), $193 (oil forced air) and $314 (heat pump). When these are coupled with annual energy costs, the total annual cost becomes:

| | FIRST COST | + | ENERGY COSTS | = | ANNUAL COST |
|---|---|---|---|---|---|
| Electric Forced Air | $196 | + | $418 | = | $614/yr |
| Oil Forced Air | $193 | + | $293 | = | $486/yr |
| Heat Pump | $302 | + | $140 | = | $442/yr |

Thus, when annual energy costs are included, the heat pump may be favorable to some conventional heating equipment. Other advantages of a heat pump system include:

1. Air conditioning as part of the system, obviating the need for further expenditures for separate air conditioning equipment, and
2. As fuel rates escalate, the operating energy cost of using a heat pump will increase one-half to one-third that of conventional equipment. This is dependent, of course, upon COP, fuel escalation rates and types of fuels used.

B. District Heating Potential

Heat pumps lend themselves well to district heating concepts. The goethermal water would be the common factor in a district concept. This would allow for reduced investment for obtaining, pumping, maintaining and discharging the geothermal water. Since underground hot water has a relatively stable year-round temperature, such a source makes it possible to choose a heat pump design of maximum efficiency (COP). Even ordinary ground water at 50°F can be more effectively used than air (as in the more common air-to-air heat pumps). However, the warmer the well water, the more efficient the system will be and the less electrical energy it will consume.

Common piping may be employed to deliver the geothermal water from a well or spring to the area of use. The costs of installation and maintenance are mutually shared, as are the risks of resource development. Individual users would normally tie in to a distribution piping system laid out in a grid fashion. To prevent too large a temperature reduction, each user would be connected in parallel as noted in Figure 6.

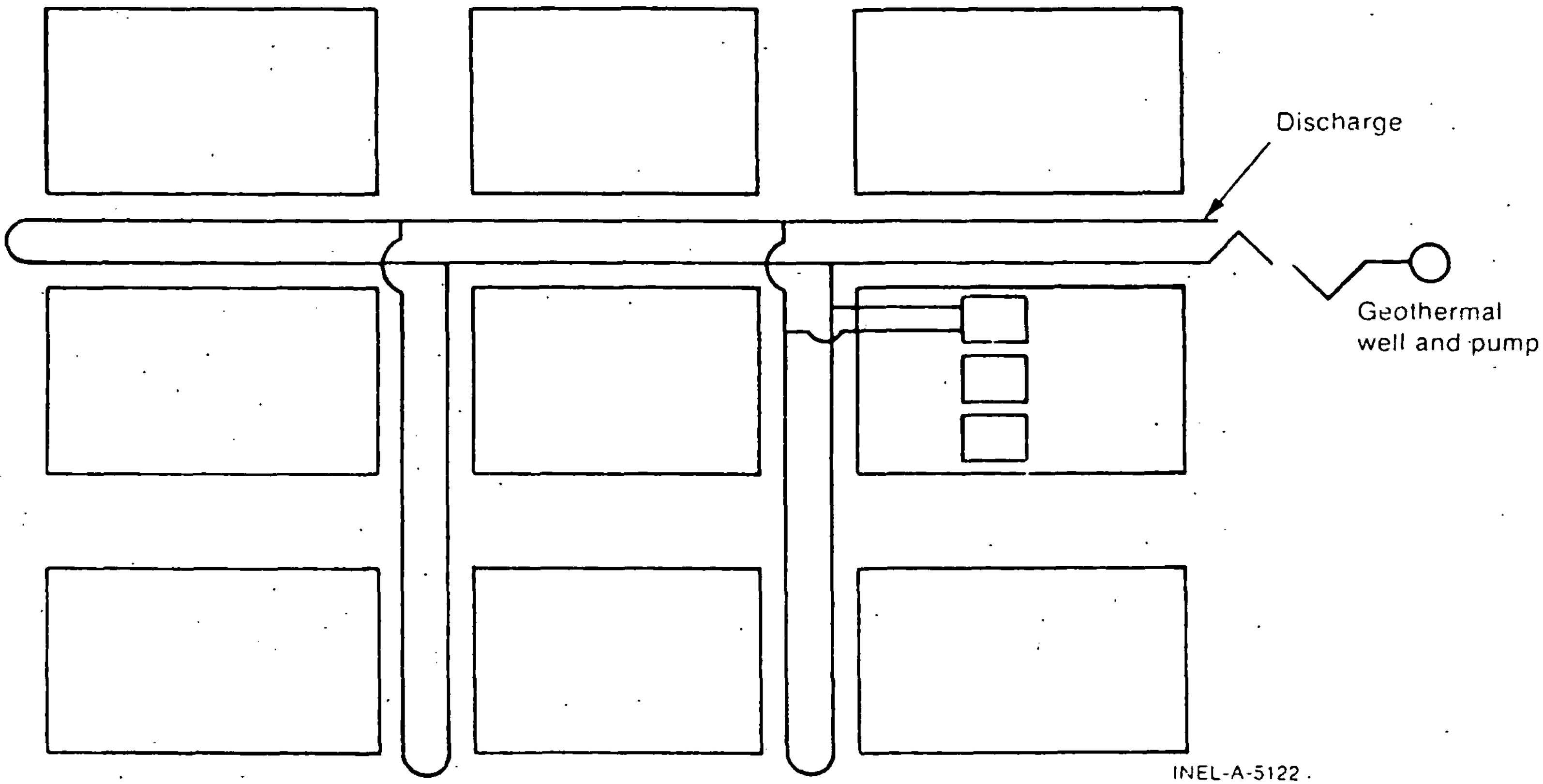


FIGURE 6
Typical Residential District Heating Scheme

A supply line might connect main segments of city blocks or subdivision areas. Each user would tap into a supply main and discharge into a return main. Thus, each user would be supplied with the same temperature water. The flow from the geothermal well would be the sum of the flows necessary for each user.

Should the geothermal water be of poor quality (i.e., corrosive to common construction materials), a heat exchanger could be installed at the well. Secondary water would be piped in a closed loop system to individual users and reheated upon return to the heat exchanger. The discharge from the primary side (poorer quality geothermal water side) of the heat exchanger would be discharged in a manner similar to a single residence application.

Methods of discharging the spent geothermal water are dependent upon its temperature, water quality and flow rate. Typical methods would include:

1. Evaporation and/or seepage into discharge ponds,
2. Reinjection of the geothermal water into the production aquifer,
3. Discharging into streams or rivers should the temperature and quality of the water be suitable, and
4. Direct use applications such as agriculture.

The economic benefit derived from collectively supplying heat for numerous users can further be increased if the annual use factor is increased, that is, by increasing the amount of time the district concept operates at full capacity. Obviously, heating and cooling using heat pumps is not a continuous operation. Several hours a day when temperature conditions are right, the geothermal district heating system user would be supplied hot water but not used.

## C. Commercial and/or Process Opportunities

A residential space conditioning system in the Pacific Northwest normally operates 40% of the time during the heating season and 20% during the cooling season. A district space conditioning system would therefore be idle 60% during the heating season and 80% during the cooling season. This unused portion of time represents a waste of capital equipment.

If a commercial or process use can be found whose use rate (load factor) is different than a residential load factor, a more beneficial use of the district system becomes possible. For example, factories which operate during the winter in daylight hours would help augment the residential sector who require greatest heat needs during the cold evenings. Most commercial and industrial food processing temperature requirements, however, are between 160°F and 300°F. For process use, several current heat pump models are capable of delivering up to 230°F when operating on 140°F water source temperatures. Several firms are developing models that will deliver temperatures as high as 350°F. If 90°F water is used in the residential district heating scheme, this could be boosted to approximately 175°F by heat pumps in the range for boiler feed water use at considerable economic savings. Other lower temperature requiremnts usually exist in commercial processes which could use 175°F water, although they may not be the prime energy uses of the process. Using 129°F in the residential district heating scheme would result in 233°F outlet water and would meet the majority of industrial needs.

D. Opportunities and Problems of Geothermal Heat Pumps

1. Current residential sized heat pump units of the water/air type normally are driven by source water temperatures between 50°F and 90°F. Larger process and commercial energy heat pumps are capable of using higher temperature water sources but are too large for individual residential use. Above 120°F conventional heat exchange equipment may be used directly. There is, therefore, a temperature gap (90°F - 120°F) in which "off-the-shelf" individual home heat pump equipment for geothermal water of this temperature range is not available. This temperature gap is not necessarily a result of insolvable technical problems but rather the preference of heat pump companies which traditionally have satisfied particular markets. Specialized units can be custom made to function in this temperature range and may be routinely marketed in the near future.

2. Minerals dissolved in the geothermal water as a consequence of prolonged exposure to various rock formations at high temperature and pressure are major problems associated with using geothermal resources. These contaminants could create problems in the form of corrosion and deposition and will influence the material selection and design of heating equipment.

Silica, particularly, becomes less soluble in geothermal water as the water is cooled. Therefore, reducing the temperature of the water by passing it through a heat pump may result in some deposition of silica on the evaporator coil for the very high temperature geothermal systems (above 300°F). Hydrogen sulfide, in addition to being an environmental problem, is a general corrosive, as it acts upon copper and silver components. The pH of the geothermal water can also be corrosive to iron-base alloys especially when oxygen ($O_2$) is present in the system. Calcite ($CaCO_3$) will not normally be a problem except whenever carbon dioxide ($CO_2$) is released from the water. Therefore, if the geothermal water is kept pressurized, thus preventing the release of $CO_2$, no deposition of calcite can occur. For the most part, each particular geothermal site must be analysed to establish the interrelationships of all possible contaminants to find their collective corrosion and deposition characteristics. Low temperature geothermal water, however, has not been of particular concern from a materials standpoint in experience gained thus far in projects for the Pacific Northwest.

# APPENDIX A

## THE FOLLOWING COMPANIES MANUFACTURE WATER/AIR HEAT PUMPS

| Trade Name | Company and Address | Telephone Number |
|---|---|---|
| Triton Heat Pump | York, Div. of Borg-Warner Corp<br>P.O. Box 1592<br>York, PA 17405 | (717) 846-7890 |
| Electro-Hydronic | Singer Co., Climate Control Div.<br>401 Randolph Street<br>Red Bud, IL 62278 | (314) 644-5200 |
| Mammoth | Mammoth Div., Lear Siegler Inc.<br>13120-B County Rd 6<br>Minneapolis, MN 55427 (James H. Langer | (612) 544-2711 |
| Friedrich (Climate Master Series) | Friedrich Air Conditioning & Refrigeration Co<br>4200 N. Pan Am Hwy. P.O. Box 1540<br>San Antonio, TX 78295 | (512) 225-2000 |
| Air Conditioning Corp | Air Conditoning Corp.<br>P.O. Box 6225<br>Greensboro, NC 27405 | (919) 273-4472 |
| Koldware | Heat Exchanger Inc.<br>8100 N. Monticello Ave.<br>Skokie, IL 60076 | (312) 267-8282 |
| Vilter | Vilter Mfg. Corp.<br>2217 S. First St.<br>Milwaukeee, WI 53207 | (414) 744-0111 |
| Century/Comfort Aire | Heat Controller Inc.<br>Losey at Wellworth<br>Jackson, MI 49203 | (517) 787-2100 |
| Weatherking | Weatherking Inc.<br>4501 E. Colonial Drive<br>Box 20434<br>Orlando, FL 32814 | (305) 894-2891 |
| McQuay Group Roofpak | McQuay Group, McQuay-Perfex Inc.<br>13600 Industrial Park Blvd.<br>P.O. Box 1551<br>Minneapolis, MN 55440 | (612) 559-2892 |

| Trade Name | Company and Address | Telphone Number |
|---|---|---|
| Whalen Co. | The Whalen Co.<br>P.O. Box W<br>Brock Bridge Rd<br>Laurel, MD 20810 | (301) 776-4030 |
| Wilcox | Wilcox Mfg. Corp.<br>13375 U.S. 19 North at 62nd Street<br>P.O. Box 455<br>Pinellas Park, FL 33565 | (813) 531-7141 |
| McMillan | McMillan Heat Pump Inc.<br>P.O. Box 5897<br>Jacksonville, FL 32207 | (904) 733-7590 |
| EnerCon | American Air Filter Co.<br>215 Central Ave.<br>Louisville, KY 40201 | (502) 637-0011 |
| FHP Manufacturing | Florida Heat Pump Corporation<br>610 Southwest Twelfth Ave.<br>Pompano Beach, FL 33060 | (904) 733-3592 |
| Command Aire | Command Aire Corp.<br>P.O. Box 7916<br>Waco, TX 76710 | (817) 753-3601 |
| Addison | Addison Products Co.<br>Their water/air system marketed under<br>Weatherking name (Weatherking Inc.) | |
| Weathermaker | Carrier Air Condition, Div. of Carrier Corp<br>Carier Pkwy<br>Syracuse, NY 13201 | (315) 463-8411 |
| Aqua-Matic | Dunham-Bush Inc.<br>175 South St.<br>West Hartford, CT 06110 | (203) 249-8671 |
| Climatrol | Mueller Climatrol Corporation<br>Woodbridge Ave.<br>Edison, NJ 08817 | (201) 981-0300 |
| | Advanced Desgin Associates, Inc.<br>Miami, FL | |
| | BudCo<br>Bloomfield, CT | |
| | ElmBrook Refrigeration, Inc.<br>Batter, WI | |
| | Lanco - Supreme, Inc.<br>Torrance, CA | |
| Templifier | Westinghouse | |