# MARYVALE TERRACE: GEOTHERMAL RESIDENTIAL DISTRICT SPACE HEATING AND COOLING

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**and**
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**CAPITOL MALL, PHOENIX, ARIZONA**



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ABSTRACT

A preliminary study of the technical and economic feasibility of installing a geothermal district heating and cooling system is analyzed for the Maryvale Terrace residential subdevelopment in Phoenix, Arizona. The development consisted of 557 residential houses constructed by the John F. Long Realty Company. The study was undertaken as a model for analyzing district heating and cooling systems for new residential developments. The design heating load was estimated to be 16.77 million Btu/hr and the design cooling load was estimated to be 14.65 million Btu/hr. Average annual energy use for the development was estimated to be 5,870 million Btu/yr and 14,650 million Btu/yr for heating and cooling, respectively. Competing fuels are natural gas for heating and electricity for cooling.

A geothermal resource is assumed to exist beneath the site at a depth of 6000 feet. Five production wells producing 1000 gpm each of 220$^{o}$F geothermal fluid are required. Total estimated cost for installing the system is \$5,079,300. First year system operations cost (including debt service) is \$974,361. The average annual geothermal heating and cooling cost per home is estimated to be \$1,750 as compared to a conventional system annual cost of \$1,145. Further, the cost of geothermal heating and cooling is estimated to be \$47.50 per million Btu when debt service is included and \$6.14 per million Btu when only operating costs are included. Operating (or fuel) costs for conventional heating and cooling are estimated to be \$15.55 per million Btu.

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## INTRODUCTION

The space heating and cooling of residential districts by systems which use geothermal energy is under investigation as one possible use of geothermal resources. A district heating and cooling system is defined by the U.S. Department of Energy as an energy system that generates thermal energy from one or more central plants to service a multiple number of buildings and customers with thermal service through a piping distribution network and, when possible, a storage facility. The piping system may extend throughout an entire urban area or may be limited to a single neighborhood. A geothermal or heat pump district heating or cooling system can be considered under this definition.

Space cooling constitutes a significant percentage of all energy used for space conditioning in Arizona. In southern Arizona, the demand for space cooling occurs during the summer from the beginning of May through the end of September. In northern Arizona, wintertime heating is also quite significant. Therefore, the use of geothermal energy in Arizona for district space heating and/or cooling may result in reduced consumption of fossil fuel energy and decreased peak power requirements.

Geothermal district space heating is practiced in such places as Boise, Idaho and Klamath Falls, Oregon and also in the countries of New Zealand, Iceland, Japan and others. However, little experience has been gained in using geothermal energy for space cooling and refrigeration. Both space heating and space cooling systems using geothermal sources are feasible from a technical viewpoint, and implementation of a space conditioning system is more dependent on economic considerations.

The John F. Long Realty Company of Phoenix, Arizona supplied information regarding Maryvale Terrace, a development which began construction in the fall of 1980. The following study was performed in order to preliminarily assess the relevant factors in district heating and cooling.

## PROJECT DESCRIPTION

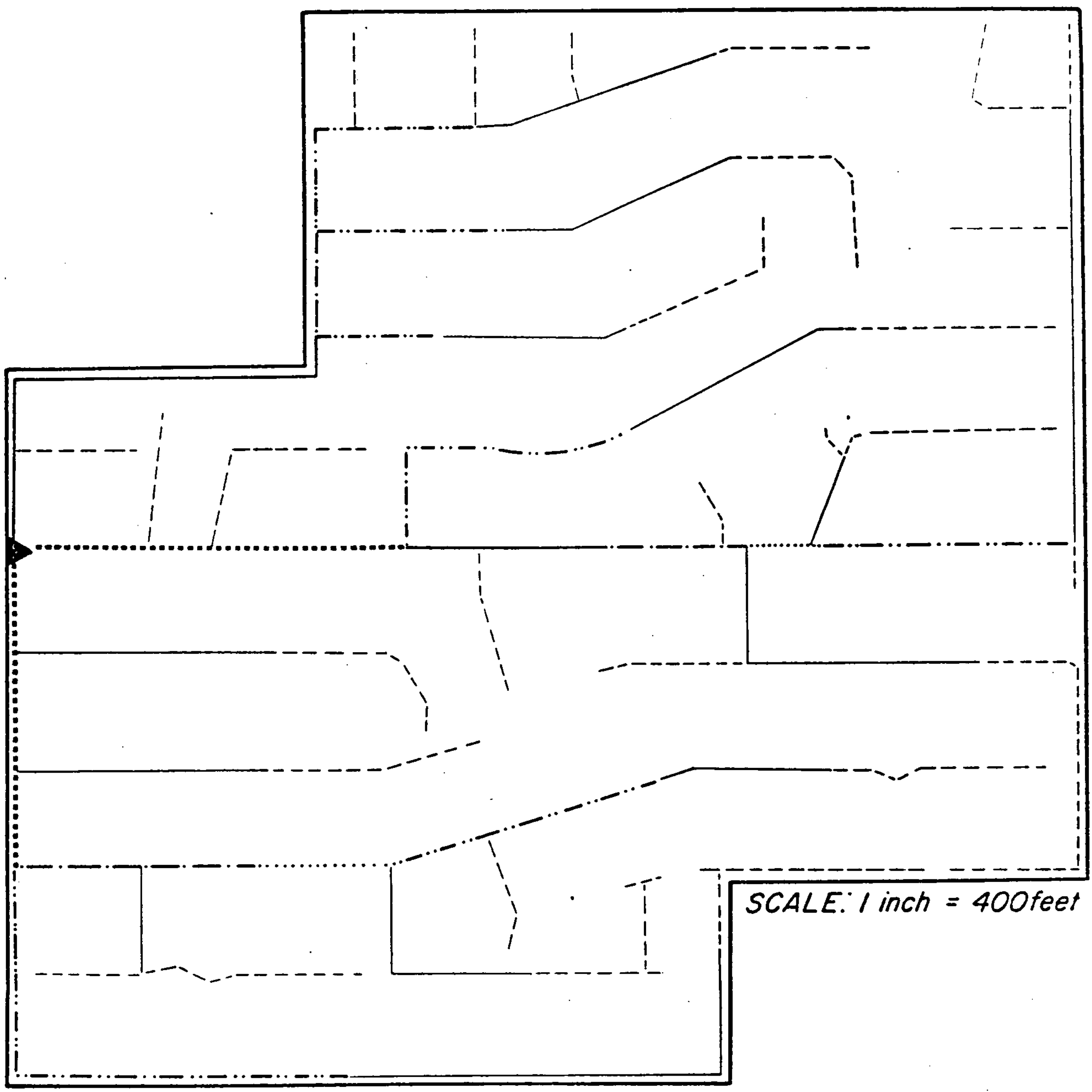
### General Information

Maryvale Terrace is a development of 557 single-family homes. Its shape is basically square, one-half mile (0.8 km) on each side (see Figure 1). The development is located in northwest Phoenix, Arizona. The property is level with a maximum elevation change of only 10 ft (3.0 m) occurring between the northwest and the southwest corner of the development.

The Maryvale Terrace receives 7.44 inches of rainfall annually; average relative humidity is 37 percent. Temperatures range from 60° to 105°F (15.6°-40.6°C) in the summertime and from 38° to 75°F (3.3°-23.9°C) in the wintertime. The average number of heating degree days is 1215 and cooling degree days is 4015.

A 220°F (104°C) resource is assumed to exist at a depth of 6000 ft (1830 m) beneath the site. The salt content of the geothermal water is estimated to be 1000 ppm, the reservior volume is assumed to be large enough to provide at least 50 years of continuous service without significant deterioration. The reservoir assumptions were necessary because resource exploration had not been performed on or near the site. However, the detailed information on geothermal resources, as given in the report on Geothermal Development Plan: Maricopa County, provides ample evidence that geothermal resources exist throughout metropolitan Phoenix. The technical and economic results of this study might be transferable to other possibly more favorable, geothermal sites in Arizona.

The sources of energy which geothermal energy had to compete with in this location were natural gas for heating and electricity for cooling.




EXPLANATION

2 inch I.D.
3 inch I.D.
4 inch I.D.
5 inch I.D.
6 inch I.D.
7 inch I.D.
8 inch I.D.
Boundary
Central plant

Figure 1: Maryvale Terrace Development and Piping System

## Geothermal System Investigated

Figure 2 is a flow diagram of the system investigated for Maryvale Terrace. It is capable of delivering either heating or cooling water to each home, but both cannot be supplied at the same time. The system also cannot supply domestic hot water. The capital expense of constructing a system which would supply all of these options was found to be prohibitively expensive.

The proposed system uses geothermal energy to heat or cool water which is circulated to each home for heating and cooling. To heat water, geothermal fluid is circulated through a heat exchanger where it transfers some of its energy to less corrosive water; water is cooled by passing geothermal fluid through lithium bromide water absorption chiller, a geothermal-driven cooling unit. The heated or cooled water is then pumped to each home via a piping system (see Figure 1). For simplication and clarity, the pipes connecting the homes to the mains are not shown in the figure.

Within each home a fan coil combination heating and cooling unit will do the actual heating or cooling. In the heating mode, the fan coil unit extracts heat from the water circulating through it, thus warming the houses. In the cooling mode, heat from the home is absorbed by the circulating water, thereby cooling the home. The water is then returned to either the heat exchanger or the absorption chiller via the district piping system.

## Heating and Cooling Loads

Maximum heating and cooling loads were 30,100 Btu/hr (8.82 kw) and 26,300 Btu/hr (7.71 kw), respectively, for an average home in Maryvale Terrace. It was assumed that there would be times when every home in the development would need its entire maximum heating or cooling load, i.e. a load factor of 1.0. Therefore, the total maximum heating and cooling loads for the 557 homes are 16.77 million Btu/hr (4920 kw) and 14.65 million Btu/hr (4290 kw),

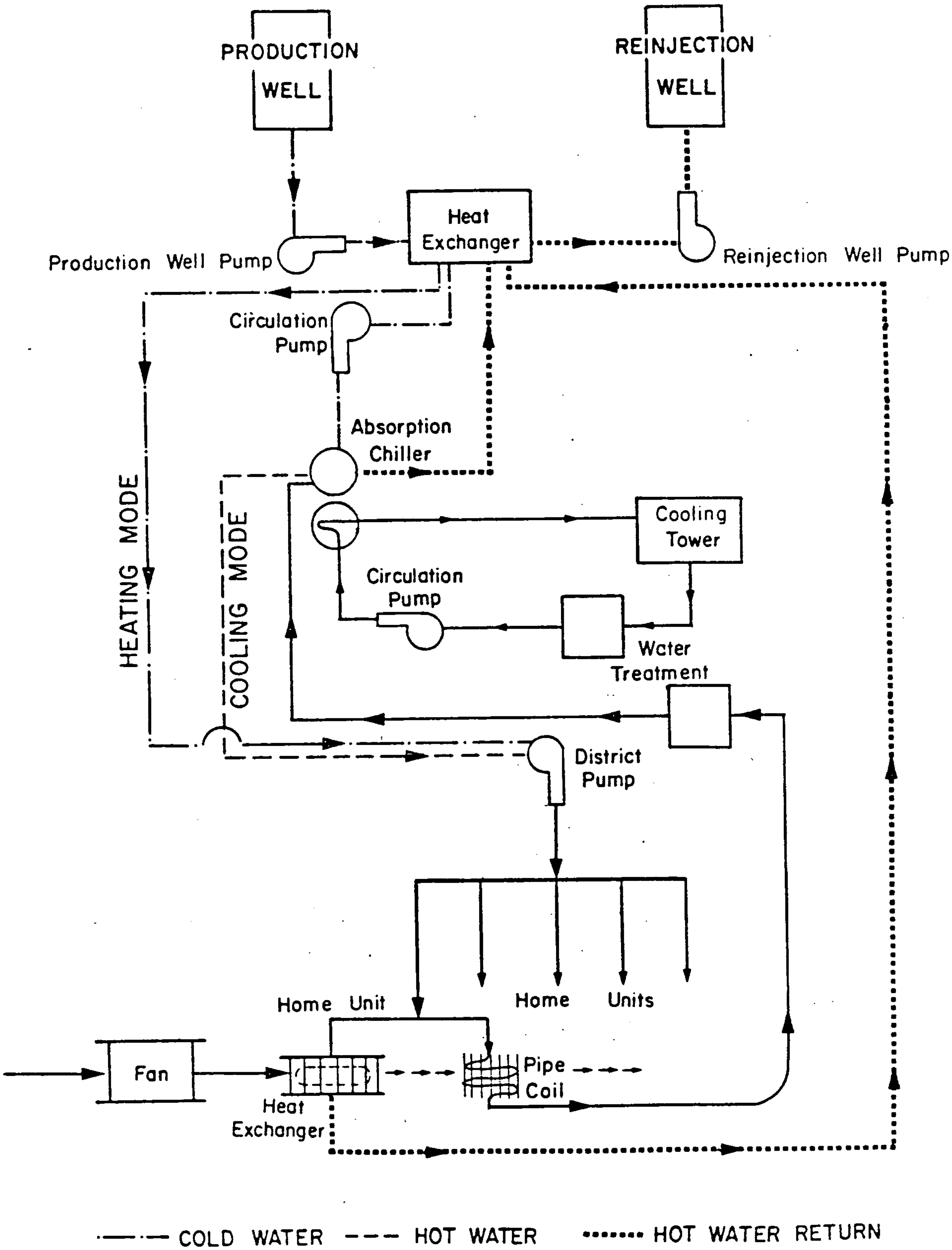



Figure 2: Flow Diagram of the Maryvale Terrace Geothermal Heating and Cooling System

respectively.

Flow Rate Requirements

A review was made of fan coil unit literature to determine the typical temperature difference between inlet and outlet water in each mode of operation. These temperature changes were then compared with typical operating temperatures of the lithium bromide-water absorption chillers and the heat exchanger could provide. Design temperature difference of $8^{O}F$ ($4.5^{O}C$) for cooling and $12^{O}F$ ($6.7^{O}C$) for heating were chosen for the fan coil units. Under this design, a flow rate of 6.575 gpm (0.42 l/sec) or 5.02 gpm (0.32 l/sec) would be required to provide the average home with its maximum cooling or heating load, respectively.

The selection of the in-home fan coil units was then made. It was decided that central air handlers would be used since they are more efficient and less expensive than smaller room-size units. Also, only one unit would be needed in each home. The Yazaki 304 Mini Handler was the recommended unit for the average home. Each would require 215 W of electric power and provide more than the design heating load. The design cooling load would also be fully met by these units.

Distribution Piping System

A two-pipe distribution system was chosen to carry the heating or cooling water to the homes. The two-pipe distribution system consists of one supply pipe and one return pipe. While a two-pipe system has more inherent disadvantages than a four-pipe system, the lower capital cost of the two-pipe system made it more attractive.

The major disadvantages of two-pipe systems are its inability to supply heating and cooling water at the same time and the fairly long time it takes to change over from one mode of operation to the other. Four-pipe systems do not have these disadvantages, but they are almost two-thirds more expensive. One- and three-pipe systems were not considered.

The decision to use a two-pipe system also affected the ability to supply heat for domestic hot water purposes. Heat for domestic hot water cannot be supplied when a two-pipe system is operating in the cooling mode. Domestic hot water heating could be supplied by adding a third distribution pipe, which would act as a heating coil for a hot water tank in each home. However, the estimated cost of heating domestic hot water per home per month was less than $10.00. Sufficient energy savings to cover the cost of a separate domestic hot water distribution system and pumping requirements were not expected.

The center of the western boundary was chosen as the location of the central heating and cooling plant (see Figure 2) since it was assumed that most home buyers would not want to be located near any large buildings. In addition, the cooling towers located at the central plant would make some noise which would also dictate locating the plant on the development perimeter.

The piping system would run along easements wherever possible and along streets where easements were not available.

The diameters of the main pipelines were chosen on the basis of a maximum fluid velocity of 8 ft/sec (2.4 m/sec) and the maximum flow rate that they would carry. Commercial steel pipe was chosen for this system due to its thermal and mechanical properties.

The maximum working pressure and temperature would be 80 psig (550 kPa) and 160$^{\circ}$F (71$^{\circ}$C). The minimum working temperature would be 45$^{\circ}$F (7$^{\circ}$C). All of the piping would be insulated with ureathane foam covered by a sheath of sheet metal aluminum. Insulation would be required primarily to prevent the cooling water from warming up as it flowed through the system. More heat transfer would occur during the heating mode than during the cooling mode due to the larger temperature differential between the water within the pipes and the soil. The amount of heat transfer during the cooling mode would be more important, however, since the cost of cooling the water is higher than the cost of heating it. The amount of heat transfer the piping system would allow when insulated to specifications would be negligible when compared to the total heating or cooling loads. The heat transfer coefficient for the heat areas would be reduced to 0.5 But/hr-ft$^2$ at 150$^\circ$F (1.58 W/m$^2$ at 66$^\circ$C) by the insulation.

Table 1 summarizes the length and costs of pipes of different diameters that the system would require. One-inch insulated commercial steel pipe would be used to connect the homes to the mains. Each house was assumed to be an average of 60 ft (18.3 m) away from the mains. In addition to piping costs, the cost of 557 energy use meters at $50 each must be added. This total is then increased by 50 percent to cover the cost of hookup. Total piping, metering and hookup cost is estimatd to be $570,914.

Pumping Requirements for District Piping System

Computations of the pumping requirements were based on frictional losses alone as no pressurization or elevation changes would occur within the two-pipe system once a steady state was established. The total power required by

TABLE 1. COST OF DISTRICT PIPING SYSTEM (COMMERCIAL STEEL PIPE)

| Diameter in | cm | Length ft | m | Cost per Unit Length $/ft | $/m | Cost $ |
|---|---|---|---|---|---|---|
| 1 | 3 | 66,840 | 20,378 | .83 | 2.72 | $ 55,477 |
| 2 | 5 | 24,360 | 7,427 | 1.77 | 5.80 | 43,117 |
| 3 | 8 | 15,960 | 4,866 | 3.59 | 11.78 | 57,296 |
| 4 | 10 | 9,720 | 2,963 | 5.19 | 17.03 | 50,446 |
| 5 | 13 | 940 | 287 | 12.03 | 40.62 | 11,308 |
| 6 | 15 | 2,400 | 732 | 12.38 | 40.62 | 29,712 |
| 7 | 18 | 3,360 | 1,024 | 14.6 | 46.13 | 47,241 |
| 8 | 21 | 3,540 | 1,079 | 16.43 | 53.90 | 58,162 |
| | | Total Pipe Cost | | | | $352,759 |
| | | Meters | | | | $ 27,850 |
| | | | | | | $380,609 |
| | | Hookup cost (est.) | | | | $190,305 |
| | | TOTAL COST | | | | $570,914 |

the system was calculated in the following way:

For each length of pipe, the following quantities were determined:

(a) a flow rate equal to the flow rate leaving that segment of the main plus 80 percent of the difference between the flow rates at each end of the pipe, i.e.,

$$\text{flow rate} = \text{flow rate}_{out} + 0.8 \times (\text{flow rate}_{in} - \text{flow rate}_{out})$$

(b) a Reynolds number and friction factor based on commercial steel pipe.

(c) a minor loss coefficient.

(d) the head loss due to friction and minor losses.

(e) the power for that segment of pipe.

Assuming a pump efficiency of 0.72, an electric motor efficiency of 0.9

and a 25 percent overdesign, all of which were assumed in all pumping calculations for this project, the power required to drive the water through the system would be 236 kw. As stated previously, a flow rate of 6.57 gpm (0.42 l/sec) would be required to provide an average home with its maximum cooling load; for the 557 homes, a pumping capacity of 3660 gpm (231 l/sec) would be required at an average head of 221 ft (67.4 m). A Peerless horizontal split case single-stage pump would be recommended for the district circulation pumping system. This pump was designed for water and clear liquids with temperatures up to 300°F (149°C) and it's pumping capacity can be as high as 5000 gpm (315 l/sec). Therefore, the district pumping requirement would be fully met by this unit. The current price of this pump was $24,900.

Lithium Bromide-Water Absorption Chillers

Based on cost, availability, reliability and maintenance, absorption cooling units were preferred over the Rankine vapor-compression cycle for the system considered for the Maryvale Terrace project. Figure 3 shows the absorption cooling cycle and Figure 4 shows a schematic of the geothermal absorption cooling system. One of the most common absorption cooling systems is the lithium bromide (Li-Br) system, which chillers would be used to chill the cooling water. Other types of absorption chillers were not available commercially in the size required by Maryvale Terrace.

Lithium bromide-water absorption units made by Trane Company and Carrier Corporation were investigated. The machines from Carrier Corporation were judged to be too small and too inefficient for use in this particular system, as they are not for use with a low temperature source of heat. Using Carrier Corporation machines, a coefficient of performance (COP) of only 0.49 could be expected. However, two Trane ABSC11A single state absorption chillers, selected according to methods given in the Trane C5 ABS-2 catalog of

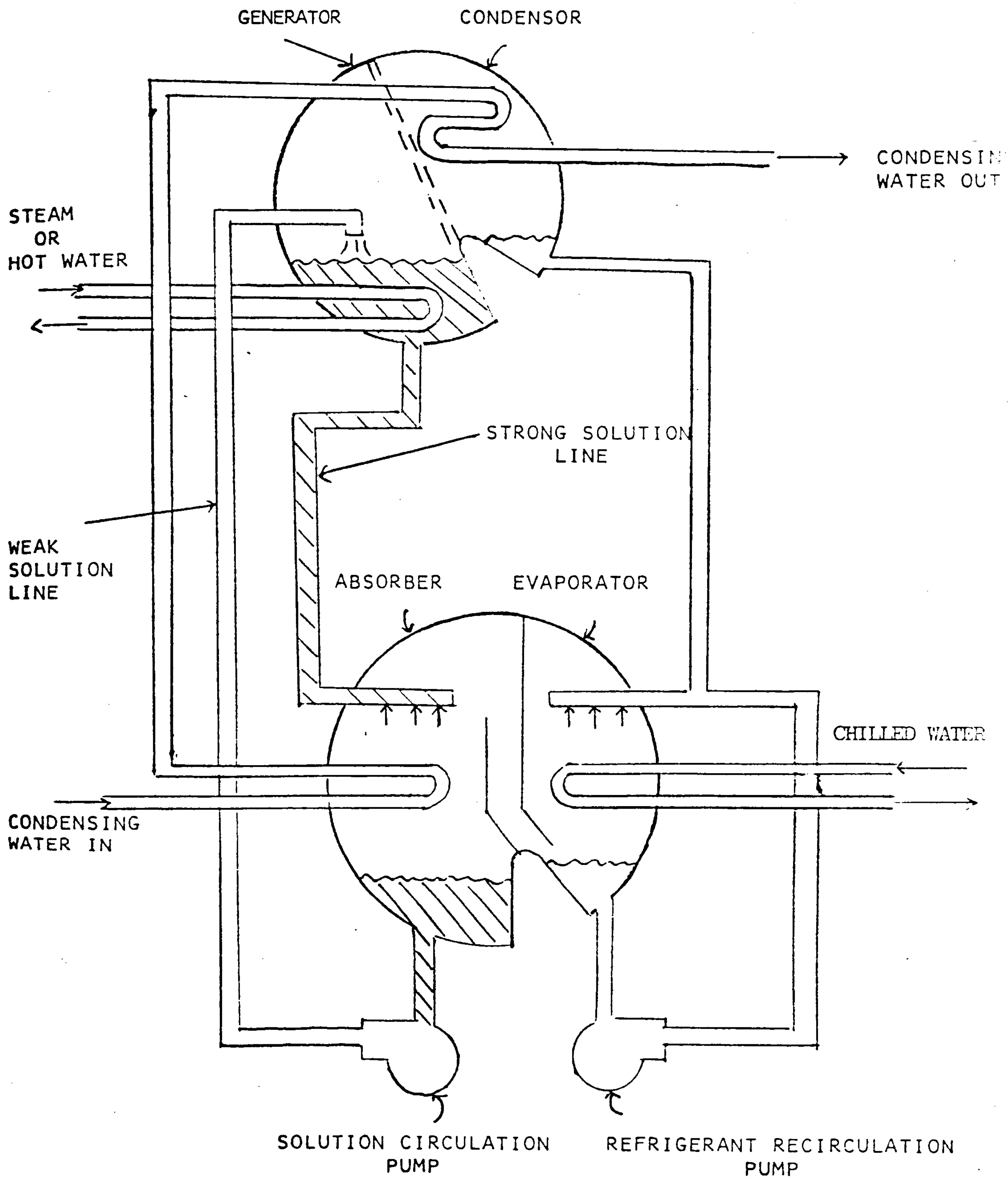



Figure 3: Absorption Cooling Cycle

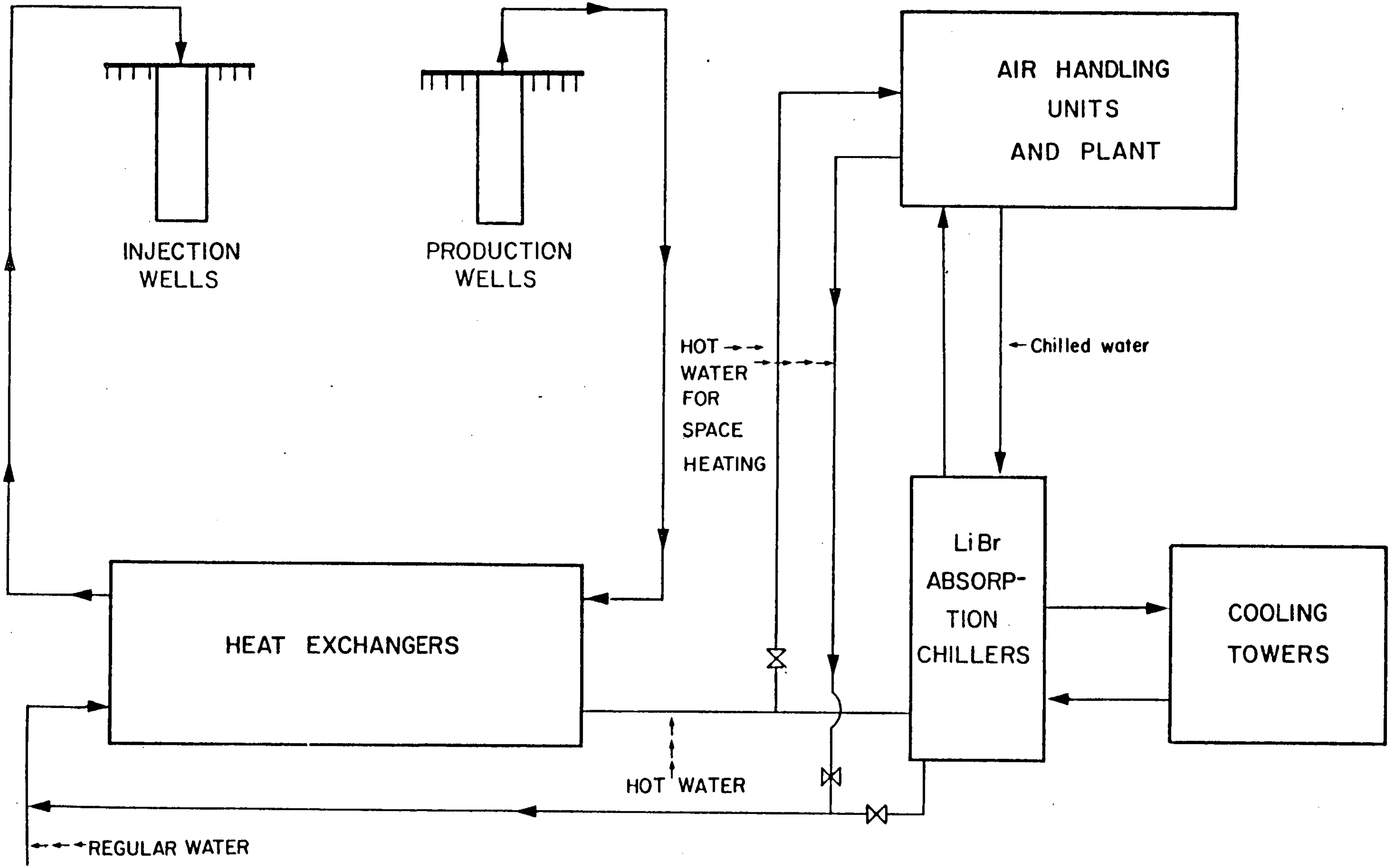



Figure 4: Simplified Schematic of Geothermal Absorption Cooling System

low temperature absorption chillers, could be used to chill the cooling water. They provided the entire cooling load of 14.65 MBtu/hr (4290 kw) but did not provide any excess capacity. The design temperature difference achieved is 4.4°C (8°F). Each machine required 15.3 kw for a COP of 0.719 at maximum operating conditions. The geothermal water powering the machine entered at 200°F (93.3°C) and exited at 191°F (88.3°C). A geothermal fluid flow rate of 4530 gpm (286 l/sec) water was necessary to supply the required heat. The installed cost of the cooling unit was $420,000.

The partial load heat requirements were not estimated as Trane did not believe the determinations could have been accurately performed without the use of their computer models. The Trane Company would have made a partial load analysis of the system but this was not requested of them.

<u>Cooling Towers</u>

The absorption machines require 30.0 MBtu/hr (10.27 kW) of cooling tower capacity. The cooling towers needed to supply 7200 gpm (454.2 l/sec) of 85°F (29.4 °C) cooling water. A Marley 454-302 two-cell cooling tower was selected to meet this need. The cooling tower required 153.2 kw of electrical power to run at full capacity and could have been installed on an already existing concrete pad for approximately $80,000. Its dimensions were 48 ft (14.6 m) long, 29 ft (8.8 m) wide, and 18 ft (5.5 m) high.

<u>Circulation Pump</u>

The circulation pump between the absorption chiller and the heat exchanger would have drive 4530 gpm (286 l/sec) through a head loss of approximately 50 ft (15.2 m) and would require about 82.4 kw of electrical power at maximum load. The Peerless horizontal split case single-stage pump was again recommended as the circulating pump between the absorption chiller and the heat exchanger. This pump delivers water with a maximum temperature of 300°F (149°C) at a rate of 4500 gpm. The price of this pump was $24,900.

Heat Exchanger

The heat exchanger provides 20.38 MBtu/hr (5970 kw) of geothermal heat to the 200°F (93.3°C) circulating water at a rate of 4530 gpm (286 l/sec). The geothermal water was assumed to be at 220°F (104.4°C) prior to entering the heat exchanger. It was assumed that a constant 20°F (11.1°C) temperature difference would be maintained between the two fluids. Within the heat exchanger, an expected temperature drop of 9°F (5°C) and a required flow rate of 4530 gpm (286 l/sec) were predicted for the geothermal brine.

As stated previously, a flow rate of 5.02 gpm (0.32 l/sec) would be required to provide a home with its maximum heating load; for 557 homes, a pumping capacity of 2800 gpm (176.4 l/sec) would be required. The heat exchanger would have provided 16.77 MBtu/hr (4920 kw) of geothermal heat to the 160°F (71.1°C) heating water flowing at a rate of 2796 gpm (176.4 l/sec). Since the heat load during the winter would be smaller than that of the summer and the temperature difference would be much greater -60°F (33.3°C) vs. 20°F (11.1°C) a much smaller geothermal flow rate would be required during the winter. A flow rate of 2000 gpm (126 l/sec) could provide the necessary heat for winter heating.

In the process and power industries and related activities, many heat exchangers are purchased as off-the-shelf items, and selection is made on the basis of cost and specifications furnished by the various manufacturers. Since the Maryvale Terrace geothermal system was a more specialized application, a particular design was needed for the heat exchanger between the brine source and the absorption chiller. Therefore, the price of the heat exchanger had to be estimated.

Only heat exchangers that met the heat-transfer requirements were considered for selection. By forcing the fluids through the heat exchanger at higher velocities the overall heat-transfer coefficient was increased, but this higher velocity results in a larger pressure drop through the heat exchanger and higher pumping costs. If the surface area of the exchanger were increased, the overall heat-transfer coefficient, and hence the pressure drop, need not be so large.

The shell and tube counterflow heat exchanger was selected as the primary heat exchanger for the Maryvale Terrace geothermal system. An overall heat transfer coefficient was determined to be 264 Btu/ft$^2$/$^o$F (1500 w/m$^2$/$^o$C). For this counterflow heat exchanger, the log-mean temperature difference is 80$^o$F (26.7$^o$C). It was assumed that the average water velocity in the 2-in-ID tubes was 1.2 ft/sec, the calculated total flow area is 8.35 ft$^2$ for the brine flow rate. The number of tubes per pass is 383. The surface area is 0.393 ft$^2$/tube-ft.

Therefore, the computed length of tube for this exchanger is 49.67 ft. The final design choice is:

Number of tubes per pass = 383

Number of passes = 1

Length of tubes per pass = 49.67 ft

The primary heat exchanger was a standard shell and tube type with the brine inside the tubes. The scaling of the inside of the tubes due to the brine would need to be cleaned periodically by chemical means in the same manner that boilers are now cleaned. The price of this heat exchanger was estimated at $180,000.

## Water Treatment

Generally speaking, three symptoms of water-caused troubles were found.

The first was a reduction in heat transfer rate. In this case, the formation of an insulating deposit on a heat transfer surface generally reduced the cooling or heating capacity of the equipment. The second symptom is reduced water flow, which resulted from a partial or complete blockage of pipelines or other openings. The third symptom was damage to, or destruction of, the equipment. This may have resulted from corrosion of metals. It may also be caused by excessively rapid wear rates of moving parts such as pumps, shafts, or seals.

Since the Maryvale Terrace cooling equipment was similar to a system at the University of Arizona, the matter of water treatment could have been handled in the same way. A typical water treatment scheme for a large cooling tower system might include scale control by means of a controlled bleed and alkalinity reduction by automatic pH-controlled sulfuric acid feed combined with corrosion control. The latter was obtained by feeding a mixed inhibitor with a concentration on the order of 50 ppm, with an efficiency that would depend both upon the maintenance of pH within a very narrow range and on periodically controlled chlorination with chlorine gas for slime control. At the University of Arizona the chemicals needed for water treatment for the cooling tower and chilled water loop cost between $1,000 and $2,000 per year. The cost of water treatment for the Maryvale cooling system was estimated to be in the same range.

Production Well - Reinjection Well Piping System

A production well-reinjection well piping system was designed using the following assumptions as concrete data was unavailable. It was assumed that:

(a) each production well could produce 1000 gpm (63.1 l/sec) of 220°F (104.4 °C) geothermal brine and would be approximately 6000 ft (1800 m) deep.

(b) a minimum distance of 1320 ft (400 m) between production wells.

(c) each reinjection well could be approximately 4000 ft (1200 m) deep and could handle approximately 2200 gpm (70 l/sec).

(d) a minimum distance of 1320 ft (400 m) between reinjection wells.

(e) no minimum distance would be required between production wells and reinjection wells.

Five production wells and two reinjection wells were needed to supply the energy required to meet the maximum load. The well locations as proposed for this system are shown in Figure 6 and piping requirements are shown in Table 2.

Pumping for Well Piping System

The maximum power necessary to drive the geothermal brine through this system would be 109.4 kw, based on frictional losses and a pressure drop of 25 ft (7.6 m) across the heat exchanger. Elevation changes and pressurization were not considered in this computation.

TABLE 2: PIPE FOR MINIMUM PRODUCTION-REINJECTION WELL SYSTEM

| Diameter in | cm | Length ft | m |
|---|---|---|---|
| 6 | 16 | 3960 | 1207 |
| 8 | 21 | 1320 | 403 |
| 10 | 26 | 660 | 201 |
| 12 | 31 | 1320 | 403 |
| 16 | 41 | 330 | 101 |

The pipes from the production wells to the heat exchangers required insulation to reduce heat losses to 0.5 Btu/hr/ft$^2$ at 150$^o$F (1.58 w/m$^2$ at 66$^o$C).

Reinjection Well Pumps

The Peerless horizontal split case multi-stage pump was selected as the

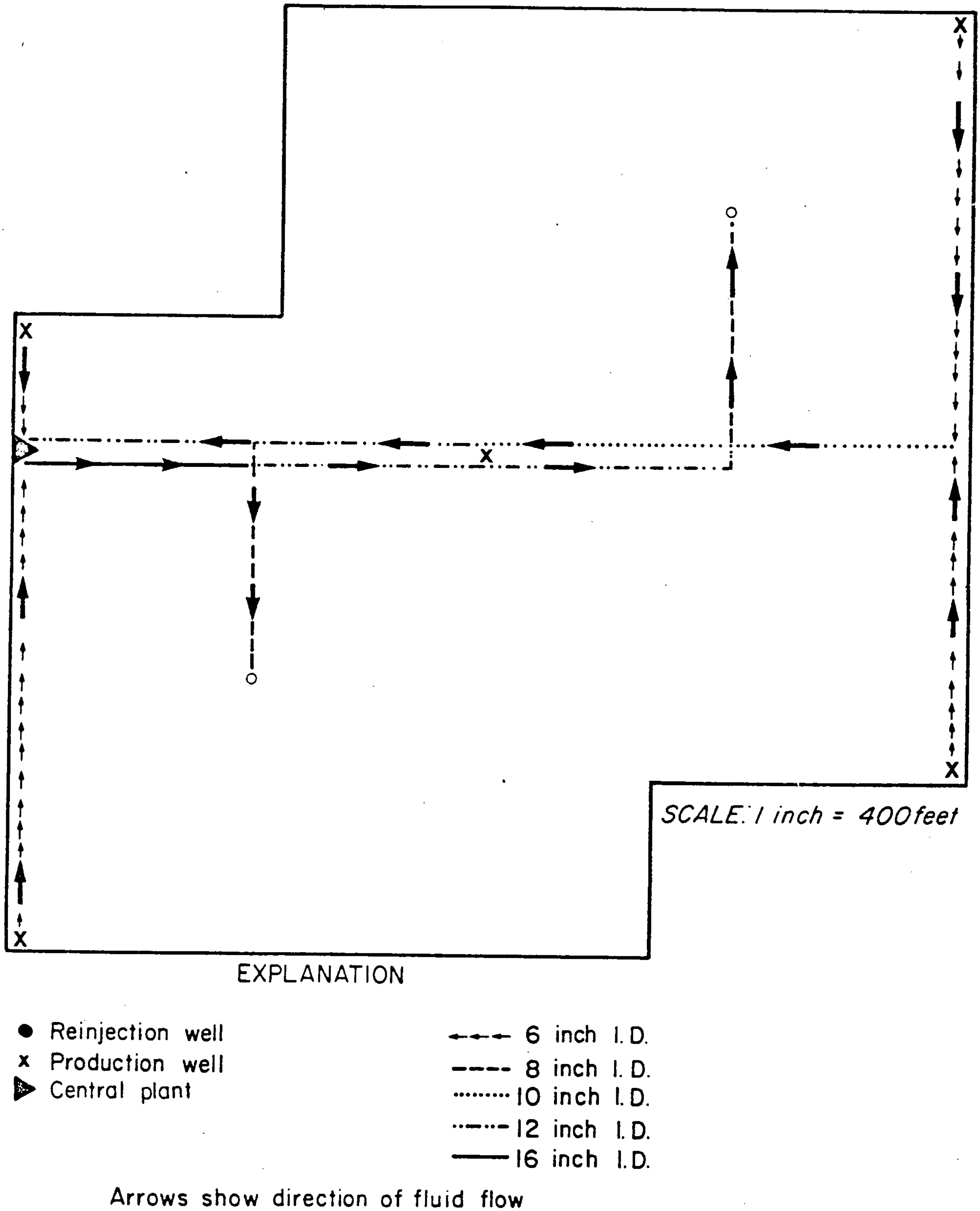



Figure 5: Production-Reinjection Well Piping System

reinjection pump. This pump was designed for water and clear liquids with temperatures as high as 300°F (149°C). One pump was required for each reinjection well. The price for the pump was $40,500.

Production Well Pumping

A variety of methods are available for providing geothermal fluids to an above-ground system. Artesian wells provide surface water naturally and some non-artesian wells can be induced to flow without pumping. However, wellhead pumps are necessary for non-flowing wells and are desirable for wells that are self flowing. An important advantage to pumping a self-flowing well is that pressure on the liquid is maintained, so downhole flashing and scaling are minimized. Also, by not allowing the fluid to flash, the pump discharge temperature can be much higher than the surface temperature of a self-flowing well.

Vertical turbine pumps have been used for many years in domestic and irrigation-water supply applications and have been successfully used in geothermal wells. Vertical turbine pumps increase fluid pressure by the centrifugal force imposed on a liquid by a shaft-driven impeller. Vertical turbine pumps are recommended for applications of the type described in this report.

The actual pumping requirement for the production wells was not directly computed as the expected pumping depth was not known. The only way to know the actual pump setting was to drill a well or infer a depth from similar wells in the area. Unfortunately, actual well data was not available in the Maryvale Terrace area. Rather, well conditions were assumed based on a reasonable expectation of well characteristics in Arizona. It is probable that such production wells would have required a 200 horsepower pump, which would have allowed for 100 feet of system head and a pumping depth of 700 feet. The assumption was made in order to estimate the capital cost for an adequate size pump and to estimate annual operating costs. A 200 horsepower pump manufactured by Johnston was estimated to cost $50,000.

Table 3 provides a summary of electrical power requirements for summer and winter operation.

TABLE 3. MAXIMUM ELECTRICAL POWER REQUIREMENTS
(all values in kw)

| Device | Summer | Winter |
|---|---|---|
| Central Air Handlers | 119.8 | ~100 |
| District Pumps | 236 | ~180 |
| Absorption Chillers | 30.6 | 0 |
| Cooling Tower | 153.2 | 0 |
| Circulation Pump | 82.4 | 0 |
| Well System Pumps | 109.4 | 50 |
| Production Well Pumps | 676 | 298 |
| TOTAL | 1,407.4 | ~628 |

## Deficiencies

All of the calculations in this report were based on average heating and cooling loads of 30,100 Btu/hr (8.8 kw) and 26,300 Btu/hr (7.7 kw) per home. If start-up capacities were not included in these values, this analysis must be considered inapplicable unless the load factor changes from 1.0 to act as a correction factor.

Example: If the average heating and cooling loads were increased by 25 percent, this analysis would still be considered correct if the load factor may be assumed to be $\frac{1}{1 + .25} = 0.8$ .

In practice, the larger-diameter pipe mains would have consisted of two smaller pipes to facilitate the hookup of the homes adjacent to them. The actual district pumping requirement was therefore a bit larger (up to 10 percent) more than the calculated value.

The decision to use a two-pipe system instead of a four-pipe system eliminated the potential energy savings of supplying both heating and cooling during the parts of the year when both are required. A four-pipe system could have supplied both hot and cold water and could also heat water for domestic purposes by means of a small water-to-water heat exchanger in every home.

No reserve capacity was supplied for the absorption chillers. Excess overdesign may have been obtained by the use of a load factor of 1.0 for this analysis.

PRELIMINARY ECONOMIC ANALYSIS

Table 4 presents a summary of the estimated costs to install a district heating and cooling system for Maryvale Terrace. The total system cost was estimated to be $5,081,300. It was assumed that the project was financed over 20 years at 16 percent interest. Annual debt service required a monthly payment of $70,694 or $848,328 per year.

In addition to debt service, annual operating and maintenance costs were estimated at one percent of the investment cost, or $50,813 per year. Operating costs were based on a commercial electrical rate of .045 cents per kilowatt hour. It was further assumed that the cooling system was at equivalent full load operation for 1000 hours and that the heating system was at equivalent full load operation for 350 hours during each year. Based upon these assumptions, the annual electrical cost for cooling was estimated to be $63,330 and for heating was $9,890. Table 5 summarizes the annual payments required for the operation of a geothermal district heating and cooling system. The total estimated cost for annual system operation was $974,361.

TABLE 4: CAPITAL COST SUMMARY

| ITEM | | COST |
|---|---|---|
| A. Wells and wellhead equipment | | |
| 1. Production well (5) @ $420,000 | $2,100,000 | |
| 2. Production well pump (5) @ $50,000 | 250,000 | |
| 3. Reinjection well (2) @ $280,000 | 560,000 | |
| 4. Reinjection well pump (2) @ $40,500 | 81,000 | |
| | Subtotal | $2,991,000 |
| B. Heat Exchanger and Cooling Unit | | |
| 1. Primary heat exchanger (1) @ $180,000 | $ 180,000 | |
| 2. Absorption chiller (2) $ $210,000 | 420,000 | |
| 3. Cooling tower (1) @ $80,000 | 80,000 | |
| 4. Circulating pump (2) @ $24,900 | 49,800 | |
| | Subtotal | $ 730,800 |
| C. District Piping and Pump | | |
| 1. District piping system | $ 571,000 | |
| 2. District pump (5) @ $24,000 | 124,500 | |
| | Subtotal | $ 695,500 |
| | TOTAL EQUIPMENT COSTS | $4,418,300 |
| D. Overhead Costs: | | |
| 1. Engineering (@ 10%) | $ 442,000 | |
| 2. Contingency (inflation @ 5%) | 221,000 | |
| | TOTAL COSTS | $ 5,079,300 |

| TABLE 5: SUMMARY OF ANNUAL COSTS | |
|---|---|
| Debt Service | $848,328 |
| Maintenance Costs | 50,813 |
| Cooling Electrical Cost | 63,330 |
| Water Treatment | 2,000 |
| Heating Electrical Cost | 9,890 |
| TOTAL | $974,351 |

Based on ASHRAE data, it was estimated that an average Phoenix home with gas heat and mechanical refrigeration spends approximately $1,145 per year for space heating and cooling. For the 557 homes in Maryvale Terrace, annual utility bills were estimated at $637,765 using conventional energy systems. In order for the geothermal developer to cover his annual costs, each homeowner was required to pay $1,750 per year for geothermal heating and cooling. Further, the cost of geothermal heating and cooling is estimated to be $47.50/MBtu including debt service. However, geothermal operating costs are calculated to be $6.14 per million Btu as compared to $15.55 per million Btu for conventional heating and cooling systems. The majority of the geothermal system expense is in the capital costs. The cost of the geothermal system, though saving fossil fuel energy, does not save the homeowner any money, nor does it provide a profitable alternative to conventional heating and cooling methods in todays energy market.

## PROMISING NEW TECHNOLOGIES

### Organic Rankine Cycles

A conventional vapor compression refrigeration machine, powered by a geothermally fired organic Rankine cycle, was being developed by the Barber Nicholas Engineering Co. of Arvada, Co. which uses R-11 as both the working fluid and the refrigerant. Preliminary tests of a 77-ton (271 kw) solar powered prototype were conducted at the Los Alamos Scientific Laboratory, National Security and Resources Center. During these tests, its overall C.O.P. was approximately that of LiBr - $H_2O$ absorption machines. It's major advantage is that it extracted 25 percent more energy per unit of mass of hot fluid, so that only 80 percent of the flow rate required by LiBr - $H_2O$ absorption machines was needed to provide the same amount of cooling.

Ammonium Nitrate-Water Absorption Refrigeration

In batch mode operation, this process has extracted 45 percent more energy per unit of mass of hot fluid and obtained a 19 percent larger C.O.P. than LiBr - $H_2O$ absorption refrigeration. Continuous operation of this process has not yet been achieved due to difficulties produced by the continuous crystallization and subsequent dissolving involved.

Heat Recovery for Heating, Ventilation and Air Conditioning (HVAC) Systems

Commercial and institutional buildings are usually provided with powered ventilation systems. Exhaust-conditioned air from inside a structure is replaced continuously with fresh outside air, which must then be treated to bring it within the design limits for temperature and humidity. The exchange of conditioned inside air for outside air requires a considerable expenditure of energy. Even in well-insulated buildings, ventilation losses of heat are proportionately larger than heat gains and losses through the building's exterior skin. Therefore, there are decisive economic advantages to be realized by providing some means of reclaiming the thermal energy in the conditioned exhaust air. Heat pipe heat exchangers are well suited for reclaiming such energy.

Wick design for heat pipes can be very simple since they can be gravity assisted, and consequently, made at lower cost. For example, if the purpose is to recover heat during the heat season, i.e., the season when the outside temperature is lower than the inside temperature, and heat pipes may be installed with the condenser end of the heat pipes (i.e., the outside air end) higher than the evaporator end of the heat pipes; the return of the condensate can then be assisted by gravity.

The same system can be used with slight modification for energy savings during the cooling season as well. This can be achieved by simply inverting the heat pipes so that during the cooling seasons the exhaust side of the heat pipe is higher than the end extending to the outside. Hence, the energy saving over the years may be considerable.

Heat Pumps

For heating and cooling purposes, heat pumps are being used quite successfully and efficiently (see specific report on cooling systems prepared on this project). Heat pumps are conventional vapor compression refrigeration machines which can drive heat from areas of lower temperature to areas of higher temperature. The C.O.P.'s of these machines increase as the difference between these two temperatures decreases.

If a source of water at 65-80$^{\circ}$F (18.3-26.6$^{\circ}$C) is available, the heat pump would be very appropriate to use in both the wintertime and summertime. In the wintertime, temperatures outside drop as much as 30$^{\circ}$F (16.7$^{\circ}$C) and therefore the efficiency of an air source heat pump drops significantly since it has to extract heat from a source with a temperature less than 70$^{\circ}$F (21.1$^{\circ}$C), the recommended space temperature. In the summertime the problem is reversed and the heat pump has to reject heat to high ambient temperatures which are quite often above 100$^{\circ}$F (37.8$^{\circ}$C). Thus, the heat pump becomes less efficient at times when one requires more heating or cooling. Therefore, a constant temperature source of water in the range of 65-80$^{\circ}$F (18.3-26.6$^{\circ}$C) serving as a heat source in the wintertime and a heat sink in the summertime would make the system more efficient. In addition, constant heating or cooling output would be provided and smaller heat pumps would be required.

## CONCLUSION

The application of geothermal energy has been successful for centuries in a few areas. Now, with the ever-escalating price of fossil fuel energy resources, geothermal energy is becoming an important energy resource. Generally speaking, for a system like the Maryvale Terrace heating and cooling system, technical problems can be solved by applying solutions achieved through previous experience in conventional heating and cooling systems. In other words, the Maryvale Terrace geothermal heating and cooling system is similar to many conventional water heating and absorption cooling systems, with the only exception being the heat source. Attention should be focused not only on the system's design, but also on the economical comparison between the Maryvale Terrace geothermal system costs and conventional heating and cooling costs.

Research done on the Maryvale Terrace geothermal system shows promise as a technically feasible project which has the capacity to replace nonrenewable energy sources with geothermal energy. The dominating factors in a geothermal heating and cooling system are the drilling costs, the annual load factor and the capital investment. On the other hand, water quality, site location and pumping depth are other factors which influence the cost of a geothermal system. As technology develops to reduce drilling costs and handle water with corrosive properties, the influence of the factors mentioned above will change. Although the Maryvale Terrace geothermal heating and cooling system currently appears to be uneconomic, it may prove to be well worth the investment at some future time.

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Peerless Pump Company, Phoenix, Arizona
Trane Corporation, Tucson, Arizona office

ADDITIONAL RELATED REPORTS

The following fifteen reports were prepared by the Evaluation of geothermal Utilization group:


1. Goldstone, L.A. and White, D.H., 1982, Geothermal Development Plan: Maricopa County, prepared for the U.S. Department of Energy, Contract No. DE-FC03-80RA50076 and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 79-8.

2. Goldstone, L.A. and White, D.H., 1982, Geothermal Development Plan: Pima County, prepared for the U.S. Department of Energy, Contract No. DE-FC03-80RA50076 and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 79-9.

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Other related reports include the following:

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Open-File reports can be obtained by writing to:

State of Arizona Bureau of Geology
845 N. Park Avenue
Tucson, Arizona 85719

or to

Arizona Solar Energy Commission
1700 W. Washington, Room 502
Phoenix, AZ 85007

In addition, reports prepared for the U.S. Department of Energy can be obtained by contract number from

U.S. Department of Energy
Technical Information Cneter
P.O. Box 62
Oak Ridge, TN 37830

## GLOSSARY OF GEOLOGICAL TERMS

Anomalously shallow depth - unusually or unexpectedly shallow depth.

Basin-range graben bound by deep faults - an area usually ten to hundreds of $km^2$ in area that has been down dropped along deep faults relative to the surrounding mountains; the grabens become filled with sediments to become valleys.

Curie-depth - the depth at which rocks become hot enough to lose their magnetic properties, ~ 525°C. Curie temperature within 5-10 km of the surface are an indicator of geothermal resource potential.

Deep circulation - the natural movement or flow of ground water, as a result of convection, whereby it descends and becomes heated at depth and then rises toward the surface.

Deep sediment-filled, faulted basin - see basin - range graben.

Depth of Curie-isotherm analysis - technique used to estimate depth to the Curie temperature.

Hot dry rock production - a method for extracting useful heat in a deep dry hole; accomplished by fracturing the hot rock between two deep holes, and pumping cold fluid into one and bringing hot fluid out of the other.

Geothermometer - an empirical formula, based on the temperature-dependent solubility of certain minerals, used for estimating deep fluid temperatures in a geothermal reservoir.

Magnetotelluric survey - an electromagnetic method in which natural electric and magnetic fields are measured. Models of the crust can then be constructed and resistivities at great depth can be predicted.

Major range bounding faults - fractures or fracture zones along which mountains have risen relative to down dropped grabens.

Shallow magmatic intrusion - a body of magma that has intruded its way upward into shallower crust.

Na-K-Ca geothermometer -- (also, quartz geothermometer, chalcedony geothermometer) - see geothermometer.

Tectonic history - the cycle that relates the larger structural features of the Earth's crust to gross crustal movements and to the kinds of rocks that form in the various stages of developments of these features.