UTILIZATION OF GEOTHERMAL ENERGY WITH AN EMPHASIS ON HEAT PUMPS

by

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Abstract

While there are uses for low temperature (≤120 degrees Fahrenheit) geothermal sources for space heating and other relatively low temperature applications, many commercial users and industries require higher temperatures. These higher temperatures (140 degrees to 220 degrees Fahrenheit) are obtainable through supplementary heating using oil, gas or electricity; however, the cost is high particularly where direct electric heating is used. Since 1975 low temperature waste heat sources (such as water normally cooled in cooling towers) have increasingly been used in conjunction with heat pumps for hot water production and space heating. This same concept can be applied to a low temperature geothermal source to amplify the temperature to a usable value or amplify the amount of energy that can be usefully extracted from a limited geothermal resource.

There is a high level of interest in the application of industrial water-to-water heat pumps for use with geothermal water in the 60 degrees to 120 degrees Fahrenheit range, considered available from wells less than 3000 feet deep. The heat in this water can then be temperature amplified to increase the deliverable temperature by as much as 80 degrees to 90 degrees Fahrenheit. The heat pump can be economically used either a) to upgrade a geothermal resource already obtained where the flow and/or temperature are insufficient to meet the utilization needs, or b) as an alternative to drilling much deeper wells to obtain needed higher use temperatures.

Background

The economy of the United States is based on a high consumption of energy; and, therefore, we are one of the countries most affected by the fast changing global energy situation. We are not, as a country, energy deficient as ample reserves of coal, oil shale and geothermal energy have been proven. However, the development of these resources has been delayed for a number of reasons. Relative to geothermal, two of the most important reasons are. . . 1) the economics of recovery, distribution and use in the face of today's relatively low gas and oil costs, and 2) geothermal is not broadly appreciated by many design engineers. These alternate sources of energy must be developed, to both lessen the negative balance of payment impact between the United States and the OPEC countries, and to reduce this country's dependence on foreign oil.

There are considerable geothermal resources in the United States which could be developed and become a significant part of the total energy supply. It is to the advantage of the United States to rapidly develop geothermal resources in a manner consistent with the overall protection of the environment.

While geothermal reservoir temperatures can range quite high, this discussion is oriented to those that are more commonly considered available. Most geothermal sources have base temperatures below 300 degrees Fahrenheit, which is the current threshold temperature for economic electrical power generation. Of identified western United States natural heat sources (hot springs, fumaroles, etc.), approximately 85 percent have base temperatures less than 300 degrees Fahrenheit. Additionally, in the eastern United States there appear to be numerous, but not yet identified, low-temperature heat sources.

Water Temperature Versus Well Depth

The temperature gradient will vary by location; however, some reasonable assumptions can be made to examine the order of magnitude of the economic alternatives. A number of test sites (1) have indicated an average temperature increase of 1 degree Fahrenheit/100 feet. Preliminary test drilling at a Maryland site (2) is indicating an increase in geothermal temperature of $2\frac{1}{2}$ degrees Fahrenheit/100 feet of well depth. These two ranges of temperature gratient are plotted in figure 1. For purposes of further analysis, a reasonable mean of $1\frac{1}{2}$ degrees Fahrenheit is used and plotted in figure 1 using the formula:

$$T = 55 + 0.015\ Z$$

where T = °F and Z = depth in feet.

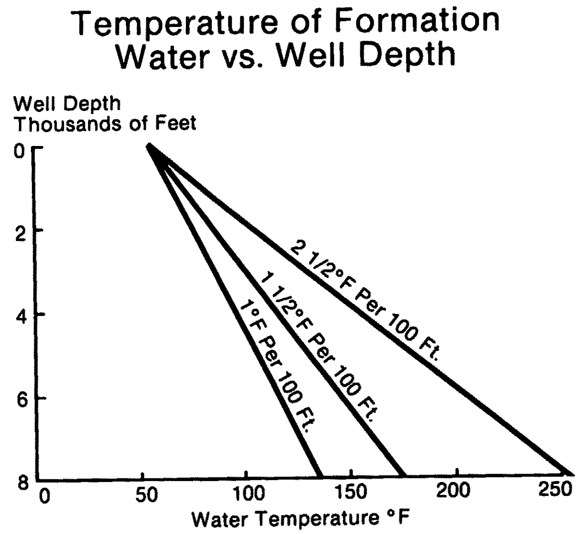

Figure 1.

Use Temperature

For extensive direct use in industrial process heat applications and most large space heating uses, the required hot water temperatures range upward from 135 degrees Fahrenheit. Using the Figure 1 correlation, this indicates a well depth requirement in excess of 5000 feet for direct use.

To provide the 150 degrees Fahrenheit hot water extensively used in the food processing and metal fabricating industries, the indicated well depth would be over 6000 feet. The cost of drilling wells to these depths could be prohibitive considering the present (and even the ten-year projected) cost of conventional energy uses to heat process water and to supply space heating.

Temperature Amplification

Recent developments in the area of high temperature heat pumps represent a potentially attractive alternative to the deeper wells through temperature amplification of the geothermal source by electric heat pumps. Where the geothermal flow is limited, considerable cooling can be accomplished, thus, extracting many more Btu's from the geothermal water.

Using the nonreversible heat pump principle, the industrial heat pump recovers low grade heat in geothermal water in the temperature range of 60 degrees Fahrenheit to 120 degrees Fahrenheit and amplifies it to higher, usable temperature levels. The heat from the geothermal water is absorbed in the heat pump evaporator by the unit's working fluid which is then increased in temperature and pressure by the compressor. From here it goes to the condenser where this heat is transferred to a delivery fluid for providing useful heat at temperatures up to 230 degrees Fahrenheit, with this 230 degrees Fahrenheit upper limit being the current state of the art.

The cycle diagram for such a system is shown in Figure 2.

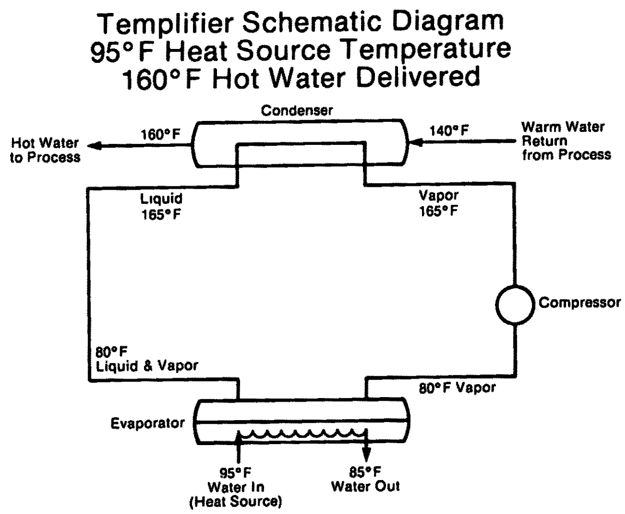

Figure 2

The measure of efficiency, called the coefficient of performance (COP), of such devices currently available from Westinghouse Electric Corporation is shown in Figure 3. The ratio of the thermal equivalent of the Westinghouse Templifier (R) heat pump electrical input to the upgraded heat output (the COP) ranges from roughly three to six. For example, 150 degrees Fahrenheit hot process water stream can be delivered from a 95 degrees Fahrenheit geothermal source cooled 10 degrees Fahrenheit (or a 105 degrees Fahrenheit source cooled 20 degrees Fahrenheit, etc.) with a COP of about 4.5.

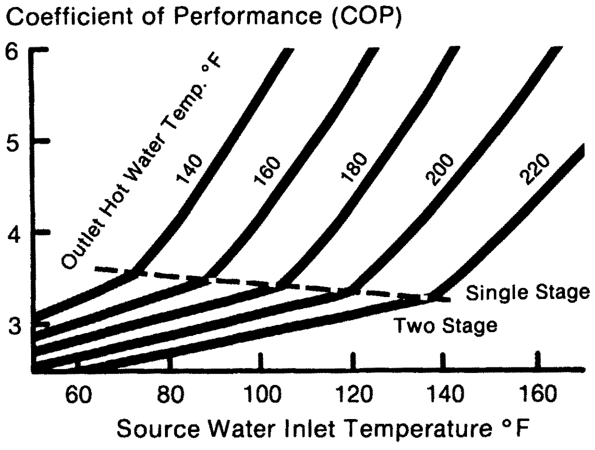

Figure 3

Usually temperature amplification is utilized in a range up to 80 degrees to 90 degrees Fahrenheit (output hot water minus leaving geothermal water) where a COP of about 3.5 is obtained. A COP of less than 3.0 is not normally used as the economics are not usually sufficiently favorable.

By applying Templifiers to the process, usable water temperatures for source heat can be obtained at well depths 2000 feet (85 degrees Fahrenheit) to 3000 feet (100 degrees Fahrenheit) and the captured heat temperature amplified to the higher use temperature.

Temperature Amplified Low Grade Heat-Closed Loop System

The objective in this example is to provide 450 gpm of 165 degrees Fahrenheit supply hot water to meet a 2.2 million Btuh heating load in a closed loop where the return hot water is 155 degrees Fahrenheit; a closed loop system being one in which the hot water is cooled by the load and then returned for reheating.

If we consider that the properties of the geothermal water are such that it should be used through a water-to-water heat exchanger to generate 165 degrees Fahrenheit fresh water to the load, in a conventional geothermal system the producing well temperature would have to deliver at least 170 degrees Fahrenheit at a 450 gpm flow rate. From Figure 1 this would require a well depth at mean gradient of approximately 7,700 feet.

A simplified example of the use of the heat pump process is shown in Figure 4. By the use of the Templifier heat pump, a more shallow well of about 3000 feet in depth could produce 100 degrees Fahrenheit water. If we take out 10 degrees Fahrenheit of heat, a flow of only 325 gpm is required to transfer 1.6 million Btuh to a 95 degrees Fahrenheit fresh water stream to supply the Templifier heat pump. Alternatively, if higher temperatures are available, lower gpm flows would be needed: 110 gpm at 120 degrees Fahrenheit or 55 gpm at 150 degrees Fahrenheit supply temperature. Or, if both higher flows and temperatures are available, a larger Btu per hour heating load could be served.

Schematic Diagram of Use of Low - Grade Geothermal Energy Temperature - Amplified for 165°F Heating Load

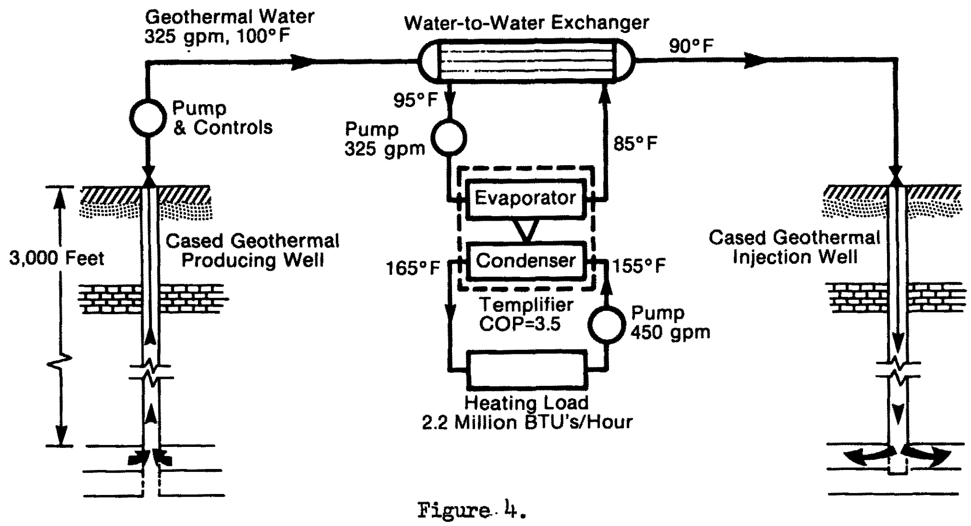

Figure. 4.

Typically, such a heat pump, with 85 degrees Fahrenheit water leaving the evaporator, will produce 165 degrees Fahrenheit hot water at a 3.5 COP. Allowing for system losses, this 1.6 million Btuh of geothermal source heat will produce the required 2.2 million Btuh for the utilization load. The Btuh difference coming from the 184 kw per hour electrical input to the heat pump.

Thus, a 3000 foot deep well delivering 325 gpm of 100 degrees Fahrenheit water plus the Templifier heat pump will meet a load that would otherwise require a 7,700 foot deep well producing 450 gpm calculated as follows:

$$\text{gpm} = \frac{2.2 \times 10^6 \text{ Btuh Load}}{10^\circ\text{F range} \times 8.15 \text{ lbs/gal} \ @\ 165^\circ\text{F} \times 60 \text{ min/hr}} = 450$$

System Design - Open Loop System

An open loop system is one where incoming feed water is heated through a relatively high temperature range and then supplied to the process load and consumed or not returned for other reasons. Such an open loop system, where the incoming water to be heated is at a temperature below the geothermal source temperature, offers significant additional opportunities.

To get the most energy out of the geothermal source with the least electrical input to the heat pump, it is necessary to transfer as much heat as possible directly by means of a heat exchanger. The remaining temperature amplification can then be provided through use of a heat pump. As the geothermal source may be in limited supply, it is desirable to drop its temperature as low as possible to maximize the energy extracted from the source. If we are to heat an incoming low temperature return or feed water supply at temperature (Tu, in) to the use level desired (Tu, out,) the geothermal source at temperature (Tg, in) is then cooled to (Tg, out) to achieve a heat balance.

Working with Westinghouse, a study (3) of several potential system designs has been conducted at the Johns Hopkins University Applied Physics Laboratory.

The five systems considered are shown in Figure 5, each using an incoming feed water temperature (Tu, in) of 60 degrees Fahrenheit and a geothermal discharge temperature (Tg, out) of 70 degrees Fahrenheit for comparison.

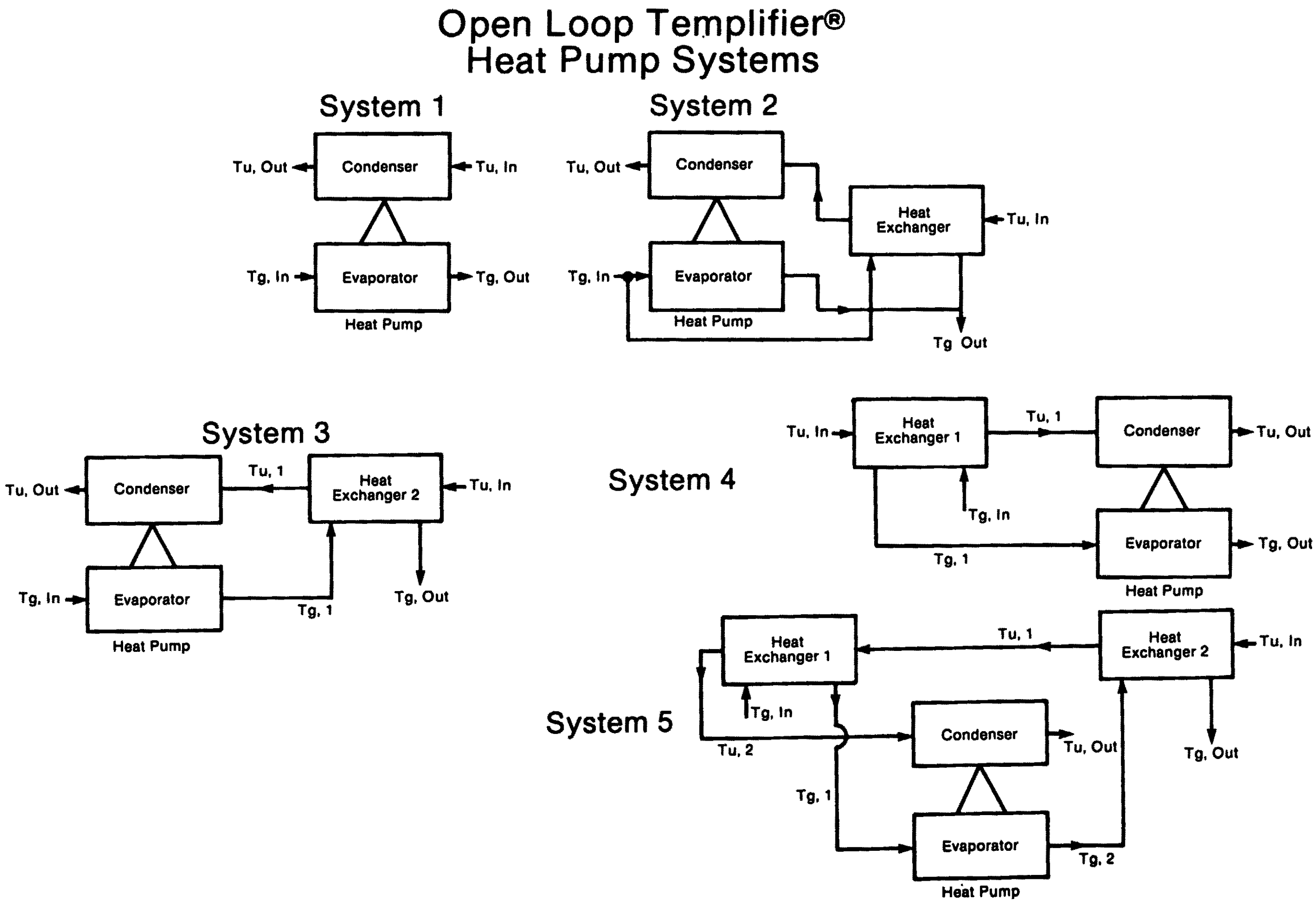

Figure 5

Using COP performance derived from Figure 3 and a heat exchanger effectiveness of 0.90 (a reasonable compromise between heat exchanger cost and performance), the systems were examined at the above selected conditions.

The operating characteristics of Systems 1 and 2 show less efficiency than Systems 3, 4 or 5 except at very low source temperatures. For System 1, all of the temperature lift must be supplied by the Templifier (R) heat pump. At very low geothermal source temperatures this incurs little penalty; however, at high geothermal source temperatures the penalty can be severe unless the geothermal supply is quite limited compared to the required hot water heat load. A similar situation exists for System 2 since in order to fully extract the energy from the source, the heat pump again is providing most of the temperature amplification.

Considering the cost of electric power, a critical operating parameter is the amount of power required to deliver a specific amount of energy (kw-hr/10^6 BTU).

Taking a geothermal inlet temperature, (Tg, in) of 120 degrees and a delivery (use) temperature, (Tu, out) of 160 degrees Fahrenheit, the results enable us to compare the energy efficiency of the systems as shown in Table 1.

Table 1
Heat Pump/Heat Exchanger Open Loop Systems

System	kw-hr/ 10^6 BTU	System COP	Wg gpm/ 10^6 BTU
1	88.4	3.3	27.9
3	60.8	4.8	31.7
4	40.7	7.2	34.5
5	35.0	8.4	35.2

It is seen that Systems 4 and 5 are better than 3 by almost a factor of two and are $2\frac{1}{2}$ times better than System 1. As electrical energy per million BTU is not the only consideration, a comparison of the source requirements of the three systems shows that System 5 also requires only a small increase in the flow of geothermal water (11% more than System 3 and 26% more than System 1). The cost of the additional heat exchangers required in System 5 is small compared to the heat pump cost. Thus with similar capital costs and lower energy costs the preferred system is number 5.

Keep in mind these are for the specific conditions stated previously and for large centrifugal Templifier heat pumps having COP's approximated by Figure 3. For analysis of other conditions for System 1, 3, 4 and 5, magnetic cards for a TI59 programmable computer have been developed in which the inputs are (Tu, in); (Tu, out); (Tg, in); Wu (use water flow gpm), E (heat exchanger effectiveness) either Wg (geothermal flow gpm) or (Tg, out) (outlet geothermal water temperature).

The computer then outputs the optimum various cycle point temperatures and heat flows (Btuh) as well as the heat pump and overall system COP and the heat pump KW. The program also can adjust for the heat pump COP factor (C).

From this information the installed cost of the Templifier and heat exchangers can be estimated and an economic evaluation made of the geothermal heat pump system versus a geothermal - boiler system or against today's conventional systems.

Another computer program is available from Westinghouse to simplify these financial analyses and output net cash flow, present value of cash flow and return on investment over a ten-year operating cycle, taking into account such important elements as the relative investment, load factor, cost of capital, maintenance, tax rates, incentive tax credits and projected energy cost escalation.

Economics - Closed Loop System

In the example shown in Figure 4, a rough order estimate of the economics can be made by making several assumptions. For specific situations, these assumptions can be varied to suit, and the results recalculated using your numbers.

The nature of the geologic formation, diameter and depth are all contributors to well costs. For this analysis we will assume a 3000 foot well delivering 325 gpm can be completed for $50 per foot; while a 7700 foot well depth for 450 gpm will cost $65 per foot; and that the injection well (if used) will be identical to the producing well. Further, that electric power costs 3¢ per kilowatt-hour and efficiencies are 60 percent for the pump and 90 percent for the driving motor. Finally, the process heating load occurs for 4000 hours per year - a typical two shift industrial operation.

The incremental pumping costs between 325 gpm from a 3000 foot well and 450 gpm from a 7700 foot well is computed to be 870 kwh per well at an annual pumping cost of $104,400 (=870 kw/h x 4000 hr/yr x $.03/kwh).

The Templifier heat pump annual operating cost calculates at $22,100 (=184 kw/h x 4000 hr/yr x $.03/kwh). The required evaporator pump operation is estimated with a 50 foot head at $700.

From this data Table 2 is constructed which demonstrates the economic opportunity for significant savings in both the first cost and in the annual operating cost.

Table 2 - Economic Analysis; Closed Loop System

2,200 Mbh Load:	Geothermal/Heat Pump		Geothermal Only	
450 gpm, 165 degrees Fahrenheit	325 gpm, 3000 Foot Well		450 gpm, 7700 Foot Well	
Delivery Hot Water	Injection Well		Injection Well	
Capital Cost	With	Without	With	Without
Producing Well	$150,000	$150,000	$500,500	$500,500
Injection Well	150,000	0	500,500	0
Templifier installed*	85,000	85,000	-	-
Total	$385,000	$235,000	$1,001,000	$500,500
Incremental First Cost Saving	$625,000	$265,500	-	-
Incremental Annual Operating Cost				
Producing Well	$ 0	$ 0	$104,000	$104,000
Injection Well	0	0	104,000	0
Templifier Heat Pump	22,100	22,100	-	-
Templifier Evap. Pump	700	700	-	-
Total	$ 22,800	$ 22,800	$208,000	$104,000
Incremental Operating Cost Saving	$185,200	$ 81,200	-	-

* Includes Templifier heat pump, evaporator water pump and associated piping system on an installed basis.

Economics - Open Loop System

In an open loop system the incoming water can be heated through a heat exchanger, extracting the most heat it can from the geothermally heated source. Then the remaining heat can be supplied by a boiler to achieve the desired discharge temperature. The arrangement would be similar to System 3, except substituting a boiler for the heat pump condenser. This can then be compared to a geothermal heat pump system.

For a typical analysis let's assume the 4000 hour per year load requires heating 100 gpm of water from 60 degrees Fahrenheit to the use temperature of 160 degrees Fahrenheit; equivalent to 5 million Btu per hour. Additionally, assume we have a resource of 176 gpm of 120 degrees Fahrenheit geothermal source water of a quality that can be utilized directly; electricity cost is 3¢ per kwh With a 5 degrees Fahrenheit approach in the heat exchanger, the incoming water can be preheated to 115 degrees Fahrenheit before going to the boiler or the heat pump.

Table 3 shows the computer program output for both the System 3 and 5 arrangement. When the boiler is used (instead of the heat pump) in the System 3 arrangement, the boiler must supply Qu or the 2.25 million Btu per hour otherwise supplied by the heat pump.

Table 3 - Geothermal Heat Pump System Computer Program Output

System 5		System 3	
User Side		**User Side**	
60.0	TIN	60.0	TIN
115.0	T1	115.0	T1
78.5	T2	60.0	T2
160.0	TOUT	160.0	TOUT
100.	GPM	100.	GPM
5,000,000.	QT	5,000,000.	QT
GEO Side		**GEO Side**	
120.0	TIN	120.0	TIN
99.3	T1	88.8	T1
80.6	T2	70.8	T2
70.1	TOUT	70.8	TOUT
176.	GPM	176.	GPM
4,392,960.	QT	4,326,080.	QT
Heat Exchanger		**Heat Exchanger**	
0.88	EFF1	0.92	EFF1
1,823,500.	Q1	2,750,000.	Q1
0.90	EFF2	0.	EFF2
928,000.	Q2	0.	Q2
Heat Pump		**Heat Pump**	
0.53	HPC	0.53	HPC
2,248,500.	QU	2,250,000.	QU
1,641,806.	QG	1,576,443.	QG
177.76	KW	197.35	KW
3.71	COP	3.34	COP
8.24	COP Total	7.42	COP Total

With this data, plus some reasonable estimates on incremental installed first cost, Table 4 can be constructed giving a rough-order comparison of geothermal heat pump systems compared to a geothermal boiler system.

Table 4 - Economic Analysis, Open Loop System

	Geothermal/Heat Pump		Geothermal/Boiler
	System 5	System 3	System 3
Capital Cost			
Heat Exchanger 1	$ 7,000	$ 9,000	$ 9,000
Heat Exchanger 2	8,000	-	-
Boiler Installed	-	-	25,000
Templifier Installed	85,000	85,000	-
Total	$100,000	$ 94,000	$ 34,000
Incremental First Cost Addition	$ 66,000	$ 60,000	-
Incremental Annual Operating Cost			
Templifier	$ 21,300	$ 23,700	-
Electric Boiler	-	-	$ 79,100
Incremental Saving	$ 57,800	$ 55,400	-

If these results are then fed into the Westinghouse economic analysis program, and we assume inflation at 7 percent and electricity escalation at 10 percent per year, together with the 46 percent corporate tax rate, 20 percent investment tax credit and a 10 percent cost of capital we find over a 10-year operating cycle - the results shown in Table 5.

Table 5 - Ten Year Economic Comparison Open Loop System

Geothermal Heat Pump Versus Geothermal Boiler System

	System 5	System 3
Added First Cost	$ 66,000	$ 60,000
Annual Operating Cost Saving at Current Cost	57,800	55,400
Energy Saved per Year	1.93×10^6 kwh	1.85×10^6 kwh
Project Net Cash Flow	$499,000	$480,000
Present Value of Cash Flow	$279,500	$270,000
Return on Investment	118%	127%

From this it can be concluded that, in this case, the geothermal heat pump system 3 is the economically preferable investment that gives the greatest financial return (ROI) of the geothermal alternative, while system 5 saves the most energy and generates the highest cash flow. In both cases the heat pump application pays for itself in just over one year.

Other Economic Considerations

Other economic aspects which have not been considered here include development and depletion allowances. According to the Internal Revenue Service(4), an operator developing geothermal properties may either deduct as expenses or charge to the capital account all intangible drilling and development costs incurred on wells begun after September 1978.

Additionally, geothermal deposits qualify for percentage depletion. The applicable percentage through 1980 is 22 percent, decreasing by 2 percent yearly through 1983. After that the rate is 15 percent.

Other Application Considerations

Some of the additional considerations in this application are items such as--

a. In areas with limited geothermal water, expended water may have to be reinjected into the aquifer from which it came to maintain formation pressures to prevent aquifer collapse with loss of permeability and to prevent depletion.

b. Investigations will be needed to prevent low temperature mineral precipitation in the aquifer that would plug the aquifer; how to screen out sediment from the water that would foul the heat exchangers and plug the aquifer.

c. The prevention of scale within the heat exchanger and the Templifier heat pump evaporator itself must be solved, for most geothermal water carries relatively high mineral content compared with surface water. This mineral tends to form scale as soon as the water temperature is lowered. In some cases a separate closed fresh water loop may be needed to facilitate and minimize maintenance, as illustrated in Figure 4.

d. Experience has indicated that at least the supply well should be drilled and tested before completing the system design.

e. In some cases the system can be designed to use the geothermal water as a heat sink for summer cooling and as the heat supply for winter heating.

Additionally, other aspects need to be examined for geothermal to take its potential place in the nation's energy supply, and work is proceeding on this through the Geothermal Resources Council and Geo-Heat Utilization Center.

Summary

With the growing need to utilize our geothermal resources to displace imported oil and gas with their rapidly rising costs and decreasing availability, it appears the geothermal heat pump system has an economic application for furnishing up to 230 degrees Fahrenheit hot water for process heat, space heat and service hot water in commerce and industry.

References

(1) Muffler and others, Assessment of United States Geothermal Resources - 1978, Geological Survey Circular 790.

(2) Eric A. Peterson, Dept. of Energy, Washington, D. C., private communication 1/30/79.

(3) C. A. Wingate, Jr., "Heat Pump System Design Charts for Geothermal Heat Pump Selection," Johns Hopkins University Applied Physics Laboratory, Report S4S-2-280 (September 1978).

(4) Internal Revenue Service, Publication 553, 1979 edition.