GL03959

TREE-1182

RESIDENTIAL SPACE HEATING COST: GEOTHERMAL VS CONVENTIONAL SYSTEMS

I.A. ENGEN

February 1978

EG&G Idaho, Inc.

IDAHO NATIONAL ENGINEERING LABORATORY

DEPARTMENT OF ENERGY

IDAHO OPERATIONS OFFICE UNDER CONTRACT EY-76-C-07-1570

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161
Price: Printed Copy $4.50; Microfiche $3.00

TREE-1182 - RESIDENTIAL SPACE HEATING COST:

GEOTHERMAL VS CONVENTIONAL SYSTEMS

APPROVED:

W. D. Gertsch
Manager, Geothermal Direct Applications

R. J. Schultz
Manager, Program Management
and
Technology Transfer

TREE-1182

DISTRIBUTED UNDER CATEGORY:
UC-66g
Geothermal Energy
TID-4500, R66

RESIDENTIAL SPACE HEATING COST:

GEOTHERMAL VS CONVENTIONAL SYSTEMS

EG&G Idaho, Inc.

IDAHO NATIONAL ENGINEERING LABORATORY

Idaho Falls, Idaho 83401

I. A. Engen

Date Published -- February 1978

PREPARED FOR THE DEPARTMENT OF ENERGY

DIVISION OF GEOTHERMAL ENERGY AND IDAHO OPERATIONS OFFICE

UNDER CONTRACT NO. EY-76-C-07-1570

ACKNOWLEDGMENTS

L. E. Donovan and J. G. Keller provided information and suggested improvements. Their aid is greatly appreciated.

ABSTRACT

This report analyzes the operating characteristics and economies of several representative space heating systems. The analysis techniques used in this report may be applied to a larger variety of systems than considered herein, thereby making this document more useful to the residential developer, heating and ventilating contractor, or homeowner considering geothermal space heating. These analyses are based on the use of geothermal water at temperatures as low as 120°F in forced air systems and 140°F in baseboard convection and radiant floor panel systems.

This investigation indicates the baseboard convection system is likely to be the most economical type of geothermal space heating system when geothermal water of at least 140°F is available. Heat pumps utilizing water near 70°F, with negligible water costs, are economically feasible and they are particularly attractive when space cooling is included in system designs.

Generally, procurement and installation costs for similar geothermal and conventional space heating systems are about equal, so geothermal space heating is cost competitive when the unit cost of geothermal energy is less than or equal to the unit cost of conventional energy. Guides are provided for estimating the unit cost of geothermal energy for cases where a geothermal resource is known to exist but has not been developed for use in residential space heating.

TABLE OF CONTENTS

FIGURES

TABLES

1.0 INTRODUCTION

Increased interest in the use of geothermal energy for residential space heating, due to recent escalation in fossil fuel costs, will lead to greater use of relatively abundant low-temperature (< 200°F) geothermal resources, provided that the economics are attractive. Relative costs for geothermal and conventional electric, natural gas, and oil fired forced air, convection and radiant floor slab residential space heating systems and factors affecting the cost of geothermal energy are examined in this report.

Due to the wide variety of operating, economic, and geothermal resource conditions which may be encountered, representative space heating systems and a representative set of operating conditions were chosen for investigation, assuming geothermal water temperatures as high as 180°F. Section Five of this report suggests methods for estimating preliminary economic feasibility at locations where an undeveloped geothermal resource is known to exist.

The following definitions are used to typify design operating conditions:

Inside Design Temperature	T	=	65°F
Outside Design Temperature	T_o	=	Local outside design temperature, °F
Design Temperature Difference	DT	=	$T - T_o$
Degree Heating Days	DD	=	One Fahrenheit degree heating day is accrued for each degree that daily mean temperatures are below 65°F
Annual Degree Days	ADD	=	Degree heating days per year
Annual Heat Load Factor	F	=	$ADD/365(T - T_o)$
Annual Operating Hours	OH	=	F x 365 x 24

It is convenient to define a residential unit to be an 1800 ft^2, rectangular, single-floor heated space. Typical heat loads for several classes of construction can then be defined as follows:

Construction Class ($1800\ ft^2$)	Design Heat Load (Btu/hr)	Annual Heat Load (Btu)
Best Energy Efficiency	DT x 500	ADD x 12,000
Average Energy Efficiency	DT x 800	ADD x 19,200
Average Residence	DT x 1200	ADD x 28,800
Poor Energy Efficiency	DT x 2000	ADD x 48,000

For heating system comparison, assume climate similar to Salt Lake City, Utah or Boise, Idaho as follows:

Design Temperature Difference	DT = 70°F
Annual Degree Days	ADD = 6,000

then

Annual Heat Load Factor	$F = 6{,}000/(365 \times 70) \sim 0.235$
Annual Operating Hours	$OH = 0.235 \times 365 \times 24 \sim 2059$

For the previously defined average energy efficient construction, the design heat load is 56,000 Btu/hr (70°F x 800 Btu/hr °F), and the annual heat load is about 1.152×10^8 Btu (6000 Degree Days x 19,200 Btu/Degree Day).

All units of measurement is this report are given in the English system, because applicable equipment and material specifications are not generally available in SI units. SI conversions are given below:

Temperature, °C	=	$(°F - 32) \times \frac{5}{9}$
Length, cm	=	in. x 2.54
m	=	cm x 0.01
Flow rate, l/s	=	gal/min x 0.063088
Heat rate, cal/hr	=	Btu/hr x 251.98
cal/sec	=	Btu/hr x 0.07

2.0 RESIDENTIAL SPACE HEATING SYSTEMS

In areas of the United States with significant heating requirements the most widely used residential space heating systems are forced air, circulating water, and radiant electric resistance. The use of electric resistance radiant heating designs has been restricted in California recently due to the inefficiency inherent in conversion of heat energy to electricity and then back to heat energy. Whether or not such restrictions will spread to other areas remains to be seen. In any event, forced air and circulating water residential heating systems will remain popular for the foreseeable future.

Design and equipment requirements of the systems considered here differ chiefly due to the different modes of transmitting heat to the conditioned space. Forced air systems transport heated air through distribution ductwork to diffusers, usually located along outside walls. Recent design innovations replace the distribution ductwork with a large plenum in the crawl space, so that the floor becomes a radiating surface that provides the comfort of electric radiant heat. Hydronic systems usually distribute heated water to baseboard convectors similarly located along outside walls, or through heating coils installed in a concrete slab floor. Typically, the installed cost of the furnace or boiler employed in these systems represents significantly less than half the total heating system cost. Air conditioning, filtration, and humidity control can readily be incorporated in a forced air system as part of either the initial design or a later retrofit. Hydronic systems, however, lack this incorporation feature. The design and size of the heating system components presented here appear in handbooks and manuals of the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), reference 1, the National Environmental Systems Contractors Association (NESCA), reference 2, and in materials available from many of the manufacturers of space heating equipment.

Geothermal Residential Space Heating

Forced air and hydronic space heating systems may be employed in geothermal residential space heating designs where appropriate geothermal water temperature and flow rates are available. Circulation of geothermal water through heating system components should be avoided where the water contains chemical constituents which are deleterious to materials of the system or which may result in deposition in the heating system. Use of heat exchangers to eliminate these problems is discussed later in this report. Some typical residential applications of geothermal space heating systems are discussed in Reference 3.

Conversion of existing conventional space heating systems to geothermal systems may be made at relatively low cost, while retaining the conventional heating capability for backup in some cases. It may be beneficial to include conventional electrical heating capability in geothermal systems to carry the peak load instead of sizing the geothermal system to carry the full heating load. Replacement of existing heating system components with geothermal components may result in cost 25-30% greater than the cost for installation of the same components in new construction, due to work in confined spaces to remove or modify the existing system and install the geothermal components. Geothermal conversion designs typically retain the existing ductwork and piping.

The conventional electric heating coil or fossil-fired burner is replaced with a hot water finned coil in geothermally driven forced air systems. Air blown through the coil is heated and distributed through ductwork as in conventional forced air systems. Selection of hot water coil design is based on the heat load of the system and the temperature and flow rate of the geothermally heated water. Heating coil ratings are based on design conditions for water temperature and flow rate, and air flow through the coil which produce a design water temperature drop in the coil. Manufacturers provide conversion factors for rating of coils operating under other than design conditions. Selection of appropriate coil design, air handling capacity and water flow rate through the coil may allow forced air systems to be used with average water temperature in the coil as low as 120°F under appropriate design conditions. Low water temperatures require increased water and air circulation rates, which entail higher operating cost and may require larger circulation pump and fan motor sizes.

A residential-sized water-to-air heat pump may be used in a forced air system where the geothermal water temperature is in the range 60-90°F, which is too low for effective use of a hot water coil. Residential heat pumps become economically feasible in locations experiencing significant space cooling as well as space heating loads which can be serviced through the capabilities of the heat pump. It is technically feasible to extend the source temperature range upward; however, equipment for residential use is not readily available for use with water temperatures greater than 90°F.

Forced air systems may be converted by replacement of the conventional heat source with a hot water coil and modification of the air handler drive system to provide adequate air movement with the additional resistance due to the water coil. This may only require a change in pulley size in some cases, while in others a more powerful fan motor may be required.

It may be practical to consider hydronic residential space heating systems using geothermally-heated water at a temperature as low as 100°F in radiant floor slab coils and as low as 140°F in baseboard convection systems. Low driving temperatures (heat source temperature) may not be practical where high heat loads are encountered due to severe climatic conditions or poor energy efficiency in home design and construction. Coil spacing and length in radiant floor slab installations and convector length in baseboard convection systems are influenced by the average water temperature in the system. Heating effect is determined from the temperature drop across the system or system component and the flow rate, and is specified as Btu/hr/ft at a specific flow rate and temperature drop. Increasing the length of a coil or convector will result in a proportional increase in heating effect only if the flow is increased to maintain the average water temperature. An increase in heating effect can be obtained by increasing the water flow rate.

This in turn reduces the temperature drop through the system and increases the temperature difference between the heating system component and the space to be heated, thus creating greater heat flow per unit time between them. Flow control is used to regulate the heating effect of hydronic systems. The systems are engineered to carry the design heat load at a specified design water flow rate and are usually designed in a zone heating context to provide for optimum distribution of heating effect and optimum control flexibility.

A practical limitation on total baseboard convector length is the length of exterior walls unless it is desired to include convector installation on interior walls in high heat loss locations such as in entry ways, family rooms, or other areas where interference with furniture placement is minimal. Standard convection units with higher heat ratings may be considered where baseboard units cannot provide adequate heating capacity and aesthetic considerations do not prohibit their use.

Principal differences between conventional and geothermal hydronic space heating systems are the omission of the conventional boiler for water heating, the use of a lower temperature working fluid in many cases, and the inclusion of a heat exchanger, if necessary, to isolate the heating system from geothermal water containing chemical constituents which may be harmful to the efficiency or material of the system.

Hydronic systems may be converted by piping the geothermally-heated water in parallel with the existing heat source and retaining it for system backup heating. In some cases, flow circuiting of the hydronic system may have to be modified and additional circulation pumping capacity may be required. This must be determined on a case-by-case basis.

3.0 HEATING SYSTEM COSTS

Many factors affect design and cost of residential heating systems. Construction materials and quality, design and configuration of the conditioned space, local climatic and economic conditions, as well as contractor experience may all have an effect on heating system capacity and cost. Geothermal space heating system design is also affected by the temperature and quality of the geothermal water.

Heating system capacity is customarily determined by computing heat losses from the heated space at design temperature conditions. The magnitude of these losses depends on the design inside-outside temperature difference ($T-T_0$), construction materials, amount of insulation used, size of the residential unit, and the amount of outside air which infiltrates the heated space through seams and openings into the space. Estimation of annual operating and fuel cost is based on residential and heating system design conditions. Climatic conditions are specified in terms of outside design temperature (T_0) and the Fahrenheit heating degree day (DD).[a] The difference between an inside design temperature of 65°F and the customary 68 - 70°F thermostat setting is accounted for by intrinsic heat sources, such as body heat and electric lights. The outside design temperature is not customarily the lowest climatic temperature, but is representative of the average cold nighttime temperature.

Estimated costs for components of representative forced air and hydronic residential heating systems, both conventional and geothermal, were obtained brom "Building Construction Cost Data 1977," reference 4, wherever possible to reduce the possibility of bias due to localized cost information. These costs include an appropriate allowance for installation, and contractor

---

[a] Degree days for a specific area (state) can be obtained by ordering the July "Climatological Data" Publication from:
Environmental Data Service
National Oceanic and Atmospheric Administration
National Climate Center
Asheville, North Carolina 28801

overhead and profit. Current costs for convectors, fan coil units, and hot water coils were obtained from vendors for small lot or single-unit purchase. Installation cost, contractor overhead and profit are assumed to equal one-third of the bare cost of hot water coils and fan coil units. Costs for corresponding conventional systems were determined as above. Oil storage tank cost and flue cost are included in the appropriate furnace or boiler cost figures. Installed costs of the representative systems are shown in Tables I through III.

Based on first costs, geothermal space heating systems without heat exchangers compare favorably with conventional systems, except natural gas forced air systems and electrical forced air systems in cases where the geothermal water temperature is below 160°F. In those cases where a heat exchanger with a tube-side flow rate greater than seven gallons per minute (gpm) is required (geothermal water temperature less than 150°F), conventional space heating systems generally have lower first costs. The baseboard convection system is the most cost-competitive geothermal system. When a heat exchanger is included, first costs for this system compare favorably with those of conventional heating systems, providing that geothermal water temperature is at least 160°F.

TABLE I

FORCED AIR HEATING SYSTEM, INSTALLED COSTS ($)
(For "Average Energy Efficient Construction" System, 56,000 Btu/hr)

System Type	Geothermal					Electric	N. Gas	Oil
Water Temperature, (°F)	70	120	140	160	180			
Temperature Drop, (°F)	10	10	12	25	35			
Flow Rate (gpm)	6	11.2	9.3	4.5	3.2			
Duct Work	1800	1800	1800	1800	1800	1800	1800	1800
Furnace, Assoc. Equip.						750	500	1500
Heat Pump (water-to-air)	1800							
Hot Water Fan Coil Unit		1000	680	545	545			
Controls		200	200	200	200			
TOTAL	3600	3000	2680	2545	2545	2550	2300	3300
Secondary System, if required - tube & shell heat exchanger (no special materials)		790	790	550	550			
TOTAL		3790	3470	3095	3095			
For retrofitting of existing Electric or Gas Furnaces: Hot water coil for conversion (pipe, valves, installation of supply/return lines not included)		210	200	170	100			

TABLE II

BASEBOARD CONVECTION HEATING SYSTEM, INSTALLED COSTS ($)
(For "Average Energy Efficient Construction" System, 56,000 Btu/hr)

System Type		Geothermal		Electric	N. Gas
Water Temperature, (°F)	140	160	180	200	200
Temperature Drop, (°F)	12	20	28	37	37
Flow Rate (gpm)	9.3	5.6	4	3	3
Distribution Pipe	240	200	180	180	180
Convectors	1700	1490	1255	1010	1010
Boiler and Controls, Expansion Tank, Circulation Pump, and Zone Control, as appropriate	270	210	210	1075	1230
TOTAL	2210	1900	1545	2265	2420
Secondary System, if required-tube and shell heat exchanger (no special materials)	790	550	550		
TOTAL	3000	2450	2095		

TABLE III

RADIANT FLOOR COIL SYSTEM, INSTALLED COST ($)[a]

(For "Average Energy Efficient Construction" System, 56,000 Btu/hr)

System Type	Geothermal			Electric	N. Gas
Water Temperature (°F)	140	160	180	200	200
Temperature Drop, (°F)	12	20	28	37	37
Flow Rate (gpm)	9.3	5.6	4	3	3
Underfloor Pipe Coil, Header					
Steel Pipe, 12 in spacing[b]		4400	4400	4400	4400
Steel Pipe, 10 in spacing[b]	5280				
Boiler and Controls	270	210	210	1075	1230
Expansion Tank, Circulation Pump, and Zone Control					
TOTAL	5550	4610	4610	5475	5630
Secondary System, if required-tube and shell heat exchanger (no special materials)	790	550	550		
TOTAL	6340	5160	5160		

[a]Floor costs, which may be affected, are not considered.

[b]Use of plastic pipe may reduce costs, if water temperature is less than 170°F.

Annual Cost for Space Heating

The annual cost for space heating is the sum of costs for heating and operating energy, maintenance, and the annualized cost of equipment based on the equipment lifetime and the cost of borrowed money. In the following examples, these costs are estimated for the typical heating systems, based on assumed unit energy costs for electricity, natural gas, and oil. A range of cost for geothermal energy is used due to the extreme variation in cost which may be encountered. Unit cost of conventional energy may also vary greatly so it is suggested that local costs be used to extend the applicability of this report. Geothermal energy cost may be estimated using the methods of the following section for specific cases. Energy cost is based on the energy requirements of the selected systems which will vary only slightly among equipment available from various manufacturers. Estimated annual energy requirements are shown in Table IV, and estimated annual energy costs, based on electricity at 2¢/kWhr, natural gas at 30¢/therm, oil at 40¢/gal, and geothermal energy at $1.75-$6.00/million Btu[a], are shown in Table V.

In an equal unit energy cost situation, the water-to-air heat pump can recover from 60 to 125 dollars per year in reduced energy cost which can to applied against the greater equipment and maintenance cost of heat pump systems. The range of cost recovery in energy expense is based on comparison with electricity and natural gas. No consideration has been given to escalation rates which may have a significant effect on cost recovery through energy savings. It is likely that costs of conventional sources of energy will escalate at a rate greater than the general economy, perhaps tending to make geothermal energy even more competitive than at present.

Annual maintenance costs for typical residential space heating systems are estimated (1975 costs) in reference 5. These costs, based on owner and contractor experience, have been increased approximately 15%, rounded to the nearest 5 dollars, and are presented in Table VI.

---

[a]This range of cost is based on rates charged by the Boise Warm Springs Water District ($1.75/million Btu), and estimated annualized cost for a new system comprised of a 3000-ft well, a disposal well, 10,000 ft of distribution and disposal piping, and 1000 gpm flow capacity, producing about 4.3 x 10^{10} Btu annually for space heating ($6/million Btu).

TABLE IV

ANNUAL ENERGY REQUIRED FOR SELECTED SPACE HEATING SYSTEMS

Annual heat load = 1.152×10^8 Btu

Annual operating time = 2060 hrs

Conventional Heating Systems	Forced Air	Convection (3 zone)	H.W. Panel (3 zone)
Heating energy source[a] & thermal efficiency			
Electricity kWhr @ 100%	33,750	33,750	33,750
Oil gal @ 70%	1,059	1,059	1,059
Natural Gas therm @ 75%	1,536	1,536	1,536
Operating energy - electricity, kWhr			
Fan 1500 cfm	626		
Circulation pump (80% efficiency)		78	192

Geothermal Heating Systems	Forced Air					Convection (3 zone)			Radiant Panel (3 zone)		
Water temperature, °F	70	120	140	160	180	140	160	180	140	160	180
Temperature drop, °F	10	10	12	25	35	12	20	28	12	20	28
Flow rate, gpm	6	11.2	9.3	4.5	3.2	9.3	5.6	4	9.3	5.6	4
Air flow, cfm	1500	1600	1500	1500	1300						
Heating Energy Source											
Geothermal, Btu x 10^5	652	1152	1152	1152	1152	1152	1152	1152	1152	1152	1152
Electrical kWhr (heat pump COP = 2.3)	14675										
Operating energy, electricity, kWhr											
Fan	626	1584	978	978	939						
Circulation pump, (80% efficiency)						393	168	114	1068	402	270

---

[a] Heating energy conversion constants

Electricity 3413 Btu/kWhr

Oil 1.45×10^5 Btu/gal

Natural gas 10^5 Btu/therm

TABLE V

ANNUAL ENERGY COST FOR SELECTED SPACE HEATING SYSTEMS ($)

Electricity @ 2¢/kWhr, 100% efficiency, ($5.86/million Btu)

Natural gas @ 30¢/therm, 75% efficiency, ($4.00/million Btu net)

Oil @ 40¢/gal, 70% efficiency, ($3.94/million Btu net)

Geothermal, $1.75-$6.00/million Btu, 100% efficiency over operating Δt, cost range based on Boise Warm Springs Water District rate and new system estimated rate

Annual Heat Load, 1.152×10^8 Btu

HEATING SYSTEM	FORCED AIR	CONVECTION	RADIANT HOT WATER FLOOR PANEL
Electric	687	676	680
Natural gas	474	465	470
Oil	436		
Geothermal[a] (geothermal energy only)	202-690	202-690	202-690
Additional energy (electricity) required for system operation (pump or fan)[b]			
Water-to-air heat pump (Δt=10°F)	300		
Operating energy, 120°F water	32		
Operating energy, 140°F water	25	8	21
Operating energy, 160°F water	20	4	8
Operating energy, 180°F water	12	2	5

[a] Heat pump requires 6.52×10^7 Btu geothermal energy @ $144-$390 annually, COP = 2.3, where COP = Btuh output/kW input x 3413 Btuh/kW.

[b] Conventional heating system cost includes electrical operating costs about equal to the 180°F geothermal systems.

TABLE VI

ESTIMATED ANNUAL MAINTENANCE
RESIDENTIAL SPACE HEATING SYSTEMS ($)

TYPE	ANNUAL MAINTENANCE ($)
Oil, gas furnaces	35
Electric furnaces	25
Electric baseboard or panel	10
Geothermal	45 (heat exchanger, $50 additional)
Heat pump	70

These average annual maintenance costs are based on owner and contractor experience.

In order to compare the overall annual cost for the various space heating systems considered the energy, maintenance, and estimated equipment costs expressed as an annual amortization cost based on an interest rate of nine percent and system lifetime of twenty-five years, can be summed; these estimated annual costs are shown in Table VII.

TABLE VII

ESTIMATED ANNUAL SPACE HEATING COSTS ($)

(Annual Heat Load 1.152×10^8 Btu)

HEATING SYSTEM	FORCED AIR	CONVECTION	RADIANT HOT WATER FLOOR PANEL
Electric (total annual cost)	965	917	1244
Natural gas (total annual cost)	736	743	1069
Oil (total annual cost)	800		
Geothermal energy (cost in addition to capital and operating costs shown below)	202-690	202-690	202-690
Water-to-air heat pump (Δt=10°F)[a]			
	837 (943)[b]		
120°F water	362 (493)		
140°F water	325 (456)	272 (404)	617 (747)
160°F water	311 (416)	240 (346)	520 (626)
180°F water	310 (415)	204 (310)	518 (624)

[a]Heat pump requires 6.52×10^7 Btu geothermal energy @ $114-$390 annually, COP = 2.3

[b]Cost with heat exchanger indicated as ( )

Table VII shows that geothermal space heating systems can be cost competitive with the corresponding conventional systems whenever the annual cost of geothermal energy is less than the difference between the annual cost of the conventional system (including energy cost) and the annual cost of the geothermal system excluding the cost of geothermal energy.

Based on the cases presented and the typical costs of conventional energy, it appears that when no heat exchanger is necessary, geothermal energy for residential space heating is cost competitive with natural gas forced air heating when the unit cost of geothermal energy is less than 90% of the net cost of natural gas ($4/million Btu net). Hydronic systems heating with 140°F water are cost competitive at unit energy cost equal to natural gas and at 180°F the cost of geothermal energy may exceed the cost of natural gas by 15 - 20%. Geothermal forced air space heating is competitive with electrical forced air space heating when the cost of the geothermal energy is less than or equal to about 95% of the cost of electrical energy at 2¢/kWhr ($5.86/million Btu net). Geothermal energy cost must be less than 90% the cost of electricity for the 120°F systems. With 160°F water, hydronic geothermal systems are cost competitive with corresponding electrically-driven systems at equal unit energy costs and at 180°F, the cost of geothermal energy may exceed the cost of electrical energy by 5 - 10%. At present, water-to-air heat pumps do not appear to be cost competitive with either natural gas forced air or with convection systems. However, if the geothermal energy is available at about half the cost of electricity (about $3/million Btu net), the cost of the heat pump operating from 70°F water is competitive with electrical space heating systems. If space cooling capability was included in the heating system, however, the cost of the heat pump would become more competitive; the heat pump system, with its inherent cooling capability, would not require the extra investment that would be necessary in the conventional system.

Inclusion of a heat exchanger in the geothermal system increases costs to the point that a water-to-air heat pump is cost competitive only if geothermal energy cost is negligible. Geothermal energy costs must be less than 75-80% of electrical energy costs or less than 60-65% of natural gas costs in order for geothermal forced air systems with heat exchanger to remain cost competitive with the respective conventional forced air systems. Geothermal hydronic systems operating on 140°F water have similar limitations for cost competition; at water temperatures of 160-180°F, geothermal energy costs for hydronic systems with a heat exchanger may be 85-95% of the cost of conventional energy. The systems should remain cost competitive with the corresponding conventional heating systems, even with the additional cost and maintenance due to the heat exchanger. A summary of these results is shown in Table VIII.

Unit energy cost is based on development and production, delivery, and overhead costs; a profit margin will be included where the energy is provided by a commercial enterprise. For the cases considered in this report, competitive unit cost of geothermal energy may range from about 60% of natural gas cost to near 120% of electricity cost, depending on the type of heating systems considered, water temperature, and water quality. By assuming that overhead and profit are equal to 25% of the annual energy cost, the remaining 75% of annual geothermal energy cost can be assumed to represent the annual amortization cost of the capital investment for the development, production, and delivery systems. If the system had a twenty-five year lifetime, and interest on borrowed money was 9%, the capital which may reasonably be expended for development, production, and delivery of geothermal energy would range from about $2200 to $6000 for each residential unit serviced[a].

[a]Based on unit costs for natural gas and electricity of 30¢/therm and 2¢/kWhr, respectively.

TABLE VIII

COMPETITIVE COST OF GEOTHERMAL ENERGY
RELATIVE TO ELECTRICITY AND NATURAL GAS

Electricity @ 2¢/kWhr, 100% efficiency ($5.86/million Btu)
Natural gas @ 30¢/therm, 75% efficiency ($4.00/million Btu net)

System Type	Water Temp. °F	Geothermal Energy % Electricity Cost		Geothermal Energy % Net Natural Gas Cost	
			With Heat Exchanger		With Heat Exchanger
Forced Air (Heat Pump)	70	55		--	
	120	87	68	78	50
	140	94	75	88	59
	160	96	80	91	66
	180	96	81	91	66
Convection	140	95	75	101	73
	160	100	84	109	86
	180	106	90	117	94
Radiant Floor Slab	140	91	72	96	68
	160	107	91	119	96
	180	108	92	120	97

4.0 GEOTHERMAL RESOURCE DEVELOPMENT

The unit cost of geothermal energy is critical in the investigation of the economic feasibility of geothermal space heating systems. Geothermal energy is an alternative only when the resource can be obtained, the energy extracted, and the disposal of spent fluids made at costs which can compete with other energy sources. Once a resource has been obtained, residential owners may be able to determine the feasibility of geothermal space heating by directly comparing geothermal and conventional energy heating system costs. The feasibility of using a surface thermal spring for space heating can readily be determined based on local costs for transmission piping, circulation pumping capacity, acceptable disposal, and heating systems which satisfy the residential heat load. Spring flow rates, temperature and chemical constituency which may necessitate expensive heat exchange equipment must be considered in the selection of appropriate materials and system designs. Royalty, lease, and easement costs must also be taken into account. Finally, the escalation of conventional energy costs may be a determining factor in the feasibility assessment. In this event, an element of risk must be assumed unless a conservative escalation rate for conventional energy costs can be determined.

A feasibility study involving geothermal energy from an undeveloped subsurface resource is more difficult. The degree of risk involved in successful development may be much greater, due to uncertainties associated with the obtainable energy production rate, the resource depth, and the chemical constituency of the geothermal fluids. Resource evaluation, well drilling, and well head equipment all increase the cost of successful development. When development of a geothermal resource provides a benefit in addition to energy for space heating, only a reasonable share of cost should be borne by the space heating application. A determination that development is not feasible results in loss of any costs incurred in arriving at that conclusion.

As above, feasibility may be investigated by comparing the costs for development and use of the geothermal heating system with conventional heating costs. Alternatively, development can be investigated by assuming the geothermal energy must be available to the space heating system at a cost which does not exceed local conventional fuel costs. An estimate of the capital which can reasonably be expended for development, system maintenance, and distribution can be made by employing an annuity relationship to determine the present value of conventional energy required to service the residential heat load over the life of the system:

$$PV = \frac{C - C(1 + I)^{-N}}{I} \qquad (1)$$

where

PV = development capital ($)
C = average annual cost of conventional energy ($)
I = current annual interest rate
N = system design life (years).

Estimating the average annual cost of conventional energy over a period of years may be a source of significant error due to uncertainty about the rate of inflation for energy rates; however, the relationship is useful in a preliminary economic feasibility assessment. Development costs can be estimated based on information characterizing a particular geothermal resource and heat load. If it appears that development may be accomplished within the estimated development cost limitation, and the risk of failure is acceptably small, development can proceed. Because a low rate of return on investment may be expected, significant risk is probably not acceptable for space heating applications.

Mechanisms for cost sharing or load leveling can improve the economics of resource development in particular cases. District heating concepts to share costs and benefits among several users should be considered. Some load days of the heating season and using supplemental conventional fuels for the necessary peak heating capacity on the coldest days will improve the load factor. Operating the geothermal system at capacity for a larger percentage of time would thus reduce unit geothermal energy costs, because additional users could obtain a large fraction of their total heating energy from the geothermal system. The additional cost of the supplementary conventional heating would be recovered by using lower capacity residential geothermal systems and reducing geothermal energy costs. The district heating concept also provides a reduced likelihood of resource degradation by reducing the number of wells required. Improved economic and thermal efficiencies are possible with a larger supply system servicing a larger heat load.

Disposal of geothermal effluent must be considered as a development cost item for any well that removes fluids from the geothermal reservoir. Surface disposal and reinjection are possibilities to consider. If the geothermal fluids are obtained from or near a thermal spring, the natural spring discharge channel may be the most economical vehicle for disposal. Other natural channels may be considered, but environmental restrictions may be more severe. If the effluent temperature is the only consideration, a cooling pond or spray pond might be considered. In appropriate situations, geothermal effluent could recharge ground water aquifers or the geothermal aquifer itself. Reservoir engineering considerations are beyond the scope of this report, however, and reinjection of the fluids is considered here only as an alternative to surface disposal.

District Heating Units

In some cases, an industrial-sized heat pump in a district heating system may be more economical than individual residential heat pumps, even considering the cost of necessary backup capacity. Model selection of individual units is based on the desired capacity, source and delivery temperatures, and an annual operation time. These fluid-to-fluid heat pumps lack reversible flow circuitry, and are available as either single- or two-stage units is based on the desired capacity, source and delivery temperatures, and an annual operation time. These fluid-to-fluid heat pumps lack reversible flow circuitry, and are available as either single- or two-stage centrifugal compressor units for either 50- or 60-cycle electric service. Standard fabrication materials are mild steel and copper, with other material selections available. The pumps were designed for operation with source temperatures in the range of 40 - 140°F, delivery temperatures in the range of 120 - 230°F, and source flow rates in the range of 40 - 2000 gpm. Unit capacity ranges from 1 - 7 x 10^6 Btu/hr with coefficients of performance (COP) in the range of 2.5 - 4.6 in appropriate applications. Single-stage reciprocating compressor units are also available with capacities in the range of 10^5 - 10^6 Btu/hr. Low-to-medium capacity units cost in the neighborhood of $15,000. In a favorable climate, this price would allow their use in district heating situations involving as few as 15 homes.

The quality of geothermal water in most locations will probably require heat exchange equipment to prevent corrosion and deposition in the residential system, where low water velocity tends to combine with low temperature. The geothermal water should be analyzed for components which may affect the choice of materials and maintenance.

Either conventional tube and shell or downhole U-tube heat exchangers are suitable for residential heating applications. Plate-type heat exchangers may be the most economical in larger systems, as discussed later.

5.0 GEOTHERMAL RESOURCE DEVELOPMENT COSTS

The per-unit cost of energy from a geothermal system is normally estimated by summing the system's amortized cost with operational costs and dividing this figure into the per-unit quantity of heat delivered by the system.

A preliminary estimation of system costs can be made by considering appropriate costs for major elements of the system: well, pipe, heat exchanger, and pumps. These costs are principally determined by sizes, capacities, and installed costs, which in turn are functions of the particular application. Local costs may vary significantly due to contractor experience and availability, labor costs, and purchase discounts.

Preliminary sizing of system elements will be determined by the heat load and the temperature of the available geothermal fluids. Material selection will be affected by the chemical content of the geothermal fluids.

Heat Load, Flow Rate, and Pumping Requirements

For space heating applications a good estimation of heat loads can be made by defining an average residential space heating unit to be 1800 ft^2 of well-insulated modern construction, having a heat load of 800 Btu/hr for each degree Fahrenheit difference between the inside and outside design temperatures. The annual heat load is then about 19,200 Btu for each annual Fahrenheit degree day. Poorly insulated construction, however, can result in heating requirements 2.5 times greater than this heat load figure.

Heat loads for multiple units or small district heating systems may be represented by proportionate values. In larger district heating systems an estimate of transmission heat loss must be made, or at least accounted for, with increased flow requirements.

The flow rate required to supply a given heat load can be computed:

$$\dot{w} = \frac{H}{500\ \Delta t} \qquad (2)$$

where

$\dot{w}$ = flow rate, gpm
H = heat load, Btu/hr
Δt = temperature drop, °F

An estimate of the temperature drop that can be realized economically, using conventional heat exchange equipment, is given by:

$$\Delta t = 0.6 \times \text{inlet temperature} - 70 \qquad (3)$$

where the inlet temperature is in °F

With a given heat load and a given geothermal water temperature drop, these relations can be employed to estimate required flow through either a residential heating system or another heat exchange mechanism.

The pumping horsepower (HP) required to produce this desired flow rate can be computed:

$$HP = K \times \dot{w} \times L \qquad (4)$$

where

$$K = \frac{2.525 \times 10^{-4}}{\text{pumping efficiency}}$$

L = pump head, ft

This equation can be used to estimate the pump horsepower required for circulation or well pumping. Improved accuracy is possible if pressure losses and a realistic pump efficiency factor are included in the values for L and K. Installed pump cost can be approximated by assuming $100/hp for circulation pumps and $400/hp for well pumps. Figures 1 and 2 show the calculated values for the above relationships. The nomograph for pump horsepower assumes 100% efficiency.

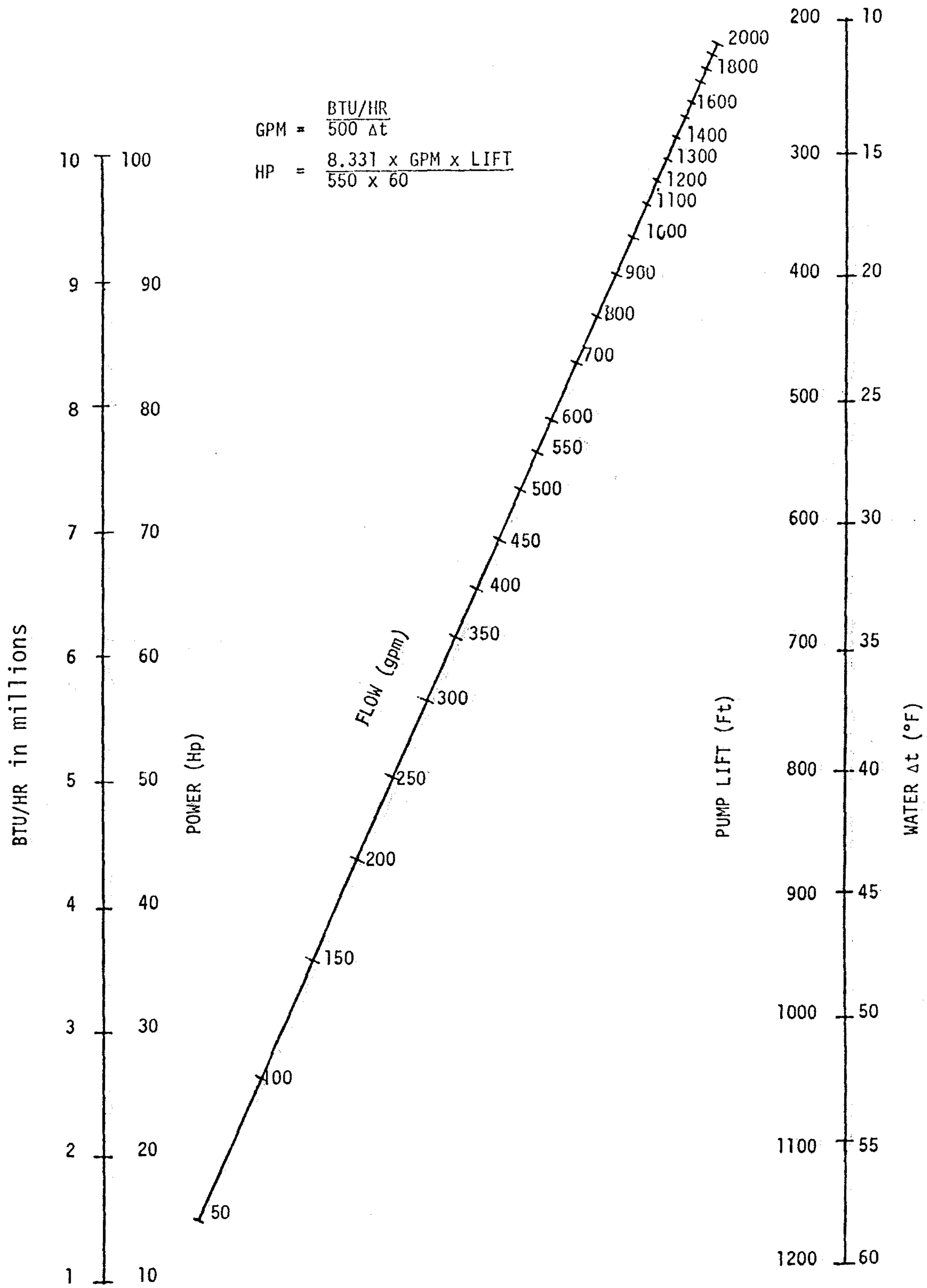

Fig. 1 Geothermal fluid flow rate, heat rate and pump horsepower nomographs.

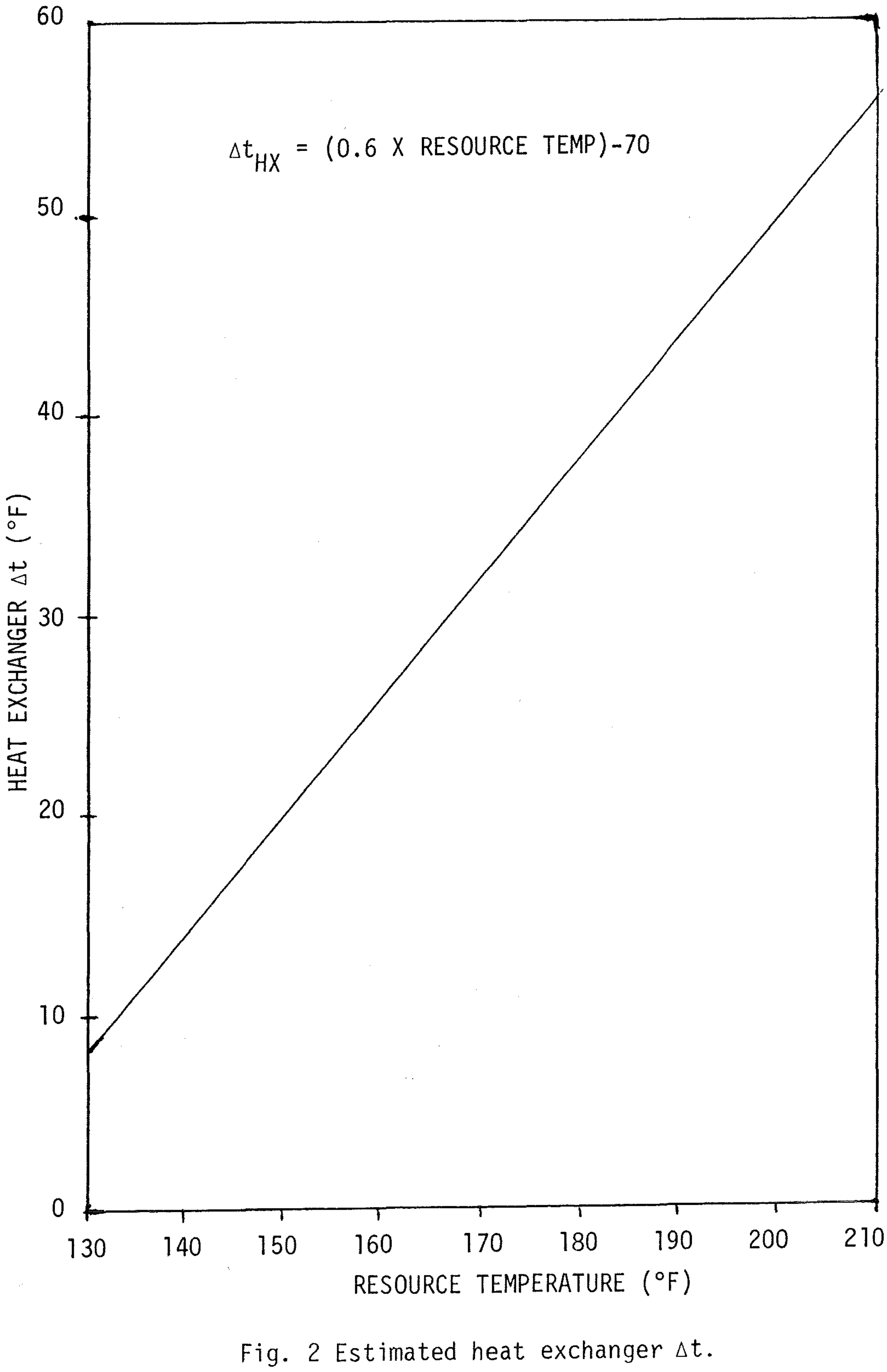

Fig. 2 Estimated heat exchanger Δt.

The selection of pipe must consider water chemistry, pressure, and temperature. Fluid velocities should be less than 8 ft/sec in circulation loops in order to prevent unreasonable friction losses and unneccessarily high pump and pumping costs. Somewhat higher velocities may be allowed in distribution system lines. Pipe diameters and friction losses, which are a function of the required flows, can be determined from Figures 3 and 4. Estimated installed costs for various types of pipe are shown in Figure 5. These costs do not include valves or fittings (fittings included - PVC). The relatively high-cost, flanged-joint, steel pipe should be used only where it may ne necessary to quickly remove a pipe section or system component, and the service line is 4 in. or larger. Pump or heat exchanger installations comprise the bulk of these applications.

Standard pipe sizes must be used and excavation and backfill added for underground placement. Valve and fitting costs must be added where appropriate, and may increase total costs significantly. For example, 4-to-10-in. cast-iron gate valves sell for from $300 to $825, installed. With type 304 ss lining, installed cost of the 4 and 6 in. sizes increases to about $1000 and $1700, respectively. Installed costs include subcontractor overhead and profit.

Well Cost

Well costs are a function of diameter, depth, and local drilling conditions. For residential-domestic wells, typical costs range from $1 to $2 per inch diameter per foot depth. Deeper, larger capacity wells will entail higher per-foot drilling costs. An inside well-casing size for providing adequate flow can be estimated using Figure 6, and the required flow for servicing a specified heat load at a reasonable temperature drop can be determined as above.

Figure 7 graphically shows a range of well costs, with cost as a function of casing diameter and well depth. Local conditions, economic and geological, will determine actual costs; however, an initial realistic estimate may be made using a value from this figure.

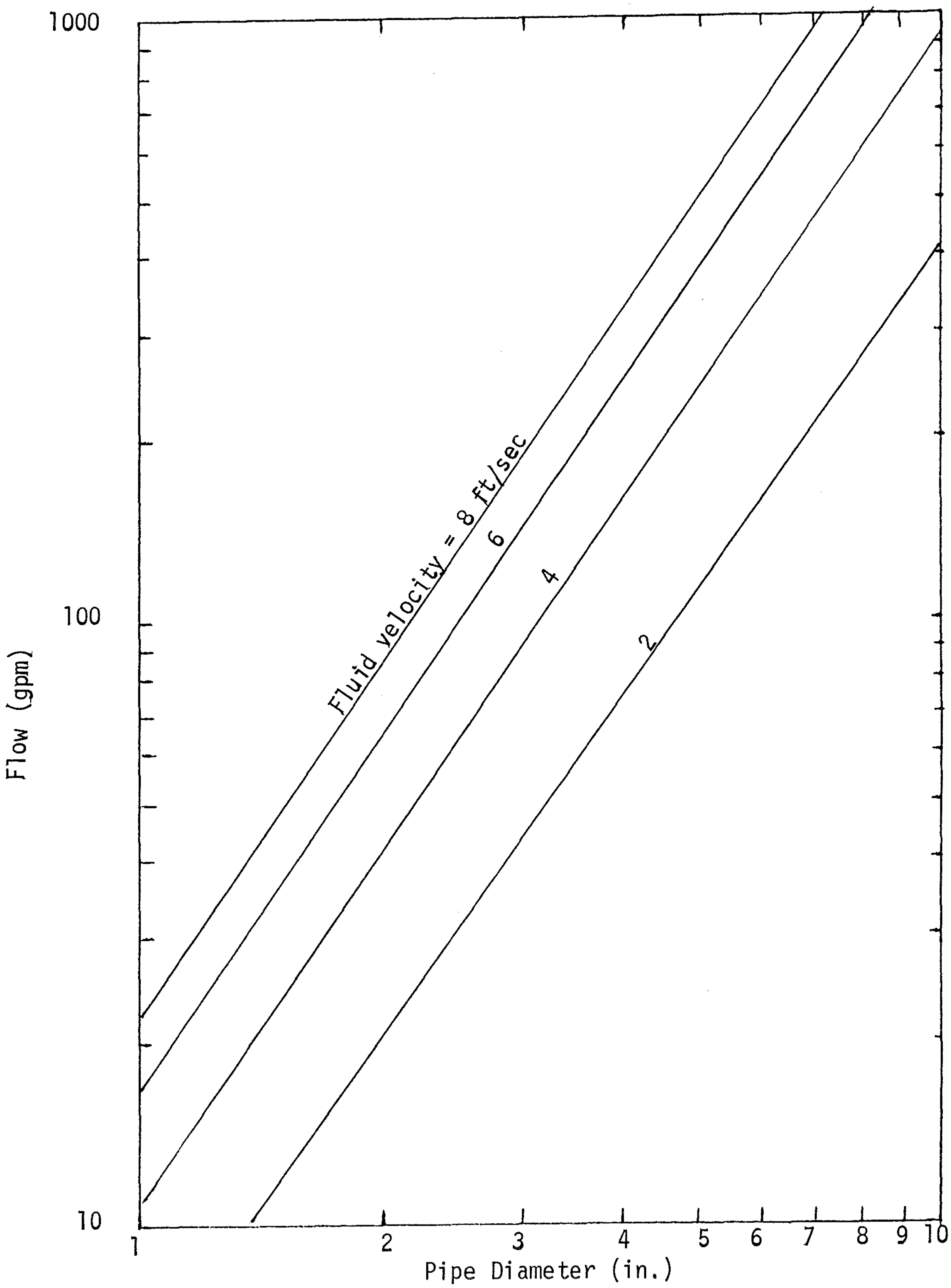

Fig. 3 Volumetric fluid flow rate versus pipe diameter and velocity, smooth steel pipe.

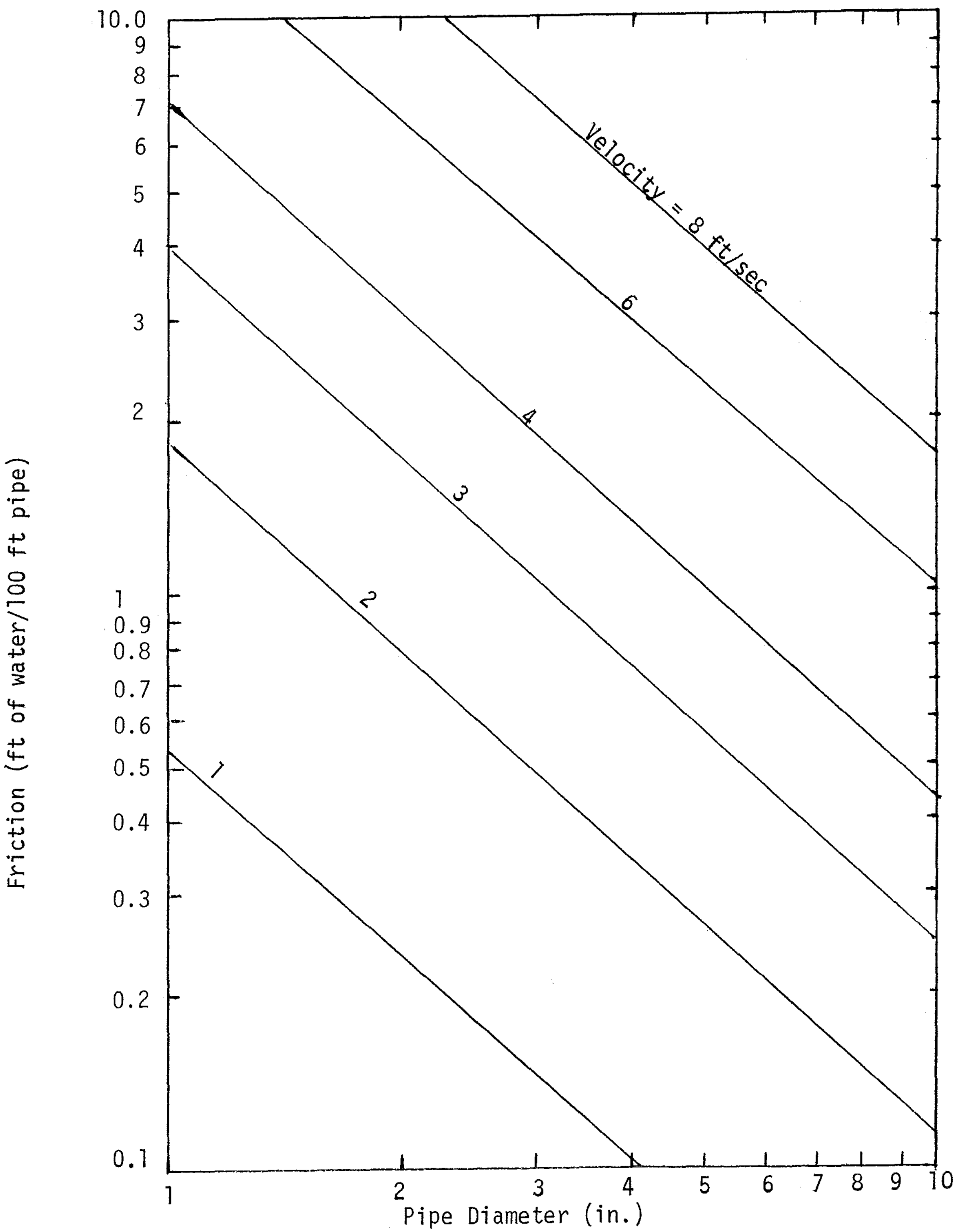

Fig. 4 Friction loss versus pipe diameter and velocity, smooth steel pipe.

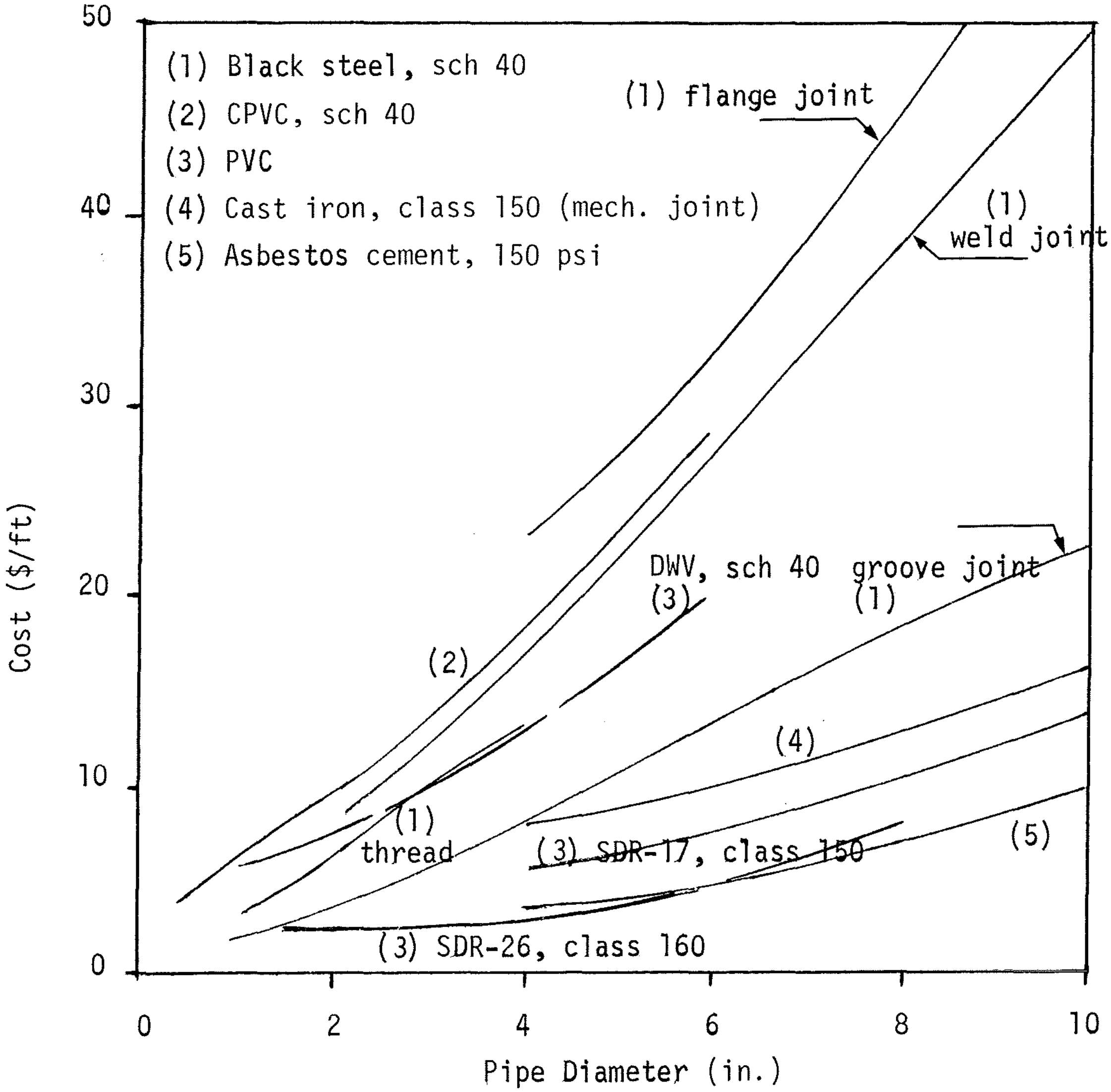

Fig. 5 Installed cost, selected pipe, various applications. Add $3/yd^3$ for buried service (trench and backfill).

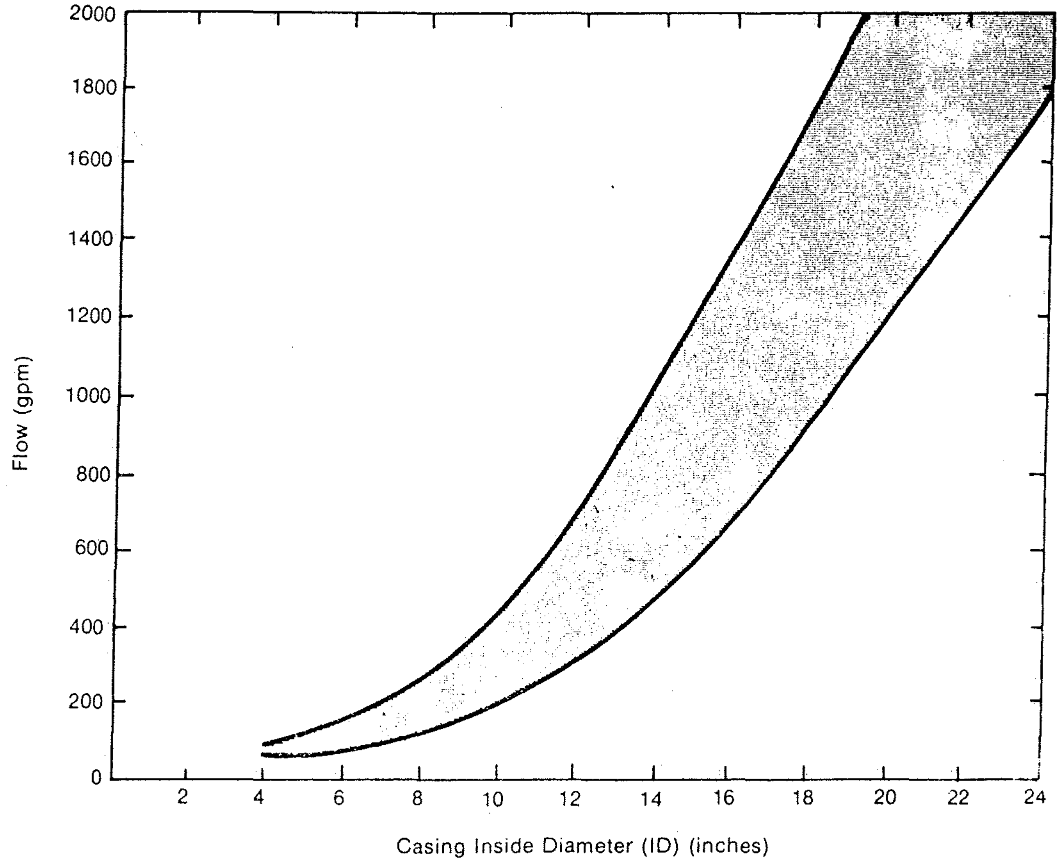

Fig. 6 Production rate versus well casing diameter.

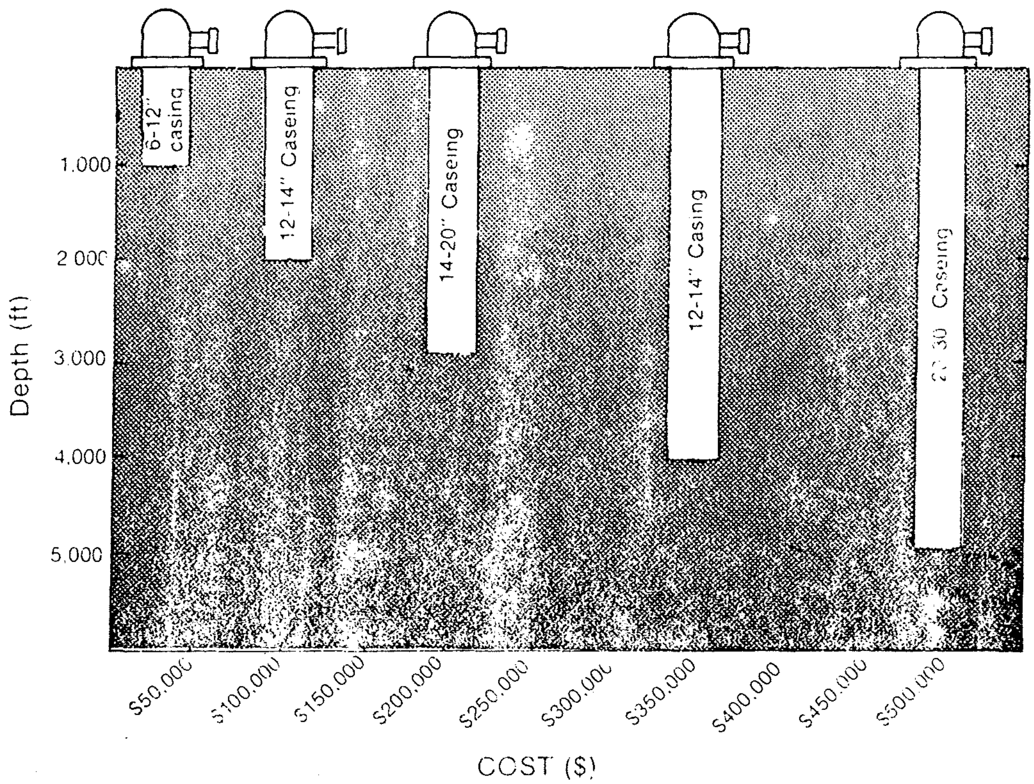

Fig. 7 Well cost versus production rate and depth.

Heat Exchanger Cost

Heat exchangers must be selected on the basis of local conditions, such as the temperature and quality of the geothermal water, and the size of the heat load to be serviced. Geothermal water quality may require a material selection which greatly increases the cost of heat exchange equipment. Typical heat exchangers which could be used in space heating applications are tube and shell, down-hole U-tube, and plate. Tube and shell and simple down-hole U-tube heat exchangers are probably the most economical for individual residential applications. In larger multi-user systems, both plate type and tube and shell heat exchangers with spiral tubes may be more competitive. Table IX shows the bare costs of representative heat exchange equipment; installation costs are not included, but may be expected to range from 10% of equipment cost for large systems to 20% for individual residential systems. Down-hole heat exchangers may entail high installation costs because of the need for derrick equipment to lower the heat exchanger into the well. Also, where corrosion is a problem, extra maintenance will contribute to the total cost.

TABLE IX

REPRESENTATIVE HEAT EXCHANGER COST

Type/Materials	Working Fluid Flow Rate (gpm)	Cost ($)
Tube-Shell/Cast I. shell, copper tubes	10	460
	150	7000
	250	20000
Tube-Shell/Cast I. shell, ss type 304 spiral tube	10-15	1100
	300	7500
Plate/type 316 ss	10	2500
	250	6000
U-tube/steel	10	500

Disposal System Cost

In general, the geothermal effluent will be reinjected into wells or discharged on the surface. Major cost items may include a reinjection well, transmission pipe, and cooling or evaporation pond. In the absence of specific information concerning location, 50% of production well cost is customarily assumed for reinjection cost. Surface discharge costs can rapidly approach this magnitude when cooling ponds or a long transmission distance is involved.

Supply and Disposal System Design Costs

Design costs for geothermal space heating supply and disposal systems probably range from 10 - 20% of system cost. For a single residential developer with his own nearby resource, these system design costs will probably be included in the installation costs specified by a subcontractor. About $500, equivalent to twenty hours of an engineering consultant's time, should be adequate.

Annual Operating Cost

Annual operating cost is determined by the lifetime of the component and the requirements for maintenance and power, together with debt service, applicable royalty or easement, and taxes. Unless specific maintenance items are known, annual maintenance cost is generally assumed to be a fraction of the capital cost of the system component. Scheduled maintenance, such as heat exchanger cleaning or pump servicing, can be based on manufacturers' recommendations and local labor costs. Typical annual maintenance costs, as a fraction of capital cost or as labor hours, are as follows: (1) heat pumps, 4%; (2) heat exchangers, 16 hrs; (3) pumps, 4 hrs; (4) pipe systems, 2-3%. Overall system lifetime must be based on local operating conditions and the operating environment; systems may be designed for a lifetime of 20 - 40 years. Amortization of capital costs over the system lifetime provides an additional element of annual operating cost.

Finally, the annual cost of electrical pumping can be estimated:

$$E(\$) = E_R \times HP \times 365 \times 24 \times F_{Load} \times 0.7457 \qquad (5)$$

where

$E(\$)$ = \$/yr electrical cost
E_R = \$/kWhr electrical rate
HP = pump horsepower
F_{Load} = load factor
1kWh = 0.7457 horsepower hour.

Cost of Geothermal Energy

The various contributing costs can be summarized, and an appropriate annual or total project capital cost can be estimated. The project capital costs should be totaled according to component lifetime, if necessary, or an appropriate determined project lifetime. Using an appropriate interest rate on borrowed money, the annual capital amortization rate for a system or component can be determined:

$$R = P \frac{i(1 + i)^n}{(1 + i)^n - 1} \qquad (6)$$

where

R = annual capital cost
P = present project value
i = interest rate (annual)
n = life of project (years).

The total annual cost of the geothermal energy can be derived by summing up the annual maintenance and tax costs, R value(s), and the annual cost of conventional energy used by the system.

The cost of energy from a geothermal system is determined by the cost of the system and its operation and the rate of heat delivery from the system; the nomograph, Figure 8, relates these factors. Actual heat cost should be determined after adjusting on-stream factors and efficiencies to actual conditions. Scaling both annual cost and flow rate by factors of 10 allows energy cost for smaller or larger projects to be determined.

The cost of geothermal energy can thus be compared with the cost of conventional energy to assess the economic feasibility of a geothermal system.

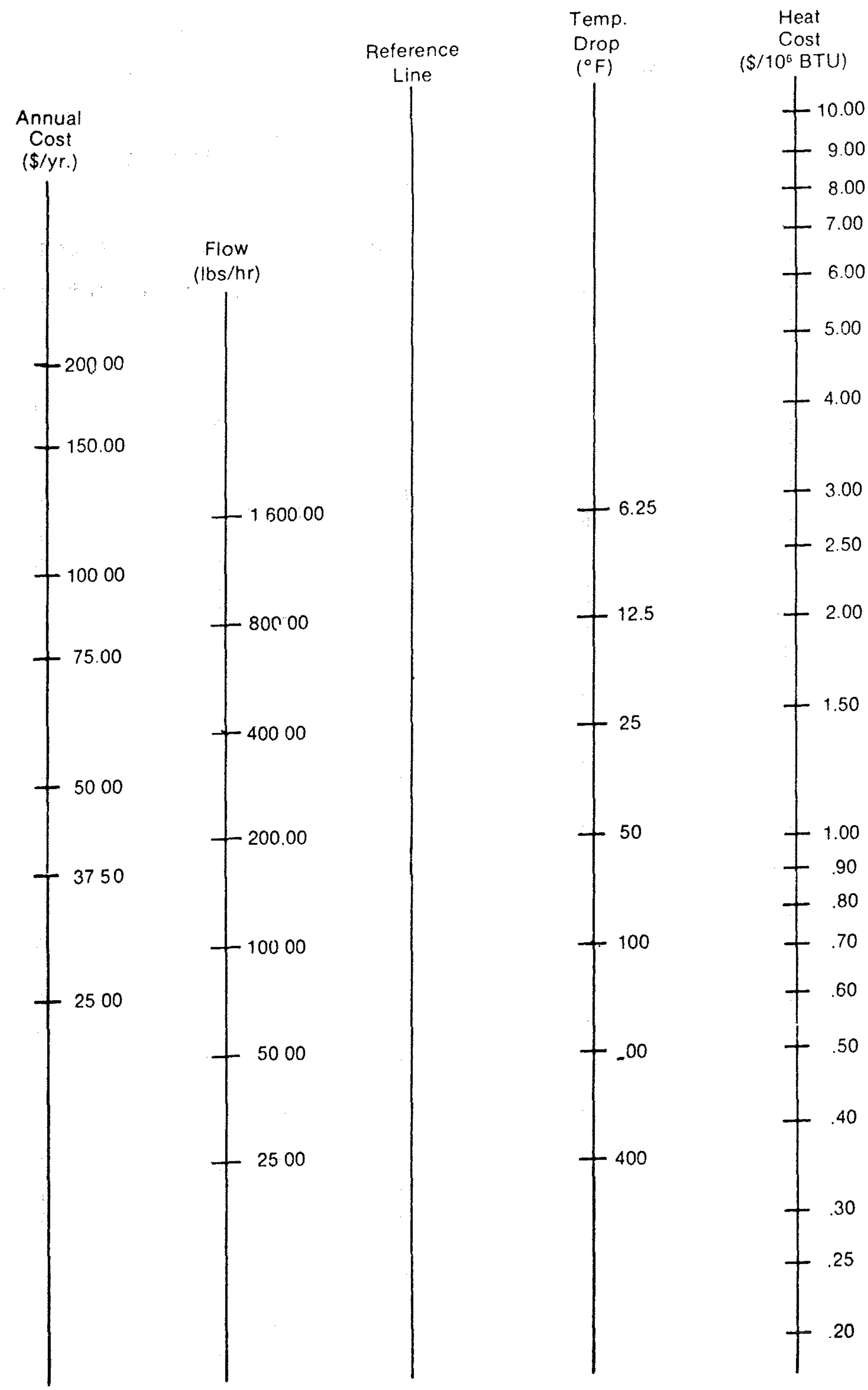

Fig. 8 Geothermal energy cost nomograph.

6.0 CONCLUSIONS

Components of geothermal residential space heating systems are currently available as off-the-shelf items from manufacturers and vendors. Hot water convection systems are probably the most economical; under suitable conditions they can use geothermally heated water at temperatures as low as 140°F. A minimum water temperature of 150°F is desirable from an economic standpoint, however. These geothermal systems are cost competitive with electric and natural gas fired systems when geothermal energy costs about the same as electricity or up to 15% more than natural gas. Hydronic radiant floor panel systems may use water at lower temperature (perhaps as low as 100°F), but the systems are relatively expensive. They probably will be used only where sufficient geothermal water is available at very low cost and the water temperature prohibits economic use of other types of geothermal heating systems.

Geothermal forced air space heating is probably the most desirable type of a residential heating system, because of the general acceptance of forced air systems and the ease of adapting the system to include additional features such as cooling, air filtration and humidity control. Geothermal forced air systems can use water at temperatures as low as 120°F. In addition, these systems respond to changing load conditions much more rapidly than hydronic systems. In many cases, existing conventional forced air systems may readily be converted to geothermal operation by adding a hot water coil, modifying the fan drive, if necessary, and providing supply and return lines for the geothermal water. Cost of geothermal energy may range up to 90 - 95% of the cost of electricity or natural gas and geothermal systems will remain cost competitive with the corresponding conventional system.

Water-to-air heat pump forced air systems can use water at much lower temperatures (below 100°F). The fact remains, though, that if heat pump systems are used only for heating they are among the most expensive of the systems considered. In cases where space cooling is required, however, these systems may compete with conventional space conditioning systems of equivalent capacity for heating and cooling.

Significant use of existing geothermal resources for residential space heating will depend largely on the availability of geothermal energy at a delivered cost which is less than that of competing conventional energy forms. For some cases, where water temperatures are above 160°F and water quality is acceptable, unit geothermal energy cost may slightly exceed conventional energy costs and still remain competitive.

7.0 REFERENCES

1. American Society of Heating, Ventilating and Air Conditioning Engineers, New York, New York.

2. National Environmental Systems Contractors Association, Arlington, Virginia.

3. G. Gene Culver, "Optimization of Geothermal Home Heating Systems," Geo-Heat Utilization Center, Oregon Institute of Technology, Klamath Falls, Oregon, 1976.

4. R. S. Means Company, Inc., "Building Construction Cost Data 1977," Duxburg, Massachusetts, 1977.

5. J. G. Keller and J. F. Kunze, "Space Heating Systems in the Northwest - Energy Usage and Cost Analysis," ANCR-1276, INEL, 1976.

6. "Rules of Thumb for Direct Geothermal Applications," Informal INEL Report, 1977.

DISTRIBUTION RECORD FOR TREE-1182

<u>Internal Distribution</u>

1 - Chicago Patent Group-DOE
9800 South Cass Avenue
Argonne, Illinois 60439

1 - C. A. Benson
Idaho Operations Office-DOE
Idaho Falls, ID 83401

1 - H. P. Pearson, Supervisor
Information Management

10 - INEL Technical Library

100 - Author

54 - Special Internal

<u>External Distribution</u>

3 - Special External

442 - UC-66g - GE: Direct Applications of Heat from Geothermal Resources, TID-4500, R66

Total Copies Printed - 612