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**SELECTED GEOTHERMAL TECHNICAL ASSISTANCE
EFFORTS AT EG&G IDAHO, INC.**

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U.S. Department of Energy

Idaho Operations Office • Idaho National Engineering Laboratory

This is an informal report intended for use as a preliminary or working document

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EG&G Idaho

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ABSTRACT

As part of DOE's geothermal outreach program, EG&G Idaho has been funded since 1977 to provide technical assistance and information to parties interested in the direct applications of geothermal energy.

Interest in information developed under this technical assistance program is widespread, but many of the efforts do not warrant publication as individual reports. This report documents a selection of these efforts related to space conditioning, district heating, and heat exchanger considerations.

CONTENTS

ABSTRACT	ii
INTRODUCTION	1
SPACE HEATING	2
Single-Family Residence--Reno, Nevada	2
Bowers' Mansion--Carson City, Nevada	6
Crystal Hot Springs Facilities--Honeyville, Utah	9
Monroe Hot Springs Facilities--Monroe, Utah	12
South Sanpete School District--Manti, Utah	16
Water Source Heat Pump Technology for Space Heating of Fish and Wildlife Service Facilities	22
Heat Pump Economics Based on Well Depth and Heat Load-- New York State	29
Greenhouse Heating with Cascaded Commercial Heat Pumps-- Boulder, Colorado	34
Greenhouse Waste Heat Recovery with Heat Pipes--Utah	40
Greenhouse Heating--Pierre, South Dakota	41
DISTRICT HEATING	46
Morningside Heights Subdivision--Boise, Idaho	49
Givens Hot Springs--Marsing, Idaho	50
District Heating Expansion--Ketchum, Idaho	53
District Heating System Cost Estimate--Midwest and Edgerton, Wyoming	57
Geothermal District Heating--Cascade, Idaho	62
HEAT EXCHANGERS	71
Residential Downhole Heat Exchanger--Idaho Falls, Idaho	71
Cistern Heat Exchanger--White Sulfur Springs, Montana	77
Septic Tank Heat Exchanger--Coeur D'Alene, Idaho	81
REFERENCES	87

FOREWORD

The Geothermal Technical Assistance Program was developed under the premise that the majority of groups or individuals with available geothermal resources do not have the experience or manpower necessary to do a preliminary engineering and economic feasibility evaluation for geothermal energy projects. In order to disseminate technical information and to facilitate expanded use of geothermal energy resources, assistance was provided through FY-1981 in a consulting format on a first-come, staff-and-funds-available basis. Technical assistance can relate to conceptualization; engineering; economics; water chemistry implications for environmental, disposal, and material selection considerations; and planning and development strategies. This report is one of a series adapted from consultation provided to requesters either through in-house efforts or through limited efforts subcontracted to local engineering firms. The Geothermal Technical Assistance (GTA) reports in this series, which are listed below, will be available for purchase early in 1982 by those with interest in specific geothermal applications from the U.S. National Technical Information Service:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 557-4650

<u>GTA</u> <u>Report Number</u>	<u>EG&G</u> <u>Report Number</u>	<u>Title</u>
1.	*EGG-GTH-5512	<u>Aquaculture Facility Potential at Boulder Hot Springs, Boulder, Montana</u>
2.	*EGG-GTH-5521	<u>Preliminary Geothermal Disposal Considerations, State Health Laboratory, Boise, Idaho</u>
3.	*EGG-GTH-5573	<u>Geothermal Conversion at Veterans Hospital, Boise, Idaho</u>

<u>GTA Report Number</u>	<u>EG&G Report Number</u>	<u>Title</u>
4.	*EGG-GTH-5574	<u>Geothermal Applications for Highway Rest Areas</u>
5.	*EGG-GTH-5575	<u>Geothermal Applications for a Tannery</u>
6.	*EGG-GTH-5599	<u>Preliminary Conceptual Design for Geothermal Space Heating Conversion of School District 50 Joint Facilities at Pagosa Springs, Colorado</u>
7.	EGG-GTH-5617	<u>Selected Geothermal Technical Assistance Efforts</u> (comprising short descriptions of ten space heating projects, five district heating projects, and three heat exchanger projects)
8.	*EGG-2137	<u>Geothermal Source Potential and Utilization for Methane Generation and Alcohol Production</u> (subcontractor report)
9.	*EGG-2138	<u>Geothermal Source Potential and Utilization for Alcohol Production</u> (subcontractor report)
10.	*EGG-2139	<u>Potential Geothermal Energy Applications for Idaho Elks Rehabilitation Hospital</u> (subcontractor report)
11.	*EGG-2144	<u>Technical Assistance Report on a Geothermal Heating Utility for Lemmon, South Dakota</u> (subcontractor report)
12.	*EGG-2145	<u>Economic Analysis for Utilization of Geothermal Energy by North Dakota Concrete Products Company</u> (subcontractor report)
13.	*EGG-2146	<u>Geothermal Feasibility Analysis II for Polo School District No. 29-2, South Dakota</u> (subcontractor report)
14.	*EGG-2147	<u>Preliminary Feasibility Study of Heating and Cooling Alternatives for Nebraska Western College, Scottsbluff, Nebraska</u> (Subcontractor report)
15.	*EGG-2148	<u>Inventory of Thermal Springs and Wells Within a One-Mile Radius of Yucca Lodge, Truth or Consequences, New Mexico</u> (subcontractor report)

<u>GTA Report Number</u>	<u>EG&G Report Number</u>	<u>Title</u>
16.	EGG-2149	<u>Utilization of Geothermal Energy, Feasibility Study--Ojo Caliente Mineral Springs Company, Ojo Caliente, New Mexico (subcontractor report)</u>
17.	*EGG-2150	<u>Geothermal Heated Office Building at Glenwood Springs, Colorado (subcontractor report)</u>
18.	EGG-2151	<u>Final Report--Dickinson Geothermal Study, Dickinson, North Dakota (subcontractor report)</u>
19.	EGG-2152	CANCELLED
20.	EGG-2153	<u>Comparison of Two Options for Supplying Geothermal Energy to the Veterans Adminis- tration Medical Center, Marlin, Texas (subcontractor report)</u>
21.	EGG-2154	<u>Geothermal Utilization at Castle Oaks Subdivision Castle Rock, Colorado (subcontractor report)</u>
22.	EGG-2155	<u>Space Heating for Twin Lakes School Near Gallup, New Mexico (subcontractor report)</u>
23.	*EGG-2156	<u>Pumping Tests of Well Campbell et al. No. 2, Gila Hot Springs, Grant County, New Mexico (subcontractor report)</u>
24.	*EGG-GTH-5739	<u>Geothermal Deicing of Highways and Bridge Structures</u>
25.	*EGG-GTH-5740	<u>Assessment of a Geothermal Application at Tucson, Arizona</u>
26.	*EGG-GTH-5741	<u>Heat Pump Systems for Spring Creek, Montana</u>
27.	EGG-GTH-5779	<u>Pipe Selection Guide</u>
28.	EGG-GTH-5804	<u>An Overview of Engineering and Agricultural Design Considerations of the Raft River Soil-Warming and Heat-Dissipation Experiment</u>
29.	EGG-GTH-5812	<u>Design of the Glenwood Springs Downhole Heat Exchanger</u>

*Published as of 4/1/82

SELECTED GEOTHERMAL TECHNICAL ASSISTANCE EFFORTS
AT EG&G IDAHO, INC.

INTRODUCTION

The Geothermal Technical Assistance Program was developed under the premise that most groups or individuals owning available geothermal resources do not have the experience or manpower necessary to evaluate the engineering and economic feasibility of using geothermal energy to develop projects. The program has provided requesters with consultative assistance in conceptualization; engineering; economics; water chemistry implications for environmental, disposal, and material selection considerations; and planning and development strategies. Since competition with private sector consultants or engineering firms was not intended, detailed engineering design, drafting, specifications, and proposal preparation were not provided under the program.

Requests for technical assistance have been varied; most have dealt with preliminary economic and engineering considerations, and some have addressed only a single aspect of a geothermal project. Most requests have been related to the use of geothermal energy for space heating, often involving conversion of an existing conventional heating system to a geothermal system.

Many of the assistance efforts made in response to these requests do not warrant formal documentation as individual reports, although the information and data developed may have potential for widespread use. Therefore, a selection of these efforts related to space heating, district heating, and heat exchanger considerations are presented in this report. Although the program does not customarily provide assistance for the use of geothermal resources with temperatures below about 90°F, ground water heat pump technology and water temperatures below 90°F are addressed in response to a limited number of requests.

SPACE HEATING

Technical assistance in preliminary evaluation of geothermal space heating potential has been provided for a variety of proposed projects, including single-family homes, various public or government facilities, recreational facilities, and commercial greenhouse developments. The following examples illustrate the variety of efforts made in responding to the needs of requesters.

Single-Family Residence--Reno, Nevada

Use of 145°F domestic well water to provide space heating and domestic hot water heating was investigated for a Reno, Nevada homeowner. A preliminary cost estimate developed for supplying a peak heat load of about 140,000 Btu/hr to the 3700 ft² home forecast a simple payback in about 16 years. The estimate and forecast were based on 1979 costs of \$4800 for a well pump, piping, heat exchangers, controls, and engineering design. The concept for using the existing well included retention of the existing hydronic heating loop without modification, retention of the existing gas furnace for backup, and spent geothermal fluid disposal in an existing, available surface channel.

System Conceptual Design

It was learned in discussion with an engineering firm in Reno that downhole heat exchangers (trombones) are used in some parts of Nevada. However, lack of information about local conditions precludes the evaluation of a downhole exchanger for the well at this particular home. Therefore, the conceptual design is based on pumping the well. A downhole heat exchanger may, however, be a viable option that would eliminate the water disposal problem. The conceptual design shown in Figure 1 served as the basis for estimating costs. This conceptual design was based on the following assumptions:

- 3700 ft² house
- 6000 degree days

Figure 1. Conceptual design of geothermal space heating conversion for single-family residence in Reno, Nevada.

- -5°F design temperature
- Design heat load of approximately 139,000 Btu/hr
- Annual heat load of approximately 268 million Btu
- 145°F geothermal water supply
- No modifications to existing heat distribution system.

Cost Estimate (1979)

Capital and annual cost estimates are given in Tables 1 and 2, respectively.

TABLE 1. CAPITAL COST OF GEOTHERMAL CONVERSION FOR A SINGLE-FAMILY RESIDENCE IN RENO, NEVADA

<u>Equipment</u>	<u>Cost (\$)</u>
Pump	1200
Pipe (to house and disposal area)	300
Hot water heater	300
Heat exchanger	1100
Valves and controls	500
Engineering	<u>200</u>
Total capital cost	4800

TABLE 2. ANNUAL COST OF GEOTHERMAL CONVERSION FOR A SINGLE-FAMILY RESIDENCE IN RENO, NEVADA

<u>Cost Source</u>	<u>Cost (\$)</u>
Yearly maintenance	90
Well pumping cost	120
Amortization (@10% over 20 years)	<u>564</u>
Total annual cost	774

Cost Comparison and Estimated Payback

The estimated geothermal energy delivery cost is approximately \$2.40/10⁶ Btu. Electricity in the area costs approximately \$14/10⁶ Btu, and natural gas costs approximately \$3 to \$4/10⁶ Btu.^a If natural gas at \$4/10⁶ Btu were used, the yearly savings would be approximately \$300. Thus the system would pay for itself in approximately 16 years.

While this payback period seems long, it should be noted that these calculations do not include:

a. Reno natural gas rates are expected to increase from \$3.05 to \$10/10⁶ Btu.

- State or federal tax benefits for conversion to alternative energy supplies
- Future increases in natural gas prices
- Future increases in electrical energy prices.

The first two items would tend to decrease the payback period.

Recommendations

The following course of action is recommended:

- Discuss the present heating system with the plumber who designed it, and try to find out what temperature he designed the system for. If the system is designed for approximately 120 to 140°F, the geothermal system installation will be simplified. Obtain any drawings or sketches used in the construction of the system.
- Talk to individuals in the vicinity who have geothermal heating systems and discuss the following issues:
 - Who designed and installed their systems?
 - Do they use downhole heat exchangers?
 - If they pump their wells, where do they discharge the water?
 - What type of maintenance problems do they have (corrosion, pump failures, leaks, etc.)?
 - What would they do differently if they redesigned their systems?

- Request a local engineering firm with geothermal experience to independently review the heating system. Ask them to propose a system and to estimate the engineering and construction costs for it. An engineering firm should perform this service at no cost or nominal cost. This estimate, based on local expertise, should provide additional information to help decide whether or not to convert to geothermal heating.

Bower's Mansion--Carson City, Nevada

Early in 1979, the Nevada State Department of Energy requested guidance and preliminary assessment of the potential of an available, low-temperature (approximately 110°F) geothermal well for providing freeze protection in a local historic structure and tourist attraction known as Bower's Mansion. Conversion to geothermal heat was being considered because of the increasing cost and scarcity of the fuel oil used in the existing oil-fired hydronic system. Constraints on conversion conceptualization included aesthetic considerations and cost limitations.

Bower's Mansion, located near Carson City, Nevada, is a two-story, granite block, residential structure, dating from 1864. The mansion, with about 3,800 ft² per floor, features 12-ft ceilings and an open staircase leading to the second floor. The mansion was restored recently and is currently maintained as a historical site and tourist attraction. Adjacent thermal pools, using thermal well water, are maintained for public bathing. A high winterime flow to the pools is maintained to prevent freeze damage.

An oil-fired, hydronic baseboard-convection space heating system is used in winter to provide an inside temperature in the range of 50 to 55°F. Although the system is capable of maintaining a higher temperature, there is no need to do so; heat is needed only to prevent freezing. Because of high fuel cost and uncertain heating oil supplies, conversion of this heating system to use geothermal water from the nearby thermal well is being considered.

The well is 207 ft deep, with a top casing diameter of 10 in. An existing water right allows production of up to 60 gpm to supply public pools at the site. A 5-hp submersible pump set at 45 ft produces the necessary flow throughout the year. A 2-1/2-in. copper supply line buried in decomposed granite at 3- to 4-ft depths carries the water from the well to a water treatment building by the pools, a distance of about 200 ft. Well water temperature has been reported to be 117°F; however, measurements in February 1979 showed temperatures of 113°F at the submersible pump and 106°F at the water treatment building. This large temperature drop indicates substantial heat loss from the 200-ft supply line. The loss is probably due to wet soil conditions around the line. Significant soil moisture seems likely in view of the springs nearby, the high soil porosity, local topography, and the presence of melting snow cover at the time of the temperature measurements.

In view of the low geothermal water temperature and the limited water right, an effective geothermal conversion of the mansion's heating system may require watertight insulation of the supply line and the return of heating system effluent to the pools.

The space heating system has a forced circulation rating of 244,000 Btu/hr, thought to be adequate to maintain an inside wintertime temperature in excess of 70°F, if desired. The chief concern, however, is maintaining the temperature above freezing.

Inspection of the heating system indicates that the baseboard convectors are appropriate for water temperatures near 190°F. The system lines appear to be of 3/4-in. tubing, with relatively small fins spaced eight or ten to the inch. Convectors are installed on most of the available exterior and interior walls of the ground floor. There is no provision for direct heating of second floor areas, but the open staircase allows heat from the ground floor to rise to these areas.

In this analysis, it is assumed that the water quality will permit direct circulation of geothermal water in the space heating system without undue corrosion or deposition. This assumption is based on the low total

dissolved solids (approximately 212 ppm); however, an analysis of the water should be performed to determine its present chemical content, particularly silica, hydrogen sulfide, dissolved oxygen, carbon dioxide, carbonates, sulfates, and pH. Possible local statutory or code limitations on the use of heating system effluent in public pools should also be investigated.

The existing baseboard system is a zoned or parallel system that avoids the low supply temperatures encountered at downstream locations in series systems. The existing systems' heating capacity can be expected to be about one-sixth the design capacity if thermal water from the nearby well is circulated through the baseboard convectors at a rate of 2 to 3 gpm.^a

The local outside winter design temperature is reported to be 7°F; with this outside temperature, the existing system should be capable of maintaining an inside air temperature near 40°F, given an inlet temperature of at least 110°F and total flow near 15 gpm. Providing a higher inside temperature under winter design conditions will require modification of the heating system.

Modifying the system to obtain greater heating capacity must not effect the aesthetic qualities of the structure. This rules out replacement of the baseboard convectors with two-tube or cabinet convectors, or conventional installation of cabinet fan-coil units in the system. A more appropriate modification might involve installation of two or more ducted fan-coil or unit heaters beneath the floor with registers strategically located near cold spots or outside doors where infiltration losses are high. Another alternative that could increase the heating capacity of the baseboard convector system would be a forced-air flow over appropriate convectors from below the ground floor. This would require air passages through the floor

a. This conclusion is based on data from the Handbook of Air Conditioning Heating and Ventilating (ASHRAE), The Industrial Press, 1965, New York, NY.

beneath selected convectors, a supply of forced air to the passages, adequate electrical circuitry, and modification of the convector covers.

Alternatively, a zoned pipe-coil system might be installed beneath the main floor, augmenting the existing convector system. This pipe coil could be of PVC or other appropriate plastic material. Since heat transfer characteristics of plastics are generally inferior to metals, more pipe will be required. However, the installed cost should be significantly less. The heat output of a 3000-ft-long grid should adequately supplement the convector system under winter design conditions, when both systems are supplied with 110°F geothermal water. The presently maintained temperature of 50 to 55°F should be attainable.

A heat exchanger and closed-circulation system for geothermal heating has not been considered because of the low geothermal supply temperature and the low total dissolved solids in the water.

These rough estimates indicate that the contracted conversion costs can be expected to be in the range of \$5,000 to \$10,000 (1979), depending on the extent of modification and the mode of conversion selected. If \$10,000 or so is to be spent, other possibilities such as complete system renovation, solar augmentation, or application of heat pump technology should be investigated--especially with a view to obtaining cost comparisons for alternative methods of reaching the desired objectives.

If, on the basis of these preliminary observations, the conversion appears warranted, an in-depth engineering analysis of the system and more precise local material and labor or contractor costs should be obtained through appropriate investigation and consultation.

Crystal Hot Springs Facilities--Honeyville, Utah

The owner of Crystal Hot Springs requested an investigation of using a 130 gpm, 140°F flow of geothermal water to provide space heating and electrical energy for a lodge and swimming pool facility.

The following assumptions were made:

- 71 to 80% relative humidity
- 7.6 mph winter windspeed (average)
- -10°F design winter temperature
- 98 to 102°F swimming pool temperature in winter and approximately 85°F in summer
- 65°F design wet bulb temperature.

Lodge Heating System

The flow and temperature of the water supply (approximately 130 gpm and 140°F) are adequate to satisfy the heating requirements of the lodge. The existing natural-gas-fired system for hot water heating could be retrofitted to allow a tie-in for the hot water generated from the geothermal resource. The existing system could be retained for backup capability or to meet subnormal winter conditions. A clean secondary water stream should be used to avoid material corrosion and heating system capacity loss due to deposition and scale buildup. Quick approximations of the lodge size and design conditions show a heat loss of nearly 190,000 Btu/hr. Oversizing this load by 25% to ensure adequate design gives about 237,500 Btu/hr. Assuming that a temperature drop of 20°F is possible through the heat exchanger, a flow of 24 gallons per minute ($0.05 \text{ ft}^3/\text{sec}$) of geothermal water is required. With a plate-type heat exchanger, a closer approach temperature and lower flow are feasible. The cost for a plate type heat exchanger would about \$1,750.00 (1980). A tube and shell type would be less expensive, but would require more complex and costly maintenance.

Swimming Pool Heating System

It was assumed that the swimming pool temperature is maintained at 98 to 101°F during the winter and about 85°F during the summer. Heat losses

$$\text{heat loss} = \frac{3.5 \text{ Btu}}{\text{hr}/^{\circ}\text{F}/\text{ft}^2} \times 1600 \text{ ft}^2 \times (100^{\circ}\text{F} - 65^{\circ}\text{F}) = 196,000 \text{ Btu/hr}.$$

The diagram illustrates a hydronic heating system layout. At the bottom, a 'Swimming pool' provides 196,000 Btu/hr of heat. Water circulates from the pool through a pump to a 'Lodge' and a 'Soaking pool'. The 'Lodge' receives 19.6 gpm of water at 140°F, which then returns to the pool at 100°F. The 'Soaking pool' receives 139.6 gpm of water at 120°F, which then returns to the pool at 98°F. A 'Mixing box' combines the return water from the lodge and the soaking pool before it is distributed to four 'Jacuzzi' units, each receiving 13.5 gpm. The system also includes a '24 gpm' flow at 140°F and a '55°F' temperature point at the top left.

Figure 2. Flow diagram of Crystal Hot Springs heating systems.

Electrical Generation

Electrical generation was examined for both the cold water resource in a hydropower application and the hot water resource in a freon engine generator.

Generation of electricity with the freon engine may be possible, although the temperature normally required for such an application is somewhat higher than the 140°F at Crystal Hot Springs. The following calculation, made with formulas from Sun Power Systems, Inc., Sarasota, Florida, shows the horsepower needed to run the freon engine generator:

$$\begin{aligned}\text{Horsepower} &= (T_h - T_c) \times 0.0035 \times \text{flow} \\ &= (140^\circ\text{F} - 55^\circ\text{F}) \times 0.0035 \times 128.91 \text{ gpm} = 38.4 \text{ hp} .\end{aligned}$$

Conversion to electrical power, assuming a 30% inefficiency loss, yields 20 kW. Twenty kW would be sufficient to handle the present electrical demand. It must be noted, however, that detailed analysis of monthly electrical consumption is needed before the final size can be selected. This analysis should consider the maximum peak hour consumption for the proper size selection. Estimated cost is about \$5,000 (1980). Detailed engineering and installation costs would be required in addition to the initial capital cost.

Monroe Hot Springs Facilities--Monroe, Utah

The owner of Monroe Hot Springs requested a review of the geothermal development potential at the hot springs. This review was based on an earlier feasibility study for expanded facilities and on engineering blueprints covering residential-restaurant-spa expansion. The existing facility is supplied by a spring-fed, open-ditch collection system that provides a maximum flow of about 200 gpm at a mixed temperature near 150°F. This system is subject to significant adverse impact through occasional surface water flooding and evaporative and seepage losses. The existing system is believed to require excessive maintenance. However, existing spa facilities are served adequately.

The blueprints and feasibility report provided were reviewed and returned to the requester. The feasibility study should be updated to consider current conditions and development plans in order to support application to financial institutions.

The design for facility expansion includes new dressing rooms, showers, private therapeutic pools, restaurant-dining facilities, etc. Air handlers and hot water coil systems designed for operation with 140°F water and a total flow of 100 gpm at peak capacity are included. It is unlikely that all systems will operate at capacity at the same time because of the different operating cycles associated with restaurant-spa demands. As is customary, excess capacity appears to be included in the system design. The excess capacity appears adequate to allow space heating for the 2900-ft² residential addition with little effect on the total flow requirement. With a 140°F water temperature, a forced-air system extracting heat from finned water coils is probably the best design choice for the residential heating. This type of system would allow air conditioning if desired. It also has a quick response to changes in outside temperature.

The proposed heating system design appears quite adequate and readily adaptable for conversion to geothermal heating. The complexity and cost of the conversion will depend to a great extent on the temperature and quality of the geothermal water. Direct circulation of the available geothermal water in the heating system components should be avoided because of the chemistry of the water. Consideration should also be given to a closed circulation loop for heating in conjunction with the heat exchanger to prevent deposition in or corrosion of heating system components. Using a heat exchanger will tend to increase capital cost, and higher temperature geothermal water will be required to minimize impact on the existing heating system design. A plate-type heat exchanger could readily provide the 140°F system design temperature from 150°F or hotter geothermal water. The geothermal flow rate required to service the existing design and residential heat load would be in the neighborhood of 110 gpm in order to minimize heat exchanger cost. Cost of an appropriate plate-type exchanger is estimated to be about \$6,000. This cost could be recovered by eliminating the coal-fired hot water boiler included in expansion plans and by locating the heat

exchanger in the boiler room, assuming that the boiler is not required for backup of the geothermal supply system. Allowing for maintenance, the heat exchanger would require a floor area of about 4 x 6 ft.

Modification of the existing copper-coil and tank heat exchanger to accommodate an increased heat load can be considered. However, in view of the intention to expand the heating system load to include a greenhouse, a 10 unit motel, and prawn ponds, it seems more appropriate to consider a more efficient heat exchange mechanism that could service the extended heat load within the estimated geothermal flow limitation of approximately 200 to 250 gpm. Preliminary estimates of peak flow requirements for elements of the expansion plans are shown in Table 3.

System concepts for raceway and pond designs using geothermal water for prawn culture should be further investigated. The optimum system temperature, near 85°F, could be maintained by the discharge from the space heating systems during the heating season. Knowledgeable people should be consulted concerning the water chemistry and flow requirements to maintain proper oxygen levels and the flow design parameters to accommodate biological loading.

TABLE 3. PEAK FLOWS^a

<u>Systems</u>	<u>Flow (gpm)</u>
Dressing rooms, private therapy pools, dining area, and lobby	46
Dressing and shower areas	22
Food preparation area	30
Residence	<u>10</u>
	108
Motel, 2500 ft ²	15
Greenhouse, 40,000 ft ²	<u>200</u>
Peak flow for full expansion	323

a. Estimates made on the basis of available information.

The existing spring-fed system for supplying thermal water to the pool and to tropical fish ponds consists of collection and supply piping, open ditch-work, and an open tank and pipe-coil heat exchanger. Total collective flow is understood to be near 200 gpm with an average or mixed temperature of 140 to 150°F. Heating demand caused by the proposed expansion of facilities appear to require full use of the available flow. It appears desirable to replace the open channels with plastic piping. This will eliminate seepage losses, and will reduce temperature losses if the plastic pipe is buried. Further, insulating and waterproofing the buried pipe where it is routed through wet ground should be considered. Piping the geothermal water to a conventional or plate heat exchanger would allow supply system pressurization by pumping and more effective extraction of the available heat. Deposition problems would be limited to the heat exchanger, and maintenance efforts would be focused on the heat exchanger and the collection system. The effects of flash flooding or inclement weather would be reduced or eliminated.

The possibility of obtaining geothermal water from the nearby well originally intended to supply a district heating system should be evaluated. Water from this well would be at a higher temperature and, if demand warranted, at a higher flowrate than the existing spring flow, thereby allowing more extensive development. Except for nearby Red Hill Spring, it is possible that production of well water will adversely affect spring flow. This possibility can be evaluated by extensive well testing. Present or future production from the well will influence supply system design since such production is assumed to result in reduction or elimination of spring flow and the substitution of flow from the well. If the well water is produced, the supply system design would be based on appropriate routing and sizing to carry the maximum flow required for the planned development. A supply pipe of 3 in. or larger is suggested for a peak flow requirement of 200 gpm or more. If the existing spring flow is developed to meet the heating demand of the expanded facilities, supply system designs which can be modified easily to accommodate geothermal water obtained from future well production should be considered. Routing and sizing of the spring-fed supply system should accommodate future conversion to supply from the well. Allowing for a future supply system conversion will undoubtedly tend to increase the initial cost of the spring-fed supply system; however, a

corresponding reduction in the cost of the future conversion can be expected. It is recommended that competent engineering consultants be hired to design the supply system for the planned expansion.

South Sanpete School District--Manti, Utah

Soon after inception of the technical assistance program in 1977, the South Sanpete School District requested a scoping analysis of using water source heat pump technology for heating and cooling in a new school district building. A comparison was made between a heat pump using a 74°F water source and a conventional coal-fired boiler system.

Advantages of heat pumps include the following:

- A heat pump supplied by a fossil-fueled electric generating plant will usually consume less fossil fuel than a conventional heating system. New electric generating plants have a 40% efficiency factor. Thus, any heat pump exceeding a COP of 1.75 uses less fuel than is expended in the direct burning of that fuel, since a typical boiler is only 70% efficient.
- Heat pumps are more heavily used during the cold nighttime hours when utility demands are minimal. Thus, electric utility companies may favor the use of heat pumps for space heating.
- Smaller, "off-the-shelf" heat pumps feature built-in air conditioning for the summer months. They are equipped with an automatic or manual switchover valve arrangement through which heat is rejected to the water from the space being served.

The following assumptions have been made:

- 6500 degree days/year
- 50 degree days/day, worst case conditions
- 40 Btu/hr/ft²

- 20,000-ft² school
- 800,000-Btu/hr total heat load
- 74°F hot spring
- 3/4-ft³/sec (337 gpm) flow
- 36% duty function on heating system
- \$0.0174/kWh electric cost
- \$26/ton delivered coal cost
- 1- to 1-1/4-mile transmission piping
- 200 to 300 ft/mile elevation drop.

Using these assumptions, a rough cost estimate was made for a coal-fired hot water boiler and for a heat pump heating/cooling system.

Heat Pump System

The heat pump system analyzed would serve 75 individual room units with below window sill installation and having the following specifications:

- 10,600 Btu/hr/unit
- Manual change over thermostat (heating/cooling mode)
- 3 gpm/unit (x 75 = 225 gpm total flow)
- 8°F heat extraction
- 71.25 kW/heat pump electrical input
- 220 V single phase

- \$200/unit installation cost
- 3.27 coefficient of performance.

Using these specifications, costs (1977) were calculated for the heat pump system. Distribution piping within the school was not included, since this cost would be equivalent to the distribution piping for a hot water boiler application. No provision was made for expansion joints or circulation pumps. The 300 ft elevation head from the spring to the new proposed school would develop 130 psi. Pipe friction losses for transporting the hot water would be 80 psi, leaving 50 psi to supply distribution flow. (Assumed velocity is 5.67 ft/sec.)

Summary

A brief overview of the comparison between heat pumps and the boiler heating system reveals the following:

- Annual fuel costs are very close--\$3700 for coal and \$3900 for electricity for heat pumps.
- Capital costs for purchasing and installing a boiler system are lower than those for a heat pump system. It should be noted that (a) even if the spring were located within school grounds, thus eliminating transportation costs, lower costs favor the boiler, and (b) the air conditioning benefit should be investigated. Heat pumps provide both heating and cooling and therefore should be compared to a combined boiler heating system and an air conditioning system.
- Adding a roof-top air conditioner to the hot water boiler heating system would cost \$90,000. The same amount is estimated for a heat pump system providing heating and cooling and supplied by a 74°F spring on school grounds. If the supply water must be transported up to one mile, the economics begin to favor the boiler system.

- Another practical concept is that of using a vapor compression water chiller. Reversing the operation of the water chiller would effectively develop the heat pump principle. The cost of this system when used in conjunction with the boiler system is favorable even if the spring water must be transported 6500 ft. The concept discussed in the last item has been considered by Westinghouse Electric Corporation, who have coined the word "Templifier" for the application of their water chillers to heat recovery systems.

We thus find that, using the 74°F spring and transporting water 6500 feet, a heat pump should be economically feasible. Therefore, the South Sanpete school district should continue to look into heating systems that could be used with the hot spring. Local codes and regulations governing geothermal use and state programs and grants for alternative energy sources should also be investigated.

Cost Analyses

Heat pump system costs are presented in Table 4.

Coal-fired hot water boiler costs, including necessary handling functions, dampers, etc. (as quoted by a Salt Lake City firm), are presented in Table 5. These costs are based on the following assumptions:

- \$12.50/ft for baseboard convectors
- \$7.80/ft installation cost
- \$250 for miscellaneous fittings
- 1370-Btu/ft baseboard convection
- 584 ft of convectors required
- \$26/ton coal cost

TABLE 4. HEAT PUMP SYSTEM COSTS (1977)

Cost Item	Schedule 40 Steel (\$)	Asbestos-Cement (\$)	PVC (\$)
Unit Costs			
Pipe, 4-in. (per ft)	3.00	2.40	0.91
Valves (each)	500	500	500
Installation, welded steel or gasket joint (per ft)	6	1	1
Insulation	0	0	0
Excavation (per ft) ^a	0	0	1.20
Heat pumps (each)	600	600	600
System Costs			
Pipe (6500 ft)	19,500	17,000	6,000
Installation	39,000	6,500	6,500
Insulation	0	0	8,000
Heat pumps (75)	<u>45,000</u>	<u>45,000</u>	<u>45,000</u>
Subtotal	119,500	84,500	81,500
Contractor O and Pr @ 25%	30,000	21,000	20,000
Contingency @ 25%	<u>30,000</u>	<u>21,000</u>	<u>20,000</u>
Total	179,500	126,500	121,500
Total, nearest \$1000	180,000	127,000	122,000
Yearly electrical cost	365 days x 24 hrs/day x 71.25 kW x 0.36 x \$0.0174 = \$3910.		

a. Trenching cost based on 2-ft bury backfill--no other special preparation.

- 11,700 Btu/lb
- 75% efficiency factor
- 143 tons/yr, approximately
- \$3718/yr fuel cost.

TABLE 5. COAL-FIRED HOT WATER BOILER HEATING SYSTEM COSTS (1977)

<u>Equipment</u>	<u>Cost (\$)</u>
Ash handling equipment	2,500
Boiler	23,000
Installation	4,000
Baseboard convectors	7,300
Installation	<u>4,555</u>
Subtotal	41,355
Contractor O and Pr @ 25%	10,340
Contingency @ 25%	<u>10,340</u>
Total	62,035
Total, nearest \$1000	62,000

Air conditioning installation costs are presented in Table 6. These costs are based on the following assumption:

- 680,000-Btu/hr total cooling load
- Installation includes diffuser and ducts.

The combined coal boiler heating and air conditioning costs are given in Table 7.

A vapor-compression water chiller modified to provide heating and cooling is now commercially available through Westinghouse Electric. The unit, known as the "Templifier," is a heat pump applied to large-scale applications. Water chiller costs are given in Table 8.

TABLE 6. AIR CONDITIONING INSTALLATION COSTS (1977)

<u>Equipment</u>	<u>Cost (\$)</u>
Roof top air conditioner	12,000
Installation	<u>6,800</u>
Total	18,800

TABLE 7. COMBINED COAL BOILER HEATING AND AIR CONDITIONING COSTS (1977)

<u>Equipment</u>	<u>Cost (\$)</u>
Ash handling equipment	2,500
Boiler	23,000
Installation	4,000
Baseboard convectors	7,300
Installation	4,555
Air conditioner	12,000
Installation	<u>6,800</u>
Subtotal	60,155
Contractor O and Pr @ 25%	15,040
Contingency @ 25%	<u>14,175</u>
Total	90,235

Water Source Heat Pump Technology for Space
Heating of Fish and Wildlife Service Facilities

A preliminary survey of the potential for using existing water source heat pump technology for space heating of facilities at the Jackson National Fish Hatchery, Jackson, Wyoming was made at the request of the Fish and Wildlife Service (FWS), Denver, Colorado. The preliminary survey information resulted in a further request to address power and water supply requirements in using ground water heat pump technology for space heating at additional FWS sites. Conceptual design, equipment specification, and

TABLE 8. WATER CHILLER COSTS (1977)

<u>Equipment</u>	<u>Cost (\$)</u>
Reciprocating water chillers (packaged unit)	28,000
Installation	2,500
Baseboard convectors	7,300
Installation	<u>4,555</u>
Subtotal	42,355
Piping (6500 ft)	6,000
Installation	6,500
Insulation	0
Valves (2)	1,000
Excavation	<u>8,000</u>
Subtotal	63,855
Contractor O and Pr @ 25%	15,964
Contingency @ 25%	<u>15,964</u>
Total	97,783
Yearly Electrical Cost	

Electrical input @ 82 kW

$$365 \text{ days} \times \frac{24 \text{ hrs}}{\text{day}} \times 82 \text{ kW} \times 0.36 \times \$0.0174 = 4,500$$

economic feasibility were to be developed by the FWS engineering personnel in support of budget requests for implementation. The information in the two subsections that follow was provided to the FWS Denver office.

Potential for Using Heat Pump Technology at Jackson National Fish Hatchery, Jackson, Wyoming

Because of rapidly escalating energy costs, the FWS Denver Office became interested in the potential for using heat pump technology to provide space heat in FWS fish hatchery facilities at Jackson, Wyoming.

A 135 gpm flow of 78°F water is supplied to the hatchery complex through 1800 ft of 6-in. pipe, indicating a low-velocity flow (greater than 2 ft/sec). Friction loss associated with the relatively low flow rate over the length of the supply pipe is estimated to be in the neighborhood of 3 to 4 psi depending on the number and type of fittings employed in the pipe system. Review of 1980 manufacturers' literature indicates that a peak coefficient-of-performance (COP)^a of 4 can reasonably be expected from water source heat pumps supplied with 78°F water. The literature indicates that a flow rate near 15 gpm and electrical consumption near 8 kW are required for each 100,000 Btu/hr of heating capacity. Thus, the 135 gpm of 78°F water has the potential to carry a 900,000 Btu/hr heat load, and the electrical load will be near 72 kW.

The exit temperature at the hatchery complex is unknown. If the uninsulated pipe is buried in dry soil below the frost line, a temperature drop of 2 or 3°F can be expected. If the pipe lies in wet soil or is above the frost line, excessive temperature loss is likely, and insulating and waterproofing those portions of the pipeline where these conditions exist should be considered. Reduction in water temperature will reduce the COP of water source heat pump equipment; however, a reduced COP may be acceptable if costs for excavation, backfill, insulation, and waterproofing are excessive. For a 10°F temperature drop, heat-pump heating capacity will be reduced by about 5 to 10%, depending on design conditions.

Water source heat pumps are available for residential or commercial applications in heating capacities ranging from 18,000 Btu/hr to more than 5,000,000 Btu/hr. Both water-to-air and water-to-water systems are available, and some manufacturers offer domestic hot water heating capability, choice of manual or automatic valve control, and appropriate circulation pumps as optional equipment.

Initial costs for water source heat pump systems may vary widely according to manufacturer. The literature indicates that initial costs for

a. COP = heat output/heat equivalent of electrical input to heat pump system.

water-to-air heat pumps with capacities ranging from 18,000 to 100,000 Btu/hr may vary by a factor of 2 (\$250 to \$500 for each 10,000 Btu/hr capacity). Comparable water-to-water heat pumps cost 15 to 20% more. Additional costs will be incurred for freight, installation, a heat distribution system (forced air or hydronic), and supply and disposal piping. It is assumed that water quality is good enough to allow direct circulation through the heat pump system.

The economic feasibility of employing water source heat pump systems for space heating can be investigated by comparing the capital and operating costs of the competing systems. Where thermal or normal ground water can be provided at low cost, the higher capital cost of heat pump systems can be recovered rapidly through savings in electrical or fossil heating energy. Evaluation of economic feasibility, which must be done on a case-by-case basis, is beyond the scope of this preliminary survey, although additional data on specific heat loads, climate, local energy, and contractor costs would allow some economic assessment.

Considerations for Using Ground Water Heat Pumps to Provide Space Heating and Tempered Water at Selected Fish and Wildlife Service Sites

Recent escalation of fossil fuel costs has led the Fish and Wildlife Service (FWS) to consider other space heating methods at sites that depend on fossil fuels for space heating and, in some cases, for tempering of water used in fish hatchery facilities. Abundant quantities of high quality water available at these sites leads to consideration of water source heat pump technology to provide the necessary heat.

Review of water source heat pump specifications and manufacturers' guidelines show that several manufacturers can provide ground water heat pump systems suitable for operation with ground water at temperatures down to about 40°F. As water temperature is reduced, the coefficient of performance (COP) and the unit amount of heat extracted from the water are also reduced so that greater amounts of water and electricity are required to service a given heat load. The effect of water temperature and flow rate on electrical consumption and the COP is shown in Table 9.

TABLE 9. ESTIMATED WATER AND ELECTRICAL CONSUMPTION FOR GROUND WATER HEAT PUMP SYSTEMS

Water Temperature (°F)	Water Flow Rate (gpm/10 ⁵ Btu/h)	Water Δt (°F)	Electrical Consumption ^a (kW/10 ⁵ Btu)	Coefficient of Performance
80	15	10	7.3	4.0
60	16.5	9	7.9	3.7
55	16.6	8.5	8.6	3.4
50	17.8	7.5	9.8	3.0
45	19.8	6.5	10.5	2.8
40	24.0	5.0	11.7	2.5

a. Does not include power for production or distribution pumping.

Water source heat pump technology is being considered for heating at FWS sites at Beulah, Wyoming; Ennis, Montana; Jones Hole, Utah; and Lawrence County, South Dakota. The Ennis site reportedly has a water flow of 15,000 gpm at 54°F, the Jones Hole site has a flow of about 11,000 gpm at 50°F, and the remaining sites have flows ranging from 400 to 1700 gpm at 51°F. Significant space heating loads exist at all sites. In addition, a 30 gpm flow of 70°F water is required at the Beulah site.

Available estimates of winter design temperatures, Fahrenheit degree days for heating, and annual use of heating system capacity for the four sites are shown in Table 10.

Space heating and water heating loads have been estimated using nominal values for the location, size, and use of structures that may be candidates for conversion to water source heat pump systems. Estimated peak and annual heat loads and power and water requirements of water source heat pump systems are shown in Table 11.

It is not possible to estimate conversion costs accurately with available information, but hydronic and forced air heating systems should present minimal conversion problems. Retaining existing heating equipment for

TABLE 10. ASSUMED DESIGN CONDITIONS

Site	Winter Design Temperature (°F)	Annual	
		Fahrenheit Degree Heating Days	Use of Capacity (%)
Beulah, Wyoming	-15	7500	--
Space heat	--	--	26
Laboratory water	--	--	100
Ennis, Montana	-25	9000	27
Jones Hole, Utah	-20	8000	26
Lawrence County, South Dakota	-20	7700	25

backup may present space restrictions on the installation of heat pump equipment, especially in smaller structures such as residences. Bare heat pump costs in residential capacities can be expected to lie in the range of \$2,000 to \$5,000, depending on capacity, selection of appropriate manual or automatic controls, and inclusion of domestic water heating capability. Larger buildings with higher heat loads may require more than one heat pump to serve zone systems. A 300,000-Btu/hr water-to-water unit will be required to heat 30 gpm of 50°F water to 70°F. Bare heat pump costs for other than residential or small buildings at the four sites will probably lie in the range of \$15,000 to \$25,000, depending largely on heating capacity required and the need for multiple units to serve zone systems.

All sites under consideration here appear to have sufficient water flow to support significant future expansion of heat loads serviced by water source heat pump equipment. It is assumed in all cases that water quality allows direct circulation through the heat pump equipment. Technically, there appears to be no barrier to the use of heat pump technology at the respective sites. The adequacy of electric power service and overall economic feasibility should be determined.

TABLE 11. ESTIMATED HEATLOADS AND ENERGY REQUIREMENTS

Site	Structure	Heat Load		Water Source Heat Pump Requirements		
		Peak	Annual	Peak		Annual
		(10^6 Btu/hr)	(10^8 Btu)	Power (kW)	Water (gpm)	Power (10^3 kWh)
Beulah, Wyoming	R&D Unit 1	0.77	17.5	77	138	175
	Ranch A-Lab ^a	0.30	26.3	30	54	263
	Residence	0.20	4.6	20	36	46
	Lodge	0.27	6.2	27	49	62
Ennis, Montana	Hatchery building	0.26	6.1	22	42	52
	Five residences	0.30	7.1	26	50	61
Jones Hole, Utah	Hatchery building	0.30	6.8	30	54	68
	Garage/shop	0.30	6.8	30	54	68
	Duplex	0.10	2.1	10	18	21
	Two residences	0.19	4.3	19	34	43
Lawrence County, South Dakota	Hatchery building	0.30	6.6	30	53	66
	Test building	0.08	1.8	8	14	18
	Three residences	0.16	2.2	10	18	22

a. Laboratory water heating to supply 30 gpm at 70°F.

Heat Pump Economics Based on Well Depth and Heat Load--New York State

At the request of the New York State Energy Research and Development Administration, estimated water source heat pump economics were compared for several heat loads, with normal ground water temperature of 55°F available at shallow depth (100 ft), and with higher temperatures due to a normal thermal gradient projected as available at greater depths.

Estimated Water Source Heat Pump Economics

A preliminary comparison of water source heat pump economics has been made using a normal ground water temperature of 55°F, available at shallow depth (100 ft, and a water temperature of 80°F obtained at depths determined by geothermal gradients of 30, 40, 50, and 60°C/km (approximately 16.5, 22, 27.4, and 33°F/1000 ft) respectively.

Peak and annual heat loads representing a school, greenhouse, single-family residence, and high rise apartment were used in the comparison. For the assumptions given above, and with electricity at 4¢/kWh, it appears that drilling wells to depths greater than those at which the normal ground water temperature is available is not economically feasible for the cases considered. Increased well drilling and production costs are not offset by increased heat pump COP. According to vendor data, the expected design COP could be increased from about 3.4 with 55°F water, to near 4.0 with an 80°F water source. These COPs are for systems operating at design conditions, which, because of changing climatological conditions, will seldom be the case in space heating applications.

From the assumptions employed, it appears that heat loads greater than those encountered for single-family residences can be satisfied economically using ground water heat pump systems supplied from shallow wells. However, if well depth exceeds a few hundred feet, the economics may not be attractive. An in-depth analysis based on site-specific conditions and costs is necessary to support more definite conclusions.

General and specific assumptions are presented below, and the data developed for comparison are shown in Tables 12 through 16; additional information on large fluid source heat pump systems and residential ground water heat pumps, respectively, can be sought from:

Mr. Richard Niess
Westinghouse Electric Corporation
P. O. Box 2510
Staunton, Virginia 24401

National Water Well Association
500 West Wilson Bridge Road
Worthington, Ohio 43085
(614) 846-9355

The following assumptions were used in this comparison:

- Climatological
 - -20°F winter design temperature
 - 7,000 Fahrenheit degree heating days
 - 23% annual system use
 - 2,015 annual operating hours

TABLE 12. HEATED STRUCTURES

Building	Peak Heat Load (10^6 Btu/hr)	Annual Heat Load (10^{10} Btu)
School (60,000 ft ²)	6.1	1.2
Greenhouse (40,000 ft ²)	4.3	0.8
Home (1,600 ft ²)	0.06	0.012
High rise apartment (100,000 ft ²)	3.4	0.7

TABLE 13. ESTIMATED WATER AND ELECTRICAL CONSUMPTION FOR GROUND WATER HEAT PUMP SYSTEMS

Water Temperature (°F)	Water Flow Rate (gpm/10 ⁵ Btu/h)	Water Δt (°F)	Electrical Consumption ^a (kW/10 ⁵ Btu)	Coefficient of Performance
80	15	10	7.3	4.0
60	16.5	9	7.9	3.7
55	16.6	8.5	8.6	3.4
50	17.8	7.5	9.8	3.0
45	19.8	6.5	10.5	2.8
40	24.0	5.0	11.7	2.5

a. Does not include power for production or distribution pumping.

TABLE 14. HEAT PUMP POWER AND WATER CONSUMPTION BY BUILDING (WATER TEMPERATURES OF 55 AND 80°F)

Building	School	Greenhouse	Home	High Rise Apartment
Heat Load				
Peak (10 ⁶ Btu/hr)	6.1	4.3	0.06	3.4
Annual (10 ¹⁰)	1.2	0.8	0.012	0.7
Water Consumption (55°F)				
Peak (gpm)	1013.	706.	10.6	565.
Annual (10 ⁶ gal)	2.04	1.42	0.2	1.14
Water Consumption (80°F)				
Peak (gpm)	945.	638.	9.6	510.
Annual (10 ⁶ gal)	1.84	1.29	0.019	1.23
Power Consumption (55°F water)				
Peak (kW)	524.6	365.5	5.5	292.4
Annual (10 ⁵ kWh)	10.6	7.4	0.1	5.9
Power Consumption (80°F water)				
Peak (kW)	445.3	210.3	4.7	248.2
Annual (10 ⁵ kWh)	9.0	6.3	0.09	5.0

TABLE 15. SYSTEM ELEMENT COST ESTIMATES (1980)

System Element	Well Depth (ft)	Estimated Costs (\$1000)			
		School	Greenhouse	Home	High Rise Apartment
Well	100	8	8	2.5	8
	764	61	61	19.0	61
	916	75	75	--	75
	1146	100	100	--	100
	1528	150	150	--	150
Pump	100	33	19	0.2	28
	764	42	26	0.5	32
	916	45	28	--	34
	1146	51	32	--	37
	1528	58	37	--	40
Annual pump power at 4¢/kWh	100	5.76	3.32	44	4.8
	764	7.28	4.48	58	5.24
	916	7.8	4.84	--	5.8
	1146	8.68	5.44	--	6.28
	1528	9.88	6.28	--	6.96
Annual maintenance	--	0.635	0.435	52	0.56
Disposal system	--	20	14	1.5	18
100-ft supply pipe	--	2.5	2.5	1.0	2.0
Heat pump system ^a	--	350	240	3.0	230
Conventional system ^a	--	200	100	1.5	130

a. Excludes identical elements of heat pump and conventional systems, duct work, terminal units, etc.

• Resource Development

- 100-ft depth to 55°F ground water
- 744-ft depth to 80°F at 60°C/km
- 919-ft depth to 80°F at 50°C/km
- 1146-ft depth to 80°F at 40°C/km

TABLE 16. ENERGY COST BASED ON ANNUAL COSTS (1980)

Cost Item	School	Greenhouse	Home	High Rise Apartment
Annual System Costs ^a with 100-ft Well and 55°F Water (\$1000)				
Well, pump, supply pipe, and disposal	7.46	5.11	0.61	6.58
Maintenance	0.64	0.44	0.05	0.56
Pump power	5.76	3.32	0.044	4.8
Net cost of heat pump system over conventional system	17.625	16.45	0.176	11.75
Heat pump power	<u>42.4</u>	<u>29.44</u>	<u>0.442</u>	<u>23.56</u>
Total	73.885	54.76	1.322	47.25
Energy Costs				
Unit energy cost (\$/10 ⁶ Btu)	8.52	9.06	10.31	9.77
Conventional fuel equivalent cost				
Oil, at 70% thermal efficiency (\$/gal) ^b	0.82	0.87	1.00	0.94
Natural gas, at 80% thermal efficiency (\$/1000 ft ³) ^b	5.82	7.25	8.25	7.82
Electricity, at 100% thermal efficiency (¢/kWh) ^b	2.91	3.10	3.5	3.3
<p>a. Annual costs based on capital cost amortization at 10% over 20 years, plus operating and maintenance costs.</p> <p>b. Thermal conversions: Oil --138,000 Btu/gal Natural gas-- 1,000 Btu/ft³ Electricity-- 3,413 Btu/kWh</p>				

- 1528-ft depth to 80°F at 30°C/km
- 100-ft supply pipe
- \$25/ft domestic well costs (1980)
 - \$70/ft for commercial production at <500 ft
 - \$80/ft for commercial production at 500 to 1000 ft
 - \$90/ft for commercial production at 1000 to 1500 ft
 - \$100/ft for commercial production at >1500 ft
- Pump Costs (1980)
 - Based at 20% total depth drawdown
 - Domestic system at \$250/hp
 - Commercial system at \$50 + \$350/hp
- Disposal system cost
 - Half the pump and well costs for a 100-ft well
- Annual system maintenance
 - Approximately 1% of the capital cost.

Greenhouse Heating with Cascaded Commercial Heat Pumps--Boulder, Colorado

Many requests are received for preliminary evaluation of using geothermal energy to heat greenhouses. In one case, a cascaded, water referenced heat pump system for up to 30 acres of greenhouses was examined for a Colorado requester. An existing well capable of producing 1400 gpm of 140°F

water was the proposed source. The investigation indicated that cascading this flow through seven heat pump stages could provide heating for about 12 acres of greenhouses under the local design conditions. The working fluid temperature at terminal heating units would be 160°F in order to obtain a heat pump COP of 6.0 in the initial stage. The cascade system could provide about 63×10^6 Btu/hr under peak heating conditions, and the capital cost for heat pump equipment would be near $\$1.3 \times 10^6$. Multiple wells would be required to heat more than 12 acres. Additional geothermal well production could be used to reduce the number of cascade stages and increase the average cascade COP by increasing the average water supply temperature.

The requester indicated that the information provided would be used by his consultant in developing appropriate design options and cost estimates, which would be included in a proposal under the Geothermal Loan Guarantee Program. The proposal for a $\$23 \times 10^6$ project was prepared for submittal during the summer of 1981. Negotiations for purchase of the good quality spent fluid by the town of Lafayette, Colorado were then in progress.

The following information developed in this assistance effort will be useful to other developers.

Water source heat pumps can be feasible for commercial greenhouse heating where a abundant supply of relatively low temperature geothermal water is available. Water at temperatures above 140 or 150°F can provide economical heat in conventionally designed terminal systems. At lower temperatures, a mechanism to increase the temperature must be employed to obtain efficient performance from the terminal heating system. Water source heat pumps can provide the necessary temperature boost.

A feasibility assessment of a greenhousing facility at the development site should consider the impacts of water chemistry and crop selection on system design and whether there is an acceptable means for disposal of the effluent. Marketability, available financing arrangements, tax law, permitting requirements, and perhaps zoning may also affect the economic feasibility and should be considered.

Assuming a flow rate of 1000 gpm at a temperature of 125°F, an imposed temperature drop of 10 to 20°F would provide from 5 to 10 x 10⁶ Btu/hr. Conventional radiant pipe-coil convectors and unit heater designs could impose a temperature drop near 10°F, while a system employing a commercial heat pump could result in 10 to 20°F reductions for single and dual-stage heat pumps, respectively. Conventional hydronic heating systems can be expected to cost from \$5000 to \$12,000 per million Btu/hr capacity, depending on system design and geothermal water characteristics. A dual-stage heat pump operating on 125°F water at a COP of 4.0 would require about 4500 gph of the 125°F fluid and 73.25 kWh of electricity for each million Btu/hr of heat output. The thermal water would be discharged at 105°F. Use of single-stage heat pumps would double the water flow requirement, and discharge temperature would be about 115°F under the same operating conditions.

As a first approximation, a greenhouse with single glazing requires a heating system capacity of about 1300 Btu/hr for each 1000 ft² of glazing and each Fahrenheit degree difference between inside and outside design temperatures. An inside design temperature of 65°F and an outside design temperature of -20°F results in a design temperature difference of 85°F, giving a heating requirement of about 1.1 x 10⁵ Btu/hr for each 1000 ft² of glazing. Double glazing should reduce the heating requirement by about 25 to 30%. Costs for greenhouse construction can be expected to be \$4 to \$5/ft² for single-glazed construction and \$5 to \$7/ft² for double glazing.

Based on the foregoing, a flow of 1000 gpm in conventional heating systems with a temperature drop of 10°F can support a greenhouse area enclosed by 45,200 ft² of single-sheet glazing, or about 64,000 ft² of double-glazed construction. Use of dual-stage heat pumps with the 1000 gpm flow could extend the double-glazed area to about 170,000 ft².

In order to maintain reasonable velocity, supply and discharge piping should be 6 to 7 in. in diameter; with pipe of this size, a well pump rated at 75 hp could provide the 1000 gpm flow under a head approaching 250 ft.

Heat exchanger use and disposal system requirements have not been addressed in the foregoing due to lack of information on water chemistry and appropriate disposal methods.

Commercial fluid-to-fluid heat pumps are available with ratings from 6×10^5 to about 20×10^6 Btu/hr (50 to 1600 tons^a). The systems may be single or two-stage centrifugal or screw compressor designs, depending on duty and manufacture. Optimum design is usually determined by the manufacturer, using proprietary computer programs and data that describe operating conditions. These designs can nominally impose a 10°F temperature drop on the heat source fluid while heating the working fluid in a closed circulating space heating loop by 10 to 35°F. Pressure drop through the heat pump condenser and evaporator can range from 2 to 20 psi, depending on size, water flow rate, and temperature. Heat pump efficiency, as indicated by COP, will vary according to design parameters and geothermal water temperatures. COP, under design conditions, can range from about 3 to 6 for source water temperatures ranging from 80 to 140°F.

Manufacturer's guidelines and data can be used to estimate the cost and performance of these systems in a cascaded greenhouse heating scheme by assuming a geothermal flow rate that is fully used at each step in the cascade. In this context, thermal water discharged from each heat pump except the last is supplied to the next heat pump in the cascade. Supply temperature is assumed to be reduced by 10°F by each heat pump in the series.

If a constant heat extraction rate from the source fluid (constant flow rate, constant temperature drop) is assumed as the source temperature varies, the gross heat output appears to increase as the heat pump COP decreases with source temperature and the electrical power required is increased. Generally, a larger, more costly heat pump will be required to fully use the source fluid at constant flow and reduced temperature. In general, neither the flow rate nor the source-fluid temperature drop across a heat pump will remain constant for various source temperatures.

a. 12,000 Btu/hr = 1 ton of air conditioning.

Heat pump COP will tend to increase with increasing source fluid temperature and to decrease with an increasing working fluid temperature requirement. Design of the terminal heating system may be influenced by considering the economics of heat pump systems operating to provide various working fluid temperatures.

From manufacturer's guidelines and data, preliminary estimates of power requirements, heat output, and bare heat pump cost for cascaded greenhouse heating can be estimated. The following assumptions were made for these preliminary estimates:

- 1400 gpm geothermal flowrate
- 5.56×10^6 Btu/acre greenhouse peak heat load
- Geothermal fluid, initially at 140°F, is cascaded through a series of heat pumps until its temperature is reduced to 70°F
- Heat pumps use total flow, and impose a 10°F ΔT on geothermal fluid
- \$250/ton heat pump cost factor (1 ton = 12,000 Btu)
- 180°F or 160°F working fluid temperature when supplied to the terminal heating system.

Data for individual heat pumps and cascaded systems under the foregoing assumptions are shown in Table 17. Each line of cascaded system data represents a system cascade from the specific source temperature to a final discharge temperature of 70°F.

Examination of data for heat pump power requirements indicates that it may not be desirable to employ the geothermal fluid at temperatures down to 80°F, where about twice as much electrical power is required to produce the same amount of heat as is produced at 140°F.

TABLE 17. CASCADED HEAT PUMPS FOR GREENHOUSE HEATING

Terminal Design Temperature (°F)	Source Flow (gpm)	Source Temperature (°F)	Heat Pump Data			Total Cascaded Systems			
			Peak COP ^a	Power Required (kW)	Delivered Heat (10 ⁶ Btu/hr)	Power Required (kW)	Delivered Heat (10 ⁶ Btu/hr)	Acres Heated	Heat Pump Cost (1980) at \$250/ton ^b (\$1000)
160	1400	140	6.0	400	8.33	4152	63.18	11.9	1316
		130	6.0	409	8.38	3752	54.90	10.4	1144
		120	5.6	447	8.54	3343	46.50	8.8	969
		110	4.8	540	8.86	2896	37.96	7.2	791
		100	4.2	643	9.21	2356	29.07	5.2	606
		90	3.5	819	9.79	1713	19.86	3.5	414
		80	3.3	894	10.07	894	10.07	1.8	210
180	1400	140	5.7	436	8.48	5086	66.41	11.4	1384
		130	5.0	513	8.75	4650	57.93	9.9	1207
		120	4.3	582	9.09	4137	49.18	8.4	1025
		110	3.7	760	9.59	3555	40.09	6.8	835
		100	3.3	894	10.07	2795	30.50	5.4	635
		90	3.2	929	10.14	1901	20.43	3.6	426
		80	3.1	972	10.29	972	10.29	1.8	214

a. Coefficient of performance.

b. 12,000 Btu/hr = 1 ton of air conditioning.

Operating cost may also be affected by the choice of design temperature for the terminal system, since the 160°F terminal temperature results in a higher heat pump COP than the 180°F design temperature allows. Whether this is a significant cost factor should be determined before final system design. Also, excessive heat pump operation under low load conditions should be avoided, and investigation of options for handling reduced heat loads may therefore be desirable. A scheme that uses fewer heat pumps, operating near design conditions, to carry the reduced heat loads may be developed through appropriate equipment sizing, backup, and distribution system designs.

If geothermal water quality requires isolation of heat pump systems from the source fluid, heat exchanger(s) will be required. An appropriate heat exchanger with a duty of 10^7 Btu/hr could cost from \$25,000 to \$75,000 depending on the type, design, and materials selected.

Assessment of the overall economic feasibility of these systems will depend on more refined cost estimates based on engineered system designs, and on the expected return from greenhouse production. When optimal heat pump configurations based on system design specifics and heat pump duty are determined, significantly increased precision and confidence in cost estimates will result.

Greenhouse Waste Heat Recovery with Heat Pipes--Utah

A Utah greenhouse operator requested preliminary assessment of using heat pipe equipment to recover waste exhaust heat lost in ventilation of a 10,000 ft² greenhouse. The recovered heat was to be used to preheat outside ventilating air.

For one air change per hour in a 10,000 ft² greenhouse with an 11-ft mean height, the rate of air change is 110,000 ft³/hr. Assuming inside and outside temperatures of 60 and 20°F, respectively, the air change represents a heat load of about 79,000 Btu/hr if the effects of differences in the humidity of the two equal air streams are neglected.

Available equipment for air-to-air heat recovery at a relatively low temperature difference includes heat pipe and heat wheel designs. Heat wheels are typically designed for larger heat loads than assumed here. Costs of heat wheel systems were not investigated. Heat pipe equipment, such as the Model 120 APS 6 ROW from Q-Dot, Incorporated, could be employed in the assumed duty cycle. On a Fahrenheit degree day basis (6,050 degree days), appropriate equipment could be used to recover about 1.8×10^8 Btu/yr under the assumed duty cycle, according to a vendor.

Equipment costs (1979) were estimated at about \$1390 by the vendor, with additional costs for installation and duct work if none exists. The vendor estimate for installation is 100% of equipment cost. Thus, in the assumed situation, capital costs will be about \$2800, exclusive of any duct work that may be required. Assuming that the recovered heat is valued at \$2.00/10⁶ Btu, the annual cost savings approach \$365. This indicated payback period may be unacceptable. Simple payback is estimated at 7.7 years. Although specific equipment manufacturers or vendors have been indicated here for illustration, no recommendation is intended. Other vendors may supply similar equipment.

Additional information on heat pipe or heat wheel equipment can be obtained by contacting respective vendors such as:

Mr. Dick Starms
Ray Industries
Boise, Idaho
(208) 375-8344

Mr. Ken Kentalla
Olympic Engineered Sales
Bellvue, Washington
(206) 454-0701

Greenhouse Heating, Pierre--South Dakota

Preliminary cost comparison between conventional oil-fired, low-pressure steam heating and geothermal heating for a small commercial greenhouse was made at the request of a Pierre, South Dakota, greenhouse operator. Escalating fuel-oil cost dictated consideration of using the

local geothermal resource for heating a 1/4-acre expansion of existing greenhouse facilities in Pierre. Local artesian geothermal wells are known to produce 112°F water at rates near 150 gpm from a depth near 1700 ft. The following analysis indicated that geothermal greenhouse heating with a low-temperature resource might be very competitive with conventional heating at 1978 costs.

Preliminary estimates of major costs associated with both conventional and geothermal heating of greenhouses in the Pierre, South Dakota, area have been made. These estimates are of a preliminary nature and are not the results of an economic feasibility study. They are based on the following assumptions:

- 140 x 52 ft greenhouse size
- 11,000 ft² glazed area
- -20°F outside design temperature
- 65°F inside design temperature
- 900,000 Btu/hr maximum heat load (double glazing)
- 2.5×10^9 Btu annual heat load (~30% use factor)
- Artesian well:
 - 1700 feet depth
 - 112°F water temperature
 - 150 gpm maximum flow rate.

An annual fuel cost of \$16,000 (1978) is estimated to represent about 35,000 gallons of fuel oil. Double glazing of the greenhouse should reduce

the annual fuel oil consumption to about 26,250 gallons, which would provide approximately 2.5×10^9 Btu/yr from a typical heating system with 70% conversion efficiency.

Although the 112°F water temperature is very low for space heating, it can be used in properly designed systems. However, these systems will be more costly than corresponding systems designed for higher water temperatures. It is advisable to retain an architectural-engineering firm to do the final system design in order to obtain optimum heating at a reasonable cost.

A conventional heating system and several geothermal alternatives are considered below for a preliminary cost comparison. The following heat systems are considered:

- Oil-fired, low-pressure steam, unit heaters
- Geothermal water, radiant plastic pipe coils
- Geothermal water, unit heaters
- Geothermal water, commercial heat pump, unit heaters.

The heat pump system includes a commercial fluid-to-fluid, dual-stage heat pump rated at 10^6 Btu/hr, with a COP of 3.5. The estimated system costs assume that all work is contracted and that contractor O&P is included.

Under design conditions, the geothermal radiant pipe coil and unit heater systems will require the entire flow capacity of the well (150 gpm), while the heat pump system will require about 65 gpm. Discharge temperatures will probably be about 92°F for the heat pump system and 100°F for the others. Temperature reduction may be required prior to using this water for cattle watering, as proposed. The heat pump will also require a maximum electrical input of about 75 kW.

Annual capital costs (1978) for each system are estimated by assuming a 20-year system lifetime and interest on borrowed money at 10%. The annual heating cost of fuel oil at 50¢/gal and electricity at 3¢/kWh are included in costs for the oil-fired and heat pump systems, respectively. Disposal, other operating costs, escalation of energy costs, possible effects of tax incentives, and depreciation allowances are not considered in this preliminary assessment.

It is difficult to estimate the cost of the 1700-ft artesian well and the supply and disposal system for the geothermal systems. Information from other locations indicates that these costs may exceed \$100,000 if deep-well drilling equipment is used. Water-well drilling equipment can be considered for wells less than 2,000 ft in depth. Well, supply, and disposal system design can all have a marked effect on costs. For comparison purposes, it is assumed that water-well drilling equipment is used at a cost of \$30,000 for the well, and that an additional \$20,000 is allowed for the supply and disposal systems and for contingency. The \$50,000 total cost is equivalent to \$5850 on an annual basis.

Under the stated assumptions, the geothermal unit heater system, which costs about 47% as much annually as the oil-fired system, appears to be the least expensive. If geothermal well, supply, and disposal system costs exceed \$117,000, the oil-fired system becomes the least expensive. The radiant pipe system appears to cost about 11% more on an annual basis than the unit heater system.

The heat pump system does not, in the stated circumstances, appear to be economically competitive with the other geothermal systems. This system would tend to be competitive for a much larger greenhouse facility. It is not known if market conditions or funding availability warrant considering a larger facility.

Estimated costs for the systems considered are summarized in Table 18.

TABLE 18. ESTIMATED GROSS AND ANNUALIZED COSTS FOR GREENHOUSE HEATING,
PIERRE, SOUTH DAKOTA (1978)

System Element	System Costs (\$)			
	Conventional Oil-Fired, Low-Pressure Steam	Geothermal		
		Radiant Pipe	Unit Heater	Heat Pump
Gross Costs				
Boiler, controls, chimney, oil storage	10,000	--	--	--
Piping, fittings, controls, circulation pumps, etc.	3,000	16,000	2,000	2,000
Unit heaters	3,000	--	8,000	3,000
Heat pump	<u>--</u>	<u>--</u>	<u>--</u>	<u>16,000</u>
Total gross costs	16,000	16,000	10,000	21,000
Annual Costs				
Amortization ^a	1,870	1,870	1,170	2.460
Fuel oil (50¢/gal)	13,130	--	--	--
Electricity (3¢/kWh)	--	--	--	6,000
Well, supply, and disposal system amortization ^b	<u>--</u>	<u>5,850</u>	<u>5,850</u>	<u>5,850</u>
Total annual cost	15,000	7,720	7,020	14,310

a. 20-yr lifetime, 10% interest.

b. \$50,000 capital cost.

DISTRICT HEATING SYSTEMS

Development of district heating systems provides a means of sharing or distributing costs of production, supply, disposal, and maintenance among a group of consumers. District heating schemes become attractive when the cost of delivered energy and its use are competitive with competing conventional heating designs. For geothermal projects, the cost of the delivered energy will tend to be lower when the production system capacity is most fully used. This implies a year around, relatively constant, near capacity load on the system. In reality, this will rarely be attainable for systems serving space heating loads. Some load leveling can be attained in residential district heating systems by including daytime peak heat load consumers such as schools and other public buildings, and retail, commercial, and office buildings where feasible. Inclusion of such consumers also provides a higher density or more concentrated heat load, thereby tending to reduce the average unit transmission cost because of shorter distribution distances. District heating systems for new subdivisions, planned developments, or installations in existing communities, requiring retrofit of terminal space heating systems, have been considered under the technical assistance program.

In order to estimate the peak volumetric flow of geothermal water needed to satisfy the space heating load for a subdivision, it is necessary to determine the total heat load that must be satisfied, the temperature drop of the water across the system at design operating conditions, and system losses. The system heat load is dependent, of course, on climatological conditions and net heat loss from the heated space and transmission lines. The water temperature drop across the system is dependent on system design and initial geothermal water temperature.

Geothermal water temperatures below about 120°F probably limit choices of heating system types to heat pump and hydronic radiant floor panel designs. Higher water temperatures would allow consideration of hot water coil, forced-air, and hydronic convection systems as well.

Review of water source heat pump specifications and manufacturers' guidelines show that several manufacturers can provide ground water heat pump systems suitable for operation with ground water at temperatures down to about 40°F. As water temperature is reduced, the coefficient of performance (COP) and the unit amount of heat extracted from the water are also reduced so that greater amounts of water and electricity are required to service a given heat load. The effect of water temperature and flow rate on electrical consumption and the COP is shown in Table 19.

TABLE 19. ESTIMATED WATER AND ELECTRICAL CONSUMPTION FOR GROUND WATER HEAT PUMP SYSTEMS

Water Temperature (°F)	Water Flow Rate (gpm/10 ⁵ Btu/h)	Water Δt (°F)	Electrical Consumption ^a (kW/10 ⁵ Btu)	Coefficient of Performance
80	15	10	7.3	4.0
60	16.5	9	7.9	3.7
55	16.6	8.5	8.6	3.4
50	17.8	7.5	9.8	3.0
45	19.8	6.5	10.5	2.8
40	24.0	5.0	11.7	2.5

a. Does not include power for production or distribution pumping.

At design operating conditions, a home with a 50,000-Btu/hr heat load could be heated with a water source heat pump system requiring about 7.5 gpm of 80°F water with electrical consumption near 3.7 kW. Under these conditions, a 200-home subdivision would require peak production and disposal of 1500 gpm of geothermal water.

A zoned, radiant floor panel residential heating system using 105°F geothermal water and designed to effect an average temperature drop of about 10°F would require 10 to 12 gpm to provide 50,000 to 60,000 Btu/hr heating; 200 such homes would require up to 2,400 gpm of geothermal water.

Availability of geothermal water at higher temperatures would allow consideration of other heating system designs, using lower flow rates in

most instances. Examples of estimated water temperature and flow required to service a 50,000- to 60,000-Btu/hr heat load are shown in Table 20:

TABLE 20. ESTIMATED WATER TEMPERATURE AND FLOW REQUIRED TO SERVICE A 50,000- TO 60,000-BTU/HR HEAT LOAD

	Water Temperature (°F)	Water ΔT (°F)	Flow (gpm)
Hot water coil, forced air	120	10	11.2
	140	12	9.3
	160	25	4.5
Baseboard convector (zoned)	140	12	9.3
	160	20	5.6
	180	28	4.0

The total geothermal water flow required for subdivision heating will depend on the available geothermal water temperature and the mix of heating system designs employed in the development. If the chemical content of the water should require use of heat exchange equipment to isolate the heating systems, additional flow may be required. An initial estimate of the geothermal water flow required to heat a subdivision could be based on an average residential design heat load and a representative mix of heating system designs, together with the most probable available geothermal water temperature. An estimate of transmission heat losses should be included.

In addition to technical aspects of district heating systems, the economic, legal, institutional, and regulatory constraints on development must be addressed in assessing the overall feasibility of district heating systems.

The technical assistance efforts involving district heating concepts that are described here briefly address particular concerns of the requesters and are not feasibility studies, as such.

Morningside Heights Subdivision--Boise, Idaho

In late 1978, JUB Engineers of Boise, Idaho, requested assistance in evaluating the potential for geothermal district heating in the Morningside Heights Subdivision then under design. Specifically, an initial concept and cost estimate for the district heating system was requested.

Morningside Heights is located near the old Idaho State Prison, encompassing development on the bench above the prison as well as on the plain between the prison and the bench. The difference in elevation is about 300 ft. The preliminary design called for construction of 123 single-family homes and 89 condominium units, ranging in size from 1800 to 3000 ft². Projected per unit sales prices ranged from \$80,000 to \$200,000 (1979 dollars). Unit design heat loads ranged from 5.5 to 10.1 x 10⁴ Btu/hr with an aggregate annual heat load of 3.3 x 10¹⁰ Btu. Also included is optional development near a school site on the lower level.

On the basis of the existing geothermal wells in the area, and on the interpretation of geologic and hydrologic data for the area, it appears reasonable to assume a high probability for successful development of geothermal wells producing 160 to 170°F water from a depth of 1200 to 1500 ft; disposal wells are assumed to be 600 to 700 ft in depth. All wells would be sited on the plain below the bench.

Production of 160 to 170°F geothermal water from one 1200- to 1500-ft supply well and disposal to two 600- to 700-ft injection wells is assumed; only one injection well site is used in estimating pipe cost for return lines. For estimating purposes, the respective production and injection well sites are adjacent to the new lower roadway, midway between the optional school site and residential lots, and at the southwest corner of the school site. Pump horsepower required for production and reinjection of the geothermal water is estimated at 425 hp. Injection of spent fluid may require two wells and pump horsepower nearly equal to production pumping requirements. A 500-ft production pump head is assumed.

Costs are based on routing the geothermal supply from the well to a 100,000-gal insulated storage tank at an elevation of 3060 ft, at a

location northeast of the well site. A maximum flow rate of 1300 gpm from the storage tank supplies the main residential development, and 160 gpm, routed directly from the production well site, supplies the optional school-site development. All supply lines are insulated and waterproofed. Good water quality is expected, which will allow direct circulation of geothermal water through the distribution grid. No expansion loops or joints and no pressure reducing stations have been included in the cost analysis, but these will have to be considered in the final design.

Supply and return line pipe costs are based on selection of asbestos-cement pipe for pipe diameters of 4 in. and larger, and of black steel, welded-joint pipe or fiberglass reinforced plastic pipe for pipe diameters less than 4 in. Estimated quantities and costs are shown in Table 21, and total estimated costs for the geothermal system are summarized in Table 22.

Givens Hot Springs--Marsing, Idaho

In 1979, the owner of Givens Hot Springs requested assistance in developing a preliminary cost estimate for the development of a district heating system to service the heat load for a 100-home development near

TABLE 21. ESTIMATED PIPE QUANTITY AND COSTS (1979) FOR MORNINGSIDE HEIGHTS DEVELOPMENT

	Pipe Diameter (in.)	Supply (ft)	Return (ft)	Unit Installation Cost (\$/ft)	Total Cost (\$)
Main Development	8	1100	1700	10	28,000
	6	1500	1600	6	18,600
	5	1000	400	5	7,000
	4	1100	1500	3	7,800
	3	1800	1900	11	40,700
	2-1/2	500	1000	10	15,000
	2	<u>1600</u>	<u>700</u>	8	<u>18,400</u>
Totals		8600	8800		135,500
Optional School Site	3	800	1000	11	19,800
	2-1/2	<u>500</u>	<u>400</u>	8	<u>7,200</u>
Totals		1300	1400		27,000

TABLE 22. MORNINGSID HEIGHTS GEOTHERMAL SYSTEM COSTS

Item	Cost (\$)
Production well (1)	100,000
Injection wells (2)	100,000
Pumps	160,000
Storage tank, insulated	60,000
Main development piping	135,500
Optional site piping	27,000
Supply line insulation	25,000
Valves, fittings, and controls	12,000
Subtotal	619,000
Design Engineering (10%)	62,000
Contingency (10%)	62,000
Total	743,000

existing swimming pool facilities. The site has several springs and artesian wells producing water for irrigation; this water then flows to the Snake River, adjacent to the site. Measured spring and well temperatures range from 93 to 132°F. Only one well is of sufficient diameter to consider pumping, and the condition of the well is unknown.

On the basis of observations at the development site and other available data, a preliminary cost estimate for a geothermal supply, distribution, and disposal system for a 100-unit development at the Givens Hot Springs site has been developed.

Two options are considered, both based on obtaining sufficient quantities of geothermal water for residential heating. The first option assumes that the supply system is sized for operation of water-to-air heat pumps with geothermal water at a temperature less than 100°F; the second option assumes that the supply system is sized for forced-air or circulating hot-water heating systems using 130°F geothermal water. The system sizes and geothermal flow rates used assume that the heat pump application requires a supply of 660 gpm and that the other heating system applications require approximately 600 gpm under local design conditions. A single-stage residential heat pump can extract sufficient heat from the water to reduce its

temperature by up to 10°F; the forced-air or circulating water systems can extract sufficient heat to reduce the water temperature by about 15°F.

Production of geothermal water from an existing 10-in. well and surface disposal using existing hot spring discharge channels is assumed; disposal piping to the Snake River is through two 4-in. lines located between Lots 34, 35, and 65, 67, respectively, on the Givens plot plan.

Preliminary cost estimates, based on well renovation with asbestos-cement piping and on surface disposal, are essentially the same for the two heating schemes; the major difference lies in the possibility of eliminating supply-pipe insulation in the heat pump supply system. If spring activity results in wet soil conditions at supply pipe installation depths, however, it may be advisable to include insulation and waterproofing on the heat pump supply system as well. Preliminary cost estimates are given in Table 23.

The feasibility of using a ripper to provide trenching and installing PCV-type pipe should be considered due to the significant savings that could be incurred.

TABLE 23. GIVENS HOT SPRINGS GEOTHERMAL SYSTEM COST ESTIMATE (1979)

Item	Cost (\$)
Well renovation, 40 hp pump	25,000
Supply and return piping	57,000
Supply line insulation and waterproofing	24,000
Trench and backfill	5,000
Valves, fittings, and controls	5,000
Insulated expansion--storage tank	5,000
Subtotal	117,000
System design (15%)	18,000
Contingency (15%)	18,000
Total	153,000

It is understood that the State Energy Office in Boise, Idaho, intends to provide a limited amount of technical assistance for geothermal resource assessment at the Givens Hot Springs area (in 1979 and 1980). This assistance may be of aid in evaluating the potential of the existing well.

District Heating Expansion--Ketchum, Idaho

Comments on legal institutional concerns related to further development of district heating in the Ketchum, Idaho, area were requested by a firm doing research for the Idaho Office of Energy. Preliminary information or data on pipe costs and sizing, delivery system heat loss, and heat delivery rates were also requested for scoping purposes.

The most obvious scenario for development of an expanded district heating system in Ketchum involves the existing, privately owned Guyer Hot Springs system. This district heating system could be improved by insulation of the pipeline to reduce heat losses and roadway damage caused by freeze-thaw cycling. Further development of the resource has been addressed by Bill Eastlake of the Idaho Office of Energy.

Orderly and timely development of an expanded district heating system might be hindered if utility easements are not readily accessible to the system developer. Development of an entity with rights of eminent domain could alleviate this problem. Acquisition of an existing system such as the Guyer System will also entail assumption of system liabilities, including contractual obligations, which should be considered.

Among the legal-institutional concerns to be addressed are:

- Acquisition, renovation, and expansion of the Guyer System
- Geothermal rights
- Permitting for production and disposal wells
- Regulatory Agency requirements, including utility regulations

- Rate structuring
- Easement and right-of-way acquisition
- Organizational structures for development and operation
- Environmental concerns and regulations
- Financing.

Thermal springs and wells in the area exhibit surface temperatures ranging from near 100°F to about 160°F. Development of these resources probably should be considered on a site-specific basis. Although most are too distant from Ketchum to be considered as alternative production sites to serve district heating loads in Ketchum, some development to serve existing needs of owners may be feasible. Estimated heat delivery rates for long runs of small diameter pipe (<6 in.) show excessive heat loss and imply an excessive cost per unit of heat delivered. For these reasons, development and use of small spring or well flows will likely be limited to appropriate uses at the production site. It should be noted that dissolved oxygen in spring water may tend to increase corrosion, and that in some thermal waters, depending on the water chemistry, temperature and pressure drops induce or increase scale deposition rates. The local water chemistry does not indicate that this is a significant concern. The amount of fluoride in local spring waters indicates that subsurface disposal of spent fluids would be required.

Assessing the potential for developing specific sites should include consideration of the need for exploratory investigation and professional evaluation of resource characteristics. Production rates attainable from geothermal wells, reservoir lifetime, and temperature increase attainable with deeper drilling cannot be estimated with confidence in the absence of geophysical exploration, hydrological evaluation, and well test information. Caution should be exercised in making assumptions coupling fluid temperature increases with depth since local spring waters may rise rapidly along faults, so that temperatures obtained by well drilling may be little different from the surface temperatures of local springs. Test wells are

necessary to confirm or dispute this conjecture. Professional advise should be sought in assessing the technical and economic feasibility of specific development concepts.

The pipe to be used in geothermal district heating projects must be selected and specified in developing the engineered system design. Due consideration must be given to applicable codes, statutes or ordinances, project requirements, engineering practice, resource characterization, system environment, and economy. Some preliminary data for selected pipe are provided below for scoping purposes.

Estimated peak flow rate as a function of pipe size is based on a water velocity of 8 fps. The average will be significantly lower. At velocities in excess of about 8 fps, frictional losses increase rapidly, tending to increase pumping costs; erosion also may become a significant problem. Flow rate and estimated installed cost (1980) are shown in Table 24, an estimate of heat delivered as a function of flow rate and system temperature drop are shown in Table 25, and an estimate of temperature loss per mile of pipe is shown in Table 26. Estimated heat delivery rates based on system temperature drop, flow rates, and vendor heat loss data for Bondstrand insulated pipe are shown in Tables 27 through 29.

TABLE 24. PRELIMINARY PIPE DATA

Diameter (in.)	Peak Flow Rate at a Velocity of 8 fps (gpm)	Estimated 1980 Installation Cost with Insulation ^a (\$/ft)		
		Black Steel	Asbestos-Cement	Bondstrand
2	80	15	--	7
4	350	27	9	16
6	775	39	15	20
8	1375	50	21	25
10	2150	63	25	30
12	3050	75	30	36

a. Costs for pumping or pressure reducing stations and for valves and fittings not included; 15% may be allowed. Costs for uninsulated disposal piping should be reduced by 15 to 20%.

TABLE 25. HEAT AVAILABLE AS FUNCTION OF FLOW RATE AND SYSTEM ΔT
(Million Btu/hr)

Water Temperature (°F)	System ΔT (°F)	Flow Rate (gpm)					
		80	350	775	1375	2150	3050
190	44	1.8	7.7	27.0	30.0	47.0	67.0
180	38	1.5	6.7	15.0	26.0	41.0	58.0
160	26	1.0	4.6	10.0	18.0	28.0	40.0
140	14	0.6	2.5	5.4	9.6	15.0	21.0

TABLE 26. ESTIMATED TEMPERATURE DROP PER MILE OF BONDSTRAND PIPELINE AT
45°F SOIL TEMPERATURE (°F)

Pipe Diameter (in.)	Flowrate (gpm)	Heat Loss Factor (Btu/hr/ft/°F)		Water Temperature (°F)				
		Wet Soil	Dry Soil	190	180	160	140	120
2	80	2.54	0.82	15.7	14.5	12.5	10.3	8.2
4	350	2.91	0.90	4.0	3.7	3.2	2.6	2.1
6	775	4.34	1.07	2.1	2.0	1.7	1.4	1.1
8	1375	3.92	1.17	1.3	1.2	1.0	0.9	0.7
10	2150	4.29	1.26	0.9	0.8	0.7	0.6	0.5
12	3050	4.65	1.35	0.7	0.6	0.5	0.5	0.4

TABLE 27. HEAT DELIVERY RATES WITH 180°F WATER OVER DISTANCES OF
0 TO 5 MILES FOR SEVERAL SIZES OF PIPE BURIED IN DRY SOIL
(Million Btu/hr)

Pipe Diameter (in.)	Distance (miles)				
	0	1/2	1	2	5
2	1.5	1.2	1.0	0.6	0.2
4	6.7	6.3	6.0	5.4	4.8
6	15.0	14.5	14.2	13.5	11.4
8	26.0	25.6	25.0	24.0	22.0
10	41.0	40.6	40.1	39.2	36.5
12	58.0	57.5	57.0	56.1	53.4

TABLE 28. HEAT DELIVERY RATES WITH 160°F WATER OVER DISTANCES OF 0 TO 5 MILES FOR SEVERAL SIZES OF PIPE BURIED IN DRY SOIL (Million Btu/hr)

Pipe Diameter (in.)	Distance (miles)				
	0	1/2	1	2	5
2	1.0	0.7	0.5	0.3	--
4	4.6	4.3	4.0	3.4	2.2
6	10.0	9.6	9.4	8.7	7.0
8	18.0	17.6	17.3	16.6	14.5
10	28.0	27.6	27.2	26.4	24.1
12	40.0	39.6	39.2	38.4	36.0

TABLE 29. HEAT DELIVERY RATES WITH 140°F WATER OVER DISTANCES OF 0 TO 5 MILES FOR SEVERAL SIZES OF PIPE BURIED IN DRY SOIL (Million Btu/hr)

Pipe Diameter (in.)	Distance (miles)				
	0	1/2	1	2	5
2	0.6	0.4	0.4	--	--
4	2.5	2.3	2.1	1.7	0.5
6	5.4	5.1	4.9	4.4	2.9
8	9.6	9.3	9.0	8.4	6.6
10	15.0	14.7	14.4	13.8	12.0
12	21.0	20.6	20.3	19.6	17.5

District Heating System Cost Estimate--Midwest and Edgerton, Wyoming

Assistance in developing preliminary cost estimates for district heating systems in Midwest and Edgerton, Wyoming, was requested by the Wyoming Geothermal Commercialization Office. These systems would be supplied with 175 to 180°F thermal water from a nearby artesian well (an abandoned gas exploratory well). The required flow would be piped 1 mile to Midwest and an additional 3/4 mile to Edgerton.

From the information provided, preliminary costs were estimated for installing supply, distribution, and disposal systems to provide geothermal space heating in Midwest and Edgerton, Wyoming. The principal assumptions used are shown in Table 30.

TABLE 30. ASSUMPTIONS FOR DISTRICT HEATING SYSTEM PRELIMINARY COST ESTIMATES, MIDWEST AND EDGERTON, WYOMING

Item	Midwest	Edgerton
Population	750	600
Single-family residences (1000 ft ²)	340	270
Business (2000 ft ²)	10	5
Heat loads		
Residential design	65,000 Btu	65,000 Btu
Business design	160,000 Btu	160,000 Btu
Total design	2.37×10^7 Btu	1.835×10^7 Btu
Annual	5.25×10^{10} Btu	4.125×10^{10} Btu
Peak geothermal flow	1860 gpm	1460 gpm
Present annual fuel cost		
Each residence	\$700	\$700
Each business	\$1,200	\$1,200
Estimated annual fuel savings (natural gas at \$3.40/million Btu)	\$250,000	\$195,000

The estimated costs (1980 dollars) are based on assumed heat loads for typical residential and business structures in the two towns. Design heat loads of 65,000 and 160,000 Btu for typical homes and business, respectively, are used, and a 25% use factor is applied to determine annual heating loads consistent with reported annual costs for natural gas space heating [\$700/home and \$1200/business at a current rate (1980) of \$3.40/million Btu]. Thermal efficiency of natural gas heating is estimated at 80%. Typical cost for heating system conversion and service connection is estimated to be \$2000/unit. Distribution grid costs are assessed at \$1000/unit, assuming that no sidewalks or paved streets are disturbed or

reconstructed. The cost of removing and replacing sidewalks and street pavement can be estimated at \$20/yd and \$75/yd for removal and replacement, respectively.

Supply system costs are based on the capacity needed to deliver 1860 gpm to Midwest and 1460 gpm to Edgerton. Peak flows are based on temperature drops of 25°F for home heating systems and 35°F for business systems. The supply system is sized to carry 3360 gpm from the source to Midwest (1 mile) and 1460 gpm from Midwest to Edgerton (3/4 mile). Supply system costs assigned to Edgerton reflect the cost for increased capacity over the 1 mile from the source to Midwest. Costs for black steel and asbestos-cement supply piping systems are included in the analysis; costs also include insulation, waterproofing, bury, and backfill. No costs are assessed for royalty, easement or right-of-way, permits, or engineering design.

The method for disposal is undefined at this time. Disposal well and pump costs are estimated at \$200,000 for each townsite. Other possibilities for disposal include surface disposal or release to subsequent energy users. Under the previously stated assumptions, the discharge temperature will be near 145°F, probably requiring cooling ponds and fenced flow channels for surface disposal. Surface disposal will result in wintertime "fogging" at cooling pond and flow channel sites. Subsequent use of effluent discharged from the heating systems will involve consideration of peak loading, demand schedule, and other requirements of specific applications.

The preliminary cost estimates are presented in Table 31. Capital and annual cost schedules for Midwest and Edgerton are developed separately, with annual costs for system amortization at 10% and 16% over 20 years. Annual operation and maintenance costs are based on 1980 costs for electrical power (3.5 ¢/kWh) and on maintenance at 2% of capital costs. Private development is not considered, and so profit and tax effects are not appropriate in the analysis.

TABLE 31. DISTRICT HEATING SYSTEM PRELIMINARY COST ESTIMATES, MIDWEST AND EDGERTON, WYOMING (1980)

Cost Item	Estimated Costs (\$)			
	Midwest		Edgerton	
	Steel Pipe	Asbestos- Cement Pipe	Steel Pipe	Asbestos- Cement Pipe
Capital Cost Element				
Supply	246,000	120,000	234,000	105,000
Distribution (\$1,000/unit)	350,000	350,000	275,000	275,000
Subtotal	596,000	460,000	509,000	380,000
Disposal	200,000	200,000	200,000	200,000
Subtotal	796,000	660,000	709,000	580,000
Retrofit (\$2,000/unit)	700,000	700,000	550,000	550,000
Total Capital Costs	1,496,000	1,360,000	1,259,000	1,130,000
Annual Operating and Maintenance Costs				
Supply and Distribution	19,000	16,000	16,000	16,000
Disposal	7,000	7,000	7,000	7,000
Capital Cost Amortization				
Supply and Distribution				
10% for 20 yr (0.1175)	70,000	54,050	59,808	44,650
16% for 20 yr (0.1687)	77,602	77,602	85,868	64,106
Disposal				
10% for 20 yr (0.1175)	23,600	--	--	--
16% for 20 yr (0.1687)	33,800	--	--	--
Retrofit				
10% for 20 yr (0.1175)	82,250	82,250	64,625	64,625
16% for 20 yr (0.1687)	118,090	118,090	92,785	92,785

Table 32 gives the approximate "worst-case" and "best-case" capital and annual costs:

TABLE 32. DISTRICT HEATING SYSTEM CAPITAL AND ANNUAL COST ESTIMATES, MIDWEST AND EDGERTON, WYOMING (1980)

Town	Worst-Case Costs ^a (\$)	Best-Case Costs ^b (\$)
Midwest		
Capital	1,500,000	1,160,000
Annual	278,000	175,000
Edgerton		
Capital	1,260,000	930,000
Annual	235,000	130,000
Total		
Capital	2,760,000	2,090,000
Annual	512,000	305,000

a. Steel supply pipe, disposal by injection well, and 16% interest on borrowed money.

b. Asbestos-cement supply pipe, no disposal cost, and 10% interest on borrowed money.

Comparison of these annual costs with the estimated annual fuel cost savings (\$250,000 for Midwest and \$195,000 for Edgerton) show that the worst-case estimate exceeds the annual fuel savings by about 12%, while the best-case estimate is less than the savings by about 30%. In view of rapidly escalating fossil fuel costs, this preliminary analysis indicates that a more detailed assessment will probably also show that geothermal space heating can be an economically attractive alternative to the present use of natural gas.

The cost estimate developed above is based on a minimum of information and should be viewed as a preliminary estimate only. A more detailed development may alter the results significantly. On the basis of available information, however, the estimated costs are believed to be reasonable.

If sufficient interest in pursuing these projects develops and a more rigorous assessment of costs is warranted, additional data relating to appropriate residential heating system designs, acquisition costs for rights-of-way and geothermal fluids, permitting requirements, local labor costs, etc., will have to be developed. A site inspection and discussion with local interested parties could be arranged, under our user assistance program, to aid in developing the necessary information.

Geothermal District Heating--Cascade, Idaho

Introduction

Cascade, Idaho, the county seat of Valley County, is a town of about 1500 population located approximately 70 miles north of Boise, Idaho. The town is near McCall, a convention and recreation site. The local economy is based principally on the timber industry and recreation.

Inquiries and expressions of interest in geothermal space heating by several residents of Cascade led to site visits and a preliminary evaluation of the potential for a local district geothermal heating system. Interest in such a system had been spurred by high energy costs, the existence of thermal springs in the area, and earlier discussions of the feasibility of developing a district heating system to use waste heat from the Boise Cascade lumber mill. Costs for piping waste-heat from the lumber mill to the point of use and the uncertainty of mill operating schedules during times of economic distress have prevented further consideration of using excess heat from the mill.

Principal energy sources for space heating in the Cascade area are fuel oil, electricity, supplemental wood burning, and, to a lesser extent, propane. Approximate unit costs for energy in the fall of 1981 included heating oil at \$1.10/gal and electricity at 3 to 4¢/kWh, depending on use; a minimum charge is imposed on both residential and commercial consumers.

Geothermal Resource

A few thermal springs exist in the area. One of these is now beneath the surface of Cascade Reservoir, adjacent to the townsite. Reportedly, the spring temperature approached 140°F, but no documentation of this temperature is available. A Boise State University study¹ reports that local thermal well water is generally alkaline, of good quality, with total dissolved solids of 200 to 350 ppm and relatively high concentrations of sodium and chlorides. Well temperatures as high as 108°F are reported. High iron and manganese concentrations are also reported in local domestic water.

The study concludes that known thermal water occurrences are controlled by local geological fault and fracture patterns and that significant effort will be needed to adequately identify and characterize the geothermal resource. A resistivity survey and two test holes are suggested for evaluation before siting a production well. Well siting should also take into account geological faulting and proximity to the point of use.

Reportedly, the Department of Interior has drilled several test holes in the area over the last several years, but information on the results is apparently not available at this time. A local well driller has stated that few wells have been drilled to a depth greater than about 300 ft. One recently drilled well reportedly produces water at about 90°F. The total depth of this well is about 1000 ft. Reportedly, a significant proportion of domestic wells in Cascade are poor producers. Some wells drilled near known fault areas within the town have had relatively low initial flows and within a short time have experienced further loss of production. Typically, these wells are shallow, 6-in. domestic wells that initially produce 16 to 18 gpm and then lose flow. A 12-in. well drilled to a depth between 225 and 230 ft is a good producer of cold water, sought for use at the Boise Cascade mill. Reportedly, the town has drilled three dry 300-ft wells within the town limits in recent years. Indications are that successful development of the geothermal resource will require significant exploratory research and assessment effort; however, future development of a producible geothermal resource with a temperature near 145°F at an economically accessible depth is believed to be a reasonable expectation.

Preliminary District Heating Evaluation

On the basis of available demographic, economic, and resource-related data, a geothermal district heating model for Cascade, Idaho, was developed and evaluated using the BTHERM computer program at the New Mexico Energy Institute (NMEI), Las Cruces, New Mexico. Modeling rationale and simplifying assumptions used in BTHERM are described in Reference 2; conversion, hookup, and retrofit costs as well as other data may differ from values shown in the reference. For this preliminary evaluation, private development by a developer with a tax position allowing full benefit of Federal energy (15%) and investment (10%) tax credits was assumed. Equity investment was fixed at 10% of project cost, and return on investment was set at 20% for 15 years and 12% thereafter. A project life of 20 years was assumed. Two years were allowed for exploration and construction, beginning in 1981, and the system was to be on-line in 1983. An annual system growth rate of 1% was assumed.

The district heating model was based on the following assumptions:

- 1500 initial population
- 1% annual growth rate
- 400 homes
- 110 multiple residence units
- 55 businesses
- 15 public building
- Public and commercial heat load estimated at 60% of the residential load
- -15°F outside design temperature
- 8831 Fahrenheit degree day heating season

- 122×10^9 Btu initial annual heat load
- Design heat loads
 - 60,000 Btu/hr for single-family homes
 - 24,000 Btu/hr for multiple-residence units
- Domestic water heating loads
 - 20 lb/hr per person, average consumption, for residential units
 - 5% of the annual commercial load for commercial units.

The resource was characterized by a temperature of 63°C (~145°F); production well depth was limited to 3000 ft; good water quality was assumed, allowing direct circulation without the need for an intermediate heat exchanger. A transmission distance of 1 mile and disposal by injection were specified. On this basis, four 400-gpm production wells and two injection wells are required initially. One additional production well is required in the 18th year of the project to allow for system growth.

The economic model used determines the geothermal energy price that will result in a break-even cash flow, including the specified return on investment as an expense; conventional energy savings are accrued to offset expenses. A summary of cost and economic data is shown in Table 33.

Computed investment costs and the necessary selling price for geothermal energy, based on the foregoing discussion and data, are shown in Table 34; a cost-benefit summary is shown in Table 35.

The results indicate a good possibility of attractive economics if an adequate resource can be identified and developed at reasonable cost. The credibility of these results, however, is somewhat questionable due to the generalized nature of the model and the assumption that the developer is

TABLE 33. ECONOMIC DATA

Economic/Cost Item	%	\$
Economic Factors		
Bond rate	8.5	--
State property tax rate	1	--
State income tax rate	5	--
State sales tax rate	3	--
Federal income tax rate	46	--
Federal tax, energy credit	15	--
Federal tax, investment credit	10	--
Equity fraction	10	--
Rate of return, 15 yr	20	--
Rate of return after 15 yr	12	--
Escalation Factors		
Alternative fuel (oil) at \$10/million Btu	5	--
Maintenance at 2.5% of capital cost	1.5	--
Operating energy at \$0.04/kWh	5	--
Unit Cost Factors		
Production well	--	150,000
Injection well	--	112,500
1-mile transmission line	--	270,000

able to make full use of tax benefits. Geothermal energy at about one-third the price of competing energy sources indicates a significant margin for accommodating higher development costs and reduced dependence on tax benefits; these factors would then tend to push the price of the geothermal energy higher, thereby reducing its attractiveness to prospective consumers. Overall, the results indicate that further investigation of the feasibility of a geothermal district heating system is warranted.

Development scenarios for smaller systems serving the larger, more concentrated local heat loads should be investigated, and the impact of reduced tax benefits should be examined for a variety of developer situations. Specific potential user systems should be evaluated to provide realistic heat loads and to assess the potential for geothermal conversion.

Examination of phased system development or integration of two or more minisystems may be necessary to evaluate the effects of timing, system

TABLE 34. INVESTMENT COSTS

Category	Present Value (1980-2000) ^a (\$)
Research investment	250,632
Design	406,335
Wells	751,351
Transmission	270,309
Distribution	
Residential retrofit	855,816
Residential hookup	297,322
Commercial conversion	361,612
Industrial conversion	0
Heat exchangers	0
Central system	<u>2,057,196</u>
Total	5,250,573

a. Discounted at cost of capital = 0.028.

sizing, and conversion costs on overall economics. Assessment of the probable cost and potential for successful resource development must be made to provide a basis for developer investment analysis.

Facilities with relatively large heat loads, which can therefore be considered for geothermal space heating conversion, include the Valley County Courthouse, Cascade High School, and the local hospital.

Of these three, the courthouse probably presents the best possibility. The building is an old masonry structure with 12-ft ceilings; a new masonry addition is about one-half of the size of the older structure. The older section of the building is heated by an oil-fired, low-pressure steam system that uses cast iron radiators. The new addition is heated by an electric forced-air system; year-round air-conditioning is required for computer facilities. Annual energy costs are about \$6500 for fuel oil at \$1.10/gal and \$12,000 for electricity at about 3¢/kWh. The electrical charge includes energy for lighting and operation of the air-conditioning system.

TABLE 35. COST AND BENEFIT SUMMARY (1980-2000)^a

Item	Amount (\$)	Year
Federal Factors		
Federal tax	549,739	--
Tax credit	1,055,831	--
Royalty	0	--
State Factors		
State tax	188,501	--
Sales tax	86,241	--
Property tax	588,130	--
Evaluation of Investment (present value)		
Investors return on investment	629,154	--
Equity investment	463,878 ^b	--
Price of geothermal energy (\$/10 ⁶ Btu)	3.49	--
Price of alternative fuel (\$/10 ⁶ Btu)	10.00	--
Net savings		
Through 1990	7,909,000	--
Through 2000	24,259,000	--
Year on line	--	1983
Investors payback year	--	1998

a. Discounted at cost of capital = 0.028.

b. Equity portion = 0.1.

Reportedly, system performance for comfort heating is unsatisfactory, with insufficient capability to control the temperature distribution; total replacement of the heating system is contemplated. The existing system could be replaced by a geothermal system to provide space and domestic water heating if an adequate geothermal resource is developed. Geothermal water supplied at a temperature near 140°F or higher would allow consideration of direct heating systems; water at significantly lower temperatures could be used in systems based on heat pump technology. Accurate characterization of the resource would allow meaningful economic comparison between geothermal and conventional replacement systems.

The new high school would be a prime candidate if a hot enough resource were available. The circulating water system used for heating employs terminal fan-coil units mounted on the outside wall to draw in air through louvers for ventilation. The system design temperature is 200°F, and the return temperature is near 170°F. Heating and domestic hot water are provided by a 125 hp, oil-fired boiler; the current annual fuel cost is \$35,743. Heating oil purchased in 10,000 gal lots currently costs \$1.04/gal.

Extensive retrofit of this system would be required to carry the design heat load with a geothermal system supplying water near 150°F. At this temperature, the heating capacity of the existing system would be reduced by about 50% under the design operating conditions. Less extensive retrofitting would provide domestic water heating and boiler feed-water preheat. Conceivably, if the quality of the geothermal water is good, it could circulate in the existing system to meet space heating requirements during that portion of the heating season in which the outside temperature is above about 30 to 35°F. The existing system could also be augmented by installing properly sized fan-coil units in areas of high infiltration losses, such as entrances and the gymnasium. The oil-fired boiler or an alternative peaking system would be required for heating during the balance of the heating season. The economics of this concept is a subject for further study.

The hospital systems consist of 5-kW electric in-room HVAC units with refrigerated air conditioning capability. The outside-wall-mounted units are similar to motel-type units. Two 10- and 15-kW electric forced air systems heat a hallway, two emergency rooms, and a basement area that is not used. There is no other existing ductwork, and the space heating system includes no piping. Domestic hot water is supplied by a 20-kW hot water heater. Conversion to geothermal heating would require replacement of most the existing system and the installation of extensive piping and duct work. Hospital personnel indicate that financing for a geothermal retrofit is not available.

Conclusions

Preliminary analysis, based on limited data, indicates that development of a geothermal district heating system would be economically attractive.

The success of such a development, however, depends on the existence and economic accessibility of an appropriate geothermal resource, which is as yet unproven. Significant effort and cost can be expected for the resource exploration and assessment work needed to reduce the uncertainty in resource characterization to an acceptable level and to provide reasonable assurance that an appropriate resource can be developed without undue risk.

From the preliminary indication of attractive economics, a more detailed investigation of the economic potential seems warranted. Characterization of the district heating system should be based on identification of specific potential consumers, and it should include appropriate cost estimates for retrofitting and an examination of the effects of phased development. A district heating system of reduced scope, initially serving large heat loads, should be considered in order to reduce the first costs of the system, the number of service agreements necessary to ensure economic viability, and the amount of developer investment required.

Representation of developer financial situations and financing of the project should reflect local conditions and expectations.

The effort expended and the increased detail and accuracy of data that will result from additional analysis will serve to give greater credibility to the results obtained.

HEAT EXCHANGERS

Heat exchangers are employed in geothermal systems where production of the resource water is not desired or necessary and where the chemical nature of the geothermal water makes isolation from the working fluid and system components necessary. Three inovative concepts are included in the following technical assistance efforts.

Residential Downhole Heat Exchanger--Idaho Falls

An Idaho Falls, Idaho, residential developer requested design suggestions for downhole heat exchangers to be placed in domestic water wells in a development in the foothills east of town.

The heat exchanger would provide heat to a closed loop supplying water to a water-referenced heat pump system for residential heating. The cost of pumping to produce domestic water from a depth of about 400 ft for this purpose would be prohibitive. Domestic wells in the area produce 72°F water from about 400 feet. Pumps of 15 hp are required, and the development is in an area experiencing rapidly increasing rates for electrical service. A closed-loop heat pump supply would permit using a circulation pump of 1 hp or less to supply the heat pump system. The well driller for the development designed and fabricated a downhole exchanger for one homeowner, and satisfactory performance was reported for this system during the mild 1980-81 heating season. Subsequent preliminary evaluation of heat exchanger designs suggest this exchanger may be undersized for design conditions, which were not reached during the 1980-81 heating season. If this is the case, less than optimum performance can be expected from the heat pump system under design conditions. Since no information on cross flow or circulation in the well is available, heat transfer characteristics cannot be adequately addressed, and less than optimum performance under design conditions seems likely. The chief differences between the installed design and the designs analyzed below are the heat transfer surface area and, in one case, the configuration of the heat exchanger. The installed exchanger consists of copper upper and lower plenums connected by six 1/2-in. copper tubes 20 ft long. The subsequent analysis suggests that approximately 113 ft² of heat transfer surface is necessary to satisfy the design.

conditions. This is about six times the surface of the existing exchanger. The existing system is not instrumented, and no operating data are available for use in resolution of the large discrepancy. It is possible that the system is operating satisfactorily although not optimally.

The following heat exchanger analyses and preliminary design suggestions were prepared by our staff from the information available. The temperature and flow conditions used in the analysis result in a rather large heat exchanger, supplying about 60,000 Btu/hr of the load serviced by the heat pump. If the heat pump were operating at a coefficient of performance (COP) of three, a total heat load near 90,000 Btu/hr could be serviced. It should be noted that the heating system will be operating at design conditions for only a small fraction of the heating season. At other than design conditions, the required flow rate and temperature drop across the heat pump may differ significantly from the design specification. Heat pump and heat exchanger specifications must be based on the heat load to be served and on the temperature and flow of water supplied to the heat pump in order to obtain optimum performance and system costs.

It is recommended that competent engineering consultation be secured for final design and specification of the exchangers and heating systems.

Downhole Heat Exchanger for Heat Pump Supply

The envelope within which the heat exchanger is designed to fit is an 8-in.-ID well casing, with a 2-in. nominal Schedule 40 pipe located concentrically within the casing. The volumetric flow rate is

$$Q_{\text{flow}} = (12 \text{ gpm})(1 \text{ ft}^3/7.481 \text{ gal})\left(\frac{1 \text{ min}}{60 \text{ s}}\right)$$

$$= 0.0267 \text{ ft}^3/\text{s} .$$

The heat transfer rate is

$$Q_{\text{heat}} = (0.0267 \text{ ft}^3)(3600 \text{ s/hr})(1 \text{ lbm}/0.016 \text{ ft}^3)\left(1 \frac{\text{Btu}}{\text{lbm}^\circ\text{F}}\right)(65-55^\circ\text{F})$$

$$= 60,100 \text{ Btu/hr} .$$

With 16 1/2-in. 16-gauge copper tubes, the fluid velocity in the tubes is

$$V = (0.0267)(144)/(16)(0.10752) = 2.24 \text{ fps} .$$

Using a water viscosity of $1 C_p$, the Reynolds Number is 6400. For a water thermal conductivity of 0.346 Btu/hr-ft°F, the Prandtl number is 7. The convective heat transfer coefficient on the inside of the tubes is

$$\begin{aligned} h_i &= (0.023)(k/D)Re^{0.8}Pr^{0.4} = (0.023)[(0.346)(12)/0.37]6400^{0.8}7^{0.4} \\ &= 623 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F} . \end{aligned}$$

A fouling heat transfer coefficient of 300 Btu/hr-ft²-°F is suggested³ for low temperature hard water flowing at low velocity. A thermal conductivity of 220 btu/hr=ft-°F was used for copper. At this point, a trial-and-error solution for the overall heat transfer coefficient was used, resulting in a convective heat transfer coefficient of 57 Btu/hr-ft²-°F for natural convection on the outside tube walls.⁴ Using the outside tube wall area, and assuming that the fouling occurs on the outside tube wall, the resulting overall heat transfer coefficient is 47 Btu/hr-ft²-°F. The log mean temperature drop, assuming that the water temperature outside the tubes is constant at 72°F, is 11.3°F.

Therefore, the needed heat transfer area is

$$A = 60,100/[(47)(11.3)] = 113 \text{ ft}^2 .$$

The length of tubes needed to provide this area is:

$$L = 113/[(16)(0.1309)] = 54 \text{ ft} .$$

Therefore, a heat exchanger made of 16 1/2-in. 16-gauge copper tubes 55 ft long should perform adequately, with good margin for fouling on the outside of the tubes.

This analysis summarizes the design of a heat exchanger for installation in a 72°F well. The assumption that only natural convection exists in the well and the 10°F ΔT across the heat pump result in a rather large heat exchanger. The design calls for a heat exchanger area of 113 ft² consisting of 16 1/2-in.-OD tubes 55 ft long, as shown in Figure 3. The overall length could be reduced by half by using 16 U-tubes or 32 straight tubes while still retaining similar performance. Reducing the length is recommended, mainly because it simplifies handling and installation. Another approach that would reduce total length and greatly simplify fabrication and installation would be to form tubes in a helical coil, as shown in Figure 4. Two 215-ft-long copper tubes, 1-in. OD x 0.042-in. wall thickness, coiled in a 5-in.-ID helix with a lead of 2-1/2 in. per turn would result in a unit 28-1/2 ft long. Performance would be comparable to the straight-tube or U-tube arrangements. The pressure drop would be 5.7 psi, which is somewhat higher than the other arrangements.

Of the configurations mentioned, the helical coil seems the most desirable and is recommended for this application. Any of the configurations could be manufactured locally by Bingham Mechanical or Holder Machine Works. The well driller may be able to form the helical coil unit in his own shop. Soft copper tubing, 1-in. OD x 0.042-in. wall thickness, is available in 50-ft coils from Metal Sales, Inc., Salt Lake City, Utah, at a cost of approximately \$975 for nine 50-ft coils.

Note that copper tubing was used in these designs. Where there is good quality potable water, there should be no problem with galvanic corrosion.

As much of the following information as possible should be determined before designing a heat exchanger for a particular installation. The result will be better performance from a smaller, less expensive unit.

- Well temperature
- Depth of water level
- Pump setting depth

INEL 2 0739

Figure 3. Heat exchanger for 8-in. wall.

Figure 4. Helical tank heat exchanger.

- Desired flow rate and the temperature in and out of the exchanger
- Casing ID
- Pump column OD, or pump discharge line OD and power cable OD if the pump is submersible
- Location of production zone
- Approximate velocity of crossflow in the well, if any.

The present installation uses the 1-1/4-in. well pump discharge line instead of a separate 3/4-in. line for the outlet. The pressure drop, just in the 350 ft of 3/4-in. inlet piping and the 350 ft of 1-1/4-in. discharge piping in the well, is approximately 55 psi at 12 gpm. The heat exchanger losses are about 3 psi if all six tubes are 1/2 in. No entrance or exit losses were considered. If the 350 ft of 3/4-in. inlet pipe in the well were 1-in. pipe, the pressure losses would be approximately 35 psi less. This effect is shown graphically in Figure 5. This would reduce the pumping power by about 60%, perhaps allowing use of a 1/4-hp circulating pump instead of the 1/2-hp pump required in the existing design. Each future installation should certainly consider line losses in selecting the line sizes.

Cistern Heat Exchanger--White Sulphur Springs, Montana

The administrator of the hospital at White Sulfur Springs, Montana requested an analysis of using a pit or cistern with submerged pipe coil for heat exchange in order to provide space heat and preheated domestic water for the small hospital and nursing home.

An analysis was performed to determine the feasibility of providing preheated domestic hot water and space heating for the hospital and nursing home with the system described. The following major assumptions were made in the analysis:

Figure 5. Pressure drop per 100 ft in 1-in. and 3/4-in. Schedule 40 pipe, for water at 60°F.

- Temperature of the geothermal water entering the pit is 118°F.
- Flow rate of the geothermal water in the pit is about 40 gpm.
- Temperature of the city water supply is 34°F.
- The city water will be preheated to about 100°F.
- The quantity of water required is 1000 gpd.

The rate at which the geothermal water is flowing through the pit will govern the average temperature of the water in the pit. If the geothermal water flow is less, the city water will tend to cool the water in the pit, resulting in less efficient operation. The temperature of the preheated water was chosen after some preliminary analysis showed that temperatures above 100°F required an excessive length of pipe in the pit.

The analysis showed that space heating with the system as described is not feasible. A feasible space heating design would require larger quantities of geothermal liquid (pumped) and a more sophisticated heat exchanger apparatus such as a plate-type heat exchanger. Optionally, the geothermal fluid could be pumped directly through radiators or through a central forced air heating unit. The analysis of the water indicates that, in the absence of air in the system, the contact of the fluid with the radiators should not be excessively corrosive. The space heating application was not pursued further.

Preheating the domestic hot water to 100°F with the system design described would require approximately 750 ft of 1-in. pipe. This long pipe length is due to the system's required maximum flow rates. For much of the time, the system would be used only to a limited extent or not at all. At times of high use, however, when velocities in the pipe are large (during laundry periods, for example), the pipe length should be sufficient to preheat the water to 100°F.

An alternative scheme that adds a storage capability to the system was analyzed. In this system, shown in Figure 6, a pump continually circulates

Figure 6. Schematic of cistern heat exchanger with heat storage system.

water between a storage tank and the heat exchanger pipe. This allows the system to extract energy from the pit at a more constant rate, and therefore, the same overall energy can be extracted with smaller equipment. As analyzed, this system used a 200-gal storage tank and a 25-gpm circulation pump. Heat exchanger pipe lengths for each of three pipe materials, using the arrangement just described, are shown in Table 36. The most economical pipe material is iron. However, there is a chance that a significant amount of dissolved oxygen, which could be highly corrosive to iron, exists in the pit water. Therefore, iron may be more expensive in the long run because of maintenance costs.

TABLE 36. STORAGE SYSTEM HEAT EXCHANGER PIPE LENGTHS

<u>Material</u>	<u>Wall Thickness (in.)</u>	<u>Length (ft)</u>	<u>Cost Factor</u>
Iron (Schedule 40)	--	200	1.0
Stainless steel	0.065	180	2.0
Corning Pyrex glass	0.125	370	9.5

The Corning Pyrex glass pipe, specifically identified by the requester in this case, is extremely expensive, and the effects of thermal and mechanical shock for the situation described are unknown. It is not recommended.

Stainless steel pipe appears to be the best choice of the three types considered and will probably be the least expensive in the long run.

An economic analysis of this system shows it to be marginally feasible. No system optimization studies were performed to determine the best tank size, pump size, and length of pipe. Such a study would require a better definition of the average rates of water use during the day and would probably result in a more cost-effective, economically feasible design.

Septic Tank Heat Exchanger--Coeur D'Alene, Idaho

A Coeur d'Alene, Idaho, homeowner requested a preliminary analysis of using his septic tank as a heat source to augment or supply his water source heat pump residential heating system. Although a concept of this nature is not customarily considered under the program, a brief effort yielded the following analysis.

Several sources of heat are available to supply the required input for a water source heat pump. For a closed loop input system, multiple heat sources, any one of which can serve as a backup upon failure of the others, can be a definite advantage. Some preliminary calculations were performed to determine the length of 1-in. copper pipe embedded in a septic tank that would recover approximately 3 to 5°F. The following assumptions were made:

- 70°F septic tank temperature
- 60°F heat pump water exit temperature
- 5 gpm required source water flow.

It was further assumed that the heat recharge into the septic tank equals or exceeds the heat withdrawal by the copper coil. A longer length of copper pipe may be used to scavage heat from a larger area, but ultimately the heat withdrawn cannot be greater than the heat recharge. With the above assumptions and including moderately severe fouling factors and film coefficients due to contact with sludge material, approximately 45 ft of 1-in. copper pipe are required. It would probably be wise to exceed this length to ensure that the copper pipe coil is installed in a pattern that will remove heat throughout the volume of the septic tank. Furthermore, 1-in. copper pipe filled with water weighs nearly 1.8 lb/ft of pipe, and therefore some support will be required.

Installation and operation of the proposed system revealed an unacceptable rate of copper pipe corrosion, resulting in a subsequent request to consider using plastic pipe to accomplish the desired heat exchange. A

polyethylene plastic pipe was selected as a logical substitution. The heat conduction through even a thin-walled plastic pipe is smaller than for an equivalent length of copper pipe, so that a longer plastic pipe will have to be used for substitution purposes.

The calculations used to determine the length of plastic pipe required follow. The main determinants are an estimate of the fouling and scaling effects on heat transfer and a suitable diameter for the plastic pipe. Scaling and film coefficients were determined from data for the existing coil and then applied to the case of a plastic pipe. Polyethylene tubing was selected since this material has a higher conductivity than PCV and costs less. If 2-in. polyethylene, Class II, Schedule 40 tubing is used, a total of about 1250 ft will be required, even under moderately severe conditions.

The formation of scale on pipe coils limits the amount of heat transfer through the pipe walls. Other factors that reduce the amount of heat conduction and convection are film resistance due to turbulent flow and eddy current formation. In summation, since the transfer of heat is impeded by these factors, they must be calculated to establish the amount of heat transfer. If plastic pipe were installed to replace the copper pipe now embedded in the septic tank, a change in the conductive heat transfer would occur. In the calculations that follow, it was assumed that the scale deposits and film resistances would remain the same. If these assumptions are correct, then the heat transfer equation can be solved to find the scale and film resistance when copper pipe was used. These scale and film resistances can then be used for the plastic pipe case and solved for the total heat transferred. Table 37 lists data assumed for the copper pipe case. A diagram is shown in Figure 7.

$$dq = \frac{t_1 - t_o}{1/h_i dA_i + 1/h_o dA_o + 1/h_s dA_s + X/kdA}$$

TABLE 37. DATA ASSUMED FOR COPPER PIPE CASE

Date	Septic Tank Temperature (°F)	Water Inlet Temperature (°F)	Water Outlet Temperature (°F)	Assumed Flow (gpm)	Assumed Gain (Btu/hr)	Heat Gain ^a Per Ft of Pipe	Scale and Film Resistance	$t_1 - t_0$ ^a (°F)
01/13/80	71	53	58	5.5	13,750	68.75	0.22530	15.5
02/11/80	56	49	54	5.5	13,750	68.75	0.0653	4.5
02/15/80	61	51	56 - 57	5.5	15,125	75.63	0.09571	7.25
03/09/80	54	48	52	5.5	11,000	55.0	0.07258	4.0

a. t_0 = septic tank temperature

t_1 = average water temperature between inlet and outlet

heat gain = 500 x flow rate x ($t_1 - t_0$) .

Figure 7. Diagram for scale formation and film resistance calculation, septic tank heat exchanger.

where

t_0 = septic tank temperature

t_1 = average water temperature between inlet and outlet

h_i = inside film coefficient

h_o = outside film coefficient

h_s = scale coefficient

X = material thickness

k = thermal conductivity of pipe

A = area.

Solving this equation for the scale and film resistances:

$$1/h_i dA_i + 1/h_o dA_o + 1/h_s dA_s = \frac{t_1 - t_o - dq(X/kdA)}{dq}$$

For the copper pipe case, the following values can be substituted:

$$k = 2688 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F-in.}$$

$$\text{ID} = 1.063 \text{ in.}$$

$$\text{OD} = 1.315 \text{ in.}$$

$$\text{Thickness} = 0.126 \text{ in.}$$

$$\text{Area/ft of pipe} = 0.311 \text{ ft}^2/\text{ft of pipe}$$

$$X/kdA = 1.498 \times 10^{-4}$$

and for the plastic pipe case, the following:

$$k = 2.300 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F-in.}$$

$$\text{ID} = 2.067 \text{ in.}$$

$$\text{OD} = 2.375 \text{ in.}$$

Thickness = 0.154 in.

Area/ft of pipe = $0.5815 \text{ ft}^2/\text{ft of pipe}$

$X/kdA = 0.188.$

This equation is then solved, since the thickness of the copper pipe, the conductivity of copper, the amount of heat transferred, and the relevant temperatures are known, as shown above or in Table 37. The resultant values for scale and film resistance are also shown in Table 37. Note that the resistance of the plastic pipe (0.188) is only slightly higher than the scale and film resistance (average of about 0.1). The heat flow can now be calculated using a sum of the resistances and the following assumptions:

$\Delta t = 5^\circ\text{F}$ (perhaps the worst case)

Scale and film resistance = 0.225 (worst case from the available data).

$$\begin{aligned} dq &= \frac{t_1 - t_0}{\text{film and scale resistance} + \text{pipe conduction}} \\ &= \frac{^\circ\text{F}}{0.225 + 0.188} = \frac{12.11 \text{ Btu/hr}}{\text{ft of pipe}} \end{aligned}$$

If 15,000 Btu/hr is required for the heat pump, as indicated in Table 37, then the total length of plastic pipe required would be 15,000 Btu/hr divided by 12.11, or 1238 ft. Note that this is the worst case situation. For 11,000 Btu/hr, a total of 908 ft would be required.

REFERENCES

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