PHASE II

FINAL TECHNICAL REPORT

Economic Feasibility Study of Residential and Commercial Heating Using Existing Water Supply Systems

Report Number DOE/CS/31744-A001-2

Mechanical Engineering Department
College of Engineering
Clemson University
Clemson, South Carolina

DISCLAIMER

PRELIMINARY

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PRELIMINARY

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ABSTRACT

A study of the use of a low-to-moderate temperature hydrothermal resource for space heating a 140-home residential community has been undertaken. The approach centers on use of the existing culinary/potable water supply system to supply heated water to the homes, the culinary water being heated at a single pumping station and then distributed throughout the community through uninsulated, buried water mains. The heated potable water is pumped through individual house water-to-air heat exchangers using sealed, magnetic-drive house pumps and returned to the street distribution lines. These house heat exchangers are either add-on, wall mounted, convective heating units or coils added to existing forced air heating systems.

The engineering feasibility of this approach has been examined and previously reported.[1] In that work, a real 140-home subdivision approximately 17 miles from the water treatment/pumping/heating plant was considered, and the results indicate that the thermal losses in the main supply lines to the subdivision and those in the subdivision street mains would be acceptable. That study also considered total water flow requirements, pumping requirements, main heat exchanger sizing, and house system design including house heat exchanger sizing for suitable ranges of design parameters. Throughout the study, a two-thirds design heating load for a typical three-bedroom house under 0°F, 15 mph wind conditions was employed. The engineering feasibility study indicated that such an approach is workable only in communities with significant water usage rates (or flow-through) to maintain a

[1]Feasibility Study of Residential and Commercial District Heating Using Existing Water Supply Systems, Report No. DOE/CS/31744-A001-1, May, 1979.

sufficiently high water temperature in the distribution lines and to supply a large percentage of the thermal load required for district or subdivision heating.

The present work focuses upon the economic feasibility of this approach to district heating, specifically for the community definition and thermal conditions of Report Number DOE/CS/31744-A001. Economic considerations were not a part of that report. The cost factors included in this study are:

- material cost of a main heat exchanger to utilize waste energy from a power plant condenser cooling water or geothermal resource
- material cost of a community flow booster pump
- material and installation cost of an individual house piping system
- material and installation cost of an individual house heat exchanger
- material and installation cost of an individual house pump
- twenty year electrical power operating costs of house and community pumps

Cost factors that were omitted in this study are (i) those for installation of the main heat exchanger and booster pump, (ii) allowance(s) for maintenance and contingencies, (iii) charges for geothermal fluid, and (iv) engineering costs.

A present worth analysis of the 20 year operating costs added to the initial installation and equipment costs formed the total heating system cost. For this analysis the escalation rate of the cost of electrical power was assumed equal to the present interest rate (approximately 11¼%). Thus multiplying the present annual electrical power cost by 20 yielded the present worth of 20 years of operating costs.

Parametric studies of the total system cost included:

- Three potable water temperatures: 135°F, 125°F, and 115°F
- Three house heating system exit air temperatures: 110°F, 100°F, and 90°F
- Electrical power costs ranging from 2¢ to 4¢ per kilowatt hour
- Heating season load from 3000-to-7000 °F-day per year
- Individual house copper pipe sizes of 1/2 inch and 3/4 inch.

A total 20 year system cost for a 140-house community ranged from $205,100 to $597,300 for 3000 and 7000 °F-day per year heating seasons, respectively, using the lowest present electrical power cost. This represents a cost of $73.25 to $213.32 per house-year. For the highest electrical power cost, this range is from $221,300 to $959,200 for 3000 and 7000 °F-day per year, respectively. This translates to a cost of $79.04 to $342.57 per house-year.

The major cost is that of "booster pumping" in the community distribution system. The community studied has a preponderance of two-inch diameter street water mains. Larger street mains would markedly reduce the operating costs.

1. INTRODUCTION

The purpose of this study is to analyze the costs involved in attempting to supply heated water to a 140-house residential area[1] using the existing culinary/potable water distribution system. Initial costs result from modifying the present water system to provide two-thirds of the design heating requirement for each residence. The modifications to the system include:

(1) A main heat exchanger and pumping installation to supply heated water to the 140-house residential area through the existing piping system.

(2) A heat exchanger, pump, and piping system for each house to provide a supply and return network from and to the street main as well as providing heated air for the house.

The total cost, for purposes of this report, consists of (i) initial costs and (ii) yearly operating costs for the life of the system. These two are combined in a present worth analysis comparing various system designs. This provides a method of selecting an optimum design from a cost standpoint.

Costs not considered in this "feasibility study" economic analysis include installation of main heat exchanger and main pump, geothermal fluid costs, allowance for maintenance, initial engineering costs, and allowance for initial installation/construction contingencies.

For the purposes of this study, the present worth method only is used for analysis, and the interest rate on borrowed money and the inflation rate on energy cost are assumed to be the same, although examples using different rates for these are included in Appendix A.

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[1] For a complete description of the residential community district heating system, including water flow, pumping requirements and thermal loads, see Reference 1.

II. INITIAL COSTS

A. Main Heat Exchanger

The size of the main heat exchanger is dependent on the following factors:

(1) Temperature of water supplied to the residential area.

(2) Available resource (hot) and ground (cold) water supply temperatures.

The water supply temperature to the residential area is the most important parameter. For this study a temperature range of 115°F - 135°F was chosen. This range was selected due to the available resource water temperatures and the necessity of a comfortable residence temperature. The midpoint temperature of 125°F was used as a third data point to allow construction of parametric curves.

As the supply temperature is reduced, the required water flow rate is increased because the energy requirement of the community is assumed constant. The energy required to heat this additional water is much larger than the energy gained in reducing the water supply temperature because a 4x flow factor is used to minimize the temperature decay in the street mains due to energy extraction in the houses. The "4x factor" is four times the flow required to supply the heat extracted for house heating in the community. Therefore, the 135°F supply temperature requires the smallest heat exchanger and also represents the lowest water flow rate.

A flat plate heat exchanger design was chosen for this application because of its low cost, small size, and commercial availability in stainless steel. The cost of a 4×10^6 Btu/hr flat-plate heat exchanger was known to be approximately \$15,000. Using the following equation as a rule of thumb

$$\left(\frac{\text{Heat Exchanger Output (Btu/hr)}}{4 \times 10^6}\right)^{0.6} \times \$15{,}000 = \text{Cost of Heat Exchanger}$$

for scale-up, the costs of the heat exchangers for the three supply temperatures were calculated. The results are shown below:

TABLE II-1. MAIN HEAT EXCHANGER COSTS

T Supply	Cost
135°F	$48,150.00
125°F	$54,550.00
115°F	$67,943.00

B. House Heat Exchanger

The heat transfer area of the individual house heat exchanger is dependent on the hot water supply temperature and the desired air exit temperature. The unit is to be installed in an existing duct, and the chosen design is a fin-and-tube type. The off-the-shelf heat exchanger selected was designed for use in solar applications where the entering water temperature is not high, and provision has been made for incorporating the unit into a house heating system. The water supply temperatures as already mentioned were 135°F, 125°F, and 115°F. To prevent excessive temperature drops in the water distribution system, the water exit temperature from the heat exchanger was limited to 100°F. The air exit temperatures used were 90°F, 100°F, and 110°F. The heat exchanger area was calculated for each of the nine possible conditions and matched to a suitable off-the-shelf hot water coil (heat exchanger).

The coil cost for each design condition is shown in the table below:

TABLE II-2. HOUSE HEAT EXCHANGER COSTS

$T_{air\ exit}$	90°F	100°F	110°F
35°F ΔT	$68.00	$88.00	$88.00
25°F ΔT	$88.00	$88.00	$110.00
15°F ΔT	$88.00	$110.00	$125.00

C. House Piping System

A piping system is required for each residence to form a supply and return network to carry the hot water from and to the main distribution system. Copper water pipe was chosen for the system because of the temperatures involved. Various pipe diameters were considered. One-half inch pipe is the most common, and pipe of smaller diameter is more expensive per unit area. This relative high pipe cost combined with a large pump and pumping power cost eliminated the use of pipe smaller than 1/2". Pipe diameters larger than 3/4" were inappropriate because of large pipe cost. The decision to use 3/4" or 1/2" was based on an analysis of material costs, installation costs, pump costs and power costs.

The material costs included that of 200 feet of copper pipe as well as the costs of the elbows and gate valve. The installation costs included the cost of installing the piping, pump, and heat exchanger. In addition, the installation cost took into account digging and backfilling the trench for the pipe and wiring of the pump by an electrician [2]*.

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* Numbers in square brackets are those of references listed on page 32.

Summing these for the 1/2" and 3/4" piping systems results in an initial cost of $860.00 and $942.00 (1979 dollars), respectively, per house. By adding the initial cost of the required pump and the present worth cost of the pump power for a suitable system life, an optimum cost piping system can be selected (see Section IV).

D. Main and House Pumps

A pump is needed in the main distribution system to provide for the additional head loss caused by the increased flow rate through the residential area. This additional head loss will be very large compared to the head loss due to consumptive water flow only as shown in reference 1.

The theoretical horsepower for pumping the water through the residential area is obtained by forming the product of the flow rate and the pressure drop and summing these for each pipe section. Then, using a centrifugal pump efficiency of 80% and a motor efficiency of 85%, which are conservative values in the ranges quoted for this size and type of equipment, the approximate size pump required is obtained [3], [4]. These results, along with the pump costs, are listed in the following table:

TABLE II-3. MAIN PUMP COST

T_{supply}	Pump Size	Cost
135°F	50 HP	$2390.00
125°F	100 HP	$3640.00
115°F	500 HP	$14250.00

The pump size for use in each house is dependent on the water temperature drop in the house heat exchanger and on the size piping used. Tables II-4 and II-5 show the cost of the pump as a function of the above parameters.

TABLE II-4. INDIVIDUAL HOUSE PUMP COST FOR 1/2" PIPE

Water ΔT	Cost
35°F	\$60.30
25°F	\$64.30
15°F	\$120.00

TABLE II-5. INDIVIDUAL HOUSE PUMP COST FOR 3/4" PIPE

Water ΔT	Cost
35°F	\$60.30
25°F	\$60.30
15°F	\$64.30

E. Multiple Main Heat Exchanger and Pump Cost Considerations

Another cost factor that should be considered from a practical point of view is the possibility of the main heat exchanger and main pump requiring maintenance during the heating season. In this case, a multiple main heat exchanger-pump design would be used to allow individual units to be cycled out of service for maintenance. The use of several small units in place of one large unit results in an added initial system cost. An estimate of additional material costs for a three-main heat exchanger design is presented in Appendix C. Note that lack of specific geothermal fluid impurity information precludes specificity of system design; hence a single unit design was employed for the majority of this economic study.

No multiple main pump system has been considered since this pump uses potable water only.

III. OPERATING COSTS

A. Main and House Pump Power Requirement

Both the house and main pump sizes required for each of the operating conditions have been determined in previous sections of this report. Since the pump sizes were selected either (i) from head-capacity curves (house pump) or (ii) by assuming a pump and motor efficiency (main pump), the exact pump efficiency and thus the power input for each of the various flow conditions are not known. Therefore, the maximum power rating of the pump was used to determine the operating energy cost. While this is a slightly conservative approach, it nevertheless represents the only practical method for estimating this fraction of the total system cost. The power input obtained in this manner was combined with cost per kilowatt-hour and heating period per year to yield the operating cost of the pump. The power cost range per kilowatt-hour for 1979 was assumed between 2 and 4 cents. A heating period range of 3000 to 7000 °F-day per year was chosen as typical for areas in the U.S. where such a project would be feasible. These ranges were used in a parametric study of operating cost versus power cost and heating period length.

The operating costs were examined for a 20 year period, assuming that the escalation rate of the cost of electrical power is equal to the present interest rate of 11¼%. Tables III-1 through III-5 give the present worth of 20 year operating costs for the house pumps as a function of supply temperature, house piping system size, power cost and heating period length. Some of the results are identical due to the same size pumps being applicable to more than one of the flow conditions.

TABLE III-1. Present worth of 20-year operating costs for a house pump for 135°F supply temperature, 1/2" pipe or 3/4" pipe.[1]

Heating Period \ Energy Cost	2¢/kw-hr	3¢/kw-hr	4¢/kw-hr
3000 $\frac{°F\text{-Day}}{Year}$	\$ 6.17	\$ 9.26	\$12.34
4000 $\frac{°F\text{-Day}}{Year}$	\$ 8.23	\$12.34	\$16.46
5000 $\frac{°F\text{-Day}}{Year}$	\$10.29	\$15.43	\$20.57
6000 $\frac{°F\text{-Day}}{Year}$	\$12.34	\$18.51	\$24.69
7000 $\frac{°F\text{-Day}}{Year}$	\$14.40	\$21.60	\$28.80

[1]Estimated operating costs for these conditions are the same as explained in text.

TABLE III-2. Present worth of 20-year operating costs for a house pump for 125°F supply temperature, 1/2" pipe.

Heating Period \ Energy Cost	2¢/kw-hr	3¢/kw-hr	4¢/kw-hr
3000 °F-Day/Year	$12.26	$18.39	$24.52
4000 °F-Day/Year	$16.35	$24.52	$32.70
5000 °F-Day/Year	$20.43	$30.65	$40.87
6000 °F-Day/Year	$24.52	$36.78	$49.04
7000 °F-Day/Year	$28.61	$42.91	$57.22

TABLE III-3. Present worth of 20-year operating costs for a house pump for 125°F supply temperature, 3/4" pipe.

Heating Period \ Energy Cost	2¢/kw-hr	3¢/kw-hr	4¢/kw-hr
3000 $\frac{°F\text{-Day}}{Year}$	$ 6.17	$ 9.26	$12.34
4000 $\frac{°F\text{-Day}}{Year}$	$ 8.23	$12.34	$16.46
5000 $\frac{°F\text{-Day}}{Year}$	$10.29	$15.43	$20.57
6000 $\frac{°F\text{-Day}}{Year}$	$12.34	$18.51	$24.69
7000 $\frac{°F\text{-Day}}{Year}$	$14.40	$21.60	$28.80

TABLE III-4. Present worth of 20-year operating costs for a house pump for 115°F supply temperature, 1/2" pipe.

Heating Period \ Energy Cost	2¢/kw-hr	3¢/kw-hr	4¢/kw-hr
3000 $\frac{°F\text{-Day}}{\text{Year}}$	$38.35	$ 57.52	$ 76.69
4000 $\frac{°F\text{-Day}}{\text{Year}}$	$51.13	$ 76.69	$102.25
5000 $\frac{°F\text{-Day}}{\text{Year}}$	$63.91	$ 95.86	$127.82
6000 $\frac{°F\text{-Day}}{\text{Year}}$	$76.69	$115.04	$153.38
7000 $\frac{°F\text{-Day}}{\text{Year}}$	$89.47	$134.21	$178.94

TABLE III-5. Present worth of 20-year operating costs for a house pump for 115°F supply temperature, 3/4" pipe.

Heating Period \ Energy Cost	2¢/kw-hr	3¢/kw-hr	4¢/kw-hr
3000 °F-Day/Year	$12.26	$18.39	$24.52
4000 °F-Day/Year	$16.35	$24.52	$32.70
5000 °F-Day/Year	$20.43	$30.65	$40.87
6000 °F-Day/Year	$24.52	$36.78	$49.04
7000 °F-Day/Year	$28.61	$42.91	$57.22

Tables III-6 through III-8 list the present worth of 20 year operating costs for the main pumps as a function of supply temperature, power cost, and heating period length, assuming equal interest and energy cost escalation rates.

In the next section of this report the operating costs of the house pumps are combined with the initial cost of the house piping systems to determine the optimum system based on pipe size, supply temperature, power cost, and heating period length for a 20 year operating life. This cost, along with the house heat exchanger cost, is multiplied by the number of houses in the residential area and added to the initial cost of the main pump and main heat exchanger along with the operating cost of the main pump to yield the total system cost as a function of supply temperature, heating period length, and house heating air exit temperature.

In Appendix B of this report the operating costs of the total system are given for one year as a function of supply temperature, cost per kilowatt-hour, and heating period length.

TABLE III-6. Present worth of 20-year operating costs for a main pump for 135°F supply temperature.

Heating Period \ Energy Cost	2¢/kw-hr	3¢/kw-hr	4¢/kw-hr
3000 °F-Day/Year	$15,340	$23,010	$30,680
4000 °F-Day/Year	$20,453	$30,680	$40,907
5000 °F-Day/Year	$25,567	$38,350	$51,134
6000 °F-Day/Year	$30,680	$46,020	$61,360
7000 °F-Day/Year	$35,793	$53,690	$71,587

TABLE III-7. Present worth of 20-year operating costs for a main pump for 125°F supply temperature.

Heating Period \ Energy Cost	2¢/kw-hr	3¢/kw-hr	4¢/kw-hr
3000 $\frac{°F\text{-Day}}{\text{Year}}$	$ 30,680	$ 46,020	$ 61,360
4000 $\frac{°F\text{-Day}}{\text{Year}}$	$ 40,907	$ 61,360	$ 81,814
5000 $\frac{°F\text{-Day}}{\text{Year}}$	$ 51,134	$ 76,701	$102,268
6000 $\frac{°F\text{-Day}}{\text{Year}}$	$ 61,360	$ 92,040	$122,720
7000 $\frac{°F\text{-Day}}{\text{Year}}$	$ 71,587	$107,380	$143,174

TABLE III-8. Present worth of 20-year operating costs for a main pump for 115°F supply temperature.

Heating Period \ Energy Cost	2¢/kw-hr	3¢/kw-hr	4¢/kw-hr
3000 °F-Day/Year	$153,400	$230,101	$306,801
4000 °F-Day/Year	$204,535	$306,802	$409,070
5000 °F-Day/Year	$255,670	$383,506	$511,341
6000 °F-Day/Year	$306,801	$406,202	$613,603
7000 °F-Day/Year	$357,936	$536,904	$715,872

IV. COMBINED INITIAL AND OPERATING COST

In sections II and III of this report all the cost factors, except installation of the main heat exchanger and the main pump, that are needed to determine the cost of a residential heating system for a 20 year operating life have been considered. Installation costs of the main heat exchanger and the main pump were not included due to the uncertainty in the relative location of the resource energy and the ease in which it can be supplied. If the installation costs are assumed to be twice the material costs, then these installation costs would range from 17% of the highest to 50% of the lowest 20 year present worth cost of the entire system. (The 20-year present worth includes, of course, the operational energy costs.)

As mentioned in the previous section, combining the initial and operating costs of the house piping system gives the optimum individual house piping system (exclusive of the house heat exchanger) as a function of pipe size, supply temperature, power cost, and heating period length based on a 20 year operating life. These results are shown in Figures 1 through 5.

For this study a 140 house community was assumed. Multiplying the house heat exchanger cost, which is a function of water supply and air exit temperatures, and the optimum piping system cost for each set of parameters by the number of houses in the community gives the cost of installing and operating the complete house piping systems for a 20 year period. By adding the initial costs of the main pump and heat exchanger, which are a function of potable water supply temperature only, and the operating cost of the main pump, which is a function of potable water supply temperature, power cost, and heating period length, the cost of the residential heating system based on a 20 year operating life is determined. These results are shown in

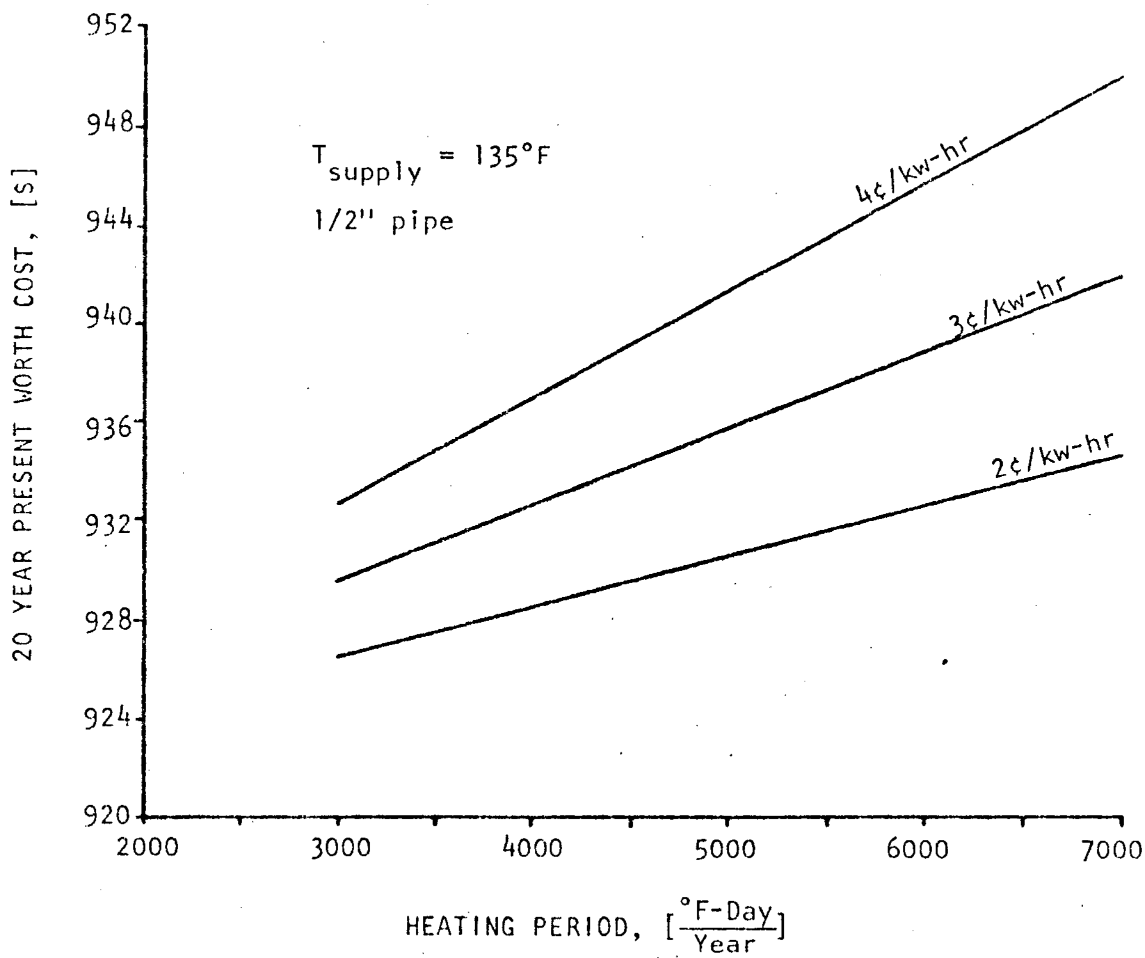

FIGURE 1. Present worth of 20-year operating costs plus initial cost for 1/2" pipe single house system, 135°F supply temperature. (House heat exchanger excluded.)

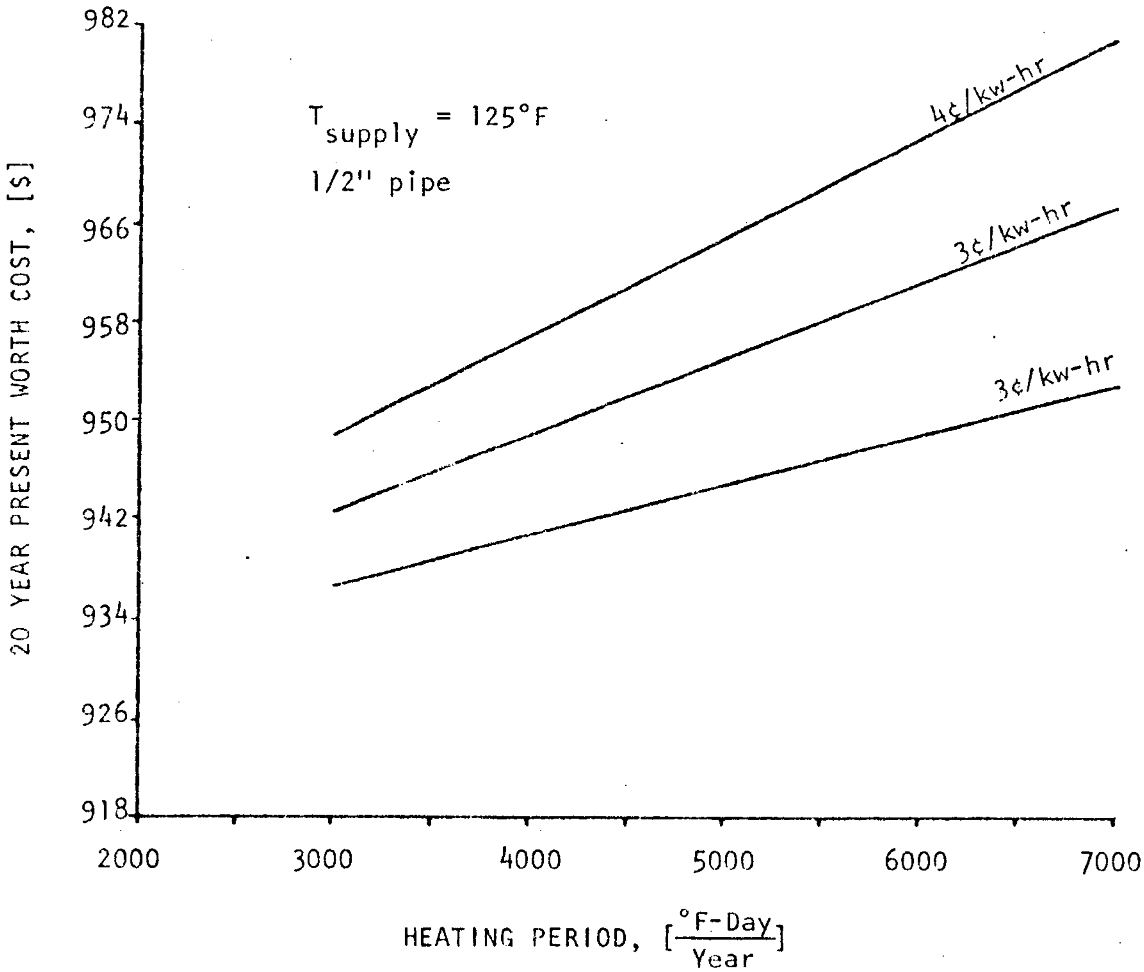

FIGURE 2. Present worth of 20-year operating costs plus initial cost for 1/2" pipe single house system, 125°F supply temperature. (House heat exchanger excluded.)

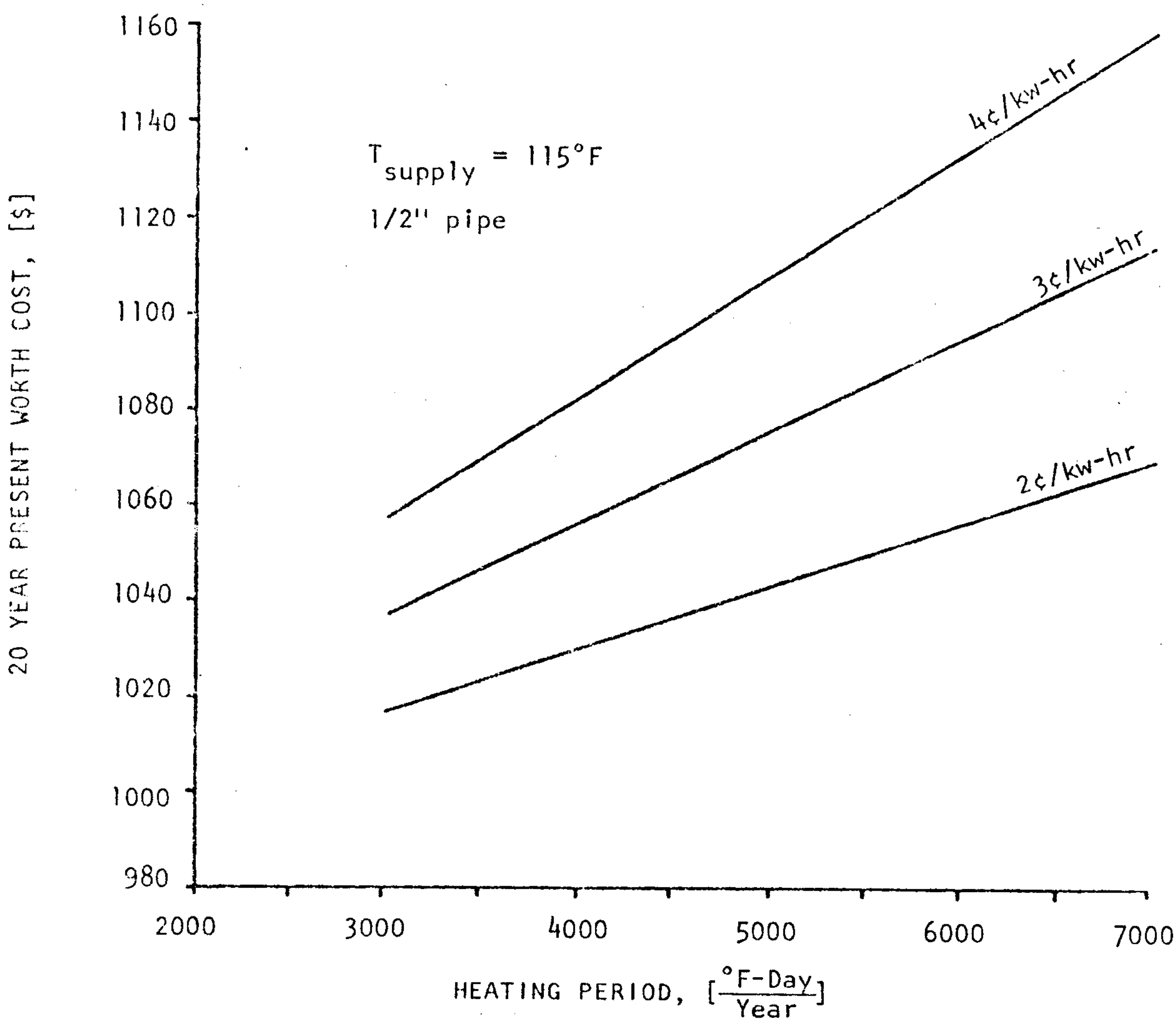

FIGURE 3. Present worth of 20-year operating costs plus initial cost for 1/2" pipe single house system, 115°F supply temperature. (House heat exchanger excluded.)

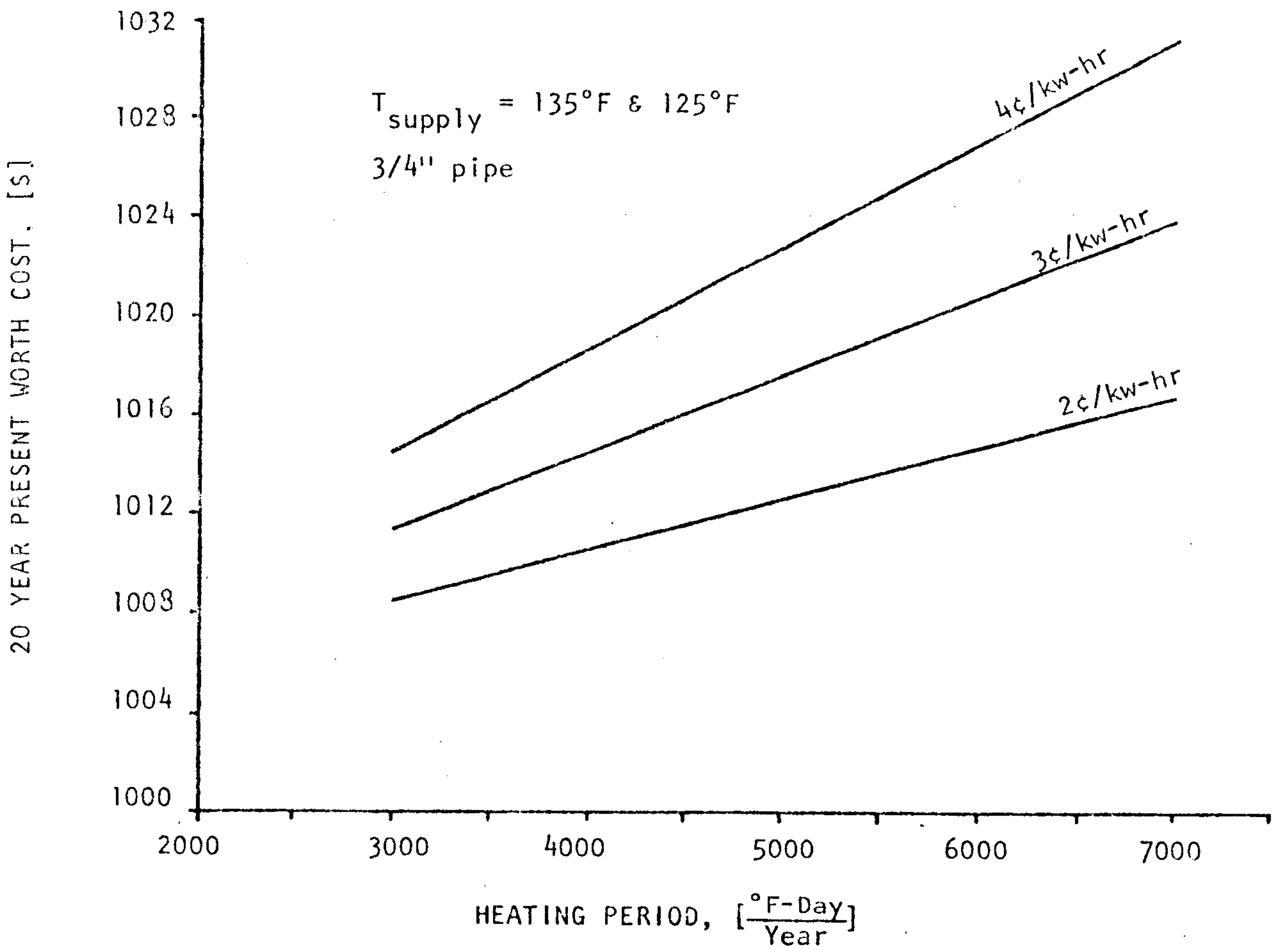

FIGURE 4. Present worth of 20-year operating costs plus initial cost for 3/4" pipe single house system, 135°F & 125°F supply temperature. (House heat exchanger excluded.)

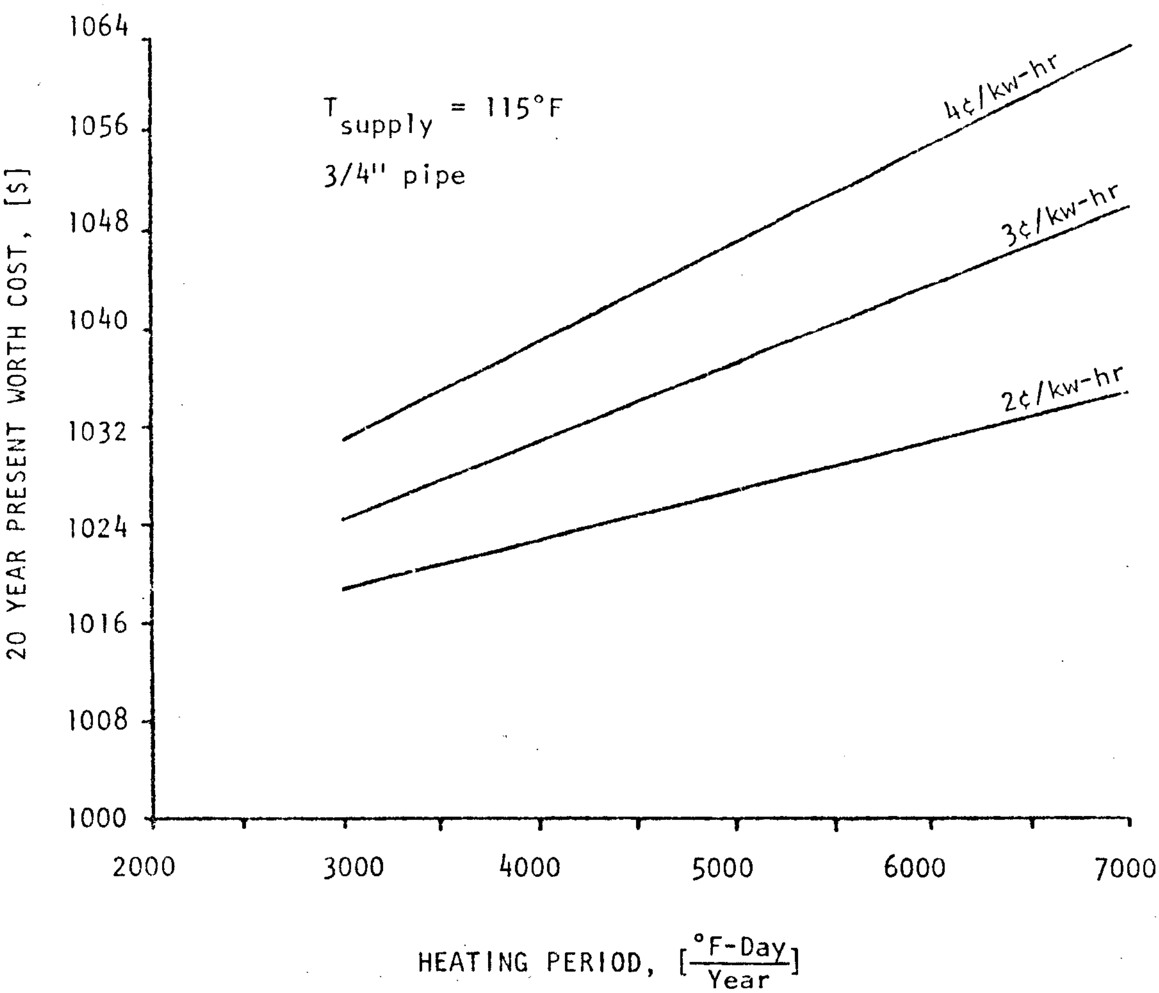

FIGURE 5. Present worth of 20-year operating costs plus initial cost for 3/4" pipe single house system, 115°F supply temperature. (House heat exchanger excluded.)

Figures 6 through 12. Some of the results are the same for different heating air exit temperatures since the same size house heat exchanger was applicable in both cases.

The initial costs of the total system are given separately in Appendix D of this report.

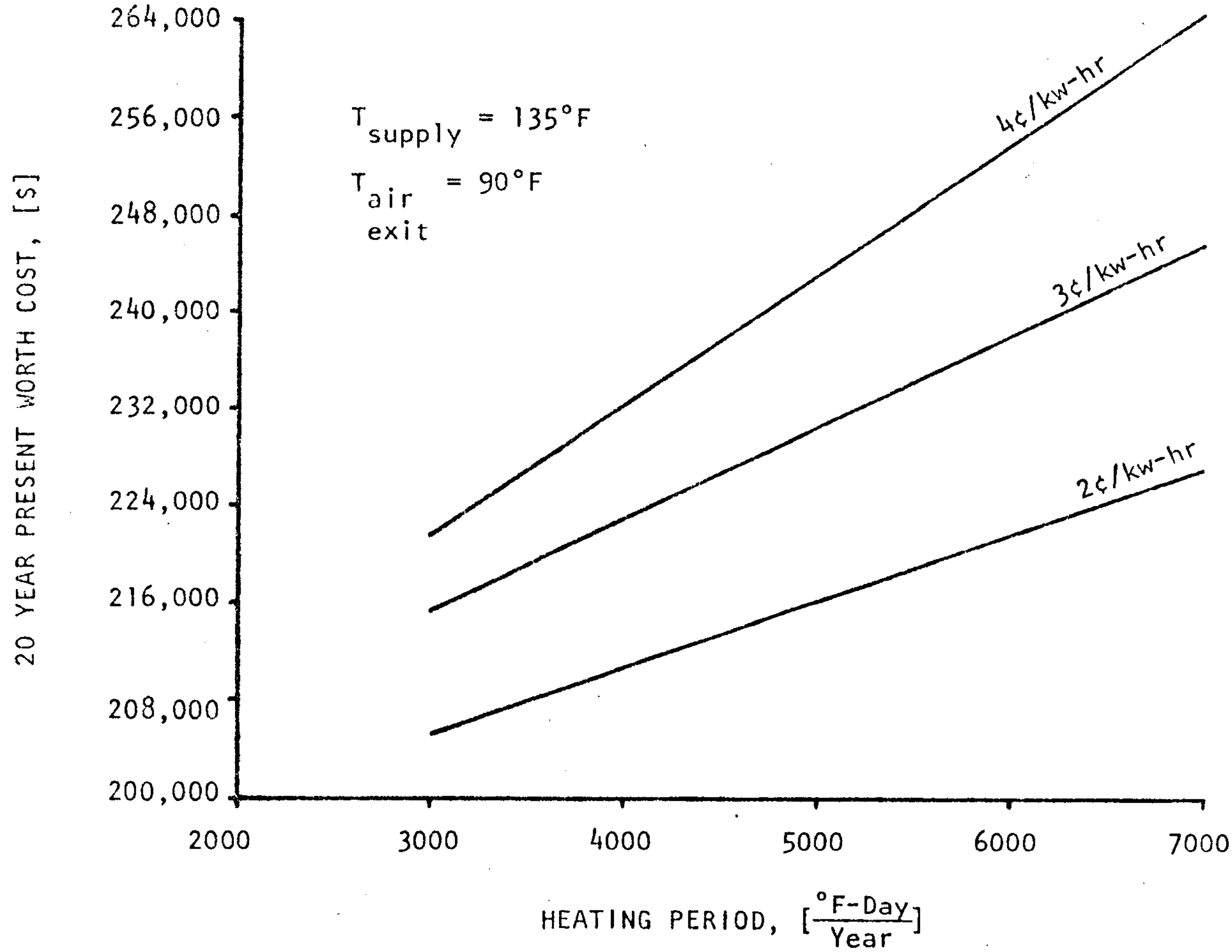

FIGURE 6. 20-year present worth cost of 140 house system for 135°F supply temperature, 90°F air exit temperature.

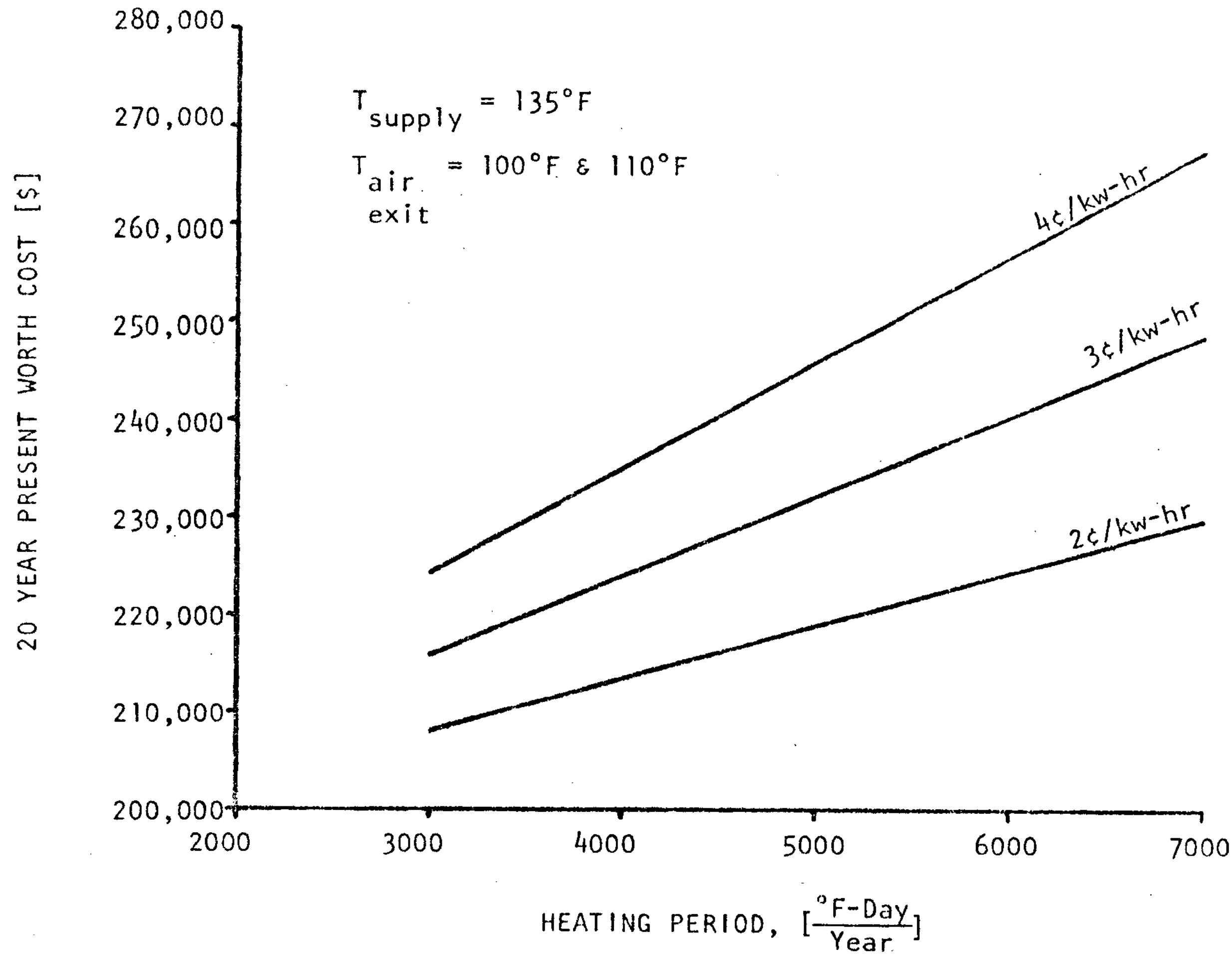

FIGURE 7. 20-year present worth cost of 140 house system for 135°F supply temperature, 100°F & 110°F air exit temperature.

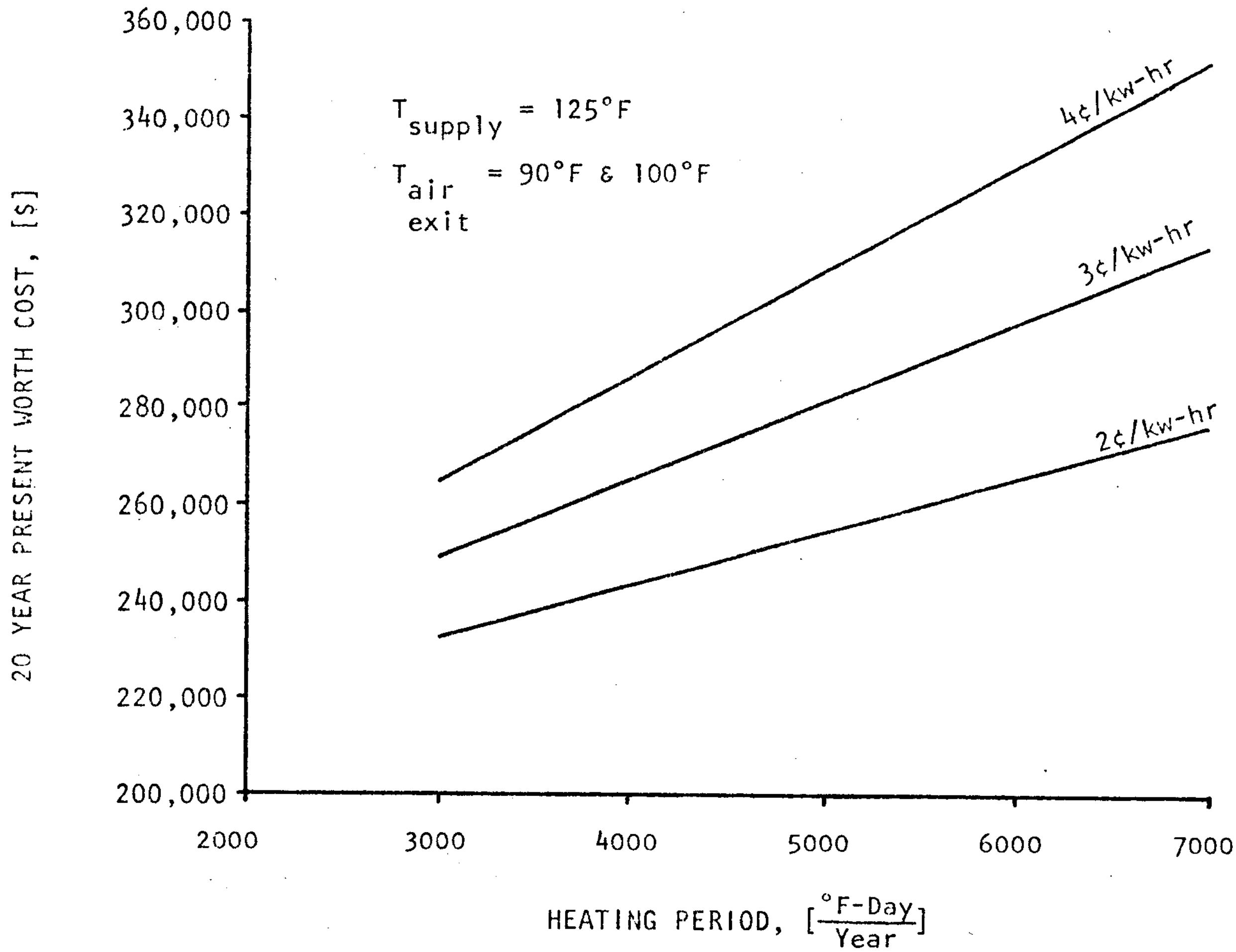

FIGURE 8. 20-year present worth cost of 140 house system for 125°F supply temperature, 90°F & 100°F air exit temperature.

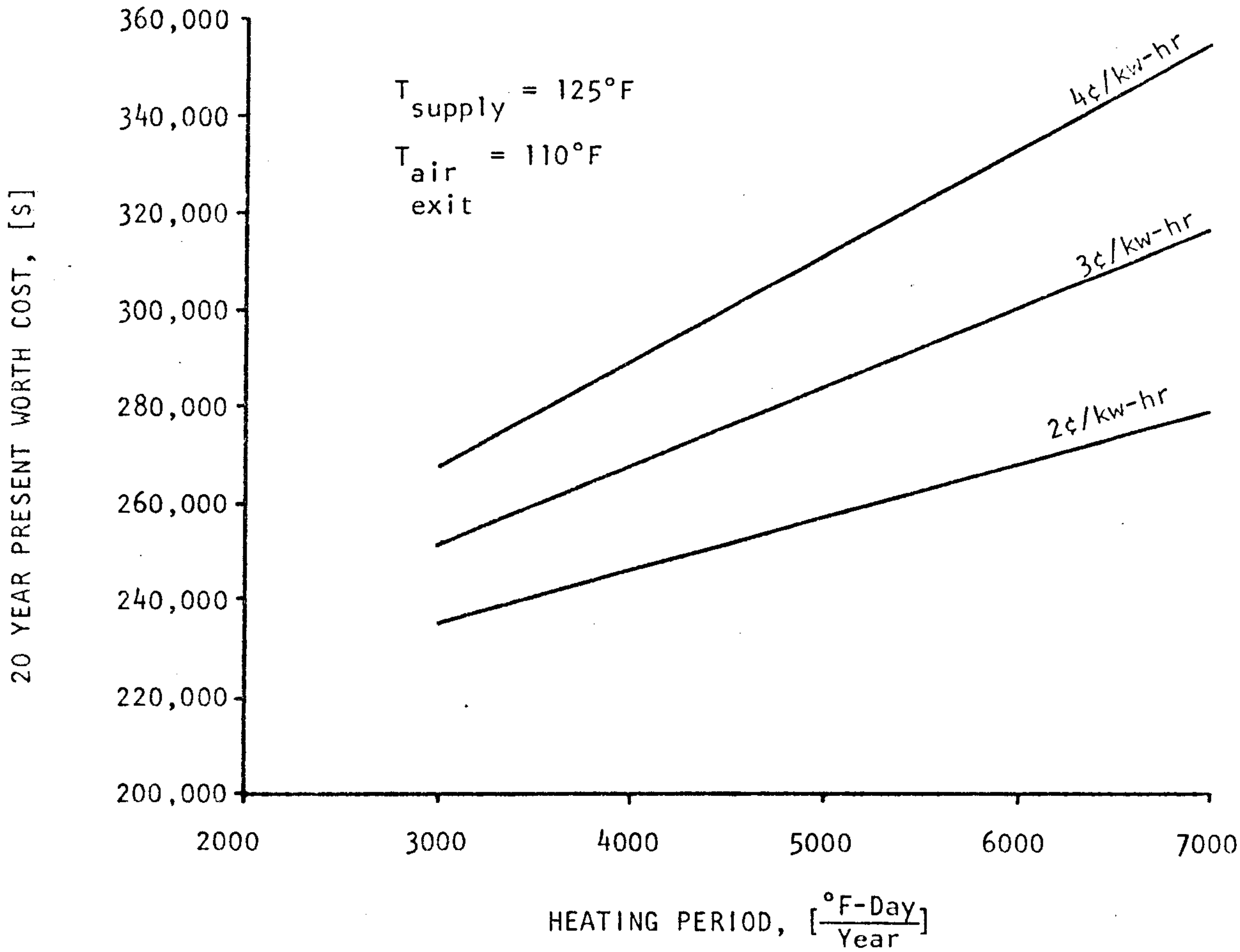

FIGURE 9. 20-year present worth cost of 140 house system for 125°F supply temperature, 110°F air exit temperature.

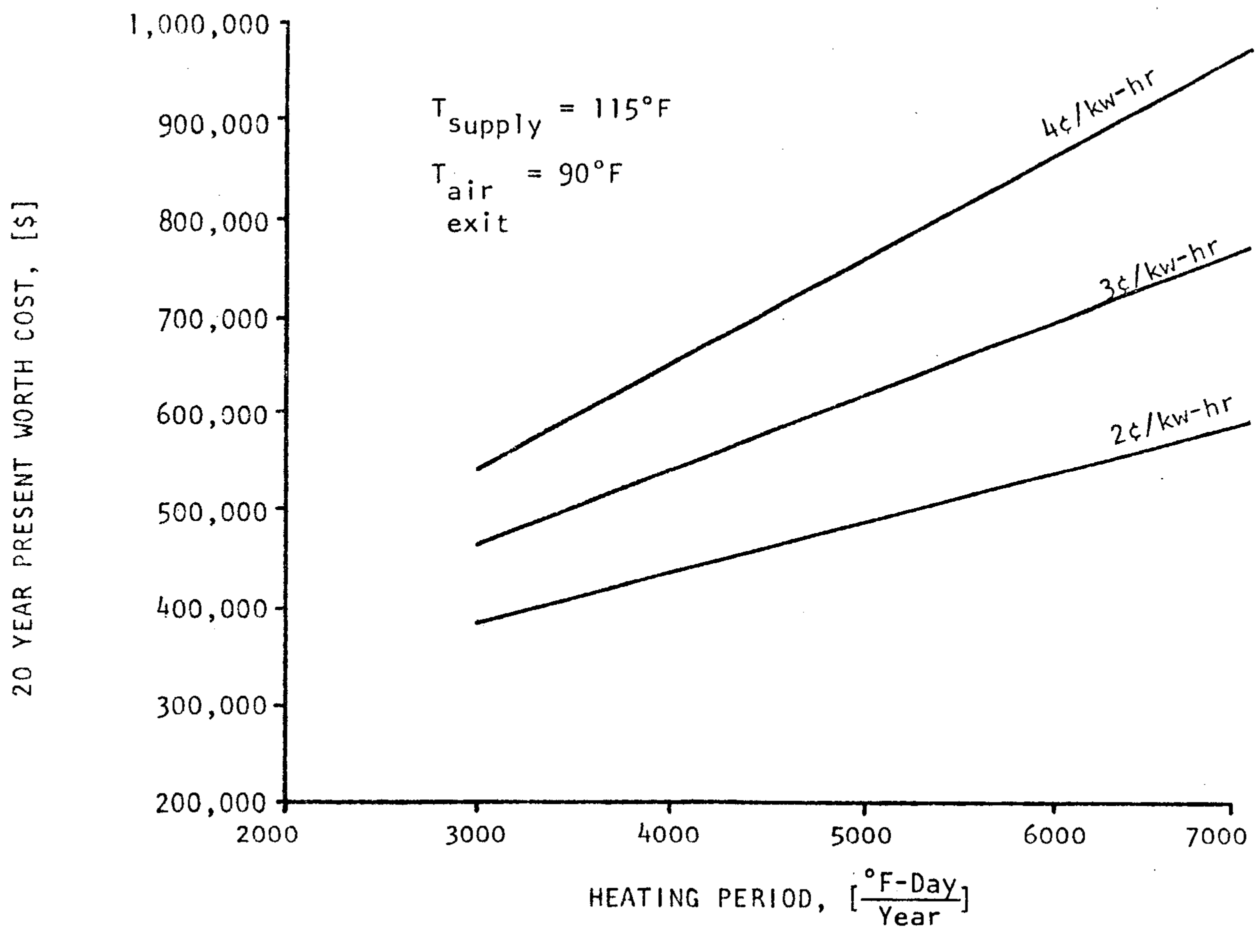

FIGURE 10. 20-year present worth cost of 140 house system for 115°F supply temperature, 90°F air exit temperature.

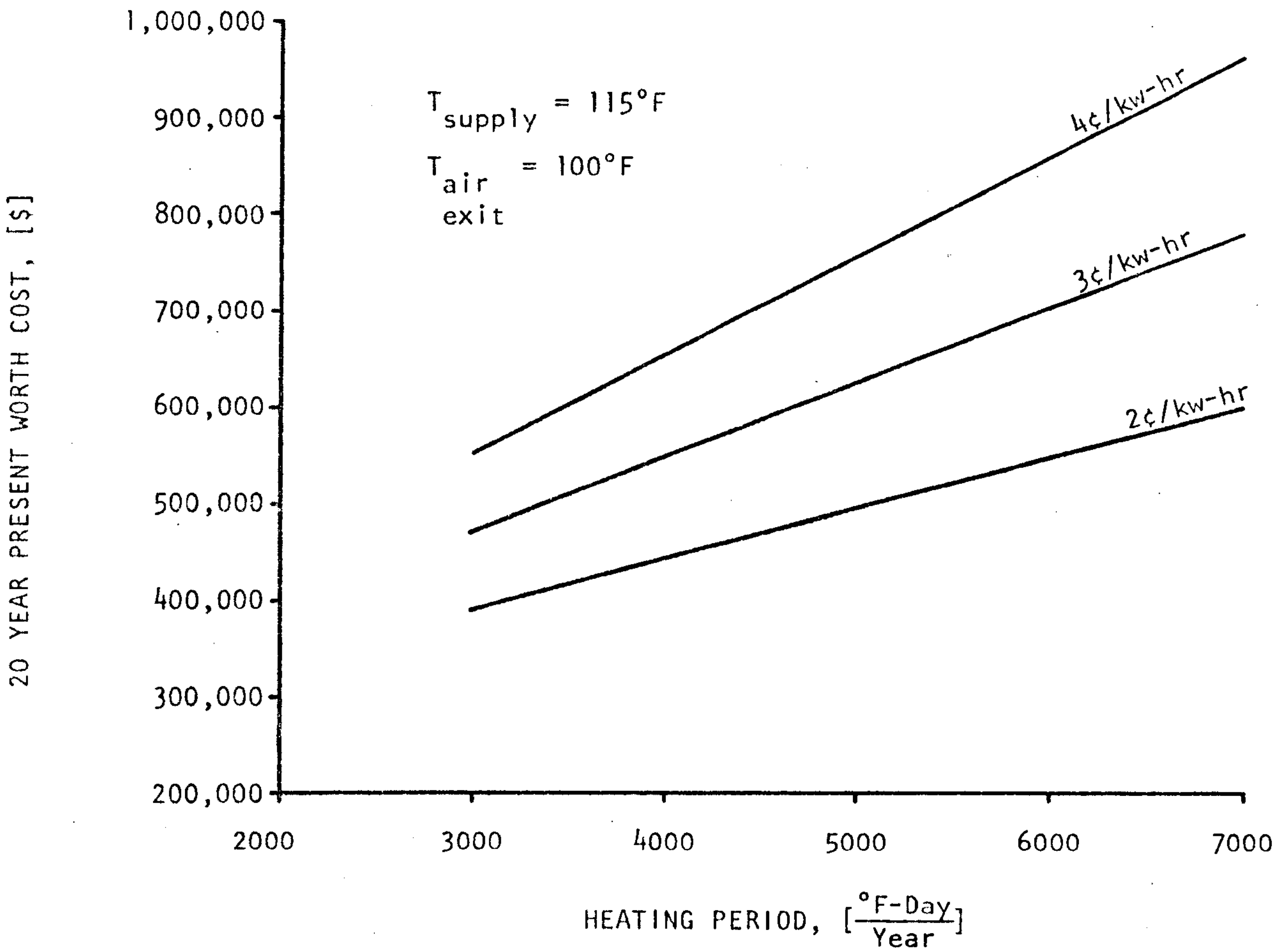

FIGURE 11. 20-year present worth cost of 140 house system for 115°F supply temperature, 100°F air exit temperature.

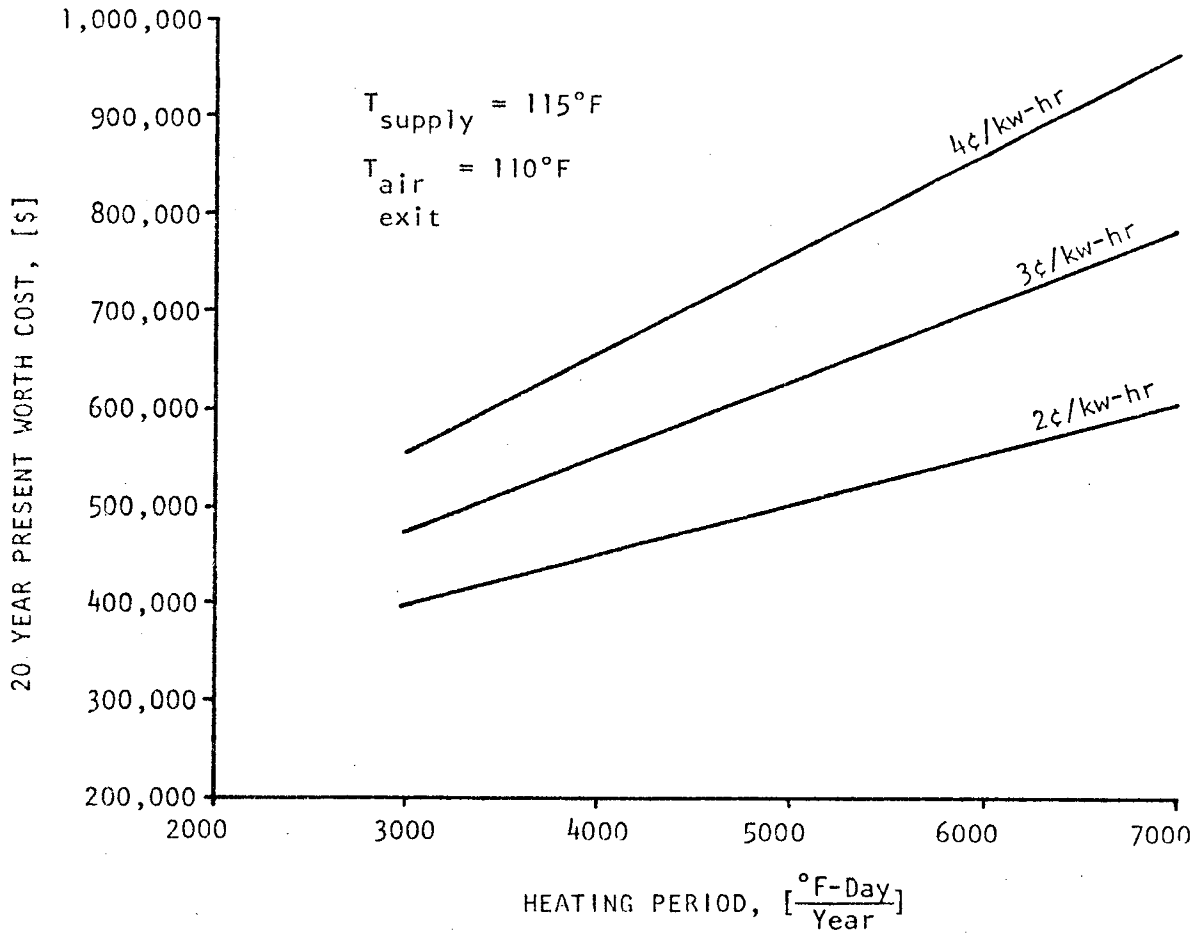

FIGURE 12. 20-year present worth cost of 140 house system for 115°F supply temperature, 110°F air exit temperature.

V. CONCLUSIONS

Upon comparing the cost of a 1/2" versus a 3/4" piping system, as shown in Figures 1-5, the following becomes apparent. First, with potable water supply temperatures of 135°F and 125°F, the 1/2" system is superior to the 3/4" system in the ranges considered regardless of the electric power cost or heating period length. This is not true for the 115°F supply temperature; in this case with power costs of 2¢, 3¢, or 4¢/kw-hr, the cost of the 3/4" piping system is less than the 1/2" system throughout the ranges considered.

The optimum system from a cost viewpoint for a 140 house community can be concluded from Figures 6-12. These figures show that the 135°F water supply temperature gives a much lower overall cost than the two lower temperatures. This is a result of the required heat rate supplied to the subdivision being constant. As mentioned earlier, this requires the water flow rate to the subdivision to increase greatly (and recall that a flow rate four times that requried to supply the heat load is used) as the supply temperature drops. The energy for heating this additional water is much greater than the energy gained by lowering the potable water supply temperature. This causes the heat exchanger area to increase as the subdivision supply temperature drops. Since the lower temperatures require larger flow rates, the pump initial cost and pumping power cost also increase. In addition, the house heat exchanger is larger for the lower supply temperatures. Therefore, it seems that the highest possible supply temperature is the most desirable since it lowers all initial costs as well as operating cost. However, the supply temperature may be limited by certain factors, such as the need to cool the water for consumption, that were not considered in this economic study.

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APPENDIX A

Present Worth of 20-Year Operating Electrical Energy Costs Using 5 and 15 Percent Assumed Annual Escalation Rates

The present worth of 20-year operating electrical energy costs is dependent on the escalation rate of energy costs for this 20 year period. As previously mentioned, the escalation rate of energy costs used in the main body of this report is equal to the present interest rate of 11¼%. Escalation rates different from this are both possible and probable, and these could significantly affect the total system cost. Tables A-1 to A-4 and Tables A-5 to A-8 show the operating costs for the system pumps for annual escalation rates of 5% and 15%, respectively. The interest rate used in these tables is 11¼%, and hot culinary water supply temperatures of 135°F and 115°F only (the extremes of this study) were considered.

By combining the operating costs from the following tables with the initial costs already given, the total cost of the 140 house heating system can be determined for either of these different escalation rates for the cost of electrical energy.

TABLE A-1. Present worth of 20-year operating costs for a single house pump for 135°F supply temperature, 1/2" or 3/4" pipe, 5% energy escalation rate.

Heating Period \ Energy Cost	2¢/kw-hr	3¢/kw-hr	4¢/kw-hr
3000 $\frac{°F\text{-Day}}{Year}$	$ 3.55	$ 5.33	$ 7.11
4000 $\frac{°F\text{-Day}}{Year}$	$ 4.74	$ 7.11	$ 9.48
5000 $\frac{°F\text{-Day}}{Year}$	$ 5.92	$ 8.88	$11.84
6000 $\frac{°F\text{-Day}}{Year}$	$ 7.10	$10.66	$14.21
7000 $\frac{°F\text{-Day}}{Year}$	$ 8.29	$12.44	$16.58

TABLE A-2. Present worth of 20-year operating costs for a single house pump for 115°F supply temperature, 1/2" pipe, 5% energy escalation rate.

Heating Period \ Energy Cost	2¢/kw-hr	3¢/kw-hr	4¢/kw-hr
3000 °F-Day/Year	$22.07	$33.12	$44.15
4000 °F-Day/Year	$29.42	$44.16	$58.87
5000 °F-Day/Year	$36.78	$55.20	$73.59
6000 °F-Day/Year	$44.14	$66.24	$88.31
7000 °F-Day/Year	$51.49	$77.28	$103.03

TABLE A-3. Present worth of 20-year operating costs for main pump for 135°F supply temperature, 5% energy escalation rate.

Heating Period \ Energy Cost	2¢/kw-hr	3¢/kw-hr	4¢/kw-hr
3000 $\frac{°F\text{-Day}}{\text{Year}}$	$ 8,828	$13,250	$17,664
4000 $\frac{°F\text{-Day}}{\text{Year}}$	$11,771	$17,667	$23,552
5000 $\frac{°F\text{-Day}}{\text{Year}}$	$14,714	$22,084	$29,440
6000 $\frac{°F\text{-Day}}{\text{Year}}$	$17,656	$26,500	$35,328
7000 $\frac{°F\text{-Day}}{\text{Year}}$	$20,599	$30,917	$41,216

TABLE A-4. Present worth of 20-year operating costs for main pump for 115°F supply temperature, 5% energy escalation rate.

Heating Period \ Energy Cost	2¢/kw-hr	3¢/kw-hr	4¢/kw-hr
3000 °F-Day/Year	$ 88,282	$132,500	$176,641
4000 °F-Day/Year	$117,710	$176,667	$235,522
5000 °F-Day/Year	$147,138	$220,836	$294,405
6000 °F-Day/Year	$176,564	$265,000	$353,282
7000 °F-Day/Year	$205,992	$309,167	$412,163

TABLE A-5. Present worth of 20-year operating costs for a single house pump for 135°F supply temperature, 1/2" or 3/4" pipe, 15% energy escalation rate.

Heating Period \ Energy Cost	2¢/kw-hr	3¢/kw-hr	4¢/kw-hr
3000 $\frac{°F\text{-}Day}{Year}$	$ 8.90	$13.35	$17.80
4000 $\frac{°F\text{-}Day}{Year}$	$11.87	$17.80	$23.74
5000 $\frac{°F\text{-}Day}{Year}$	$14.84	$22.25	$29.67
6000 $\frac{°F\text{-}Day}{Year}$	$17.80	$26.70	$35.61
7000 $\frac{°F\text{-}Day}{Year}$	$20.77	$31.15	$41.54

TABLE A-6. Present worth of 20-year operating costs for a single house pump for 115°F supply temperature, 1/2" pipe, 15% energy escalation rate.

Heating Period \ Energy Cost	2¢/kw-hr	3¢/kw-hr	4¢/kw-hr
3000 $\frac{°F\text{-Day}}{\text{Year}}$	$ 55.31	$ 82.96	$110.63
4000 $\frac{°F\text{-Day}}{\text{Year}}$	$ 73.75	$110.61	$147.50
5000 $\frac{°F\text{-Day}}{\text{Year}}$	$ 92.19	$138.27	$184.38
6000 $\frac{°F\text{-Day}}{\text{Year}}$	$110.63	$165.92	$221.25
7000 $\frac{°F\text{-Day}}{\text{Year}}$	$129.06	$193.57	$258.13

TABLE A-7. Present worth of 20-year operating costs for main pump for 135°F supply temperature, 15% energy escalation rate.

Heating Period \ Energy Cost	2¢/kw-hr	3¢/kw-hr	4¢/kw-hr
3000 °F-Day/Year	$22,128	$33,188	$44,256
4000 °F-Day/Year	$29,504	$44,251	$59,008
5000 °F-Day/Year	$36,881	$55,314	$73,761
6000 °F-Day/Year	$44,256	$66,377	$88,512
7000 °F-Day/Year	$51,632	$77,439	$103,265

TABLE A-8. Present worth of 20-year operating costs for main pump for 115°F supply temperature, 15% energy escalation rate.

Heating Period \ Energy Cost	2¢/kw-hr	3¢/kw-hr	4¢/kw-hr
3000 °F-Day/Year	$221,281	$331,883	$442,562
4000 °F-Day/Year	$295,042	$442,512	$590,084
5000 °F-Day/Year	$368,805	$553,144	$737,610
6000 °F-Day/Year	$442,562	$663,766	$885,123
7000 °F-Day/Year	$516,323	$774,395	$1,032,645

APPENDIX B

Material Costs of a Multi-Unit Main Heat Exchanger Design

The main heat exchanger costs given in Section II-A are for one large heat exchanger and this precludes unit cleaning, etc., during the heating season. Depending upon the geothermal fluid, it is possible that impurities in the resource water would require multiple heat exchangers to allow individual units to be cycled out of service for maintenance. If, for example, a three-unit main heat exchanger design is chosen, four heat exchangers will be required to allow one unit to be cycled out for service. Using the same scale-up method as before (Section II-A) to obtain main heat exchanger costs, the cost of a three-unit main heat exchanger design as a function of potable water supply temperature is shown in Table B-1.

TABLE B-1. Material costs of a three-unit main heat exchanger design as a function of potable water supply temperature.

T_{supply}	Main Heat Exchanger Cost (4-units)
135°F	$ 99,627
125°F	$112,870
115°F	$140,583

Note that the costs in Table B-1 are for four heat exchangers; hence this represents a one-third reserve heating capacity for extreme weather.

APPENDIX C

Yearly Operating Costs For A 140 House Heating System

Tables C-1 to C-3 show the operating electrical energy costs of the total system (this consists of the electrical operating costs for the main pump and for 140 house pumps) as a function of potable water supply temperature, electric energy cost per kilowatt-hour, and heating period length. As discussed previously, the cost per kilowatt-hour was assumed to range between 2 and 4 cents, and the heating season range was assumed between 3000 - 7000 °F-Day/year.

TABLE C-1. Yearly electrical operating costs for 140 house heating system for 135°F potable water supply temperature.

Heating Period \ Energy Cost	2¢/kw-hr	3¢/kw-hr	4¢/kw-hr
3000 °F-Day/Year	$ 810	$1215	$1621
4000 °F-Day/Year	$1080	$1621	$2160
5000 °F-Day/Year	$1350	$2025	$2701
6000 °F-Day/Year	$1621	$2431	$3240
7000 °F-Day/Year	$1890	$2836	$3752

TABLE C-2. Yearly electrical operating costs for 140 house heating system for 125°F potable water supply temperature.

Heating Period \ Energy Cost	2¢/kw-hr	3¢/kw-hr	4¢/kw-hr
3000 $\frac{°F\text{-Day}}{\text{Year}}$	$1619	$2430	$3240
4000 $\frac{°F\text{-Day}}{\text{Year}}$	$2160	$3240	$4319
5000 $\frac{°F\text{-Day}}{\text{Year}}$	$2700	$4049	$5399
6000 $\frac{°F\text{-Day}}{\text{Year}}$	$3240	$4860	$6479
7000 $\frac{°F\text{-Day}}{\text{Year}}$	$3780	$5670	$7559

TABLE C-3. Yearly electrical operating costs for 140 house heating system for 115°F potable water supply temperature.

Heating Period \ Energy Cost	2¢/kw-hr	3¢/kw-hr	4¢/kw-hr
3000 $\frac{°F\text{-Day}}{Year}$	$ 76,785	$115,180	$153,573
4000 $\frac{°F\text{-Day}}{Year}$	$102,382	$153,574	$204,763
5000 $\frac{°F\text{-Day}}{Year}$	$127,978	$191,967	$255,956
6000 $\frac{°F\text{-Day}}{Year}$	$153,537	$230,359	$307,145
7000 $\frac{°F\text{-Day}}{Year}$	$179,168	$268,753	$358,336

APPENDIX D

Total Initial Cost of 140 House Heating System

The initial costs of the heating system are discussed in Section II of this report. By summing the initial unit costs (not installed) of (i) the main pump and (ii) the main heat exchanger with the installed cost of (iii) 140 individual house heating systems, the total initial cost of the district heating system was obtained. Table D-1 lists this cost as a function of potable water supply temperature and house heating air exit temperature only, since the house and main initial costs are in effect dependent on these two parameters only. Some of the values are identical due to the same size heat exchanger or pump being applicable to more than one set of conditions.

TABLE D-1. Total initial cost of 140 house heating system

T_{supply} \ $T_{air\ exit}$	110°F	100°F	90°F
135°F	$191,702	$191,702	$188,902
125°F	$202,992	$199,912	$199,912
115°F	$240,575	$238,475	$235,395

APPENDIX E

Basic Cost Factors

The data given below were used in the study of calculating the initial costs of the residential heating system.

1. Labor and equipment rates for late 1978 were obtained from John Austin, CH2M Hill, Boise, Idaho. These are:

   Unskilled laborer - - - - - - - - - - - - $ 9.30/hour

   Pipefitter/plumber - - - - - - - - - - - $10.00/hour

   Backhoe operator - - - - - - - - - - - - $11.65/hour

   Electrician - - - - - - - - - - - - - - $12.50/hour

   Backhoe machine rate - - - - - - - - - - $30.00/hour

2. The approximate excavation cost per house for installing the house supply and return piping system underground was calculated using reference 1. The amount of soil excavated was obtained by assuming the house to be 75 feet from a street main and the trench being 2 feet wide and 3 feet deep. The man-hours required for digging this trench with a backhoe in medium soil and backfilling by hand was 1.85 man-hours and 13.34 man-hours, respectively. In order to provide a margin for rough terrain, rock, etc., the time for digging the trench with a backhoe was increased to 4 man-hours.

3. The house pump requires wiring and installation of a control panel by a electrician for operation. It was assumed this would require 4 man-hours for completion for each house pump.

   The installation of the house heat exchanger in existing house ductwork was assumed to require 7 man-hours. The labor rate chosen was the same as the pipefitter/plumber labor rate.

4. The following material costs were used in addition to those given previously in the body of the report to calculate the initial costs.

   1/2" rigid copper pipe - - - - - - - - - 49¢/foot

   3/4" rigid copper pipe - - - - - - - - - 79¢/foot

   1/2" 90° bend - - - - - - - - - - - - - - 19¢ each

   3/4" 90° bend - - - - - - - - - - - - - - 43¢ each

   1/2" gate valve - - - - - - - - - - - - $6.08 each

   3/4" gate valve - - - - - - - - - - - - $7.23 each

The house piping system consisted of 200 feet of pipe, 5 elbows, and 1 gate valve (in addition to the pump and heat exchanger).

5. A sealless magnetic-drive pump was chosen for use in the house piping system. The cost of the pump for each design flow condition was obtained from the Cole-Parmer Instrument Company 1979-1980 Catalog. Listed below is the catalog number, horsepower rating, and cost of each of the pumps.

Catalog Number	HP	COST
7004-10	1/50	$60.30
7004-30	1/25	$64.30
7023	1/8	$120.00

6. A Crane-Deming centrifugal pump was chosen for the main or "booster" pump. By using the assumptions stated in Section II-D, pump sizes of 50, 100, and 500 horsepower were required for the potable water supply temperatures of 135°F, 125°F, and 115°F, respectively. The total cost of 50, 100, and 400 horsepower pump-motor units were obtained from Tidewater Machinery and Machine Tool Company, Greenville, SC, with the 500 horsepower pump-motor unit being extrapolated from these costs. The costs of these pump-motor units are given below.

Catalog Number	HP	COST
5061	50	$2390
5062	100	$3640
5064	400	$12,300
	500	$14,250 (approximate)

7. Solar hot water coils, manufactured by the Magic Aire Division - United Electric Company, Wichita Falls, Texas, were selected for the house heat exchangers. The costs of coils only are listed below:

Model	Face Area	Cost
SHW-130	12½ x 15	$68
SHW-208	15 x 20	$88
SHW-347	20 x 25	$110
SHW-417	20 x 30	$125

APPENDIX F

Review and Critique by CH2M Hill