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*Geothermal Energy Development
in the Eastern United States*

**TECHNICAL ASSISTANCE REPORT NO. 5
GEOTHERMAL SPACE HEATING—
NAVAL AIR REWORK FACILITY
NORFOLK, VIRGINIA**

F. K. HILL

R. W. HENDERSON

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THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY

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JUNE 10, 1980

THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY
Johns Hopkins Road, Laurel, Maryland 20810
Operating under Contract N00024-78-C-5384 with the Department of the Navy

Geothermal Space Heating

Naval Air Rework Facility, Norfolk, Virginia

PREFACE

This is one in a series of reports on technical assistance in the utilization of geothermal energy. The scope of technical assistance is limited to basic technical and economic feasibility to assist those interested in scoping the problem and deciding whether detailed engineering is warranted now or in the future. This effort is supported by the U. S. Department of Energy's Division of Geothermal Energy, Dr. David B. Lombard, Program Manager. The Laboratory's assistance is limited to the Eastern United States.

The analysis documented in this report was initiated at the request of Mr. William J. Maxwell of the Industrial Engineering Department of the Naval Air Rework Facility, and with the concurrence of Mr. Thomas Ladd of The Naval Facilities Command, code-NAUFAC 1113C Hoffman Building, Arlington, Virginia.

Other technical assistance reports are as follows:

1. Geothermal Space Heating - Crisfield High School, APL/JHU Technical Assistance Report No. 1.
2. Geothermal Energy Applied to the Mariculture Industry on the Eastern Shore of Maryland, APL/JHU Technical Assistance, February 18, 1980; Report No. 2.
3. Geothermal Vaporization of LNG by Geothermal Water. APL/JHU Technical Assistance Report No. 3.
4. Geothermal Space Heating - Pittsville Middle/Elementary School, APL/JHU Technical Assistance Report No. 4.

I. Introduction

The objective of this technical evaluation was to determine whether geothermal energy obtained from a well could be used to heat a building at the Naval Air Rework Facility (NARF) and produce a significant saving of oil used without an economic loss. The electronic integration hangar, designated LP-167, was selected for study, as it was a single-story building with a large floor area. Because of the high ceiling and the sliding doors necessary to admit aircraft, the heat loss rate, based on floor area, was about twice that of commercial buildings. It was furnished with an oil-fired hot water heating system capable of high thermal output to meet heating requirements in the coldest weather.

On the basis of the known characteristics of geothermal sources for the Atlantic Coastal Plain, Refs. 1 and 3, and wells drilled and assayed in the Norfolk area, Ref. 2, a reasonable estimate of the parameters of a well drilled at NARF was made. This included a low temperature output from the well of only 107°F, Ref. 4, so that direct transfer of warm water between the wellhead heat exchanger (HX) and the hot water radiating system in the building was not practical. It was calculated that the well would produce heat via warm water pumped to the surface at a rate about 1/5 of the maximum heating rate demand of the building for the coldest weather, but, because of the continuous daily output, it more than met the net demand over a 2 to 7 day span and over a heating season the geothermal output was more than twice the building demand.

II. Design Options

In order to utilize the geothermal source to heat the building it was necessary either to design an alternate radiation and convection system in the building for using low temperature water, or to boost the temperature of the well output to near 180°F for the existing LP-167 hot-water system. Furthermore, to supply heat rates 2 to 5 times that of the well output, a storage reservoir had to be included to store heat during non-working hours. Raising the temperature out of the well HX necessitated the use of heat pumps (HP), and this introduced the possibility of using "waste" heat from the well HX via a HP to supply more heat. These choices are dealt with separately as particular case applications and denoted for convenience as Options A, B, C and D. For each option we show a) a block diagram to indicate the functions of the major equipments, b) a table of the capital and operating costs as well as power ratings, and c) an amortization schedule in graphical form to indicate the recovery (or non-recovery) of the capital costs. These data and figures are given in Appendices A, B, C and D.

Option A uses the geothermal heat directly in a floor radiative system and retains the existing oil fired heaters for additional (peak) heating (15% of total) during only the coldest weather. Option B, on the other hand, by means of a heat pump, raises the temperature of the well output so that the hot water can be used in the existing heating system, thus providing 73% of the annual heat load. Options C and D are variations of B, but include the installation of a storage reservoir nearby and another heat pump to provide all the heat required by the building. It is noted that with heat pumps available, almost twice the thermal energy from the well is recoverable so that with a storage reservoir heat could be provided to heat a second and even a third building without significant additional capital investment.

III. Conclusions

1. Because of the single story, large floor area characteristic of aircraft hangar buildings, they are particularly suitable and adaptable to the use of low temperature geothermal energy. The application requires the installation of a 6-inch thick concrete slab over the existing floor with pipes inside to allow water circulation

2. A warm water storage reservoir is very useful and moderately expensive to install and use for a variety of heating systems. It solves the peak heating problem and can furnish enough heat to sustain a second, and, in the case of Option C, a third building.

3. Current inflation rates, as well as the escalation rates for oil and electricity make rather costly capital equipment apparently economically feasible for long pay back periods. Thus options A and B can be amortized theoretically in less than 23 years and displace 50,000 to 62,000 gallons of fuel oil per year.

4. However, amortization beyond 20 yrs is questionable regardless of the options, because economic conditions, newer equipment and industrial growth rates may change significantly. On the other hand in 20 yrs, energy supply availability may outweigh cost.

5. a) Additional work is required to locate and evaluate an optimum well site.
- b) The possible disposal of waste water in the Atlantic Ocean should be determined.

- c) Combined heat pump heating and cooling use would increase utilization and improve the economics. There are at least two research and development programs assessing the possibility of heat pumps for cooling using moderate temperature as energy source. As these develop they may be applicable to the Naval Air Rework Facility.
- d) Modifications in costs due to changes in the resource characteristics such as output temperature, pumping rate, drawdown, etc. are possible. The extent of these changes must await operating experience with geothermal wells in the Coastal Plains, on a model of the hydrology and thermal properties of the resource.

6. As the next step, it is recommended that a well be drilled and logged as close as possible to the LP-167 Building to confirm the prediction of temperature at Depth. Alternately to extend one of the shallower gradient wells. In addition to confirming the temperature at Depth, the well logs will identify the potential production and reinjection zones. It is further recommended that pump test of these zones be made of permeability and flow rates for the onset of turbulent flow.

IV. Boundary Conditions

The results obtained in computing the costs are very dependent on the physical conditions imposed by the user of geothermal source, the source itself and the efficiency of the equipment selected to distribute the heat. The conditions and performances are:

A. Characteristics of NARF Building LP-167, Ref. 10

1. Size: 640 ft long, 225 ft wide, ~ 30 ft ceiling
Floor area: 144,000 ft² total
120,000 ft² available
2. Heating via oil-fired system:
Two burners, each use 83.4 g/hr of #6 fuel oil
Hot water heaters operate at 180°F
Average annual consump. = 73,100 gal.
Heat output = 2 (7.03 x 10⁶) Btu/hr
Heat trans. coef., U, = 2 Btu/°F hr ft² floor

B. Properties of Geothermal Well

1. Depth: 2500 ft (Ref. 4)
Reinjection well: 2200 to 2500 ft
2. Output: 225 gpm at 107°F
3. Maximum drawdown: 1500 ft
4. Heat exchanger 107°F input, 85°F out, well water
102°F out, 80°F in, exchange water
5. Well runs continuously throughout the heating season, but the rate may vary dependent on the heat load required by the weather and the reservoir capacity.

C. Costs

1. Inflation rate = 7 1/2%, 1977-1980
= 9%, 1980 on.
2. Oil escalation rate = 3 1/2%
3. Electricity escalation rate = 1 1/2%
4. Capital Interest Rate (NARF current) = 10%
5. Heat pump cost (in 1980 dollars), Ref. 6
5.05 (Q)^{0.67};
Q is the heat pump output in Btu/hr

6. Heat exchanger cost in 1980 dollars
 $0.057 (Q)^{0.84}$;
 Q is the HX throughput in Btu/hr
7. Well drilling, \$75/ft
8. Concrete delivered, premixed, \$35/cu yard.
9. Labor, carpenters, plumbers, electricians @ \$10/hr.

D. Weather

At Norfolk, based on Weather Almanac records, Ref. 5, average temperatures, 1936 to 1975, fitted to a normal distribution curve

$$\Delta T = 65^{\circ}\text{F} - T = 23.7 \exp \left\{ -1/2 \left(\frac{t-144}{61.714} \right)^2 \right\} \quad (1)$$

where t = time

$$\int_0^{\infty} \Delta T dt = 3600 \text{ deg-days} \quad (2)$$

See Fig. E-1 for comparison of eq(1) with Norfolk average temperature data, where it can be seen that the normal distribution has been fitted to bias the total to colder weather, i.e. more deg days. By altering the fit near the extremes, in October and April, values of 3400 degree days can be obtained. Fig. E-2 shows the No. of deg-days vs ΔT used to determine the demand of the building as a function of temperature.

V. Results

The results of the computations made for the four options are shown in Table I, Cost Summary. The net saving on operating cost is made up of: a) the cost of oil, escalating at 3 1/2% plus a 9% inflation rate; b) the electrical operating cost of the equipment in the geothermal system, 1 1/2% escalation plus 9% inflation for electricity as well as any oil costs for peak heating; and c) the maintenance cost of the geothermal system less the maintenance cost of the oil-fired system. The net operating return each year is given by

$$[(\text{oil cost in 1980})(1.125)^n + \text{maintenance cost of oil-fired system}]$$

$$- [(\text{elec. pwr cost in 1980})(1.105)^n + (\text{peaking oil cost in 1980})(1.125)^n$$

$$+ \text{maintenance cost of geothermal systems}]$$

where oil cost in 1980 = 73,100 gal x \$0.90/gal. = \$65.79K.

Electric pwr = 0.05 x No. Kw hr. for each equipment

Maintenance = % of capital cost, depending on equipment.

Only options A and B present amortization of less than 23 years. Both C & D have large capital costs with correspondingly large electrical cost figures. Thus for C and D the amortization, although positive, takes a very long time.

Several factors to be noted:

- (1) The large floor area and rather effective floor-to-ceiling convective system make the floor radiant heating option (Option A) very attractive. By using 83% of the floor area the radiant system supplies 85% of the demand heat load.
- (2) A water storage reservoir, $\sim 0.6 \times 10^6$ gal of water, provides 1.1×10^8 Btu storage capacity, sufficient to meet peak load demands for 2 weeks in the coldest weather, see Table III.
- (3) Although Option C represents the largest capital cost, it also provides the maximum utilization of geothermal heat by reducing the reinject temperature from 85°F to 60°F. This doubles the heat extracted from the well and stored in the reservoir.
- (4) Utilization of the energy stored in the reservoir could heat a second building very efficiently, since the cost of additional heat pumps and auxiliary piping would amount to less than 50% of the capital cost shown for Option C. Alternatively pumping rates and drawdown can be reduced.
- (5) The calculations here presume the shut-down of the well during the (4 1/2) summer months. The well could operate continuously throughout the summer and provide much additional energy if a means could be found of efficiently using the low thermal source, washing air planes, for example.

One additional calculation is significant in assessing the oil saving of the geothermal system. This is shown in Table II, Oil Use. In this table the conserving of oil at NARF as derived in Table I is shown and the corresponding potential oil use transferred to the electrical power company by increased electrical power usage of the geothermal system; e.g., we see that for Option A the oil use at NARF would be decreased from 73,100 g/yr to 10,965 g/yr. The electricity required by the geothermal well and circulating pump system could require as much as 12,058 additional gal of oil to be burned at the power plant (if oil is used, rather than coal or nuclear). Thus the net saving in oil consumption would amount to 50,077 gal in so far as the national use was concerned. Similar calculations are shown for the other options, pointing out that not only is the economic cost in dollars over a period of years significant, but also the net oil saving to the nation.

Table I. COST SUMMARY

<u>Costs</u>	A	B	C	D
<u>Capital</u>	\$560.2K	\$501.1K	\$914K	\$829.1K
<u>Operating</u>	Geo. 17.9K(1.105) ⁿ + 9.87K(1.125) ⁿ 100% Oil 65.79K(1.125) ⁿ + 4K(1.09) ⁿ	Geo. 39.32K(1.105) ⁿ + 17.76K(1.125) ⁿ 100% Oil 65.79K(1.125) ⁿ + 4K(1.09) ⁿ	Geo. 49.68K(1.105) ⁿ + 6.8K(1.09) ⁿ 100% Oil 65.79K(1.125) ⁿ + 4K(1.09) ⁿ	Geo. 74.4K(1.105) ⁿ + 5.96(1.09) ⁿ 100% Oil 65.79K(1.125) ⁿ + 4K(1.09) ⁿ
<u>Net</u>	55.92K(1.125) ⁿ - 17.9K(1.105) ⁿ	55.13K(1.125) ⁿ - 39.32K(1.105) ⁿ	65.79K(1.125) ⁿ - 49.68K(1.105) ⁿ - 2.8K(1.09) ⁿ	65.79K(1.125) ⁿ - 74.4K(1.105) ⁿ - 1.96K(1.09) ⁿ
<u>Amortization</u>	11.5 yrs	22.5 yrs	26 yrs	< 40 yrs
<u>Equipment</u>	Geothermal well source Reinject well Heat exchanger Floor rad. system Use existing oil-fired boiler system for 15% heat Storage reservoir (100' x 100' x 8')	Geothermal well source Reinject well Heat exchanger Heat pump (391 hp) Use oil-fired system for 27% heat load	Geothermal well source Reinject well Heat exchanger 3 heat pumps 391 hp 327 hp 756 hp Storage reservoir (100' x 50' x 6')	Geothermal well source Reinject well Heat exchanger 2 heat pumps 195 hp 1004 hp Storage reservoir (100' x 50' x 6')

Table II. OIL USE

<u>Option</u>	<u>Capital</u>	<u>Amortization</u>	<u>Oil used at NARF(LP-167)</u>	<u>Oil at Power Plant*</u>	<u>Net Saving</u>
Oil-Fired System now existing	--	--	73,100 gal. (avg.)	0	0
A	\$560.2K	11.5 yrs	10,965 gal.	12,058 gal	50,077 gal
B	501.1	22 1/2	19,737	33,000	20,363
C	914	26	0	41,694	31,406
D	829.1	< 40	0	62,441	10,659

*Coal or nuclear would zero this item.

Notes:

- 1) Both A and B retain use of the existing oil-fired hot water system for peak heating, needed only in the coldest weather.
- 2) C uses the waste heat from the Geothermal Well, thus doubling its useful output, and also provides a large reservoir of heat available for heating a similar building in the area. If additional use is made of this heat the savings in oil burned could increase significantly and the amortization time decrease as well.
- 3) D is less desirable and more expensive, although this system also makes available the 24-hr output of the well which is twice the total annual demand of Bldg. LP-167.

Table III.

STORAGE RESERVOIR		GEO THERMAL WELL	BUILDING USE
A (for OPTION A)	B (for OPTIONS C,D)		
100' x 100' x 8'	100' x 50' x 6'	225 gpm at	14 x 10 ⁶ Btu/hr, Peak
6 x 10 ⁵ gal.	2.2 x 10 ⁵ gal.	107°F	or
5 x 10 ⁶ Btu/°FΔT	1.9 x 10 ⁶ Btu/°FΔT	2.5 x 10 ⁶ Btu/hr	7 x 10 ⁷ Btu/da.
= 1.1 x 10 ⁸ Btu	1 x 10 ⁸ Btu	3 x 10 ⁸ Btu/wk(5da)	3.5 x 10 ⁸ Btu/wk
		6 x 10 ⁸ Btu/2 wk	7 x 10 ⁸ Btu/2 wk

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2. Plot and geological description of well drilled at Norfolk near NARF, #27, U.S. Dept. of Interior Geological Survey, Professional Paper 796, Plate 31, Geologic Cross-Section H-H from 6-157 Well, Northampton County, N.C. to Chesapeake Bay Bridge-Tunnel, City of Virginia Beach, Va.--Well designated VA.-NOR T-12, 36°52'20"N, 76°12'00" W.
3. Yu Kwang, "Transient Radial Flow in Horizontal Aquifers," APL/JHU Report QM-79-219.
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10. R. C. Niess, "Utilization of Geothermal Energy with an Emphasis on Heat Pumps," Templifier Dept., Westinghouse Electric Corp., A Symposium of Geothermal Energy and Its Direct Use in the Eastern United States, Special Report No. 5 by Geothermal Resources Council, April 1979.
11. Drawings and Specifications of NARF building LP-167, furnished by Mr. William Maxwell.

APPENDIX A

Option A

Use of the output of the geothermal well at its low temperature supply requires a radiating area large enough to provide as much of the heat load as possible. For a heated floor area the heat output per unit time is approximated by

$$\frac{dQ}{dt} = \left\{ A \left[\alpha (T_h - T_s) + \beta (T_h - T_a)^{1.25} \right] \right\} \quad (1)$$

where A is the heating area with T_h its average temperature, T_s the average temperature of the surrounding surfaces and T_a the air temperature in the heated space. Values of α as a function of T_s and β are given in Refs. 8 and 9. The first term of Eq. (1) represents the radiant heat and the second, the convective effect of air movement over the heated floor surface. For a heated water supply at 102°F into a floor radiation system with an outlet temperature of 80°F, the average value becomes 91°F for T_h . When the outside temperature is 20°F the value of $\alpha = 0.85$. $\beta = 0.48$ and the inside air temperature is to be 65°F. Then Eq. (1) becomes

$$\frac{dQ}{dt} = A (60.35 + 28.18) \text{ Btu/hr.} \quad (2)$$

showing that 68% is radiated from the floor and 32% is convected. Eq. (2) also indicates that for a floor radiating area of 120,000 ft² (Bldg. LP-167 has approximately 144,000 ft² area) the heat flow would be 10.6×10^6 Btu/hr. Since the heat transfer coefficient for this building as related to its floor area is about 2 Btu/ft²hr°F, a heat supply of 10.6×10^6 Btu/hr would provide the necessary heating for a ΔT of 36.9° or an outside temperature of 28.1°F. An estimate from the temperature records and annual temperature distribution throughout the last 35 years of Norfolk climate indicates not more than 500 deg-days below 28°F, or 15% of the annual heating load. Consequently, an allowance of 15% of the average oil consumption now used appears to be a conservative allowance for peaking or auxiliary oil-fired heating.

Figure A-1 shows, schematically, the addition of a geothermal well, heat exchanger, storage reservoir, and floor radiation system for augmenting the heating system now used for heating Bldg. LP-167. It assumes that the well would be used to supply 85% of the annual heat load, and 15% would come from the existing oil-fired conventional hot water system. Table A-I shows the capital costs and expected operating expenses, based on today's prices for oil and electricity. Fig. A-2 shows how the total investment of \$560.2K would grow with time over the next 25 yrs and what the savings would be by using 85% geothermal heat. Oil and electricity were assumed to escalate at 3.5% and 1.5%, respectively, above the projected inflation rate of 9%. A capital interest rate of 10% was used in accordance with existing Navy rates in the Norfolk area (as well as other armed services, governmental and commercial rates). It is interesting that, in spite of the very high capital

costs for a geothermal installation (e.g., note a \$75/ft cost of well drilling some three times year earlier costs), that the net savings amortize the well cost in about 11 1/2 years.

For this case conservative estimates are that: a) the well operate continuously on a 24 hr basis for 230 days (7 1/2 mo.); b) the well is not used productively for 4 1/2 months; c) a second well would not aid the situation because the existing well produces more heat during the heating season than does the 73,100 gal of no. 6 fuel oil (even at 100% efficiency) and the use of low temperature potential geothermal energy is limited by the available floor area in Bldg. LP-167.

In this case the maintenance costs for the pumps, heat exchanger floor radiation system and storage reservoir amounted to about that for a 100% oil burner system. Hence, no maintenance allowance has been included in the amortization schedule.

Table A-I
Option A Equipment

<u>Equipment</u>	<u>Op. Parameters</u>	<u>Cap. Cost</u>	<u>Op. Cost</u>
1. <u>Geothermal Well</u>			
a) Depth 2500 ft	\$75/ft	\$187.5K	--
b) Output: 225 gpm at 107°F			
c) Drawdown, max. 1500 ft			
d) Submersible pump	85 hp 24 hr/day for 230 da.	10.0	17.5K (1.105) ⁿ
e) Reinject well, 2200 ft	\$75/ft	\$165K	--
or			
[Ocean disposal, 5000 ft line and 5 hp pump]		[15K]	[1.03K(1.105) ⁿ]
2. <u>Heat Exchanger</u>	107°F → 85°F	2.5 x 10 ⁶ Btu/hr	15K
3. <u>Circulating Pumps</u> (1 hp) and electrically controlled valves (0.1 hp)		0.6K	0.4K (1.105) ⁿ
4. <u>Floor Radiation System</u>			
120 x 10 ³ ft ² area		131.5K	--
2" dia. pipes in 6" concrete (Poured on existing floor)			
5. <u>Storage Reservoir</u> - 600,000 gal.			--
100 ft x 100 ft x 8 ft with 1 ft concrete insulated walls, floor & top, See Table A-I		50.6K	
6. Auxiliary oil fired heat from existing system, 15% of load		--	9.87K (1.125) ⁿ
		\$560.2K	17.9K (1.105) ⁿ + 9.87K (1.125) ⁿ

Table A-II

COST of H₂O THERMAL RESERVOIR, 100' x 100' x 8', 6 x 10⁵ gal.

(1' thick walls & bottom, 1/2' top)

CONCRETE: 734 yds. @ 35/yd =

\$25K

EXCAVATION

1.25K

MATERIALS: WOOD, CONSTRUCTION LMBR.

1.8

STEEL STRUCTURAL,

3.675

INSULATION

2.32

PIPE, FITTINGS, VALVES

6.94

LABOR: CARPENTERS @ \$10/hr.

6.--

PLUMBERS

3.6

\$50.585K

\$0.63/ft³

COST of H₂O THERMAL RESERVOIR, 100' x 50' x 6', 2.2 x 10⁵ gal.

100' x 50' x 6'

(1.5 rate for larger reservoir)

\$30K

APPENDIX B

Option B

Use of a Heat Pump to Raise the Well Temperature-- Use Existing Heating System

By using a heat pump to raise the temperature of the water from the wellhead exchanger output, heat may be supplied directly to the existing building radiation system from the geothermal source, see Fig. B-1. A heat pump, utilizing water-to-water heat transfer, can raise the temperature to 180°F from 102°F with a coefficient of performance, COP, of 3.5.* This requires a 391 hp unit which adds its electrical energy to the heat output, providing a total of 3.48×10^6 Btu/hr delivered continuously to the building. This would then supply 73% of the heat load, leaving a balance of 27% to be supplied by the existing oil-fired hot-water system. The operating conditions, capital and operating costs are shown in Table B-I. This system pays out in 18 years as may be seen from the operating costs. The net operating cost of the existing 100% oil-fired system less the combined geothermal and oil fired system is

$$\$65.79K (1.125)^n - [\$39.32K (1.105)^n + \$17.76K (1.125)^n].$$

The amortization rate is shown in Fig. B-2.

The LP-167 building now uses 6 separate airconditioning refrigeration units with a combined capacity of 9.688×10^5 Btu/hr. At 5¢/kw hr operation of these units, (approximately 161.5 hp) costs \$48/8-hr day. (For 365-230 = 135 days this would be approximately \$6.5K annually for electrical air conditioning). For the heat transferred this amounts to $6.72/10^6$ Btu.

The geothermal heat pump--at 391 hp--could supply more than 6 times (2.4 times in size, with a 2.5 to 4 COP, overall 6 times) the cooling capacity of the existing system. For 135 day, 8-hr/day cooling season at \$0.05/kw hr the cost would be \$15.75K/yr. The cost using the heat pumps would be approximately $\$4.20/10^6$ Btu. The savings over the present system would amount to $(\$6.22 - \$4.20) \times 0.9688 \sim \$2/\text{hr}$. For 135 x 8 hr, the savings would be \$2.1K.

For maintenance costs it was found that the combined geothermal and HP maintenance systems were less expensive than the existing oil fired system.

* See Ref. 9 for heat pump design information.

Table B-I
Option B Equipment

<u>Major Items</u>	<u>Op. Parameters</u>	<u>Cap. Cost</u>	<u>Op. Cost</u>
1. <u>Geothermal Well</u>			
a) Depth 2500 ft	\$75/ft	\$187.5K	--
b) Output 225 gpm at 107°F			
c) Draw down, max. 1500 ft			
d) Submersible pump	85 hp	10.0K	\$17.5K (1.105) ⁿ
	24 hr/day-230 da.		
e) Reinject well, 2200 ft	\$75/ft	165K	
or			
[Ocean disposal, 5000 ft line and 5 hp pump]		[15K]	[1.03K(1.105) ⁿ]*
2. <u>Heat Exchanger</u>	107°F → 85°F	2.49 x 10 ⁶ Btu/hr	16.7K ⁽³⁾
3. Heat Pump #1	COP:3.5	3.48 x 10 ⁶ Btu/hr	121.9K ⁽⁴⁾ 21.82K (1.105) ⁿ
	391 hp	at 180°F	
[3.48 x 10 ⁶ Btu/hr to Bldg heat system]		8 hr/day for 144 da.	
		4 hr/day for 86 da.	
4. <u>Auxiliary Oil-Fired Heating System</u>			
[27% heat req.]			
			17.76K(1.125) ⁿ
		\$501.1K	
			\$39.32K(1.105) ⁿ + \$17.76 K
			(1.125) ⁿ

*Not included in total cost figures.

APPENDIX C

Option C

Use of Heat Pumps & Storage to Provide 100% Heat Load

The geothermal heat derived in options A and B amounts to over 50% of the maximum daily heat load for the coldest days. If the reject temperature is reduced to 60°F (compared to the 85°F in options A and B) at the heat exchanger, the geothermal energy extracted may be doubled, thus providing on a 24-hour basis all the heat required by the building. This, however, requires a storage means so that for the coldest days the heat flow during the working hours may be sufficiently high. A means of doing this is to store heat in a water reservoir adjacent to the building. This can be done by using the heat pump #1, shown in Fig. B-1 to supply the LP-167 building directly during working hours with heat from the heat exchanger, and extracting additional heat from the HX water via another heat pump to a (water) storage reservoir, from which heat can be drawn on demand by heat pump #3, as illustrated in Fig. C-1. [It may be possible to use heat pump #1 to charge the storage tank during non-working hours of the building.] The difficulty with this system is basically as shown in Table C-I that the cost of the heat pumps is substantial. Also, since the heat pumps are large, 327 hp and 756 hp, their consumption of electricity is significant, although not used for very long periods. The net operating cost of this system, utilizing heat pumps with thermal storage and no oil, is

$$\$65.79K (1.125)^n - \$49.68K (1.105)^n - 2.8K (1.09)^n$$

The third term $2.8K (1.09)^n$ represents the excess maintenance cost of the geothermal system over that calculated for the 100% oil-fired heating system. Twenty-six years are required for the operating cost of the geothermal system to amortize the capital cost, as seen in Fig. C-2.

Table C-I
Option C Equipment

<u>Major Items</u>	<u>Op. Parameters</u>	<u>Cap. Cost</u>	<u>Op. Cost</u>
1. <u>Geothermal Well</u>			
a) Depth	2500 ft @ \$75/ft	\$187.5K	
b) Output 225 gpm at 107°F			
c) Drawdown 1500 ft, max.			
d) Submersible pump contin. op. 230 da.-85 hp		10.0K	\$17.5K(1.105) ⁿ
e) Reinject well, 2200ft	\$75/ft	165K	
or			
[Ocean disposal, 5000 ft line + 5 hp pump]		[15K] [*]	[1.03K(1.105) ⁿ]
2. <u>Heat Exchanger</u>	107°F → 60°F, 4.75×10^6 Btu/hr	16.5 ⁽³⁾	
3. <u>Heat Pump #1</u>	391 hp	3.48 x 10 ⁶ Btu/hr	121.9K ⁽³⁾
		@ 180°F	21.82K(1.105) ⁿ
	COP:3.5	8 hr/day for 144 days	
		4 hr/day for 86 days	
4. <u>Heat Pump #2</u>	327 hp	3.66 x 10 ⁶ Btu/hr	126.1K ⁽⁴⁾
		@140°F	
	COP:4.4	12 hr day for 40 da.	5.85K(1.105) ⁿ
5. <u>Heat Pump #3</u>	756 hp	10.58 x 10 ⁶ Btu/hr	
		@ 180°F	256.8K
	COP:5.5	4 hr/day for ~ 40 days	4.51K(1.105) ⁿ
6. <u>Storage Reservoir</u>		30K	
(100' x 50' x 6' with 1 ft walls, concrete, insulated, floor & top)			
		\$914K	\$49.68K(1.105) ⁿ

$$\text{Annual Op. cost} = 65.79K (1.125)^n - 49.68K (1.105)^n$$

* Not included in cost figures, unless reinject well costs are eliminated.

APPENDIX D

Option D

Use of Heat Pumps to Provide a Thermal Store for Heating

An alternate system to that described in Option C is simply to use two heat pumps, the first operating continuously throughout the heating season to store heat in the reservoir at 140°F and the second heat pump to supply heat as demanded by the building. The first pump is sized to handle the heat available from the heat exchanger, about 2.5×10^6 Btu/hr, and the second, to match the peak load as provided by the two oil-fired boiler systems, $\sim 14 \times 10^6$ Btu/hr. These pumps, especially the second, are large so that the capital cost is high, as shown in Table D-1. Although the capital cost in this option is not as high as that in option C, the operating expense is larger than that of the all oil-fired system. It requires over 8 years to just break even on operating costs, and over 40 years to amortize as shown in Fig. D-2, clearly an uneconomic system. The operating cost equation is

$$\$65.74K (1.125)^n - \$74.4K (1.105)^n - \$1.96K (1.09)^n$$

Again, as in case C, the maintenance costs for the geothermal system are larger by $\$1.96K (1.09)^n$ than those for the 100% oil-fired system.

Table D-I
Option D Equipment

<u>Major Items</u>	<u>Op. Parameters</u>	<u>Cap. Cost</u>	<u>Op. Cost</u>
1. <u>Geothermal Well</u>			
a) Depth 2500 ft	\$75/ft	\$187.5K	
b) Output 225 gpm at 107°F			
c) Drawdown 1500 ft max.			
d) Submersible pump	85 hp 24 hr/day-230 da.	10K	\$17.5K(1.105) ⁿ
e) Reinject well 2200ft	\$75/ft	165K	
2. <u>Heat Exchanger</u>	107°F → 85°F	2.49 x 10 ⁶ Btu/hr	16.7K ⁽³⁾
3. <u>Heat Pump #1</u>	105°F → 140°F, COP=6.		
	E _{HP} = 0.497 x 10 ⁶ Btu/hr		
	= 195 hp	109.9K	40.2K(1.105) ⁿ
	Q = 2.98 x 10 ⁶ Btu/hr		
4. <u>Heat Pump #2</u>	140°F → 180°F, COP=5.5		
	E _{HP} = 2.556 x 10 ⁶ Btu/hr		
	= 1004 hp	310K	16.7K(1.105) ⁿ
	(445 hrs op.)		
	Q = 14.06 x 10 ⁶ Btu/hr		
5. <u>Storage Reservoir</u>		30K	
(100' x 50' x 6')			
		\$829.1K	\$74.4K(1.105) ⁿ

Annual Operating cost = \$65.79K (1.125)ⁿ - \$74.4K (1.105)ⁿ

Fig. A-1 Option A. - Geothermal energy used directly, radiant/convective space heat.

Fig. A-2 Option A - Pay back period.

Fig. B-1 Option B - Geothermal energy with heat pump boosting its temperature - space heat.

Fig. B-2 Option B - Pay back period.

Fig. C-1 Option C - Geothermal energy and heat pumps boosting its temperature and recovering energy prior to disposal.

Fig. C-2 Option C - Pay back period.

Fig. D-1 Option D - Geothermal energy with heat pumps boosting temperature - with intermediate storage.

Fig. D-2 Option D - Pay back period.

Fig. E-1 Comparison of Norfolk average temperature data (o) to fitted normal distribution Norfolk area.

Fig. E-2 No. of heating degree day distribution vs. temperature below 65°F .

Fig. E-3 Heat demand for LP-167 building vs. ambient temp.

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