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WESTERN SOUTH DAKOTA USAGE OF
GEOTHERMAL ENERGY FROM THE MADISON FORMATION

Final Report
January 1, 1978 through January 31, 1979

John Iszler
Dr. Dan D. Carda
Dale Skillman
Dr. W. L. Reuter, P.E.
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January 1979
Work Prepared Under Contract No. ET-78-S-07-1707

Edgemont School District 23-1
Edgemont, South Dakota 57735

U. S. DEPARTMENT OF ENERGY
Geothermal Energy

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**Prepared for
U.S. Department of Energy
Division of Geothermal Energy
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ABSTRACT

Complete water analyses were performed on existing Madison wells, shallower wells, and surface waters. Corrosion testing included measurements in standard weight loss, stress corrosion, and electrochemical analysis to determine suitable alloys for the project. Low-pressure steam, heat pumps, and direct heating alternatives were analyzed and compared. All buildings were modeled on a digital computer to determine heat gains and losses and the sensitivity of the net annual heat loss to changes in various building and operating parameters. Parameters with the highest sensitivities were further analyzed to determine the optimum cost-benefit ratio and the optimum net present worth of proposed changes. Finally, a control scheme was conceptually designed for monitoring and controlling a geothermal heating system.

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1. INTRODUCTION.

Where economical and practical, energy from geothermal resources should be utilized to replace energy obtained from fossil fuels. One such sizeable source of geothermal energy is the Madison limestone group in Wyoming, Montana, North Dakota, and South Dakota.

In considering the economic aspects, it appears evident that geothermal wells should not be drilled and the water wasted just for the sake of energy. Instead existing wells should be utilized, especially if they are flowing and thereby do not require energy for pumping.

The City of Edgemont, located in southwestern South Dakota as shown in Figures 1.1 and 1.2, has four flowing wells (#1 drilled in 1911 and presently flowing at 175 GPM, #2 drilled in 1936 and presently flowing at 175 GPM, #3 drilled in 1946 and presently flowing at 325 GPM, and #4 drilled in 1962 and presently flowing at 200 GPM). If it were feasible to only lower the water temperature an average of 100F during a six-month heating season by extracting heat energy, over four million BTU's would be made available every hour. Over the six-month period this would add up to over 17 billion BTU's of heat energy, which is equivalent to nearly 200,000 gallons of fuel oil after accounting for typical furnace or boiler efficiencies.

With the present rate of inflation, the potential annual savings is rapidly approaching \$100,000. If inflation would continue to increase at a rate comparable to the prevailing interest rates, then an initial investment of \$2,000,000 could be paid back in less than 25 years.

Even though a substantial investment may be justified economically, it is still necessary to convince the community that it is practical to utilize the geothermal resource. The problem of practicality is further complicated by the fact that the developed resource is not readily available to everyone and is not large enough nor hot enough to provide direct heat for all buildings in the community.

One approach towards utilizing at least part of the resource would be to select a building or complex that is owned by the community and that has a large annual heat-energy budget. The most likely candidates in Edgemont, as in many towns of this size, are the six school buildings, which comprise about 65,000 square feet of floor area. These buildings are a particularly good choice because they were constructed during an era of inexpensive energy--one in 1931, two in 1936, one in 1955, and the last two in 1963. As a consequence, relatively little insulation was used and there are large areas of single-pane windows, as shown in Figure 1.3. This has resulted in a present annual consumption for the campus in excess of 60,000 gallons of #2 fuel oil, which costs \$300.00 per day during the coldest weather.

Upon considering the above costs, the finite reserve of fossil fuels, and the potential of geothermal energy, the Edgemont Board of Education commissioned Dunham Associates, Inc., in 1977 to conduct a preliminary evaluation of the energy requirements and of the alternatives available to reduce these requirements and substitute other available sources of energy. Dunham Associates was selected because of their prior experience of successfully converting the Midland School System to geothermal in the early 1960's.

FIGURE 1.1 Geographical location of Edgemont, South Dakota

FIGURE 1.2 Aerial View of Edgemont, South Dakota

FIGURE 1.3 Edgemont School Complex

It quickly became evident that geothermal energy was the most probable long-range solution to supplying the heat energy needs. Consequently, during the summer of 1977, an application was made to the Department of Energy for funding a detailed feasibility study.

The funding was granted, and the study started in early 1978. As the work progressed, it became apparent that the campus needs could be reduced to requiring less than 20% of the developed geothermal resource. Thus, other buildings in the community could also benefit substantially from the resource. Besides the six school buildings, almost 400 energy-efficient, average-sized residences could be heated to the extent that their fuel bills would decrease at least 75%.

The feasibility study shows that it is indeed economical to heat the school campus with geothermal energy, even though new mechanical systems would be required for three of the buildings. The study also indicates the potential for heating residences but does not provide cost estimates to illustrate either the economics or the practicality of installing a geothermal distribution system and retrofitting existing buildings.

2. SCOPE.

This research project was divided into four basic tasks. They were Geology and Chemistry, Alternate Heating, Modeling, and Control System. Each task had individual task leaders to spearhead the research. Each task was independent, yet interdependent of one another.

The first task was Geology and Chemistry. Dr. Dan Carda, Head of the Experiment Station at South Dakota School of Mines and Technology, Rapid City, South Dakota was the Task Leader. Dr. Stanley Howard, Metallurgy Department, assisted in materials evaluations. Karen Knirsch, graduate student, worked on environmental geology and Greg Adel, graduate student, provided electrochemical measurements.

One of the problems to be evaluated in this section was the source of heat for the water. Extensive evaluation of trace elements and mineral compositions of the various waters did not clarify the exact source of the heat. It does appear that the anhydrite gypsum reaction may be contributing a portion of that heat. The effect of accelerated pumping did not appear to have any significant change in the temperature of the waters as was projected by local citizens.

Environmental effects of the Madison water were investigated. Areas considered were a city park pond and two stock dams receiving and discharging Madison water for more than ten years. The concern of possible heavy salt deposits was found to be non-existent. Various forms of plant life including cattails were readily visible in the ponds. Various species of fish are being caught in the city park pond.

Corrosion research found the Edgemont water rich in sulfide and chloride. These corrosion tests were needed to determine which metal alloys would be best to use in our piping and heat exchangers. Weight loss measurements were conducted using a weight loss test rack. Twenty-six various metals were tested. A stress corrosion cracking test rack was also installed. The most resistant metals to corrosion were placed in the three point stress rack. No apparent cracking was noticed although pitting was observed.

Electrochemical polarization measurements were used as another form of corrosion testing. Test results show that an increase in the water velocity will very significantly increase the rate of corrosion. The stagnant water test found that velocity was more detrimental than stagnant water in most of the tested sample metals.

The Alternate Heating Task was lead by Mr. Dale Skillman. Mr. Skillman was a member of the Mechanical Engineering Department at the South Dakota School of Mines and Technology, Rapid City, South Dakota. Mr. Augustine Cheung assisted in the final efforts for this section of the report. The main goal was to determine and design the backup heating system.

The alternate heating systems considered were a hot water boiler, low pressure steam, and an electric heat pump. The systems were examined to determine the compatibility with the geothermal system, its operating efficiency, the first cost, and its non-space heating related energy savings.

The system selected was a hot water boiler. Work was done in the heating load calculations to determine the heat losses through the walls, floors, ceiling, windows and doors, as well as infiltration and ventilation losses.

A variety of terminal heating units will be used. Depending on the required need, it has been determined to use classroom unit ventilators, air handling units (and) hot water heating units, cabinet unit heaters, baseboard radiators and space unit heaters.

Selection of pumps and piping for the district and building loops were selected. This includes such items as the size and length and the friction loss of selected pipe. Two basic types of pumps were selected; one for the main district loop and the other for the secondary loops.

One of the design tasks was to determine the proper heat exchanger. The selected choice is the APV type R56 paraflow plate heat exchanger. The ease of cleaning, future capacity for expansion, excellent heat transfer coefficient, and other mentioned characteristics provided the background for its selection. All of the above items are included in the final cost analysis program.

For a fixed supply water temperature and heating load, the computer model will select the terminal units and determine the flow rate required, the water pressure drop, and the return water temperature; the whole computer procedure is repeated for all of the six buildings.

These results will be used to determine the heat exchanger area, the district loop pipe and pump sizes. Finally the computer program will provide the total cost for the whole system. This will include terminal unit cost, piping cost, pumping cost, and the control package cost.

The Modeling Task was directed by Dr. William Reuter with the assistance of Dr. Albert Riemenschneider and Mr. Lloyd Brown, all of Dunham Associates, Rapid City, South Dakota. The major goal was to evaluate the cost effectiveness and optimum use of the geothermal energy by simulating each building on a computer.

The energy requirements of the buildings were based on local hourly weather data, and equations describing energy gains and losses. A sensitivity analysis of the model provided a method for evaluating the significance of each parameter. Thus those building parameters which will possibly produce the greatest energy savings could be identified.

The economic analysis made a comparison of the cost-benefit ratio method and the net-present-worth criteria. Of these two methods, the net-present-worth criteria is more appropriate for public buildings which have long and assured life expectancies.

The control system task was directed by Mr. George Dunham with the assistance of Mr. Larry Beckwith, both of Dunham Associates, Rapid City, South Dakota. The original philosophy was to heat the school complex using geothermal heat with a night and weekend setback. This would have allowed additional heat for about 50 small residences and the school complex in their entirety. However, by not using the night setback, the entire school complex and about 150 small residences could be heated. An even better usage of the geothermal resource would be to load the resources to its capacity for more hours each year. This would allow the entire school complex plus about 400 small residences to benefit from the heat source at least 75 percent of the time.

This projected approach was checked by simulating the high school building. It was found that a supplementary heating system needs to supply only three percent of the net heat loss for the entire school year.

A control system that can meet the needed requirements for all buildings can be designed around a microprocessor with limited memory, an internal time clock, and a slow-speed printer. There would be five parameters monitored for each building. Printed calculations of the results would be received in nine major areas. Three limits would be monitored by the system and there would be three major equipment controls operated by the control system for each building.

3. GEOCHEMISTRY AND CORROSION.

The Edgemont Madison wells are somewhat of an anomaly as far as their temperatures are concerned. These wells are located close to the outcrops, are not relatively deep, but do have rather high geothermal gradients in the 2.1°F/100 ft. range. In addition these wells are of the sodium chloride type which usually result in very aggressive corrosion environments.

3.1 Geochemistry.

There are several theories as to the source of the heat of the Madison wells at Edgemont. One has it that there may be an underground exposed igneous intrusion which is cooling down and giving off heat. Another theory is that there is an enriched concentration of uranium or thorium at depth which is generating heat. Another theory that has been advanced is that the water is coming into contact with the evaporites in the Minnelusa formation, notably anhydrite.

3.1.1. Geohydrology.

The geochemical examination of the waters from the area surrounding Edgemont and the southern Black Hills area had hoped to determine if possible which of the above three theories would be the most logical as an explanation for the source of heat and to develop a better understanding of the hydrology of this area. Water samples were collected from surface sources (streams, springs, and ponds), shallow wells, and deep wells. Figure 3.1 and Figure 3.2 show the locations of the sampling sites. Complete mineral and selected trace element analyses were performed on the water samples. Table 3.1 and Table 3.2 give the results of these analyses.

The igneous intrusion theory should have shown some unusual levels of trace elements associated with igneous activity. At first it appeared that lithium was anomalous; however, when compared to samples collected from Midland and Philip Madison wells it was decided that lithium was not anomalous. The radio-activity theory does not appear to be strongly supported due to a lack of radio-isotopes as determined by an on-going investigation in the Chemistry Department at SDSM&T which substantiates data obtained by the U.S.G.S. in 1971. The evaporite theory contends that when surface waters hit the anhydrite and it is converted to gypsum heat is given off, which is true. However, it would also be expected that the water would become enriched with calcium and sulfate ions but this water is NaCl rich.

3.1.2 Accelerated Pumping.

In addition it was decided that since the one well had an existing pump installed which would increase the flow, this would perhaps tend to increase the dissolved solids content. It was also expected that the pumping test would determine whether or not the temperature of the water would fluctuate during accelerated pumping over a seven-day period. Figure 3.3 shows the 40-horsepower pump on the well head. The accelerated pumping tests were conducted over two separate one-week intervals. The 40-horsepower shaft-driven pump was turned on after a water sample and temperature check

EDGEMONT WATER SAMPLE SITES

- a = Edgemont City Park Well (flowing)
- b = Edgemont City Park Pond - near railroad tracks
- c = Edgemont City Well #2 (flowing)
- d = Edgemont City Well #4 at airport (flowing)
- e = Runoff from Well #4, $\frac{1}{2}$ distance between well and pond #1
- f = Intake at Pond #1
- g = Outflow at Pond #1
- h = Pond #2

FIGURE 3.2 Edgemont sample sites

TABLE 3.1. MINERAL ANALYSES OF SAMPLED WATERS

Map #	TDS	HCO ₃	SO ₄	Cl	SiO ₂	Ca	Mg	Na	K	pH	Temp (°F)	Well
m	460	208	177	2.0	13.8	108.5	27.6	1.8	2.1	7.09	86	Upton #2
n	428	208	177	2.0	13.4	113.1	20.4	1.2	1.7	7.19	87	Upton #4
l	324	218	30.3	2.0	13.4	85.9	10.2	1.4	1.5	7.29	76	Osage #2
k	332	222	82.7	2.5	13.4	95.0	15.8	1.6	1.5	7.33	74	Osage #1*
j	266	216	57	2.5	13.8	76.9	20.1	2.1	1.9	7.55	79	Newcastle City Shop
j	316	212	78	2.0	13.8	81.4	21.8	2.4	2.1	7.13	76	Newcastle City Water Tanks
i	2160	168	1370	3.0	13.0	529.2	106.2	4.6	2.1	6.76	-	Lak Ranch**
t	2288	142	1540	2.0	12.3	533.7	47.8	3.8	2.2	7.06	56	Bear Butte
r	540	208	710	2.0	13.0	149.2	11.8	1.8	1.6	7.39	-	Ranch A***
q	196	176	11.2	2.0	13.0	72.4	.6	1.5	1.4	7.38	49	Cole 3A
p	262	198	8.5	3.0	12.6	81.4	4.0	1.3	1.3	7.33	49	Cole 3
o	538	202	217	1.5	13.4	135.7	24.5	2.6	1.6	7.16	69	Devil's Tower
s	164	-	12.7	3.0	18.6	54.2	7.1	7.6	2.3	-	20°C	Streeter Ranch
u	228	-	66.7	3.0	14.1	72.4	5.0	5.4	2.5	-	-	Cobb Ranch****
a	1074	176	395	239	44.7	153.8	6.8	210	20	7.19	-	Park Pond In
b	914	136	395	218	12.3	117.6	17.7	185	29	7.76	-	Park Pond Out
d	1080	176	425	265	44.7	158.3	19.7	200	21	6.96	-	Edgemont #4
e	1188	120	470	277	46.2	149.3	20.7	225	23	7.92	-	Edgemont #4 Overflow
f	1078	58	460	300	14.9	117.6	24.3	154	15	8.16	-	Ranch Pond In
g	934	72	440	290	40.4	122.1	34.9	240	25	8.72	-	Ranch Pond #1 Out
c	1074	176	440	244	44.7	153.8	15.7	190	21	7.04	-	Edgemont Well #1

*May be mixing with Minnelusa; **Spring; ***Spring; ****Well is in Minnelusa; - Data unavailable.

TABLE 3.2. TRACE ELEMENT ANALYSES IN PPM

Li	Co	Sr	Ni	S ⁼	
.30	.050	3.2	n.d.	.04	Edgemont #1
.32	.060	2.5	n.d.	.06	Edgemont #4
.29	.060	2.3	n.d.	4.42	Edgemont Park
.25	.070	1.8	n.d.	-	Provo #1
.31	.072	2.1	n.d.	-	Provo #2
.07	.02	7.5	n.d.	-	Cascade Springs
<.05	.02	.05	n.d.	-	Newcastle City Water Tank
<.05	.02	<.05	n.d.	-	Newcastle City Shop
<.05	.02	7.5	n.d.	-	Lak Ranch
<.05	.02	<.05	n.d.	-	Osage #2
<.05	.02	<.05	n.d.	-	Osage #1
<.05	.02	2.9	n.d.	-	Upton #2
<.05	.02	1.0	n.d.	-	Upton #4
<.05	.02	1.2	n.d.	-	Ranch A
<.05	.02	<.05	n.d.	-	Cole 3
<.05	.02	<.05	n.d.	-	Cole 3A
<.05	.02	1.4	n.d.	-	Devil's Tower
<.05	.02	6.0	n.d.	-	Bear Butte
<.05	.02	<.05	n.d.	-	Streeter Ranch
<.05	.02	<.05	n.d.	-	Cobb Ranch
.11	.02	9.0	n.d.	-	Harry Prince*
<.05	.02	6.0	n.d.	-	Philip**

- not analyzed

n.d. = nothing detectable

* Stanley County

** Haakon County

FIGURE 3.3 . Photo of pump on Well #4.

were obtained. The temperature was then measured each successive day to observe the change in temperature. Neither the chemical analyses of the waters nor the temperature fluctuated during the test indicating little or no rapid reaction underground as a result of the pumping tests.

3.1.3 Environmental.

Another portion of the geochemical evaluation program was to examine the water quality of several ponds which received overflow water from the Madison wells, for evaluation of the environmental effects. The water was examined several times over a period of varying weather conditions to determine whether or not there was a problem of salinity buildup due to evaporation.

There were two specific areas of ponding which were examined. One is located right in town (Figure 3.4) which receives the flow of a well which has a high concentration of sulfide. This pond is the one at which youngsters had been observed fishing with good results at various times. This pond has cattails and other forms of plant life growing in it. There were no evidences of heavy salt deposits formed either in the lake bottom or shore line. The chemical evaluation of this pond is listed in Table 3.3. These results do not indicate an unusual or brine solution being developed. This pond receives rainfall and some drainage water from the surrounding terrain and has an overflow which discharges eventually into the Cheyenne River.

The second ponding area (Figure 3.5) receives overflow water from the two Madison wells on top of the hill. This overflow water runs down a draw of approximately 300 yards to a series of two stock ponds. These ponds are used for watering livestock. By the time the water flows down the open channel to the first pond it has cooled down sufficiently to be satisfactorily consumed by the livestock. This pond in turn cascades down into two smaller ponds and then is discharged into the Cheyenne River. The chemical water quality of the pond is given in Table 3.3. The pond is located on sparsely vegetated shale which has been often shown to leach salts in various locations. In fact during the course of the project a cooling pond being constructed at the top of the hill developed a problem of sodium chloride leaching which resulted in the need for a pond liner. This observation is mentioned as a possible explanation for the white deposit which is found along the ditch through which the overflow water runs to the pond. The quality of the pond water does not indicate that there is a brine formation problem in this site either.

3.2 Corrosion.

3.2.1 Weight Loss Measurements.

Due to the complicated chemical composition of the Edgemont water, sulfide and chloride rich, it was obvious that extensive corrosion evaluation tests would have to be performed to determine which metal alloys would provide the most cost effective results for the piping and heat exchangers at this site. A standard weight loss test rack, Figure 3.6, constructed of 4-inch diameter PVC

FIGURE 3.4. Park pond in downtown Edgemont.

FIGURE 3.5. Rancher's pond.

FIGURE 3.6. Tall weight loss rack and short stress rack at Well #2.

TABLE 3.3 ANALYSES OF POND WATERS

	pH	Alk	Cl	SiO ₂	Ca	Mg	Na	K	TDS
Pond #1	7.91	86	260	26.7	122	21	218	28	952
Pond #2	7.38	66	155	43	118	22	160	22	814
Park Well	6.87	164	239	42.6	145	17	200	25	938
Park Pond @ RR Tracks	7.55	98	231	6.5	95	18	176	28	788
Airport	6.83	176	252	41.3	154	18	200	25	1100
Cooling Pond	6.83	180	265	40.1	154	18	200	23	1056
Cheyenne River (under bridge)	8.00	160	151	12.9	190	34	336	12	1738

plastic pipe was installed. This test rack had 26 2-inch diameter metal alloy coupons installed. The water was permitted to flow continuously through the test rack at a fixed rate which would approximate conditions experienced within a heating system. Table 3.4 gives the results of the weight loss test rack.

A weight loss test rack of this type is perhaps the most accurate method of measuring potential corrosion problems in a geothermal heating system. The main problem with this method of testing is the long period of time required to obtain data. Another problem with this weight loss rack is that not all portions of the heating system are flat plates. This is the reason the next type of test rack was installed.

3.2.2 Stress Corrosion Measurements.

The stress corrosion cracking test rack was installed because many portions of a heating system use pressed, stretched, and formed parts which have stressed zones that are often sites of localized attack by chloride and sulfide ions. Figure 3.8 shows the stress corrosion rack. The metal alloys selected to go into this test rack were based on the preliminary results of the weight loss rack. That is, the metals which appeared to be most resistant to the corrosion in the weight loss rack were placed in the three-point stress rack. Due to the fact that it is necessary to test the materials in the weight loss rack before the stress rack was set up, a relatively short period of time was available to perform the stress test. Consequently, there was not any clear evidence of stress corrosion cracking on any of the alloys tested. However, there were several samples which developed distinctly linear patches of pin-point deposits. These tiny deposits may actually be the beginning sites of stress corrosion cracking.

3.2.3 Electrochemical Measurements.

Another form of corrosion testing performed was electrochemical polarization measurements. This was done largely to determine the effects of velocity on the rate of corrosion. The weight loss test rack had clear evidence of velocity effects and it was hoped to quantitate this phenomena to some degree. This is very important in the design of the piping systems. Sharp elbows and abrupt changes in the direction of the fluid flow often lead to serious corrosion problems. The results of the polarization measurements showed that an increase in velocity can increase the rates of corrosion very significantly. Table 3.5 shows the rates of corrosion and rates of flow. Figure 3.8 shows the polarization equipment set up for use.

3.2.4 Stagnant Water Measurements.

Stagnant water has been feared to be more corrosive than the dynamic flowing water. This could be important during summer periods when the system is shut down. To examine this potential problem a sample of water was collected and transported back to the lab. Then the same metal alloys were cleaned, weighed, and suspended in sealed containers of this cooled Edgemont water. The samples were allowed to sit undisturbed for a period of 30

TABLE 3.4. RESULTS OF WEIGHT LOSS TESTS IN FLOWING AND STAGNANT WATERS

	Flowing mils/yr	Stagnant mils/yr
Ampco 8	.10	.085
Ampco 8 welded	.15	.070
Ampco 483	.13	--
Ampco 483 annealed	.36	--
Ampco 483 welded	.15	.034
Copper	.24	.17
Admiralty Brass	.43	.23
70:30 Cu:Ni	.45	.08
Monel 400	1.19	.014
304 SS	.014	.013
316 SS	.008	.006
Carbon Steel	15.2	2.33
Al 3003	--	2.66

FIGURE 3.7. Close-up view of stress rack.

FIGURE 3.8. Polarization equipment at well site.

days. The samples were then descaled and reweighed. The weight loss then was determined and the rate of corrosion was calculated.

As the data on Table 3.5 indicates, the effects of higher velocities on the rates of corrosion can be quite significant. With this information in hand it is very important that velocities of the geothermal water be kept to as low a level as practicable. It is also important in the design to minimize the abrupt changes in direction of flow to avoid turbulent flow conditions.

TABLE 3.5. RESULTS OF CORROSION VERSUS RATES OF FLOW USING POLARIZATION MEASUREMENTS

<u>Velocity ft/min</u>	<u>Mils/yr</u>	<u>Alloy</u>
45	3.15	483 Ampco
9072	10.95	483 Ampco
24.5	.0268	316 SS
9072	1.97	316 SS

3.3 Summary.

The results of the geochemical survey indicate that the water from the Madison wells at Edgemont does not appear to be mixing with water from the upper sandstone aquifers. The source of the heat is really not clearly identified as a result of the trace element evaluation but does appear to favor the theory of heat acquired as a result of the reaction of anhydrite and water. There is no reason for concern as to effluent water being ponded and utilized. The ponded water over the last 10 to 20 years in the various ponds has not resulted in brine bogs as was feared.

The corrosion evaluation portion of the study has confirmed some expected results and revealed other unexpected data. The predicted scaling problem does not appear to be a significant problem, based on the film formed in the corrosion racks. The importance of velocity effects was clearly brought out in the flowing weight loss rack and also the polarographic examinations. The corrosion products formed on the metal alloys at this site were quite different than those at the other Madison test sites indicating a site specific corrosion evaluation will be necessary at each new geothermal development within the Madison limestone aquifer, to maximize material performance. The potential scaling should be monitored closely if a large temperature drop is experienced at the heat exchanger.

At the Edgemont site it appears that stainless steel 316 or Ampco 483 aluminum bronze would be the best alloys to choose for maximum corrosion resistance. PVC plastic pipe should be suitable for the distribution lines from the wells to the buildings to be heated. These alloys should perhaps be confirmed with longer term stress testing or on-site performance monitoring. The recommendation of PVC piping is made based on the observations of the test racks which were constructed of PVC and showed no adverse effects of contact with the water.

4. ALTERNATE HEATING SYSTEM.

In order to economically take advantage of the energy available from geothermal hot water sources for space heating applications, it is essential to consider carefully the operating temperatures available. These include the geothermal water temperature, the space supply temperature, and the outside air temperature. When the outside temperature approaches peak heating design conditions, it becomes increasingly difficult to deliver adequate heat to the space with hot water temperatures ranging from 50 to 60°C (122 to 140°F). In order to optimize the installed space heating unit's capacities, it is essential that an alternate heating system be integrated with the geothermal system that will provide the additional heating capacity required during peak cold periods. The backup system selected must be carefully determined in order to optimize the use of the available geothermal energy.

4.1 System Comparisons.

Three specific types of backup systems were investigated for use in conjunction with the geothermal system. The systems are:

- Conventional hot water boiler system
- Low pressure steam system
- Electric heat pump system

The operating characteristics of each system are analyzed and considered in light of the following criteria:

1. Compatibility with geothermal system
2. Operating efficiency
3. First cost
4. Energy-related savings

4.1.1 Hot Water Boiler System.

Figure 4.1 shows a piping schematic for the proposed hot water boiler backup system. A plate heat exchanger transfers heat from the geothermal water source to the district water loop. A secondary building loop, connected with the district loop, supplies hot water to each individual terminal unit in the building. An auxiliary boiler is installed in each building loop. These boilers are to be controlled by thermostatic control activated by temperature gradient between the inside and outside air temperature. When the outside air temperature drops below design peak temperature, or when the building heating load exceeds peak condition, the water supply temperature can be raised by activating the auxiliary boiler. This provides an effectual backup for each building. Detail system design will be given in a later section.

4.1.2 Low Pressure Steam System.

Figure 9.4.1 layout #2 shows the schematic of the proposed low pressure steam system. Water is evaporated into low pressure steam at the evaporator, thus heat is delivered to each individual heating unit at a temperature very nearly the same as the geothermal source temperature. The feasibility of this low pressure steam system as

FIGURE 4.1 The District Loop Pipe Layout

backup for the geothermal system is discussed and analyzed in more detail in Appendix 9.4.1.

4.1.3 Electric Heat Pump.

Several possible heat pump assisted alternate heating systems are considered in Appendix 9.4.2. The layout selected for further analysis is shown in Figure 9.4.3. In this layout the heat pump evaporator is used to cool the space return water. The geothermal energy is utilized by circulating the cooler water from the evaporator through the geothermal heat exchanger. This provides an improved coefficient of performance for the heat pump and also increases the amount of energy available from the geothermal source through a larger temperature difference, thus allowing us to take full advantage of the available geothermal energy during periods when geothermal by itself would be inadequate. Further discussion of this system and its performance analysis are given in detail in Appendix 9.4.2.

4.1.4 Selection of the Alternate Heating System.

From the analyses in Appendix 9.4.1 and 9.4.2, it is clear that the low pressure steam and the heat pump system are both impractical and extremely expensive as an alternate heating system. On the other hand all existing buildings have fuel fired boilers that can be converted to hot water boilers and be used as back up. Thus the selection of the fuel fired boiler system as the alternate heating system becomes very obvious even at a fairly early stage of the project. After careful evaluation, decision was made for the group to concentrate on the design and modeling of the conventional hot water boiler system as back up. The results and modeling technique are presented in the following sections.

4.2 Alternate Heating System Design and Analysis.

The Edgemont school complex consists of six buildings; the junior high, the high school, the grade school, the primary, the armory, and the multi-purpose building. Due to the variety of buildings and the difference in construction, many different types of terminal units have to be used.

The junior high building is currently heated by hot water supplied by an existing boiler. The terminal units which include classroom unit ventilators and cabinet unit heaters can be used directly without modification. However, due to the low supply water temperature baseboard radiators have to be added to various locations to supplement the heating capacity.

The high school and the grade school buildings both have to be retrofitted with classroom unit ventilators, classroom unit heaters, and baseboard heaters.

The primary building is separated into two zones. Currently steam heating coils are used to heat the air delivered to each zone through a central air handling unit. For geothermal hot water application the steam heating coils have to be replaced by high performance hot water heating coils. Supplementary electric resistance heaters exist in each room and can be used as back up.

The armory has to be retrofitted with an air handling unit in the auditorium. Unit heaters, classroom unit ventilators, cabinet unit heaters, and baseboard heaters have to be used in the basement and other rooms on the first floor.

The multi-purpose building has existing hot water heating system using classroom unit ventilators, cabinet unit heaters, and unit heaters. For geothermal low temperature application, baseboard heaters will also be added when necessary.

In the system design the first step is to obtain an accurate room by room heating load estimate. From the information obtained by these estimates, a set of appropriate design conditions and criteria can then be formulated. The next step will involve selection of appropriate terminal units for each room. After all the terminal units in each building have been selected, one can then determine the pipe and pump sizes for both the building and the district loop. The final step will involve selection of the geothermal heat exchanger and evaluation of the overall cost of the system.

4.2.1 System Design Criteria.

The primary design requirement is to provide comfort air conditioning (heating and ventilation) for the whole school complex in Edgemont by using geothermal hot water. Other requirements include simplicity of design and cost effectiveness.

The indoor design temperature selected is 68°F instead of the 72°F recommended by the ASHRAE standard.* This is in compliance with recent energy conservation guidelines from HUD. The outdoor winter design temperature used is -10°F as recommended by the ASHRAE Handbook.

In order to achieve proper circulation and to provide comfort air conditioning in a classroom, an air supply rate of 6 to 9 air changes per hour is recommended by ASHRAE. This recommendation is followed in the terminal unit selection, hence the classroom units are selected pretty much based on its air handling capacity rather than its heating capacity.

The Edgemont geothermal hot water temperature ranges from 122°F to 140°F (40°C to 60°C). For design purposes the average geothermal water temperature used is only between 125°F to 130°F. This range is felt to be more realistic in terms of year-round availability. Presently the maximum allowable flow rate of geothermal hot water is fixed at 875 gpm. This is determined from the flow rate of the currently available wells.

For the design of the terminal units, selection of the supply water temperature is of primary importance. The range of supply temperature tested in the present design comparison is between 115°F to 125°F. The overall system and operating cost for the different supply water temperature is compared. The optimum operating temperature will then be selected.

*ASHRAE Handbook of Fundamentals 1972
ASHRAE Guide and Data Book-Systems 1970
ASHRAE Guide and Data Book-Application 1971

Initially one may think that by selecting the terminal units based on a low outside air temperature (-10°F) and supply water temperature (115 to 125°F) the cost of the system will be greatly inflated. A closer look at the available data, however, proves otherwise. First, it should be emphasized that according to the ASHRAE standard the selection of terminal units in a classroom is fixed by the air handling requirement. The cost of these units is therefore fairly independent of the designed heating load.* Secondly, the manufacturer quoted cost data indicates that additional cost for oversizing any terminal unit by one or two sizes amounts to less than ten percent of the base cost. Thus it does not seem to be too big a penalty to design with fairly low outside air temperature and supply water temperature.

Ventilation requirement is fixed at 5 cfm/person in the classrooms and offices. This is in accordance with the uniform building code. Ventilation in all cases should exceed the exhaust make up air requirements. Ventilation in odor concentrated areas like lavatory, dressing room, and others are also adjusted according to the building code.

4.2.2 Heating Load Calculation.

The heat loss through a room is determined by summing the heat losses through all walls, floors, ceilings, windows, and doors. Infiltration and ventilation losses are also included. The heat loss through any barrier is calculated using the concept of overall heat transfer coefficient. For a composite wall the heat transfer equation becomes

$$Q = UA (T_r - T_{OA}),$$

where U is the overall heat transfer coefficient,
A is the surface area,
 T_r is the room temperature, and
 T_{OA} is the outside air temperature.

The overall heat transfer coefficients are selected from suitable tabulated values in the ASHRAE handbook. Architectural plans and actual on-site inspection of existing building conditions are used as the determining factors.

Infiltration load is determined by the air change method. The number of air changes used in each room is based on inspection of existing window and door conditions. The heat loss can be calculated by the following equation:

$$Q = \text{cfm} \times \rho \times C_p \times (T_r - T_{OA})$$

where cfm is the infiltration of air flow
 ρ is the density of air, and
 C_p is the specific heat of air.

*For different heating loads there is actually a small difference in the cost due to different heating coils in the classroom units.

Ventilation load is calculated based on 5 cfm outside air per person. In cases where infiltration rate is higher than the required ventilation, only the infiltration loss is considered. When ventilation requirement is greater than infiltration loss, only the ventilation load is considered.

A summary of the building heating load is tabulated in Table 4.1.

TABLE 4.1
BUILDING LOAD SUMMARY

BUILDING	SENSIBLE LOAD BTU/HR	VENTILATION LOAD BTU/HR	TOTAL LOAD BTU/HR
Jr. High	212,777	130,572	343,349
High school	475,514	151,632	627,146
Grade school	346,410	136,890	483,300
Primary school	322,355	58,968	381,323
Armory	673,605	210,600	884,205
Multi-purpose building	240,608	67,392	308,000

4.2.3 Terminal Units Selection.

4.2.3.1 Classroom Unit Ventilators.

Classroom unit ventilators are used primarily in classrooms where quiet operation and large air handling and heating requirements are to be met. The unit selected is Trane Company's classroom unit ventilators with top discharge, bottom return and with face and bypass control. Each ventilator is selected based on its air handling capacity so as to provide 6 to 9 air change per hour per room.

Due to the lower supply water temperature, high capacity heating and cooling coils are selected with each ventilator. Performance curves for this type of classroom units are given in Trane bulletin DS-UVI-370-176R. These performance curves have been modeled in a computer program. For any given classroom the required air circulation is first determined. The size of the ventilator is then fixed. For any given design inside and outside temperature, heating load and supply water temperature, one can then calculate the required water flow, water pressure drop, and leaving air temperature. Thus the performance of these ventilators at different input conditions can be predicted.

4.2.3.2 Cabinet Unit Heaters.

Cabinet unit heaters are used mainly in offices where air circulation requirements are not as strict and where baseboard heaters are

not sufficient to meet the heating load. The type selected is Trane Company's Model B Vertical Cabinet Force-Flo cabinet heaters.

The heating capacities and performance characteristics for Force-Flo cabinet heaters are tabulated in Trane bulletin DS-CAB 2. These tabulated data are stored in the computer. Thus for given heating requirement and supply water temperature, the program will select the appropriate unit size, compute all output parameters including water flow rate, water pressure drop, water temperature rise, and leaving air temperature. Selection begins with the smallest unit. A comparison statement directs the program to select the next larger unit when the water flow rate exceeds 2.5 gpm. This maximum water flow is imposed to limit the total water flow in each building to a manageable amount.

4.2.3.3 Baseboard Radiators.

Baseboard radiators are used primarily for comfort considerations in classrooms under the windows, or in area where heating load is small and requires no ventilation. The type of baseboard selected is Trane's Architectural Wall Fin Baseboard with type S sloping top enclosure.

The performance of wall fin using low temperature hot water is given in Trane bulletin EB FIN-6. Due to the limited application of these baseboard radiators, the series 60 fin element with 1 1/4" copper-aluminum tubing is the only type used. The water flow velocity is fixed at 3 fpm, which in turn fixed the flow rate. This selection represents a compromise between comfortable heating requirement, noise control and available water flow rate.

For any given space load requirement and supply water temperature, the length of baseboard required, the water pressure drop, the water temperature drop, and the return water temperature can all be determined from the program.

4.2.3.4 Unit Heater.

Unit heaters are used primarily in area where space available is limited and where a long throw is required to get proper air distribution and temperature down in the occupied zone. The type selected is Trane Company's model S unit heater with horizontal discharge.

Selection and performance of these unit heaters for low temperature hot water applications are tabulated in Trane bulletin EB-UH-21 and has been stored in the program. The required water flow rate is determined based on an assumed 15 degree F water temperature drop. The unit size is then selected based on the calculated flow rate and the corrected heating capacity. Selection begins with the smallest unit and gradually steps up in sizes when the rated heating capacity based on the flow rate does not meet the required heat flow. This allows for an automatic selection of units when the supply water temperature or heating requirement changes.

4.2.3.5 Air Handling Unit and Hot Water Heating Coil.

Hot water heating coils are used for buildings with existing central forced air system like the primary building, and for buildings with large air handling requirement like the Armory building. The air handling unit selected is Trane Company's Unit 17 Torri-vane with fan and bypass control. Heating coils selected are the type W heating coil with either series 15 or 18 fins.

The heating coils are selected based on design outside air and supply water temperature, space heating load, and required air flow. Once the number of coils and fin series are determined, the program calculates the water flow rate, water pressure drop, water temperature drop, the leaving air temperature, and the water temperature drop as output.

4.2.4 Piping and Pump Selection.

The circulating arrangement for the district and the building loops is shown schematically in Figure 4.1. All buildings are served by a main district loop with its district pump. Each building, in turn, is served by its own secondary loop with circulating pump. The existing boiler for each building is tied into the secondary loop to provide back up for the buildings they presently heat. Both loops employ the two pipe reverse return system. The pipes are schedule 40 standard black iron pipe. They are selected from the Heating, Ventilating, Air Conditioning Guide's friction loss chart based on a water flow velocity of 4 ft/sec.

The length of each pipe section associated with each terminal unit is scaled from the building plan. Pressure loss can be calculated using the friction chart data. An additional 50% of the piping friction is added to each length to account for losses through valves and fittings. Two types of pump are used in the system. A smaller pump for the secondary building loop and a larger pump for the district loop.

The secondary loop pumps selected are Bell and Gossett series 60 in-line centrifugal pumps. These pumps can deliver up to 120 gpm of water with pressure head up to 35 ft. of water. The performance characteristic of these pumps are given in Bell and Gossett's bulletin B-105 and have been programmed numerically. By checking with the smallest size pump first, the program can automatically select the most appropriate pump and motor for the particular building.

The district loop pump selected is Bell and Gossett series 1531 foot mount centrifugal pump. This pump has capacity up to 1500 gpm with pressure head up to 400 ft. of water. The performance of this pump is given in bulletin B-305 and has the horsepower required, the impeller size, the available pressure head, and other pertinent outputs can be determined.

4.2.5 Plate Heat Exchanger.

Proper design of the heat exchanger is paramount to the success of any geothermal heating system. Initially both the shell and tube type and the plate type heat exchanger are both reviewed for possible adaption to the present system. After careful review of the literatures and reading of manufacturer's data, it is found that the plate

heat exchanger is better suited for the present application. The reasons for this selection are:

1. For liquid/liquid duties, the plate heat exchanger will usually give a higher overall heat transfer coefficient with only slightly higher pressure loss.
2. The effective mean temperature difference is usually higher with the plate heat exchanger.
3. Although the tube is the best shape of flow conduit for withstanding pressure, it does not provide for optimum heat transfer performance since it has the smallest surface area per unit cross sectional flow area.
4. A plate heat exchanger usually occupies considerably less floor space than a tubular heat exchanger for the same duty.
5. Since stainless steel has to be used in the present application to prevent rust and corrosion, sheet metal plate is more economical than tube of the same thickness.
6. Plate heat exchangers can be quickly and easily disassembled exposing all plate surfaces for cleaning or inspection whenever required.
7. Temperature differences as low as 2 degree F and recovery efficiencies over 90% can produce economic operation for the plate heat exchanger.
8. Extremely low liquid hold-up in plate heat exchanger results in lowest residence time.
9. Plate surface can be easily added for future capacity increases.

The heat exchanger selected is the APV type R56 paraflow plate heat exchanger. It consists of a frame in which closely spaced metal plates are clamped between a head and follower. The plates have corner parts and are sealed by gaskets around the ports and along the plate edges. The plates are grouped into passes with each fluid being directed evenly between the parallel passages in each pass. The paraflow plates are pressed into form with special trough and dimple pattern which strengthens the plates, increases the effective heat transfer area, and produces turbulence in the liquid flow between the plates.

For given geothermal inlet water temperature, space supply water temperature, space water flow rate, and required heat transfer, one can calculate all the necessary output parameters.

For a counter flow heat exchanger as shown, the heat transfer equations can be written as

$$Q = m_s c_p (T_{so} - T_{si}) \quad (4.1)$$

$$Q = m_g c_p (T_{gi} - T_{go}) \quad (4.2)$$

where m_s is the space water flow rate,

m_g is the geothermal water flow rate,

T_{si} , T_{so} inlet and outlet water temperature on the space side,

T_{gi} , T_{go} inlet and outlet water temperature on the geothermal side, and

Q is the space load to be supplied by geothermal source.

Equation (4.1) can be arranged as:

$$T_{si} = T_{so} - \frac{Q}{m_s c_p} \quad (4.3)$$

Now for a counter flow heat exchanger we can also express the heat transfer as:

$$Q = FUA \frac{(T_{gi} - T_{so}) - (T_{go} - T_{si})}{\ln [(T_{gi} - T_{so}) / (T_{go} - T_{si})]} \quad (4.4)$$

where F is the correction factor for deviation from counter flow,

U is the overall heat transfer coefficient,

A is the total heat transfer surface.

Design of the plate heat exchanger involves finding the minimum heat exchanger surface area that will satisfy the required space load, the mass flow rate, and the input temperatures. This can be accomplished by first eliminating T_{go} from equation (4.4) with equation (4.2) and rewriting the equation as:

$$UA = \frac{Q \ln (T_{gi} - T_{so}) / (T_{gi} - T_{si}) - Q/m_g c_p}{F[Q/m_g c_p - (T_{so} - T_{si})]} \quad (4.5)$$

Values of U and F depend on the design of the heat exchanger, the plate material and the number of passes. Direct communication with the manufacturer recommended an average U value of 500 BTU/hr ft² degree F to be used, an F value of .95 for two passes. These values are employed throughout the design. Now in order to find the minimum UA values for the given conditions, we can differentiate equation (4.5) with respect to $1/m_g c_p$ once and set it equal to zero.

$$\frac{\partial (UA)}{\partial (1/m_g c_p)} = \frac{Q/m_g c_p - T_{so} - T_{si}}{(T_{gi} - T_{si}) - \frac{Q}{m_g c_p}} \ln \frac{T_{gi} - T_{so}}{(T_{gi} - T_{si}) - \frac{Q}{m_g c_p}} \quad (4.6)$$

Equation (4.6) can be used to solve for the optimum geothermal water flow rate. Once m_g is known equation (4.5) can be used to find the optimum value of UA . The pressure drop in the heat exchanger can be predicted by the following equations as recommended by the manufacturer:

$$f = 2.5 (G D_h / \mu)^{-0.3} \quad (4.7)$$

Figure 4.2 System cost versus supply water temperature.

$$\Delta P = \frac{2fg^2L}{g \rho D_h}$$

where $G = m_g/A$,
 A = total flow area,
 L = length of flow channel, and
 D_h = hydraulic diameter.

4.2.6 Cost Analysis.

In order to determine the feasibility of the geothermal system, the initial cost for the overall system at different design conditions must be evaluated. Costs for the plate heat exchanger, all terminal units, piping, pumps, and other components are obtained by either direct quoting from the manufacturer or from retail suppliers in Rapid City.

A flat \$200 has been added to each terminal unit for the control package. Secondary piping costs including both supply and return pipes are included in the terminal unit cost calculation. The district loop piping and pump costs and the plate heat exchanger costs are evaluated separately. All costs are for the material or equipment only, no labor or installation cost added.

4.3 System Modeling.

The first step in the system design is to assign specific type of terminal units in each room by inspection of the building plans. The types of terminal unit required in each room are determined based on heating requirement, space confinement, and specific application. Once the type of terminal unit has been assigned, the supply and return piping can be laid out in the building plan. For a fixed supply water temperature and heating load, the flow rate required, the water pressure drop, and the return water temperature will be determined. These procedures are repeated for every room in the building. When all the rooms in one building have been analyzed, the total flow rate through the building, pressure drop for the complete building loop, and the return water temperature can then be determined. The whole procedure is then repeated for all six buildings. The results from all six buildings are then used to determine the heat exchanger area, the district loop pipe and pump sizes. Finally the total cost for the whole system including terminal unit cost, piping cost, pump cost, and control package cost are determined.

The above procedures together with the performance characteristics of all the components have been modeled numerically. For any given supply water temperature and space load distribution, the computer program will systematically size all the terminal units, size the pipe and the pump, and calculate the corresponding pressure drop, temperature changes, and total cost. A summary of the computer program, the building code used, and the terminal unit code used is outlined in Appendix 9.4.3. An example of a typical computer run output for this program is also contained in Appendix 9.4.3.

4.4 Summary.

Our task called for the evaluation of different alternate heating sys-

tems, specifically the hot water boiler system, the electric heat pump system, and the low pressure steam system. From simple thermodynamic and heat transfer analysis, it is found that both the electric heat pump system and the low pressure steam system are not suitable for geothermal hot water heating at Edgemont. The conventional hot water boiler system seems to be both adequate and suitable for the job. A computer program was written that can perform the complete system design from terminal unit sizing to total equipment cost estimate for any fixed supply water temperature. Figure 4.2 shows a plot of the total cost versus different supply water temperature.

The results indicate that the total cost of the heating system is not directly proportional to the supply water temperature. The total cost of the geothermal system increases only slightly when the design supply water temperature is lowered. Therefore it is better to oversize the system slightly. Since the whole system is designed based on a design outside air temperature of -10 degree F, it is believed that the geothermal system is capable of supplying all of the heating most of the heating season. Furthermore, it is found that, due to the recent advance in solar low temperature application, manufacturers now have equipment that are particularly suited for low temperature hot water application. One final word of caution is that the designed system has by no means been optimized dynamically. A final design has to depend on the daily variation load requirements and possible building envelope improvement.

5. MODELING.

Evaluating the cost effectiveness and optimum use of geothermal energy for heating the Edgemont School System requires detailed information about the gains and losses for each of the six buildings. This information was obtained by simulating each building on a computer and using local hourly weather data as the input function. This approach provided the ability to readily simulate a change in any parameter and thereby provide the information necessary to determine how sensitive the energy requirements are to a change in any parameter. Once the more significant parameters were identified, a cost-benefit ratio and a present-worth factor were calculated in order to make economic evaluations and optimize any investment in modifying the buildings and the heating systems.

5.1 Energy Requirements.

Existing building simulation programs, such as TRNSYS by the University of Wisconsin and NBSLD by the National Bureau of Standards, were not used for this modeling task because of their complexity and extensive computer time requirements. Instead the structural components of each building were simulated by using equations derived from the ASHRAE Handbook & Product Directory, 1977 Fundamentals.

The resulting program, which is listed in Appendix 9.5.1, accepts commonly used building parameters and weather data and calculates component and total energy gains and losses on an hourly basis. Facilities for night, weekend, and vacation setback are provided. Also, equivalent thermal storage capacity is included to simulate the decay and rise of the inside temperature during and after setback.

All of the major model parameters and use factors are read into the computer at the beginning of each simulation run. A title card, the parameters, and the first hour of weather data used are then printed so as to provide an identification record for each simulation.

In addition to the hourly calculations, run totals are accumulated for every hour that the building has a net heat loss. These totals are printed at the end of the simulation run.

A sample of the input parameters, the hourly output, and the run totals is given in Appendix 9.5.1.

5.1.1 Weather Data.

The weather data used for this modeling task was recorded at Rapid City, South Dakota, by the National Weather Service in 1971. Where necessary the actual data was interpolated to provide hourly values. The interpolation was done under the direction of Dr. Don Hopkins, Chairman, Physics Department, South Dakota School of Mines and Technology.

In addition to the hourly interpolations, the hourly solar intensities normal to north, east, south, and west vertical walls were calculated. In the process the total solar beam intensity was calculated. As a result, it was apparent that the solar measurements were consistently high, and peaks were observed to occur at sunrise and sunset. Similar

peaks were observed by Kusuda and Ishii and published in the NBS Building Science Series 96, National Bureau of Standards, April, 1977.

A smoothing technique was utilized at sunrise and sunset to eliminate the peaks and thereby provide more realistic solar input data to the building model. In addition, comparison of the beam intensity to the theoretical maximum indicated that the hourly interpolations were approximately 10 percent high. Consequently, all solar gain calculations were corrected by a multiplier, which was set at 0.9 for this modeling task.

Wind speed can also be scaled up or down. This is accomplished by changing a multiplier input to the program before each simulation run.

5.1.2 Structure Equations.

The general equation used to model energy gains and losses in BTU/hr for various components of a building envelope has the following form:

$$Q = -UA (\tau/U + \alpha/h_o) I_t + UA \Sigma(\Delta R/h_o) + UA (T_i - T_o) \quad (5.1)$$

where U = thermal transmittance (BTU/hr-ft²-°F),

A = surface area (ft²),

τ = normal component of the transmittance coefficient,

α = normal component of the absorptance coefficient,

h_o = outside surface conductance, which is a function of wind speed, (BTU/hr-ft²-°F),

I_t = solar energy component normal to the surface (BTU/hr-ft²),

ΔR = difference between longwave and blackbody radiation (BTU/hr-ft²),

T_i = indoor dry-bulb temperature (°F),

T_o = outdoor dry-bulb temperature (°F).

The first, second, and third terms of this equation represent the solar gain, radiation loss, and conduction loss, respectively.

Application of the above equation to all wall, roof, and fenestration areas along with equations for infiltration, ventilation, floor loss, basement wall loss, lighting, and the effects of occupancy provides the basis for the building model. These equations are summarized as follows:

Walls:

$$Q = -UA (\alpha/h_o) I_t + UA (T_i - T_o) \quad (5.2)$$

Roof:

$$Q = -UA (\alpha/h_o) I_t + UA \Sigma(\Delta R/h_o) + UA (T_i - T_o)$$

$$\text{where } \Sigma(\Delta R/h_o) = 7^\circ\text{F}. \quad (5.3)$$

Fenestration:

$$Q = -S FA I_t + UA (T_i - T_o) \quad (5.4)$$

where S = shading coefficient

$$F = \tau + \alpha_o N_i \text{ for single glazing,} \quad (5.5)$$

$$F = \tau + \alpha_o N_i + \alpha_i N_{ij} \text{ for double glazing,} \quad (5.6)$$

α_o = outside solar absorptance coefficient,

α_i = inside solar absorptance coefficient,

$$N_i = h_i / (h_o + h_i), \quad (5.7)$$

$$N_{ij} = U (h_o + h_s) / (h_o h_s), \quad (5.8)$$

$$U = 1 / ((1/h_o) + (1/h_s) + (1/h_i) + (1/h_d)), \quad (5.9)$$

h = inner space conductance,

h_s = inside surface conductance,

h_d = drape conductance.

In these equations τ and α are functions of the incident solar angle.

Infiltration:

$$Q = 0.96 CFM_I (T_i - T_o) \quad (5.10)$$

where CFM_I is a function of wind speed and crack area.

Ventilation:

$$Q = 0.96 CFM_V (T_i - T_o) \quad (5.11)$$

where CFM_V is the ventilation requirement.

Slab Floor:

$$Q = FL (T_i - T_o) \quad (5.12)$$

where F = loss coefficient,

L = floor perimeter.

Basement Walls:

$$Q = UA (T_i - T_g) \quad (5.13)$$

where U = an average thermal transmittance, which is a function of depth,

T_g = ground temperature.

Basement Floor;

$$Q = UA (T_i - T_g) \quad (5.14)$$

where T_g = ground temperature at floor depth.

Lights:

$$Q = -3.41 W \quad (5.15)$$

where W = electrical power.

People:

$$Q = -NP \quad (5.16)$$

where N = number of people,
 P = heat gain per hour per person.

The net heat loss per hour, excluding thermal storage effects and any other heat sources, becomes the summation of all of the above components as follows:

$$Q_{\text{Total}} = Q_W + Q_R + Q_F + Q_I + Q_V + Q_{SF} + Q_{BW} + Q_{BF} + Q_L + Q_P \quad (5.17)$$

where Q_W and Q_F are applied to each wall (north, east, south, and west).

The above equation along with the building thermal storage effects, setback operations, and the heating system make up the building model.

5.1.3 Parameters.

The parameters used in the above equations and associated equations defining the wind effects on outside surface conductance and infiltration are listed in the following two tables. Table 5.1 lists those parameters that are a function of the building structure. Table 5.2 lists those parameters that are the same for all six buildings.

Some of the parameters appear to have anomalies. For example, the basement floor areas for two of the buildings exceed the respective roof areas because sections of the basement walls have heat loss characteristics similar to the basement floors. In another case, two adjoining buildings have no values listed for one wall because there is no heat transfer through the common wall when the buildings are at the same inside temperature.

For reference purposes, each building was simulated for a school year using the 1971 weather data and the parameters listed in Tables 5.1 and 5.2. The results were compared to the available fuel history of the Edgemont School System to verify that the model was a realistic simulation in terms of total energy requirements. These results are listed in Table 5.3.

5.2 Sensitivities.

Sensitivity analysis of a model provides a means for evaluating the significance of each parameter and thereby identifying those building parameters which will tentatively produce the greatest energy savings. The sensitivity equation used is as follows:

$$S_K^Q = \frac{dQ/Q}{dK/K} = \frac{K}{Q} \frac{dQ}{dK} \quad (5.18)$$

where $Q = Q_{\text{Total}}$ in Equation (5.17),
 K = parameter in question.

TABLE 5.1
BUILDING PARAMETERS

SYMBOL	DESCRIPTION (DIMENSIONS)	HIGH SCHOOL	PRIMARY	MULTI- PURPOSE	INTER- MEDIATE	JUNIOR HIGH	ARMORY
A	Area (ft ²)						
	Walls	3919	2761	3944	5282	3781	10008
	Roof	6300	9145	5960	3922	4853	9333
	Fenestration	1826	1029	258	1078	775	591
	Basement Walls	753	-	-	-	-	1495
	Basement Floor	6507	-	-	-	-	9530
L	Slab Perimeter (ft)	-	429	376	254	209	100
CFM _v	Ventilation CFM	625	625	3000	675	500	2000
W	Electrical Power (W)	9800	22400	17800	10900	20400	4000
N	Number of People	99	98	50	106	79	40
P	Occupancy Heat Gain (BTU/hr-person)	230	210	345	230	230	635
C _v	Infiltration Coeff (CFM/in. w.c.)						
	North Wall	936	937	1182	31	-	3022
	East Wall	2247	455	292	1615	1109	139
	South Wall	-	1006	1895	213	1125	228
	West Wall	1895	397	346	1605	1063	136
QCDF	Thermal Capacity (BTU/°F)	200000	100000	80000	150000	120000	200000
U	Transmittance (BTU/hr-ft ² -°F)						
	Walls	0.34	0.26	0.32	0.34	0.36	0.35
	Roof	0.12	0.13	0.09	0.12	0.11	0.48
	Basement Walls	0.26	-	-	-	-	0.20
	Basement Floor	0.02	-	-	-	-	0.02
H _s	Conductance (BTU/hr-ft ² -°F)	-	1.17	-	-	-	-
α	Absorptance						
	Walls	0.70	0.50	0.50	0.70	0.70	0.50
	Roof	0.90	0.70	0.70	0.90	0.80	0.90
S	Shading Factor	1.00	0.36	1.00	1.00	1.00	1.00
F	Slab Loss Coeff (BTU/hr-ft-°F)	-	0.81	0.51	0.81	0.51	0.81

TABLE 5.2

COMMON PARAMETERS

SYMBOL	DESCRIPTION (DIMENSIONS)	VALUE
SUN	Solar Multiplier	0.9
WIND	Wind Multiplier	1.0
$\Sigma(\Delta R/H_0)$	Radiation Factor ($^{\circ}\text{F}$)	7.0
H_I	Inside Surface Conductance (BTU/hr-ft ² - $^{\circ}\text{F}$)	1.36
H_0	Outside Surface Conductance Coefficients	
	Walls	
A	Velocity Squared Coefficient	0.001
B	Velocity Coefficient	0.32
C	Constant	2.2
	Roof	
A	Velocity Squared Coefficient	0.0
B	Velocity Coefficient	0.464
C	Constant	2.04
	Fenestration	
A	Velocity Squared Coefficient	-0.00125
B	Velocity Coefficient	0.262
C	Constant	1.45
	Velocity Pressure Coefficients	
	North Wall	0.58
	East Wall	-0.35
	South Wall	-0.35
	West Wall	-0.38

TABLE 5.3
BUILDING GAINS AND LOSSES
IN MILLIONS OF BTU'S

DESCRIPTION (DIMENSIONS)	HIGH SCHOOL	PRIMARY	MULTI- PURPOSE	INTER- MEDIATE	JUNIOR HIGH	ARMORY
Dry-Bulb Temperatures (°F)						
Occupied	68	68	68	68	68	68
Unoccupied	68	68	68	68	68	68
Transmittances (BTU/hr-ft ² -°F)						
Walls	0.34	0.26	0.32	0.34	0.36	0.35
Roof	0.12	0.13	0.09	0.12	0.11	0.48
Hours Simulated	6336	6336	6336	6336	6336	6336
Hours of Net Loss	5123	5195	5585	5027	4750	5808
Solar Gains						
Walls	-8.0	-5.6	-13.1	-17.6	-14.1	-32.0
Roof	-10.9	-12.4	-8.0	-6.0	-4.2	-97.0
Fenestration	-82.7	-32.6	-27.8	-61.3	-43.3	-63.3
Radiation Losses						
Roof	27.1	43.2	21.0	16.6	17.7	182.1
Conduction Losses						
Walls	252.0	134.4	250.8	335.5	241.7	704.7
Roof	142.9	222.6	106.6	87.9	94.8	901.2
Fenestration	340.7	102.8	50.6	198.8	135.7	117.3
Slab Floor	-	65.0	38.1	38.4	18.9	16.3
Basement Walls	32.4	-	-	-	-	53.1
Basement Floor	27.0	-	-	-	-	36.0
Infiltration Loss	23.0	19.8	27.3	3.4	2.4	13.6
Ventilation Loss	15.6	10.2	81.7	15.1	6.5	59.3
Light Gain	-22.7	-27.1	-45.8	-21.3	-19.1	-12.7
People Gain	<u>-15.4</u>	<u>-7.3</u>	<u>-13.0</u>	<u>-14.0</u>	<u>-5.0</u>	<u>-23.7</u>
Net Building Loss	720.7	512.8	468.2	575.4	432.0	<u>1856.0</u>
Net Campus Loss						4565.1

If Q is a linear function of K , the sensitivity may be readily determined by taking the derivative of Equation (5.17) as indicated by Equation (5.18). If Q is not a linear function of K , the sensitivity is more readily determined by simulating the building with a small change in the parameter and then utilizing the following approximation:

$$S_K^Q = \frac{K \Delta Q}{Q \Delta K} \bigg|_{K=K_0} \quad (5.19)$$

where K_0 = existing parameter value.

The sensitivities of the major parameters are listed in Table 5.4. Comparison of these results indicates that any parameter sensitivity greater than 0.2 should be considered in more detail.

5.3 Economic Analysis.

Parameter sensitivity is not a sufficient condition for determining the cost effectiveness of an envelope improvement. A change in a building parameter may involve unrealistic costs even though the sensitivity may indicate the largest potential for energy savings.

In addition to sensitivity analysis, an economic analysis is necessary, especially for those improvements that have both fixed and variable cost factors. To illustrate the effects of these two factors, a cost-benefit ratio and a net-present-worth equation have been derived and applied to the more significant parameters in Table 5.4.

5.3.1 Cost-Benefit Ratio.

The cost-benefit ratio for increasing the insulation resistance is as follows:

$$\frac{C(\Delta R)}{B(\Delta R)} = (F R / \Delta R + (F + V) + V \Delta R / R) / B(\infty) \quad (5.20)$$

where R = existing thermal resistance,

ΔR = proposed increase in R ,

$C(\Delta R)$ = dollar investment required to increase R by an additional ΔR ,

$B(\Delta R)$ = first-year dollar savings resulting from increasing R by an additional ΔR ,

F = fixed dollar cost to increase R by any non-zero amount,

V = variable dollar cost to double existing thermal resistance ($\Delta R = R$)

= (CLM) $A D$,

where CLM = dollar cost of labor and materials per unit of area and per unit of depth,

A = insulation area,

D = depth of additional insulation required such that $\Delta R = R$,

$B(\infty)$ = maximum possible first-year dollar savings, which results from ΔR approaching infinity (conduction heat loss approaching zero)

= (CE) Q/E ,

TABLE 5.4
PARAMETER SENSITIVITIES

SYMBOL	DESCRIPTION (DIMENSION)	HIGH SCHOOL	PRIMARY	MULTI- PURPOSE	INTER- MEDIATE	JUNIOR HIGH	ARMORY
A	Area (ft ²)						
	Fenestration	0.34	*	*	*	*	*
CFM _V	Ventilation CFM	0.02	0.02	0.18	0.03	0.02	0.03
W	Electrical Power (W)	-0.03	-0.05	-0.10	-0.04	-0.04	-0.01
N	Number of People	-0.02	-0.01	-0.03	-0.02	-0.01	-0.01
Q _I	Infiltration Loss	0.03	0.04	0.06	0.01	0.01	0.01
U	Transmittance (BTU/hr-ft ² -°F)						
	Walls	0.35	0.26	0.54	0.58	0.56	0.38
	Roof	0.20	0.43	0.23	0.15	0.22	0.49
	Basement Walls	0.04	-	-	-	-	0.03
	Basement Floor	0.04	-	-	-	-	0.02
α	Absorptance						
	Walls	-0.01	-0.01	-0.03	-0.03	-0.03	-0.02
	Roof	-0.02	-0.02	-0.02	-0.01	-0.01	-0.05
F	Slab Loss Coeff (BTU/hr-ft-°F)	-	0.13	0.08	0.07	0.04	0.01
WIND	Wind Multiplier	0.12	*	*	*	*	*
Σ(ΔR/HO)	Radiation Factor	0.04	0.08	0.04	0.03	0.04	0.10
H _I	Inside Surface Cond	0.34	*	*	*	*	*
T _i	Thermostat Setting	2.20	*	*	*	*	*
	Unoccupied Setback						
	Inside Temp	0.58	*	*	*	*	*
	Thermal Capacity	0.06	*	*	*	*	*

* Data Unavailable

where CE = first-year dollar cost per unit of heat energy,
 Q = conduction heat loss through existing R for a typical heating season,
 E = combined boiler and heating system efficiency.

Table 5.5 lists the values of R, F, V, and $B(\infty)$ for the more significant building parameters. Figures 5.1 through 5.6 show the results of using these values to plot the cost-benefit ratio as a function of increasing thermal resistance. These curves illustrate that the ratio is initially large because of the fixed costs involved. However, the ratio quickly approaches a minimum value and then begins rising as the variable cost becomes the dominant factor.

The dashed portion of each curve indicates those values of increased thermal resistance that are considered impractical for physical reasons. In these regions Equation (5.20) starts to become inaccurate, and in actuality the curves begin a dramatic swing upwards because V is no longer a constant.

5.3.2 Net Present Worth.

The optimum cost-benefit ratio emphasizes those building envelope improvements that provide a relatively large energy savings per dollar spent. Consequently, the cost-benefit approach emphasizes short-range instead of long-range paybacks. As an alternative, a formula based on the difference between the present worth of a potential energy savings and the initial cost of a proposed increase in insulation was derived with the following result:

$$NPW(\Delta R) = (K \cdot B(\infty) \cdot \Delta R / (R + \Delta R)) - F - (V \cdot \Delta R / R) \quad (5.21)$$

where $NPW(\Delta R)$ = present worth of resulting energy savings over n years minus the dollar investment required to increase R by an additional ΔR ,

K = present worth factor

$$= (1/(1+i)^n) \cdot ((1+i)^n - (1+r)^n) / (i-r),$$

where i = annual interest rate,

r = annual inflation rate of energy,

n = system and/or building life expectancy

$$= -21.52 \text{ (for } i = 6.5\% \text{ and } r = 8.0\% \text{ over 20 years),}$$

Figures 5.7 through 5.12 show the results of this equation for each of the six buildings. Comparison to cost-benefit curves shows that the optimum net present worth for a given modification is always at a larger value of ΔR than the optimum cost-benefit ratio. This is a result of the factor K, which is based on a 20-year life and thereby emphasizes the long-term energy savings. A comparison of results is given in Tables 5.6, 5.7, and 5.8.

5.4 Summary.

The cost-benefit criteria maximizes the return on the investment and would therefore be more attractive to the private investor. However, for public buildings, especially schools, which normally have a long and assured life expectancy, the net-present-worth criteria is more appro-

TABLE 5.5

**BUILDING ENVELOPE IMPROVEMENT
COST AND SAVINGS PARAMETERS**

IMPROVEMENT and BUILDING	TYPE	EXISTING THERMAL RESISTANCE (R)	1978 FIXED COST (F)	1978 VARIABLE COST (V)	MAXIMUM FIRST-YEAR BENEFIT (B(∞))
Wall Insulation:					
High School	Batt	2.94	\$ 5673	\$ 397	\$1018
Primary	Styrofoam	3.85	3258	443	517
Multipurpose	Batt	3.33	5342	336	970
	Styrofoam	3.33	4422	520	970
Intermediate	Batt	2.94	7437	441	1315
Junior High	Styrofoam	3.45	4273	521	936
Armory	Batt	3.13	11678	760	1937
Roof Insulation:					
High School	Loose Fill	8.33	500	2541	680
Primary	Loose Fill	7.70	500	1525	1056
Multipurpose	-	-	-	-	-
Intermediate	Loose Fill	8.33	500	1583	418
Junior High	Loose Fill	9.10	500	1092	458
Armory		4.0	500	1356	2140
Window Insulation:					
High School	Drape	0.95	10294	114	970
Intermediate	Drape	0.95	6080	114	573

FIGURE 5.1 Cost-Benefit Ratio as a Function of Change in Thermal Resistance for Various Envelope Improvements to the High School Building

FIGURE 5.2 Cost-Benefit Ratio as a Function of Change in Thermal Resistance for Various Envelope Improvements to the Primary Building

FIGURE 5.3

Cost-Benefit Ratio as a Function of Change in Thermal Resistance for Various Envelope Improvements to the Multipurpose Building

FIGURE 5.4 Cost-Benefit Ratio as a Function of Change in Thermal Resistance for Various Envelope Improvements to the Intermediate Building.

FIGURE 5.5

Cost-Benefit Ratio as a Function of Change in Thermal Resistance for Various Envelope Improvements to the Junior High Building

FIGURE 5.6 Cost-Benefit Ratio as a Function of Change in Thermal Resistance for Various Envelope Improvements to the Armory

FIGURE 5.7 Net Present Worth as a Function of Change in Thermal Resistance for Various Envelope Improvements to the High School Building

FIGURE 5.8 Net Present Worth as a Function of Change in Thermal Resistance for Various Envelope Improvements to the Primary Building

FIGURE 5.9 Net Present Worth as a Function of Change in Thermal Resistance for Various Envelope Improvements to the Multipurpose Building

FIGURE 5.10 Net Present Worth as a Function of Change in Thermal Resistance for Various Envelope Improvements to the Intermediate Building

FIGURE 5.11 Net Present Worth as a Function of Change in Thermal Resistance for Various Envelope Improvements to the Junior High School Building

FIGURE 5.12 Net Present Worth as a Function of Change in Thermal Resistance for Various Envelope Improvements to the Armory Building

TABLE 5.6

WALL INSULATION
COST-BENEFIT RATIO AND
NET PRESENT WORTH COMPARISONS

BUILDING	CONDITION	INCREASED THERMAL RESISTANCE (ΔR)	1978 MODIFICATION COST (C)	FIRST- YEAR BENEFIT (B)	COST BENEFIT RATIO (C/B)	NET PRESENT WORTH (NPW)
High School	Min C/B	11.1			8.9	
	Max NPW	18.9				\$10733
	Batt	22.0	\$8643	\$ 898	9.6	10682
Primary	Min C/B	10.4			11.8	
	Max NPW	15.4				3871
	Styrofoam	10.0	4408	373	11.8	3628
Multipurpose	Min C/B	13.3			8.6	
	Max NPW	23.0				10572
	Batt	22.0	7762	842	9.2	10358
Intermediate	Min C/B	12.1			8.8	
	Max NPW	20.6				14237
	Batt	22.0	10737	1160	9.3	14226
Junior High	Min C/B	9.9			8.3	
	Max NPW	18.0				9912
	Styrofoam	10.0	5783	696	8.3	9195
Armory	Min C/B	12.3			9.5	
	Max NPW	20.0				19509
	Batt	22.0	17035	1696	10.0	19463
	TOTALS		\$54368	\$5665		\$67552

TABLE 5.7

ROOF INSULATION
COST-BENEFIT RATIO AND
NET PRESENT WORTH COMPARISONS

BUILDING	CONDITION	INCREASED THERMAL RESISTANCE (ΔR)	1978 MODIFICATION COST (C)	FIRST- YEAR BENEFIT (B)	COST- BENEFIT RATIO (C/B)	NET PRESENT WORTH (NPW)
High School	Min C/B	3.7			7.8	
	Max NPW	11.7				\$ 4479
	Loose Fill	23.0	\$ 7515	\$ 499	15.1	3223
Primary	Min C/B	4.4			3.6	
	Max NPW	22.0				11983
	Loose Fill	23.0	5054	790	6.4	11947
Multipurpose	Min C/B	-	-	-	-	-
	Max NPW	-	-	-	-	-
	-	-	-	-	-	-
Intermediate	Min C/B	4.7			9.2	
	Max NPW	11.6				2531
	Loose Fill	23.0	4870	307	15.9	1737
Junior High	Min C/B	6.2			6.7	
	Max NPW	18.4				3887
	Loose Fill	23.0	3260	328	9.9	3799
Armory	Min C/B	2.9			1.6	
	Max NPW	19.3				31104
	Loose Fill	23.0	8297	1823	4.6	30934
TOTALS			\$28996	\$3747		\$51640

TABLE 5,8

WINDOW LOUVER DRAPES
COST-BENEFIT RATIO AND
NET PRESENT WORTH COMPARISONS

BUILDING	CONDITION	INCREASED THERMAL RESISTANCE (ΔR)	1978 MODIFICATION COST (C)	FIRST- YEAR BENEFIT (B)	COST- BENEFIT RATIO (C/B)	NET PRESENT WORTH (NPW)
High School	Min C/B	9.0			13.0	
	Max NPW	11.9				\$ 7604
	Proposed	7.4	\$11179	\$ 859	13.0	7302
Intermediate	Min C/B	7.0			13.7	
	Max NPW	9.0				3994
	Proposed	7.4	6960	507	13.7	3957
	TOTALS		\$18139	\$1366		\$11259

priate. In addition, it favors larger increases in thermal resistance, which results in more long-term energy savings.

Assuming that all building envelope improvements have a 20-year life expectancy, capital improvements should be made starting with the largest net present worth, which is insulating the armory roof. Furthermore, the armory roof should be insulated as much as practical even though that value may exceed the optimum value of 19.3. Even though the net present worth is decreasing past 19.3, it is still much greater than the next best choice, that is, insulating the armory walls. In other words, as capital becomes available, invest it in the next best curve either until additional improvement becomes physically impractical or until the net present worth of that investment finally equals the next best choice, which ever comes first.

If the armory does not have a 20-year life expectancy, then a new value of K must be calculated for Equation (5.21). After redrawing the curves, a comparison can again be made to determine where and to what extent capital should be invested.

Because capital improvements can no longer be made in 1978, it is important to realize that the values of F , V , and $B(\infty)$ in Table 5.5 must be updated to account for inflation. Experience indicates that F and V must be increased by at least 10% per year. In fact, recent data on the price of residences indicates that the increase could be as high as 17% per year.

Once the values are updated and a capital improvement is selected, the cost of that improvement should be estimated by a qualified architect or engineer with the estimate being derived without using F and V . One reason for this approach is to provide a crosscheck and accurately evaluate the practicality of adding as much insulation as possible. Another reason is to account for any recent changes in building codes. For example, all cost estimates in this report presumed that no changes would be required in the existing electrical or mechanical systems. If changes in these systems are required, the values for F and V would increase substantially without increasing the anticipated savings.

Table 5.9 summarizes the potential energy savings that could occur without modifying the windows or using night setback. Comparing to Table 5.3 and assuming a 64% boiler and heating system efficiency results in an estimated annual energy savings of over 4000 million BTU's. Considering the present cost of fuel oil and the expected inflation rate, it is recommended that the buildings be insulated as quickly as possible, even if the costs are substantially higher than estimated for 1978.

The potential energy savings are admittedly larger than anticipated. The major reason is the effect of the armory. A second reason might be the original solar intensity data, which is known to consistently exceed the theoretical limits. More research is needed to determine what effects this error in weather data has on projected energy savings.

BUILDING GAINS AND LOSSES
IN MILLIONS OF BTU'S
AFTER ADDING INSULATION

DESCRIPTION (DIMENSIONS)	HIGH SCHOOL	PRIMARY	MULTI- PURPOSE	INTER- MEDIATE	JUNIOR HIGH	ARMORY
Dry-Bulb Temperature (°F)						
Occupied	68	68	68	68	68	68
Unoccupied	68	68	68	68	68	68
Transmittance (BTU/hr-ft ² -°F)						
Walls	0.04	0.07	0.04	0.04	0.07	0.04
Roof	0.03	0.03	0.09	0.03	0.03	0.04
Hours Simulated	6336	6336	6336	6336	6336	6336
Hours of Net Loss	4812	4866	5500	4438	4241	5586
Solar Gains						
Walls	-0.6	-1.1	-1.5	-1.1	-1.4	-3.3
Roof	-2.2	-2.0	-7.2	-0.9	-0.6	-6.9
Fenestration	-55.1	-21.3	-25.6	-29.3	-21.7	-54.5
Radiation Losses						
Roof	6.4	9.3	20.6	3.7	4.3	14.6
Conduction Losses						
Walls	29.0	34.9	31.6	37.3	45.1	79.5
Roof	34.9	49.5	107.4	20.8	24.8	74.1
Fenestration	333.0	99.0	51.0	187.4	129.5	115.9
Slab Floor	-	62.8	38.4	36.3	18.2	16.1
Basement Walls	31.6	-	-	-	-	51.7
Basement Floor	26.3	-	-	-	-	35.0
Infiltration Loss	22.4	18.5	27.5	3.1	2.2	13.3
Ventilation Loss	12.6	1.5	76.2	8.4	0.7	54.9
Light Gain	-17.3	-3.1	-40.3	-10.0	-1.6	-10.5
People Gain	-11.8	-0.8	-11.5	-6.6	-0.4	-19.6
Net Building Loss	409.2	247.3	266.7	249.2	199.1	360.3
Percent of Table 5.3	57%	48%	57%	43%	46%	19%
Net Campus Loss						1731.8

6. CONTROL SYSTEM.

The conceptual design of a control system utilizing geothermal energy depends on many of the results of the previous section. In particular, the potential heat-energy requirements need to be established, especially when they can be substantially reduced by economical building envelope improvements. These potential improvements can significantly affect the control philosophy and the geothermal system requirements.

6.1 Philosophy.

General approximations of building heat-energy requirements are used in the following development of a control philosophy. These numbers are not meant to represent any particular school building. They are used only to develop perspective and to make general comparison.

To establish a control philosophy, it is necessary to investigate the potential geothermal resource capability and the immediate and prospective community loads. Up to 875 gallons of water are potentially available per minute at a temperature between 52.2°C (126°F) and 60.5°C (140.9°F). If all 875 gallons per minute were reduced only 5°C (9°F) via direct heat exchangers, almost 4,000,000 BTU's would be made available every hour. If the buildings being heated were reasonably energy efficient and required no more than 40 BTU's per square foot per hour for early morning warmup after night setback during the coldest expected weather conditions, the geothermal resource could heat at least 100,000 square feet of floor space. Thus, the resource could provide the entire warmup and daily needs for the school complex plus approximately another 45,000 square feet or 45 small residences.

The foregoing approach is obviously not an effective utilization of the available geothermal resource. For example, if night setbacks were not used, the same energy efficient buildings would typically require a peak demand of only 20 BTU's per square foot per hour to maintain the buildings at design temperature during the coldest expected weather conditions. Thus, without night setback the resource could heat at least 200,000 square feet of floor area. This could include the school complex and an additional 145,000 square feet or 145 small residences.

The above approach still utilizes the entire available geothermal resource only a few hours each year, which is not an effective utilization of such an important and sizeable resource. Clearly, some measure of effectiveness is needed in order to determine the optimum community load. One possibility is that the geothermal resource be loaded up to such an extent that any additional load would require more BTU's from another energy source for cold weather supplementary heating than the additional BTU's obtained from the geothermal resource during warm weather. Assuming that wind is independent of outside temperature, application of this criteria results in a total community load such that the resource is fully loaded when the outside temperature drops to -2°C (28.4°F). The total load that could be supplied at this temperature is nearly 450,000 square feet or the school complex and 395 small residences.

If the geothermal resource remains fully loaded below -2°C, the 450,000 square-foot load will require that approximately 25% of the total annual heat energy requirements be supplied by another source providing supplementary heating during approximately 1800 hours of each year. In other words, instead of heating only 200,000 square feet for 100% of the time,

the criteria is equivalent to heating nearly 337,500 square feet for 100% of the heating season.

The foregoing approach theoretically minimizes the annual use of fossil fuels by the entire user group. However, to achieve this goal, each user could only apply 75% of the annual cost of fossil fuel towards amortizing the investment required to obtain geothermal heat. For a small residence on fuel oil this represents about \$230 initially per year minus maintenance costs and any charges that the community as a whole might levy on the geothermal energy. Whereas this certainly could be practical for new construction, it might not be practical for existing buildings. As a consequence, it might be necessary to decrease the maximum size of the user group towards the 200,000 square-foot load and thereby increase the potential savings towards 100% of the annual fossil fuel cost in order to attract users. However, until the active needs exceed the 4,000,000 BTU's per hour in the coldest weather, each user should be allocated enough flow to satisfy 100% of the heating requirements without setback. When the resource is finally being used to capacity at least once each year, then additional users would require that user allocations be established and eventually lowered, if possible, to supply 75% of the heating needs.

Knowing that geothermal heat allocations might eventually be implemented is essential from the standpoint of control system design. One of the immediate results is that night setback is no longer as advantageous as it is when all of the heat energy is supplied by fossil fuels. In fact, for buildings with a large thermal mass, it is advantageous to use as much of the fixed geothermal allocation as possible and store any excess heat energy in the thermal mass. Typically, this will occur in the daytime. Then at night when the outside temperature typically drops, have the control system use 100% of the geothermal allocation without supplementary heat. As the inside temperature drops, stored heat energy will automatically be extracted from the thermal mass. If the temperature drops below an acceptable occupancy level, have the control system wait until the last possible minute to bring the space up to temperature with the auxiliary heating system.

Considering the thermal mass of the high school buildings and the relatively large daytime heat gains due to lights, people, and the sun, supplementary heat will be required for warmup only after the coldest nights and after weekends. Therefore, the supplementary heating requirements will actually be significantly less than 25% of the annual heat energy requirements.

This philosophy was checked by simulating the high school building with the geothermal resource allocation reduced to 30% of the flow required to maintain the building at 68°F during the coldest weather. As a result, the geothermal resource was limited to supplying less than 115,000 BTU's per hour when the inside temperature was 68°F while the peak demand was actually 215,000 BTU's per hour. Even with this reduced geothermal allocation, the supplementary heating system had to supply only 3% of net heat loss for the school year.

The reason for the minimal supplementary heating requirements is that the source of heat energy was limited to the geothermal allocation whenever the building was unoccupied, except for warmup just before occupancy.

As a result, the inside temperature dropped to 61°F during the coldest weather. With this lower inside temperature the losses decreased, and the geothermal system was able to supply 125,000 BTU's per hour.

6.2 Requirements.

In order to provide the flexibility required by the proposed control philosophy and the capability required for monitoring, alarming, and changing parameters, the operating algorithm should be easy to modify. In addition, the control system should be able to provide historical information about each building, including energy demands in any heating zone of any building at any time. This would allow the total campus geothermal allocation to be distributed to the six buildings such that the total supplementary heat energy requirements could be minimized. This capability would also provide the means to evaluate and compare the heating energy efficiency of each building.

With the above capabilities, additional building envelope improvements could be evaluated and compared so that potential energy savings can be maximized for the dollar spent. Also, information would become available so that the effectiveness of each additional building envelope improvement could be analyzed.

A control system than can meet these requirements for all six buildings can be designed around a microprocessor with limited memory, an internal timeclock, and a slow-speed printer. Such a system would interface with the outside world via analog-to-digital converters and binary control hardware. The parameters to be sensed include the following:

1. Outside temperature,
2. Inside temperatures,
3. Supply water temperatures,
4. Return water temperatures,
5. Equipment run status.

Results calculated and printed by the system would include the following:

1. Building heat-energy loads,
2. Heat energy supplied by the geothermal resource,
3. Heat energy supplied by the auxiliary sources.
4. Energy stored or released from the building thermal mass,
5. Minimum time required for warmup,
6. Geothermal heat-exchanger effectiveness,
7. Equipment run times,
8. Maximum and minimum temperatures and loads
9. Alarms.

Limits monitored by the system would include the following:

1. Minimum unoccupied temperature,
2. Minimum acceptable occupied temperature,
3. Maximum acceptable occupied temperature.

Equipment controlled by the system would include the following:

1. Pump motors,

2. Boiler burners,
3. Control valves.

The peak hourly heat-energy requirements are listed in Table 6.1. Also shown are the terminal equipment constants and the geothermal flow rates required to maintain each building at 68°F for all but a few hours of the year. For those hours the auxiliary heating system is required to maintain 68°F.

6.3 Algorithm.

A proposed heating system schematic is provided in Figure 6.1. The schematic shows sensor locations and control points for the proposed algorithm.

A flow chart of the algorithm is provided in Figures 6.2 through 6.11. The major features of the algorithm are as follows:

1. Each building is limited to obtaining heat only from the geothermal allocation during unoccupied hours, except for warmup and for those times when the inside temperature falls below a preset unoccupied minimum value.
2. A minimum warmup time is predicted dependent upon existing conditions so that the auxiliary heating system is utilized at full capacity for the least amount of time immediately prior to occupancy.
3. If needed during occupancy, the boiler is used to increase the supply water temperature only to that level required to handle the existing load so that heat energy is still extracted from the geothermal source.

6.4 Summary.

With the proposed control system, terminal equipment, and additional insulation, the school complex could be maintained at 68°F by using 166 gallons of 125°F water per minute with minimal supplementary heat energy. As the community demand increases, this geothermal allocation could be gradually reduced by up to 75% or to less than 50 gallons per minute. This lower allocation would typically supply the total unoccupied heat energy needs for the six buildings down to an outside temperature of 32°F. The anticipated supplementary heating requirements for colder weather should amount to less than 5% of the net annual heat loss.

Considering the foregoing results, it is important to emphasize that the geothermal system should be sized to initially supply the total heating requirements without night or weekend temperature setbacks and with the buildings insulated as much as practical. The geothermal system should also be designed to allow for a substantial reduction in the initial flow requirements so as to maximize the utilization of the available resource.

TABLE 6.1

**TERMINAL EQUIPMENT CAPACITIES
AND PEAK HOURLY HEATING LOADS**

DESCRIPTION (DIMENSIONS)	HIGH SCHOOL	PRIMARY	MULTI- PURPOSE	INTER- MEDIATE	JUNIOR HIGH	ARMORY
Dry-Bulb Temperature (°F)						
Occupied	68	68	68	68	68	68
Unoccupied	68	68	68	68	68	68
Transmittance (BTU/hr-ft ² -°F)						
Walls	0.04	0.07	0.04	0.04	0.07	0.04
Roof	0.03	0.03	0.09	0.03	0.03	0.04
Equipment Capacities						
Unit Ventilator	3441	2446	814	2130	2061	1972
Fin Tube and Unit Heater	789	-	1554	626	153	1006
Preheat Coil	-	-	970	-	-	-
Air Flow (CFM)						
Fan	13500	8000	3000	11500	7750	15000
Preheater	-	-	2700	-	-	-
Primary Heat Exchanger Effectiveness	0.50	0.50	0.50	0.50	0.50	0.50
Geothermal Supply						
Temperature (°F)	125	125	125	125	125	125
GPM Allocation	40	23	28	26	21	28
Peak Hourly Load (10 ³ BTU/hr)	230	134	216	141	112	198

FIGURE 6.1 Geothermal & Auxiliary Heating System Schematic

FIGURE 6.2 Initialize Sample Time Loop

FIGURE 6.3 Read,Store & Test Sample Time Data

FIGURE 6.4 Calculate Loads, Test & Control Building Pump

FIGURE 6.5 Control Heat Exchanger Pump & Calculate HX Effectiveness

FIGURE 6.6 Control Boilers & Pumps

FIGURE 6.7 Print Status, Loads & Totals

FIGURE 6.8 Determine Occupancy Status, Control Heat Exchanger

FIGURE 6.9 Determine Warm-up Requirements & Control

FIGURE 6.10 Determine Auxiliary Heat Requirements & Control

FIGURE 6.11 Forecast Future Requirement for Boiler Operation

7. MAJOR CONCLUSIONS

With present data, the Geochemistry and Corrosion Task has found no apparent mixing of the waters from the Madison wells with water from the upper sandstone aquifers. The heat source is not clearly identified but favors the theory of a result of the reaction of anhydrite and water. There appears to be no reason for concern as to the suitable useage of effluent water.

Corrosion evaluations showed that the predicted severe scaling problem did not occur. However velocity tests proved the importance of the selection of metals. Corrosion characteristics are found to vary from other tested Madison well sites in the state. These results are definitely site-specific.

Stainless stell 316 or Ampco aluminum bronze displayed the best resistance to corrosion. PVC plastic pipe will also work well in the distribution lines. Due to the limited time period the stress corrosion rack was installed, the true potential for stress cracking of 316 stainless is not completely known. Before final material selection is made a longer duration test would be very desirable.

The Alternate Heating System Task has selected the hot water boiler as the back up system. The system was designed by considering such factors as heating load, comfort and ventilation requirements. The useable types of terminal units, piping circuit, pumps and plate heat exchanger were selected and a cost analysis for the entire system was presented. These were done by a computer program which performed the complete system design from terminal units sizing to the total equipment cost estimate for any fixed supply water temperature.

The Modeling Task established the parameters of each building which allowed the computer to determine the sensitivities of various building improvements. Optimal and economic evaluations were made by comparing the cost-benefit ratio to the present-worth factor. The net-present-worth criteria was selected as the better method. This is due, in part, to the fact of public buildings having a long and assured life expectancy. It also favors larger increases in thermal resistance which results in more long-term energy savings.

Total heating of the Edgemont School Complex plus additional heat utilization possibilities were analyzed by the Control System Task. Geothermal heat can provide 100% of the annual heating requirements for the Edgemont School Complex plus reserve energy for 285 homes of approximately 1,000 square foot each. Partial allocations of geothermal energy would allow up to 395 small residences and the school complex to be heated down to the outside temperature of -2°C (28°F).

It is definitely feasible to heat the entire Edgemont School Complex using geothermal energy from the Madison Group. In addition there could be considerable heat available for the community to use as required for direct heating, especially if envelope improvements are made to each of the six buildings.

The estimated cost in 1978 dollars for renovating and converting all six buildings to direct geothermal heating is \$650,000. Slightly over \$100,000 of this total is recommended for building-envelope improvements in order to

reduce the demands on the geothermal system and to release more of the resource for the rest of the community. Nearly \$300,000 is required to install three new mechanical systems to replace the three oldest systems, which are not readily adaptable to utilizing geothermal energy. Another \$50,000 is required for environmental impact studies and professional design services. The remaining \$200,000 is required for the geothermal loop, heat exchangers, heating system modifications, control system, and monitoring equipment.

If all of the fuel oil can be saved by converting to geothermal energy and if the energy inflation rate is comparable to prevailing interest rates, the \$650,000 would be paid back in less than 30 years. In addition, the school district would realize improved building envelopes and three new mechanical systems. As economically attractive as this may seem, there is still the practical problem of convincing the community to make the investment, especially considering the present financial problems of the Edgemont School District. A modified form of guaranteed loans is perhaps an answer to this dilemma. This modification would be to make funds available under the condition that all fuel savings would be used as realized to retire the loan.

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APPENDICES

APPENDIX 9.4.1

Possibilities for a steam heating system supplied by energy from low temperature geothermal water.

The Edgemont school building complex has space heating units of both steam and hot water types. These units could be used without requiring any changes, if steam could be generated from the geothermal water. Since the geothermal water temperature is only 125 degree F, and a typical steam heating system operates at 222 degree F (5 psig), some means of upgrading the temperature is required. One such means is by using an electric motor driven compressor to raise the pressure from the 1 to 2 psia in the evaporator to the 18 psia of the supply. Figure 9.4.1, layout 1, shows a schematic diagram of such a system. The critical element in this layout is the compressor. How large will the compressor have to be? How much power will it require? The answers to these questions depend on the evaporator temperature. The lower we set the evaporator temperature, the more of the space load that can be supplied by geothermal energy, but the larger the compressor. Table 9.4.1 gives the results of calculations based on use of a compressor having a isentropic efficiency of 80%, and an evaporator effectiveness of .90. A geothermal water flow rate of 500 GPM is assumed.

The compressor required is quite large and complex. Three or four centrifugal stages would be required with the diameter of the first stage being about three times the inlet pipe diameter. There are no such machines available on the commercial market. Electrical power consumption is large. Therefore the compressed water vapor system is not feasible.

If the space heaters were all changed, it might be possible to use the steam at low temperature, as depicted in layout #2. This system has the disadvantages that the entire steam distribution system is at a vacuum, and therefore subject to air leaks into the system. A rather large vacuum pump would be needed to remove the air from the evaporator. Also, the large specific volume of the low temperature steam would require unusually large distribution pipe sizes. This is shown in Table 9.4.2. This system also does not appear to be feasible.

TABLE 9.4.1
CALCULATED PERFORMANCE OF A
COMPRESSED WATER VAPOR SYSTEM

EVAPORATOR:			
TEMP °F	120	115	110
PRESS PSIA	1.69	1.47	1.27
COMPRESSED VAPOR TO SYSTEM:			
PRESS PSIA	18	18	18
TEMP, °F	222	222	222
COMPRESSOR:			
PRESSURE RATIO	10.65	12.24	14.2
No. OF STAGES	3	4	4
WATER VAPOR FLOW RATE:			
LB/HR	1098	2190	3276
FT ³ /min	3721	8466	14491
COMPRESSOR: (inlet velocity = 100 FT/s)			
INLET AREA, FT ²	.62	1.41	2.41
INLET PIPE DIA, FT	.89	1.34	1.75
POWER, KW	82	174	276
ENERGY BALANCE AT DESIGN LOAD (3,534,000 BTU/hr)			
% GEOTHERMAL ENERGY	28.7	57.0	85.2
% COMPRESSOR POWER	7.9	16.8	26.7
% AUXILIARY BOILER	63.4	26.2	0
	<u>100.0</u>	<u>100.0</u>	<u>111.9</u>

TABLE 9.4.2

CALCULATED PERFORMANCE OF A LOW
TEMPERATURE WATER VAPOR SYSTEM

SYSTEM:

TEMP °F	120	115	110
PRESS, PSIA	1.69	1.47	1.27

WATER VAPOR FLOW RATE:

LB/HR	1098	2190	3276
FT ³ /MIN	3721	8466	1441
PIPE DIA., FT	.89	1.34	1.75

ENERGY BALANCE AT DESIGN LOAD

% GEOTHERMAL	31.9	63.8	95.6
% AUXILIARY BOILER	68.1	36.2	4.4
	100.0	100.0	100.0

FIGURE 9.4.1

Layouts of low temperature steam systems employing geothermal energy.

Layout 1: Vapor compression, existing space heaters

Layout 2: Low temperature vapor, all new space heaters

APPENDIX 9.4.2

Application of Heat Pump to Geothermal Space Heating.

Introduction

The heat pump can be used to increase the temperature of the supply water in a hot water space heating system. This is accomplished by extracting energy from the geothermal water at low temperature and adding the energy to the supply water at high temperature. One potential advantage of the heat pump in a retrofit situation is that by increasing supply temperature above the geothermal water temperature, existing space heater units may be used. Whereas, a low temperature geothermal source used directly for space heating will require additional space heater units in order to provide the design load. A heat pump assisted system may not require additional retrofit of terminal units other than changing the existing steam radiators to hot water units. Another potential advantage of the heat pump is that it may reduce the amount of supplemental heating required from the fossil-fuel fired boiler. Economics will dictate whether or not these potential advantages apply in a particular case. The economics will have to include the amortized cost of the heat pump and the cost of additional electrical energy required for operation of the heat pump. Balanced against the heat pump costs will be the savings realized by eliminating the need for added space heating units, and the savings from reduced consumption of fossil-fuels in the boiler.

Consideration for Design of a Heat Pump Assisted System.

The considerations for a heat pump system are different for a retrofit situation on existing buildings than for an all-new installation. At Edgemont school, where boilers and space heater units are installed and operating, it seems best to try to use these in the retrofit. Of course, those buildings currently heated by steam would have to be changed over to hot water, and a central distribution pipe network will be required. The heat pump should be located nearby the geothermal heat exchanger. The boilers will be used to provide the needed heat in very cold weather, but the heat pump will carry the load in mild weather. In this way, the geothermal energy may be used to the maximum.

Several possible layouts of the heat pump system will be described, and the rationale for selection of one of the layouts will be discussed.

In layout 1, Figure 9.4.2, all the geothermal energy is channeled through the heat pump. Therefore, the heat pump must operate continuously. In this layout a plate type heat exchanger supplies heat to circulating water which in turn supplies heat to the evaporator. The reasons for using the circulating water loop rather than direct heat exchange from geothermal water to the evaporator are two-fold. First, cleaning/descaling on the geothermal water side will be facilitated in the absence of high pressure refrigerant. Second, in the event that corrosion caused leakage in the heat exchanger, the geothermal water would not be contaminated. (This consideration arises because the cooled geothermal water will be used for the city domestic water supply).

In layout 2, the circulating water is heated first by the geothermal water and then heated by the heat pump condenser. The heat pump evaporator is

FIGURE 9.4.2

Layout 1: Heat pump and boiler in series circuit.
(all geothermal energy goes to evap.)

Layout 2: Two geothermal heat exchangers share the heating load.

Layout 3: Heat pump chills the return water.

then heated by the partially cooled geothermal water. For reasons enumerated about Layout 1, another circulating water loop should be incorporated between the heat exchanger and the evaporator. This layout has the advantage that geothermal energy may be transferred to the space load without running the heat pump. The system would operate in three modes:

Mode 1: when space load is small, all energy supplied by HX1.

Mode 2: when space load is moderate, energy supplied by both HX1 and HX2. The heat pump warms the circulating water to a higher temperature than can be achieved in Mode 1.

Mode 3: when space load is large, the boiler supplies the major part of the energy. The return water temperature may be higher than the geothermal temperature. If so, then HX1 will be bypassed.

Layout 3 uses the heat pump evaporator to cool the return water. Flowing cooler water through the geothermal heat exchanger produces a greater amount of energy recovery from the geothermal water, i.e. greater ΔT . This layout is simpler than layout 2 since one heat exchanger and one circulating pump are eliminated. Operation of the system would be in the same three modes as layout 2.

In selecting the heat pump layout, factors of simplicity, flexibility of operation, and system reliability should be considered. Layout 3 is the best on all accounts. It has the least number of components, therefore is the simplest. It permits 3 modes of operation, which is the maximum attainable flexibility of operation. It may operate on either geothermal heat exchanger or boiler independently, so therefore it is reliable. Accordingly, layout 3 has been selected for performance analysis.

Performance Analysis of a Heat Pump Assisted System.

To evaluate any possible advantage that the heat pump may have with respect to sizing the space heating units, performance calculations were made for supply temperature of 140 degree F and 120 degree F at the design space load using the layout shown in Figure 9.4.3.

In the calculations, which are described in Table 9.4.3, it was necessary to fix the size of the heat pump and the effectiveness of the geothermal heat exchanger. Three different heat pump sizes were considered. .25, .50, 1.0 million BTU on the evaporator side of the heat pump. Also, three different levels of geothermal heat exchanger effectiveness, (.5, .7, .9) were considered. Results of these calculations are given in Table 9.4.4. There, it is shown that the % load carried by the geothermal heat exchanger is vanishingly small when a supply temperature of 140 degree F is used. The reason for this is that most of the return flow must bypass the evaporator in order to allow the evaporator to cool part of the return flow down to a temperature less than the geothermal temperature. If a larger heat pump is used, then the energy returned to the supply at the condenser will cause an overtemperature condition on the supply.

At a 120 degree F supply temperature, a properly sized heat pump will allow up to 87% of the space load to be carried by the geothermal heat exchanger. Of course, at 120 degree F supply, the geothermal heat exchanger can be sized so as to carry most of the space load, without requiring a heat pump. Thus a comparison should be made of geothermal heat exchanger size required with

FIGURE 9.4.3

System Notation for Heat Pump Calculations.

TABLE 9.4.3

Calculations for heat pump system using notation shown on Figure 9.4.3

$$1) \text{ Circulating water flow rate} = W_2 = \frac{\text{Space Load}}{(T_{\text{supply}} - T_{\text{return}})}$$

$$2) \text{ Bypass ratio} = 1 - \frac{Q_{\text{EVAP}}}{W_2(T_6 - T_1)}$$

$$3) \text{ Heat pump evaporator temperature} = T_6 + \frac{(T_1 - T_6)}{\epsilon_{\text{evap}}}$$

4) Geothermal water heat exchanger

Geothermal water flow rate = W_1

Circulating water flow rate = $(1 - B)W_2$

$$T_2 = T_1 - \epsilon \frac{(1 - B)W_2}{W_1} (T_1 - T_1 - T_{\text{in}})$$

5) Bypass mixing valve energy balance energy:

$$(1 - B)W_2 (T_3 - T_2) = (B) W_2 (T_{\text{return}} - T_3)$$

$$\text{solve for } T_3: T_3 = B T_{\text{return}} + (1 - B) T_2$$

6) Heat pump energy balance and COP

Condenser energy = Evaporator energy + compressor energy

$$\text{COP} = \frac{\text{Condenser energy}}{\text{Compressor energy}} = f(T_{\text{evap}}, T_{\text{cond}})$$

$$\text{Cond} = \frac{T_4 - T_3}{\epsilon} + T_3$$

These three equations must be satisfied simultaneously. Solution is by an iterative technique.

The COP function was determined from data in ERDA-tr-260 report and is of the form:

$$\text{COP} = \left(\frac{T_{\text{cond}}}{T_{\text{cond}} - T_{\text{evap}}} \right) + a + (T_{\text{cond}} - T_{\text{evap}})^b$$

where a and b are constants for a centrifugal type refrigeration compressor.

7) System energy balance

$$\% \text{ Geothermal} = \frac{(1 - B) W_2 (T_2 - T_1)}{\text{Space load}}$$

$$\% \text{ Compressor energy} = \frac{W_2 (T_4 - T_3) / \text{COP}}{\text{Space load}}$$

$$\% \text{ Auxiliary energy (boiler)} = \frac{W_2 (T_5 - T_4)}{\text{Space load}}$$

8) Heat exchanger size

$$e^D = \frac{1 - \epsilon}{1 - \frac{\epsilon}{\frac{W_1}{W_2}}}$$

$$D = \ln e^D$$

$$UA = \frac{D}{\frac{1}{W_1} - \frac{1}{W_2}}$$

TABLE 9.4.4, DESIGN LOAD

HEAT PUMP PERFORMANCE FOR SPACE LOAD = 3,082,699 BTU/hr

EVAPORATOR

COOLING CAPACITY BTU/HR	TEMP °F	BY-PASS RATIO	ε	GEOHERMAL HEAT EXCHANGER			HEAT PUMP COMP POWER % LOAD	BOILER ENERGY % LOAD	T _s /T _r °F	
				UA	T1 °F	T2 °F				% LOAD
----- 140° SUPPLY TEMPERATURE -----										
1.0x10 ⁶	108.05	.77	.5	110.00	111.70	3	11	86	140/127.59	
"	"	"	.7	"	112.38	4	11	85	"	
"	"	"	.9	"	113.07	6	11	83	"	
0.5x10 ⁶	"	.89	.5	"	110.85	1	6	94	"	
"	"	"	.7	"	111.19	1	6	93	"	
"	"	"	.9	"	111.53	1	6	93	"	
.25x10 ⁶	"	.94	.5	"	110.43	0	3	97	"	
"	"	"	.7	"	110.60	0	3	97	"	
"	"	"	.9	"	110.77	0	3	97	"	
----- 120°F SUPPLY TEMPERATURE -----										
1.0x10 ⁶	103.12	0	.5	247260	103.56	114.19	2.64 86	11	3	120/107.59
.53x10 ⁶	104.71	.17	.7	402566	105	116.46	2.35 76	6	17	"
.48x10 ⁶	"	.26	.9	843690	"	118.26	2.45 79	6	15	"
.5x10 ⁶	"	.22	.5	174617	"	112.70	1.49 48	6	46	"
"	"	"	.7	362818	"	115.78	2.08 68	6	26	"
"	"	"	.9	949971	"	118.86	2.68 87	6	7	"
.25x10 ⁶	"	.61	.5	75545	"	108.85	.37 12	3	85	"
"	"	"	.7	140305	"	110.39	.52 17	3	80	"
"	"	"	.9	296103	"	111.93	.67 22	3	75	"

and without a heat pump. For this comparison the UA (in units of BTU/hr°F) will be used. Values of UA may be computed from the flow rates and effectiveness. As shown in Table 9.4.5, and in the graph, Figure 9.4.4, there is not much advantage in using the heat pump. In fact, unless the heat pump is sized properly, there can be a disadvantage to having the heat pump in the system. Even with an optimum size heat pump, the size of the geothermal heat exchanger may be reduced to only about one half of that required without a heat pump. Of course, the heat pump system would have the heat exchangers for the evaporator and condenser in addition to the geothermal heat exchanger. When total cost is considered, the heat pump system will prove uneconomical.

Conclusions.

For the design parameters pertaining to the Edgemont school buildings, a heat pump assisted geothermal heating system will not permit use of existing space heaters, which are designed for 180 degree F supply temperatures. Therefore, the buildings will have to be retrofitted with larger space heaters, using a 120 degree F supply temperature. With a 120 degree F supply temperature, the space load can be carried by a geothermal water heat exchanger without assistance from a heat pump. No economic advantage would be found for use of a heat pump at Edgemont.

TABLE 9.4.5

EVAPORATOR COOLING CAPACITY BTU/HR	GEOHERMAL HEAT EXCHANGER EFFECTIVENESS	REQUIRED UA (BTU/hr °F)	% of SPACE LOAD CARRIED BY GEOHERMAL
0	.3	106236	42
	.5	247260	69
	.7	573569	97
.25x10 ⁶	.5	75545	12
	.7	140305	17
	.9	296103	22
.50x10 ⁶	.5	174617	48
	.7	362818	68
	.9	949971	87
1.0x10 ⁶	.5	247260	86
.53x10 ⁶ *	.7	402566	76
.48x10 ⁶ *	.9	843690	79

* Heat pump size limited by condenser temp.

FIGURE 9.4.4

RELATIONSHIP BETWEEN HEAT PUMP SIZE
AND GEOTHERMAL HEAT EXCHANGER SIZE

SPACE LOAD = 3.08 MILLION BTU/HR

SUPPLY/RETURN TEMP = 120/107.6 °F

GEOTHERMAL FLOW = 500 GPM @ 125°F

$\frac{UA}{10^6}$, MILLION BTU/HR °F

GEOTHERMAL HEAT EXCHANGER SIZE

APPENDIX 9.4.3

System Simulation Program

Building codes

- 1 - Jr. High
- 2 - High School
- 3 - Grade School
- 4 - Primary building
- 5 - Armory
- 6 - Multi Purpose Building

Terminal unit codes

- 10 - Series - Classroom Ventilators
- 20 - " - Cabinet Unit Heaters
- 30 - " - Base Board
- 40 - " - Unit Heaters
- 50 - " - Air Handling Units

Room codes are same as room numbers.

Figure 9.4.5

```

1      PROGRAM MAIN(INPUT,OUTPUT,DATA,TAPE5=INPUT,TAPE6=OUTPUT
      *,TAPE7=DATA)
      DIMENSION IROOM(6,2,33),ITUC(6,2,33),ITUPL(6,2,33),QUNIT(6,2,33),
      *CFMOA(6,2,33),TUGPM(33),TUPWD(2,33),TOTLWPD(2),LS(33),LR(33)
5      *GSUM(33),BLENGT(6,2,33),Q1(33)
      REAL LOPWPD
      REAL ITUCOST(33)
      TS=122.5
      SYSGPM=0.0
10     SYSCOST=0.0
      SYSQ=0.0
      DO 112 J=1,6
      BCOSTOT=0.0
      TUTOT=0.0
15     BLOPTOT=0.0
      OBLDG=0.0
      GPMSUM=0.0
      C READ IN BUILDING FLOOR+UNIT NO.
      C
20     WRITE(6,301)J
      301 FORMAT(77,'READ BUILDING',I4)
      READ(7,*)IRLDG,IFLOOR,LLFP
      IRLDG=IRLDG+1-2+1
      C SET UP FLOOR LOOP
      C
25     DO 200 K=1,IFLOOR
      COSTLOP=0.0
      LOPWPD=0.0
      TUSUM=0.0
30     READ(7,*)IUNIT
      DO 83 L=1,IUNIT
      83 READ(7,*)IROOM(J,K,L),ITUC(J,K,L),ITUPL(J,K,L),QUNIT(J,K,L),
      *CFMOA(J,K,L),BLENAT(J,K,L)
      CALL QCALCII(TS,IROOM,ITUC,QUNIT,IUNIT,BLENGT,Q1,J,K)
35     C SET UP UNIT DO LOOP
      GPMSUM2=0.0
      DO 100 L=1,IUNIT
      QUNIT(J,K,L)=Q1(L)
      C
40     C RENAME VARIABLES
      C
      Q=QUNIT(J,K,L)
      N7=ITUC(J,K,L)
      CFM2=CFMOA(J,K,L)
45     BLEN=BLENAT(J,K,L)
      LENGTH1=ITUPL(J,K,L)
      C
      C CHECK FOR CALL OF SUBROUTINE
      C
50     IF(ITUC(J,K,L).GE.10.AND.ITUC(J,K,L).LT.20)CALL CLASS(Q,N7,CFM2,
      *TS,LFNATH1,GPM,WPD,PIPSIZE,TUCOST)
      GO TO 762
761 ITUC(J,K,L)=20
762 IF(ITUC(J,K,L).EQ.20)CALL CABINET(Q,TS,CFM2,LENGTH1,GPM,N2,WPD,
      *PIPSIZE,TUCOST)
55     IF(ITUC(J,K,L).EQ.30)CALL BASEBOA(Q,TS,LENGTH1,GPM,WPD,BUL,TUCOST,
      *BLEN,BNOTENO)

```

```

      IF(ITUC(J,K,L).EQ.30.AND.BNOTENO.GT.0) GO TO 761
      IF(ITUC(J,K,L).GE.40.AND.ITUC(J,K,L).LT.50) CALL UNITHTR(Q,
60  *TS,LENGTH1,GPM,WPD,N12,PIPSIZE,TUCOST)
      IF(ITUC(J,K,L).EQ.50) CALL AHU1(TS,Q,LENGTH1,GPM,WPD,TUCOST)
      IF(ITUC(J,K,L).GT.50) CALL AHU2(TS,Q,LENGTH1,GPM,WPD,TUCOST)
      C
      TUGPM(L)=GPM
      65  ITUCOST(L)=TUCOST
      C
      C SUM COST,GPM,Q
      C
      QRLDG=QRLDG+QUNIT(J,K,L)
      70  GPMSUM2=GPMSUM2+GPM
      TUSUM1=TUSUM1+TUCOST
      C
      C RENAME TERMINAL UNIT WATER PRESSURE DROP
      C
      75  TUMPD(K,L)=WPD
      C
      100 CONTINUE
      WRITE(6,430)
      430 FORMAT(5X,/,/'THE FOLLOWING TABLE LISTS TERMINAL UNIT INPUT AND*
80  *'-OUTPUT PARAMETERS.*/
      WRITE(6,431)
      431 FORMAT(2X,/'ROOM=ROOM NUMBER, ITUC=TERMINAL UNIT CODE, QUNIT=
      *TERMINAL UNIT LOAD.*/
      WRITE(6,432)
      85  432 FORMAT(2X,/'TUGPM=TERMINAL UNIT GPM, TUMPD=TERMINAL UNIT WATER
      *PRESSURE DROP IN FT.*/,'ITUCOST=TERMINAL UNIT COST*/)
      WRITE(6,401)
      401 FORMAT(6X,/'ROOM',6X,/'ITUC',6X,/'QUNIT',5X,/'CFMOA',6X,
      *TUGPM',5X,/'TUMPD',5X,/'ITUCOST')
      90  WRITE(6,402)('ROOM(J,K,L),ITUC(J,K,L),QUNIT(J,K,L),CFMOA
      *J,K,L),TUGPM(L),TUMPD(K,L),ITUCOST(L)),L=1,IUNIT)
      402 FORMAT(2110,4X,5F10.2)
      GPMSUM=GPMSUM+GPMSUM2
      C SEARCH FOR MAXIMUM WATER PRESSURE DROP FOR TERMINAL UNIT ON I FLOOR
      95  WPDMAX=0.0
      DO 20 LK=1,IUNIT
      IF(TUMPD(K,LK).GT.WPDMAX) GO TO 10
      GO TO 20
      10 WPDMAX=TUMPD(K,LK)
      100  LK=LK
      20 CONTINUE
      C
      C
      C CALL PIPLDP
      105  C
      CALL PIPLDP(LS,LR,GPMSUM2,TUGPM,WPDMAX,LL,COSTLOP,LOPMPD,IUNIT)
      TOTLWPD(K)=LOPMPD
      IF(J.EQ.1) TUSUM1=0.0
      IF(J.EQ.6) TUSUM1=0.0
      110  IF(J.EQ.1) COSTLOP=0.0
      IF(J.EQ.6) COSTLOP=0.0
      C SUM COSTS
      WRITE(6,433)
      433 FORMAT(2X,/,/'THE FOLLOWING VALUES ARE FOR A SINGLE BUILDING*

```

```

115      ** LOOP, #1
      WRITE(6,434)
434  FORMAT(2X, #TUSUM1=SUM OF COST OF TERMINAL UNITS ON LOOP, #
      ** LOOPWPD=LOOP WATER PRESSURE DROP IN FT. #)
      WRITE(6,435)
120  435  FORMAT(2X, #GPMSUM2=LOOPFLOW RATE IN GPM, COSTLOP= COST OF #,
      ** PIPE IN LOOP, #17/)
      WRITE(6,308)
308  FORMAT(3X, #TUSUM1, 5X, #LOPWPD, 4X, #GPMSUM2, 3X, #COSTLOP)
      WRITE(6,105) TUSUM1, LOPWPD, GPMSUM2, COSTLOP
125  RCOSTOT=RCOSTOT+COSTLOP+TUSUM1
      TUTOT=TUTOT+TUSUM1
      RLOPTOT=RLOPTOT+COSTLOP
200  CONTINUE
130  C FIND WHICH FLOOR HAS MAX WPD
      C
      IF (IFLOOR.EQ.2) GO TO 30
      GO TO 40
30  IF (TOTLWPD(2).GT.TOTLWPD(1)) GO TO 50
135  40  BWPD=TOTLWPD(1)
      GO TO 60
50  RWPD=TOTLWPD(2)
60  CONTINUE
      CALL PIPE(GPMSUM, LFP, PIPSIZE, PLFPLOS, CLFPCOS)
140  RWPD=RWPD+PLFPLOS
      C PUMPCOST
      CALL PUMP(RWPD, GPMSUM, SIZE, HP, RPUMCST)
      C NOW SUM ALL COST FOR BUILDINGS
      RCOSTOT=RCOSTOT+RPUMCST+CLFPCOS
145  RLOPTOT=RLOPTOT+CLFPCOS
      C OUTPUT OF BUILDING DATA INCLUDE CALCULATION OF PARAMETER
      C
      GPMSUM, DELTA T, TS, TR, COST
      DELTAT=QBLDG/(500.*GPMSUM)
      T=TS-DELTAT
150  WRITE(6,460) J
460  FORMAT(2X, //, #THE FOLLOWING OUTPUT CONSISTS OF TOTALS FOR #,
      ** BUILDING #, 14, //)
      WRITE(6,1000)
1000 FORMAT(5X, #TUTOT, 9X, #RLOPTOT, 3X, #BPUMCST, 3X, #BCOSTOT, 6X,
      ** RWPD, 6X, #GPMSUM, 4X, #HP, 6X, #TS, 10X, #TR, 8X, #QBLDG, #)
155  WRITE(6,1001) TUTOT, RLOPTOT, RPUMCST, BCOSTOT, BWPD, GPMSUM, HP,
      ** TS, TR, QBLDG
1001 FORMAT(3X, F8.2, 6X, F8.2, 4X, F6.2, 4X, F8.2, 5X, F5.2, 5X, F6.2,
      ** 4X, F3.2, 5X, F6.2, 5X, F6.2, 4X, F10.2)
160  SYS6PM=SYS6PM+GPMSUM
      SYSCOST=SYSCOST+BCOSTOT
      SYSQ=SYSQ+QBLDG
112  CONTINUE
      SYSDELTA=SYSQ/(500.*SYS6PM)
      SYSRT=TS-SYSDELTA
165  WRITE(6,520)
520  FORMAT(//3X, #SYS6PM, 9X, #SYSCOST, 12X, #SYSQ, 15X, #TS, 15X,
      ** #SYSRT, #)
      WRITE(6,521) SYS6PM, SYSCOST, SYSQ, TS, SYSRT
170  521  FORMAT(2X, F6.2, 10X, F8.2, 9X, F10.2, 10X, F6.2, 10X, F6.2)
      105  FORMAT(2X, F8.2, 5X, F5.2, 6X, F8.2, 3X, F8.2)

```

```

CALL HFXCH(ITS,SYSQ,TGEOP,TSI,SYSGPM,GPMGEO,UA,HEWPDG,
+HEWPDG,HECOST)
CALL DTSPIPL(SYSGPM,DLCCOST,DLWPD,LSI,LR1,DLSSIZE,SLSIZE,HEWPOS
175 +,FLOSS)
WRITE(6,6)
6 FORMAT(2X,/,/,#THE DISTRICT LOOP PIPE:,,//,6X,#SUPPLY PIPE LENGTH#
+6X,#RETURN PIPE LENGTH#6X,#MAIN DISTRICT LOOP SIZE#
+6X,#SECONDARY LOOP SIZE#7X,#LOOP PIPE COST#)
180 WRITE(6,7)LSI,LR1,DLSSIZE,SLSIZE,DLCCOST
7 FORMAT(9X,14,# FT#,16X,14,# FT#,17X,F3.1,# IN#,26X,F3.1,
+IN#,70X,#S#,F8.2)
WRITE(6,23)FLOSS
23 FORMAT(2X,/,/,#DISTR. LOOP PIPE LOSS#7,8X,F6.2,# FT#)
185 CALL DPUMP(SYSGPM,DLWPD,DPCOST,DLPHP)
WRITE(6,80)
80 FORMAT(2X,/,/,# THE DISTRICT LOOP PUMP:,,//,26X,#TOTAL HEAD
+26X,#PUMP SIZE#26X,#PUMP COST#)
WRITE(6,90)DLWPD,DLPHP,DPCOST
190 90 FORMAT(26X,F6.2,# FEET#15X,F4.1,# HP BAG SERIES 1531 3 IN.#
+AR 53500 RPM#10X,#S#,F7.2)
WRITE(6,33)
33 FORMAT(2X,/,/,#THE GEOTHERMAL WATER PIPE:,,//)
195 CALL GFOPIF(GPMGEO,GEOLS,GEOLR,GEOWPD,PSIZE,GEOPCST,HEWPDG)
WRITE(6,17)GPMGEO,GEOLS,GEOLR,GEOWPD,PSIZE,GEOPCST
17 FORMAT(2X,#GEO FLORATE#9X,#SUPP. PIPE LENGTH#9X,
+RETURN PIPE LENGTH#9X,#GEO WATER PRESS. DROP#7X,#PIPE SIZE#
+7X,#PIPE COST#7,7X,F5.1,#GPM#13X,F7.1,# FT#15X,F7.1,
+FT#16X,F6.2,# FT HEAD#12X,F4.1,# IN#9X,#S#,F8.2)
200 C THE HEAT EXCHANGER SUBROUTINE
C
WRITE(6,18)TGEOP,TSI,GPMGEO,UA,HEWPDG,HECOST
18 FORMAT(2X,/,/,#THE HEAT EXCHANGER:,,//)
+2X,#TEMP. GEO RET.#5X,#TEMP. SPACE SUPP.#5X,
205 +GEO FLOWRATE#14X,# UA #10X,#H.EXCH. PRESS. DROP#5X,
+H. EXCHANGER COST#7,12X,F10.2,# FT#12X,F7.2,# FT#9X,F6.2,
+GPM#11X,F10.2,10X,F5.2,# FT#11X,#S#,F10.2)
COSTOT=SYSCOST+DLCCOST+DPCOST+GEOPCST+HECOST
WRITE(6,1003)COSTOT
210 1003 FORMAT(2X,/,/,#THE TOTAL COST:,,//,2X,#TOTAL COST# 3#,F10.2)
CALL EXIT
END

```

```

1      SUBROUTINE CLASS(G,N7,CFM2,TS,LENGTH1,GPM,WPD,PIPSIZE,TUCOST)
      C
      C
      C
5      IF(N7-11)20,30,40
      20 CFM1=750.
      GO TO 60
      30 CFM1=1000
      GO TO 60
10     40 IF(N7-12)45,45,50
      45 CFM1=1250
      GO TO 60
      50 CFM1=1500
      60 PSCUTAR=CFM2/CFM1
15     MIXARTE=70.-1PSCUTAR*80.)
      ITD=TS-MIXARTE
      QCITD=ITD/(ITD*1000.)
      IF(N7-11)65,70,80
      65 GPM=-35.4922549+316.6297294*QCITD-917.728294*(QCITD**2.)+904.75069
      +73*(QCITD**3.)
      WPD1=-4.7473253+3.9281838*GPM+0.3791754*(GPM**2.)
      C
      COSTU=1020
      IF(GPM-4.)100,100,22
25     22 GPM=52.134769894+224.853907919*QCITD+252.373995576*(QCITD**2.)
      WPD1=-.282452148+.254521929*GPM+0.10401114*(GPM**2.)
      COSTU=1091.
      GO TO 100
      70 GPM=-26.1453282+181.5479001*QCITD-405.380183*(QCITD**2.)+311.57288
      +10*(QCITD**3.)
30     WPD1=-1.4591516+1.4307954*GPM+0.1137432*(GPM**2.)
      C
      COSTU=1162
      IF(GPM-4.)100,100,33
35     33 GPM=22.808105935+77.643995724*QCITD+72.304422445*(QCITD**2.)
      WPD1=-.272946562+.29120341*GPM+.11392215*(GPM**2.)
      COSTU=1231.
      GO TO 100
      80 IF(N7-12)90,90,95
40     90 GPM=-33.7681826+199.2087946*QCITD-375.2637362*(QCITD**2.)+239.71172
      +331*(QCITD**3.)
      WPD1=-0.6996899+0.4201065*GPM+0.0727882*(GPM**2.)
      C
      COSTU=1247
45     IF(GPM-4.)100,100,44
      44 GPM=14.77033179+42.831781114*QCITD+35.676821241*(QCITD**2.)
      WPD1=2.107805085-.649083581*GPM+.188429397*(GPM**2.)
      COSTU=1333
      GO TO 100
50     95 GPM=19.5316985-88.0938661*QCITD+123.4665514*(QCITD**2.)-44.3494879
      +*(QCITD**3.)
      WPD1=0.9295139-0.3539795*GPM+0.1768703*(GPM**2.)
      C
      COSTU=1297
55     IF(GPM-4.)100,100,55
      55 GPM=-.850828434-3.400840985*QCITD+7.455240142*(QCITD**2.)
      WPD1=-.071440036+.137276806*GPM+.066682578*(GPM**2.)

```


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1 SUBROUTINE CABINET(IQ,TS,CFM2,LENGTH1,GPMHM,N2,WPD00,PIPSIZE,TUCOST

*)

C

C

5 DIMENSION GPM(50),WPD(10),COST(10),CODCABI(10),Z(10)

REAL MAT

COST(1)=239.

COST(2)=261.

COST(3)=290.

10 COST(4)=370.

COST(5)=468.

COST(6)=738.

COST(7)=772.

COST(8)=790.

15 CODCABI(1)=2.

CODCABI(2)=3.

CODCABI(3)=4.

CODCABI(4)=6.

CODCABI(5)=8.

20 CODCABI(6)=10.

CODCABI(7)=12.

CODCABI(8)=13.

C

25

C

C

C

C

30

C

C

C

N=1

35 Z(1)=220.

Z(2)=300.

Z(3)=420.

Z(4)=570.

Z(5)=880.

Z(6)=1040.

40 Z(7)=1200.

Z(8)=1260.

C

5 MAT=(17*(N)-CFM2)*70.*(CFM2*(1-10))/Z(N)

FACTOR=-0.0984777-0.0069376*MAT*(0.0088545-0.0000074*MAT)*TS

45 R1=C/(FACTOR*1000.)

GPM(1)=-17.2212235+3.6896303*R1-0.2564941*(R1**2.)+0.0060793*(R1**3.)

GPM(2)=-16.4828661+2.5725304*R1-0.1292911*(R1**2.)+0.0022123*(R1**3.)

50 GPM(3)=-9.8321556+1.3108191*R1-0.0552355*(R1**2.)+0.0008083*(R1**3.)

GPM(4)=-6.8126937+0.7143576*R1-0.0231134*(R1**2.)+0.0002639*(R1**3.)

55 GPM(5)=10.5474-0.55105*R1+0.0079725*(R1**2.)

GPM(6)=11.3478-0.521495*R1+0.005563*(R1**2.)

GPM(7)=8.8856-0.370594*R1+0.0043608*(R1**2.)

GPM(8)=8.5872381-0.32244*R1+0.003427*(R1**2.)

$$-WPR(1) = -0.0226727 + 0.1015699 * GPM(1) + 0.1713191 * (GPM(1))^{**2} - 0.004546$$

1(GPM(1)**3.)

60

$$-4PD(2) = -0.0266242 + 0.1115359 * GPM(2) + 0.2052308 * (GPM(2) ** 2) - 0.006094$$

8 (GPM (7) **3.)

$$WPO(3) = -0.0305443 + 0.1498643 * GPM(3) + 0.2667376 * (GPM(3))^2 = -0.007182$$

49* (GPM (3) **3.)

$$WPD(4) = -0.0620685 + 0.221106 * GPM(4) + 0.3044756 * (GPM(4))^{**2} - 0.0067811$$

65

*(GPM(4)***3.)*

WP0751-00539

$$WPN(6) = -0.023018 + 0.029501 * GPM(6) + 0.101026 * (GPM(6) ** 2.)$$
$$WPD(7) = 0.0861371 + 0.1149905 * GPM(7) + 0.078247 * (GPM(7) ** 2.)$$
$$WPH(8) = -0.116807 + 0.14494 * GPM(8) + 0.063346 * (GPM(8) ** 2.)$$

-70-

IF(GPMINT)=2.5/20,20,10

10 N=N+1

GO TO 5

20 $N_1 = N$

AZ=WPB(N1)
COMM=COM/

75

~~GPMM=GP4(N1)~~

—K2#E0HCAH1 (N) A
CALL 0325 (CBM)

```

CALL PIPE (NPMMA, LENGTH1, PIPESIZE, FRICT10, COST1F,
COST1I=COST1(N))

```

COST=COST*(WT)
WBDDD=A3+EBICT

~~TOP SECRET//COMINT//COS~~

60

TUCOST#COSTU+COSTIF
RETURN

RETURN
FBI

END

SUBROUTINE BASEBOA		73/74	OPT=2	PTN 4.6+439	79/02/08. 16.06.45	PAGE	1
1		SUBROUTINE BASEBOA(G,TS,LENGTH1,GPM,WPD,BUL,TUCOST,BLEN,BNOTENO)					
	C						
		GPM=7.65					
		IF (TS=120) 10,20,30					
5	10	OACT=355					
		WPD1=1.3655					
		GO TO 80					
	20	OACT=480					
		WPD1=1.3771					
10		GO TO 80					
	30	IF (TS=160) 40,50,60					
	40	OACT=771					
		WPD1=1.2876					
		GO TO 80					
15	50	OACT=1884					
		WPD1=1.2432					
		GO TO 80					
	60	OACT=1433					
		WPD1=1.1877					
20	80	BUL=O/OACT					
		IF (BUL<LT,BLEN) GO TO 84					
		QRPESTR=OACT*BLEN					
		BUL=BLEN					
		BNOTENO=C-QRPESTR					
25	84	WPD2=WPD1*BUL/100					
		IF (BUL<LT,BLEN) BNOTENO=0.0					
		CALL PIPE(GPM,LENGTH1,PIPSIZE,FRIC10,COST1)					
		COST2=17.*BUL					
		WPD=WPD2*FRIC10					
30		TUCOST=COST1+COST2					
		RETURN					
		END					

1 SUBROUTINE PIPLOP(LS,LR,GPMSUM,GPMS,WPDMAX,LLTCOSTLOP,LOPWPDI,UNIT)

C

REAL LOPVPI

DIMENSION GPM(33),LS1(33),LR1(33),SPIPSZ(33),RPISZ(33)

FRIC105=0.0

FRIC103=0.0

FRIC104=0.0

COSTP3=0.0

READ(7,*) (LS1(I),I=1,UNIT)

READ(7,*) (LR1(I),I=1,UNIT)

WRITE(6,440)

440 FORMAT(2Y,/,/,*,THE FOLLOWING TABLE LISTS THE SUPPLY AND RETURN*,

, PIPE FLOW RATE IN GPM,/,*, FOR EACH SECTION OF THE 2-PIPE*,

, REVERSE RETURN PIPE LOOP./

WRITE(6,441)

441 FORMAT(2X,*,I=PIPE SECTION NO., SGPM=FLOW RATE IN RETURN*,

, PIPE SECTION./

WRITE(6,442)

442 FORMAT(2X,*,GPMS=FLOW RATE IN SUPPLY PIPE SECTION I, GPMS*,

,SUM=TOTAL LOOP FLOW RATE./,,)

C

WRITE(6,316)

316 FORMAT(4X,*,I,*,8X,*,SGPM*,11X,*,GPMS*,10X,*,SUPP. PIPE DIAM.*/

,10X,,RETURN PIPE DIAM.*/

DO 120 I=1,UNIT

SGPM=0.0

N1=1

LS=LS1(I)

LR=LR1(I)

30 20 IF (N1-1) 30,30,40

30 SGPM=SGPM+GPM(N1)

N1=N1+1

GO TO 20

40 GPMS=GPMSUM-SGPM+GPM(I)

35 CALL PIPE(GPMS,LS,PIPSIZE,FRIC101,COSTP1)

SPISZ(I)=PIPSIZE

CALL PIPE(SGPM,LR,PIPSIZE,FRIC102,COSTP2)

RPISZ(I)=PIPSIZE

IF(I.FH.LL) GO TO 60

IF(I.GT.LL) GO TO 70

FRIC103=FRIC103+FRIC101

GO TO 115

60 FRIC105=FRIC101+FRIC102

GO TO 115

45 70 FRIC104=FRIC104+FRIC102

115 COSTP3=COSTP3+COSTP1+COSTP2

WRITE(6,7) (I,SGPM,GPMS,SPISZ(I),RPISZ(I))

7 FORMAT(15,F12.2,2,9X,F7.2,16X,F4.2,22X,F4.2)

120 CONTINUE

50 WRITE(6,443) GPMSUM

443 FORMAT(2X,*,*,GPMSUM=*,F7.2)

COSTLOP=COSTP3

LOPWPDI=(FRIC103+FRIC104+FRIC105+WPDMAX)*1.5

RETURN

55 END

SUBROUTINE PIPE	73/74	OPT=2	FTN 4.6*439	79/02/08. 16.06.45	PAGE	1
1	SUBROUTINE PIPE(GPM,LENGTH1,PIPSIZE,FRIC10,COSTP)					
	DIMENSION P(20),C(20)					
	P(1)=0.5					
	P(2)=0.75					
5	P(3)=1.					
	P(4)=1.5					
	P(5)=2.					
	P(6)=2.5					
	P(7)=3.					
10	P(8)=4.					
	P(9)=6.					
	P(10)=8.					
	C(1)=0.37					
	C(2)=0.44					
15	C(3)=0.62					
	C(4)=0.97					
	C(5)=1.3					
	C(6)=1.86					
	C(7)=2.44					
20	C(8)=3.55					
	C(9)=7.89					
	C(10)=11.22					
	IF(GPM<4.770,76.88					
80	SIZE=0.2733333679*(GPM**0.5271033755)					
25	GO TO 90					
	70 N=2					
	FRIC10=0.4134518*(GPM**0.782999889)*LENGTH1*0.01					
	GO TO 110					
	90 N=1					
30	5 IF(SIZE-P(N))20,20,10					
	10 N=N+1					
	GO TO 5					
	20 FRIC10=40.41685185*(GPM**(-0.622413019))*LENGTH1*0.01					
	110 PIPSIZE=P(N)					
35	FRIC10=FRIC10*1.5					
	COSTP=C(N)*LENGTH1					
	RETURN					
	END					

SUBROUTINE	UNITHTR	73/74	OPT=2	FTN 4.6+439	79/02/08. 16.06.45	PAGE	1
1		SUBROUTINE-UNITHTR(G,T,S,LENGTH1,GPM,WPD,N,PIPSIZE,COST)					
		Q1=Q/1000.					
		GPM1=G1*1000.7/(485*15)					
		FACTOR=-.4978571+.0071321*TS-.0000004*(TS**2.)					
5		QACT=Q1/FACTOR					
		Q186=62.7844801+11.9247677*GPM1-.4616254*(GPM1**2.)					
		IF (Q186-QACT) 30,10,10					
10		N=186					
		GPM=27.322469861-.687384657*QACT+.004705616*QACT**2.					
10		WPD1=-.3055*61+.3290570*GPM+.0397125*(GPM**2.)					
		COSTU=397.					
		GO TO 100					
		30 Q230=94.5481929+8.7498684*GPM1-.1904744*(GPM1**2.)					
		IF (Q230-QACT) 50,40,40					
15		40 N=230					
		GPM=43.616533232-.833256446*QACT+.004233542*(QACT**2.)					
		WPD1=-.1910926+.1156726*GPM+.00816*(GPM**2.)					
		COSTU=451.					
		GO TO 100					
20		50 N=260					
		GPM=29.110*30319-.521915186*QACT+.002611033*(QACT**2.)					
		WPD1=.1432006+.1044533*(GPM+.00869004*(GPM**2.))					
		COSTU=493.					
		100 CALL PIPE(GPM,LENGTH1,PIPSIZE,FRICTIO,COSTP)					
25		WPD=WPD1+FRICTIO					
		COST=COSTU+COSTP					
		RETURN					
		END					

SUBROUTINE AHU1	73/74	OPT=2	FTN 4.6+439	79/02/08. 16.06.45	PAGE 1
1	SUBROUTINE-AHU1(TS,G,LENGTH1,GPM,WD,COST)				
	O3=0/1000.				
	GPM=32168.78-524.0959*TS+2.1412679997*TS**2+(-179.8364				
	+2.92468959274*TS-.01192724309*TS**2)*O3+(.25839431108-				
5	+.00419078283				
	TS+.00001704946*TS2.)*O3**2.				
	FPS=(1.66*GPM)/30.				
	D1=4.*(-.05313243458+.21783108644*FPS+.2888739096*FPS**2.)				
	WPD1=2.*(-.01952380952+.01619047619*FPS+.08866479925*FPS**2.)				
10	TAVE=52.4-778195517+.3468170426*TS+(-1.35330827067+.014402255				
	+64*TS)*GPM				
	FACTOR=1.763785535-.008168777*TAVE+.000022052*(TAVE**2.)				
	WPD2=D1*FACTOR				
	CALL PIPE(GPM,LENGTH1,PIPSIZE,FRICTIO,COSTP)				
15	WPD=WPD1+WPD2+FRICTIO				
	COSTU=4300.				
	COST=COSTP+COSTU				
	RETURN				
	END				

SUBROUTINE PUMP

73/74 OPT=2

FTN 4.6+439

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```

1      SUBROUTINE-PUMP(WPD,GPM,SIZE,HP,COST)
      IF(WPD.LE.15.AND.GPM.LE.80)GO TO 111
      IF(WPD.LE.15.AND.GPM.GT.80)GO TO 112
      IF(WPD.GT.15.AND.WPD.LE.20.AND.GPM.LE.90)GO TO 112
5      IF(WPD.GT.20.AND.WPD.LE.25.AND.GPM.LE.90)GO TO 113
      IF(WPD.GT.20.AND.WPD.LE.25.AND.GPM.GT.90)GO TO 114
      C
      IF(WPD.GT.25.AND.WPD.LE.30.AND.GPM.LE.100)GO TO 115
10     IF(WPD.GT.25.AND.WPD.LE.30.AND.GPM.GT.100)GO TO 116
      IF(WPD.GT.30.AND.WPD.LE.40.AND.GPM.LE.90)GO TO 115
      IF(WPD.GT.30.AND.WPD.LE.40.AND.GPM.GT.90)GO TO 116
      C
      C
      C
15     111 SIZE=1.
      HP=.5
      COST=516.
      GO TO 257
      112 SIZE=2.
20     HP=.75
      COST=516.
      GO TO 257
      113 SIZE=3.
      HP=1.
25     COST=634
      GO TO 257
      114 SIZE=4.
      HP=1.5
      COST=634
30     GO TO 257
      115 SIZE=5.
      HP=1.5
      COST=398
      GO TO 257
35     116 SIZE=6.
      HP=2
      COST=527
      C
      C
      C
40     257 WRITE(6,258)
      258 FORMAT(//,1X,SIZE#,5X,HP#,3X,COST#)
      WRITE(6,259)SIZE,HP,COST
      259 FORMAT(1X,F3.1,3X,F4.2,3X,F5.1)
45     RETURN
      END

```

SUBROUTINE	AMU2	73/74	OPT=2	FTN 4.6+439	79/02/08, 16.06.45	PAGE	1
1	SUBROUTINE-AMU2(TS,R,LENGTH1,GPM,YPD,COST)						
	GPM=7.45249899988-.7181848*TS*(.00083092783+.00000288158*TS)*Q						
	FPS=(1.66*GPM)/30.						
	YPD1=2.*(-.002660675+.003620909*FPS+.129017297*(FPS**2.))						
5	D1=4.*(-.05341594+.207289849*FPS+.270265662*(FPS**2.))						
	TAVE=34.41518011171+.49088893059*TS*(-2.77121206746+.03331						
	.467129*TS)*GPM*(.0616465291+.00068202627*TS)*GPM**2.						
	FACTOP=1.763785535-.008168777*TAVE+.000022052*(TAVE**2.)						
	YPD2=D1*FACTOR						
10	CALL PIPE(GPM,LENGTH1,PIPSIZE,FRICTIO,COSTP)						
	YPD=YPD1+YPD2*FRICTIO						
	COSTU=350.						
	COST=COSTP+COSTU						
	RETURN						
15	END						

1 C THIS SUBROUTINE WILL DETERMINE THE SIZE, COST, PRESS. DROP
C AND TEMPERATURES OF HEAT EXCHANGER.

SUBROUTINE HEXCH (TS, SYSQ, TGEOR, TSI, SYSGPM, GPMGEO, UA, HEWPDG, HEWPD5,
*HECOST)

5 GEOM=600 * CPS=500 * CP6=500 * VISG=3.447E-4 * U=500 * FC=.95

VIS=4.14E-4 * DENG=61.537 * DENS=61.843 * HLEN=5.1033

HWID=16.375 * GAP=.15 * TGEOS=130 *

TSI=TS-SYSQ/(SYSGPM*CPS)

DTS=TS-TSI

10 DTO=TGEOS-TS

DTI=TGEOS-TSI

XT=1/(GEOM*CP6)

10 QSX=SYSQ*XT

A1=QSX-DTS

A2=DTI-QSX

15 FP1=(A1/A2)-ALOG(DTO/A2)

IF (ABS(FP1).LE.1.E-5) GOTO 101

DFD1=SYSQ*A1/A2**2

XC=XT-FP1/DFD1

20 XT=XC

GOTO 10

101 GPMGEO=1/(XC*CP6)

IF (GPMGEO.GE.GEOM) GPMGEO=GEOM

UA=SYSQ*ALOG(DTO/A2)/A1

25 TGEOP=TGEOS-SYSQ*XC

AFCH=HWID*GAP/144

AHT=UA/(U*FC)

NP=AHT/5.6+.501

RNPAS=2

30 IF (NP.LT.100) NPAS=1

NCH=NP/(2*NPAS)

RNPAS=NP/(NCH*2)

APAS=NCH*AFCH

35 G1=GPMGEO*CP6/(3600*APAS)

DH=4*AFCH/12*(HWID*GAP/12)

F1=2.5*((G1*DH/VISG)**(-.3))

DP1=2*F1*(G1**2)*HLEN/(32.2*DENG*DH*144)

HEWPDG=DP1*RNPAS*2*144/62.4

40 C A FACTOR OF 2 HAS BEEN ADDED TO ACCOUNT FOR INLET AND
C EXIT PORTS AND OTHERS

C

C THE SPACE SIDE

G2=GPMGEO*CPS/(3600*APAS)

F2=2.5*((G2*DH/VIS)**(-.3))

45 DP2=2*F2*(G2**2)*HLEN/(32.2*DENS*DH*144)

HEWPD5=DP2*RNPAS*2*144/DENS

HECOST=1832.1+.9.5*AHT+.00409*AHT*AHT*.7.E-7*AHT**3

RETURN

END

SYMBOLIC REFERENCE MAP (R=1)

SUBROUTINE DISPIPL 73/74 OPT=2

FTN 4.6+439

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1 SUBROUTINE DISPIPL(SYSGPM,DLCOST,DENPD,LS1,LR1,DLSIZE,SESIZE,
+HEWPOS,FLOSS)

C
C THIS SUBROUTINE WILL DETERMINE THE DISTRICT LOOP SIZE,
C COST, AND PRESSURE DROP.

C
C DIMENSION PSIZE(20),COST(20)

LEN1=120

LEN2=750

10 LENGTH1=600

LENGTH2=1000

LS1=(LEN1+LEN2)/2

LR1=LS1

CALL PIPE(SYSGPM,LENGTH1,DLSIZE,FL1,COST1)

15 CALL PIPE(SYSGPM,LENGTH2,DLSIZE,FL2,COST2)

PCOST1=COST1*LEN1/LENGTH1

PCOST2=COST2*LEN2/LENGTH2

FLOSS=FL1+FL2

20 DENPD=(FL1+FL2)*1.5+HEWPOS

DLCOST=PCOST1+PCOST2

RETURN

END

SUBROUTINE DPUMP

73/74

OPT=2

FTN 4.6+439

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PAGE

1

1

C

C THE DISTRICT LOOP PUMP SIZING

C

SUBROUTINE DPUMP(SYSGPM,DLWPD,DPCOST,DLPHP)

5

C-THIS SUBROUTINE WILL DETERMINE THE DISTRICT LOOP PUMP
C SIZE AND COST.

DIMENSION HP(20),COSTP(20)

HP(1)=5

10

HP(2)=7.5

HP(3)=10

HP(4)=15

HP(5)=20

HP(6)=25

HP(7)=30

15

COSTP(1)=765

COSTP(2)=812

COSTP(3)=960

COSTP(4)=1092

20

COSTP(5)=1317

COSTP(6)=1445

COSTP(7)=1662

HPD=(2.528E-4)*SYSGPM*DLWPD

C ASSUME PUMP EFFICIENCY OF .65

HPA=HPD/.65

25

N=0

1001 N=N+1

IF (HPA-HP(N))23,23,27

27 GOTO 1001

23 DPHP=HP(N)

30

DPCOST=COSTP(N)

RETURN

END

```

1      C GEOTHERMAL PIPE
      C
      SUBROUTINE GEOPIPE(GPMGEO,GEOLST,GEOLR,GEOWPD,PSIZE,GEOPCST,HEWPDG)
      C
5      C THIS SUBROUTINE WILL SIZE THE GEOTHERMAL PIPE. IT WILL ALSO
      C CHECK THE PRESSURE DROP AND COMPARE IT WITH THE GEOTHERMAL WATER
      C PRESSURE AVAILANCE.
      C
      DIMENSION RIPS(20),COSTGT(20)
10     GEOLST=192.5
      C THE NO. OF ELBOWS, Z
      Z=6
      C THE GEOTHERMAL WATER PRESSURE, GEOP
      GEOP=115
15     GEOLR=GEOLST
      LENGTH=2*GEOLST+(Z*30)
      CALL PIPE(GPMGEO,LENGTH,PSIZE,FLGEO,COST)
      C HEAT EXCHANGER PRESSURE DROP, HEPD
      GEOPCST=GCOST*2*GEOLST/(2*GEOLST+180)
20     GEOWPD=(FLGEO*1.51+HEWPDG)
      Y=GEOWPD-GEOP
      IF (GEOWPD.LT.GEOP) GOTO 113
      WRITE(4,203)Y
203    FORMAT(2X,4THE PIPE FRICTION LOSS PLUS THE HEAT EXCHANGER#,
25     *PRESSURE DROP IS GREATER THAN THE AVAILABLE GEO WATER PRESSURE,
      *//,4 THEREFORE, THIS SYSTEM REQUIRES A PUMP WHICH CAN CARRY,
      *4.14 FT OF HEAD,///)
113    WRITE(6,204)
204    FORMAT(2X,7THIS SYSTEM REQUIRES NO GEOTHERMAL WATER #,
30     *PUMP. THE GEOTHERMAL WATER PRESSURE IS CAPABLE OF OVERCOMING,/,
      *THE FRICTION LOSS AND THE PRESS. DROP ACROSS THE HEAT EXCH.,///)
      RETURN
      END

```

```

1  SUBROUTINE-OCALCU(ITS,IPOOM,ITUC,GUNIT,IUNIT,BRENGT,Q1,J,K)
   DIMENSION IPM(33),ITU(33),RL(33),Q1(33),ORM(10),IT(10),IROOM(6,2,3)
   3) ITUC(6,2,33),GUNIT(6,2,33),BRENGT(6,2,33),B(33)
   DO 5 L=1,IUNIT
   5  IPM(L)=IROOM(J,K,L)
      ITU(L)=ITUC(J,K,L)
      RL(L)=BRENGT(J,K,L)
      5 Q1(L)=GUNIT(J,K,L)
      IRATE=1
10  DO 20 LL=1,IUNIT
      K5=1
      DO 10 N=1,IUNIT
      IF(ILL.EN.N)GO TO 10
      IF(IPM(LL).NE.IRM(N))GO TO 10
15  QPM(IT)=IT(LL)
      IT(1)=ITU(LL)
      R11=RL(LL)
      IRM(LL)=IRM(LL)+IRATE*10000+K5*1000
      K5=K5+1
20  ORM(K5)=Q1(N)
      IT(K5)=ITU(N)
      R(K5)=RL(N)
      IRM(N)=IRM(N)+IRATE*10000+K5*1000
      10 CONTINUE
25  IF(ITS.EQ.K5)GO TO 30
      QTOTDIF=0.0
      MM=0
      DO 12 NN=1,K5
      IF(IT(NN).NE.30)GO TO 12
30  MM=MM+1
      IF(ITS-120)91,92,93
      91 GACT=355.
      GO TO 86
      92 GACT=489.
      GO TO 86
35  93 GACT=771.
      86 QNEW=GACT*R(NN)
      QDIFFER=ORM(NN)-QNEW
      ORM(NN)=QNEW
      QTOTDIF=QTOTDIF+QDIFFER
40  12 CONTINUE
      IF(K5.EQ.MM)GO TO 101
      QADD=QTOTDIF/(K5-MM)
      DO 15 JJJ=1,K5
45  IF(IT(JJJ).EQ.30)GO TO 15
      ORM(JJJ)=ORM(JJJ)+QADD
15  CONTINUE
101 K1=1
      DO 17 NNNN=1,IUNIT
50  IF(IPM(NNNN).LT.IRATE*10000.OR.IRM(NNNN).GT.(IRATE+1)*10000)
      GO TO 17
      Q1(NNNN)=ORM(K1)
      K1=K1+1
17  CONTINUE
55  IRATE=IRATE+1
20  CONTINUE
      RETURN

```

READ:BUILDING 1

THE FOLLOWING TABLE LISTS TERMINAL UNIT INPUT AND OUTPUT PARAMETERS.

IRROOM=ROOM NUMBER, ITUC=TERMINAL UNIT CODE, GUNIT= TERMINAL UNIT LOAD,
TUQPM=TERMINAL UNIT GPM, TUMPD=TERMINAL UNIT WATER PRESSURE DROP IN FT.,
ITUCOST=TERMINAL UNIT COST

IRROOM	ITUC	GUNIT	CFMOA	TUQPM	TUMPD	ITUCOST
105	11	26532.00	200.00	1.35	1.33	1189.28
209	30	7598.00	0	7.65	2.84	177.45
208	30	5560.00	0	7.65	4.88	139.95
210	30	1968.00	0	7.65	4.99	61.37
206	30	5560.00	0	7.65	5.56	142.43
106	12	33294.00	250.00	1.85	1.45	1273.84
205	12	51275.00	250.00	2.45	2.49	1347.96
107	20	18816.00	0	1.82	2.54	359.92
203	30	5936.00	0	7.65	10.86	169.94
108	30	4157.00	0	7.65	12.37	136.30
104	20	17084.00	0	1.37	1.67	365.20
204	30	7552.00	0	7.65	9.35	200.00
202	12	51539.00	250.00	2.48	2.84	1349.72
103	11	35826.00	200.00	2.28	4.19	1191.48
102	20	11959.00	0	1.92	2.24	290.48
101	11	26515.00	200.00	1.35	1.22	1184.88
201	11	32178.00	200.00	1.87	2.27	1176.96

THE FOLLOWING TABLE LISTS THE SUPPLY AND RETURN PIPE FLOW RATE IN GPM

FOR EACH SECTION OF THE 2-PIPE, REVERSE RETURN PIPE LOOP.

I=PIPE SECTION NO., SGPM=FLOW RATE IN RETURN PIPE SECTION.

GPMS=FLOW RATE IN SUPPLY PIPE SECTION I, GPMSUM=TOTAL LOOP FLOW RATE.

I	SGPM	GPMS	SUPP. PIPE DIAM.	RETURN PIPE DIAM.
1	1.35	72.28	3.00	.75
2	9.00	70.93	3.00	1.00
3	16.65	63.28	2.50	1.50
4	24.30	55.63	2.50	1.50
5	31.95	47.98	2.50	2.00
6	33.79	40.33	2.00	2.00
7	36.24	38.49	2.00	2.00
8	38.06	36.04	2.00	2.00
9	45.71	34.22	2.00	2.50
10	53.36	26.57	2.00	2.50
11	54.73	18.92	1.50	2.50
12	62.38	17.55	1.50	2.50
13	64.86	9.90	1.00	2.50
14	67.14	7.42	1.00	3.00
15	69.06	5.14	.75	3.00
16	70.41	3.22	.75	3.00
17	72.28	1.87	.75	3.00

GPMSUM= 72.28

THE FOLLOWING VALUES ARE FOR A SINGLE BUILDING LOOP.

TUSUM1=SUM OF COST OF TERMINAL UNITS ON LOOP., LOOPWPD=LOOP WATER PRESSURE DROP IN FT.
 GPMSUM2=LOOPFLOW RATE IN GPM, COSTLOP= COST OF PIPE IN LOOP.

TUSUM1	LOPWPD	GPMSUM2	COSTLOP
0	44.33	72.28	0

SIZE	HP	COST
1.0	.50	516.0

THE FOLLOWING OUTPUT CONSISTS OF TOTALS FOR BUILDING 1

TUTOT	BLOPTOT	BPUNKST	BCOSTOT	BWPD	GPMSUM	HP	TS	TR	QBLDG
0	378.20	516.00	894.20	50.88	72.28	.50	125.00	115.50	343349.00

READ:BUILDING 2

THE FOLLOWING TABLE LISTS TERMINAL UNIT INPUT AND OUTPUT PARAMETERS.

IROOM=ROOM NUMBER, ITUC=TERMINAL UNIT CODE, QUNIT= TERMINAL UNIT LOAD.

TUGPM=TERMINAL UNIT GPM, TUWPD=TERMINAL UNIT WATER PRESSURE DROP IN FT.,

ITUCOST=TERMINAL UNIT COST

IROOM	ITUC	QUNIT	CFMOA	TUGPM	TUWPD	ITUCOST
105	30	13878.00	0	7.65	2.28	313.44
105	13	47622.00	200.00	3.59	2.60	1301.84
105	30	15420.00	0	7.65	2.14	346.82
108	20	14266.00	0	1.84	1.34	295.72
109	13	58270.00	250.00	3.30	1.68	1522.84
106	20	9235.00	0	.96	.42	273.32
101	10	23061.00	125.00	1.60	.47	1024.84
102	13	46261.00	175.00	3.39	2.41	1302.28
103	20	11092.00	0	1.41	.72	268.48
104	30	10023.00	0	7.65	8.71	252.00
104	30	10794.00	0	7.65	3.94	251.64
105	13	41422.00	200.00	1.91	1.16	1302.72
105	30	7500.00	0	7.65	2.35	173.43

THE FOLLOWING TABLE LISTS THE SUPPLY AND RETURN PIPE FLOW RATE IN GPM

FOR EACH SECTION OF THE 2-PIPE, REVERSE RETURN PIPE LOOP.

I=PIPE SECTION NO., SGPM=FLOW RATE IN RETURN PIPE SECTION.

GPMS=FLOW RATE IN SUPPLY PIPE SECTION I, GPMSUM=TOTAL LOOP FLOW RATE.

I	SGPM	GPMS	SUPP. PIPE DIAM.	RETURN PIPE DIAM.
1	7.65	56.23	2.50	1.00
2	11.24	48.58	2.50	1.00
3	18.89	45.00	2.50	1.50
4	20.72	37.35	2.00	1.50
5	24.02	35.51	2.00	1.50
6	24.98	32.22	2.00	1.50
7	26.57	31.26	2.00	2.00
8	29.94	29.66	2.00	2.00
9	31.37	26.27	2.00	2.00
10	39.02	24.86	1.50	2.00
11	46.67	17.21	1.50	2.50
12	48.58	9.56	1.00	2.50
13	56.23	7.65	1.00	2.50

GPMSUM= 56.23

THE FOLLOWING VALUES ARE FOR A SINGLE BUILDING LOOP.

TUSUM1=SUM OF COST OF TERMINAL UNITS ON LOOP., LOOPWPD=LOOP WATER PRESSURE DROP IN FT.
 GPM SUM2=LOOPFLOW RATE IN GPM, COSTLOP= COST OF PIPE IN LOOP.

TUSUM1	LOPWPD	GPM SUM2	COSTLOP
8629.37	53.28	56.23	1013.15

THE FOLLOWING TABLE LISTS TERMINAL UNIT INPUT AND OUTPUT PARAMETERS.

IROOM=ROOM NUMBER, ITUC=TERMINAL UNIT CODE, QUNIT= TERMINAL UNIT LOAD.
 TUGPM=TERMINAL UNIT GPM, TUWPD=TERMINAL UNIT WATER PRESSURE DROP IN FT.,
 ITUCOST=TERMINAL UNIT COST

IROOM	ITUC	QUNIT	CEMDA	TUGPM	TUWPD	ITUCOST
207	13	75264.00	175.00	6.91	4.79	1520.48
208	20	21393.00	25.00	2.36	2.19	331.74
209	30	1709.00	0	7.65	7.20	63.72
210	13	51770.00	175.00	2.87	1.04	1519.74
206	20	14820.00	0	2.14	1.77	296.16
201	10	24959.00	125.00	1.78	.99	1022.20
202	13	50659.00	175.00	2.73	.99	1520.20
203	20	12204.00	0	2.12	1.27	264.52
204	30	5396.00	0	7.65	8.29	148.74
205	13	63212.00	175.00	4.59	3.14	1520.20
206	20	14280.00	0	1.84	1.20	292.20

THE FOLLOWING TABLE LISTS THE SUPPLY AND RETURN PIPE FLOW RATE IN GPM

FOR EACH SECTION OF THE 2-PIPE, REVERSE RETURN PIPE LOOP.

I=PIPE SECTION NO., SGPM=FLOW RATE IN RETURN PIPE SECTION.

GPMS=FLOW RATE IN SUPPLY PIPE SECTION I, GPMSUM=TOTAL LOOP FLOW RATE.

I	SGPM	GPMS	SUPP. PIPE DIAM.	RETURN PIPE DIAM.
1	6.91	42.65	2.00	1.00
2	9.27	35.74	2.00	1.00
3	16.92	33.38	2.00	1.50
4	19.79	25.73	2.00	1.50
5	21.93	22.86	1.50	1.50
6	23.71	20.72	1.50	1.50
7	26.44	18.94	1.50	2.00
8	28.56	16.21	1.50	2.00
9	36.21	14.09	1.50	2.00
10	40.81	6.44	.75	2.00
11	42.65	1.84	.75	2.00

GPMSUM= 42.65

THE FOLLOWING VALUES ARE FOR A SINGLE BUILDING LOOP.

TUSUM1=SUM OF COST OF TERMINAL UNITS ON LOOP., LOOPWPD=LOOP WATER PRESSURE DROP IN FT.
 GPMSUM2=LOOPFLOW RATE IN GPM, COSTLOP= COST OF PIPE IN LOOP.

TUSUM1	LOPWPD	GPMSUM2	COSTLOP
8499.94	65.83	42.65	804.75

SIZE	HP	COST
1.0	.50	516.0

THE FOLLOWING OUTPUT CONSISTS OF TOTALS FOR BUILDING 2

TUTOT	BLOPTOT	BPUMCST	BCOSTOT	BWPD	GPMSUM	HP	TS	TR	QBLDG
17129.31	1924.40	516.00	19589.71	66.87	98.88	.50	125.00	111.96	644510.00

READ:BUILDING 3

THE FOLLOWING TABLE LISTS TERMINAL UNIT INPUT AND OUTPUT PARAMETERS.
 IROOM=ROOM NUMBER, ITUC=TERMINAL UNIT CODE, QUNIT= TERMINAL UNIT LOAD,
 TUGPM=TERMINAL UNIT GPM, TUWPD=TERMINAL UNIT WATER PRESSURE DROP IN FT.,
 ITUCOST=TERMINAL UNIT COST

IROOM	ITUC	QUNIT	CFMOA	TUGPM	TUWPD	ITUCOST
101	12	45500.00	200.00	3.33	2.56	1255.80
105	30	7000.00	0	7.65	7.29	180.39
106	30	7000.00	0	7.65	7.63	181.63
102	12	45800.00	200.00	3.41	2.74	1256.24
103	12	49500.00	200.00	2.50	2.74	1347.96
108	20	19500.00	0	2.07	2.44	345.40
104	12	46500.00	200.00	3.63	3.58	1259.76
107	20	12800.00	0	1.30	.68	293.52

THE FOLLOWING TABLE LISTS THE SUPPLY AND RETURN PIPE FLOW RATE IN GPM

FOR EACH SECTION OF THE 2-PIPE, REVERSE RETURN PIPE LOOP.

I=PIPE SECTION NO., SGPM=FLOW RATE IN RETURN PIPE SECTION.

GPMS=FLOW RATE IN SUPPLY PIPE SECTION I, GPMSUM=TOTAL LOOP FLOW RATE.

I	SGPM	GPMS	SUPP. PIPE DIAM.	RETURN PIPE DIAM.
1	3.33	31.54	2.00	.75
2	10.98	28.22	2.00	1.00
3	18.63	20.57	1.50	1.50
4	22.04	12.92	1.50	1.50
5	24.54	9.50	1.00	1.50
6	26.61	7.01	1.00	2.00
7	30.24	4.93	.75	2.00
8	31.54	1.30	.75	2.00

GPMSUM= 31.54

THE FOLLOWING VALUES ARE FOR A SINGLE BUILDING LOOP.

TUSUM1=SUM OF COST OF TERMINAL UNITS ON LOOP., LOOPWPD=LOOP WATER PRESSURE DROP IN FT.

GPMSUM2=LOOPFLOW RATE IN GPM, COSTLOP= COST OF PIPE IN LOOP.

TUSUM1	LOPWPD	GPMSUM2	COSTLOP
6120.69	44.17	31.54	440.74

THE FOLLOWING TABLE LISTS TERMINAL UNIT INPUT AND OUTPUT PARAMETERS.

IROOM=ROOM NUMBER, ITUC=TERMINAL UNIT CODE, QUNIT= TERMINAL UNIT LOAD.

TUGPM=TERMINAL UNIT GPM, TUWPD=TERMINAL UNIT WATER PRESSURE DROP IN FT.,

ITUCOST=TERMINAL UNIT COST

IROOM	ITUC	QUNIT	CFMOA	TUGPM	TUWPD	ITUCOST
205	12	47500.00	200.00	3.98	3.30	1254.04
209	30	7500.00	0	7.65	6.28	187.69
210	30	7500.00	0	7.65	6.62	188.93
206	12	50500.00	200.00	2.44	2.62	1344.44

208	12	51500.00	200.00	2.80	2.46	1340.92
212	20	17200.00	25.00	1.22	.81	337.92
207	12	52000.00	200.00	2.88	2.78	1343.56
211	20	16000.00	0	1.19	.71	334.84

THE FOLLOWING TABLE LISTS THE SUPPLY AND RETURN PIPE FLOW RATE IN GPM
FOR EACH SECTION OF THE 2-PIPE, REVERSE RETURN PIPE LOOP.
I=PIPE SECTION NO., SGPM=FLOW RATE IN RETURN PIPE SECTION.
GPMS=FLOW RATE IN SUPPLY PIPE SECTION I, GPMSUM=TOTAL LOOP FLOW RATE.

I	SGPM	GPMS	SUPP. PIPE DIAM.	RETURN PIPE DIAM.
1	3.98	30.00	2.00	.75
2	11.43	26.02	2.00	1.00
3	19.28	18.37	1.50	1.50
4	21.92	10.72	1.00	1.50
5	24.72	9.08	1.00	1.50
6	25.94	5.29	.75	2.00
7	28.82	4.07	.75	2.00
8	30.00	1.19	.75	2.00

GPMSUM= 30.00

THE FOLLOWING VALUES ARE FOR A SINGLE BUILDING LOOP.

TUSUM1=SUM OF COST OF TERMINAL UNITS ON LOOP., LOOPWPD=LOOP WATER PRESSURE DROP IN FT.
GPMSUM2=LOOPFLOW RATE IN GPM, COSTLOP= COST OF PIPE IN LOOP.

TUSUM1	LOOPWPD	GPMSUM2	COSTLOP
6332.34	49.94	30.00	509.93

SIZE	HP	COST
1.0	.50	516.0

THE FOLLOWING OUTPUT CONSISTS OF TOTALS FOR BUILDING 3

TUTOT	BLOPTOT	BPUMCST	BCOSTOT	BWPD	GPMSUM	HP	TS	TR	QBLDG
12453.03	1034.37	516.00	14003.40	52.04	61.54	.50	125.00	109.29	483300.00

READ:BUILDING 4

THE FOLLOWING TABLE LISTS TERMINAL UNIT INPUT AND OUTPUT PARAMETERS.

IROOM=ROOM NUMBER, ITUC=TERMINAL UNIT CODE, QUNIT= TERMINAL UNIT LOAD.
TUGPM=TERMINAL UNIT GPM, TUWPD=TERMINAL UNIT WATER PRESSURE DROP IN FT.,
ITUCOST=TERMINAL UNIT COST

IROOM	ITUC	QUNIT	CFMOA	TUGPM	TUWPD	ITUCOST
1	55	210152.00	350.00	16.60	4.50	374.25
2	55	226547.00	350.00	24.32	6.15	379.10

THE FOLLOWING TABLE LISTS THE SUPPLY AND RETURN PIPE FLOW RATE IN GPM

FOR EACH SECTION OF THE 2-PIPE, REVERSE RETURN PIPE LOOP.

I=PIPE SECTION NO., SGPM=FLOW RATE IN RETURN PIPE SECTION.

GPMS=FLOW RATE IN SUPPLY PIPE SECTION I, GPMSUM=TOTAL LOOP FLOW RATE.

I	SGPM	GPMS	SUPP. PIPE DIAM.	RETURN PIPE DIAM.
---	------	------	------------------	-------------------

1	16.60	40.93	2.00	1.50
2	40.93	24.32	1.50	2.00

GPMSUM= 40.93

THE FOLLOWING VALUES ARE FOR A SINGLE BUILDING LOOP.

TUSUM1=SUM OF COST OF TERMINAL UNITS ON LOOP., LOOPWPD=LOOP WATER PRESSURE DROP IN FT.

GPMSUM2=LOOPFLOW RATE IN GPM, COSTLOP= COST OF PIPE IN LOOP.

TUSUM1	LOOPWPD	GPMSUM2	COSTLOP
753.35	39.19	40.93	431.60

SIZE	HP	COST
1.0	.50	516.0

THE FOLLOWING OUTPUT CONSISTS OF TOTALS FOR BUILDING 4

TOTOT	BLOPOT	BFUNCST	BCOSTOT	BWPD	GPMSUM	HP	TS	TR	QBLDG
753.35	882.70	516.00	2152.05	60.07	40.93	.50	125.00	103.66	436699.00

READ:BUILDING 5

THE FOLLOWING TABLE LISTS TERMINAL UNIT INPUT AND OUTPUT PARAMETERS.

IRROOM=ROOM NUMBER, ITUC=TERMINAL UNIT CODE, QUNIT= TERMINAL UNIT LOAD.

TUGPM=TERMINAL UNIT GPM, TUMPD=TERMINAL UNIT WATER PRESSURE DROP IN FT.,

ITUCOST=TERMINAL UNIT COST

IRROOM	ITUC	QUNIT	CFMOA	TUGPM	TUMPD	ITUCOST
107	20	17060.00	0	1.37	1.09	342.32
101	41	42500.00	0	8.55	12.90	426.14
107	20	17060.00	0	1.37	1.13	343.64
13	30	1126.00	0	7.65	7.20	50.87
14	30	2588.00	0	7.65	4.83	74.42
5	20	14791.00	0	2.12	2.08	302.32
12	30	5256.00	0	7.65	7.26	141.93
18	20	18905.00	0	1.85	2.51	357.28
11	30	4091.00	0	7.65	7.24	116.24
10	30	3902.00	0	7.65	7.24	112.08
106	20	17850.00	0	1.54	1.52	347.60
106	20	17850.00	0	1.54	1.52	347.60
101	41	42500.00	0	8.55	12.90	426.14
105	20	15675.00	0	1.14	.77	340.56
6	30	1360.00	0	7.65	9.25	63.47
7	30	1668.00	0	7.65	9.25	70.26
8	30	2103.00	0	7.65	9.26	79.85
104	20	15740.00	0	1.15	1.06	355.96
104	20	15740.00	0	1.15	.83	343.64
103	20	24752.00	0	2.33	2.28	764.40
103	20	24752.00	0	2.33	2.00	760.00
102	30	6939.00	0	7.65	11.91	195.78
3	30	4159.00	0	7.65	11.86	134.48
102	20	6580.00	0	.87	.35	253.08
104	20	14791.00	0	2.12	2.20	304.52
1	20	15140.00	0	2.34	2.34	300.12
18	20	18905.00	0	1.85	1.82	341.00
101	50	400000.00	2500.00	19.84	8.62	4361.11
17	40	28561.00	0	2.22	1.34	409.32
..	..	..	0	..	..	..

17	40	28561.00	0	2.22	1.24	407.56
17	40	28561.00	0	2.22	1.24	407.56
15	30	5834.00	0	7.65	8.13	157.78
108	20	19905.00	0	1.85	1.85	341.88

THE FOLLOWING TABLE LISTS THE SUPPLY AND RETURN PIPE FLOW RATE IN GPM
 FOR EACH SECTION OF THE 2-PIPE REVERSE RETURN PIPE LOOP.
 I=PIPE SECTION NO., SGPM=FLOW RATE IN RETURN PIPE SECTION.
 GPMS=FLOW RATE IN SUPPLY PIPE SECTION I, GPMSUM=TOTAL LOOP FLOW RATE.

I	SGPM	GPMS	SUPP. PIPE DIAM.	RETURN PIPE DIAM.
1	1.37	154.69	4.00	.75
2	9.91	153.32	4.00	1.00
3	11.28	144.77	4.00	1.00
4	18.93	143.41	4.00	1.50
5	26.58	135.74	4.00	2.00
6	28.70	128.11	4.00	2.00
7	36.35	125.79	4.00	2.00
8	38.20	118.34	4.00	2.00
9	45.85	116.49	4.00	2.50
10	53.50	108.84	4.00	2.50
11	55.04	101.19	4.00	2.50
12	56.59	99.64	4.00	2.50
13	65.13	98.10	4.00	2.50
14	66.27	89.55	3.00	2.50
15	73.92	88.41	3.00	3.00
16	81.57	80.76	3.00	3.00
17	89.22	73.11	3.00	3.00
18	90.38	65.46	2.50	3.00
19	91.53	64.31	2.50	3.00
20	93.86	63.16	2.50	3.00
21	96.19	60.83	2.50	4.00
22	103.84	58.49	2.50	4.00
23	111.49	50.84	2.50	4.00
24	112.37	43.19	2.00	4.00
25	114.49	42.32	2.00	4.00
26	116.83	40.20	2.00	4.00
27	118.68	37.86	2.00	4.00
28	138.52	36.01	2.00	4.00
29	140.74	16.17	1.50	4.00
30	142.96	13.95	1.50	4.00
31	145.18	11.73	1.50	4.00
32	152.83	9.50	1.00	4.00
33	154.69	1.85	.75	4.00

GPMSUM= 154.69

THE FOLLOWING VALUES ARE FOR A SINGLE BUILDING LOOP.
 TUSUM1=SUM OF COST OF TERMINAL UNITS ON LOOP., LOOPWPD=LOOP WATER PRESSURE DROP IN FT.
 GPMSUM2=LOOPFLOW RATE IN GPM, COSTLOP= COST OF PIPE IN LOOP.

TUSUM1	LOOPWPD	GPMSUM2	COSTLOP
13780.91	49.04	154.69	2240.46

SIZE	HP	COST
1.0	.50	516.0

THE FOLLOWING OUTPUT CONSISTS OF TOTALS FOR BUILDING 5

TUTOT	BLOPTOT	BPUMCST	BCOSTOT	BWPD	GPMSUM	HP	TS	TR	GBLDG
13780.91	2459.36	516.00	16956.27	52.14	154.69	.50	125.00	113.57	884205.00

READ:BUILDING 6

THE FOLLOWING TABLE LISTS TERMINAL UNIT INPUT AND OUTPUT PARAMETERS.
 IROOM=ROOM NUMBER, ITUC=TERMINAL UNIT CODE, QUNIT= TERMINAL UNIT LOAD.
 TUGPM=TERMINAL UNIT GPM, TUWPD=TERMINAL UNIT WATER PRESSURE DROP IN FT.,
 ITUCOST=TERMINAL UNIT COST

IROOM	ITUC	QUNIT	CFMQA	TUGPM	TUWPD	ITUCOST
309	30	6000.00	0	7.65	4.20	147.18
310	20	6000.00	0	.76	.31	256.60
308	40	50000.00	0	6.59	18.34	491.92
308	40	50000.00	0	6.59	15.34	484.88
305	30	7000.00	0	7.65	5.14	62.70
307	30	2000.00	0	7.65	6.87	68.90
303	13	65000.00	400.00	3.29	3.34	1534.92
302	20	13500.00	0	1.52	1.28	304.72
303	20	20000.00	0	2.28	3.11	348.92
301	20	13500.00	0	1.52	1.01	297.48
303	13	65000.00	400.00	3.29	1.83	1524.16
304	20	15000.00	0	2.25	1.94	296.14

THE FOLLOWING TABLE LISTS THE SUPPLY AND RETURN PIPE FLOW RATE IN GPM
 FOR EACH SECTION OF THE 2-PIPE, REVERSE RETURN PIPE LOOP.
 I=PIPE SECTION NO., SGPM=FLOW RATE IN RETURN PIPE SECTION.
 GPMS=FLOW RATE IN SUPPLY PIPE SECTION I, GPMSUM=TOTAL LOOP FLOW RATE.

I	SGPM	GPMS	SUPP. PIPE DIAM.	RETURN PIPE DIAM.
1	7.65	51.05	2.50	1.00
2	8.41	43.40	2.00	1.00
3	15.01	42.63	2.00	1.50
4	21.60	36.04	2.00	1.50
5	29.25	29.45	2.00	2.00
6	36.90	21.80	1.50	2.00
7	40.19	14.15	1.50	2.00
8	41.71	10.86	1.00	2.00
9	43.99	9.34	1.00	2.50
10	45.51	7.06	1.00	2.50
11	48.80	5.54	.75	2.50
12	51.05	2.25	.75	2.50

GPMSUM= 51.05

THE FOLLOWING VALUES ARE FOR A SINGLE BUILDING LOOP.
 TUSUM1=SUM OF COST OF TERMINAL UNITS ON LOOP., LOOPWPD=LOOP WATER PRESSURE DROP IN FT.
 GPMSUM2=LOOPFLOW RATE IN GPM, COSTLOP= COST OF PIPE IN LOOP.

TUSUM1	LOPWPD	GPMSUM2	COSTLOP
0	58.64	51.05	0

SIZE	HP	COST
1.0	.50	514.0

THE FOLLOWING OUTPUT CONSISTS OF TOTALS FOR BUILDING A

TUTOT	BLOPTOT	BPUMCST	BCOSTOT	BWPD	GPMSUM	HP	TS	TR	QBLDG
0	167.40	514.00	683.40	43.34	51.05	.50	125.00	112.93	308000.00

SYSGPH	SYSCOST	SY8Q	TS	SY8RT
479.37	54259.02	3100043.00	125.00	112.07

THE DISTRICT LOOP PIPE:

SUPPLY PIPE LENGTH	RETURN PIPE LENGTH	MAIN DISTRICT LOOP SIZE	SECONDARY LOOP SIZE	LOOP PIPE COST
435 FT	435 FT	8.0 IN	8.0 IN	\$ 9761.40

DISTR. LOOP PIPE LOSS
20.81 FT

THE DISTRICT LOOP PUMP:

TOTAL HEAD	PUMP SIZE	PUMP COST
43.79 FEET	10.0 HP B&G SERIES 1531 3 IN. AB @3500 RPM	\$ 960.00

THE GEOTHERMAL WATER PIPE:

THIS SYSTEM REQUIRES NO GEOTHERMAL WATER PUMP. THE GEOTHERMAL WATER PRESSURE IS CAPABLE OF OVERCOMING THE FRICTION LOSS AND THE PRESS. DROP ACROSS THE HEAT EXCH.

GEO FLORATE	SUPP. PIPE LENGTH	RETURN PIPE LENGTH	GEO WATER PRESS. DROP	PIPE SIZE	PIPE COST
479.8GPH	1920.0 FT	1920.0 FT	90.25 FT HEAD	8.0 IN	\$43084.80

THE HEAT EXCHANGER:

TEMP. GEO RET.	TEMP. SPACE SUPP.	GEO FLOWRATE	UA	H.EXCH. PRESS. DROP	H. EXCHANGER COST
117.08 F	112.07 F	479.79 GPM	619316.55	12.58 FT	\$ 19619.75

THE TOTAL COST:

TOTAL COST= \$ 127684.97
RUN COMPLETE.

APPENDIX 9.5.1

COMPILER PACK NUMBER 721914

LABEL	CONT	2.....3.....4.....5.....6.....7.....	PAGL IN	ERROR
00000	0	PGEOMAX FORT/FN CNN NNN PB1N032		
*	P	AUTHORREITER	000010	
*	P	OPTION	000020	
*	F	05000 P110R002	000030	
*	F	06620 P01136	000040	
*	F	07136 R 0268F 0512 GENNEW001WDATA	000050	
*	F	23	000060	
*	F	3002901 2197	000070	
C			000080	
C			000090	
C		EDGEHONT SCHOOL SYSTEM	000100	
C			000110	
C		DOE GEOTHERMAL PROJECT	000120	
C			000130	
C		COMM. NO. 1-78006	000140	
C			000150	
C		1971 WEATHER DATA	000160	
C			000170	
C		BUILDING MODE-ING	000180	
C			000190	
C			000200	
C		DIMENSION HR(8), BTU(8), MPH(8), DBT(8), IN(8), IS(8), IE(8), IW(8), IB(8)	000210	
1		HR(8), AW(4), AG(4), COSI(4), AJ(6), T(6), ALPD(4), TAUD(4),	000220	
2		CV(4), PK(4), P(4), COSNS(8), COSEW(8)	000230	
C			000240	
C		COMMON/RDATA1/QCDF, NSUP, DFAC, INCR, TOUT, CFMV, HSTART, HSTOP, WATTS,	000250	
1		BTUMP, USEFAC, NP, ARR, UR, ALPR, AR, RR, CR, DRHO, A1, B1, C1, RD, HI, HS,	000260	
2		FS2, SFAC, AW, AG, UW, ALP, A, B, C	000270	
C			000280	
C		COMMON/RDATA2/CV, PK, ABF, PRIMB, PRIMS, F2, DMAX, FI1, FI2, UBF,	000290	
1		T1, T2, T3, CFHS, TEMGEO, XCEFF, GPH, BLREF, PCFM, THAX, QAVLU, QAVLO	000300	
C			000310	
C		COMMON/ANRHS/TOTSUN, TOTLVV, TOTLV, TOTHR, IDHR, NETLOS, LMINT, CFM1,	000320	
1		OLITE, OSOI G, QCONG, QSLAB, QPEQP, OSOLW, QCONW, QBASF, QVENT, OSOLH, QCONR,	000330	
2		QBASH, QINFL, QRAD, QTOTL, SOBLR, SOPREHT, SOGEO, QHAX	000340	
C			000350	
C		REAL IN, IS, IE, IW, NP, IB, NI	000360	
C			000370	
C		INTFGER FI AG1, FLAG2, DUM1, DUM2, DUM3, DUM4, DUM5, DUM6, DUM7, DUM8, DUM9,	000380	
1		SDAY1, SDAY2, DAY1, DAY2, HR, HBT, DBT, TOTHR	000390	
C			000400	
C		DEFINE FILE 07(2196, 52, U, NREC)	000410	
C		WRITE(6, 10)	000420	
10		FORMAT(1H1)	000430	
C			000440	
C		READ(5, 18)	000450	
C		WRITE(6, 18)	000460	
18		FORMAT(15H)	000470	
C			000480	
C		CALL RCARD1	000490	
C			000500	
C		CALL RCARD2	000510	
C			000520	

APPENDIX 9.5.1

LABEL	CONT	1...../.....2...../.....3...../.....4...../.....5...../.....6...../.....7.....	PAGLIN	ERROR
C	50	AJ(1)=0.1154	000530	
		AJ(2)=0.77474	000540	
		AJ(3)=3.94657	000550	
		AJ(4)=8.57881	000560	
		AJ(5)=8.38135	000570	
		AJ(6)=3.01188	000580	
C		TJ(1)=0.08885	000590	
		TJ(2)=2.71235	000600	
		TJ(3)=0.62062	000610	
		TJ(4)=7.07329	000620	
		TJ(5)=9.75995	000630	
		TJ(6)=3.89922	000640	
C		NREC=1	000650	
C		QSOI G=0.0	000660	
		QSOI W=0.0	000670	
		QSOI R=0.0	000680	
		QRAN=0.0	000690	
		QCONG=0.0	000700	
		QCONW=0.0	000710	
		QCONR=0.0	000720	
		QTOTL=0.0	000730	
		QSLAB=0.0	000740	
		QRASH=0.0	000750	
		QRASF=0.0	000760	
		QINFL=0.0	000770	
		QVENT=0.0	000780	
		QPEAP=0.0	000790	
		QLITE=0.0	000800	
		TOTSUN=0.0	000810	
		TOTLV=0.0	000820	
		TOTI VV=0.0	000830	
		TOTHR=0	000840	
		IDHR=0	000850	
		NETLOS=0	000860	
		LMTNT=150	000870	
		QC=0.0	000880	
		SQRI R=0.0	000890	
		SQPRENT=0.0	000900	
		SQGF0=0.0	000910	
		QMAX=0.0	000920	
		ITEST=50	000930	
		KBLR=1	000940	
C		WRITE(6,271	000950	
C		CGXUN=1.0/((1.0/(T1+T2))+((1.0/(500.0*GPM)))+((1.0/XCEFF)-1.0)))	001000	
		CGXOC=CGXUN*T1*CFMV/((T1+T2)*CFMS)	001010	
C		P(1)=PK(1)+0.000429	001020	
		PL=0.0	001030	
			001040	
			001050	
			001060	

LABEL	CONT	...	1....	2....	3....	4....	5....	6....	7....	PAGLIN	ERROR
										001070	
										001080	
										001090	
										001100	
										001110	
										001120	
										001130	
										001140	
										001150	
										001160	
										001170	
										001180	
										001190	
										001200	
										001210	
										001220	
										001230	
										001240	
										001250	
										001260	
										001270	
										001280	
										001290	
										001300	
										001310	
										001320	
										001330	
										001340	
										001350	
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										001370	
										001380	
										001390	
										001400	
										001410	
										001420	
										001430	
										001440	
										001450	
										001460	
										001470	
										001480	
										001490	
										001500	
										001510	
										001520	
										001530	
										001540	
										001550	
										001560	
										001570	
										001580	
										001590	
										001600	

LABEL	CONT	PAGLIN	ERROR
C	FIRST DISK RECORD ECHO CHECK	001610	
C		001620	
C		001630	
70	WRITE(6,25)SDAY,HO,DAY,FLAG,HR(JSTART),BTU(JSTART),	001640	
1	MPH(JSTART),WBT(JSTART)	001650	
25	FORMAT(1H0,11HRECD SDAY,I11,7H HO ,I11,7H DAY ,I8,3X,	001660	
1	4HFLAG,I8,7H HOUR,I8,7H HORZ,F8,1,7H WIND,I8,7H WBT ,I8)	001670	
C		001680	
	WRITE(6,26)DBT(JSTART),IN(JSTART),IS(JSTART),IE(JSTART),	001690	
1	IWI(JSTART),IB(JSTART),COSNS(JSTART),COSEW(JSTART)	001700	
26	FORMAT(1H0,11H DBT ,I11,7H NRTH,F11,1,7H S0TH,F8,1,3X,	001710	
1	4HEAST,F8,1,7H WEST,F8,1,7H BEAN,F8,1,7H SCOS,F8,4,	001720	
2	7H ECOS,F8,4)	001730	
C		001740	
	WRITE(6,10)	001750	
	WRITE(6,32)	001760	
32	FORMAT(1H ,48HMO DAY OCC HR WND TEMP -COND LOSS/SOLAR GAIN-	001770	
1	56HRASEW RADN INFIL LIGHTS HOUR LOSS KBLR REQUIRE BOILER ,	001780	
2	27HSTEMP PRE- IF THERMAL ROOM)	001790	
	WRITE(6,34)	001800	
34	FORMAT(1H ,14X,3HSUN,8X,37HGLASS WALLS ROOF BASEF SLAB ,	001810	
1	57HVENT PEOPLE RESERVE ITST SUPPLY GEO RWTEMP HEAT 4 ,	001820	
2	12HSTORAGF TEMP)	001830	
C		001840	
C		001850	
75	TG=45.2-27.0+COS(SDAY+3.14159/182.5)	001860	
C		001870	
C		001880	
C	DO 775 J=JSTART,JSTOP	001890	
C		001900	
	IF (NR(J)-1169,68,69	001910	
68	KBLR=1	001920	
69	CONTINUE	001930	
	GRFR=0.0	001940	
	QCSHP=0.0	001950	
	QFUTURE=0.0	001960	
	QHLR=0.0	001970	
	QPRFMT=0.0	001980	
	QGFN=0.0	001990	
	SWT=TI	002000	
	RWT=TI	002010	
	TOTNR=TOTNR+1	002020	
	V=WFAC*MPH(J)	002030	
	HO=4*V+V+R+V+C	002040	
	HOR=AR+V+V+BR+V+CR	002050	
	HOG=A1*V+V+B1*V+C1	002060	
	RDBT=DBT(J)+1.	002070	
	IF (HS190,90,95	002080	
C		002090	
90	UQ=HOG+HI/(HOG+HI)	002100	
C		002110	
92	GO TO 97	002120	
C		002130	
95	UQ=1.0/(1.0/HOG+1.0/HI+1.0/HS)	002140	

LABEL	CONT	1...../.....2...../.....3...../.....4...../.....5...../.....6...../.....7.....	PAGLIN	ERROR
C			002150	
97	IF(I1B(J),105,105,110		002160	
C			002170	
105	SOLG=0.0		002180	
	SOLW=0.0		002190	
	SOLR=0.0		002200	
	UG=UG/(UG*RD+1.0)		002210	
C			002220	
	GO TO 264		002230	
C			002240	
C			002250	
110	IF(I1H(J),120,120,130		002260	
C			002270	
120	COSI(2)=IE(J)/IB(J)		002280	
	COSI(4)=0.0		002290	
C			002300	
	GO TO 140		002310	
C			002320	
130	COSI(4)=IW(J)/IB(J)		002330	
	COSI(2)=0.0		002340	
C			002350	
C			002360	
140	IF(I1S(J),150,150,160		002370	
C			002380	
150	COSI(1)=IN(J)/IB(J)		002390	
	COSI(3)=0.0		002400	
C			002410	
	GO TO 170		002420	
C			002430	
160	COSI(3)=IA(J)/IB(J)		002440	
	COSI(1)=0.0		002450	
C			002460	
C			002470	
170	IF(I1B(J-1),200,200,180		002480	
C			002490	
180	IF(I1B(J+1),190,190,220		002500	
C			002510	
190	BTU(J)=BTU(J)+IB(J-1)/(IB(J)+2.1		002520	
	IB(J)=IB(J-1)/2.1		002530	
C			002540	
	GO TO 210		002550	
C			002560	
200	BTU(J)=BTU(J)+IB(J+1)/(IB(J)+2.1		002570	
	IB(J)=IB(J+1)/2.1		002580	
C			002590	
210	IN(J)=IB(J)+COSI(1)		002600	
	IE(J)=IB(J)+COSI(2)		002610	
	IS(J)=IB(J)+COSI(3)		002620	
	IW(J)=IB(J)+COSI(4)		002630	
C			002640	
C			002650	
220	IF(I1S),230,230,260		002660	
C			002670	
230	NI=UG/HOG		002680	

LABEL	CONT	1...../.....2...../.....3...../.....4...../.....5...../.....6...../.....7.....	PAGLIN	ERROR
C			002690	
C			002700	
240		DO 249 K=1,4	002710	
C			002720	
		COSA=COS(I(K))	002730	
		ALPD(K)=(AJ(1)+(AJ(2)+(AJ(3)+(AJ(4)+(AJ(5)+(AJ(6)+COSA)+COSA)	002740	
	1	*COSA)+COSA)+COSA)	002750	
		TAUD(K)=(TJ(1)+(TJ(2)+(TJ(3)+(TJ(4)+(TJ(5)+(TJ(6)+COSA)*	002760	
	1	COSA)+COSA)+COSA)+COSA)	002770	
249		CONTINUE	002780	
C			002790	
250		SOLG=((TAUD(1)+NI*ALPD(1))+AG(1)+IN(J)+(TAUD(2)+NI*ALPD(2))+AG(2)+	002800	
	1	IE(1)+(TAUD(3)+NI*ALPD(3))+AG(3)+IS(J)+(TAUD(4)+NI*ALPD(4))+AG(4)+	002810	
	2	IW(J))*SFAC	002820	
C			002830	
		GO TO 262	002840	
C			002850	
260		SOLG=FS2*(AG(1)+IN(J)+AG(2)+IE(J)+AG(3)+IS(J)+AG(4)+IW(J))*SFAC	002860	
C			002870	
262		SOLW=(UW*ALP/HO)*(AW(1)+IN(J)+AW(2)+IE(J)+AW(3)+IS(J)+AW(4)+IW(J))	002880	
	1	*SFAC	002890	
		SOLR=SFAC*UR*ARR*ALPR*BTUI(J)/HOR	002900	
C			002910	
264		HRI=HR(J)	002920	
		FLAG1=FLAG1+IADDR	002930	
C			002940	
		IF(FLAG1)268,268,266	002950	
C			002960	
266		IF(HRI=HSTART)268,267,267	002970	
C			002980	
267		IF(HSTOP=HRI)268,269,269	002990	
C			003000	
268		VENT=0.0	003010	
		HLITE=0.0	003020	
		PEOPL=0.0	003030	
		IFLAG3=0	003040	
C			003050	
		GO TO 270	003060	
C			003070	
269		VENT=0.96*CFHV*(TI-DBT(J))	003080	
		HLITE=3.41*WATTS*USEFAC	003090	
		PEOPL=NP*RTUHP	003100	
		IFLAG3=1	003110	
C			003120	
270		CONG=UG*(AG(1)+AG(2)+AG(3)+AG(4))*(TI-DBT(J))	003130	
		CONV=UW*(AW(1)+AW(2)+AW(3)+AW(4))*(TI-DBT(J))	003140	
		CONR=UR*ARR*(TI-DBT(J))	003150	
		SLARF=F2*PRHS*(TI-DBT(J))	003160	
		RAD=UR*ARR*DRHO	003170	
C			003180	
C			003190	
310		BASEW=UW*PRHS*(TI-TG)	003200	
		BASFF=UBF*ABF*(TI-TG)	003210	
C			003220	

LABEL	CONT	1...../.....2...../.....3...../.....4...../.....5...../.....6...../.....7.....	PAG	IN	ERROR
320	IF (V1322,322,330		003230		
C			003240		
322	HINFL=0.0		003250		
C			003260		
324	GO TO 380		003270		
C			003280		
330	CFHI=CFHI*(V**1.3)		003290		
	HINFL=0.9A*CFHI*(TI=0BT(J))		003300		
C			003310		
380	CONTINUE		003320		
C			003330		
430	QHOUR=SLARF*HLITE+BASEW*BASEF-PEOPL*HINFL+VENT-SOLR+		003340		
	RAD*CONR-SOLG+CONG-SOLW+CONW		003350		
C			003360		
440	IF (QHOUR)471,471,442		003370		
C			003380		
442	IF (QHOUR-QMAX)455,455,445		003390		
C			003400		
445	QMAX=QHOUR		003410		
C			003420		
455	NETLOS=NETLOS+1		003430		
	TOTLV=TOTLV+V		003440		
	TOTI VV=TOTLVV+V+V		003450		
	TOTSUN=TOTSUN+BTU(J)		003460		
C			003470		
	IF (45-0BT(J))460,460,458		003480		
C			003490		
458	IDHR=IDHR+65-0BT(J)		003500		
C			003510		
C			003520		
460	QTOTL=QTOTL+QHOUR		003530		
470	QCONG=QCONG+CONG		003540		
	QCONW=QCONW+CONW		003550		
	QCONR=QCONR+CONR		003560		
	QSLAB=QSLAB+SLABF		003570		
	QBASE=QBASE+BASEW		003580		
	QBASEF=QBASEF+BASEF		003590		
	QVENT=QVENT+VENT		003600		
	QINFL=QINFL+HINFL		003610		
	QLITE=QLITE+HLITE		003620		
	QPEOP=QPEOP+PEOPL		003630		
	QSOLG=QSOLG+SOLG		003640		
	QSOLW=QSOLW+SOLW		003650		
	QSOLR=QSOLR+SOLR		003660		
	GRAD=GRAD+RAD		003670		
C			003680		
	GO TO 475		003690		
C			003700		
471	IF (0BT(J)-LMINT)473,473,475		003710		
C			003720		
473	LMINT=0BT(J)		003730		
C			003740		
475	TIHOLD=TI		003750		
C			003760		

LABEL	CONT	1...../.....2...../.....3...../.....4...../.....5...../.....6...../.....7.....	PAGLIN	ERROR
		QC=QC-QHOUR	003770	
		GEOLIM=CGXUN*(TEMGEQ-TI)	003780	
C			003790	
485		IF(FLAG11550,550,490	003800	
C			003810	
490		ITEST=KBLR*(HSTART-1-HRI)	003820	
C			003830	
		IF(ITEST)495,495,492	003840	
492		QFUTURE=(QSUP*(HSTART-HRI))-(QHOUR*(HSTART-HRI))-(QCHAX-QC)	003850	
C			003860	
		IF(QFUTURE)493,493,550	003870	
C			003880	
493		KBLR=0	003890	
C			003900	
495		IF(HRI-EG.0.0)HRI=24.	003910	
		IF(HSTOP-HRI)550,496,496	003920	
496		IFLAG4=3	003930	
		IF(QC-QCOFF)496,767,497	003940	
497		QC=QCOFF	003950	
		GO TO 767	003960	
498		QREQ=QCOFF-QC	003970	
		IFLAG4=2	003980	
		IF(FLAG31500,500,499	003990	
499		GEOLIM=GEOLIM+CGXOC*(TI-RDRT)	004000	
500		IF(QREQ-QFOLIM)600,600,501	004010	
501		QREQ=QCHAX-QC	004020	
		IFLAG4=0	004030	
		IF(QREQ-QFOLIM)502,600,503	004040	
502		QREQ=GEOLIM	004050	
		IFLAG4=1	004060	
		GO TO 600	004070	
503		IFLAG4=-1	004080	
		IF(QREQ-QSUP)600,600,504	004090	
504		QREQ=QSUP	004100	
		IFLAG4=-2	004110	
		GO TO 600	004120	
C			004130	
550		IFLAG4=14	004140	
		IF(QC-QCOFF)551,767,767	004150	
551		QREQ=QCOFF-QC	004160	
		IFLAG4=12	004170	
		IF(QREQ-GEOLIM)600,600,552	004180	
552		QREQ=GEOLIM	004190	
		IFLAG4=10	004200	
		GO TO 600	004210	
600		IF(FLAG31620,620,640	004220	
620		SWT=QREQ/(T1+T2)+TI	004230	
		RWT=SWT-QREQ/(500.+GPM)	004240	
		QPRFHT=0.0	004250	
		GO TO 690	004260	
C			004270	
640		THA=TI-(ICFHV-PCFM)/CFMS1*(TI-RDRT)	004280	
		IF(40.-RDRT)650,650,655	004290	
650		QPRFHT=0.0	004300	

LABEL	CONT	2...../.....3...../.....4...../.....5...../.....6...../.....7.....	PAGE IN	ERROR
	TEMPH=ROBT		004310	
	GO TO 670		004320	
C			004330	
655	OPRFMT=0.48*PCFM*(40+ROBT)		004340	
	TEMPH=40.		004350	
C			004360	
670	SWT=(OREQ-OPREHT*(1+YHAT+T2+T1)+(T3+TEMPH))/(T1+T2+T3)		004370	
	RWT=SWT*(OREQ-OPREHT)/1500.*GPM		004380	
C			004390	
690	OC=OC+OREQ		004400	
	IF (TEMGEQ=4.-RWT/750./750./700		004410	
700	GST=XCEFF*(TEMGEQ-RWT)+RWT		004420	
	IF (GST-SWT/720./710./710		004430	
710	OGFN=OREQ-OPREHT		004440	
	OBLR=0.0		004450	
	GO TO 760		004460	
720	OGFN=(GST-RWT)*OPH*500.		004470	
	OBLR=OREQ-OPREHT+OGFN		004480	
	GO TO 760		004490	
750	OBLR=OREQ-OPREHT		004500	
	OGFN=0.0		004510	
760	SQR=R=SQR R+OBLR		004520	
	SOPREHT=SOPREHT+OPRFMT		004530	
	SOGFO=SOGFO+OGFN		004540	
767	T1=TIUN+IOC/OCDF		004550	
	IF (TOTHR=10UT/775./775./775		004560	
770	WRITE(6,31)H01,DAY1,FLAG1,HR(J),MPH(J),DBT(J),CONG,CONW,CONR,		004570	
	BASFW,RAD,WINFL,HLITE,QHOUR,KBLR,OREQ,OBLR,SWT,OPREHT		004580	
31	FORMAT(1H01,12,14,13,214,15,F9.0,F8.0,F8.0,F6.0,3F7.0,F10.0,13,		004590	
	F9.0,F8.0,F5.0,F7.0)		004600	
	WRITE(6,45)1B1,J1,SOLG,SOLW,SOLR,BASF,SLABF,VENT,PEOPL,QFUTURE,		004610	
	ITEST,OC SUP,OGFN,RWT,IFLAG4,OC,THOI D		004620	
45	FORMAT(11H,13X,F5.0,14X,F9.0,2F8.0,F6.0,3F7.0,F10.0,13,F9.0,		004630	
	F8.0,F5.0,7X,12,F5.0,F4.0)		004640	
	10UT=10UT+INCR		004650	
775	CONTINUE		004660	
780	SDAY1=SDAY2		004670	
	M01=M02		004680	
	DAY1=DAY2		004690	
	FLAG1=FLAG2		004700	
C			004710	
C			004720	
790	DO 791 K=1,4		004730	
	HR(K)=HR(K+4)		004740	
	BTU(K)=BTU(K+4)		004750	
	MPH(K)=MPH(K+4)		004760	
	WHT(K)=WHT(K+4)		004770	
	DBT(K)=DBT(K+4)		004780	
	IN(K)=IN(K+4)		004790	
	IS(K)=IS(K+4)		004800	
	IE(K)=IE(K+4)		004810	
	IN(K)=IN(K+4)		004820	
791	IB(K)=IB(K+4)		004830	
C			004840	

LABEL	CONT	1	2	3	4	5	6	7	PAGLIN	ERROR
793	CONTINUE								004850	
C									004860	
	GO TO 60								004870	
C									004880	
C									004890	
C									004900	
795	WRITE(6,2P)								004910	
C									004920	
	CALL WANSW								004930	
C									004940	
	STOP								004950	
	END								004960	

/RDATA1 / ALLOCATION

00000 QCDF	00004 QSUP	00008 DFAC	0000C INCR	00010 IQUT
00014 CFHV	00018 HSTART	0001C HSTOP	00020 WATTS	00024 BTUMP
00028 USEFAC	0002C NP	00030 ARR	00034 UR	00038 ALPR
0003C AR	00040 BR	00044 CR	00048 DRHO	0004C A1
00050 B1	00054 C1	00058 RD	0005C HI	00060 HS
00064 FS2	00068 SFAC	0006C AH	0007C AG	0008C UW
00090 ALP	00094 A	00098 B	0009C C	

/RDATA2 / ALLOCATION

00000 CV	00010 PK	00020 ABF	00024 PRIMB	00028 PRIMS
0002C F2	00030 DMAX	00034 F11	00038 F1P	0003C USF
00040 T1	00044 T2	00048 T3	0004C CFMS	00050 TENGE0
00054 XCEFF	00058 GPM	0005C BLREF	00060 PCFM	00064 TMAX
00068 QAVLU	0006C QAVLO			

/ANSWRS / ALLOCATION

00000 TOTLUN	00004 TOTLVV	00008 TOTLV	0000C TOTHR	00010 IDHR
00014 NETLOS	00018 LMINT	0001C CFM1	00020 QLITE	00024 QSOLB
00028 QCONG	0002C QSLAB	00030 QPEOP	00034 QSOLW	00038 QCONW
0003C QBASF	00040 QVENT	00044 QSOLR	00048 QCONR	0004C QBASH
00050 QINFL	00054 GRAD	00058 QTOTL	0005C QSBLR	00060 SOPREHT
00064 SQGEO	00068 QMAX			

CALLED SUBROUTINE

QDEFIN	QFNRT	QFINIO	QFREAD	RCARD1	RCARD2	ICHS
QRTOR	ABS	ICNVIR	ICNVIR	QINOUT	QRD18C	QUREAD
EOS	WANSW	QSTOP	EXIT			

SCALAR ALLOCATION

0013C NREC	00140 GC	00144 ITEST	00148 KBLR	0014C COXUN
00150 CBXOC	00154 PL	00158 CL	0015C K	00160 PI
00164 UBN	00168 K1	0016C DUM1	00170 DUM2	00174 ISTART
00178 DUM3	0017C ISTOP	00180 DUM4	00184 TIUN	00188 DUM5
0018C TI0C	00190 DUM6	00194 WFAC	00198 DUM7	0019C JSTART

LABEL CONT2.....3.....4.....5.....6.....7.....PAOLIN ERROR

001A0 DUMR	001A4 JSTOP	001A8 DUM9	001AC IADDR	001B0 QCMAX
001B4 QCOFF	001B8 TI	001BC SDAY1	001C0 M01	001C4 DAY1
001C8 FLAG1	001CC I	001D0 SDAY2	001D4 M02	001D8 DAY2
001DC FLAG2	001E0 IG	001F4 J	001E8 QREG	001EC QCSUP
001F0 QFUTURE	001F4 QBLR	001F8 QPRENT	001FC QGED	00200 SWT
00204 RWT	00208 V	0020C HQ	00210 HOR	00214 HQB
00218 RDBT	0021C UG	00220 SOLQ	00224 SOLH	00228 SOLR
0022C NI	00230 COSA	00234 HRI	00238 VENT	0023C HLITE
00240 PEOP	00244 IFLAG3	00248 CONG	0024C CONW	00250 CONR
00254 SLARF	00258 RAD	0026C BASEW	00260 BASEF	00264 MINFL
00268 CFMT	0026C QHOUR	00270 TIMOLD	00274 GEOLIN	00278 IFLAG4
0027C TMA	00280 TEMPH	00284 GST		

ARRAY ALLOCATION

00288 HR	00298 BTU	002A8 MPH	002B8 DBT	002C8 IN
00328 IS	00348 IE	00368 IN	00388 IS	003A8 WBT
003C8 COSI	003D8 AJ	003F0 TJ	00408 ALPD	00418 TAUD
00428 P	00438 COSNS	00458 COSEN		

LABEL	CONT	1...../.....2...../.....3...../.....4...../.....5...../.....6...../.....7.....	PAGLIN	ERROR
C	INPUT	SUBROUTINE	004970	
C		SUBROUTINE RCARD1	004980	
C		COMMON/ RDATA1/ QCDF, QSUP, DFAC, INCR, INUT, CFMV, HSTART, HSTOP, WATTS, BTUMP, USEFAC, NP, ARR, UR, ALPR, AR, RR, CR, DRHO, A1, B1, C1, RD, HI, HS, FS2, SFAC, AH(4), AG(4), UN, ALP, A, B, C	004990	
C		READ(5,40) DUM1, DUM2, QCDF, DUM3, QSUP, DUM4, DFAC, DUM5, INCR, DUM6, IOUT	005000	
1		WRITE(6,30) DUM1, DUM2, QCDF, DUM3, QSUP, DUM4, DFAC, DUM5, INCR, DUM6, IOUT	005010	
2		READ(5,20) DUM1, DUM2, CFMV, DUM3, HSTART, DUM4, HSTOP	005020	
C		WRITE(6,21) DUM1, DUM2, CFMV, DUM3, HSTART, DUM4, HSTOP	005030	
C		READ(5,20) DUM1, DUM2, WATTS, DUM3, BTUMP, DUM4, USEFAC, DUM5, NP	005040	
C		WRITE(6,21) DUM1, DUM2, WATTS, DUM3, BTUMP, DUM4, USEFAC, DUM5, NP	005050	
C		READ(5,20) DUM1, DUM2, ARR, DUM3, UR, DUM4, ALPR, DUM5, AR, DUM6, BR, DUM7, CR, DUM8, DRHO	005060	
1		WRITE(6,21) DUM1, DUM2, ARR, DUM3, UR, DUM4, ALPR, DUM5, AR, DUM6, BR, DUM7, CR, DUM8, DRHO	005070	
C		READ(5,20) DUM1, DUM2, A1, DUM3, B1, DUM4, C1, DUM5, RD, DUM6, HI, DUM7, HS, DUM8, FS2, DUM9, SFAC	005080	
1		WRITE(6,21) DUM1, DUM2, A1, DUM3, B1, DUM4, C1, DUM5, RD, DUM6, HI, DUM7, HS, DUM8, FS2, DUM9, SFAC	005090	
C		READ(5,20) DUM1, DUM2, AH(1), DUM3, AG(1), DUM4, UN, DUM5, ALP, DUM6, A, DUM7, B, DUM8, C	005100	
1		WRITE(6,21) DUM1, DUM2, AH(1), DUM3, AG(1), DUM4, UN, DUM5, ALP, DUM6, A, DUM7, B, DUM8, C	005110	
C		READ(5,20) DUM1, DUM2, AH(2), DUM3, AG(2), DUM4, UN, DUM5, ALP, DUM6, A, DUM7, B, DUM8, C	005120	
1		WRITE(6,21) DUM1, DUM2, AH(2), DUM3, AG(2), DUM4, UN, DUM5, ALP, DUM6, A, DUM7, B, DUM8, C	005130	
C		READ(5,20) DUM1, DUM2, AH(3), DUM3, AG(3), DUM4, UN, DUM5, ALP, DUM6, A, DUM7, B, DUM8, C	005140	
1		WRITE(6,21) DUM1, DUM2, AH(3), DUM3, AG(3), DUM4, UN, DUM5, ALP, DUM6, A, DUM7, B, DUM8, C	005150	
C		READ(5,20) DUM1, DUM2, AH(4), DUM3, AG(4), DUM4, UN, DUM5, ALP, DUM6, A, DUM7, B, DUM8, C	005160	
1		WRITE(6,21) DUM1, DUM2, AH(4), DUM3, AG(4), DUM4, UN, DUM5, ALP, DUM6, A, DUM7, B, DUM8, C	005170	
C		FORMAT(A4,2(A4,F7.0),6(A4,F5.0))	005180	
20		FORMAT(1H0,A4,2(3X,A4,F11.5),2(3X,A4,F8.2),4(3X,A4,F8.4))	005190	
21		FORMAT(1H0,A4,2(3X,A4,F11.0),3X,A4,F8.0,2(3X,A4,I9))	005200	
30		FORMAT(A4,2(A4,F7.0),A4,F5.0,2(A4,I6))	005210	
40		RETURN	005220	
C		END	005230	

/RDATA1 / ALLOCATION

LABEL CONT ***1****/****2****/****3****/****4****/****5****/****6****/****7****PAGLIN ERROR

00000 QCDF	00004 QSUP	00008 DFAC	0000C INCR	00010 IOUT
00014 CFMV	00018 HSTART	0001C HSTOP	00020 WATTS	00024 RIUMP
00028 USEFAC	0002C NP	00030 ARR	00034 UR	00038 ALPR
0003C AR	00040 BR	00044 CR	00048 DRWD	0004C A1
00050 B1	00054 C1	00058 RQ	0005C HI	00060 HS
00064 FS2	00068 SFAC	0006C AM	0007C AG	0008C UW
00090 ALP	00094 A	00098 B	0009C C	

CALLED SUBROUTINE

OFREAD QINOUT OFINIO OFWRIT

SCALAR ALLOCATION

0000C RCARD1	00010 DUM1	00014 DUM2	00018 DUM3	0001C DUM4
00020 DUM5	00024 DUM6	00028 DUM7	0002C DUM8	00030 DUM9

ARRAY ALLOCATION

LABEL	CONT	2...../.....3...../.....4...../.....5...../.....6...../.....7.....	PAGLIN	ERROR
C			005480	
C			005490	
		SUBROUTINE RCARD2	005500	
C			005510	
		COMMON/RDATA2/CV(4),PK(4),ABF,PRIM8,PRIMS,F2,DMAX,FI1,FI2,UBF,	005520	
	1	T1,T2,T3,CFMS,TEMGE0,XCEFF,GPH,BLREF,PCFH,THAX,QAVLU,QAVLO	005530	
C			005540	
		READ(5,20)DUM1,DUM2,CV(1),DUM3,CV(2),DUM4,CV(3),DUM5,CV(4),DUM6,	005550	
	1	PK(1),DUM7,PK(2),DUM8,PK(3),DUM9,PK(4)	005560	
		WRITE(6,21)DUM1,DUM2,CV(1),DUM3,CV(2),DUM4,CV(3),DUM5,CV(4),DUM6,	005570	
	1	PK(1),DUM7,PK(2),DUM8,PK(3),DUM9,PK(4)	005580	
C			005590	
		READ(5,20)DUM1,DUM2,ABF,DUM3,PRIM8,DUM4,PRIMS,DUM5,F2,DUM6,DMAX,	005600	
	1	DUM7,FI1,DUM8,FI2,DUM9,UBF	005610	
		WRITE(6,21)DUM1,DUM2,ABF,DUM3,PRIM8,DUM4,PRIMS,DUM5,F2,DUM6,DMAX,	005620	
	1	DUM7,FI1,DUM8,FI2,DUM9,UBF	005630	
C			005640	
		READ(5,20)DUM1,DUM2,CFMS,DUM3,T1,DUM4,T2,DUM5,T3,DUM6,TEMGE0,	005650	
	1	DUM7,XCEFF,DUM8,GPH,DUM9,BLREF	005660	
		WRITE(6,21)DUM1,DUM2,CFMS,DUM3,T1,DUM4,T2,DUM5,T3,DUM6,TEMGE0,	005670	
	1	DUM7,XCEFF,DUM8,GPH,DUM9,BLREF	005680	
C			005690	
		READ(5,41)DUM1,DUM2,QAVLU,DUM3,QAVLO,DUM4,PCFH,DUM5,THAX	005700	
		WRITE(6,31)DUM1,DUM2,QAVLU,DUM3,QAVLO,DUM4,PCFH,DUM5,THAX	005710	
C			005720	
	20	FORMAT(A4,2(A4,F7.0),6(A4,F5.0))	005730	
	21	FORMAT(1H0,A4,2(3X,A4,F11.5),2(3X,A4,F8.2),4(3X,A4,F8.4))	005740	
	31	FORMAT(1H0,A4,2(3X,A4,F11.0),2(3X,A4,F8.0))	005750	
	41	FORMAT(A4,4(A4,F8.0))	005760	
C			005770	
		RETURN	005780	
		END	005790	

/RDATA2 / ALLOCATION

00000 CV	00010 PK	00020 ABF	00024 PRIM8	00028 PRIM5
0002C F2	00030 DMAX	00034 FI1	00038 FI2	0003C UBF
00040 T1	00044 T2	00048 T3	0004C CFMS	00050 TEMGE0
00054 XCEFF	00058 GPH	0005C BLREF	00060 PCFH	00064 THAX
00068 QAVLU	0006C QAVLO			

CALLED SUBROUTINE

QFREAD QINOUT QFINIO QFWRT

SCALAR ALLOCATION

0000C RCARD2	00010 DUM1	00014 DUM2	00018 DUM3	0001C DUM4
00020 DUM5	00024 DUM6	00028 DUM7	0002C DUM8	00030 DUM9

ARRAY ALLOCATION

LABEL CONT1..../....2..../....3..../....4..../....5..../....6..../....7....PAGE IN ERROR

LABEL	CONT	1...../.....2...../.....3...../.....4...../.....5...../.....6...../.....7.....	PAGLIN	ERROR	
C	OUTPUT SUBROUTINE		005800		
C			005810		
	SUBROUTINE WANSW		005820		
C			005830		
	COMMON/ANSWRS,TOTSUN,TOTLVV,TOTLV,TOTHR,IDHR,NETLOS,LMINT,CFM1,		005840		
1	QLITE,QSOLG,QCONG,QLAB,QPEOP,QSOLW,QCONW,QBASQ,QVENT,QSOLR,QCONR,		005850		
2	QBASH,QINFL,QRAD,QTOTL,QBLR,QPREHT,QGEO,QMAX		005860		
C			005870		
	WRITE(6,10)		005880		
10	FORMAT(1H1)		005890		
C			005900		
	WRITE(6,598)TOTSUN,TOTLVV,TOTLV,TOTHR,IDHR,NETLOS,LMINT,CFM1		005910		
598	FORMAT(1H0,13H	TOTSUN,F9.0,8H	TOTVV,F10.0,8H	TOTLV,F7.0,	
1	8H	TOTHR,F7.8H	DEGHR,F7.9H	LORSHR,F6.10H	MINTMP,F5,
2	7H	CFM1,F8.4)			
C			005940		
	WRITE(6,22)		005950		
22	FORMAT(1H0)		005960		
C			005970		
	WRITE(6,599)QBLR,QPREHT,QGEO,QMAX		005980		
599	FORMAT(1H0,12HHEAT	QBLR,15X,E13.6,8H	QPREHT,9X,E13.6,		
1	8H	QGEO,9X,E13.6,8H	QMAX,9X,E13.6)		
C			006000		
	WRITE(6,22)		006010		
C			006020		
	WRITE(6,600)QLITE,QSOLG,QCONG,QLAB		006030		
600	FORMAT(1H0,12HLOSS	QLITE,15X,E13.6,8H	QSOLG,9X,E13.6,		
1	8H	QCONG,9X,E13.6,8H	QLAB,9X,E13.6)		
C			006040		
	WRITE(6,602)QPEOP,QSOLW,QCONW,QBASQ		006050		
602	FORMAT(1H0,12H	QPEOP,15X,E13.6,8H	QSOLW,9X,E13.6,		
1	8H	QCONW,9X,E13.6,8H	QBASH,9X,E13.6)		
C			006060		
	WRITE(6,604)QVENT,QSOLR,QCONR,QBASW		006070		
604	FORMAT(1H0,12H	QVENT,15X,E13.6,8H	QSOLR,9X,E13.6,		
1	8H	QCONR,9X,E13.6,8H	QBASH,9X,E13.6)		
C			006080		
	WRITE(6,606)QINFL,QRAD,QTOTL		006090		
606	FORMAT(1H0,12H	QINFL,15X,E13.6,8H	QRAD,9X,E13.6,		
1	33X,5HQTOTL,9X,E13.6)				
C			006100		
	RETURN		006110		
	END		006120		
			006130		
			006140		
			006150		
			006160		
			006170		
			006180		
			006190		
			006200		
			006210		
			006220		

/ANSWRS / ALLOCATION

00000 TOTSUN	00004 TOTLVV	00008 TOTLV	0000C TOTHR	00010 IDHR
00014 NETLOS	00018 LMINT	0001C CFM1	00020 QLITE	00024 QSOLG
00028 QCONG	0002C QSLAB	00030 QPEOP	00034 QSOLW	00038 QCONW
0003C QBASH	00040 QVENT	00044 QSOLR	00048 QCONR	0005C QBASH
00050 QINFL	00054 QRAD	00058 QTOTL	0005C QBLR	00060 QPREHT
00064 QGEO	00068 QMAX			

FULL FORTRAN IV RPOB

PROGRAM GEORAX 00/000

DATE 17/11/78

PAGE 017

LABEL CONT1..../....2..../....3..../....4..../....5..../....6..../....7....PAGLIN ERROR

CALLED SUBROUTINE

QFWRT QFINIO QINDUT

SCALAR ALLOCATION

00008 WANSW

ALLOCATION	START ADDR	END ADDR	DEC LENGTH	START ADDR	END ADDR	DEC LENGTH	START ADDR	END ADDR	DEC LENGTH
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*** OBJECT PROGRAM ON PACK 001212

TOTAL MEMORY			32624						
RESIDENT EXEC			3584						
PROGRAM	00 0E00	00 7BF4	28144						
TOTAL COMMON	00 7C84	00 7E00	380						
EXEC OVERLAY AREA			512						

MAIN PROGRAM (RES)	00 0E00	00 5DF0	20448						
BUFFERS	00 0E00	00 1000	512						
FILE-BUFFER TABLES	00 1000	00 1104	464						
CLASS 1 SUBRTNES	00 1104	00 35AC	9176						
OVERLAY DIRECTORY	00 35AC	00 35CC	32						
CODING AND DATA	00 35CC	00 5DF0	10260						
CLASS 2 SUBRTNES	00 7BF4	00 7BF4	0						

COMMON ALLOCATION									
/RDATA1	/	00 7C84	00 7D24	160					
/RDATA2	/	00 7D24	00 7D94	112					
/ANSWRS	/	00 7D94	00 7E00	108					
/COMMON	/	00 7E00	00 7E00	0					

UNITABLA	00 1104	ICMS	01	00 12C8	IIAND0	02	00 12DC
IGQDR	29 00 1CF0	APREJCT	02	00 1DF4	CDDECTBA00		00 1E04
CDVY1	16 00 1F0C	GET	05	00 1F48	NEATPOC	09	00 1FA0
PCREAD	16 00 20EC	PRINTPUT12		00 2100	PRVY1	05	00 2238
PZWRITE	07 00 2254	ORTOR	26	00 2298	SINE	17	00 2508
VELO8	24 00 26DC	VEXPO	25	00 2848	VFY6565700		00 29D4
XABSOL	13 00 2A64	ZFLARITH41		00 2AC8	ZFLOAT	21	00 3228
ZFXASCBN19	00 32C0	ZFXBNASC06		00 337C	ZIFIX	21	00 3434
ZZAERROR21	00 3534						

*** GEOMAX	00 35CC	00 5DR0	10212
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TEXT	00 3A44	00 5DR0	
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GROUP 01	00 5DE0	00 7D04	5364
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OVERLAY 01-001	00 5DE0	00 5F34	340
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ZZSTOP	09 00 5DF0		
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OVERLAY 01-002	00 5DE0	00 72D4	5364
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IINOUT	05 00 5DEC		
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GROUP 02	00 72D4	00 7590	700
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OVERLAY 02-003	00 72D4	00 7338	100
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ZDECODE	18 00 72D8		
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OVERLAY 02-004	00 72D4	00 7410	316
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FULL FORTRAN IV RPO8 PROGRAM GEOMAX 007001 MEMORY MAP DATE 17/11/78 PAGE 003

ALLOCATION	START ADDR	END ADDR	DEC LENGTH	START ADDR	END ADDR	DEC LENGTH	START ADDR	END ADDR	DEC LENGTH
TSREAD 1#	00 7208								
OVERLAY 02-005	00 7204	00 7590	700						
ZFLASCBN25	00 7208								
OVERLAY 02-006	00 7204	00 7550	636						
ZFLBNASC24	00 7208								
GROUP 03	00 7590	00 78F4	1636						
OVERLAY 03-007	00 7590	00 78F4	1636						
*** RCARD1	00 7594	00 78FC	1624						
TEXT	00 75C8	00 78FC							
OVERLAY 03-008	00 7590	00 7940	944						
*** RCARD2	00 7594	00 7938	932						
TEXT	00 75C8	00 7938							
OVERLAY 03-009	00 7590	00 7954	964						
*** HANSH	00 7594	00 794C	952						
TEXT	00 75A0	00 794C							

—HIGH-SCHOOL: FEB (REDUCED GEO)—

DYNN	OCDF	200000	OSUP	800000	DFAC	25	INCR	1	IOUT	1						
VENT	CFMV	625.00000	HSTR	9.00000	HSTP	15.00										
LTPE	WATS	9800.00000	BTUP	230.00000	USFC	1.00	NP	99.00								
ROOF	RDFA	6300.00000	UROF	0.03000	ALPR	0.90	A	0.00	B	0.4640	C	2.0400	DRHO	7.0000		
GLAS	A	-0.00125	B	0.26200	C	1.45	RD	0.00	HI	1.3600	HS	0.0000	FSTO	1.0000	SUN	0.9000
NRTH	WALA	1244.00000	GLAS	385.00000	UHAL	0.04	ALPH	0.70	A	0.0010	B	0.3200	C	2.2000		
EAST	WALA	1313.00000	GLAS	745.00000	UHAL	0.04	ALPH	0.70	A	0.0010	B	0.3200	C	2.2000		
SOTH	WALA	0.00000	GLAS	0.00000	UHAL	0.04	ALPH	0.70	A	0.0010	B	0.3200	C	2.2000		
WEST	WALA	1362.00000	GLAS	696.00000	UHAL	0.04	ALPH	0.70	A	0.0010	B	0.3200	C	2.2000		
INFL	CYN	936.00000	CVE	2247.00000	CVS	0.00	CVH	1895.00	PKN	0.5800	PKE	-0.3500	PKS	-0.3500	PKW	-0.3800
BASE	ABF	6507.00000	PRIS	251.00000	PRIS	0.00	FSLB	0.00	DMAX	3.0000	FONE	0.4100	FTNO	0.9140	UBF	0.0250
HEAT	CFMS	13500.00000	T1	3441.00000	T2	789.00	T3	0.00	TREQ	125.0000	XEFF	0.1500	GPH	40.0000	BEFF	0.6500
HEAT	AVLU	215000	AVLO	215000	PCFM	0	THAX	78								

FEB	STRT	187	STOP	355	TIUN	68.0	TIOC	68.0	WIND	1.00	JSRT	2	JSTP	5	IADD	0
RECD	SDAY	32	MO	2	DAY	1	FLAG	1	HOUR	1	HORZ	0.0	WIND	12	WBT	9
DBT	11	NRTH	0.0	SOTH	0.0	EAST	0.0	WEST	0.0	BEAM	0.0	SCUS	0.0000	ECOS	0.0000	

MO	DAY	OCC	MR	RND	TEMP	COND LOSS/SOLAR GAIN	BASLM	RADN	INFIL	LIGHTS	HOUR	LOSS	KBLR	REQUIRE	BOILER	SWTLP	PRE	IF THERMAL ROOM
SUN						GLASS	WALLS	ROOF	BASEF	SLAB	VENT	PEOPLE	RESERVE	1781	SUPPLY	GEO	HWTEMP	HEAT & STORAGE TEMP
2	1	1	1	12	11	108211.	8935.	10773.	8111.	1323.	7565.	0.	151677.	1	109670.	0.	94.	0.
						0.	0.	0.	0.	0.	0.	0.	5034910.	7	0.	109670.	88.	10 -42006. 68.
2	1	1	2	8	11	101287.	8902.	10733.	8070.	1323.	4450.	0.	141489.	1	110074.	0.	94.	0.
						0.	0.	0.	0.	0.	0.	0.	4426081.	4	0.	110074.	88.	10 -73421. 68.
2	1	1	3	10	11	104585.	8878.	10704.	8039.	1323.	5931.	0.	146158.	1	110377.	0.	94.	0.
						0.	0.	0.	0.	0.	0.	0.	3703474.	5	0.	110377.	88.	10 -109202. 68.
2	1	1	4	12	10	109078.	9006.	10859.	8004.	1323.	7626.	0.	152560.	1	110721.	0.	94.	0.
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2	1	1	5	14	10	111141.	8974.	10819.	7963.	1323.	9284.	0.	156140.	1	111123.	0.	94.	0.
						0.	0.	0.	0.	0.	0.	0.	2268258.	2	0.	111123.	88.	10 -136058. 67.
2	1	1	6	12	9	110146.	9095.	10966.	7920.	1323.	7701.	0.	153750.	1	111556.	0.	93.	0.
						0.	0.	0.	0.	0.	0.	0.	1588943.	2	0.	111556.	88.	10 -238251. 67.
2	1	1	7	10	8	108603.	9219.	11115.	7878.	1323.	6158.	0.	150861.	1	111962.	0.	93.	0.
						0.	0.	0.	0.	0.	0.	0.	909165.	1	0.	111962.	88.	10 -277150. 67.
2	1	1	8	8	7	106324.	9345.	11267.	7840.	1323.	4671.	0.	74750.	1	351901.	351901.	150.	0.
						1462.	71207.	827.	519.	0.	0.	0.	0.	0.	0.	0.	132.	-1 0. 67.
2	1	1	9	9	8	109007.	9406.	11340.	8111.	1323.	5479.	33418.	14534.	1	114018.	0.	93.	0.
						2924.	113458.	1263.	1981.	0.	36000.	22770.	0.	-1	0.	114018.	87.	1 99484. 68.
2	1	1	10	10	9	109875.	9328.	11245.	8208.	1323.	6230.	33418.	62010.	1	113024.	0.	93.	0.
						264.	67465.	757.	2326.	0.	35698.	22770.	0.	-2	0.	113024.	87.	1 150499. 68.
2	1	1	11	11	11	108217.	9053.	10915.	8258.	1323.	6845.	33418.	102435.	1	112407.	0.	93.	0.
						2634.	24559.	368.	2954.	0.	34651.	22770.	0.	-3	0.	112407.	88.	1 180471. 69.
2	1	1	12	13	11	111033.	9061.	10925.	8288.	1323.	8513.	33418.	132125.	1	112313.	0.	93.	0.
						263.	0.	0.	2379.	0.	34651.	22770.	0.	-4	0.	112313.	88.	1 190660. 69.
2	1	1	13	16	12	112154.	8889.	10717.	8248.	1323.	10939.	33418.	109319.	1	112426.	0.	93.	0.
						290.	25209.	324.	2125.	0.	34022.	22770.	0.	-5	0.	112426.	88.	1 193767. 69.
2	1	1	14	18	12	113982.	8891.	10720.	8251.	1323.	12753.	33418.	49493.	1	112397.	0.	93.	0.
						290.	88901.	073.	1842.	0.	34031.	22770.	0.	-6	0.	112397.	88.	1 186671. 69.
2	1	1	15	13	13	111534.	8768.	10971.	8293.	1323.	11676.	33418.	28873.	1	111927.	0.	93.	0.
						292.	105483.	893.	1240.	0.	33560.	22770.	0.	-7	0.	111927.	88.	1 269726. 69.
2	1	1	16	14	14	107460.	8678.	10461.	8374.	1323.	8976.	0.	85022.	1	107075.	0.	95.	0.
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2	1	1	18	13	17	100372.	8191.	9878.	8355.	1323.	7694.	0.	142775.	1	107261.	0.	95.	0.
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						0.	0.	0.	0.	0.	0.	0.	0.	-11	0.	107602.	89.	10 126955. 69.
2	1	1	20	12	21	91081.	7814.	9060.	8293.	1323.	6382.	0.	130444.	1	107872.	0.	94.	0.
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2	1	1	21	10	19	92007.	7810.	9416.	8271.	1323.	5217.	0.	130937.	1	108089.	0.	94.	0.
						0.	0.	0.	0.	0.	0.	0.	0.	-13	0.	108089.	89.	10 141515. 69.

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