ENERGY

CONSERVATION

ORNL/Sub/81-7685/1 & 92

TECH House I Horizontal Coil Ground Coupled Heat Pump: 1982–83 Heating Season Performance

S. Johnson

B. A. McGraw

A. F. G. Bedinger

F. Conlin

S. Wix

THE UNIVERSITY OF TENNESSEE
ENERGY, ENVIRONMENT, AND RESOURCES CENTER
327 South Stadium Hall
Knoxville, Tennessee 37996

Work performed for

OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the

U.S. DEPARTMENT OF ENERGY

OFFICE OF BUILDINGS ENERGY
RESEARCH AND DEVELOPMENT

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A05; Microfiche A01

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ORNL/Sub/81-7685/1 & 92
Dist. Category UC-95d

TECH House I Horizontal Coil Ground Coupled Heat Pump: 1982-83 Heating Season Performance

S. Johnson
B. A. McGraw
A. F. G. Bedinger
F. Conlin
S. Wix

September 1983

Date Published: February 1984

Report Prepared by

The University of Tennessee
Energy, Environment, and Resources Center
327 South Stadium Hall
Knoxville, Tennessee 37996

under

Subcontract 7685 PA X92

for

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. W-7405-eng-26

ABSTRACT

A ground-coupled heat pump (GCHP) system having a 200 m (675 ft) horizontal serpentine ground coil was installed at the Tennessee Energy Conservation in Housing (TECH) facility. Experimental results for the 1982-1983 heating season showed a heating seasonal performance factor (SPF) of 2.60. Had the system been located outside the conditioned space the SPF would have been 2.04. No auxiliary electric heat was required.

Soil temperature measurements indicate that the ground near the pipe never went below 0°C.

A discussion of soil moisture measurement techniques and devices is included. Moisture sensors have been installed near the coil and will be used to determine drying trends during the 1983 cooling season.

TABLE OF CONTENTS

CHAPTER		PAGE
1	INTRODUCTION	2
2	PROJECT HISTORY	4
3	SYSTEM DESCRIPTION	7
4	INSTRUMENTATION	12
5	THERMAL PERFORMANCE DATA	20
	5.1 Soil Temperature Measurements	20
	5.2 Brine Temperature Measurements	29
	5.3 Heat Pump Performance Data	34
	5.4 Heat Pump Performance Factors	35
6	SOIL MOISTURE MEASUREMENTS	38
	6.1 Introduction	38
	6.2 Measurements	40
	6.2.1 In Situ Soil Thermal Conductivity Measurements	40
	6.2.2 Moisture Meters	42
	6.2.3 Calibration Procedure	44
7	CONCLUSIONS AND RECOMMENDATIONS	49
	REFERENCES	50
	APPENDIX A Project History 9/15/81-10/31/82	52
	APPENDIX B Design Parameter Discrepancies	62
	APPENDIX C Downtimes	63
	APPENDIX D Drilling Data	64

CHAPTER 1. INTRODUCTION

The University of Tennessee Energy, Environment, and Resources Center has been contracted by the Oak Ridge National Laboratories (ORNL) for the procurement, installation, maintenance, operation and instrumentation of a horizontal ground coil heat (GCHP) pump system. Tech House I at the Tennessee Energy Conservation in Housing (TECH) Facility incorporates the horizontal ground coil heat pump system.

ORNL contracted with Battelle, Inc. to design the GCHP system for Tech House I. That design (based on the cooling load) called for a ground coil pipe length of 700 feet utilizing 1-1/4" IPS polybutylene pipe. The brine in the ground coil is a solution of water, 20% (by weight) of methanol, and corrosion inhibitors. In addition to the design of the GCHP system, Battelle was to recommend an instrumentation scheme for that system. The existing heat pump was to be utilized with the exception that the existing water to refrigerant heat exchanger should be replaced with a Standard Refrigeration, Inc. model KY-500 shell and tube. The heat pump initially used in the system was a General Electric unit, 30,000 Btuh total cooling and 30,000 Btuh (high temp.) heating at ARI standard conditions.

As instructed by ORNL, the existing heat pump system was removed during October, 1982. A TETCO water-to-water heat pump was then installed. Even though this unit is a heating only heat pump, space cooling is provided via water valves that redirect the flow of brine between the ground coil, heat pump, and water-to-air coil.

The GCHP was utilized during the winter of 1982-83 to provide space heating for TECH House I. During mid-winter (February 14, 1983) the existing water-to-air coil was replaced with a larger, more efficient coil. Data were recorded hourly with few interruptions throughout the heating season. Those data are presented and discussed in this report.

CHAPTER 2. PROJECT HISTORY

A discussion of the project history from the project's inception through October 31, 1982 is presented in detail in Appendix A.

During October, 1982 it had been determined that the existing water-to-air coil should be replaced with one that would more closely match the heat release capability of the heat pump. Due to the time necessary to procure that coil, it was not installed until halfway through the 1982-83 heating season.

During the first 2-3 weeks of the heating season, the system would rapidly (2-4 minutes) build up high head pressure resulting in shut down of the compressor by the overload protection device. It was determined that under the existing water and air flow conditions, the water-to-air coil was not capable of transferring the heat to the space load at the rate being produced by the heat pump. Hence, it was decided to replace the water-to-air coil with one that would more closely match the heat release capability of the heat pump. When the ground and ambient air temperature had decreased due to the colder weather, the system was capable of operation (although with high refrigerant pressures) with the former water-to-air coil.

On November 24, 1982, the ground temperature probes and soil moisture sensing blocks were dug up and realigned. The original locations of the temperature sensors extended no further than 6-1/2 inches from the pipe wall. From observations of summer 1982 data it was concluded that the high density of temperature sensors near the

pipe did not provide sufficient data to adequately describe the thermal response of the soil. Upon excavation it was noted that the disturbed soil was saturated with water. The undisturbed soil, however, was moist but not saturated.

On December 27, 1982 Geologic Associates, Inc. was contracted to drill a hole to a depth of ten feet at a location "far field" from the horizontal ground coil. The exact location of that hole is shown on Figure 4.2. Soil samples were taken at three different depths while drilling. A copy of the drilling report can be found in the appendix. Thermocouples were then placed at one foot intervals in the hole and then the hole was backfilled. These temperatures will be recorded manually once every 1-2 weeks to provide far field temperature data required for the computer simulation of the ground coil system.

On January 1, 1983, Dr. Stan Johnson, Professor of Mechanical Engineering, began working on the project. He is working with the graduate students and providing technical assistance for the project.

The new water to air coil for Tech House I was installed on February 14, 1983. A subsequent check of hourly C.O.P.s indicated a marked improvement in the thermal performance with the new coil under comparable conditions. Hourly C.O.P.s of about 2.7 were measured with the new coil compared with 2.3 measured with the former coil. Also, the temperature of the brine entering the new coil was about 10°C cooler than with the former coil (resulting in lower refrigerant pressures).

Due to the concern about the durability and repeatability of the initially installed gypsum soil moisture measurement devices, a

literature survey was conducted on replacement devices. In March, 1983 it was decided to purchase ceramic soil moisture measurement devices. They will be installed prior to the 1983 cooling season.

The heating system in Tech House I was shut down on April 25, 1983. The cooling system will be activated during the latter half of May, 1983.

Calibration tests on the gypsum soil moisture blocks as well as the newly acquired ceramic soil moisture measurement devices have been conducted. Curves relating the devices' resistivity to soil moisture content have been developed. Those curves are presented in Chapter 6, "Soil Moisture Measurements."

CHAPTER 3. SYSTEM DESCRIPTION

Figure 3.1 is a schematic of the ground coupled heat pump system in use from September, 1982 to the present time. The heat pump is a TETCO hydronic, heating only heat pump. Space cooling is accomplished by re-directing the water-methanol brine with three way valves as shown in Figure 3.1. The position of the three way valves (controlled manually) determines the mode of operation (heating or cooling). When the thermostat engages, the compressor, indoor fan, and brine circulation pumps are powered.

Both circulation pumps are Gorman-Rupp series 14520 (240 volt) pumps. The measured flow rates in each loop for each mode of operation are listed in Table 1.

Table 1. Measured Flow Rates (gpm)

	Heating	Cooling
Ground Coil	9.6	9.3
Old Fan Coil	7.4	6.7
New Fan Coil	8.9	9.6

A plan view of the ground coil layout is depicted in Figure 3.2. The pipe is polybutylene nominal 1-1/4" IPS with an inside diameter of 1.380 inches and a wall thickness of 0.120 inches. The pipe length,

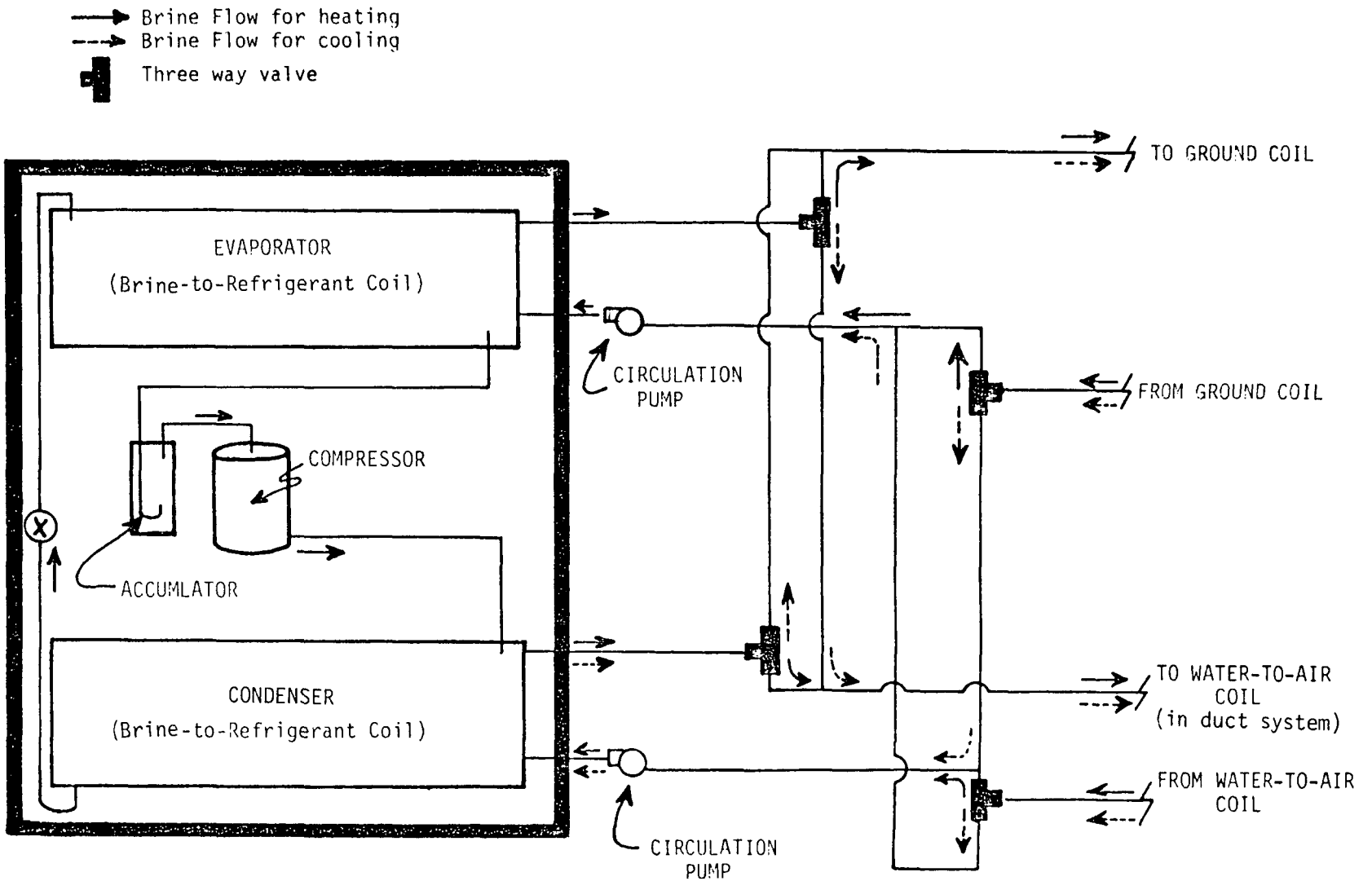

Figure 3.1 Schematic of Ground Coupled Heat Pump (September 1982 - Present)

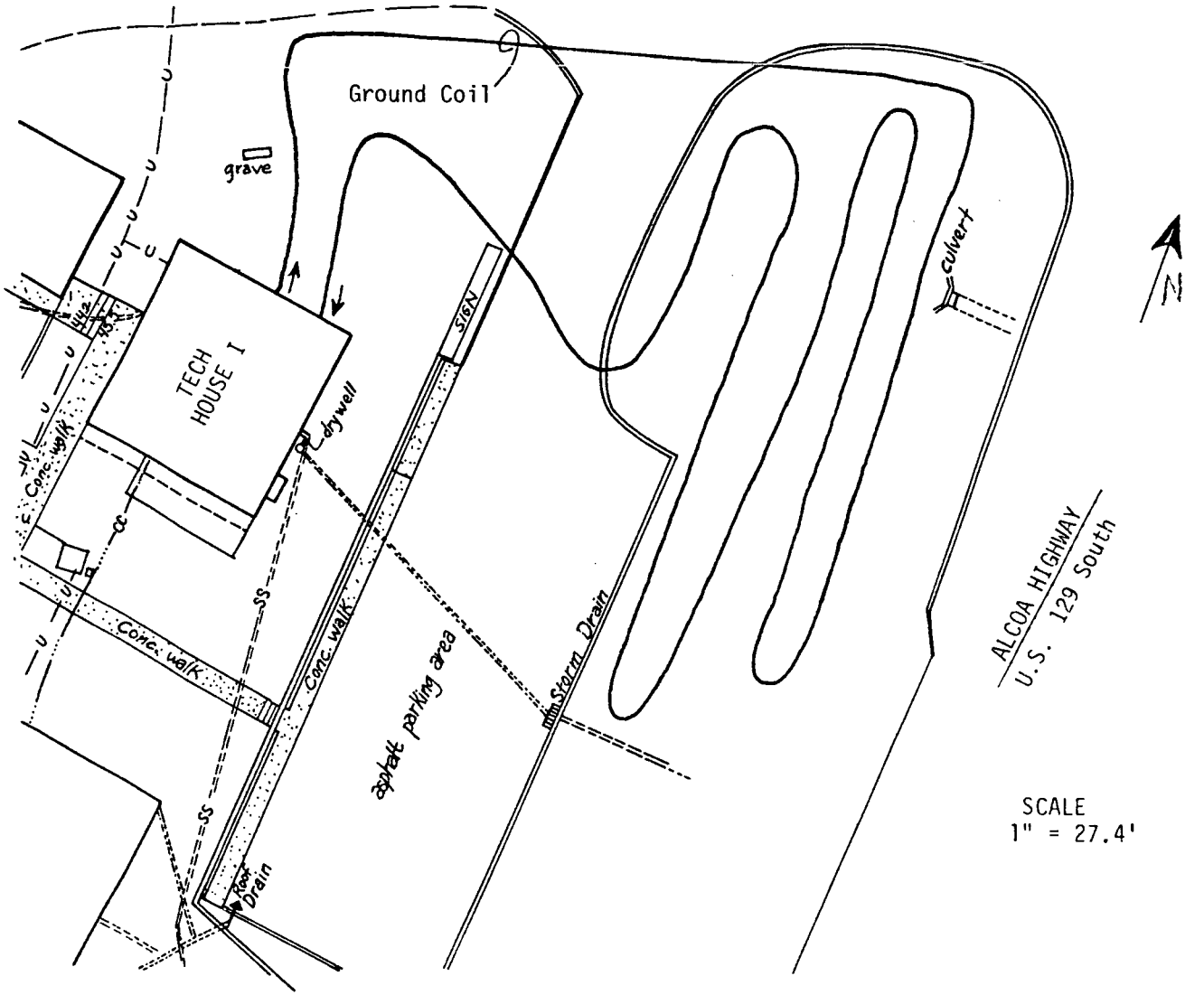

Figure 3.2 Plan View of Horizontal Ground Coil

as installed, was measured to be 675 feet. The pipe was buried approximately four feet deep.

On February 14, 1983, the existing water-to-air coil was replaced with a larger, more efficient coil. This new coil more closely matches the heat release capability of the heat pump. According to information supplied by ORNL personnel, the existing coil is capable of delivering 22,500 BTUH with 102°F entering water at 6.4 gpm and 1100 CFM air flow. It was estimated that the heat pump will deliver approximately 36,000 BTUH at the flow conditions stated above. The replacement coil will deliver 36,000 BTUH with 105°F entering water at 9 gpm and 1100 CFM air flow. The same coil will closely match the cooling load of approximately 24,000 BTUH by reducing the air flow rate to 800 CFM and reducing the water flow rate to 4.1 gpm.

It was estimated that the installed cost of the ground coupled heat pump system was $5290. This estimate is for the ground coil, heat pump and associated piping and controls and does not include costs for ductwork. Table 2 shows a breakdown of the costs of the major items associated with the systems installation. The cost of the heat pump is the factory cost to an individual buying units in lots less than 100. In lots of 100 the cost is $1370.

Table 2. Estimated Ground Coupled Heat Pump Cost Breakdown

		1982 dollars
Earth Coil		585
Earth Coil Installation		350
Heat Pump		2500
Water Coil		655
Air Handling Unit		200
Heat Pump & Water Coil Installation		1000
	Total	$5290

CHAPTER 4. INSTRUMENTATION

Table 3 is a listing of all the measured parameters from the ground coil heat pump system used after September, 1982. All parameters measured by the data acquisition system (DAS) are assigned a unique data number. That number is utilized for data retrieval.

Conditioned space dry and wet bulb temperature measurements are made with solid state temperature transducers. The solid state device is a two terminal monolithic integrated circuit temperature transducer which produces an output current that is proportional to absolute temperature.

All other temperatures are measured with platinum resistance temperature devices (RTDs) using standard resistance thermometry. These RTDs were selected for durability, electrical stability, and linearity.

On November 24, 1982 the RTDs and gypsum blocks in the vicinity of the pipe midpoint were dug up and repositioned. Figure 4.1 depicts the new location of these RTDs around the pipe. Figure 4.2, point A, depicts in plan view the location of these measurements. RTDs #16 and 17 (point D on Figure 4.2) are measuring the temperature of the ground at the surface, and ten feet deep respectively. RTD #18 located at point B on Figure 4.2 is installed in contact with pipe wall at 25% of the pipe length. Point C on Figure 4.2 depicts the location of RTD #19 which is also installed in contact with the pipe but at 75 percent of the pipe length. Point E is the location of the far-field temperature measurement (not recorded by the DAS).

Table 3. Measured Parameters (after September, 1982)

**********ANALOG SIGNALS**********

CABLE #	RTD #	DATA #	MEASUREMENT
1	1	120	T1
2	2	121	T2
3	3	122	T3
4	4	123	T4
5	5	124	T5
6	6	125	T6 GROUND TEMPERA-
7	7	126	T7 TURES NEAR PIPE
8	8	147	T8 MIDPOINT (See
9	9	148	T9 Figure 4.1 for
10	10	149	T10 Location)
11	11	150	T11
12	12	151	T12
13	13	152	T13
14	14	153	T14
15	15	154	T15
16	16	155	Surface of ground
17	17	156	Ten feet deep in ground
18	18	157	Temperature of pipe 169 ft from where it enters the ground (25% of the Pipe Length)
19	19	158	Temperature of pipe 506 ft from where it enters the ground (75% of the pipe length)

********** OTHER TEMPERATURE MEASUREMENTS **********

CABLE #	DATA #	MEASUREMENT
20	159	$GRND_i$ (Temperature of brine entering the ground coil)
21	160	$GRND_o$ (Temperature of brine exiting the ground coil)
22	161	Hdry (Space dry bulb temperature)
23	162	Hwet (Space wet bulb temperature)
31	163	Fan_i (Temperature of brine entering the water to air coil)
32	164	Fan_o (Temperature of brine exiting the water to air coil)

********** DIGITAL SIGNALS **********

CABLE #	DATA #	MEASUREMENT
24	67	GRND (Heat flow into/from the ground)
25	66	WTAC (Water to air coil)
27	41	HTPu (Heat pump outdoor unit)
28	36	BLWR (Blower)
29	40	Phtg (Circulation pumps)
30	35	SOLR (Tech house 1 total power)

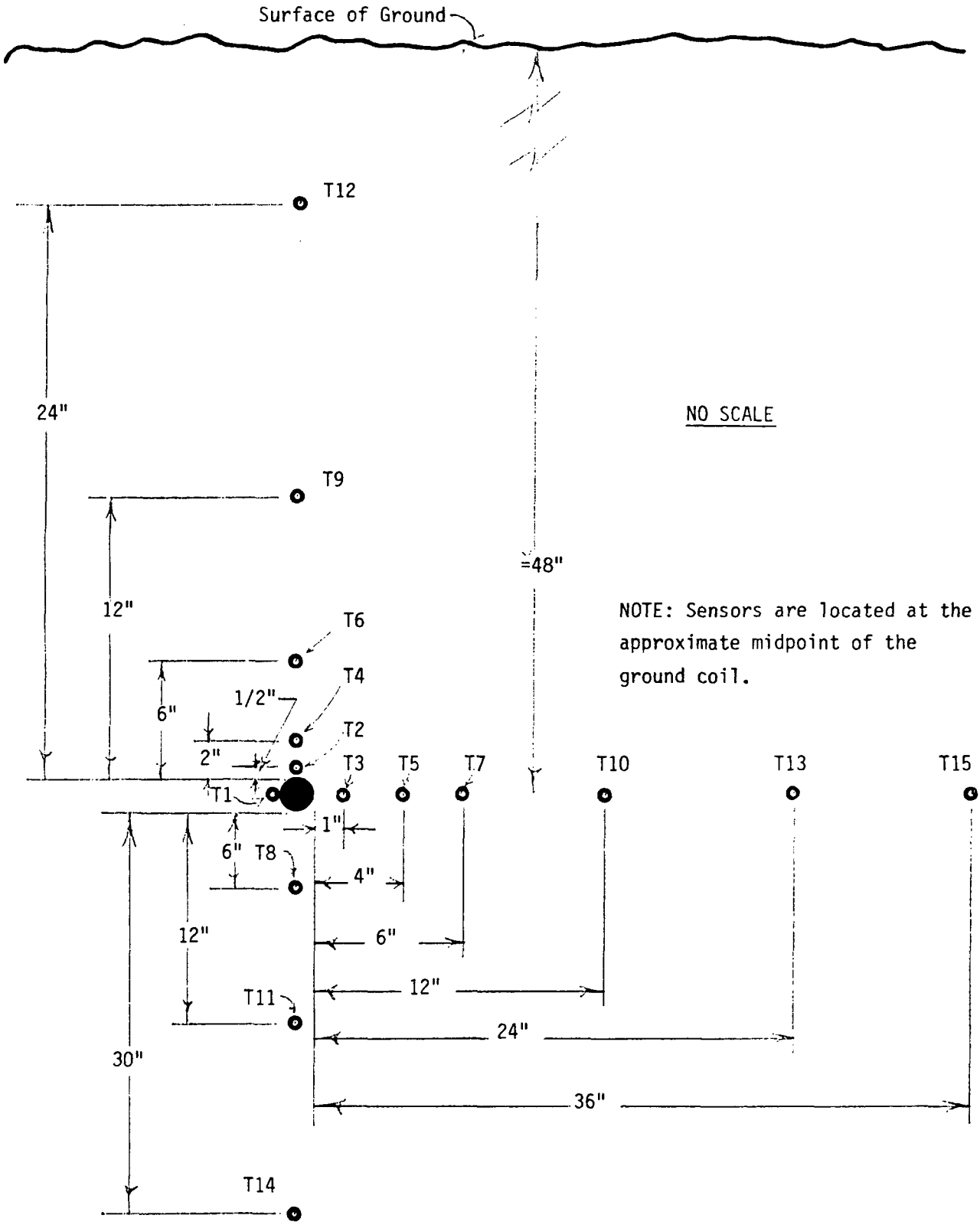

Figure 4.1 Location of Ground Temperature Probes(T1-T15) After November 24,1982

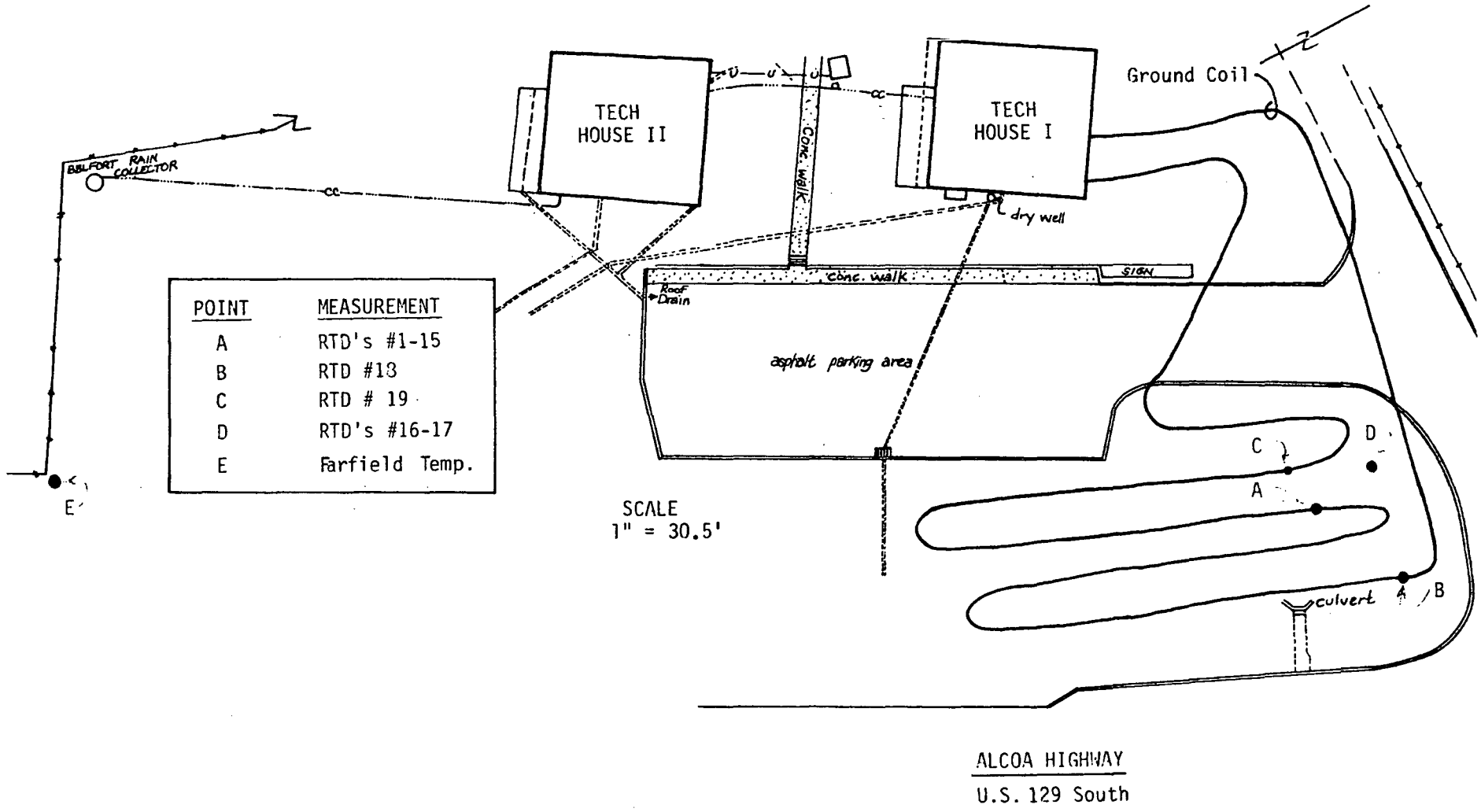

Figure 4.2 Plan View of Horizontal Ground Coil Showing Sensor Locations

Gypsum blocks have been used to measure the moisture content of the soil. The electrical resistivity of those blocks changes with moisture content. Figure 4.3 depicts their location prior to November 24, 1983 and Figure 4.4 depicts the positioning after that date.

Four watt-hour meters are used to measure the power consumption of the heat pump compressor, supply air blower, brine circulation pumps, and total house power. In each of these meters the revolutions of the eddy disk are counted by optical sensors. The output of each optical sensor is digitized and then sent to a summing circuit or counter.

A flow meter and two RTDs form the basis of each water side heat flow. The heat into/out of the ground, and the water to air coil heat flow are measured with these devices. The temperature difference, measured by the two RTDs, is electronically converted to a frequency. That frequency is then electronically multiplied by the frequency output of the flow meter. The product of the flow rate and the temperature difference, which is directly proportional to the heat flow, is sent to a summing circuit in the DAS.

The digital heat flow and electric power signals from the different modes of system operation are each accumulated by counters in the Hewlett-Packard data system, and each hour all counters as well as all analog signals are scanned, their contents recorded on magnectic tape and printed on paper. The counters are then zeroed. The magnetic tape contains then the hourly heat flows, energy consumptions and specified temperatures in each system as well as complete outdoor meteorological conditions. Data on these tapes are massaged weekly by

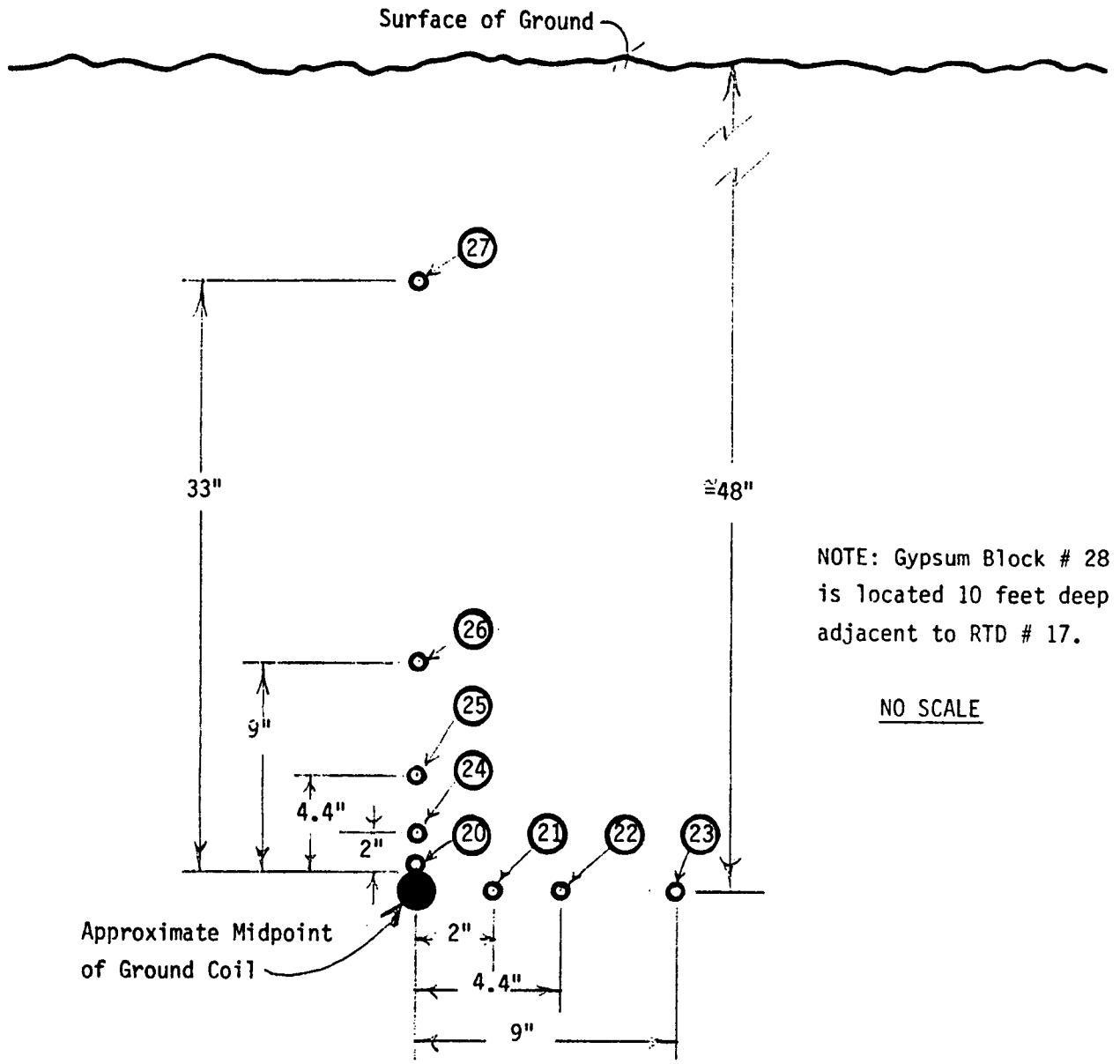

Figure 4.3 Gypsum Block Soil Moisture Sensor Locations Prior to November 24,1982

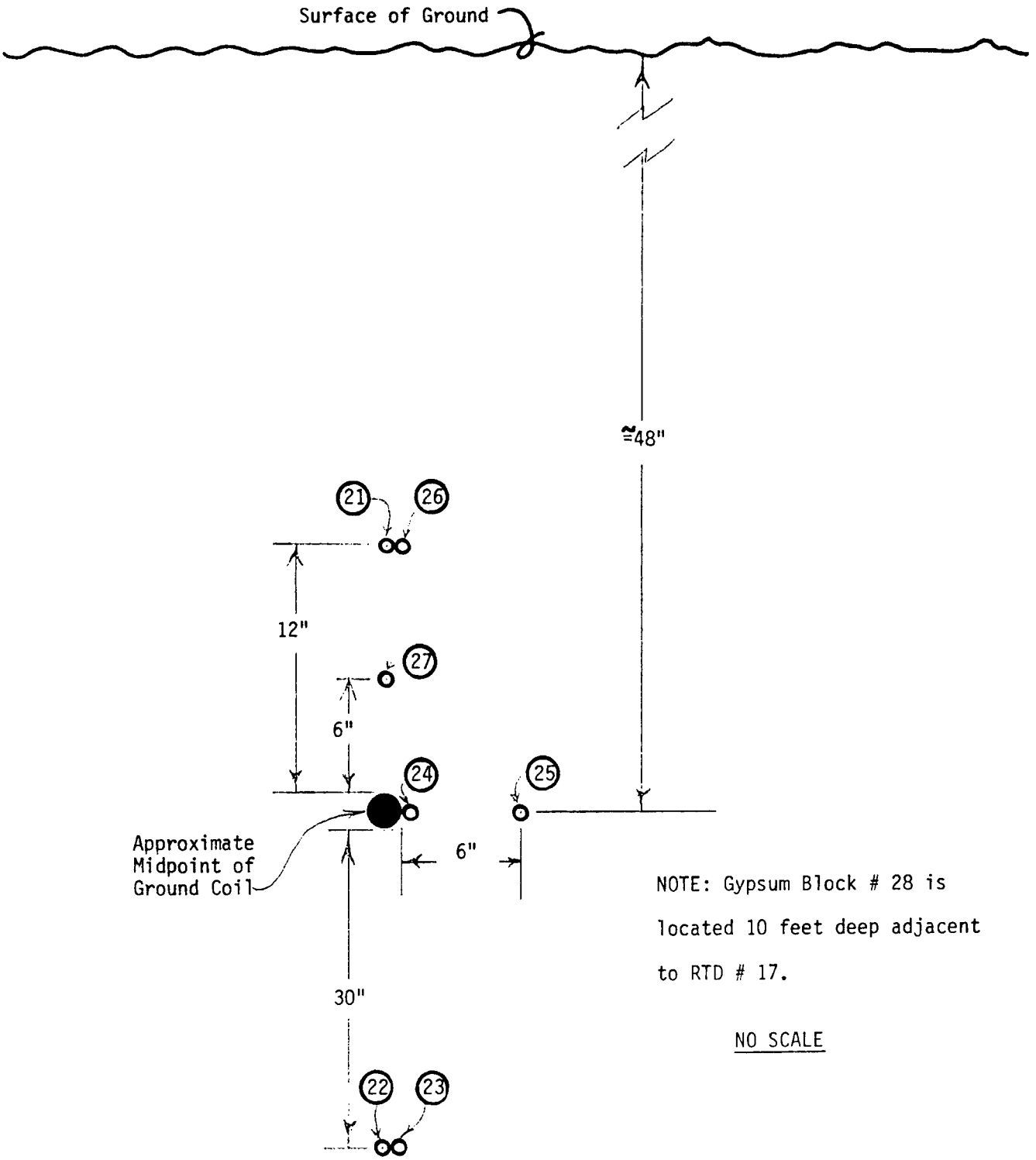

Figure 4.4 Gypsum Block Soil Moisture Sensor Locations After November 24,1982

computer software to produce weekly reports of the ground coupled heat pump system performance.

CHAPTER 5. THERMAL PERFORMANCE DATA

5.1. Soil Temperature Measurements

A significant factor influencing the performance of the ground coupled heat pump system is the thermal response of the soil to heat extraction. Temperature values in the soil were recorded hourly from 19 locations about the pipe field almost continuously throughout the heating season November '82 - April '83 (See Appendix C).

For analysis, the ground temperature data at each location were averaged for each day and plotted with time. Figures 5.1 through 5.5 describe the thermal response of the soil during the heating season at increasing horizontal distances from the pipe. As expected, the temperature fluctuations of the soil are less prominent as distance from the pipe increases, and the temperatures increase slightly with increasing distance from the pipe. The pipe temperatures in different radial directions from the pipe are illustrated in an isotherm diagram of the pipe cross section, Figure 5.6. The temperature of the soil surrounding the pipe did not display radial symmetry about the pipe. This phenomenon is not unexpected, as the soil nearer the surface is influenced more by the ambient air temperature.

As distance from the influence of the ground coil is increased, especially in the downward direction, the pattern displayed by the plot of soil temperature versus time resembles more closely the characteristic sine wave pattern describing far field earth temperatures as a

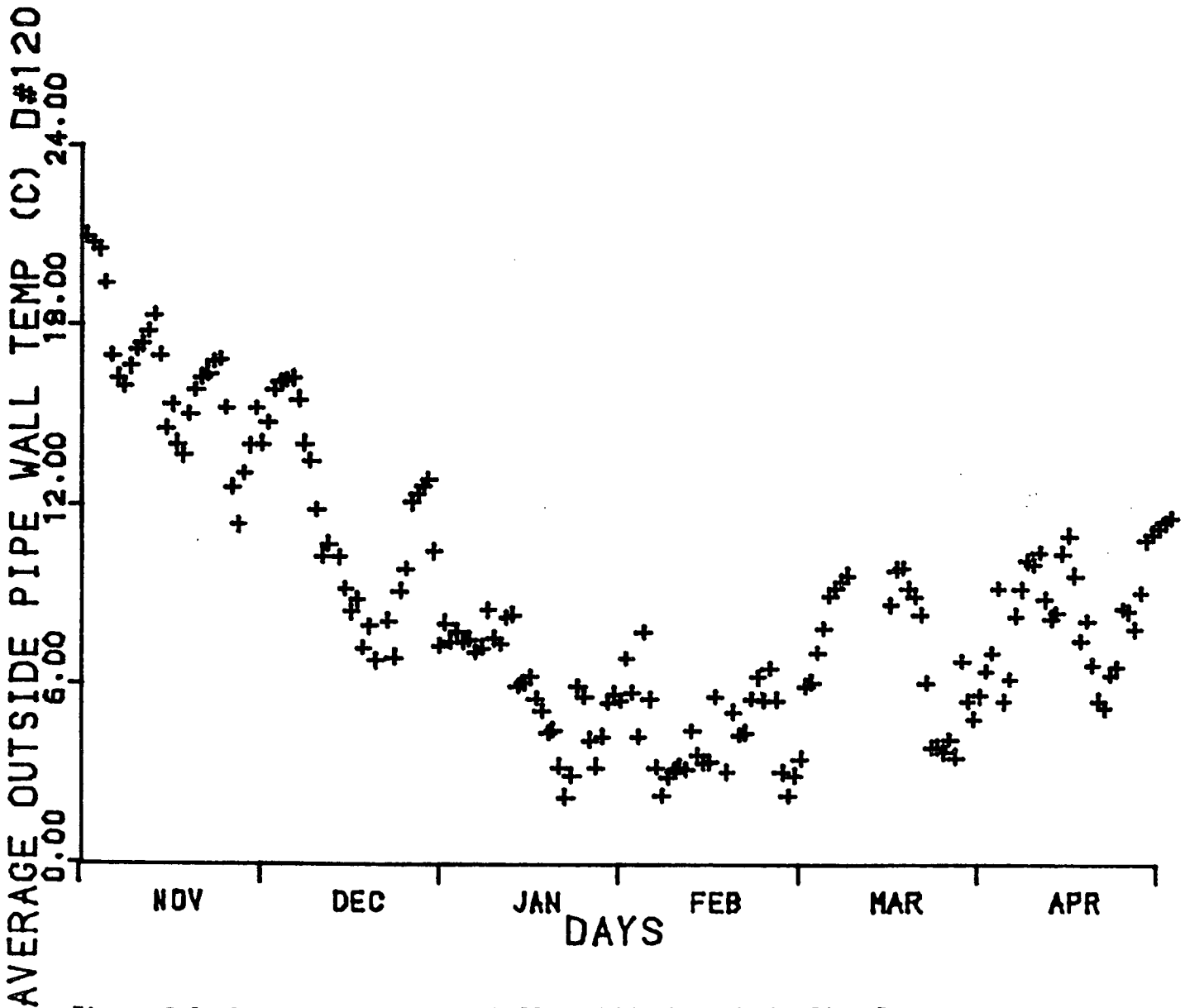

Figure 5.1 Temperature of Pipe Wall at Midpoint of the Pipe Run

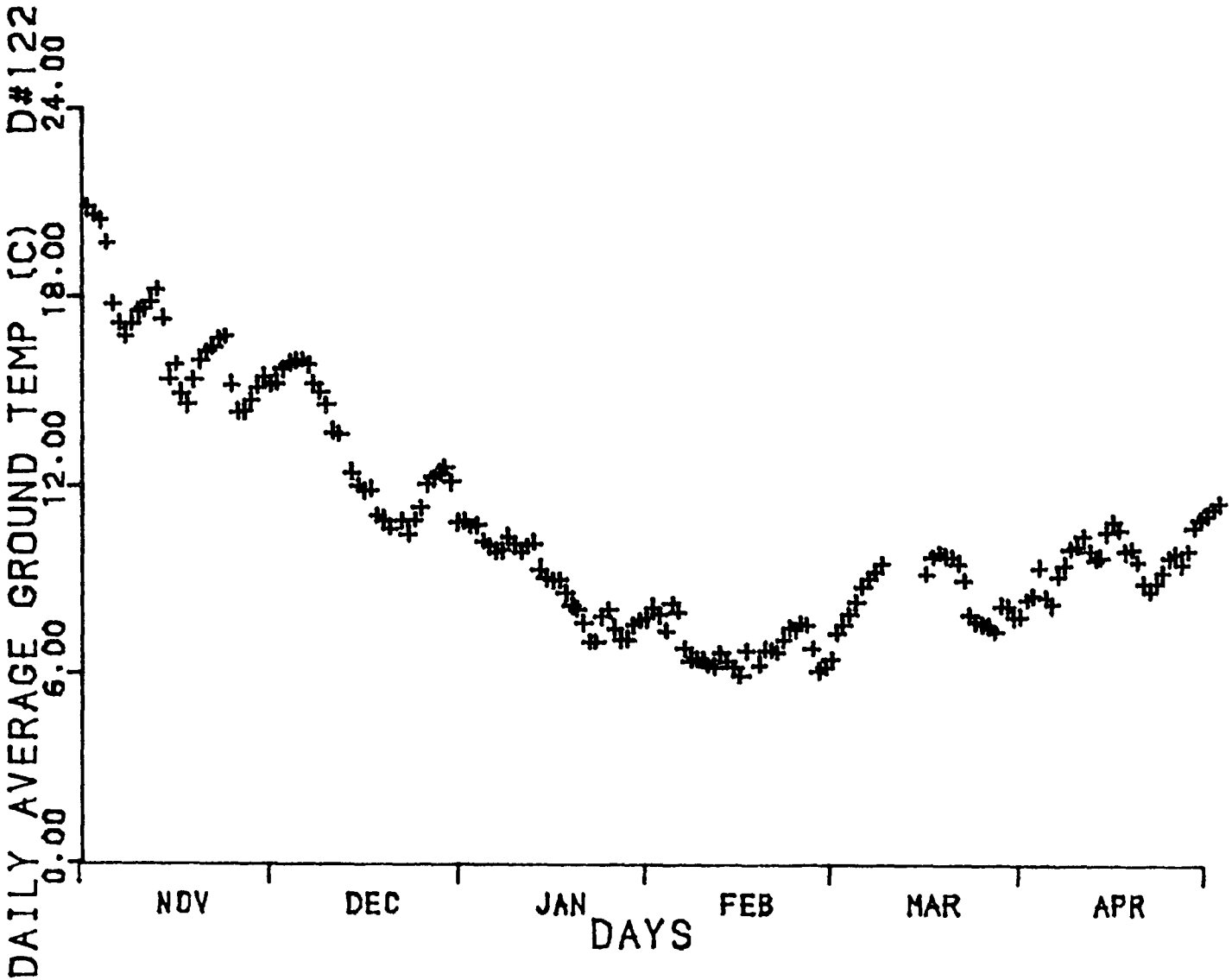

Figure 5.2 Temperature of the Soil 1.0 Inch from the Pipe Wall at Midpoint of the Pipe Run

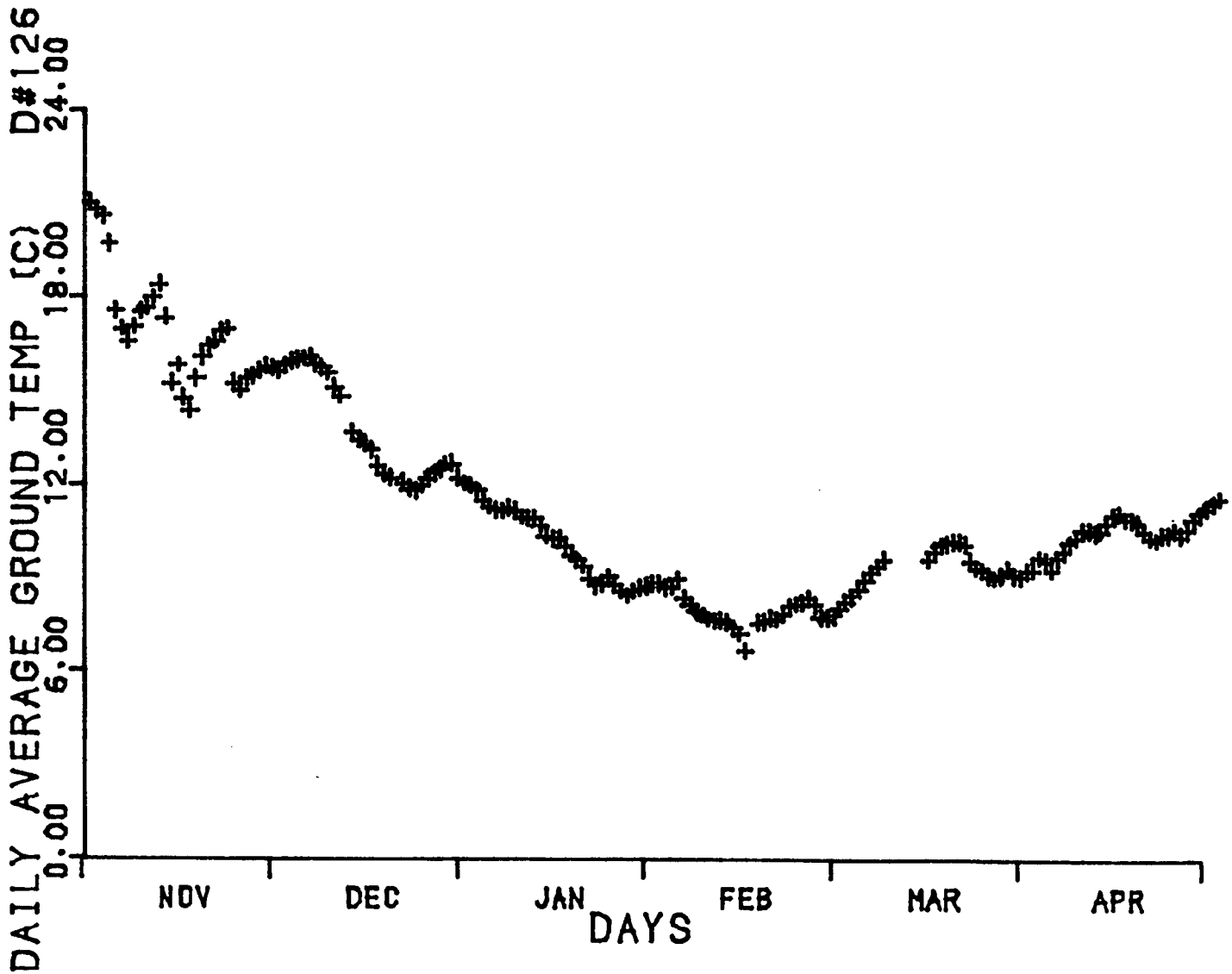

Figure 5.3 Temperature of the Soil 6.0 Inches from the Pipe Wall at the Midpoint of the Pipe Run

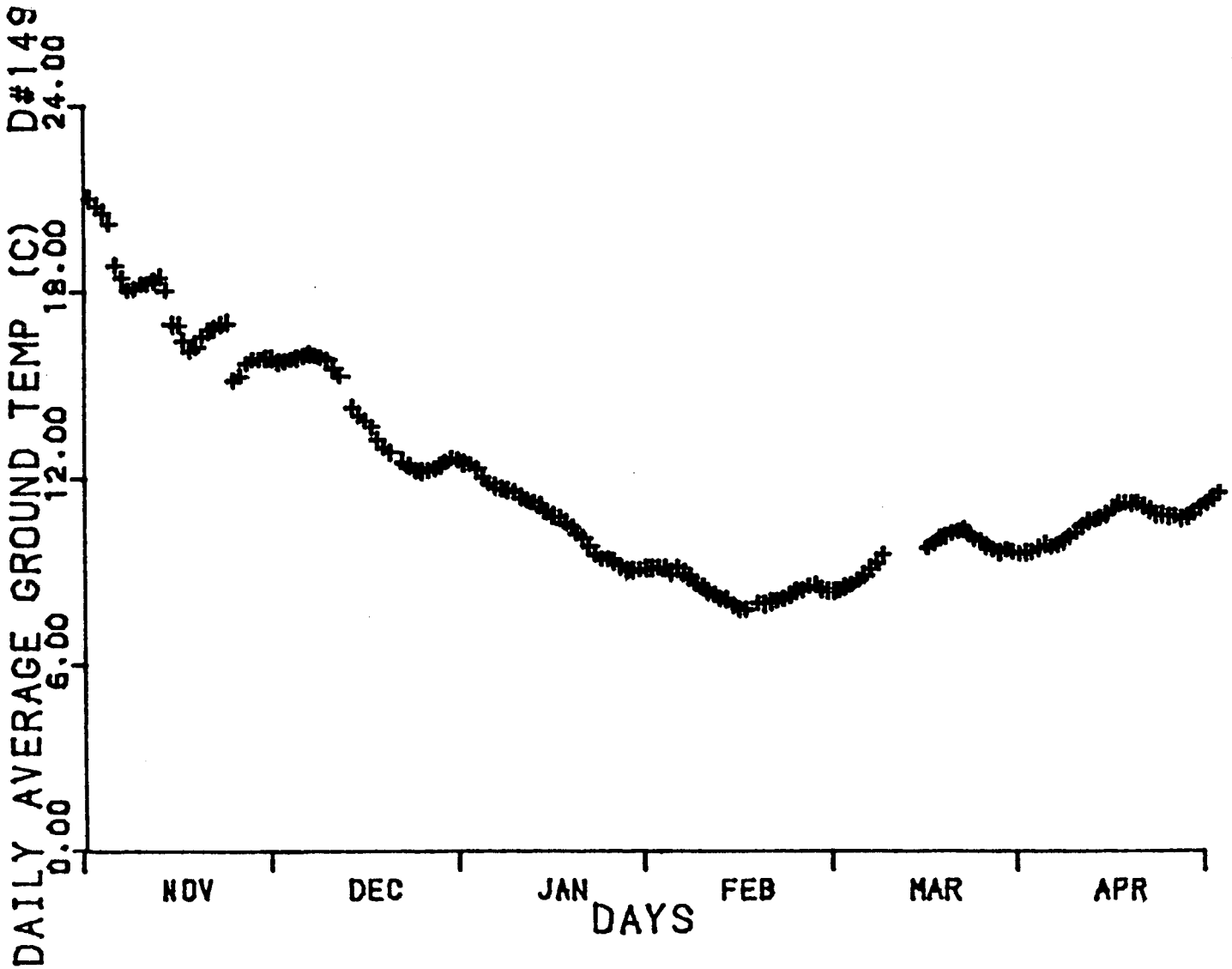

Figure 5.4 Temperature of the Soil 12.0 Inches from the Pipe Wall at the Midpoint of the Pipe Run

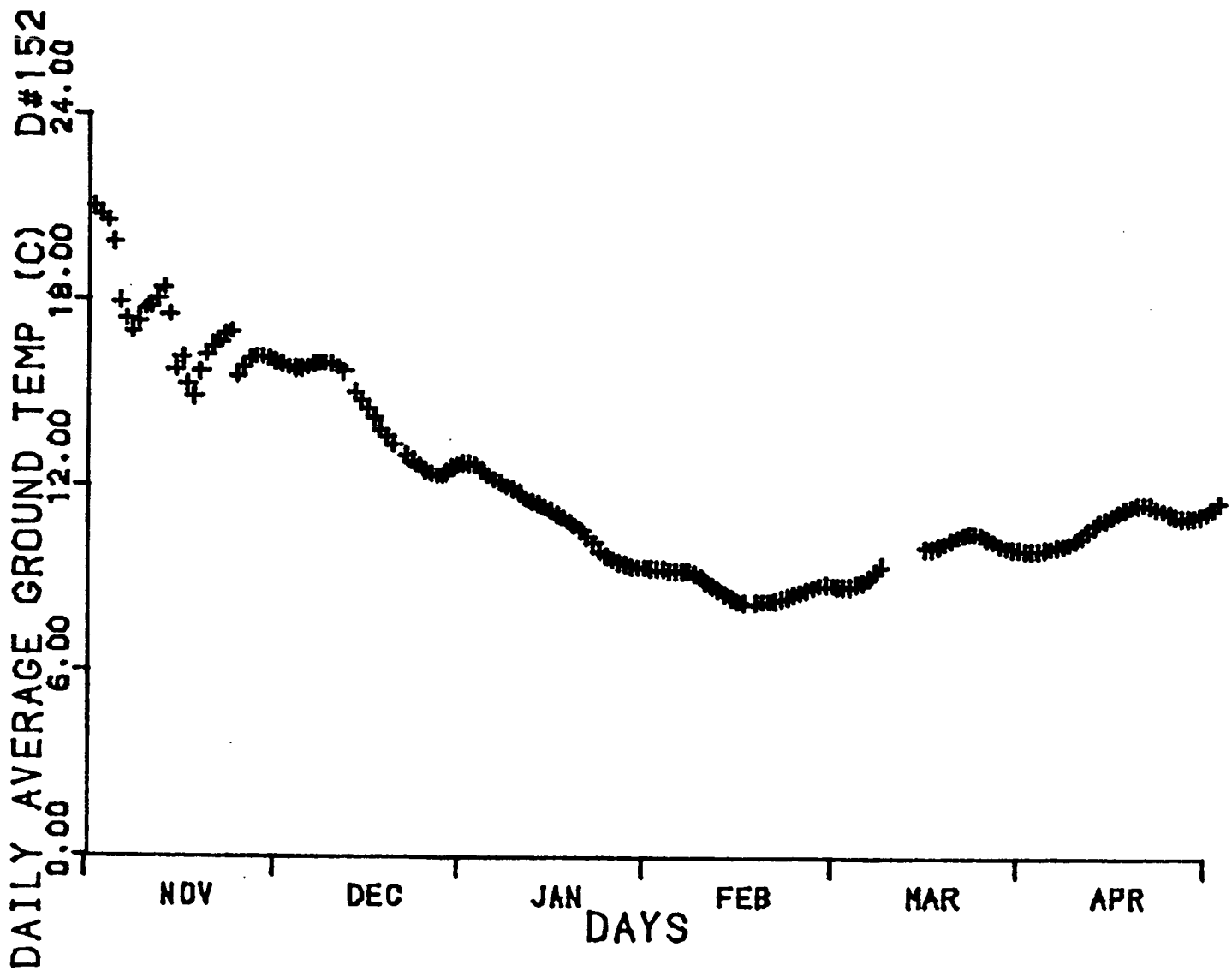

Figure 5.5 Temperature of the Soil 24.0 Inches from the Pipe Wall at the Midpoint of the Pipe Run

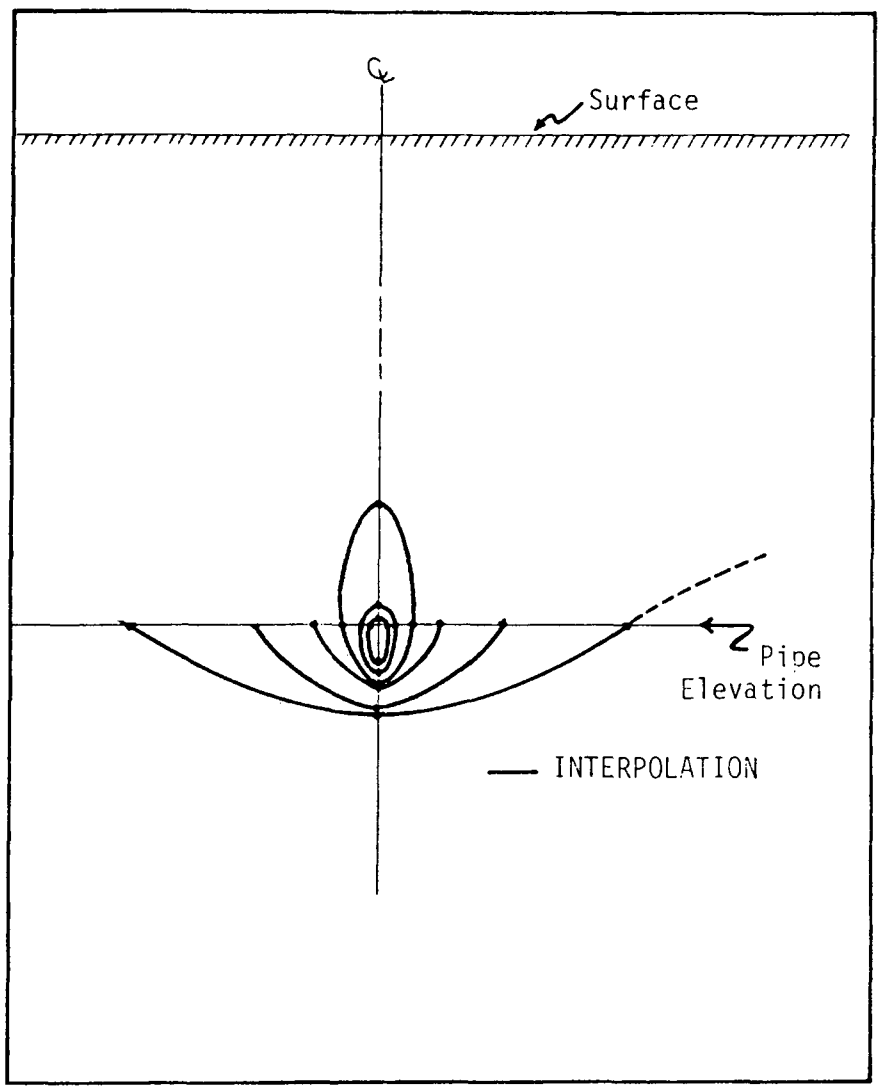

Figure 5.6 Typical Pipe Cross Section
Isotherm Diagram--Mid January, 1982

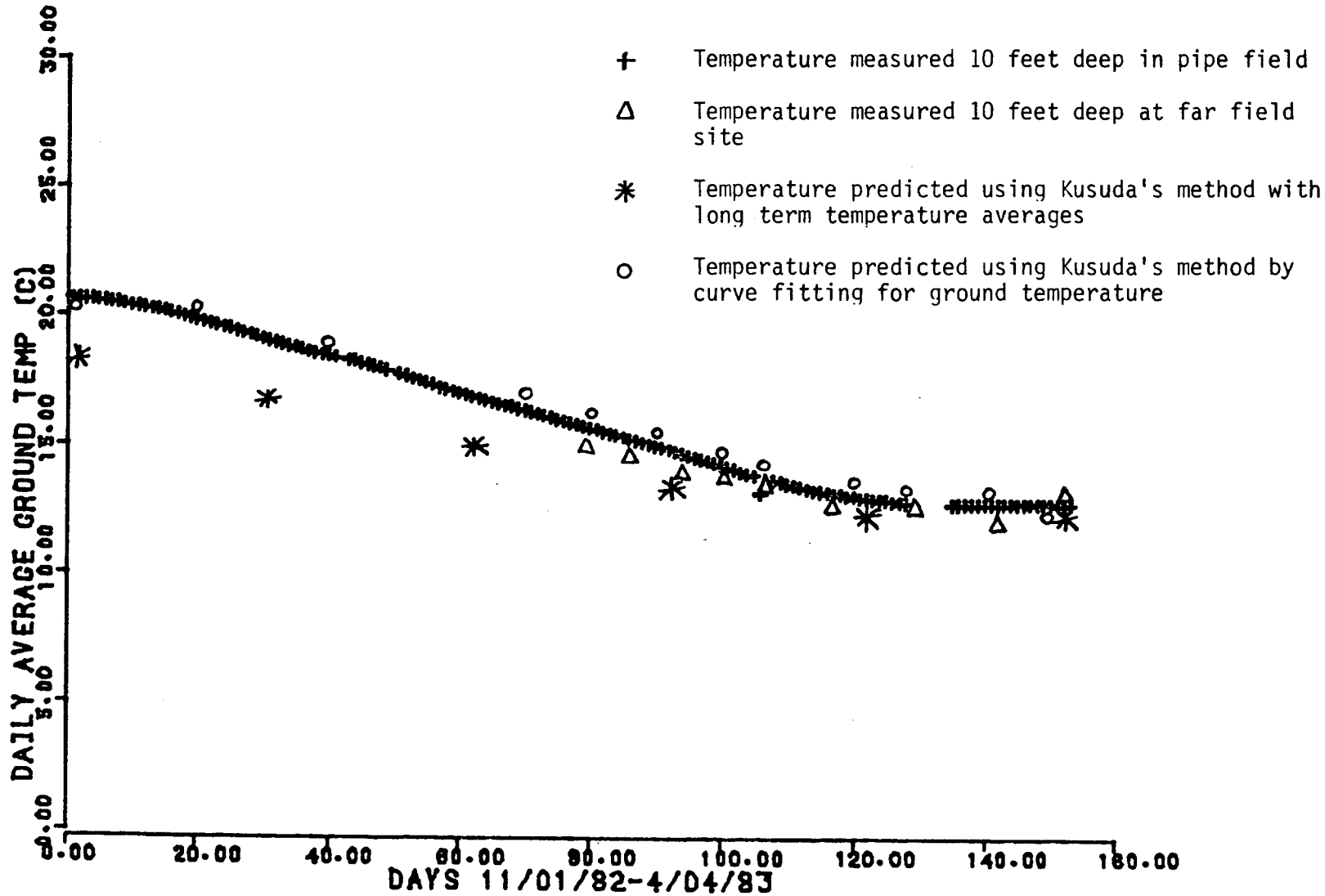

Figure 5.7 Far Field Temperatures (Measured & Predicted)

function of time of year and depth as described by Kusuda (1). Figure 5.7 shows temperature data collected from the earth at a depth of 10 feet at a location near the pipe field. Also plotted on this figure are data from the far-field soil temperature site. (Point E in Figure 4.2.) In addition an analytical estimate of ground temperatures using the Kusuda method is shown. From Figure 5.7 one can see that the soil temperatures at a depth of 10 feet in the pipe field are essentially the same as the far-field soil temperatures at the same depth. The ground heat exchanger has no measureable influence on the soil 6 feet below the pipe. The analytical estimate predicted using the Kusuda method, underestimates the ground temperature by as much as 2°C during the time period shown in the figure. This discrepancy might be partially explained from the difference of the long term temperature averages of the soil and the ambient air used in the Kusuda prediction, with the more recent mild weather experienced at the site. Also, differences between conditions at the experimental site and those at the nearest earth temperature station listed in the Kasuda tabulation (in Jackson, Tennessee) could be a factor. The Kusuda relation 5.1 was curve fitted to force it to match the far field data, and this equation can be used to obtain a good estimate of far field temperatures which were not measured during the experiment.

$$t = A - BO\left(\exp -\sqrt{\frac{\pi}{DT}}\,X\right)\cos\left(\frac{2\pi\theta}{T} - \sqrt{\frac{\pi}{DT}}\,X - PO\right) \qquad (5.1)$$

where:

t is the monthly average earth temperature
θ is the time coordinate in hrs beginning January 1
T is the period of the temperature cycle = 8766 hrs

A is the annual average earth temperature
D is the thermal diffusivity of the soil
X is the depth of the soil
BO is the earth temperature amplitude at the surface
PO is the surface temperature phase angle

5.2. Brine Temperature Measurements

Of particular interest to the performance of the heat pump is the thermal response of the brine used as the working fluid in the ground heat exchanger. The brine temperatures entering and exiting the ground are functions of the heat pump load and ultimately of the ambient air temperature. The measured brine temperatures were also averaged for an entire day and plotted against time on Figures 5.8 and 5.9. Indeed, the peaks of the brine temperature curve match well with those of the ambient temperature curve, Figure 5.10. The difference in the brine inlet and exit temperature gives an idea of how well the ground heat exchanger was able to deliver the heat required. This difference is shown on Figure 5.11. The difference in the inlet and outlet brine averaged over an entire day remained essentially constant throughout the heating season. Had this average delta brine temperature decreased during the season, one could conclude that the heat extraction from the ground became more difficult as the season progressed. The average delta brine temperature being constant indicated that the ground coil is of adequate length and dimensions to provide for the heating load experienced thus far.

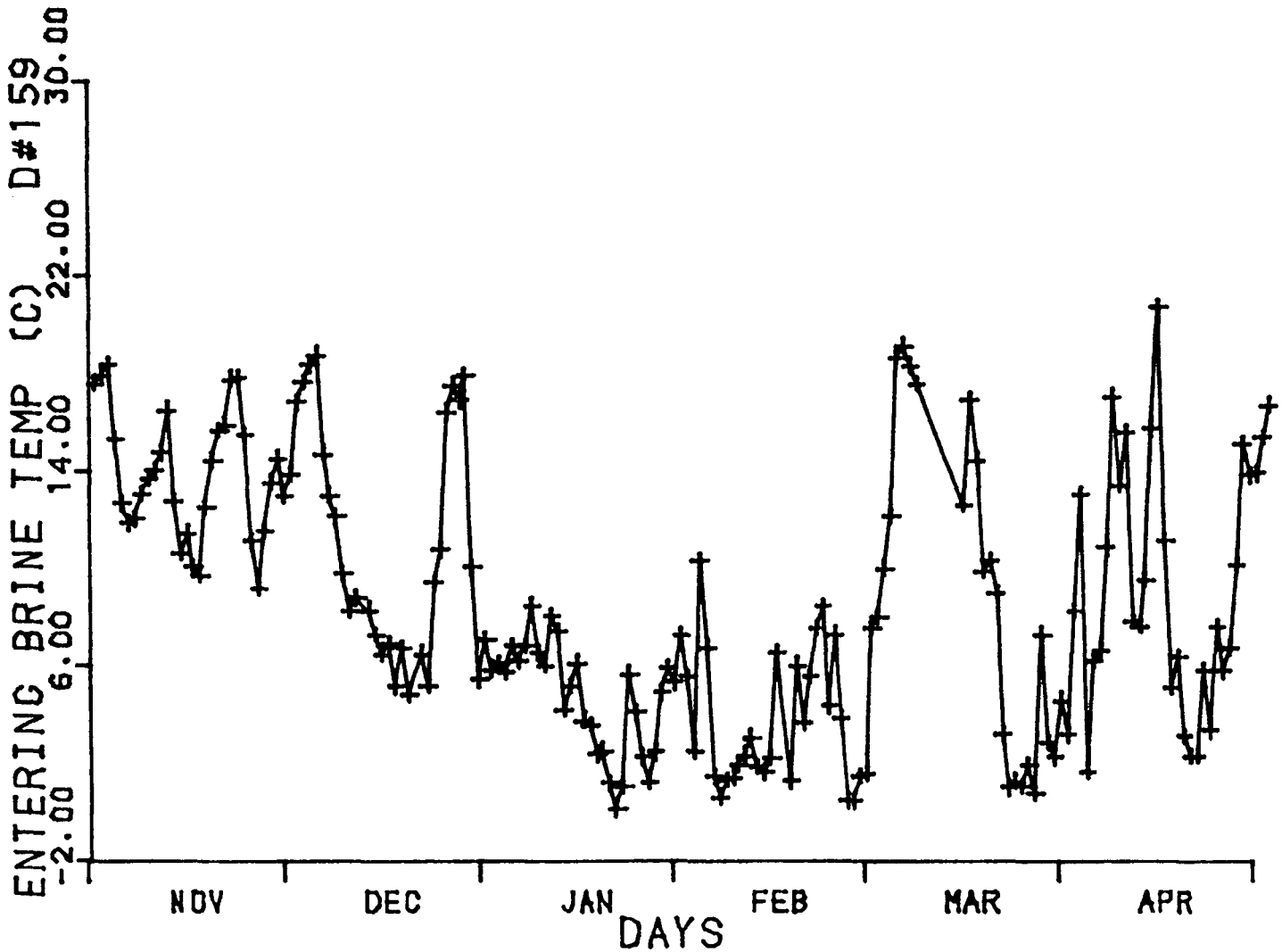

Figure 5.8 Daily Average Temperature of the Brine Entering the Ground Coil

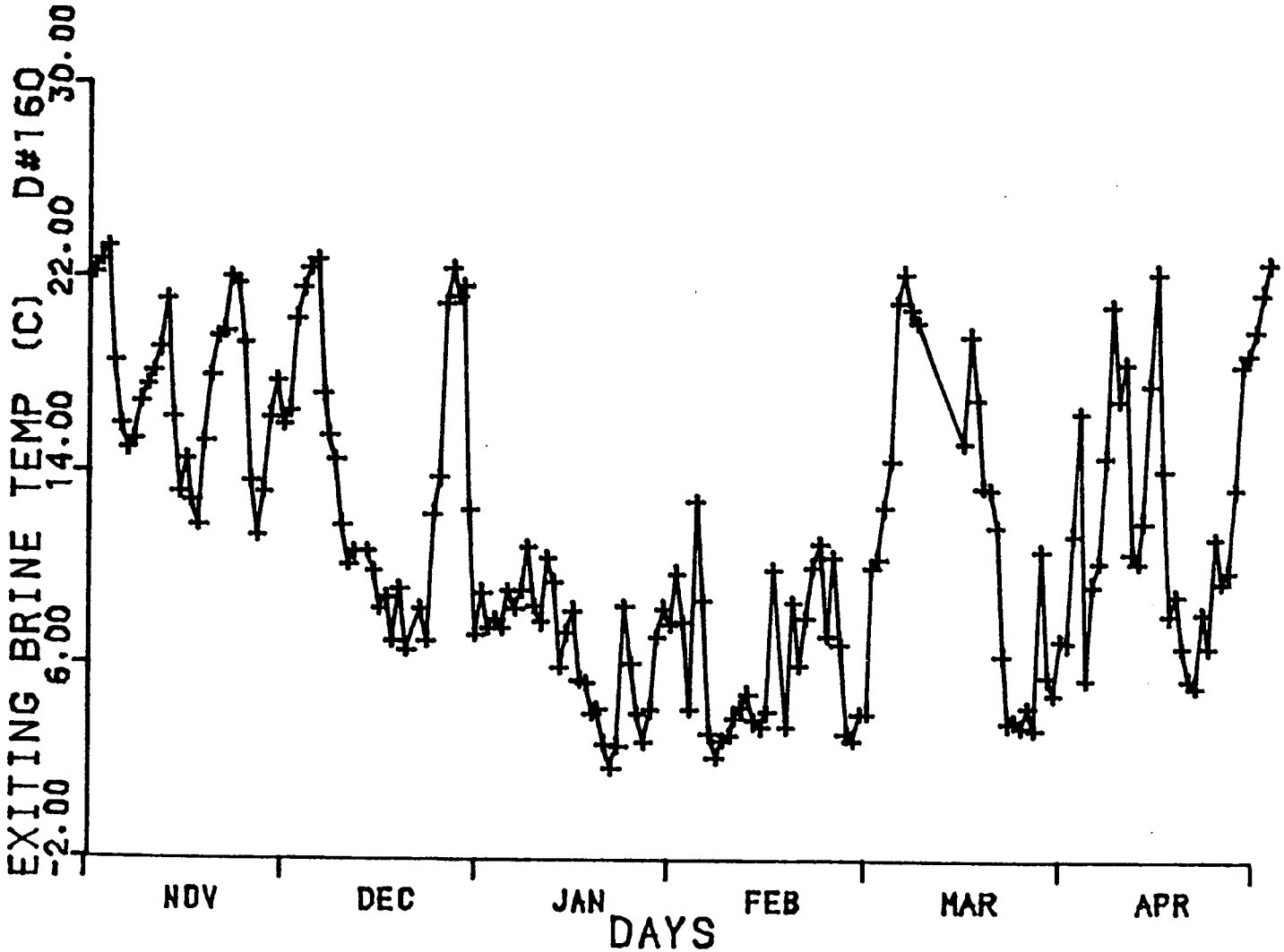

Figure 5.9 Daily Average Temperature of the Brine Exiting the Ground Coil

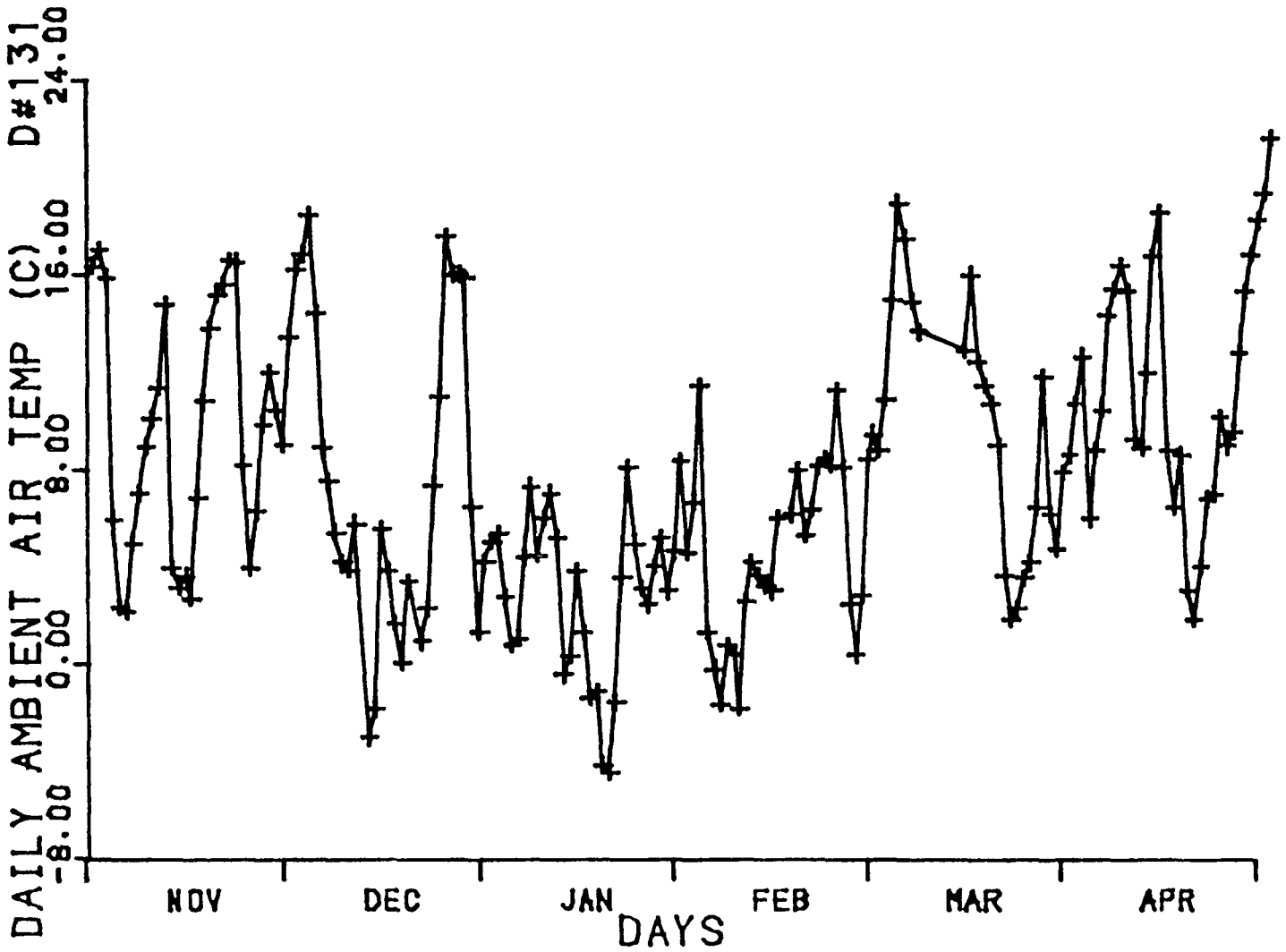

Figure 5.10 Daily Average Ambient Air Temperature

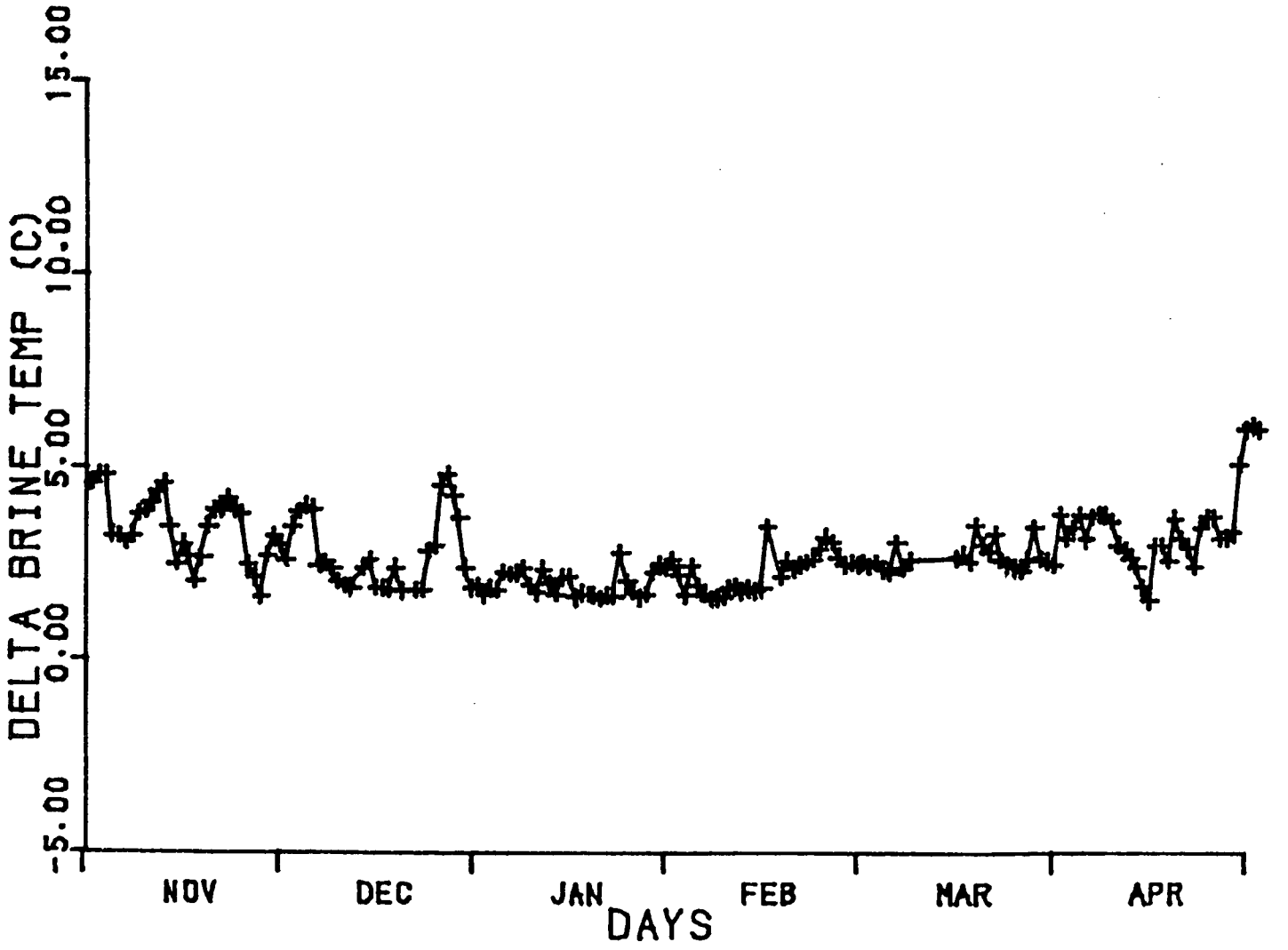

Figure 5.11 Difference Between Daily Average Temperature of the Brine Entering & Exiting the Ground Coil

5.3. Heat Pump Performance Data

Specific temperatures, heat flows, power consumptions, and weather data pertinent to the performance of the ground coupled heat pump were recorded hourly from November 1, 1982 through April 25, 1983. During that time period, data were obtained during 3961 hours out of a possible 4200 hours (94.3%). Monthly values are presented in Table 4. Information regarding downtime can be found in the appendix.

Table 4. Actual & Total Possible Hours of Data

Month	Possible Hours	Hours of Recorded Data	Performance
Nov 82	720	719	99.9%
Dec 82	744	701	94.2%
Jan 83	744	744	100.0%
Feb 83	672	657	97.8%
Mar 83	744	564	75.8%
Apr 83	576	576	100.0%
TOTAL	4200	3961	94.3%

Presented in Table 5 are the monthly and seasonal totals of the three electric power consuming components of the system, the water side heat flows, and the number of heating degree days. Of the total electric power consumed during the season, the blower consumed 14.1% of the total, the pumps consumed 8.8%, and the compressor, 77.1%.

Table 5. Measured Electric Power Consumptions and Heat Flows (kwh).

Month	Blower	Pumps	Compressor	Total System Power	Air Coil	Ground Coil	°F days
Nov 82	66	40	414	520	1054	1007	457
Dec 82	109	68	649	826	1871	1352	592
Jan 83	187	115	1026	1328	2384	1850	845
Feb 83	144	87	714	945	1806	1359	661
Mar 83	66	47	340	453	1040	820	371
Apr 83	61	38	316	415	997	800	364
TOTAL	633	395	3459	4487	9152	7188	3290

The ground coupled heat pump system was capable of providing heat to the conditioned space throughout the heating season without the need for auxiliary electric resistance heat as is required in conventional air to air heat pumps. This phenomenon is of particular interest to electric utilities. The highest electric demand with the ground coil heat pump was approximately 5 kW. Had the conditioned space utilized an air to air heat pump, the peak electric demand could have been as much as 12 kW.

5.4 Heat Pump Performance Factors

The seasonal performance factor (SPF) is defined as the total useful heat provided to the conditioned space divided by the total purchased power required to deliver that heat. Since the ground coupled heat pump system is packaged in such a manner that it could be installed either inside or outside the conditioned space, two methods of calculating the performance are presented. SPF_i is the

performance factor for the case in which the heat pump package and all other power consuming components (pumps and the blower) are located within the conditioned space. The ground coupled heat pump system is presently installed in this manner. The heating SPF_i is then calculated as the sum of the total system purchased electric power and the ground coil heat flow divided by the total system purchased electric power.

SPF_o is the performance factor for the case in which the heat pump package and all other power consuming components are located outside the conditioned space (i.e., a garage). The heating SPF_o is then calculated as the total heat delivered via water to air coil divided by the total system purchased electric power.

Table 6 presents the SPF values for each month and the entire heating season. Clearly SPF_i is beneficial to the consumer during the winter, but will be a detriment during the summer months.

Table 6. Seasonal Performance Factors

Month	SPF_i	SPF_o
Nov 82	2.94	2.03
Dec 82	2.64	2.27
Jan 83	2.39	1.80
Feb 83	2.44	1.91
Mar 83	2.81	2.30
Apr 83	2.93	2.40
ENTIRE SEASON	2.60	2.04

When evaluating the monthly trends in the SPF values, one must remember that a smaller, less efficient water to air coil was utilized from November 1, 1982 through February 14, 1983.

CHAPTER 6. SOIL HEAT TRANSFER

6.1. Introduction

Heat flow through the soil occurs by several different mechanisms. Conduction heat transfer takes place in the solid particles of the soil, through the water present, and through the air in the soil pores. Consequently, for a particular type of soil, the effective thermal conductivity is a function of water content, composition, density, and temperature.

Heat transfer also occurs through movement of water in both the vapor and liquid phase. Vapor diffusion is due to vapor pressure gradients caused by temperature gradients in the soil. Phase change heat transfer also occurs because the water is evaporated in the warmer soil regions and condenses in the cooler soil regions. Latent heat released by freezing of the soil moisture can contribute significantly to the overall heat transfer.

The liquid water movement in the soil is caused by differences in water surface tension between the warm and cool soil regions. As the temperature of the water in the soil increases, the surface tension of the water decreases. According to Gurr, Marshall and Hutton (2) the decrease in surface tension causes an increase of the hydrostatic pressure of the water in the soil. A pressure gradient results and causes liquid water movement in the direction of decreasing soil temperature. These mechanisms of heat transfer point out that the moisture content of the soil has an affect on the thermal conductivity of soil and ultimatly, the heat transfer through the soil. Throughout the literature in the field of heat and mass transfer in soils, it has

been shown that a higher moisture content corresponds to a higher soil thermal conductivity. Several researchers (3,4,5) have reported that the largest rate of change in soil thermal conductivity occurs with temperature changes at low moisture contents. Research in prediction of thermal conductivity from the moisture content for particular soils has been conducted by de Vries, Woodside, Gemant and Webb (6,7,8,9).

Other factors that affect the thermal conductivity of a soil are the thermal properties of the solid material in the soil, the soil texture and the soil density. Observation by Smith (10), Kersten (11) and Sepaskhah and Boersma (5) show that if different textured soils are tested for thermal conductivity at equal moisture contents and densities, coarse-grained soil such as gravels and sands will have a higher thermal conductivity than fine-grained soils such as silt loams and clays. Kersten notes that sandy soils are usually found in nature with a higher density and a lower mosture content than silt or clay soils. The net effect of an increase in density and a decrease in moisture content can cause a decrease in soil thermal conductivity. Therefore, the difference in effective thermal conductivity, due to different soil textures, that was observed under laboratory conditions may not be the same as in soils found in nature.

The density of the soil is another important factor affecting soil thermal conductivity. Kersten reported that an increase in density, with the moisture content remaining constant, will cause the soil thermal conductivity to increase. An increase in density causes several things to happen. The amount of solid material per unit volume increases obviously. But, there is also a reduction in the volume of the voids present. The void volume reduction causes the soil permeability to reduce thus causing the moisture movement in the soil to reduce. Soil density can be altered artificially by man and/or naturally in situ by swelling or shrinking.

An increase in soil temperature can either increase or decrease the soil thermal conductivity dependent upon the soil moisture content. Increasing thermal conductivity is attributed to enhanced vapor transfer through the air-filled pores. Sepaskhah and Boersma report a peak increase in thermal conductivity of nearly three times for a temperature increase of 20°C in silty clay loam when the soil pores are approximately 35 percent filled with water. When the soil pores are approximately 45 percent full of water, the increase in thermal conductivity drops by a factor of one and one half for a temperature increase of 20°C.

6.2. Measurements

6.2.1. In Situ Soil Thermal Conductivity Measurements

There are two well established methods of measuring soil thermal conductivity in situ (13). The methods are the sphere method and the

transient needle method. A spherical shell containting a heater and temperature measurement devices located on the heater and in the soil are used in the sphere method. A known steady amount of power is supplied to the heater until steady-state conditions are obtained. The temperature measurement devices can be used to determine when steady-state conditions are achieved by taking temperature measurements at regular intervals. The soil thermal conductivity is computed by using the steady-state conduction heat transfer solution of a sphere in an infinite medium.

The transient needle method uses a heated probe containing a temperature measurement device. Power is supplied to the heated probe and temperature is recorded at regular intervals of time. The transient conduction heat transfer solution of an infinitely-long line source of heat in an infinite medium is used to compute the soil thermal conductivity.

Errors in both methods can arise if the heater output is not constant and if the time-temperature record is not accurate. Nonuniformities and disturbances of the soil can also cause errors. Makowski and Mochlinski (12) point out that neither method takes into account any effect the addition of heat into the soil has on soil thermal conductivity. The heat addition could be a large source of error, dependent upon the power output of the heater.

These methods have not been used at the University of Tennessee Tech Site. Since the thermal conductivity of soil around the heated

horizontal earth coil is of interest and both methods rely upon the addition of energy to the soil, it is felt that these methods cannot differentiate between energy addition from the ground coil pipe and from the heater of the measurement device.

6.2.2. Moisture Meters

A theoretical estimate of the thermal conductivity of soil can be made if the soil mineral composition, porosity, and water content are known. de Vries (6) first presented the method in 1963 and gave several examples of the actual calculations.

Several types of soil moisture content meters are presently available on the market. These soil moisture content meters can be classified as one of three types: suction meters, capacitance meters and equilibrium meters. A suction meter consists of a water-filled tube with a porous tip at one end and a gauge at the other end. The tube is placed with the porous tip into the ground thus allowing water to move between the meter and soil. When the soil dries, water moves from the tube to the soil causing a needle deflection on the gauge. When moisture is added to the soil the needle deflection is in the opposite direction. These meters give an indication of changes in the amount of moisture in the soil but not the absolute amount of moisture. For this reason and also because the meters have a limited depth of usage, the suction type meter was not used in this research effort.

Capacitance meters are basically an oscillator arranged so the oscillator frequency is sensitive to the capacitance of a pair of electrodes mounted in a sensor that is placed in the ground. The walls

of the sensor are the electrodes and are separated by an insulated gap. An electric fringe field penetrates the soil in the region of the insulated gap and connects the electrodes electrically. The fringe field is sensitive to changes in moisture in the soil and through some signal conditioning circuits, the soil moisture content can be determined. The main objections to the use of the capitance meter are the probe size and the cost.

Equilibrium meters are made of porous material which absorbs and releases moisture at approximatly the same rate as the surrounding soil. Electrodes are embedded in the blocks so the resistance of the block can be measured. The electrodes are treated to prevent any interference from stray currents in the soil affecting the meter ouput. The measured electrical resistance changes with the moisture content of the blocks and thus with the soil moisture content. Therefore, the soil moisture content can be determined with the assumption that equilibrium is maintained between the block and soil. The equilibrium meters are the type selected for this research project.

Two problems encountered with the equilibrium meters are polarization and deterioration. Polarization can happen if a D.C. ohm meter is used. Deterioration of the block occurs when acids and/or salts in the soil attacks the block.

Another problem with any in situ measurement technique is disturbance of the soil structure. Smith (10) considered the possibility that soils in the field may have a distinct structure or laminations which may affect the soil thermal conductivity. He found

that for most dry soils, the conductivity of undisturbed soil is greater than the thermal conductivity of the same soil after structure has been broken down. In some cases, the disturbed soil thermal conductivity may be twice the value of the restructured sample. The change in thermal conductivity was not observed in granular soils such as sand and gravel.

6.2.3. Calibration Procedure

Two types of blocks are undergoing calibration presently. The difference between the blocks is the type of material used. One type is made of gypsum and the other type is made of a porous ceramic.

The calibration procedure consists of three main steps: sample preparation, a resistance measurement of the block and determination of soil moisture content. The soil used in the calibration procedure was taken from an area near the horizontal earth coil. The soil has been classified as sequoya silty clay loam based on information from a 1980 core sample and a 1942 United States Department of Agriculture soil survey. The soil dry density from the core sample was 84.4 lb/ft^3.

The sample preparation consists of adding a known amount of water to a known amount of soil on a mass basis. The sample is mixed in order to make the mixture as homogeneous as possible. The sensor is then placed in the soil which is then compressed to approximately the in situ dry soil density.

Some problems were encountered with the sample preparation. At low moisture contents the soil becomes nonuniform in the moisture

distribution. Clumps of clay formed but the clumps were broken down as fine as possible during the mixing process.

Compression of the soil is also very difficult at low moisture contents. A compression on one side of the soil sample tends to loosen soil on the opposite side of the sample. A wide object was used to compress the material in an attempt to avoid the soil loosening.

Several methods of measuring the resistance of the moisture sensors were attempted. An ohmeter that output 30 volts D.C. for resistance measurements was tried first. Using this meter caused the sensors to polarize, in effect, causing the sensors to become batteries. A second ohmeter that output 1.5 volts D.C. was tried in an attempt to reduce the polarization of the blocks to an acceptable level. After using both of the ohmeters, it was felt that the accuracy of resistance readings was unacceptable and the use of a D.C. ohmmeter was discarded.

An A.C. ohmeter supplied by the maker of the gypsum block moisture sensors was also considered. This meter lacked an adequate range, and was not used.

An A.C. bridge circuit similar to a Wheatstone bridge circuit with an adjustable resistance or "decade" box was also used. The circuit is shown in Figure 6.1 (14). Resistance R_x is the block resistance and R_1 is the decade box resistance. Resistances R_2 and R_3 are preset equal resistances. When resistance R_x and R_1 are equal, there is no deflection on the galvanometer "G." The decade box is adjusted until resistances R_x and R_1 are equal.

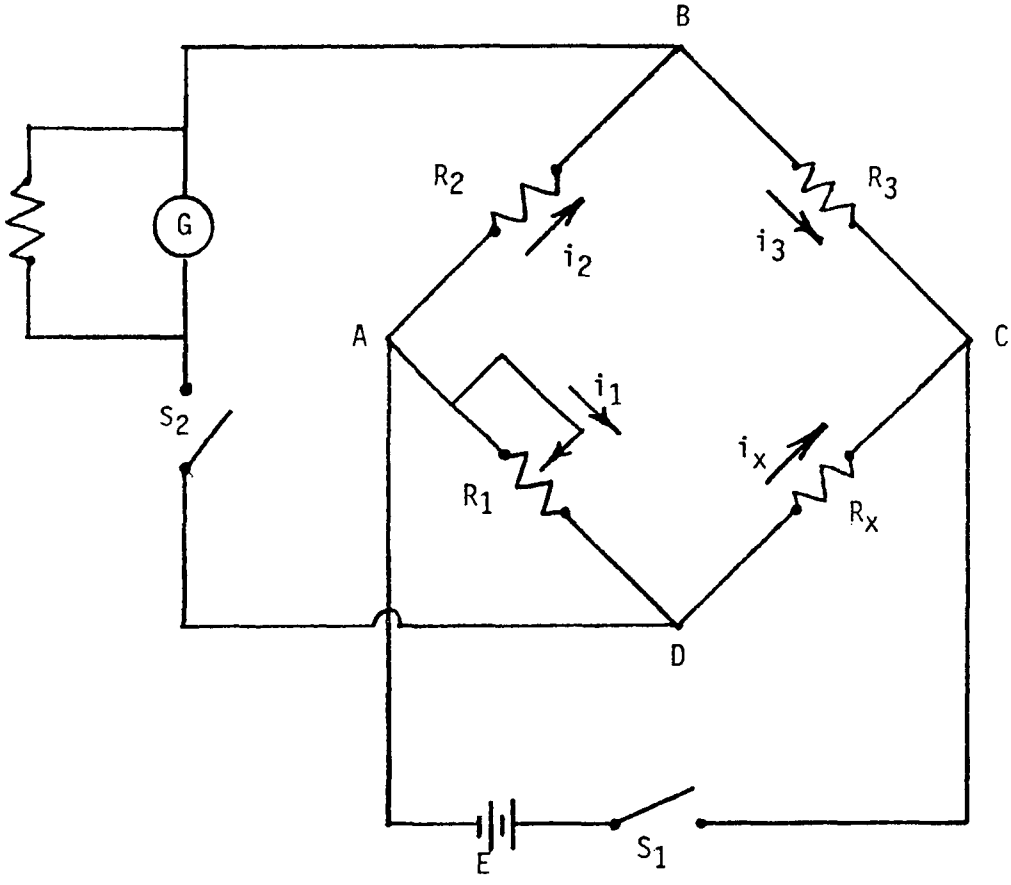

Figure 6.1 A.C. Bridge Circuit

This method of measuring sensor resistance gives accurate resistance readings if the decade box is a high quality, accurate instrument. The decade box used in this research project is accurate to 0.05 percent of the setting.

An instrument on loan from the Tennessee Valley Authority is also under consideration. The instrument measures conductance of the sensors.

Determination of the moisture content of the soil is made by a weight difference technique. A sample of the soil from near the block is taken and weighed. The sample is then dried in an oven overnight and weighed again. The difference in soil weight is assumed to be the amount of water in the original sample. Since the wet and dry soil weight and the weight of the water is known, the moisture content can be calculated on a mass basis.

Figure 6.2 is a plot of the ceramic block moisture sensor calibration curve as generated using the aforementioned calibration procedure. A slight problem was encountered while calibrating the ceramic block involving a small drift of the resistance readings. This drift was attributed to the possibility of the ceramic blocks not being completely in equilibrium with the soil. A criterion of a change in the resistance reading of less than two percent in a one hour interval was used to determine equilibrium conditions.

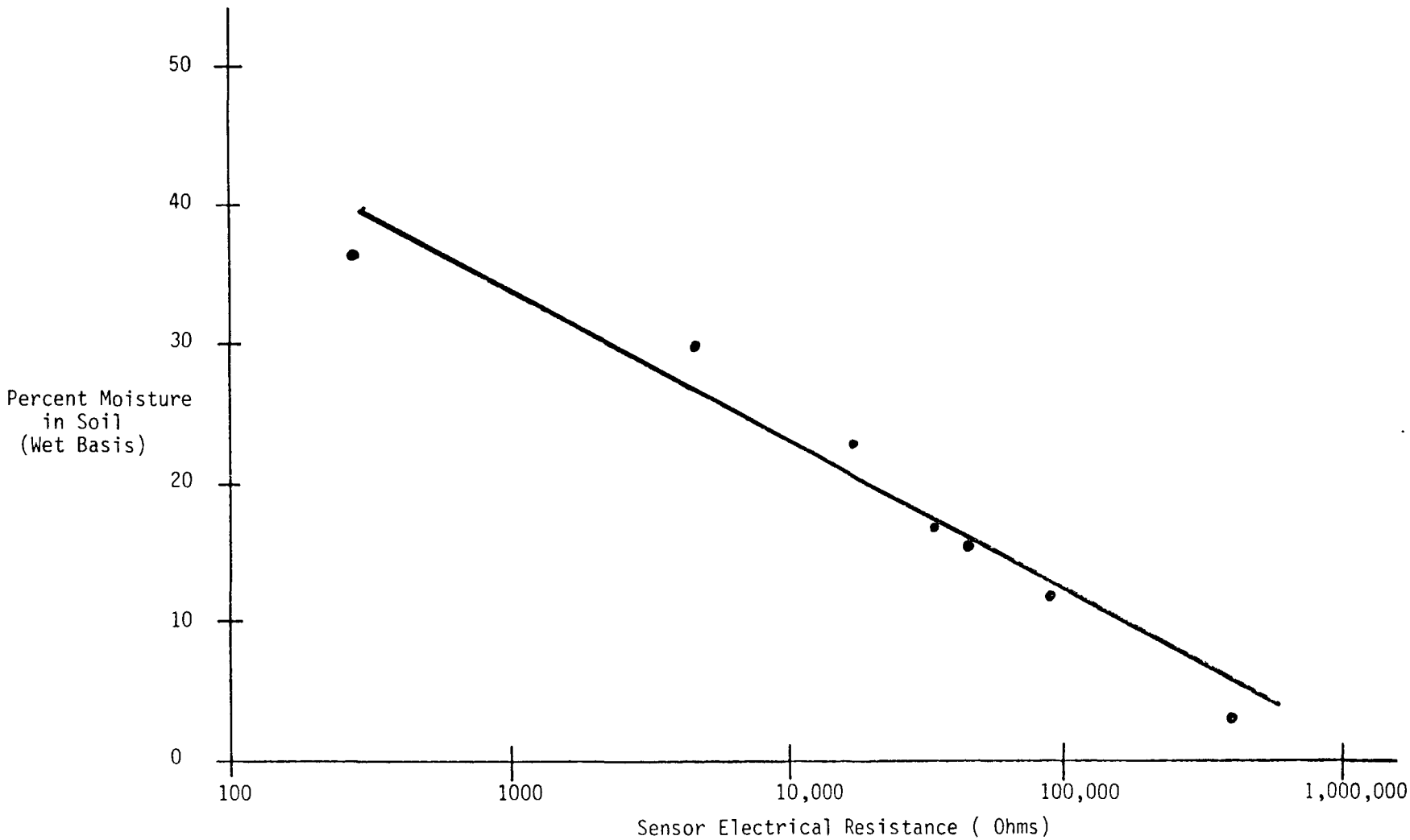

Figure 6.2 Ceramic Block Soil Moisture Sensor Calibration Curve

CHAPTER 7. CONCLUSIONS & RECOMMENDATIONS

Data for a complete heating season with the Ground Coupled Heat Pump system have been obtained with only a small fraction of that data being discarded. From these data it is concluded that the outdoor coil has adequate heat transfer capacity to supply the heating needs of TECH House I during an average winter season. The heating loads were met without auxiliary electrical resistance heat which would be required by a conventional air-to-air heat pump system.

The seasonal performance factor (SPF) with the entire heat pump package located within the conditioned space was 2.60, compared to 1.98 for a state-of-the-art (SOA) air-source heat pump in TECH House III during the same 1982-83 heating season (16), a 30% better SPF. These initial results are encouraging in view of the fact that a smaller, less efficient water-to-air coil was utilized from November 1 through mid-February and, further, that current commercially available water-source heat pump equipment is not designed for efficient performance in this ground-coupled application.

Although the capacity of the ground coil was adequate for the heating season, it is anticipated that the coil may be marginal or inadequate for the cooling season (See Appendix B). Data gathered during the 1983 cooling season should confirm or refute this opinion.

REFERENCES

(1) Kusuda, Achenbach, "Earth Temperature and Thermal Diffusivity at Selected Stations Stations in the United States," ASHRAE Transactions, Vol. 71, Part 1, 1965, pp. 61-74

(2) Gurr, Marshall, and Hutton, "Movement of Water in Soil due to a Temperature Gradient," Soil Science, Vol 74, No. 5, 1951, pp. 335-345.

(3) Salomone, Singh, and Fisher, "Geotechnical Considerations for Designing Underground Transmission Lines," Dames and Moore, 6 Commerce Drive, Crawford, N.J. 07016.

(4) Salomone, Fisher, and Watson, "Procedures Used to Evaluate the Thermal Properties of Soils Adjacent to Buried Extra High Voltage Lines," Journal of Testing and Evaluation, Vol 2, No. 6, A.S.T.M, 1974, pp. 496-502.

(5) Sepaskhah and Boersma, "Thermal Conductivity of Soils as a Function of Temperature and Water Content," Soil Sci. Soc. Am. J, Vol 43, 1979, pp. 439-444.

(6) de Vries, "Thermal Properties of Soils," Physics of Plant Environments. North-Holland Publishing Co, Amsterdam, 1963, Ch. 7, pp. 211-235.

(7) Woodside, "Calculation of the Thermal Conductivity of Porous Media," Canadian Journal of Physics, Vol 36, 1958, pp. 815-823.

(8) Gemant, "The Thermal Conductivity of Soil," J. Appl. PhyS, Vol. 21, 1950, pp. 750-752.

(9) Webb, "The Thermal Conductivity of Soil," Nature, Vol. 177, 1956, p. 989.

(10) Smith, "Thermal Conductivity in Moist Soils," Soil Sci. Soc. Am. Proc, Vol 4, 1939, pp. 32-40.

(11) Kersten, "Thermal Properties of Soils," Highway Research Board, Special Report #2, Frost Action in Soils - a Symposium, 1952, pp. 161-166.

(12) Makowski and Mochlinski, "An Evaluation of Two Rapid Methods of Assessing the Thermal Resistivity of Soil," Proceedings, Institute of Electric Engineers, Vol. 103, Pt A, No. 11, Oct. 1956.

(13) Smith and Yamuchi, "Thermal Conductivity of Soils for Design of Heat Pump Installations," ASHVE Transactions, V56, 1950, pp. 355-370.

(14) Holman, "Experimental Methods for Engineers," McGraw-Hill Publishing Co. Inc., 1978, pp. 110-117.

(15) Fisher, "Design of Ground-Coupled Heat-Pump System for the UT Solar House", Heat Pump Technolgy Conference, Paper XIII Oklahoma, State University Engineering Extension, 1982.

(16) Baxter and Moyers, "Air-Source Heat Pump: Field Measurement of Cycling, Frosting, and Defrosting Losses, 1981-83", ORNL/CON-150 (to be published.

APPENDIX A. Project History September 15, 1981-October 31, 1982

Work on the project began in mid October, 1981 as soon as the University of Tennessee received the contract (dated September 15, 1981) from ORNL. A literature search was conducted to determine which transfer fluid and ground coil pipe material would be best suited for the project. It was determined that thick walled polybutylene pipe and a water/methanol brine were the better choices of materials. Bob Fischer of Battelle had also reached the same conclusion. Bids on 900 feet (3 rolls @ 300ft each) of thick walled 1-1/4" polybutylene pipe were requested by the U.T. purchasing department during the first week of November, 1981. Low bidder was Vanguard Plastics Inc. with a price of 65¢/foot. The pipe was delivered to the TECH Facility on November 30, 1981.

The water-to-refrigerant heat exchanger specified by Battelle was a Standard Refrigeration Inc. model KY-500. That heat exchanger was also ordered and received during November, 1981.

UT-EERC received in the first week of December, 1981 the Battelle report specifying the layout of the ground coil. The design called for the coil to be at least 700 feet long and buried at least four feet deep. Due to the lack of sufficient open and flat space for a serpentine grid, it was determined that the coil should be installed as an isolated coil with at least six feet between the supply and return sections.

On December 8-9, 1981, the ground was trenched to an approximate depth of four feet and 700 feet of the polybutylene pipe was placed in the trench. At no point was any pipe run closer than six feet to an adjacent pipe run. At four points in the loop, the pipe depth was only 3 feet deep due to obstructions in the ground. Those obstructions were a telephone cable and rocks.

The ground coil was pressurized with water to 30 psig to check for leaks. After it was determined to be free of leaks, the trench was backfilled and tamped to eliminate air cavities near the pipe. The ground was then landscaped and seeded.

In January, 1982, the polybutylene ground coil was connected to the heat pump system. The ground coil pump, expansion tank, and fill valves were installed. The methanol and distilled water, provided by ORNL, were delivered at the end of January.

On February 5, 1982, the system was charged with the methanol/water solution. The system was then placed in the heating mode and operation began.

Instrumentation plans were finalized in February. The air side heat flow (ASHF) measurement (heat delivered to the conditioned space by the refrigerant-to-air coil) was installed but problems were encountered when calibration was attempted. The problem was that the ASHF calibration "constant" was not constant over a range of various heat inputs. Extenisve tests were made during February. It was concluded that (1) the old water to air coil still in the supply duct between the two temperature sensors was causing a significant thermal

lag in the ASHF measurement and (2) the return air duct (under negative pressure) was in such poor condition that a significant amount of crawl space air was being drawn into the duct.

By March 17, 1982 all the required modifications to make the ASHF measurement work properly were completed. The ASHF was successfully calibrated the afternoon of the 17th.

Installation and calibration of the watthour meters was completed on February 23, 1982. The meters measure electric power used by the (1) heat pump compressor, (2) circulation pump, (3) indoor fan, and (4) total house.

On March 3, 1982, ORNL delivered the electronics necessary to measure the energy flow into (GNDi) and from (GNDo) the ground. Calibration of the GNDi/GNDo energy flow was completed that afternoon. Also, at the time the flow-rate in the ground loop was determined to be 4.4 gpm. Even though a ground coil flow rate was never specified by Battelle, it was felt that this flow rate was too low for efficient operation. An experiment was conducted to ascertain the effect on ground heat flow with various flow rates. The flow was throttled and allowed to reach steady state conditions. A graph of the flow rate versus heat flow out of the ground is shown in Figure A.1. It was then decided that a larger circulation pump should be installed. ORNL personnel were to provide that pump.

On several occasions in March the heat pump compressor would build up high head pressure resulting in shut down of the compressor by the overload protection device. At other times, the refrigerant in the

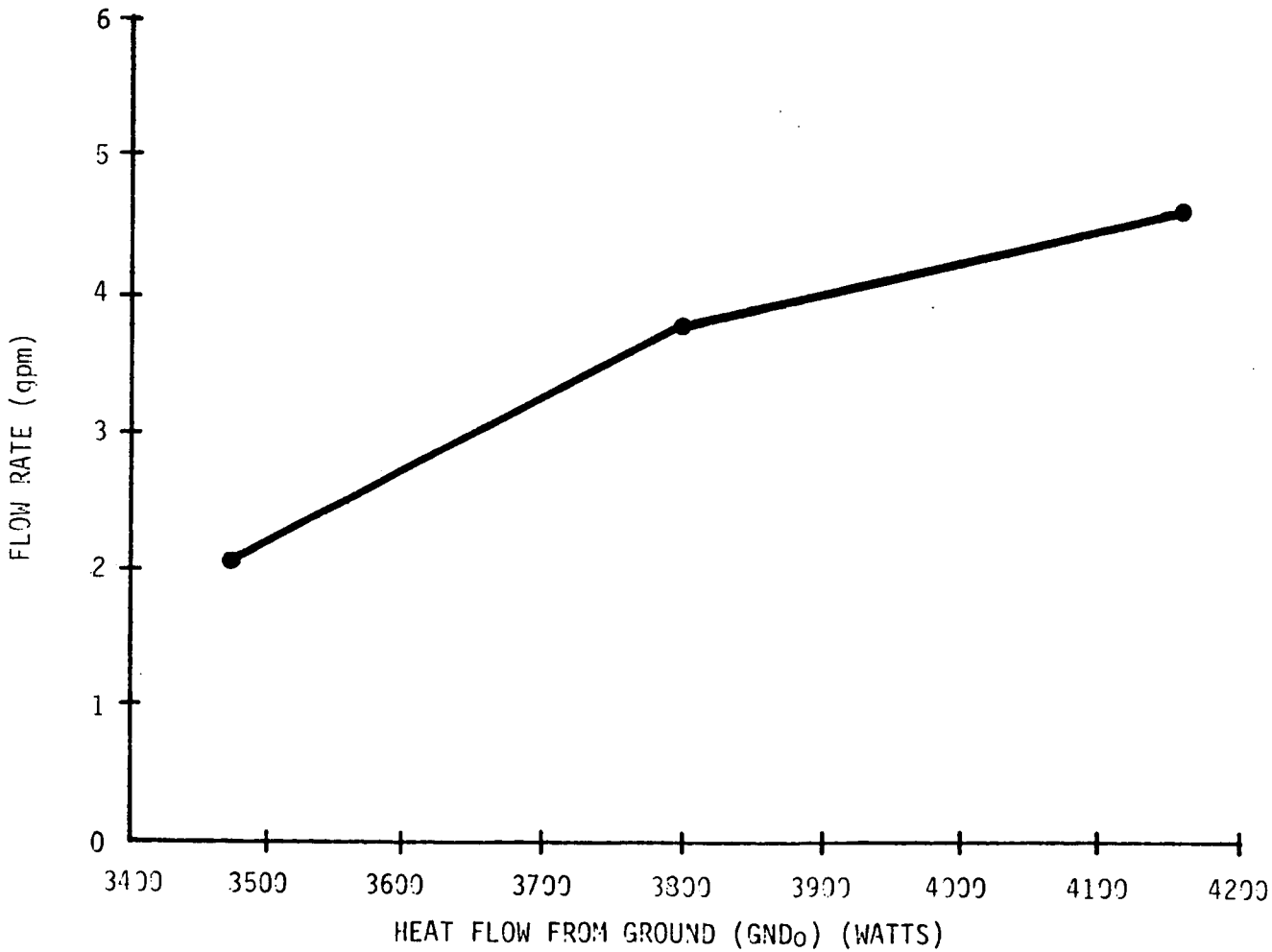

Figure A.1 Effect of Flow Rate on Heat Flow from Ground

condensor was condensing at only 80-85°F. A faulty refrigerant check valve was found to be the source of those problems.

During the last week of March, 1982, the compressor locked up. Apparently, liquid refrigerant had reached the compressor. A new compressor was ordered as well as an accumulator to prevent liquid from reaching the new compressor. Also, it was decided that the capillary tube on the indoor coil should be replaced with an expansion valve. These repairs and modifications were completed in early May, 1982.

During April, 1982 the cables to connect the ground resistance temperature devices (RTDs) to the electronic interface in TECH House I and from TECH House I to the DAS were cut, labeled, and installed. In early May, 1982 the RTDs for ground temperature measurement were delivered by ORNL. The RTDs were calibrated and installed on May 5, 1982. Gypsum moisture sensing blocks were also installed in the ground at the same time. Figure A.2 shows the positioning of the RTDs.

On May 20, a "split spoon" sample of the earth down to ten feet deep was made. The samples were taken at the surface, 4 feet, and 10 feet deep. The moisture content at those depths was, respectively, 23.8 percent, 25.8 percent, and 27.4 percent. A copy of the results of that sampling is in Appendix D. The ten foot deep hole was then utilized for placing of the ten foot deep probe and the surface probe. Due to an undetected leak in the refrigerant lines, the system was down from May 28 - June 3, June 5-10 and June 12-16.

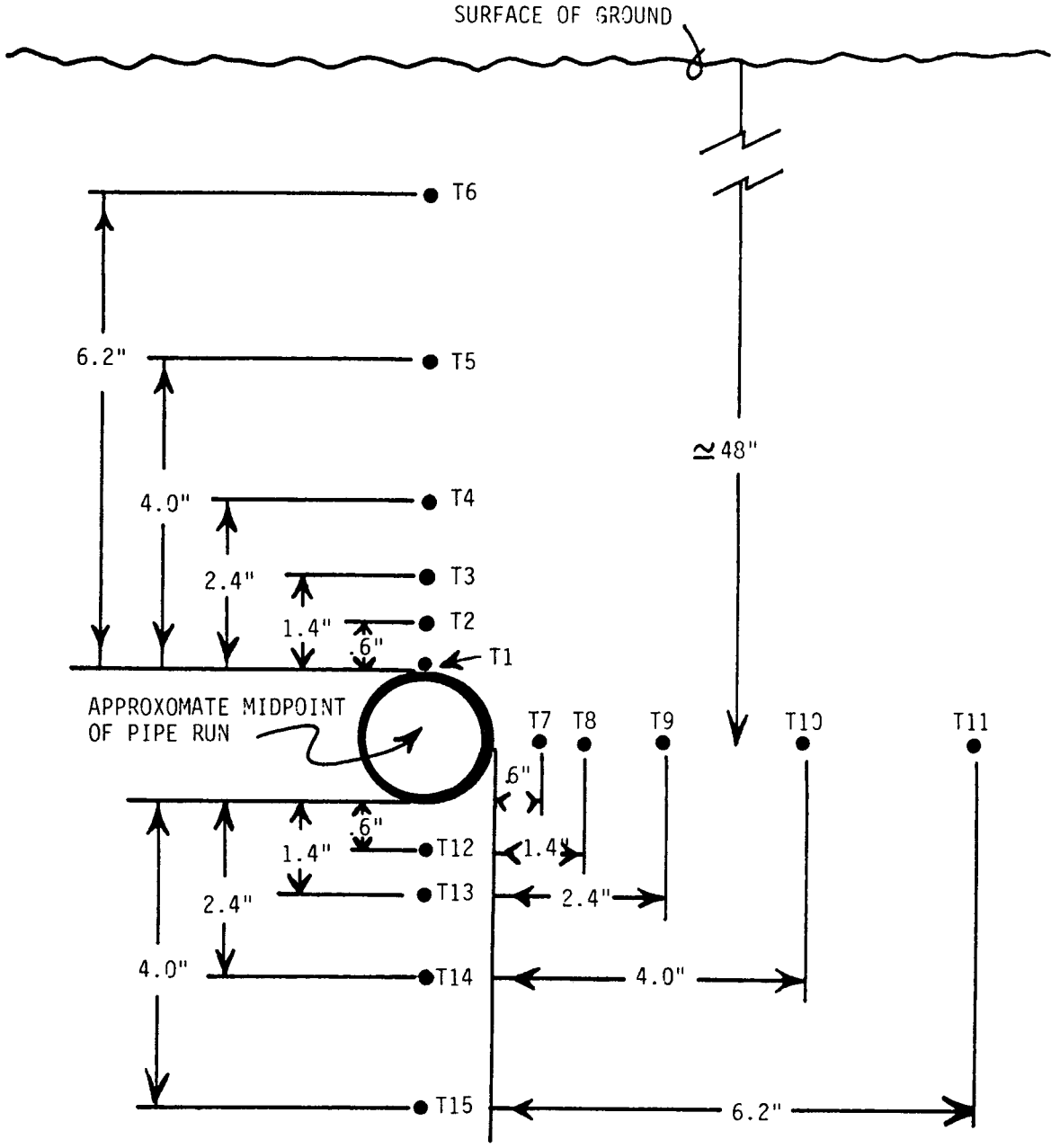

Figure A.2 Location of RTDs 1-15

On June 16 the leak was finally discovered and the system was operational until July 2, 1982.

On June 29 some steady state C.O.P. tests were performed on the system. It is desired to determine the C.O.P. curve over the range of operating temperatures. However, during the tests the temperature range was limited to 35.9°C - 40.0°C.

On July 2, the system automatically stopped operation due to high refrigerant pressure. Subsequent tests showed that when the fluid from the ground coil loop entering the condenser reached 41°C the compressor head pressure was sufficiently high enough to cause the thermal overload protection device to de-energize the compressor.

On July 13, a circulation pump with a greater capacity than the original pump was provided by ORNL and installed. The flow rate in the ground coil with this pump was measured to be 6.0 gpm. (The flow-rate with the original pump was 4.4 gpm). The higher flow rate mardedly improved the performance of the system. At a fluid temperature of 41°C, the compressor was consuming 560 watts of power less than with the former pump. However, the larger pump required 560 watts more power than the original pump. It was thought that the increased flow in the ground coil would eliminate the high head pressure problem. However, on July 17 the system again de-energized due to high head pressure. Subsequent tests revealed that the thermal overload device was de-energizing the compressor at a fluid temperature of 44.1°C entering the condenser.

On July 19 the ground water-to-refrigerant condenser was valved off and the outdoor refrigerant-to-air coil valved on. This change was made because there was a need to keep the building cool and it was desireable to have conventional cooling data for comparison.

On July 29 it was discovered that on the prior day the electric power to the TECH Facility had been off for about five hours due to utility lightning damage. During the same storm lightning also did extensive damage to the DAS for the entire TECH Facility. Every digital signal in the DAS was inoperative. Only six of the twenty-one RTD signals in TECH House I were operative. (The damage was not in the RTD itself but in the electronic circuitry.) All of the measurements related to the Ground Coupled Heat Pump Project were repaired by the end of August, 1982.

The ground water-to-refrigerant condenser was valved on in early August. However, due to an unknown (at that time) problem, the system would rapidly develop high head pressures (even at low entering water temperatures) and consequently the compressor would de-energize as a result of high head pressure. At that time, ORNL had already decided to utilize a TETCO water-to-water heat pump. Therefore, the existing heat pump system was dismantled to make room for the TETCO unit. When the heat pump system was dismantled a loose piece of brazing was found in the condenser. Evidently, it had been lodging against the check valve exiting the condenser, restricting refrigerant flow which resulted in excessive head pressure.

Installation of the TETCO water-to-water heat pump was completed in the early part of October. The piping was charged with a methanol-water brine (20% by weight of methanol). In the heating mode, the system would rapidly (2-4 minutes) build up high head pressure resulting in shut down of the compressor by the overload protection device. It was determined that under the existing water and air flow conditions the water-to-air coil in the system was not capable of transferring the heat to the space load at the rate being produced by the heat pump. It was decided to replace the water-to-air coil with one that would more closely match the heat release capability of the heat pump.

According to information supplied by ORNL personnel, the existing coil is capable of delivering 22.526 BTUH with 102°F intering water at 6.4 gpm and 1110 CFM air flow. It was estimated that the heat pump will deliver approximately 36,000 BTUH at the flow conditions stated above. After a considerable number of attempts at computer selection for a coil a replacement unit was identified. The replacement coil will deliver 36,000 BTUH with 105°F entering water at 9 gpm and 1100 CFM air flow. The same coil will closely match the cooling load of approximately 24,000 BTUH when the air flow rate is reduced to 800 CFM and the water flow rate is reduced to 4.1 gpm.

During the last week of October, 1982, the system was operated continuously for 72 hours in the cooling mode. Air entering the evaporator was preheated with electric resistance heat in order to more closely match summertime conditions and to provide comfort for the

building occupants. This test was made in order to analyze ground temperature response in the vicinity of the ground coil in the heat rejection mode.

APPENDIX B. Design Parameter Discrepancies

The installation of the ground coil for TECH House I followed the design recommendations furnished by Battelle Columbus Laboratories (15). Approximately 675 feet of pipe buried 4 feet deep serves as the ground coil for the heat pump. The recommendation for this pipe length was based on a cooling UA for TECH House I of 626 BTUH-°F or 1.57 tons at 78°F inside and 95°F outside temperature.

It is recommended that the calculations performed by Battelle Columbus Laboratories to optimize the ground coil be re-done using 3 tons as the design cooling load. At this time, it is felt that the resulting recommendation on coil length will increase somewhat over 700 feet. The cooling load for TECH House I has been calculated to be 1.83 tons at 78°F inside and 95°F outside temperature. The peak sensible cooling load when the maximum outdoor temperature was 88°F was measured to be 2.2 tons. One can reasonably assume that the sensible heat ratio of TECH House I is on the order of .75. As such, the total cooling load as measured during the above period of investigation is estimated to be approximately 2.96 tons. During periods of outdoor temperature greater than 88°F one would expect the total peak cooling load of TECH House I to be somewhat greater than 2.96 tons.

APPENDIX C. Downtimes

Data tapes from the D.A.S. would infrequently give values beyond the realm of possiblity (usually all 99999.999). These values usually reflected some discontinuity in data collection or a general system shutdown. A criterion was set for deciding whether a day had enough real values to be worthy of record. If a day had 1/2 or more of its values in error, then the day was not used in analysis.

Days with consistently erroneous values during the 82-83 heating season (Nov 82 - April 83) are:

12/12/82	
12/20/82	
2/15/83	Installed to new water to air side coil; also, D.A.S. was down.
3/9-3/14/83	D.A.S. inoperable

APPENDIX D Drilling Data

GEOLOGIC ASSOCIATES, INC.

Franklin, Tennessee 615 794-3596 Knoxville, Tennessee 615 573-7383

GA File 82-548

DRILLER'S LOG

SHIFT REPORT OF DRILLING OPERATIONS AT	ACES Site, Alcoa Highway, Knoxville, Tennessee		
HOLE LOCATION	located by Bernie McGraw - UT	SHIFT 1	DATE 5/20/82
SURFACE ELEVATION	determined by others	RIG NO. CME-55	HOLE NO. 1
DEPTH AT BEGINNING OF SHIFT	0.0	TOP ROCK	unknown
FOOTAGE FISHTAILED	--	BOTTOM OF HOLE	10.0
FOOTAGE SAMPLED	10.0	DRILLER	T. Lane
FOOTAGE CORED	--	HELPER	G. Akins
DEPTH AT END OF SHIFT	10.0	DRILLED FOR	University of Tennessee

SAMPLING RECORD

SPLE NO.	FROM	TO	SPLE BLOWS	DESCRIPTION AND REMARKS
1	0.0	1.5	3/5/5	Clay, silty, brown and yellowish-brown with traces
				of topsoil (fill): moisture content = 23.8%
Auger	1.5	4.0	-	Probably as above - moderately firm drilling
2	4.0	5.5	6/6/7	Silt, clayey, yellowish-brown mottled reddish-brown
				(natural ground): moisture content = 25.8%
Auger	5.5	8.5	-	Probably as above - firm drilling
3	8.5	10.0	5/6/6	Silt, clayey, brown mottled black (natural ground):
				moisture content = 27.4%
				Bottom of hole @ 10.0 - No refusal
				Hole dry upon completion.

GEOLOGIC ASSOCIATES, INC.

Franklin, Tennessee 615 794-3596 Knoxville, Tennessee 615 573-7383

GA File 82-644

DRILLER'S LOG

SHIFT REPORT OF DRILLING OPERATIONS AT U.T. Energy Environmental Resources Center, Alcoa Highway SITE

HOLE LOCATION	By U.T. Representative	SHIFT 1st	DATE 12/27/82
SURFACE ELEVATION	By U.T. Representative	RIG NO. ATV 550	HOLE NO. 2
DEPTH AT BEGINNING OF SHIFT	0.0	TOP ROCK ?	
FOOTAGE ~~DISHTURBED~~	Augered	BOTTOM OF HOLE 10.0	
FOOTAGE SAMPLED	10.0	DRILLER Lane	
FOOTAGE CORED		HELPERS Akins and Akins	
DEPTH AT END OF SHIFT	10.0	DRILLED FOR Mr. Bernie McGraw	

SAMPLING RECORD

SPLE NO.	FROM	TO	SPLE BLOWS	DESCRIPTION AND REMARKS
1	0.0	1.5	3/5/6	Light brown silty clay with weathered brown shale
	1.5	5.0		Brown weathered shale, firm drilling
2	5.0	5.5	51	Brown weathered shale
	5.5	10.0		Brown weathered shale, firm drilling
				No refusal at 10.0
				Hole dry on completion

Dist. Category UC-95d

INTERNAL DISTRIBUTION

1. V. D. Baxter
2. R. S. Carlsmith
3. F. A. Creswick
4. R. C. DeVault
5. R. D. Ellison
6-9. P. D. Fairchild
10. S. K. Fischer
11. W. Fulkerson
12. V. O. Haynes
13. F. R. Kalhammer, Consultant
14. S. V. Kaye, Consultant
15. T. R. LaPorte, Consultant
16. V. C. Mei
17. J. W. Michel
18. R. E. Minturn
19. W. R. Mixon
20. L. I. Moss, Consultant
21. J. C. Moyers
22. E. A. Nephew
23. W. H. Williams, Consultant
24-25. Central Research Library
26. Document Reference Section
27. Laboratory Records - RC
28-29. Laboratory Records Department
30. ORNL Patent Section

EXTERNAL DISTRIBUTION

31. Phil Albertson, Manager, Charles Machine Works, Inc., P.O. Box 66, Perry, OK 73077
32. C. H. Atkinson, Environmental Division, Acres Consulting Serv., Ltd., 5259 Dorchester Road, Niagara Falls, Ontario 12E G61
33. B. Backstrom, Chalmers University of Technology, Jordvarme Gruppen, S-41296, Goteborg, Sweden
34. Michael K. Bergman, Staff Scientist, American Public Power Association, 2301 M Street, N.W., Washington, DC 20037
35. W. Z. Black, Professor, School of Mechanical Engineering, GA Institute of Technology, Atlanta, GA 30332
36. James E. Bose, School of Technology, Oklahoma State University, Stillwater, OK 74078
37. David Cabot, President, Avondale Solar Corporation, P.O. Box 501, 44 Avondale Road, Westerly, RI 02891
38-42. James M. Calm, Project Manager, Heat Pump Development, Electric Power Research Institute, 3412 Hillview Avenue, Palo Alto, CA 94303
43. Lee Culpepper, Tennessee Valley Authority, 330 401 Building, Chattanooga, TN 37401
44. Barry J. Dempsey, Department of Civil Engineering, University of Illinois, Urbana, IL 61801
45. R. J. Denny, Air-Conditioning & Refrigeration Institute, 1815 N. Fort Meyer Drive, Arlington, VA 22209
46. Charles E. Dorgan, University of Wisconsin, 825 Extension Building, 432 North Lake Street, Madison, WI 53706
47. Richard Dougall, Department of Mechanical Engineering, University of Pittsburgh, Pittsburg, PA 15261

48. G. D. Duffy, Air Conditioning News, P.O. Box 2600, Troy, MI 48007
49. David G. Dutton, Vice President - Marketing, McElroy Manufacturing, Inc., P.O. Box 15580, Tulsa, OK 74112
50. John A. Edwards, North Carolina State University, Department of Mechanical and, Aerospace Engineering, P.O. Box 5246, Raleigh, NC 27607
51. Don Ellis, Genesis Energy Systems, Division of Hattersly & Sons, Inc., 3989 Mobil Avenue, Fort Wayne, IN 46896
52. R. J. Fiskum, Energy Conversion Equipment Branch, CE-113.2, Department of Energy, 1000 Independence Avenue S.W., Washington, DC 20585
53. Dan Folkmann, Center for Urban Community Development, University of Wisconsin-Milwaukee, 929 North 6th Street, Milwaukee, WI 53203
54. Victor Goldschmidt, Ray W. Herrick Laboratories, Purdue University, W. Lafayette, IN 47907
55. E. Granryd, Department of Applied Thermodynamics and Refrigeration, Royal Institute of Technology, S-10044 Stockholm, Sweden
56. Robert M. Gregson, Vice President, Alten Northwest, 1134 Poplar Place, S., Seattle, WA 98144
57. G. C. Groff, Director, Research Division, Carrier Corporation, Carrier Parkway, Syracuse, NY 13201
58. Floyd Hayes, Thermal Systems, The Trane Company, 3600 Pammell Creek Road, LaCrosse, WI 54601
59. Mark R. Hogan, Manager, Westinghouse Electric Corporation, R&D Center, Purdue Industrial Research Park, 1291 Cumberland Avenue, West Lafayette, IN 47906
60. Michael Hughes, Friedrich Air Conditioning & Refrigeration, 2007 Beechgrove Pl., Utica, NY 13507
61. Patrick J. Hughes, P.E., W. S. Fleming & Associates, Inc., 5802 Court Street Road, Syracuse, NY 13206
62. G. Hultmark, Secretary, Chalmers University of Technology, Jordvarme Gruppen, S-41296, Goteborg, Sweden
63. Douglas Jardine, Kaman Sciences Corporation, 1500 Garden of the Gods Rd., Colorado Springs, CO 80907
64. William S. Johnson, P.E., University of Tennessee, Energy, Environment and, Resources Center, Knoxville, TN 37916
65. W. A. Jury, Association Professor of Soil Physics, Department of Soil & Environ. Sci., University of California, Riverside, CA 92521
66. Herbert Kaufman, ARCO Comfort Products Company, 1271 Avenue of the Americas, New York, NY 10020
67. Richard Kurtz, Naval-Base-Housing Engineering, Naval Civil Engineering Laboratory, Port Hueneme, CA 93043
68. Edward A. Kush, 119 Woodbury Road, Huntington, NY 11743
69. Arvo Lannus, Residential & Commercial Applications, Electric Power Research Institute, 3412 Hillview Avenue, P.O. Box 10412, Palo Alto, CA 94303
70. Terry R. Larson, Marketing Services Manager, PLEXCO, 3240 N. Manniheim Road, Franklin Park, IL 60131
71. J. H. Lehr, Executive Director, National Well Water Association, 500 West Wilson Bridge Road, Suite 135, Worthing, OH 43085
72. Calvin D. MacCracken, Calmac Manufacturing Company, 150 South Van

Brunt Street, Englewood, NJ 07631

73. M. J. McCabe, Building Equipment Division, Department of Energy, CE-113, GH-068, 1000 Independence Avenue, S.W., Washington, D.C. 20585
74. Philip Metz, Brookhaven National Laboratory, Building 701, Upton, NY 11973
75. W. Calvin Moore, 360 Tri-Hill Drive, York, PA 17403
76. P. Munter, Teknologisk Institut, Gregersensvej, DK-2630 Tastrup, Denmark
77. Joseph P. Murphy, Director of Education and Training, Oasis Energy Systems, 4425 N. High Street, Columbus, OH 43214
78. Richard A. O'Neil, Niagara Mohawk Power Corporation, 300 Erie Boulevard West, Syracuse, NY 13202
79. Sven G. Oskarsson, Cantherm, 8089 Trans-Canada Hwy., St. Laurent, Quebec H4S 1S4
80. Jerald Parker, School of Mechanical & Aerospace Engineering, Oklahoma State University, 218 Engineer North, Stillwater, OK 74078
81. James R. Partin, GeoSystems, Inc., 3623 N. Park Drive, Stillwater, OK 74074
82. M. Porsvig, Danish Geotechnical Institute, 1 Maglebjergvej, DK-2800 Lyngby, Denmark
83. Gary G. Purcell, Electric Power Research Institute, 3412 Hillview Avenue, Palo Alto, CA 94303
84. Larry A. Raffensberger, Product Planning Manager, Borg Warner Central, Environmental Systems, P.O. Box 1592, York, PA 17405
85. J. Rizzuto, New York State Energy Research & Development Authorization, Agency Building No. 2, Rockefeller Plaza, Albany, NY 12223
86. G. Rosenbald, Chalmers University of Technology, Jordvarme Gruppen, S-41296, Goteborg, Sweden
87. J. D. Ryan, Energy Conversion Equipment Branch, CE-113.2, Department of Energy, 1000 Independence Avenue S.W., Washington, DC 20585
88. Maxine Savitz, 5019 Lowell Street, N.W., Washington, DC 20016
89. Paul W. Scanlon, Manager, Engineering, Burt, Hill, Kosar, Rittelmann Association, 400 Morgan Circle, Butler, PA 16001
90. F. Schabkar, Graz University of Technology, Kopernikusgasse 24, A-8010 GRAZ, Austria
91. Ralph Schlichtig, P.E., Unconventional Heat and Power Sources, 11212 3rd Avenue, S., Seattle, WA 98168
92. A. H. Schroer, Sales Development Manager, Shell Chemical Company, Polybutylene Department, One Shell Plaza, P.O. Box 2463, Houston, TX 77002
93. Howard N. Shapiro, Department of Mechanical Engineering, Engineering Research Institute, Iowa State University, Ames, IA 50010
94. David N. Shaw, Shaw Engineering Associates, 1799 Farmington Avenue - Building B, Unionville, Conn. 06085
95. Graham Siegel, TVA Chattanooga, Research & Development, 1850 Commerce Union Bank Building, Chattanooga, TN 37401
96. Gary Skartvedt, American Heliothermal Corporation, Denver, CO 80222

97. Mason Somerville, Professor, Department of Mechanical Engineering, University of Arkansas, Fayetteville, AR 72701
98. Mario A. Sophocleous, Kansas Geological Survey, University of Kansas, Lawrence, KS 66044
99. Don Stephenson, National Research Council, Division of Buildings Research, Montreal Road, Ottawa, Canada KIA OR6
100. Lee Sumner, Research Engineer, York Division, Borg-Warner Corporation, P.O. Box 1592, York, PA 17405
101. O. J. Svec, Geotechnical Section, Division of Building Research, National Research Council of, Canada, Ottawa, Ontario KIA OR6
102. M. Keith Swinehart, Vanguard Plastics, Inc., 831 N. Vanguard Street, McPherson, KS 67460
103. Ralph Tilney, Alco Controls, 336 Chasselle, St. Louis, MO 63141
104. S. E. Veyo, Manager, Heat Exchange Systems, Westinghouse R&D Center, 1310 Beulah Road, Pittsburgh, PA 15235
105. Warren W. Walkley, Manager, Energy Office, General Electric Company, 777 14th Street, NW, Washington, DC 20005
106. Michael R. Warfel, Senior Scientist, Geraghty & Miller, Inc., 6800 Jericho Turnpike, Syosset, NY 11791
107. Jeffrey W. Wright, Engineering Consultant, Kansas Gas and Electric Company, Wichita, KS
108. Office of the Assistant Manager for Energy R&D, U.S. Department of Energy, Oak Ridge Operations, Oak Ridge, TN 37831

109-135. Technical Information Center, Department of Energy, P.O. Box 62, Oak Ridge, Tn 37831