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ABSTRACT

Performance of the ground-coupled heat pump system in TECH House I at the Tennessee Energy Conservation in Housing Facility is reported for the summer of 1983. The overall seasonal performance factor (SPF) was 1.11 with the system located within the conditioned space. If the system had been outside the conditioned space, an SPF of 1.31 would have been realized. This low performance level, below that of a conventional air-to-air heat pump, is primarily due to poor performance of the ground heat exchanger. Degraded soil heat transfer characteristics due to drying and the occurrence of voids around the pipe in the trench backfill were primary reasons for poor performance. In addition, it appears that the underground coil length needs to be increased in order to match the peak cooling loads of the house.

The sensible load on the house was met by the system only for ambient temperatures below 98°F. The latent load was often not met because the inside coil temperature was not sufficiently below the dew point temperature of the inside air.

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CHAPTER 1. INTRODUCTION

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

The GCHP was utilized during the winter of 1982-83 to provide space heating for TECH House I, as described in Reference [1].

This report deals with the 1983 cooling season operation of the GCHP located in TECH House I. Data were recorded hourly with few interruptions throughout the cooling season and are presented and discussed herein.

CHAPTER 2. SYSTEM DESCRIPTION

Figure 2.1 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 manually controlled three way valves as shown in Figure 2.1.

A plan view of the ground coil layout is depicted in Figure 2.2. The pipe, which is 675 feet in length, is polybutylene nominal 1-1/4" IPS and is buried approximately four feet deep. A complete description of the system is given in Reference [1].

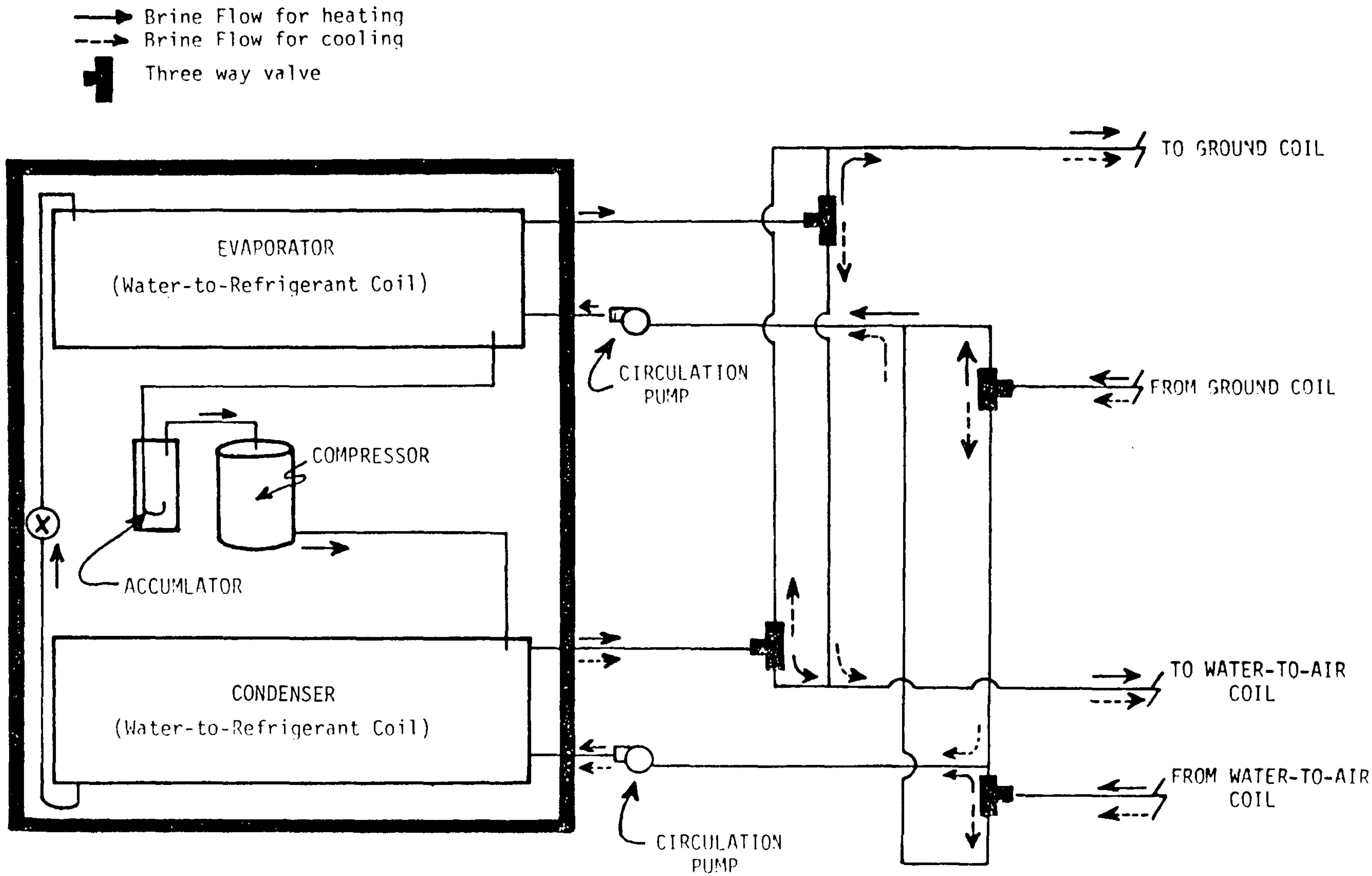


Figure 2.1 Schematic of Ground Coupled Heat Pump

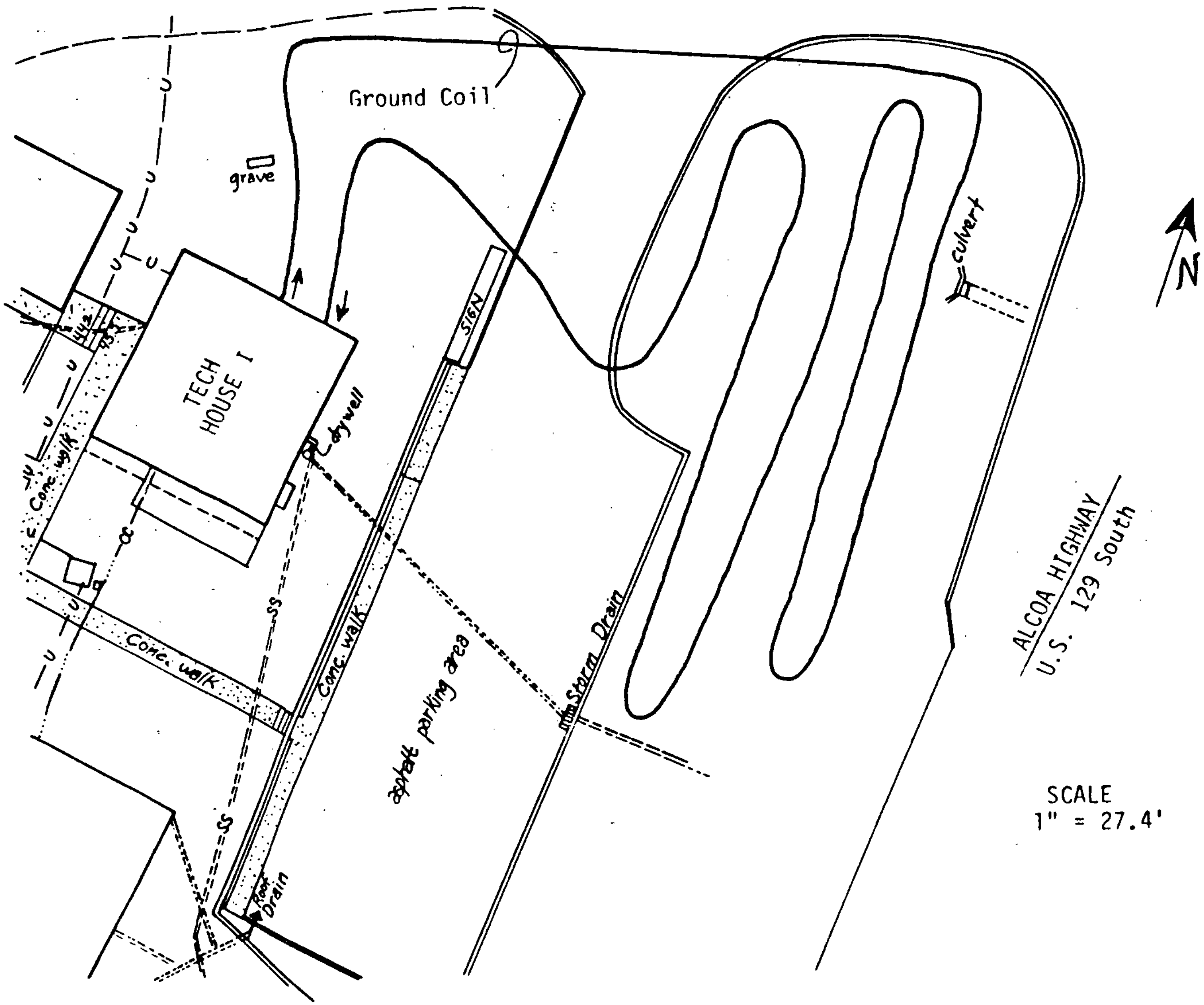


Figure 2.2 Plan View of Horizontal Ground Coil

CHAPTER 3. INSTRUMENTATION

Table 3 is a listing of all the measured parameters from the ground coil heat pump system. Conditioned space dry and wet bulb temperature measurements are made with solid state temperature transducers. All other temperatures are measured with platinum resistance temperature devices (RTDs) using standard resistance thermometry.

The location of the RTDs and soil moisture sensors in the vicinity of the pipe are depicted in plan view in Figure 3.1. The location of the RTDs 1-15 near the midpoint of the ground are depicted in elevation view in Figure 3.2.

Ceramic soil moisture sensing devices were utilized to measure the moisture content of the soil. The electrical resistivity of these devices changes with moisture content. Figures 3.3 and 3.4 depict their location relative to the ground coil.

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.

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 latent cooling load is measured by recording the total mass of condensate removed from the air by the water-to-air coil. The condensate flows by gravity through a pipe to a tipping bucket rain gauge. Each tip of the bucket sends a 10 volt digital signal to the

Table 3. Measured Parameters

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

RTD #	MEASUREMENT
1 thru 15	T1 thru T15 Ground temperatures near pipe midpoint (See Figure 3.2 for location)
16	Surface of ground
17	Ten feet deep in ground
18	Temperature of pipe 169 feet from where it enters the ground (25% of pipe length)
19	Temperature of pipe 506 feet from where it enters the ground (75% of pipe length)

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

GRND (Heat flow into/from the ground)
WTAC (Water-to-air coil)
Cond (pounds of condensate)
HTPu (Heat pump compressor)
BLWR (Blower)
Phtg (Circulation pumps)
SOLR (Tech house 1 total power)

**************************OTHER MEASUREMENTS*************************

$GRND_i$	(Temperature of brine entering the ground coil)
$GRND_o$	(Temperature of brine exiting the ground coil)
Hdry	(Space dry bulb temperature)
Hwet	(Space wet bulb temperature)
Fan_i	(Temperature of brine entering the water-to-air coil)
Fan_o	(Temperature of brine exiting the water-to-air coil)

************************MOISTURE MEASUREMENTS***********************

SENSOR #	MEASUREMENT
31 32	Soil moisture sensors located near end of ground coil (Figure 3.4)
33 34	Soil moisture sensors located near beginning of ground coil (Figure 3.4)
35 thru 43	Soil moisture sensors located near midpoint of ground coil (Figure 3.3)

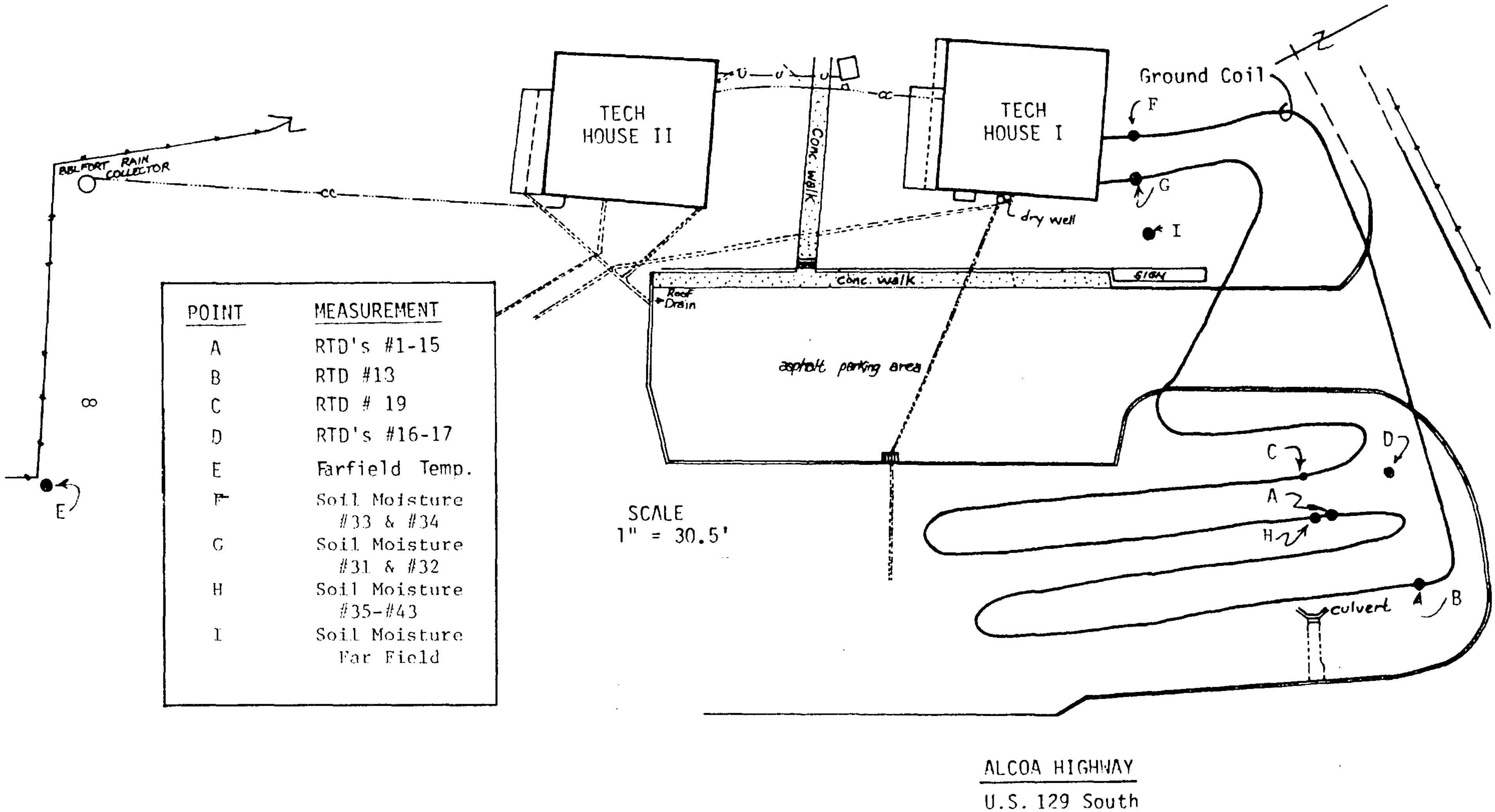


Figure 3.1 Plan View of Horizontal Ground Coil Showing Sensor Locations

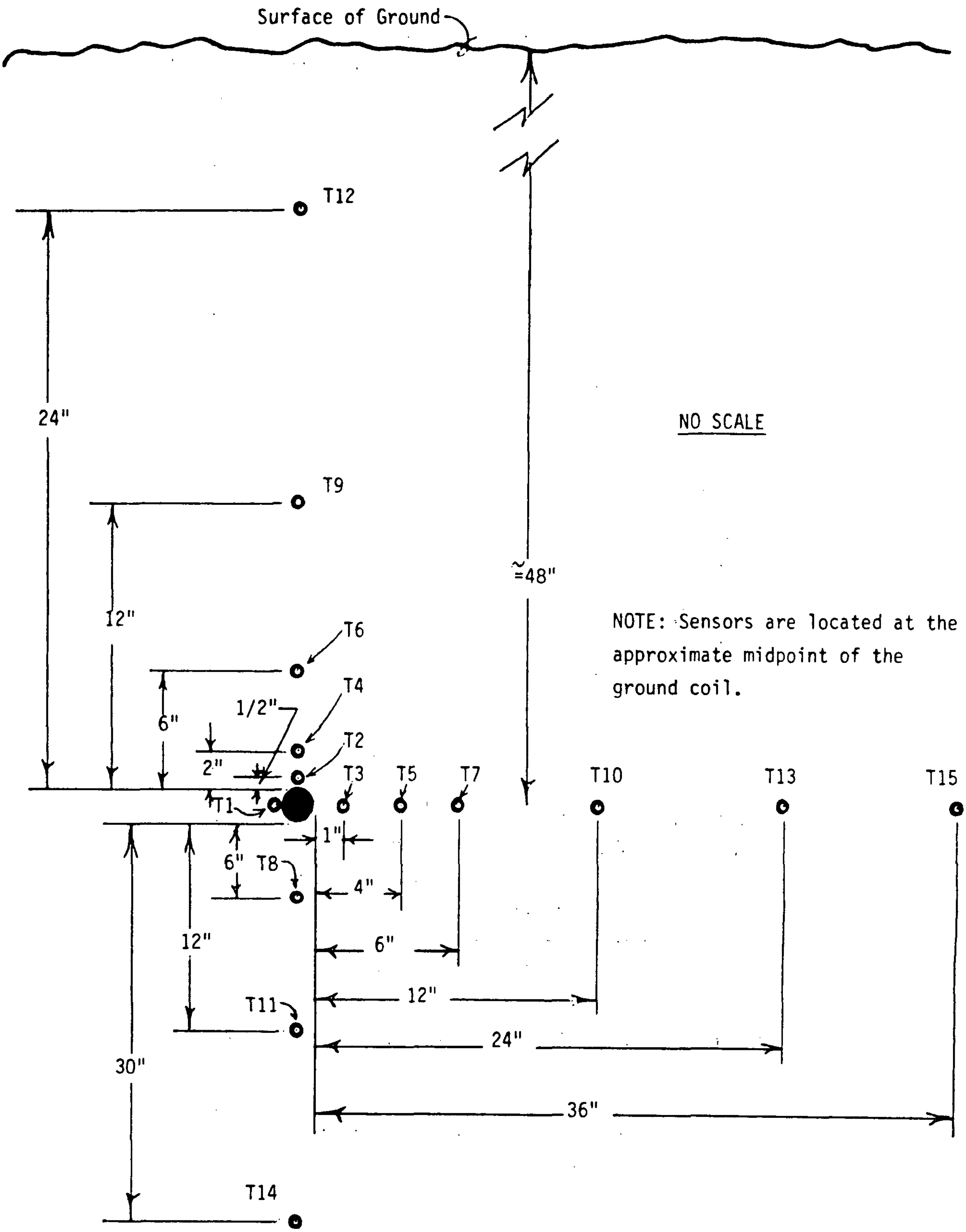
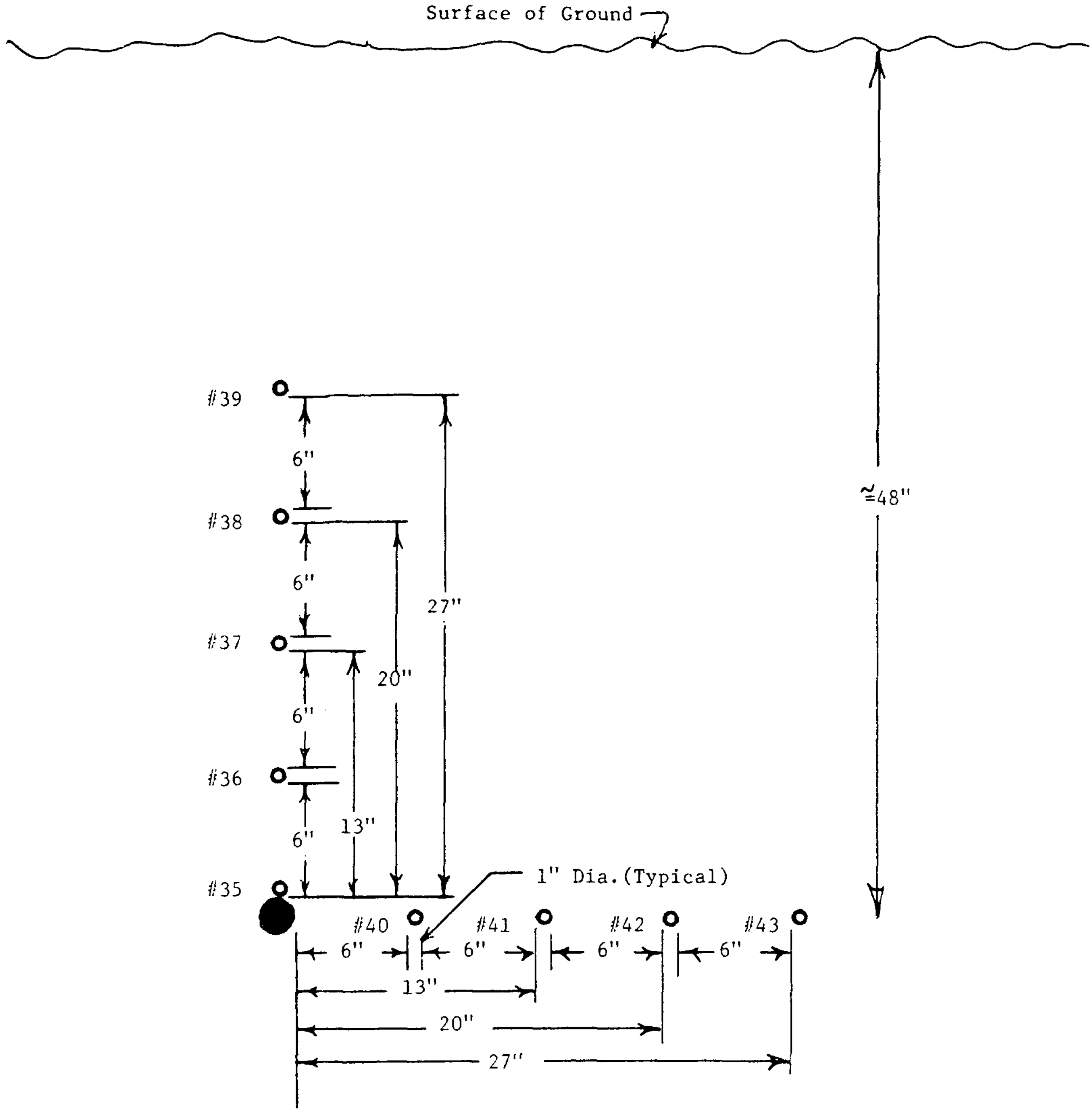
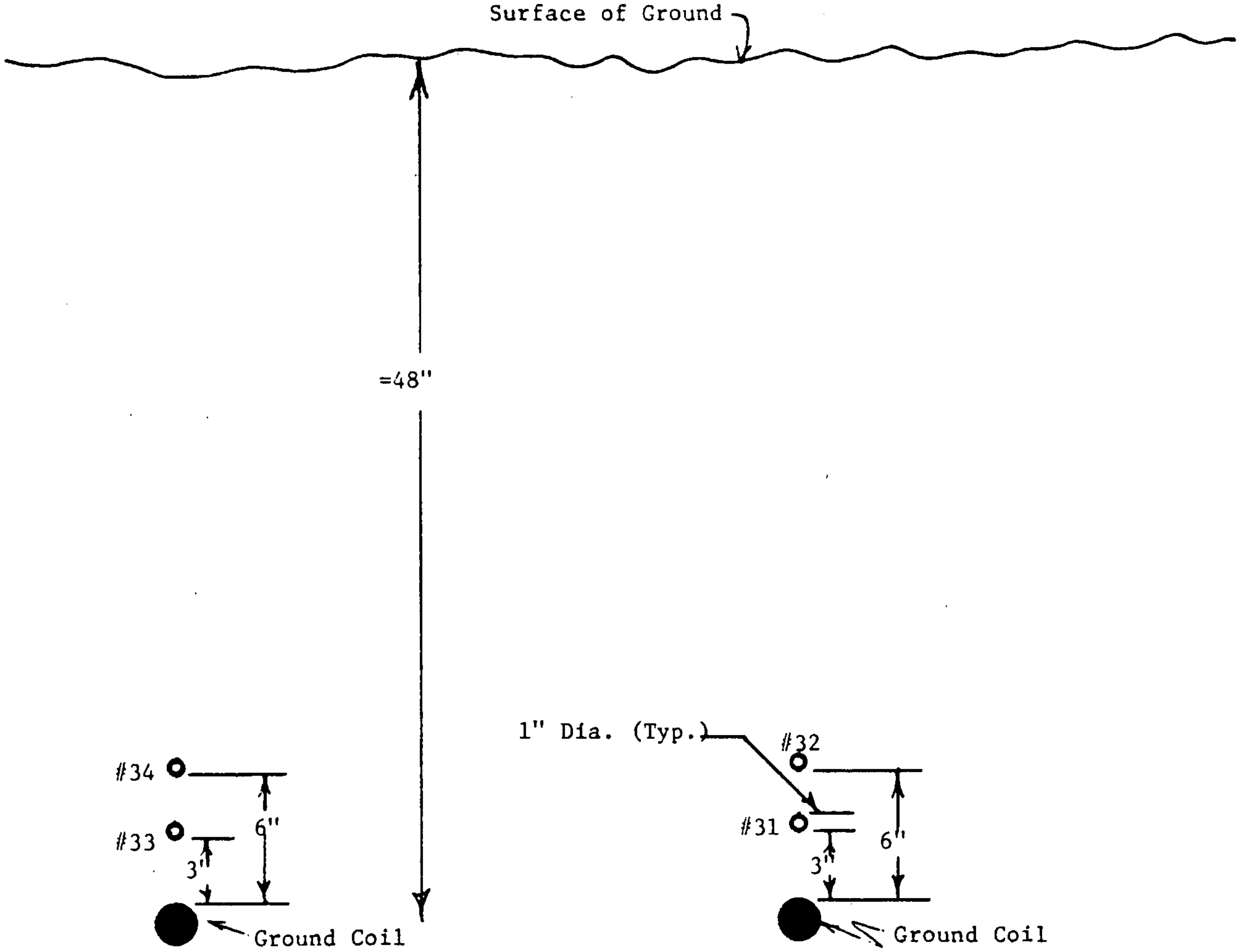


Figure 3.2 Location of Ground Temperature Probes(T1-T15)



NOTE: Sensors are located at the approximate midpoint of the ground coil

Figure 3.3 Location of Ceramic Soil Moisture Sensors #35 through 43



Note: Located near beginning of ground coil. See Point F on Figure 3.1 for further details.

Note: Located near end of ground coil. See Point G on Figure 3.1 for further details.

Figure 3.4 Location of Ceramic Soil Moisture Sensors #31 through 34 data acquisition system (DAS). Knowing the mass of water required to tip the bucket, one can then determine the mass of the condensate.

The digital heat flow and electric power signals from the different modes of system operation are accumulated by counters. Each hour on the hour the counters are summed (and then zeroed) and the analog signals are scanned. These data are recorded on magnetic tape and printed on paper. 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 used to produce weekly reports of the ground coupled heat pump system performance.

CHAPTER 4. THERMAL PERFORMANCE DATA

A ground-coupled heat pump must operate with a higher yearly system efficiency than an air-to-air heat pump in order to justify the higher initial cost. Therefore, heat must be transferred to and from the soil in an efficient manner. Physical and thermal properties of the soil, such as moisture, density, and thermal conductivity play an important role in the heat transfer phenomena. A detailed discussion of the role that soil plays in heat transfer is presented in Reference [1].

4.1 Heat Pump Performance Data

The coefficient of performance (COP) is useful for evaluating the thermodynamic efficiency of a heat pump system. As discussed herein, the COP does not consider the interaction between the heat pump and the conditioned space. It is defined as the ratio of the cooling energy provided by the water-to-air coil to the electric power consumption of the heat pump.

$$COP = Q_a/W \qquad (4\text{-}1)$$

where, Qa = cooling energy delivered through the water-to-air coil, and
W = total system electric power consumption.

Table 4.1 presents the weekly heat pump COP for the summer of 1983.

Figure 4.1 is a plot of hourly COP. This figure illustrates the system performance deterioration with respect to time. In order to minimize the transient effects of the heat pump system upon the plot, data were not used unless the heat pump was operating for 80 percent of a given hour. There are several reasons for the performance deterioration. First the house cooling load was underestimated during the design phase of the heat pump which led to a possible undersizing of the ground coil heat exchanger (See Appendix B). Second, the cooling loads steadily increased during the summer with June being cooler than normal and July and August being warmer than normal. The total cooling degree days were about 7 percent higher than the average (See Appendix D.)

Table 4.1. Heat Pump Performance Data

		Electric Power Consumption			
Week Beginning	Water to Air Coil (kWh)	Compressor (kWh)	Blower (kWh)	Pumps (kWh)	COP
6/6/83	98.6	42.1	5.8	4.0	1.90
6/13/83	134.5	54.0	7.8	5.5	2.00
6/20/83	464.6	202.0	32.8	21.5	1.81
6/27/83	453.5	217.6	35.2	22.8	1.64
7/4/83	356.7	173.3	28.2	17.9	1.63
7/11/83	548.1	292.9	45.7	28.8	1.49
7/18/83	588.4	327.7	50.1	31.4	1.44
7/25/83	550.1	312.8	48.9	30.1	1.40
8/1/83	639.8	360.8	53.9	34.3	1.42
8/8/83	541.9	312.1	46.1	29.6	1.40
8/15/83	618.1	354.5	52.7	33.6	1.40
8/22/83	671.2	448.3	65.2	41.6	1.21
8/29/83	473.1	305.1	45.2	29.1	1.25
9/5/83	435.4	261.8	38.6	25.1	1.34
9/12/83	136.2	75.2	10.7	7.0	1.47
9/19/83	72.8	42.3	5.7	3.7	1.41
9/26/83	0.0	10.2	0.0	0.0	0.0

Third, soil drying early in the summer reduced soil thermal conductivity. In addition to normal drying from the heated pipe, the rainfall during the summer of 1983 was substantially lower than normal (See Appendix D). Soil drying affected the system performance in two

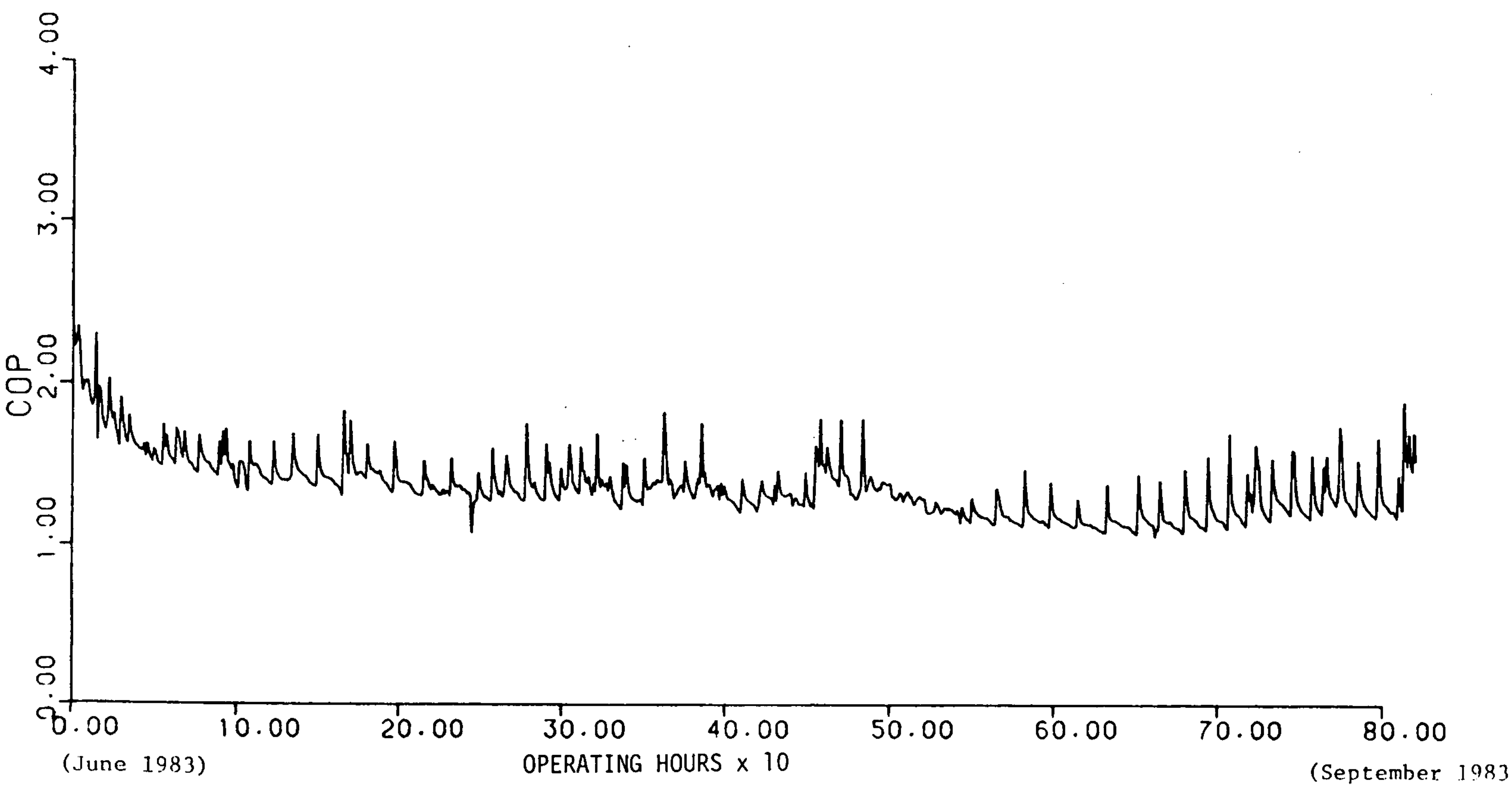


Figure 4.1 Steady State COP Deterioration During the Summer

different ways; the expected reduction in soil thermal conductivity with reduced moisture, and the drying out of void spaces around the pipe (See Section 4.4). During the winter season, these void spaces filled with water and had little effect on performance, but for the summer season, the moisture was driven off leaving air pockets having very low thermal conductivity.

The seasonal performance factor (SPF) is useful for evaluating the overall efficiency of a heat pump system. The cooling SPF based on the net cooling effect delivered to the conditioned space considers the interaction between the heat pump and the conditioned space. That is, any internal heat source associated with the operation of the heat pump system is subtracted from the total cooling delivered by the evaporator. This can be expressed mathematically as,

$$SPF = (Q_a - Q_{IL})/W \qquad (4\text{-}2)$$

where Q_{IL} is the summation of internal heat sources associated with the operation of the heat pump and Q_a and W are as defined previously. The SPF is based on totals of the cooling capacity, internal heat sources and work.

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_1 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 cooling SPF_1 is then calculated as,

$$SPF_1 = \frac{WTAC-BLWR-PUMPS-CCL}{POWER} \quad (4-3)$$

where:

WTAC is the water-to-air coil heat flow.
BLWR is the electric power consumed by the blower.
PUMPS is the electric power consumed by the circulation pumps.
CCL is the compressor can loss calculated as the sum of the WTAC and compressor electric power consumption less the ground coil heat flow.
POWER is the total system purchased electric power.

SPF_2 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 cooling SPF_2 is then calculated as,

$$SPF_2 = \frac{WTAC - BLWR}{POWER} \quad (4-4)$$

Table 4.2 presents the heat pump performance data for each month and the entire cooling season. Clearly, locating the heat pump package outside the conditioned space is more beneficial than locating it inside the space during summer months. The converse is true, however, in winter months.

Table 4.2. Monthly Heat Pump Performance Data

	Electric Power (kWh)				Heat Flows (kWh)			
Month	Blwr	Pumps	Comp	Total	WTAC	GRND	SPF_1	SPF_2
Jun	67	45	426	538	968	1274	1.37	1.67
Jul	187	118	1197	1502	2227	3218	1.14	1.36
Aug	242	154	1631	2027	2701	4130	1.04	1.21
Sep	77	50	538	665	891	1373	1.06	1.22
Jun-Sep	573	367	3792	4732	6787	9995	1.11	1.31

WTAC: Water-to-Air Coil Heat Flow
GRND: Ground Coil Heat Flow

The overall seasonal performance factor for the cooling system is poor when compared to air-to-air heat pump systems. For comparative purposes, the SPF for the TECH house III air-to-air heat pump system was measured and was found to be about 2.3 for the same time period [2]. However, the compressor used in TECH House III is more efficient than that used in TECH House I, and is also outside the conditioned space. Therefore, the TECH House III air-to-air heat pump SPF cited is intended only for a rough comparison of performance.

Figures 4.2, 4.3, and 4.4 present the hourly ground coil temperature, hourly soil temperature 0.5 inches from the coil, and hourly soil temperature 6.0 inches from the coil, respectively. From these figures, it can be seen that there is a large amount of damping of the cyclic temperature swing 0.5 inches from the coil. The temperature swing is due to the cyclic operation of the heat pump. At a distance of 6.0 inches from the coil the temperature swing is almost entirely damped out. During winter operation, however, the temperature swing at this location was greater, indicating the expected response for a higher soil thermal conductivity.

In order for the cooling system to provide for dehumidification (1) the system must operate a sufficient amount of time (usually no more than three on-off cycles per hour) and (2) the temperature of the coil must be sufficiently below the dew point of the air in the conditioned space. A coil temperature of 45°F is generally sufficient to provide for dehumidification.

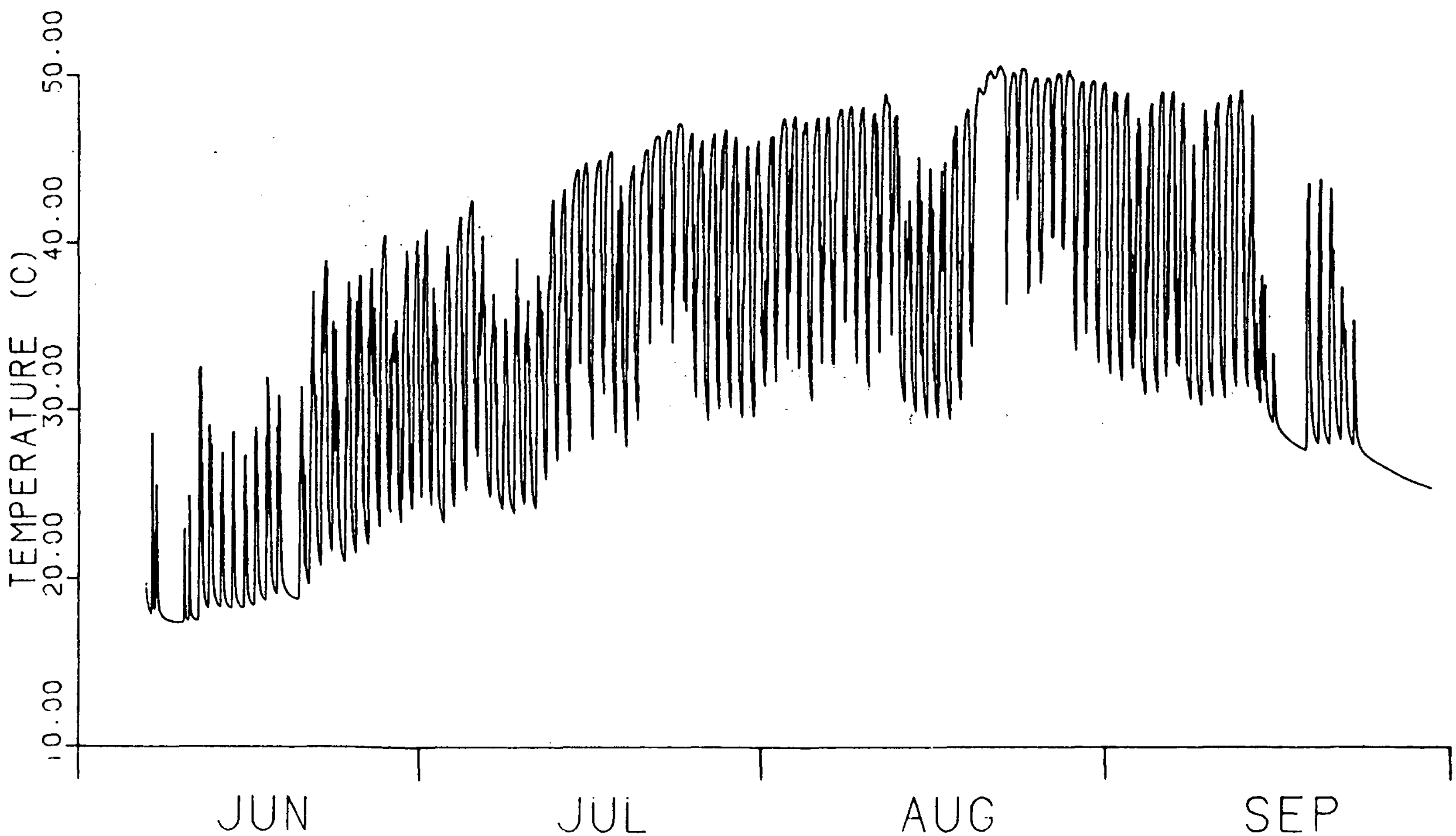


Figure 4.2 Hourly Temperature of Ground Coil Wall (Measurement T1, Data #120)

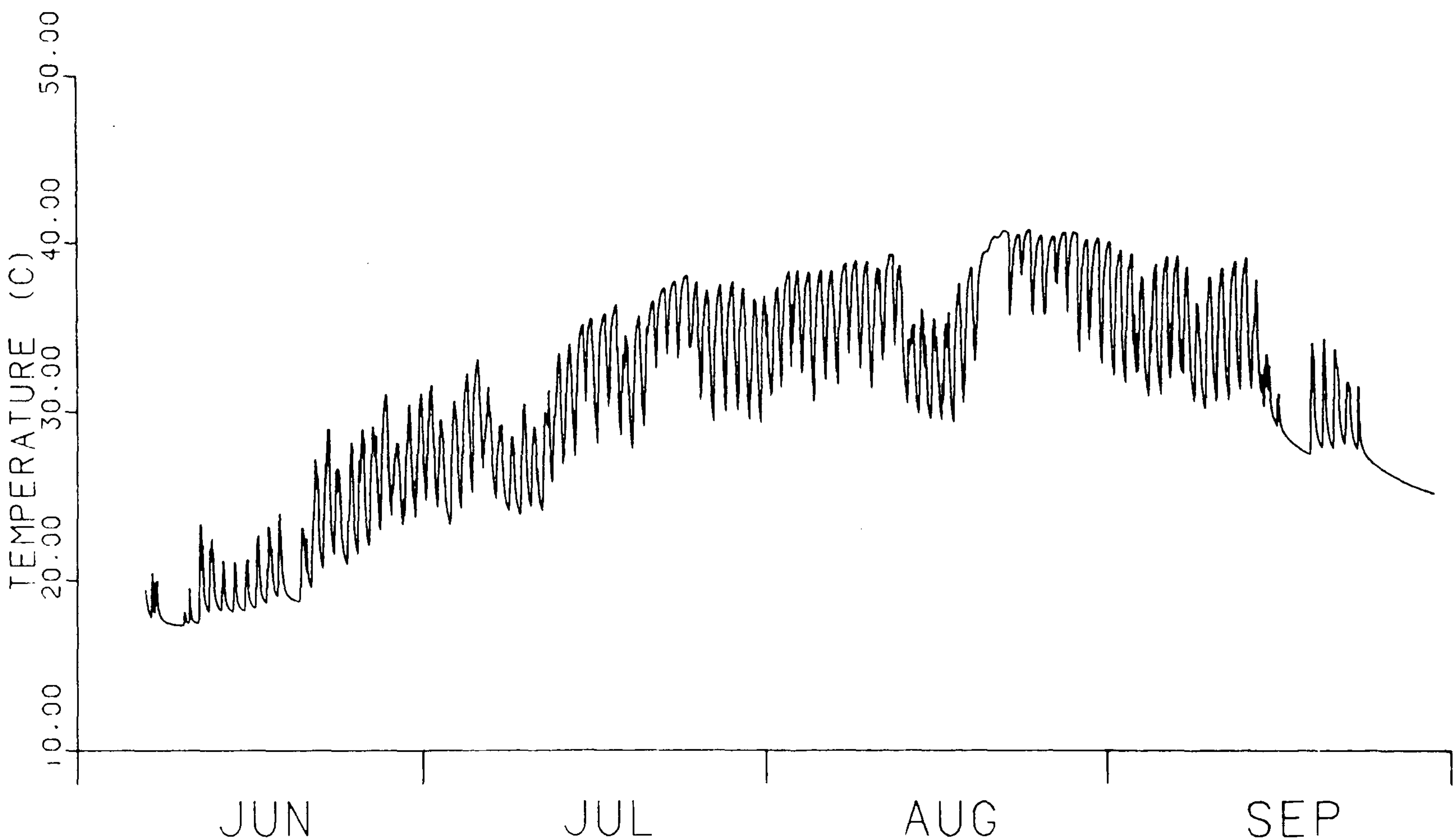


Figure 4.3 Hourly Temperature of Soil 0.5 Inches above Ground Coil (Measurement T2, Data #121)

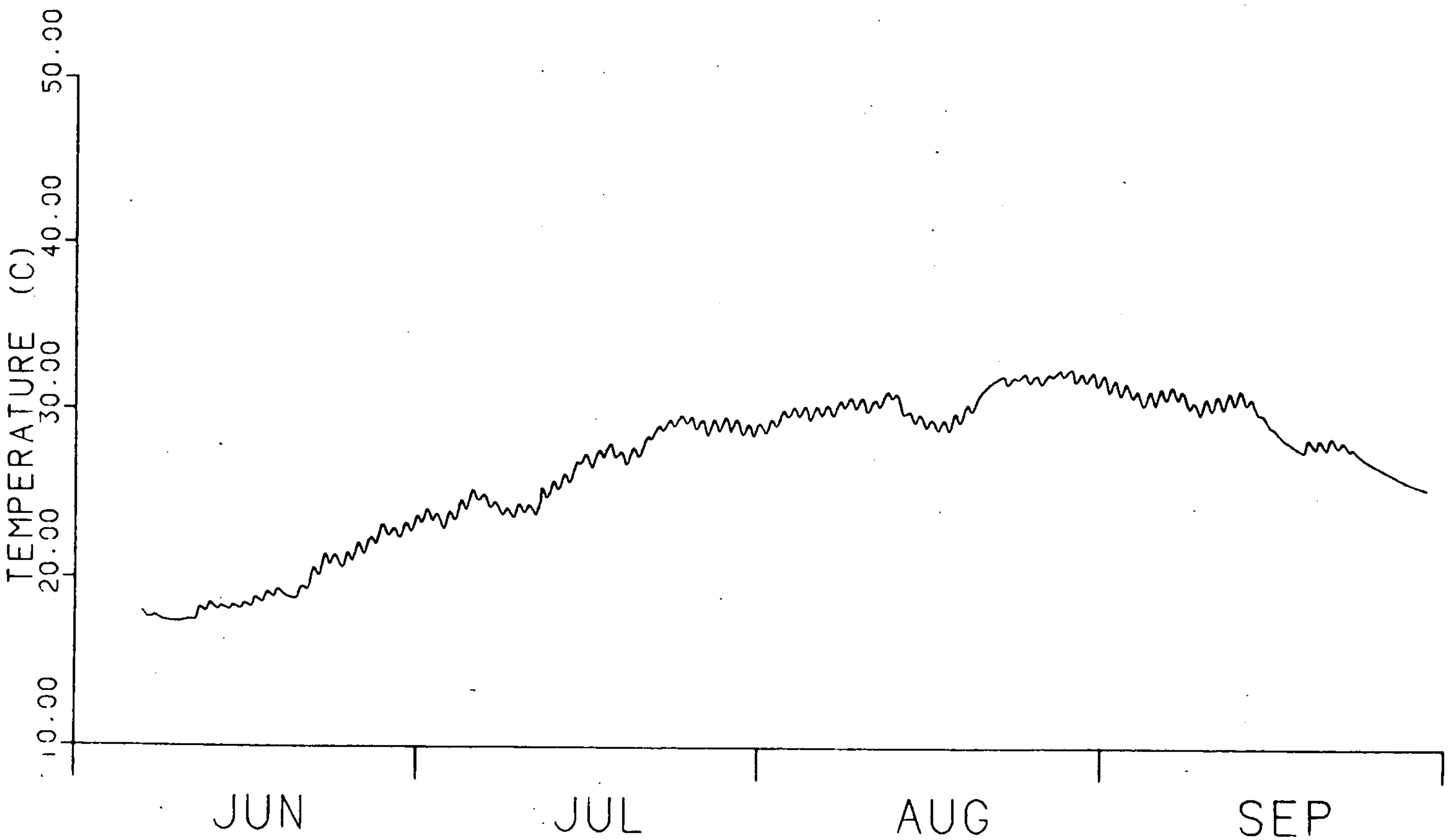


Figure 4.4 Hourly Temperature of Soil 6.0 Inches Horizontal from Ground Coil (Measurement T7,Data #126)

Figure 4.5 is a plot of the temperature of the brine entering the water-to-air coil. During the first 2-3 weeks of June, the brine temperature was about 45°F. After that time, however, the temperature rose to about 60°F. The latent load was measured to be only 10 percent of the total cooling load. The latent load is typically 25 percent of the sensible cooling load in residential buildings [3]. Although the system provided most of the sensible cooling load, only a fraction of the latent load was met. Consequently, the system was unable to maintain the conditioned space within the human comfort zone. A complete tabulation of brine temperatures and soil temperatures for the last three seasons (1982-83 heating season, 1983 cooling season, and 1983-84 heating season) will be included as an appendix in the next report in this series.

4.2 Experimental Soil Thermal Conductivity

Since the performance of a ground-coupled heat pump can be significantly limited by the thermal conductivity of the soil, thermal conductivity was calculated using measured temperature and energy flow data. The heat transfer from the ground coil to the surrounding soil was modeled as steady one dimensional radial heat flow through a composite horizontal cylinder. It was assumed that there was no mass transfer and the soil was homogenous. The thermal conductivity was assumed to be constant for a given hour of data.

Any transient effects due to heat pump cycling were minimized by using only data that met a certain criterion. The heat pump had to be operating a minimum of 54 minutes during a given hour for the data to be accepted. Otherwise, the data were discarded. A total of 769 data points met the criterion. Figures 4.6 and 4.7 show typical temperature profiles under conditions which met the above criterion. These

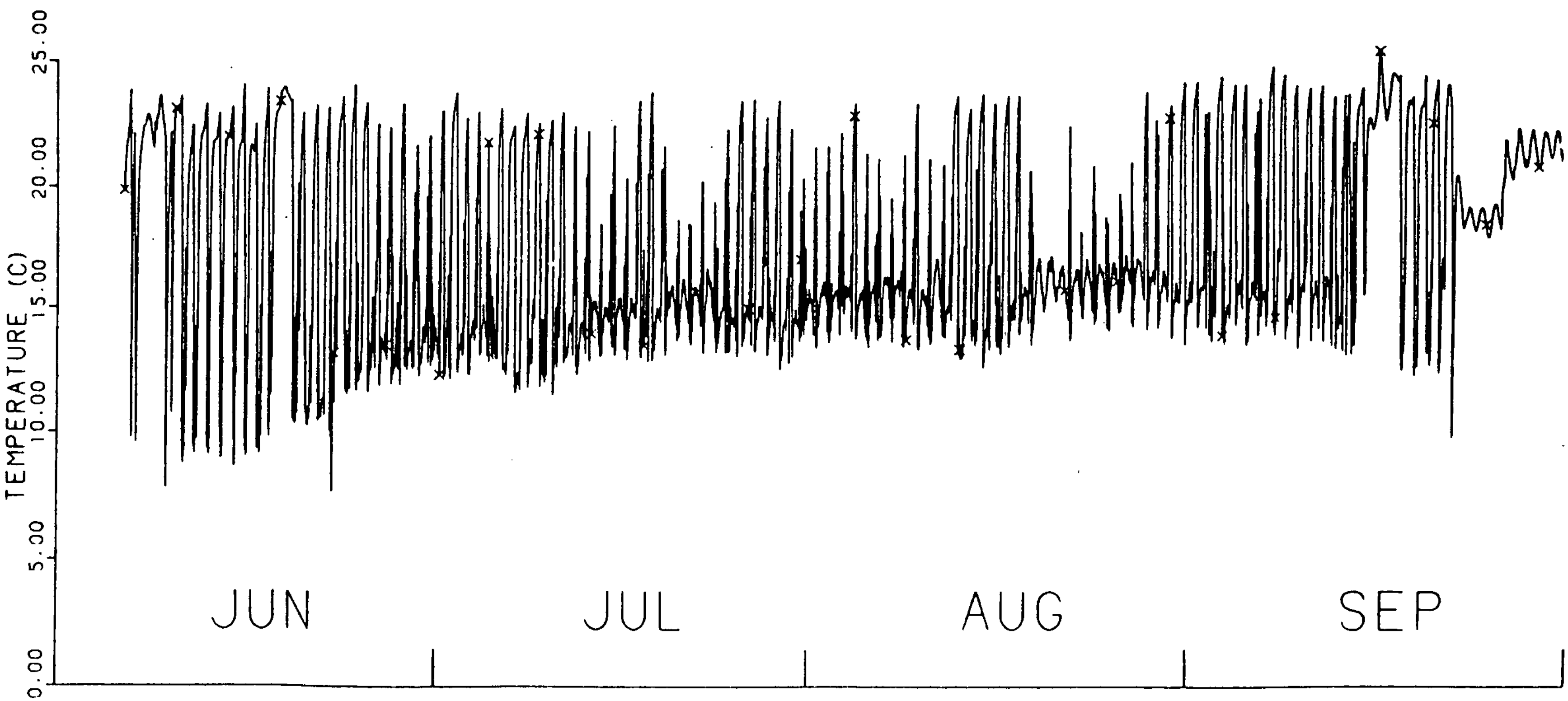


Figure 4.5 Temperature of Brine Entering the Water to Air Coil

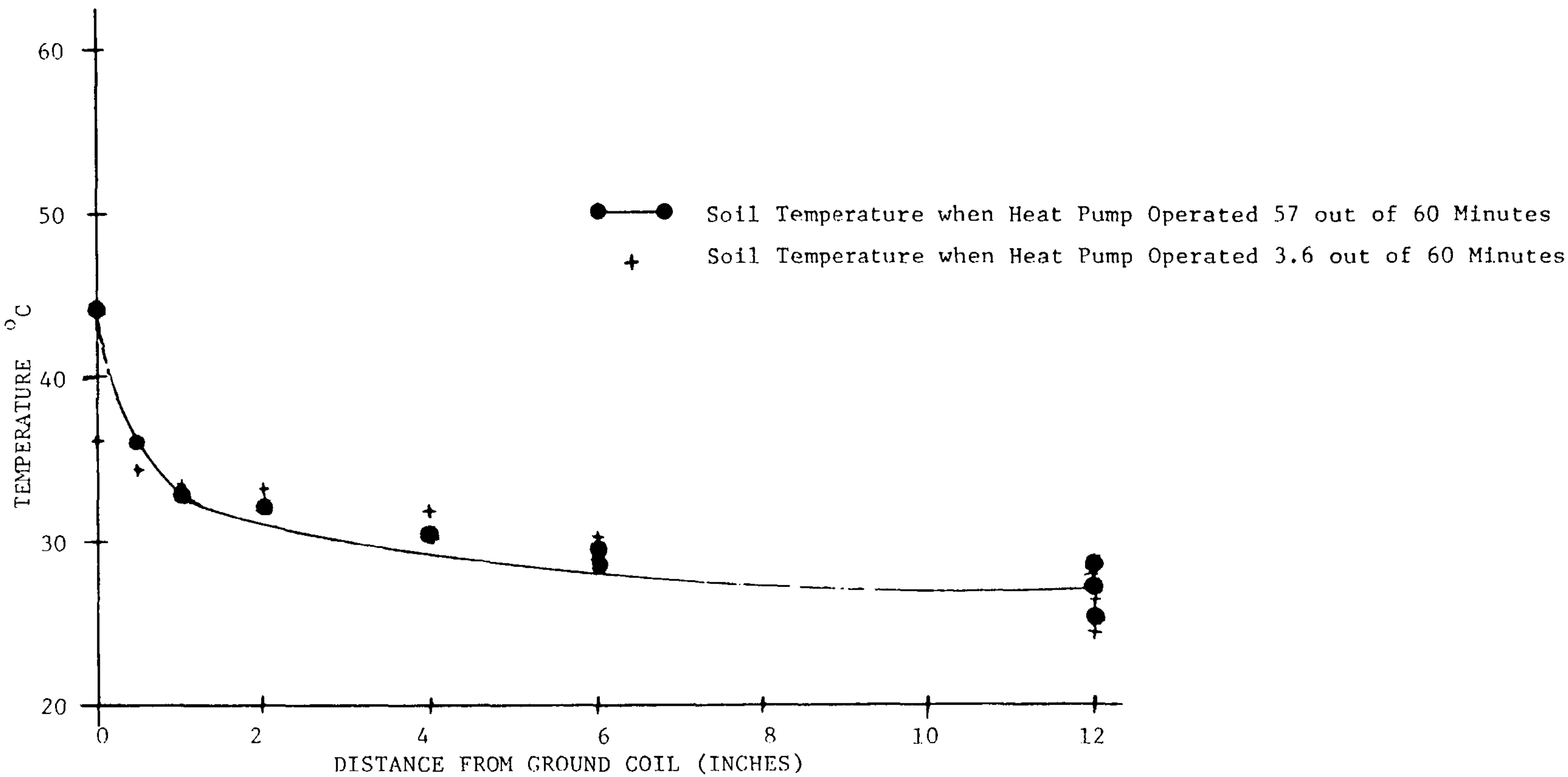


Figure 4.6 Soil Temperature Profile During Two Hours Of Operation On July 25, 1983

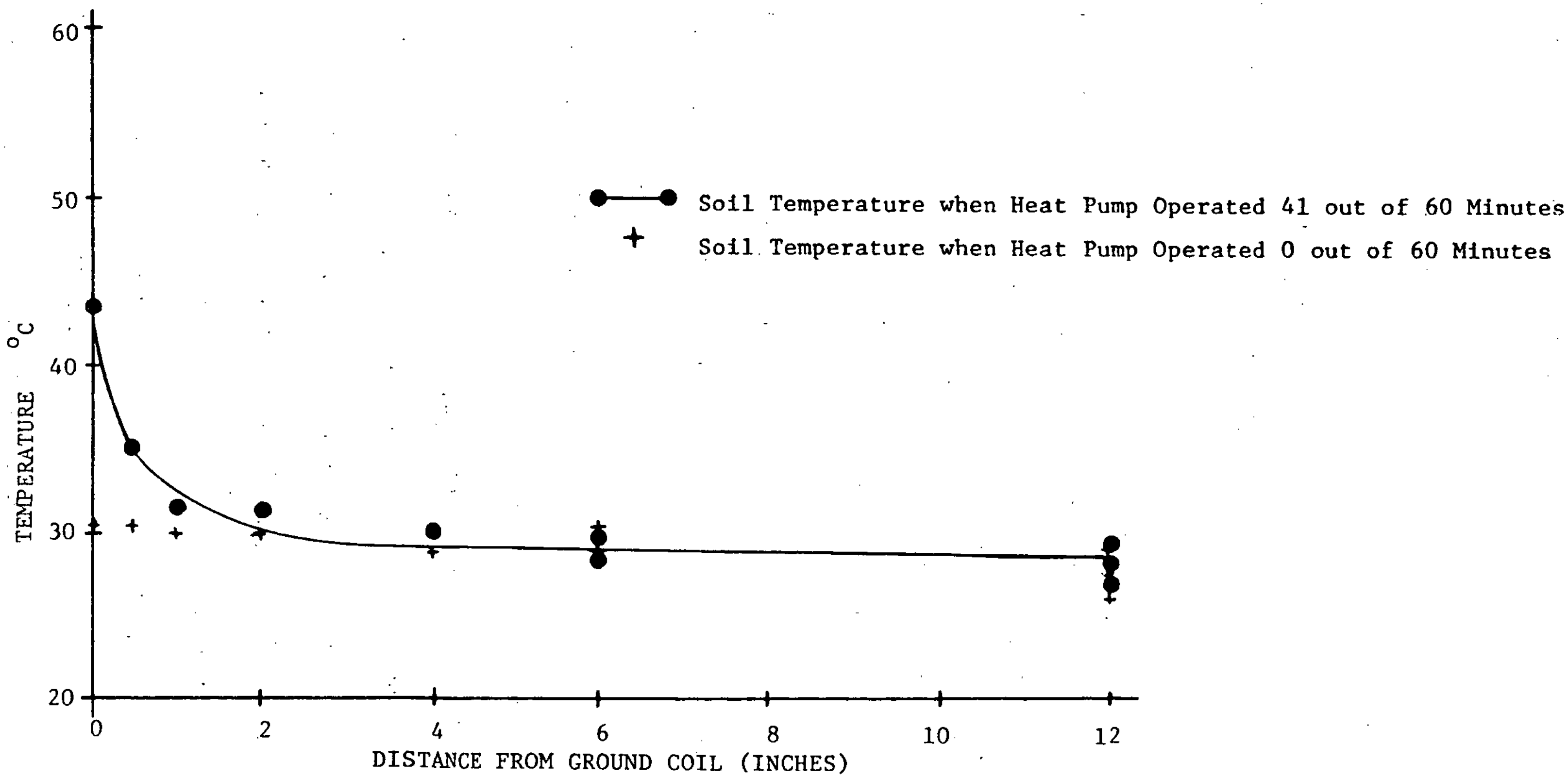


Figure 4.7 Soil Temperature Profile During Two Hours Of Operation On August 15, 1983

profiles are seen to closely approximate expected profiles for steady, radial heat flows.

From Kreith [4], the equation for steady radial heat flow in a composite media is

$$Q = \frac{T_1 - T_3}{\frac{\ln(r_2/r_1)}{2 k_1 L} + \frac{\ln(r_3/r_2)}{2 k_2 L}} \qquad (4.6)$$

where

L	= length (m)
Q	= steady-state heat transfer across the control volume (W)
k_1	= pipe thermal conductivity, .2 W/m°C
K_2	= soil thermal condctivity, (W/m°C)
r3	= soil outer radius, (m)
r2	= pipe outer radius, (m)
r1	= pipe inner radius, (m)
T3	= temperature at r3, (°C)
T1	= temperature at r1, (°C)

The control volume used in the above analysis extended from the pipe inside radius to a point in the soil having a radius of 15 cm where the temperature fluctuations with time were very small (See Figure 4.4). Because the pipe flow was well into the turbulent regime, the inside film coefficient could be ignored.

The thermal conductivity for the soil was calculated for each hour of data where the runtime criterion was met. The hourly thermal conductivities were averaged and a seasonal soil thermal conductivity of 0.56 W/m°C was calculated. This value represents a weighted average thermal conductivity based on runtime.

Sundberg [5] and Lunardini [6] report thermal conductivity of clay soils as a function of moisture content. Table 4.3 shows values calculated from this study compared to predictions from the data of References [5] and [6].

Table 4.2. Comparision of Thermal Conductivities, k(W/m°C)

		Thermal Conductivity		
Week	Moisture Content	Measured (Apparent)	Lunardini	Sundberg
June 6	30%	1.05	1.2	1.1
July 18	25%	.58	.95	.80

For the week of June 6 at the beginning of the cooling season, the soil was near saturation and agreement is reasonably good. However, on July 18, the soil has dried out somewhat and measured values are considerably lower than predicted. This difference could be attributed to (1) void spaces near the pipe wall, which are discussed in Section 4.4, (2) significant drying in a thin layer around the pipe (moisture sensors are large enough that such drying would not be detected) or, (3) location of the moisture sensors where conditions were unlike the conditions surrounding much of the pipe.

Figure 4.8 is a plot of weekly experimental soil thermal conductivities. It is noted that there is a similarity in the trends of the heat pump system performance deterioration, Figure 4.1, and the decrease in experimental thermal conductivity, Figure 4.8. Note that the majority of the heat pump performance deterioration occurs at the beginning of the cooling season as does the major portion of change in the thermal conductivity. Also between weeks 11 and 12 there is a decrease in the apparent thermal conductivity and a corresponding decrease in heat pump performance. The comparison between the experimental thermal conductivity and the heat pump performance indicates that the apparent soil

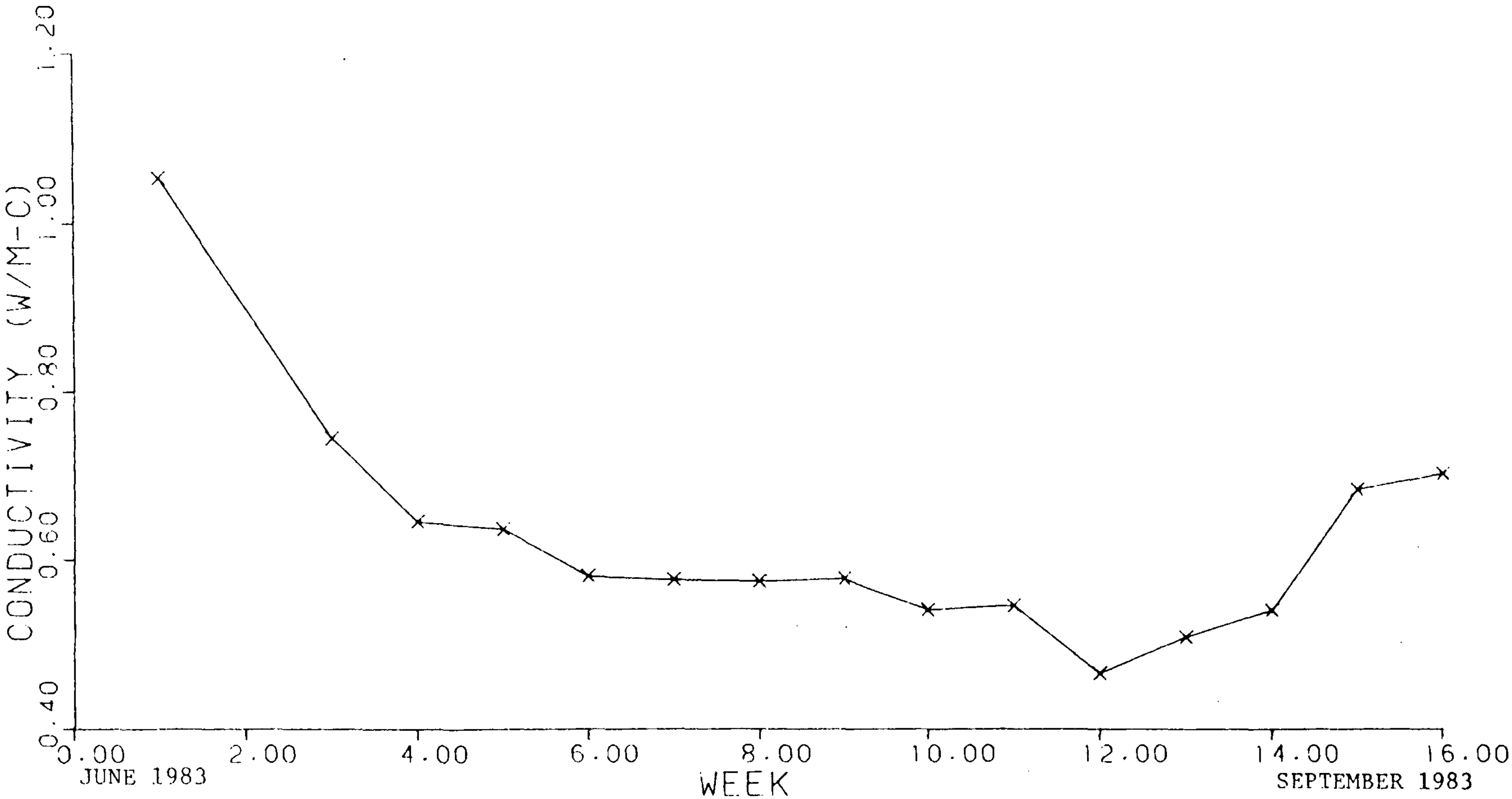


Figure 4.8 Apparent Thermal Conductivity of Soil Versus Time

thermal conductivity is a major contributor toward the heat pump performance deterioration.

4.3 Soil Moisture Measurements

Soil moisture measurements were taken at periodic intervals throughout the summer of 1983. Figure 4.9 presents data from three sensor locations at the mid-length of the ground coil. The sensors used in Figure 4.9 were located (1) at the ground coil wall, (2) at a distance of 6.5 inches from the coil in the horizontal plane, (3) at a distance of 6.5 inches from the coil in the vertical plane.

As can be seen in Figure 4.9, there was some drying of the soil throughout the summer. Figure 4.9 also shows that the soil next to the coil is drier than at the other locations. This phenomenon can be interpreted as a slight amount of moisture migration from the region directly adjacent to the coil. Figure 4.10 presents a time average soil moisture profile during July, 1983. In the horizontal plane, there is only a one percent change in moisture from the 6.5 inch location to the 27.5 inch location. The majority of the change in moisture occurs between the 20.5 inch location and the 27.5 inch location in the horizontal plane. The change in moisture is greater in the vertical plane. In that plane there is a 2 percent change between the 6.5 inch location and the 21.5 inch location. The relatively constant moisture profile in both the vertical and horizontal planes implies that the coil influence on the moisture distribution does not extend further than about 6.5 inches from the coil.

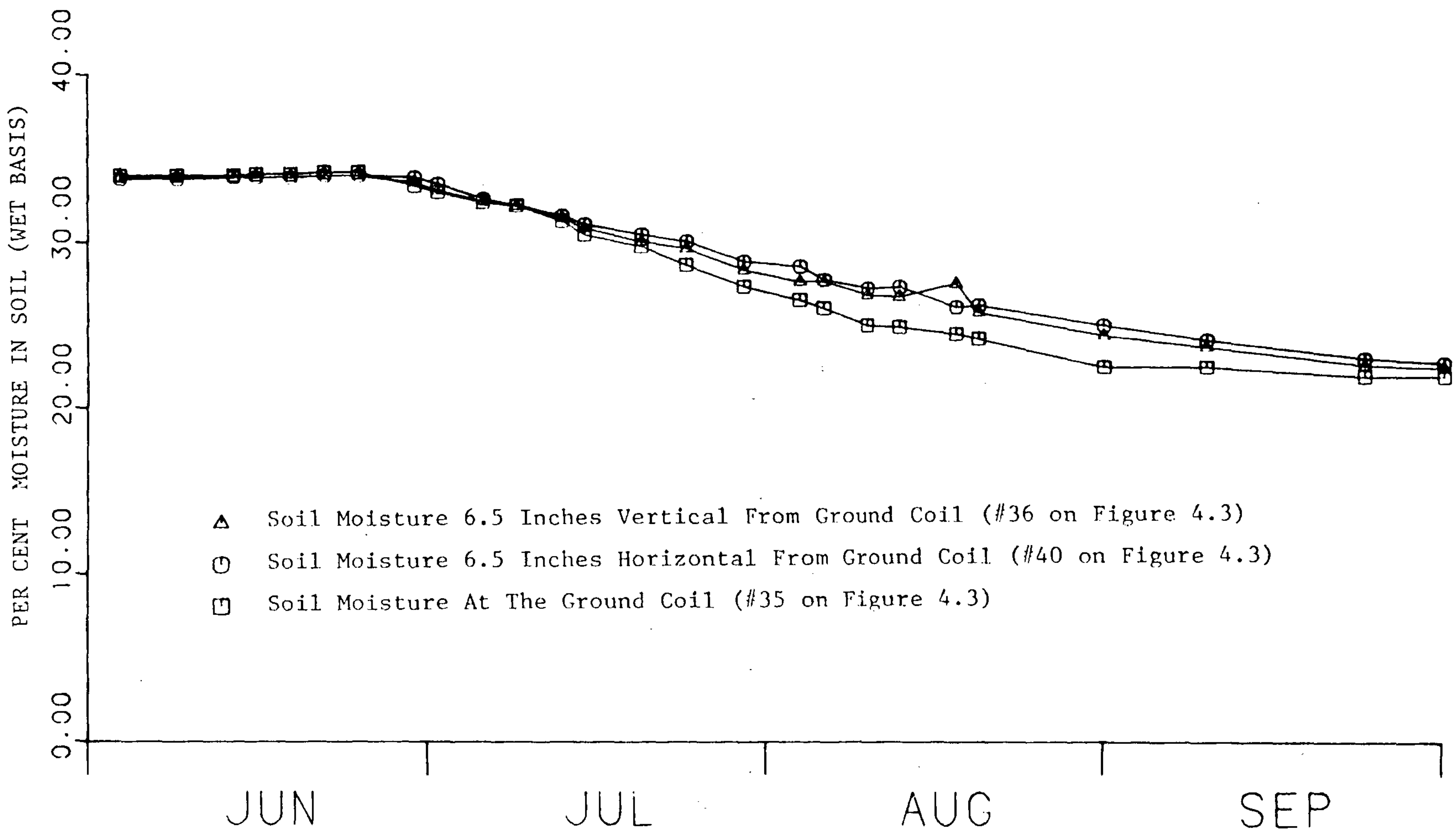


Figure 4.9 Moisture Content of Soil Versus Time

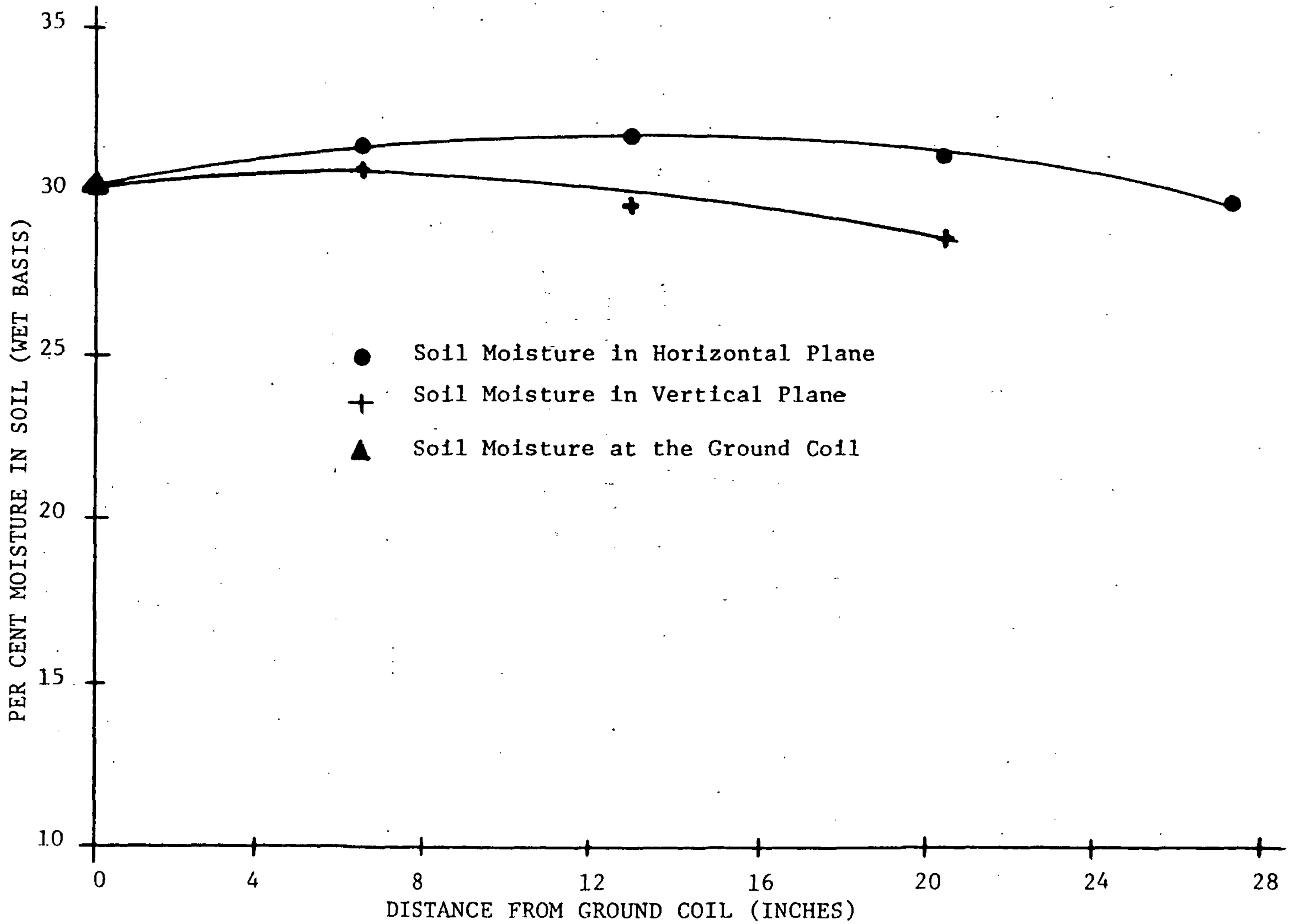


Figure 4.10 Time Average Soil Moisture Profile During July 1983

The susceptibility of the sensors above the pipe to weather effects accounts for part of the difference in the average sensor readings in tne horizontal and vertical planes (Figure 4.10).

4.4 Soil Observations

Two soil samples were taken at the TECH site on July 14, 1983. The samples were analyzed for porosity, texture, percent moisture, density, and several other soil properties. One sample was taken in the trench where the pipe was buried and the second sample was taken nearby in undisturbed soil. The soil was found to be approximately 85 percent clay and silt and 15 percent sand. A detailed description of the soil is presented in Appendix E.

A hole was dug in the ground coil field near the mid-length on August 9, 1983, in order to inspect the ground coil and surrounding soil. As the hole was dug, air gaps were observed at the interface between the soil in the trench in which the coil was buried, designated as disturbed soil, and the surrounding undisturbed soil. The gaps at the interface occurred intermittently from the surface to the depth of the coil, approximately five feet from the surface. Several other air spaces were encountered in the disturbed soil as the hole was dug.

After the hole was dug, an air gap approximately two inches long and 0.25 inches wide was discovered parallel to and in contact with the coil wall. This air gap occurred where the coil approached the interface between disturbed and undisturbed soil and was not evident when the coil was in the middle of the disturbed soil.

The soil in contact with the top of the coil was light in color and dry to the touch in several locations. In other locations along the top of the coil, the soil was darker. The soil along the bottom of the coil was dark in color and plastic to the touch. The disturbed soil, with the exception of the soil on top of the coil, was darker in color than the undisturbed soil. Soil color can be a rough indication of soil moisture content since, for a given soil, the darker the soil, the greater the moisture content.

On October 2, 1983, a second hole was dug at about 20 percent of the total coil length toward the inlet to the ground. There, the interface between the disturbed and undisturbed soil was not as distinct as the interface of the hole dug in August. Air gaps were not encountered as the hole was dug. The soil seemed well packed and moist to the touch in the vicinity of the coil.

Based on only two excavations, it is not possible to determine the extent of the void spaces as found in the first hole throughout the remainder of the field. However, the lower thermal conductivity reported in Section 4.2 indicates that this effect may not be negligible.

4.5 Soil Thermal Stability

The problem of soil thermal stability must be examined before designing ground coupled heat pumps for cooling. If the soil is thermally unstable adjacent to the coil, then the soil will dry rapidly and significantly degrade the performance of the ground coupled heat pump. For this reason, a thermally stable soil is desirable adjacent to the ground coil.

The data from Martin, Bush, et.al., [7] were used in an attempt to determine if the soil adjacent to the ground coil was thermally stable or unstable. Data were taken for sample of Georgia Red Clay at 20 percent moisture content for heat fluxes down to 51 W/m which is about twice the average daily heat flux measured in this study. This may indicate that there is little potential for a thermally unstable soil adjacent to tne coil. Soil drying characteristics as measured near the pipe indicate that thermal instability did not occur since the moisture leveled off at about 25 percent and remained almost constant through the summer.

CHAPTER 5. CONCLUSIONS & RECOMMENDATIONS

Data for a complete cooling season with the Ground Coupled Heat Pump (GCHP) system have been obtained with only 2 percent of the data being unobtainable or discarded. From these data it is concluded that the ground coil does not have adequate heat transfer capacity to supply the total cooling load of TECH House I. Although the sensible cooling load was met as long as ambient temperature remained below 98°F, the latent load was only met during the first 2-3 weeks of the summer, prior to soil drying.

A second, unanticipated conclusion is the need to backfill carefully to avoid poor soil-pipe contact. Although the soil was ground fine by the ditching machine, it apparently formed hard lumps before it was put back in the trench, and even extended ground settling did not produce good pipe-soil contact. Excavation and inspection of the ground coil and surrounding soil at two locations along the length revealed that at one location gaps (air spaces) had remained in the disturbed (backfilled) soil despite the significant soil settling that had occurred and the saturated soil conditions previously observed during heating season operation. Air gaps were not encountered at the second inspection location. Soil moisture measurements taken during the summer season indicate some slight moisture migration effect near the coil, but the poor cooling performance of the ground heat exchanger is apparently directly related to the contact resistance (air gap) effect on the heat transfer. In clay soils, it may be necessary to backfill around the pipe with a material such as sand.

The overall performance of this GCHP system was inferior to a standard air-to-air system primarily because of poor performance of the ground heat exchanger. Both inadequate heat transfer area and poor soil heat transfer characteristics are responsible. Modifications under consideration for improving cooling performance are as follows.

1. Reinstall the ground coil, carefully backfilling with sand or a similar material to eliminate voids near the pipe.

2. Redesign the coil based on a cooling load of 3 tons to provide ample area for heat transfer to the ground.

3. Include a heat exchanger in the brine loop to provide domestic hot water during the summer season and consequently, reduce the required ground heat transfer.

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APPENDIX A. Project Chronology May 1, 1983 - October 31, 1983

A discussion of the project history from the project's inception through April 30, 1983, is presented in detail in the preceding report in this series [1].

Ceramic soil moisture sensing devices were installed during the first two weeks of May, 1983. The location of those devices is discussed in Chapter 3 "Instrumentation".

As requested by ORNL, preparations were made for the installation of new soil moisture sensing devices developed by ORNL. Those preparations completed in mid May, 1983, included excavation at the probe site, installation of new conduit between Tech House I and the probe site, and installation of cable between the probe site and the central data acquistion system (DAS) in Tech House II. The probes were installed by ORNL, however, electronic problems made recalibration necessary and prevented their use during the 1983 cooling season.

Calibration of the GCHP heat flows and temperature sensors were attempted in late May but not successfully completed until the first week of June 1983 due to electronic problems. Apparently, a cable connecting the DAS and Tech House I was damaged while installing new cable for the ORNL soil moisture sensors. A new cooling condensate measurement device was also calibrated and installed.

The GCHP system operated throughout the summer without a system failure. By the end of the summer, however, temperatures exiting the ground coil had risen to 110-120 °F.

In August, core samples were taken of distributed soil in the trenched area above the ground coil and the undisturbed soil adjacent to the trenched area. The data from those samples are presented in Appendix E.

An oral presentation was made on September 9, 1983 to the ORNL project personnel. That presentation primarily covered the 1982-1983 winter GCHP system performance, but also included preliminary 1983 summer data.

The GCHP operation in the cooling mode was concluded on September 30, 1983.

APPENDIX B. Design Parameter Discrepancies

The installation of the ground coil for TECH House I followed the design recommendations furnished by Batelle Columbus Laboratories [8]. There exists approximately 675 feet of pipe buried 4 feet deep serving 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 Btu/hr-°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 and a more realistic summer soil thermal conductivity. 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 using standard ASHRAE standard methods. The peak sensible cooling load when the maximum outside 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 [3]. 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 Drilling Data

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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 5/20/3
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 Tenness

SAMPLING RECORD

SPLIT NO	FROM	TO	SPLIT 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.

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DRILLER'S LOG

GA File 82-644

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

HOLE LOCATION	By U.T. Representative	SHIFT	1st	DATE	12/27/8
SURFACE ELEVATION	By U.T..Representative	RIG NO	ATV 550	HOLE NO	2
DEPTH AT BEGINNING OF SHIFT	0.0	TOP ROCK	?		
FOOTAGE [illegible]	Augered	BOTTOM OF HOLE	10.0		
FOOTAGE SAMPLED	10.0	DRILLER	Lane		
FOOTAGE CORED		HELPER	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

APPENDIX D. WEATHER DATA

The following data were obtained from the Knoxville Airport Weather Station.

SUMMER 1983

	June	July	Aug.	Sept.	Total
Cooling °F Days (Base 65)	235	425	462	217	1339
Average Temperature (°F)	72.5	78.5	79.5	70.3	
Rainfall (Inches)	2.89	2.11	1.69	0.64	7.33

LONG TERM WEATHER CONDITIONS

	June	July	Aug.	Sept.	Total
Cooling °F Days (Base 65)	283	391	372	209	1255
Average Temperature (°F)	74.3	77.6	77.0	71.5	
Rainfall (Inches)	3.95	4.33	3.02	2.99	14.29

APPENDIX E. SOIL SAMPLE DATA

	DISTURBED SOIL (in trench)	UNDISTURBED SOIL (outside trench)
Porosity (%)	58.8	35.0
Wet Density (lb/ft^3)	98.09	124.68
Natural Moisture (%)	24.0	17.0
Degree of Saturation (%)	54.4	78.0
Liquid Limit (%)	42.0	34.0
Plasticity Index	16	13
Soil Texture (%)	Clay & Silt 85 Sand 15	Clay & Silt 87 Sand 13

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