Submitted to 2nd International Conf.
on Alternative Energy Sources;
Miami Beach, FL; December 10-13,1979.

EXPERIMENTAL RESULTS FROM THE FIRST YEAR OF OPERATION OF THE SOLAR GROUND COUPLING RESEARCH FACILITY AT BROOKHAVEN NATIONAL LABORATORY*

BNL-27137

CONF-791204--19

PHILIP D. METZ
Brookhaven National Laboratory, Upton, New York, U.S.A.

MASTER

ABSTRACT

Results from the first year of operation of the solar ground coupling research facility at Brookhaven National Laboratory (BNL) are presented. Nine experiments which are first generation ground coupled heat transfer and storage devices for a solar source heat pump system have been operated since December, 1978. A computer program called GROCS which models the heat transfer between these devices and the earth has been written (and subsequently integrated with the solar energy system simulation program TRNSYS by John W. Andrews). In this paper the ground coupling research program, the first generation experiments, and the underground heat flow model GROCS are described. Experimental results from December, 1978 to September, 1979 are presented and compared to model predictions.

1. INTRODUCTION

1.1 Solar Source Heat Pump Systems

A solar source heat pump system is a solar heating system also containing a heat pump in which the solar heat is placed in storage and then used as a heat source for the heat pump when the storage temperature is not high enough for direct heating. The advantages of this approach are that inexpensive solar collectors not always suitable for direct heating may be used, and that the heat pump is available for space cooling.

All solar heating systems of reasonable size require some form of auxiliary heating due to the intermittancy of sunlight. In solar heat pump systems one has the option of using any available low temperature heat source as input to the heat pump to provide this auxiliary heat (and also as a heat sink for space cooling). The advantage of doing so is that the amount of purchased electricity required to drive the heat pump is less than that required for electric resistance heating. Further, because of the second law of thermodynamics, the higher the temperature of the heat source, the less electricity the heat pump will consume for heating.

* Work performed under the auspices of the U. S. Department of Energy, Systems Development Division, Solar Applications, Office of Assistant Secretary.

DISCLAIMER

1.2 The Solar Ground Coupling Research Program at Brookhaven National Laboratory (BNL)

The solar ground coupling research program at BNL studies ground coupling - the use of the earth as a heat source/sink and storage element - for solar source heat pump systems. The plausibility of using the earth in this way has been discussed in an earlier paper [1]. The goal of our research program is to determine the feasibility of ground coupling for solar source heat pump systems, and if feasibility is demonstrated, to specify the optimal configurations of ground coupling devices for various climates, sites and applications in a Handbook. A key step toward this goal is the development of an experimentally validated model of ground coupling so that ground coupling devices can be designed reliably on paper. This is a practical necessity as the length of ground coupling experiments ($\sim$ years) and the great diversity of space conditioning needs and underground properties make design based purely upon experiment unfeasible.

Our research program began with a review of ground coupling, ground behavior and heat flow modeling literature. Simple analytical heat flow models were written and used to roughly size ground coupling devices for solar source heat pump systems. Eventually, a computer program called GROCS was written to more accurately model the behavior of ground coupling devices. GROCS was also used to help design our first generation heat flow experiments (and has subsequently been integrated with TRNSYS by John W. Andrews [2]). These have been operated since December, 1978, and the results from them are used to test and refine the computer model so that a (locally) validated model can be created.

2. THE FIRST GENERATION EXPERIMENTS

2.1 Soil Property Experiments

Two classes of first generation experiments have been conducted. The first class consists of soil thermal property experiments which are necessary to provide thermal property data input for the computer model. The soil volume heat capacity ($c\rho$) and moisture content were measured via calorimetry of soil samples. The thermal diffusivity (α) has been determined from the far field underground temperature variations with depth and time. The thermal conductivity (k) can also be deduced from those experiments ($k=\alpha c\rho$). Additional property experiments are planned to directly measure the thermal properties and moisture content under the influence of heat flows and temperature gradients relevant to ground coupling devices.

2.2 The First Generation Heat Flow Experiments

The first generation heat flow experiments were designed to provide the experimental information necessary to produce a validated model of ground coupling. Two types of devices were constructed; (1) buried tanks made from precast concrete rings, and (2) buried fields of serpentine 1 1/2" nominal size flexible polyethylene pipe.

In operation, each experiment is provided with heat inputs or outputs derived from a TRNSYS or GROCS-TRNSYS computer simulation of a solar heat pump system and a residential load in the local (New York) climate. Each computer simulation explores a different control strategy scenario. The load simulated is a fairly well insulated 150 m^2 (1500 ft^2) house with a full basement and a heating requirement of about 1.9 X 10^7 J/°C day (10,000 Btu/degree day). The average Long Island heating season contains about 2800 °C day/year (5,000 degree days/ year) for a total annual building heat requirement of 5.3 X 10^{10} J/year (50,000,000 Btu/year). The annual cooling requirement is about 1.6 X 10^{10} J/year (15,000,000 Btu/year). The solar collector simulated is a single glazed collector with an abscissa intercept of $\Delta T/I = 0.11\ m^2$-°C/watt (0.6 ft^2-hr-°F/Btu). The heat pump simulated has an efficiency which is approximately 50% of the theoretical Carnot efficiency over the temperature range of interest. The design, construction and operation of these experiments were described in detail in an earlier paper [3]. In section 3 physical descriptions of these experiments are given and the experimental results from December 1978 to September 1979 compared to computer model predictions.

2.3 The Computer Program GROCS

GROCS is a 3-dimensional heat flow finite element computer program specially designed to study underground heat flow around ground coupling devices. Since naturally occurring ground inhomogeneities limit the accuracy of any model based on bulk thermal properties to about 10%, models which contain more elements than are needed for this level of accuracy provide no additional value although they do use additional computer time. Also, it is necessary to model many different ground coupling configurations (e.g. at BNL there are 8 different experimental designs) so that it is desirable that model creation not be time consuming. In short, a computer program of moderate accuracy and great flexibility is required for this application.

At present GROCS uses up to 30 finite elements or "blocks" of earth divided into two types with 10 "rigged blocks" and 20 "free blocks". The rigged blocks surround the free blocks and provide the necessary spatial boundary conditions. The temperatures of the rigged blocks are determined at each timestep by a function subprogram called TINTERP which contains a table of ground temperatures based on experimental measurement [4] for depths of 0.00 m, 1.52 m, 3.05 m, 6.10 m, and 12.20 m, for each month of the year. (Note: The monthly 0.00 m temperatures used are the average of the mean monthly ambient and three inch temperatures while the 12.20 m temperature is set constant at the annual average 6.10 m value.) At every timestep in GROCS, the subprogram is told the time of year and depth of the center of the block whose temperature it is to compute. TINTERP then determines the temperature of the block by linearly interpolating with respect to time and depth between the relevant table entries.

The initial temperature of each free block is specified as data input to GROCS, or if a default value is specified, by TINTERP as described above. At all subsequent timesteps, however, the temperatures of the free blocks are determined by their thermal interactions with all of the other blocks, and by heat inputs placed in them to simulate the presence of an operating ground coupling device. The version of GROCS used to generate the results presented in section 3 (GROC3) requires weekly heat inputs for the free blocks (the GROCS-TRNSYS program uses heat inputs provided by TRNSYS at each TRNSYS timestep).

GROCS requires three types of data input:

(1) The heat input data described above.

(2) One value of the ground thermal conductivity (k) for all of the blocks, and one value of the volume heat capacity (cρ) for each free block. The values used were determined experimentally as described above.

(3) Physical information about the particular ground coupling device model being used including the volume of each free block, the depth of each

block, and heat transfer surface areas and center-to-center distances between adjacent blocks. This information is derived from a hand drawn model (one of which was illustrated previously [5]). An experienced person can draw the model and extract the information required for a typical buried tank or outline of a pipe field in a few hours.

The major approximations used by GROCS at present are:

(1) Twenty finite size free blocks of earth,
(2) A finite time step interval,
(3) One constant thermal conductivity (k) for every block,
(4) One constant volume heat capacity (cρ) for each block,
(5) Horizontal boundary conditions a finite distance from the device modeled,
(6) Linearly interpolated boundary conditions,
(7) No consideration of variations in ground moisture content, of moisture flow, or of freezing,
(8) Weekly heat inputs (for the version which produced the results presented in this paper).

3. EXPERIMENTAL RESULTS VERSUS COMPUTER RESULTS

3.1 Method of Comparison

After the nine first generation heat flow experiments were operated from December 3, 1978 to September 15, 1979, weekly experimental heat flow totals (which appear as histograms in Figures 2, 3, 4, 6, 7, 8, 9, and 10) were computed for each and used as input to GROCS. The thermal properties used in all computer runs were:

$$k = 2.8 \text{ J/msec°C } (1.6 \text{ Btu/ft-hr-°F})$$

$$\text{and } c\rho = 1.7 \times 10^6 \text{ J/m}^3\text{°C } (26 \text{ Btu/ft}^3\text{-°F})$$

$$(c\rho = 4.18 \times 10^6 \text{ J/m}^3\text{°C [62.4 Btu/ft}^3\text{-°F] for water in the tanks.)}$$

The iteration time step was one hour.

Physical models were created for eight of the experiments (due to time limitations one is omitted) and GROCS was run. Space does not permit a detailed description of each model but these are available from the author upon request. No model has any block with a dimension smaller than 0.3 m (1 ft). The output of GROCS for each experiment contains the temperatures of all the free blocks at regular time intervals. Midweek temperatures of those free blocks which correspond to each ground coupling device were extracted. In cases where two free blocks with different temperatures corresponded to one device, a simple average was taken. For the tank experiments, these temperatures are simply the computer model predictions of the tank water temperatures. For the serpentine pipe fields, however, these temperatures are the <u>average</u> ground temperature in the block containing the pipe and do not coincide with the pipe fluid temperature unless there is no heat flow. Thus, additional calculations are needed to compute the fluid temperatures in the field experiments. The method used for this analysis is described in section 3.3. The computer predicted (with additional computations for the field experiments) midweek fluid temperatures are shown as circles in Figures 2, 3, 4, 6, 7, 8, 9, and 10.

The experimental fluid temperatures used for comparison with the computer derived fluid temperatures were obtained from the data of a particular experimental run each week. The run was selected for typicality, i.e. for having temperatures and heat flow rates common for that experiment during that week, and for closeness in time to midweek. Usually the experimental temperatures vary over a considerable range during a run of several hours (all runs selected were at least one hour long, much longer if possible). Thus, the experimental temperature range, plotted as a "bar" placed in midweek for each experiment in Figures 2, 3, 4, 6, 7, 8, 9, and 10, is the basis for comparison with the computer model temperature results.

There are two important approximations which enter into this analysis:

(1) The heat flow inputs to GROCS are weekly. The computer program divides these inputs evenly into (hourly) pieces in contrast to the experiments which are operated for comparatively short times at high heat flow rates and then left idle much of the time.

(2) The far-field underground temperatures used as boundary conditions in GROCS are based on experimental data taken over a number of years and do not coincide exactly with the far-field temperatures in any particular year.
To illustrate this point, consider Figure 1 which compares midweek experimental underground temperatures measured from December, 1978 to September, 1979 to the values used in GROCS. During the winter of 1978-9, the 3.7 m (12 ft) temperatures and the 2.4 m (8 ft) temperatures measured closely coincided with the GROCS values (almost always within 1°C) while the 1.2 m (4 ft) and 0.6 m (2 ft) temperatures are close on the average with a noticeable warm spell at the beginning of January and a very cold period toward the end of February evident in the 1978-1979 data. In the summer, the 1979 temperatures were systematically high at all depths, about 1 to 2°C at 3.7 m (12 ft), about 2°C at 2.4 m (8 ft), from 2 to 4°C at 1.2 m (4 ft), and from 2 to 5°C at 0.6 m (2 ft). These differences are significant and must be borne in mind when considering the absolute accuracy of the computer model temperature predictions.

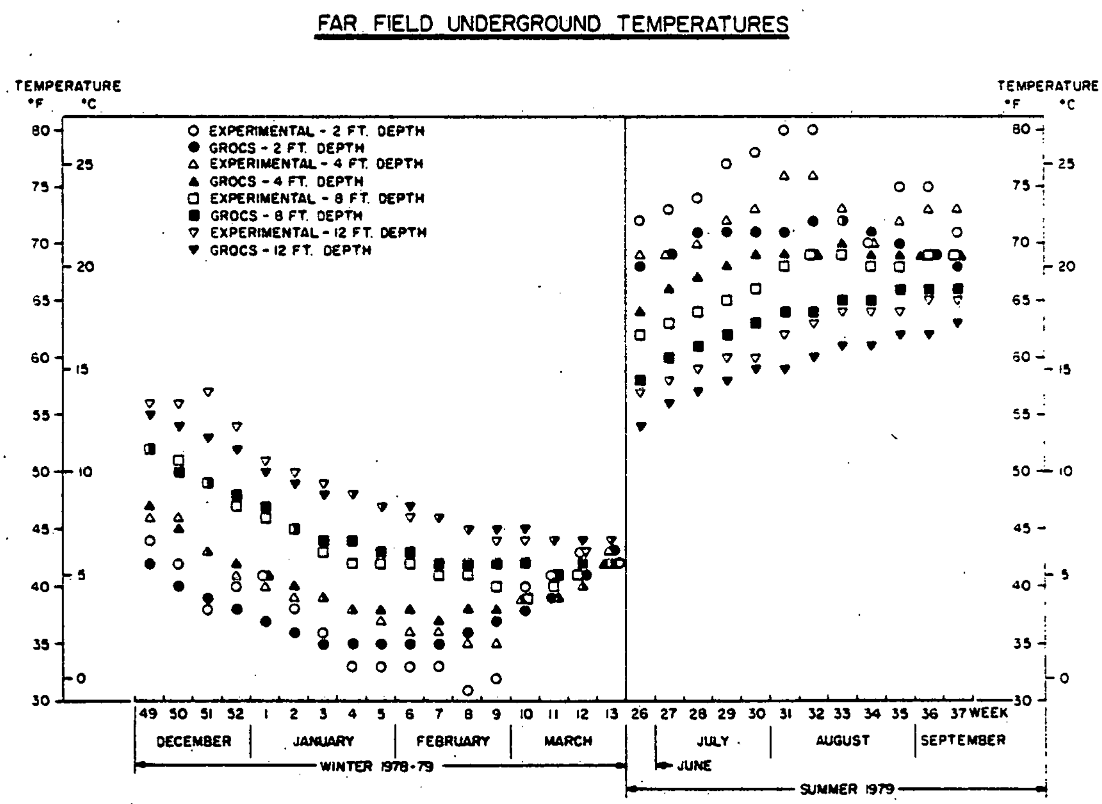


Fig. 1. December, 1978 to September, 1979 far field underground temperatures.

3.2 The Tank Experiments

Analysis has been completed for three tank experiments. All are vertical cylinders made from precast concrete rings and are 2.4 m (8 ft) high and 2.2 m (7 ft 4 in.) inner diameter with their bases 3.7 m (12 ft) deep. Tank A also has 2 in. of polystyrene foam sheet insulation covering its top half. No effort was made to seal the gaps between the sheets. The insulation was simulated in GROCS by using an extra interblock distance of 2.4 m (8 ft) where appropriate (equivalent to an effective average "R Value" of 2.5 ft^2-hr-°F/Btu per inch) with no additional heat capacity provided. Tanks C and E are identical in design (except for Coil E surrounding Tank E, see section 3.3) and thus use the same GROCS physical model.

Figures 2, 3 and 4 contain the experimental weekly heat histograms and compare the resultant computer generated midweek tank temperatures to the experimantally observed temperatures for Tanks A, C and E respectively. For the winter of 1978-9, all three figures show excellent agreement between experiment and computer model with the computer value never more than about 2°C from the center of the experimental range, and usually much closer. For the summer of 1979, the Tank A computer results are generally within the experimental range with some dispersion, the Tank C computer results are consistantly about 4°C below the center of the experimental range, while the Tank E computer temperatures are a bit low averaging less than 3°C below the center of the experimental range. The computer result error introduced by using historical far field data instead of 1978-9 data, as discussed in section 3.1, can be removed to first order by adding the average error (experimental 1978-9 data minus historical GROCS data) at the 2.4 m (8 ft) depth - which is the middepth of the three tanks - to the computer generated tank temperatures. This error, as seen in Figure 1, was almost 0°C in winter and about 2°C in summer. Adding this error

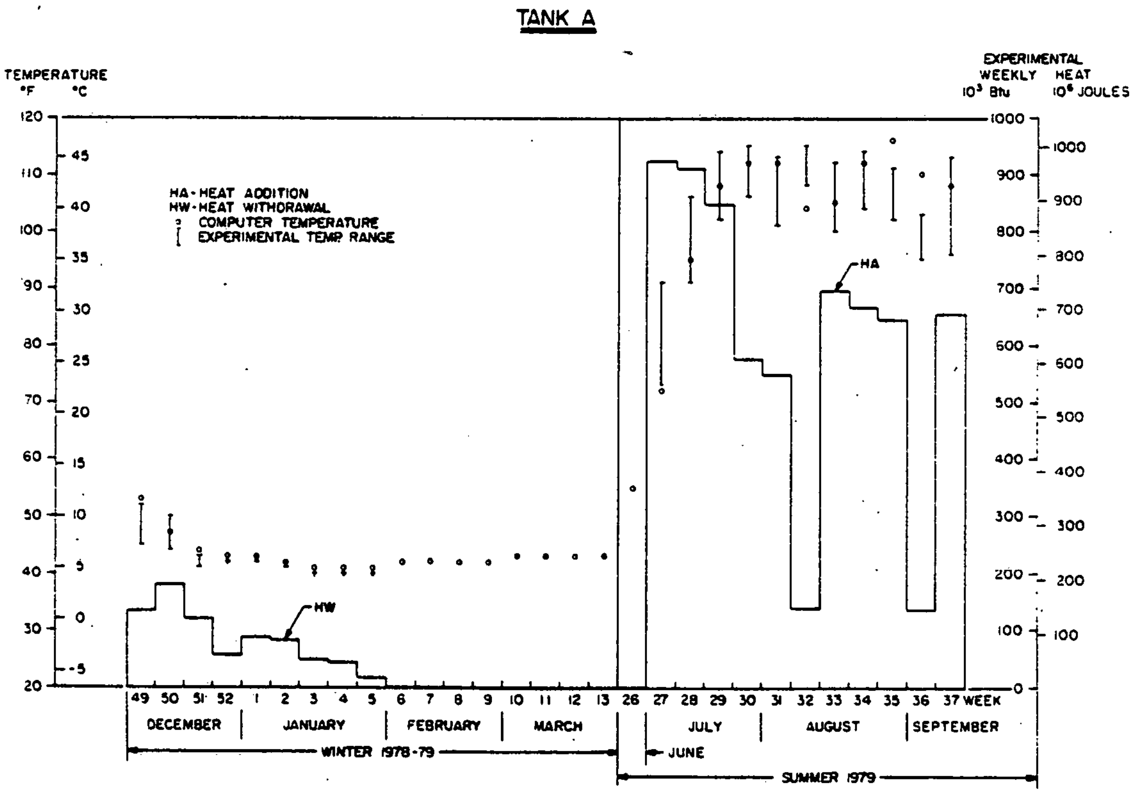
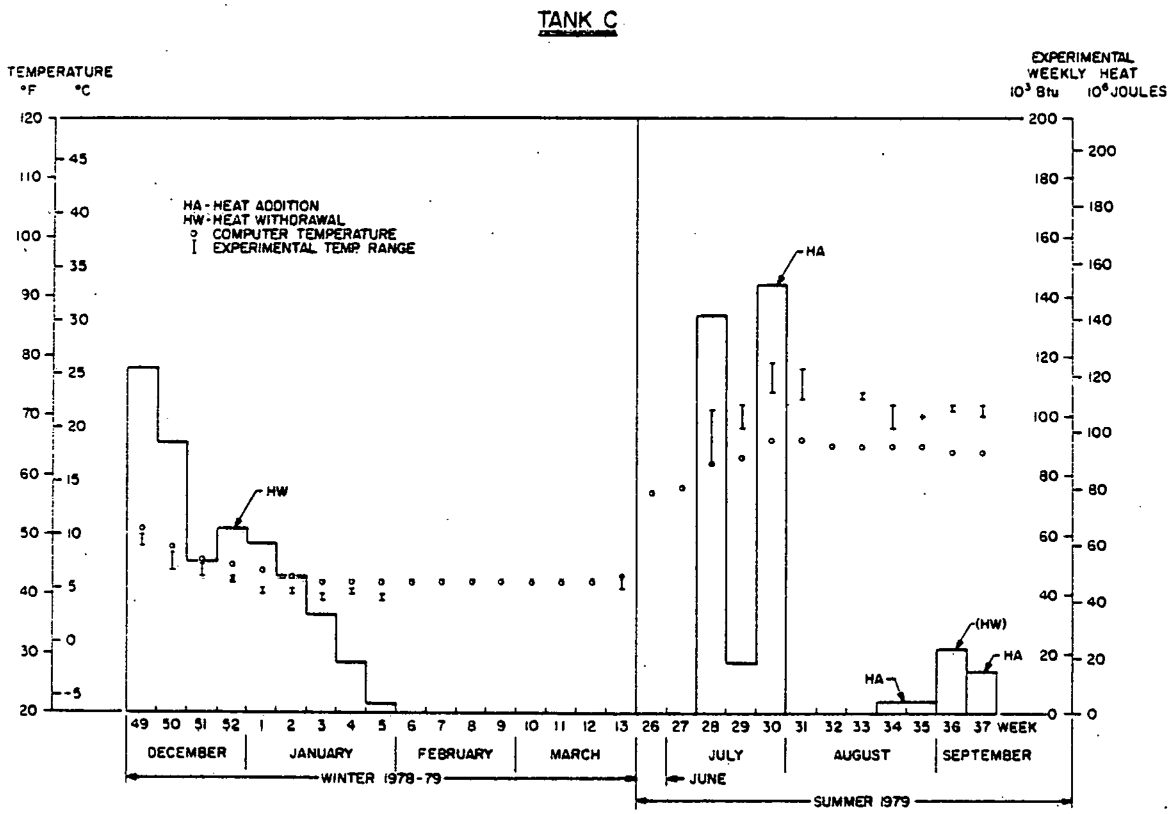
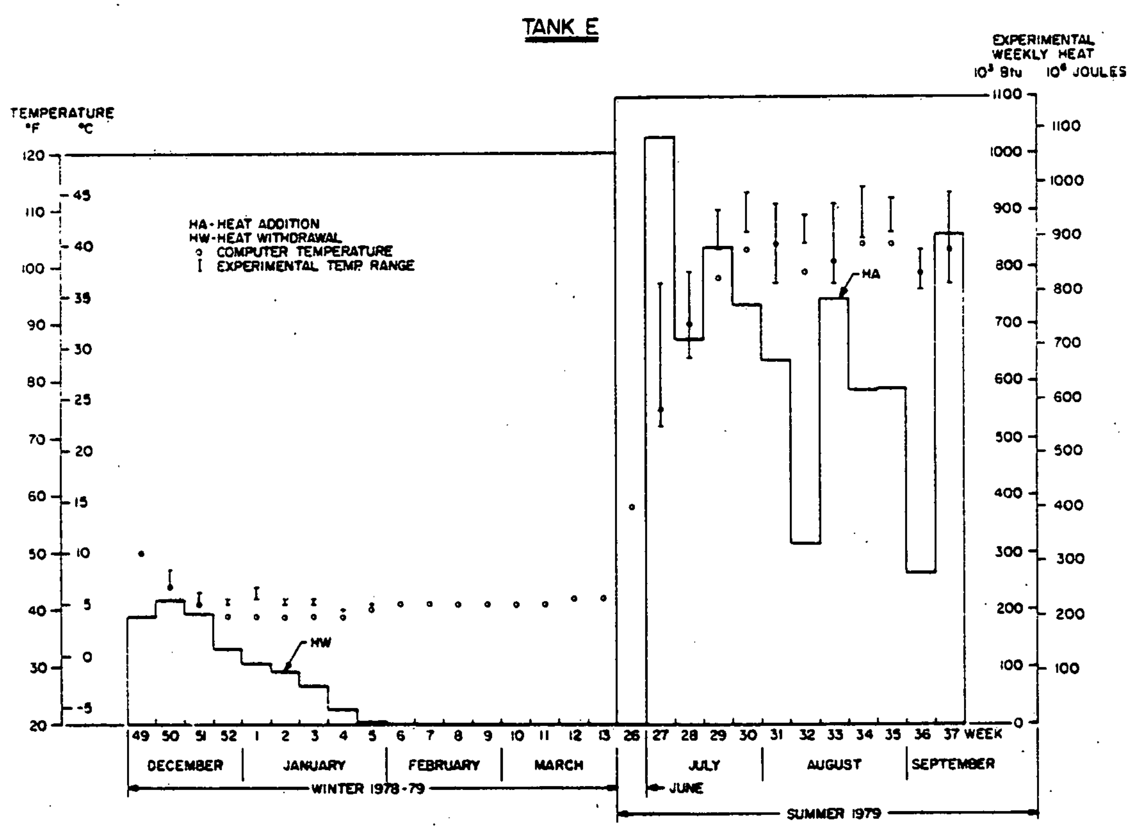


Fig. 2.



TANK C
TEMPERATURE
°F °C
EXPERIMENTAL
WEEKLY HEAT
10³ Btu 10⁶ JOULES
HA - HEAT ADDITION
HW - HEAT WITHDRAWAL
○ COMPUTER TEMPERATURE
I EXPERIMENTAL TEMP. RANGE
HA
HW
(HW)
WEEK
DECEMBER
JANUARY
FEBRUARY
MARCH
JULY
AUGUST
SEPTEMBER
JUNE
WINTER 1978-79
SUMMER 1979

Fig. 3.



TANK E
TEMPERATURE
°F °C
EXPERIMENTAL
WEEKLY HEAT
10³ Btu 10⁶ JOULES
HA - HEAT ADDITION
HW - HEAT WITHDRAWAL
○ COMPUTER TEMPERATURE
I EXPERIMENTAL TEMP. RANGE
HA
HW
WEEK
DECEMBER
JANUARY
FEBRUARY
MARCH
JULY
AUGUST
SEPTEMBER
JUNE
WINTER 1978-79
SUMMER 1979

Fig. 4.

makes the summer computer results for Tank A still generally within the experimental range but a bit high, for Tank C about 2°C below the middle of the experimental range, and for Tank E less than 1°C below the middle of the experimental range.

The computer results for Tank A cannot provide an absolute gauge of the accuracy of GROCS because of the existance of a free parameter, the effective R value of the polystyrene insulation. The value chosen, although quite reasonable, was selected because it yielded the fit shown in Figure 2 while other values gave poorer fits. The results for the identical Tanks C and E, however, contain no such free parameter and thus provide an absolute and sensitive measure of the accuracy of GROCS. Both the winter and summer results shown in Figures 3 and 4 are consistant with an experimental heat transfer rate for Tank C which is somewhat lower than the rate for Tank E. Because the two computer models are identical, actual differences in the earth surrounding the two tanks are probably responsible, which means that the extent of the error inherent in any model relying on bulk thermal properties is indicated by this difference.

3.3 The Field Experiments

Five serpentine pipe experiments, shown in Figure 5 and described in Table 1, have been analyzed.

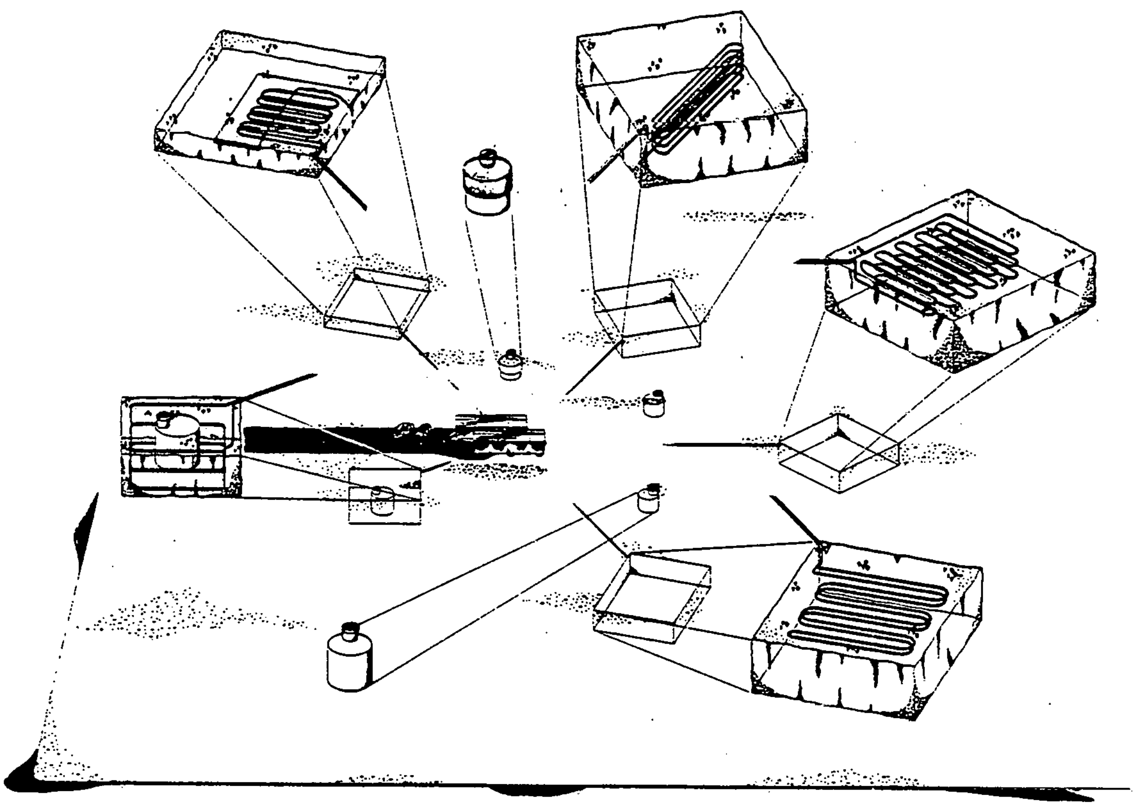


Fig. 5 Perspective drawing of the first generation heat flow experiments.

Table 1.

Experiment	Location in Fig. 5	Description	Length
Coil E (surrounding Tank E)	8 o'clock	3 coils at depths of 1.2 m (4'), 2.4 m (8'), and 3.7 m (12') respectively, each 6 m (20') on a side	82 m (270')
Field A	1 o'clock	5 coils each 15 m (50') long, 1.2 m (4') wide, spaced 0.6 m (2') apart from 1.2 m (4') to 3.7 m (12') depth	174 m (570')
Field B	3 o'clock	3 planes with 0.9 m (3') pipe spacing, each about 8 m (26') × 8 m (26') at depths of 1.2 m (4'), 2.4 m (8') and 3.7 m (12')	274 m (900')
Field C	5 o'clock	1 plane 1.2 m (4') deep with 0.9 m (3') spacing, about 12 m (40') × 10 m (32')	162 m (530')
Field F	11 o'clock	1 plane, 0.6 m (2') deep with 0.5 m (1.5') spacing, about 5 m (18') × 7 m (24'), covered with 2" sheets of polystyrene foam extending 1.2 m (4') beyond the edges of the field	102 m (334')

Modeling the near-pipe behavior of serpentine pipe fields solely by computer would require a great increase in the number of blocks used in GROCS and a reduction of the iteration time step, a time consuming and expensive to operate process. Therefore, in this first examination of the model, a simple calculation procedure has been adopted to approximately model the near-pipe heat flow. This method assumes that the near-pipe heat flow is approximately steady state which permits the use of a formula for the steady state thermal resistance per unit length of pipe between a row of equal size and temperature equally spaced pipes and a mass (the free block containing the pipes) bounded by two parallel planes. The resistance per unit length is [6]:

$$\Omega(s,h) = \frac{1}{2\pi k_e} \ln \left[\frac{s}{\pi R_2} \sinh\left(\frac{\pi h}{s}\right)\right] + \frac{1}{2\pi k_p} \ln\left(\frac{R_2}{R_1}\right) \qquad (1)$$

where: k_e = thermal conductivity of the earth

s = spacing between the centers of the pipes

h = half-thickness of the block

k_p = thermal conductivity of the pipe (0.42 J/msec°C)

R_2 = outer radius of the pipe (0.023 m)

R_1 = inner radius of the pipe (0.020 m)

The first term in Eq. (1) describes the thermal resistance between the outside of the pipe and the block of earth, while the second term accounts for the resistance of the pipe itself. The fluid-pipe interface resistance is neglected.

Strictly speaking, Eq. (1) is valid for an infinite number of infinitely long pipes.

$\Omega(s,h)$ is used as an effective local resistance which means that:

$$\dot{Q} = \frac{L\ \Delta T}{\Omega(s,h)} \tag{2}$$

where: $\dot{Q}$ = total rate of heat flow from the fluid to the ground
L = pipe length
and ΔT = temperature difference between pipe fluid and the planes bounding the block

In use, Eq. (2) is rearranged to give:

$$\Delta T = \dot{Q}\,\frac{\Omega}{L}\,(s,h) \tag{2a}$$

Then, for each experiment $\Omega(s,h)$ is computed, L is known, and the average rate of heat flow for the experimental run of interest is used for $\dot{Q}$, yielding a value for ΔT. Using the computer generated free block temperature, T_{GROCS}, as the temperature of the bounding planes,

$$T_{Fluid} = T_{GROCS} + \Delta T \tag{3}$$

so that the computer generated block temperature and the experimental heat flow rate (together with physical parameters) provide an approximate computer derived value for the pipe fluid temperature to be compared with experiment. These are the values shown as circles in Figures 6, 7, 8, 9, and 10.

The results for Coil E are shown in Figure 6. Because of the extremely short length of this field, winter heat extraction was small until antifreeze

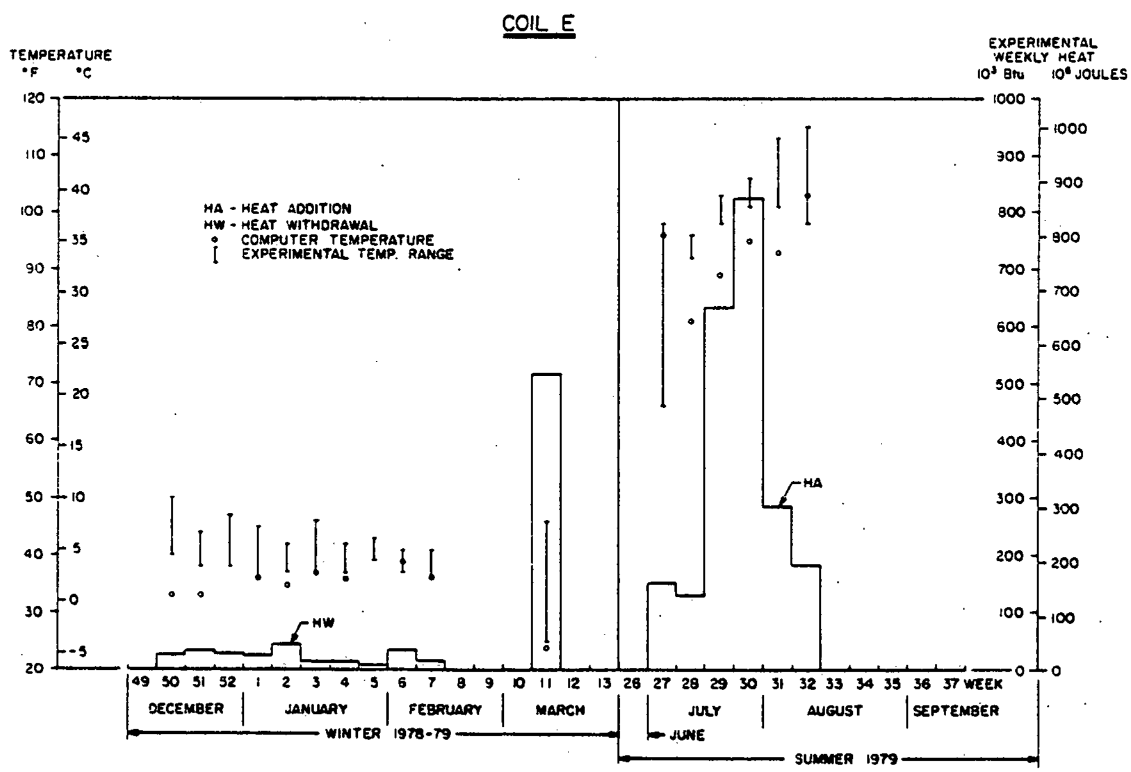


Fig. 6.

was added in February. The computer derived temperatures are systematically low, slightly in winter but considerably in summer. Points for weeks 52 and 5 were omitted from Figure 6 because of small heat flow, but both are within the experimental ranges. Pipe fields usually operate near their extreme temperatures (low end of range in winter and high end in summer), so that the winter computer results for Coil E are quite reasonable, while the summer results, even with the far field correction, are usually too low.

The results for Fields A and B, the largest pipe fields, are shown in Figures 7 and 8 respectively. The computer physical models used for both of these experiments used blocks somewhat too small to enclose the rows of pipes so that the model for Field A actually describes two rows of pipe 0.6 m (2 ft) apart instead of 1.2 m (4 ft) apart and the model for Field B describes three planes of pipe 0.8 m (2.7 ft) apart instead of 1.2 m (4 ft) apart with the central plane still 2.4 m (8 ft) deep. The result of these model approximations is a decreased near-field heat capacity and consequent enhanced temperature extremes in the model predictions. The Field A computer results are slightly low in winter, tailing off at the end of March and usually within the experimental range in summer. The situation for Field B is similar, with very good winter agreement and good to high summer computer results. Model improvement would probably enhance winter agreement for Field A, but lower the summer computer results of both, perhaps enough to decrease the agreement with experiment.

Fields C and F (see Figures 9 and 10) both have good computer models with the pipes contained in free blocks 0.6 m (2 ft) and 0.3 m (1 ft) thick respectively. The winter computer temperatures are in good agreement with experiment for both of these fields. Computer results for Field C for weeks 50, 51, 52, 3, and 5, omitted because of negligible heat flow rates, are all within 2°C of the experimental range center, usually within 1°C. Weeks 8 through 13 are

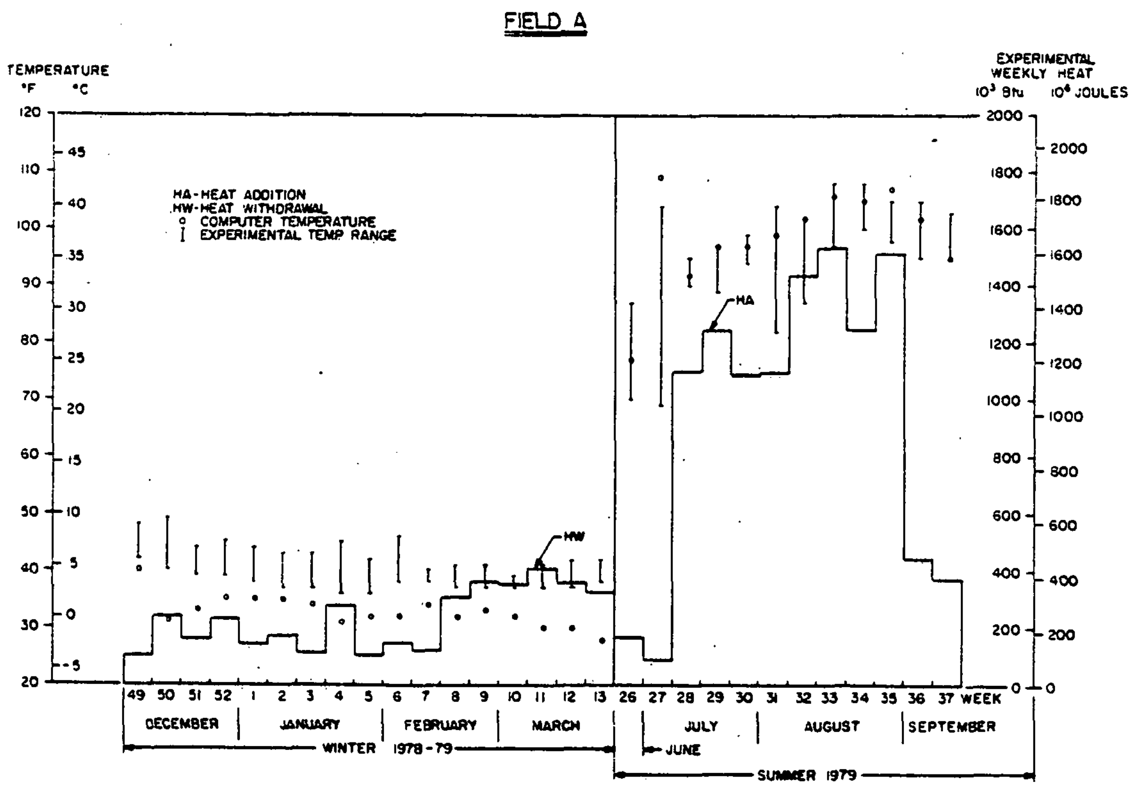


Fig. 7.

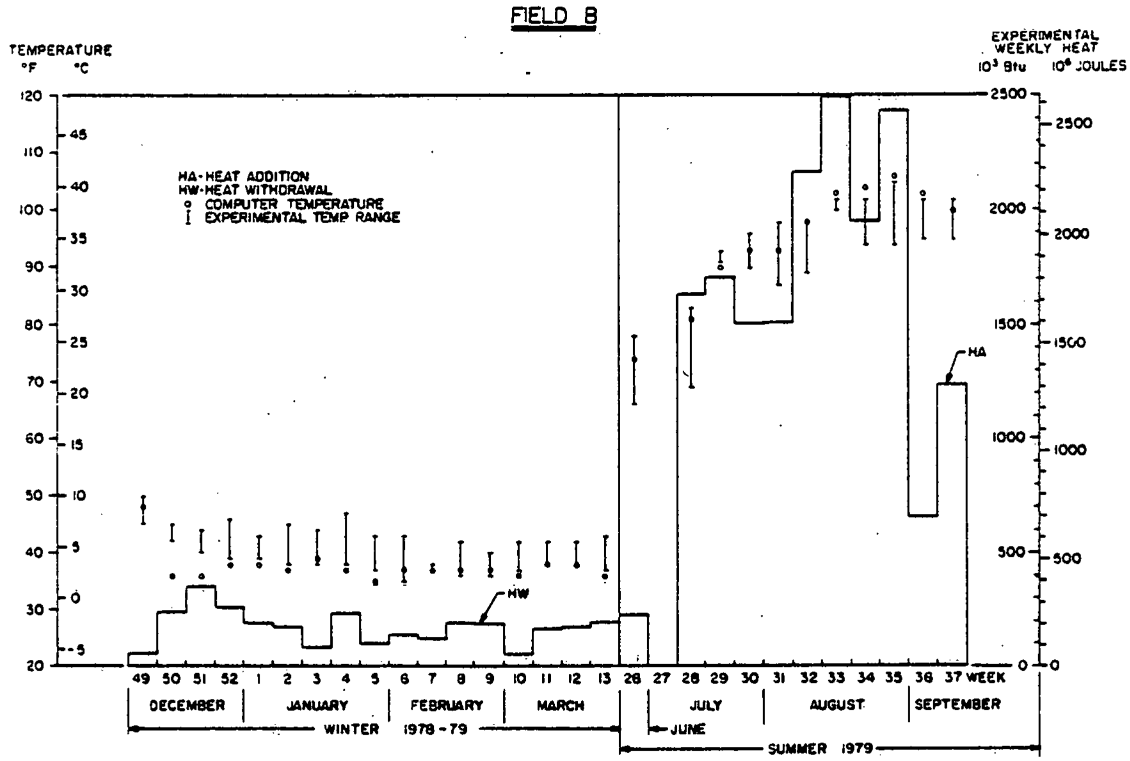

FIELD B
TEMPERATURE
°F °C
EXPERIMENTAL WEEKLY HEAT
10³ Btu 10⁶ JOULES
HA-HEAT ADDITION
HW-HEAT WITHDRAWAL
COMPUTER TEMPERATURE
EXPERIMENTAL TEMP RANGE
HW
HA
WEEK
DECEMBER
JANUARY
FEBRUARY
MARCH
JULY
AUGUST
SEPTEMBER
JUNE
WINTER 1978-79
SUMMER 1979

Fig. 8.

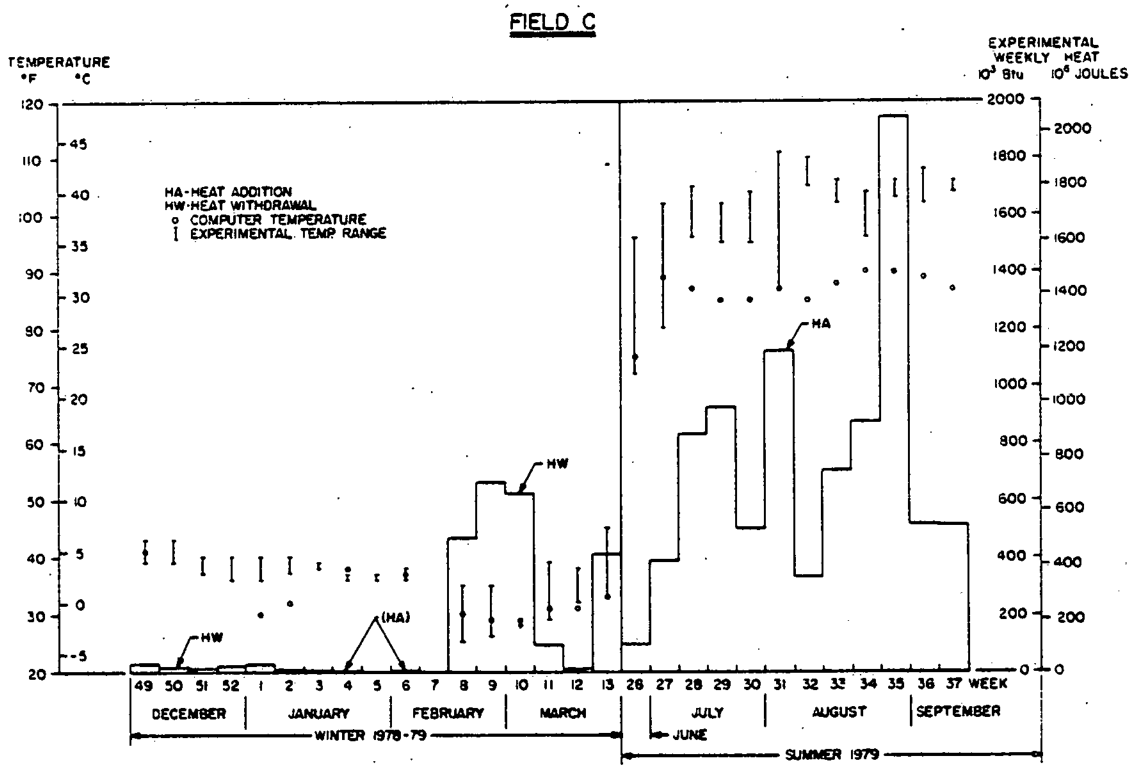

FIELD C
TEMPERATURE
°F °C
EXPERIMENTAL WEEKLY HEAT
10³ Btu 10⁶ JOULES
HA-HEAT ADDITION
HW-HEAT WITHDRAWAL
COMPUTER TEMPERATURE
EXPERIMENTAL TEMP RANGE
HW
(HA)
HA
WEEK
DECEMBER
JANUARY
FEBRUARY
MARCH
JULY
AUGUST
SEPTEMBER
JUNE
WINTER 1978-79
SUMMER 1979

Fig. 9.

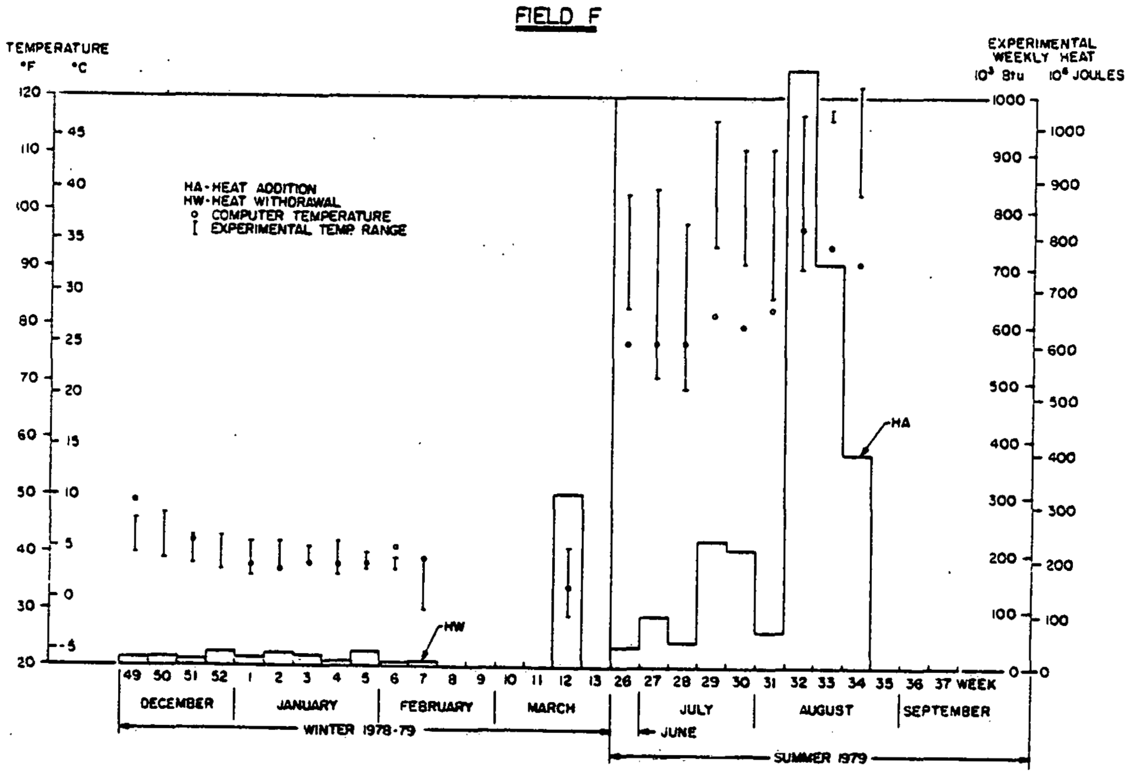


Fig. 10.

the most important for Field C because of the large heat flow rates obtained. The agreement between computer and experiment was good during these weeks, as during the analogous week 12 for Field F. The summer computer derived results for both experiments are systematically low, even after allowing for the considerable far-field correction, particularly toward the end of the summer.

3.4 Analysis

The winter computer generated temperatures are very close to those experimentally observed for all experiments with good computer models (Tanks A, C, and E, Coil E, and Fields C and F), and low for those experiments using models containing undersized blocks (Fields A and B), probably because of the reduced heat capacity of these blocks. The summer computer generated tank temperatures, after the far field correction, are quite close to the experimental results with evidence of a difference in ground thermal behavior between the identical Tanks C and E.

The summer computer generated temperatures for the fields with good models (Coil E, and Fields C and F) are systematically low, particularly toward the end of the summer. Since this behavior is apparent for the fields but not for the tanks, it is probably related to high heat fluxes, and not merely to high temperatures. Plausible explanations include deviations from constant thermal properties due to soil drying, and underestimation of the computer derived temperatures because of the even division of heat inputs by GROCS (as described in section 3.1). It is not completely clear how model improvement will affect the computer results for Fields A and B, but it should moderate computer temperature results.

4. CONCLUSION

A simple and flexible computer program called GROCS has been written to model ground coupling devices for solar source heat pump systems. Model predictions have been compared to experimental results obtained during the first year of operation of the solar ground coupling research facility at Brookhaven National Laboratory as a first step toward the creation of an experimentally validated model of ground coupling. Although using constant thermal properties, averaged heat inputs and (for the field experiments) a near-pipe steady state heat flow approximation, model predictions generally are in good agreement with experiment, providing a basis for further refinement and improvement.

REFERENCES

1. Metz, P. D., "The Potential for Ground Coupled Storage Within the Series Solar Assisted Heat Pump System," Proc. of 1978 Annual Meeting American Section of the International Solar Energy Society, Denver, CO, August 28 - 31, 1978, (BNL 24579).

2. Andrews, J. W., "A TRNSYS-Compatible Model of Ground-Coupled Storage," BNL 51061, September, 1979.

3. Metz, P. D., "Design, Construction and Operation of the Solar Assisted Heat Pump Ground Coupled Storage Experiments at Brookhaven National Laboratory," Proc. of 4th Annual Heat Pump Technology Conf., Oklahoma State University, Stillwater, OK, April 9-10, 1979, (BNL 25908).

4. Nagle, C. M., "Climatology of Brookhaven National Laboratory 1949 Through 1973," BNL 50466, pp. 3, 13, November 1975.

5. Andrews, J. W. and Metz, P. D., "Computer Simulation of Ground Coupled Storage in a Series Solar Assisted Heat Pump System," Proc. of 1979 International Solar Energy Society Congress, Atlanta, GA, May 28 - June 1, 1979, (BNL 26216).

6. Kutateladze, S. S., Fundamentals of Heat Transfer, p. 93, Academic Press, NY, 1963.

ACKNOWLEDGEMENT

I thank Anthony Sganga who designed the physical model for Field F and modified GROCS to accept weekly heat inputs.