SPECIAL REPORT 91-19

CRREL

Field Measurements of Heat Losses From Three Types of Heat Distribution Systems

Gary E. Phetteplace, Martin J. Kryska, and David L. Carbee

November 1991

For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, *published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.*

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U.S. Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Field Measurements of Heat Losses From Three Types of Heat Distribution Systems

Gary E. Phetteplace, Martin J. Kryska, and David L. Carbee

November 1991

Prepared for
U.S. ARMY ENGINEERING AND HOUSING SUPPORT CENTER

PREFACE

This report was prepared by Gary E. Phetteplace, Mechanical Engineer, Martin J. Kryska, Mechanical Engineer, and David L. Carbee, Engineering Technician, Applied Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory.

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Field Measurements of Heat Losses From Three Types of Heat Distribution Systems

GARY E. PHETTEPLACE, MARTIN J. KRYSKA, AND DAVID L. CARBEE

INTRODUCTION

Problem statement

Most major Department of Defense facilities are heated with central heat distribution systems. The heat from the central heating plants is usually distributed to the buildings as high temperature hot water or steam through buried piping systems. DoD has approximately 6,000 miles of heat distribution piping systems in service (Segan and Chen 1984). The Army owns and operates over 3,000 miles of this (Department of the Army 1988). Many of our systems are old and in need of major repairs or replacement. To replace these systems currently costs about $300 per lineal foot. Thus we are facing monumental costs for replacement. In addition, the technology now being used by DoD is problematic, and many systems that have been recently replaced have failed prematurely. A previous study by the Corps of Engineers (Segan and Chen 1984) identified many problems caused by improper design, installation and maintenance. Most of these problems led to premature failure of the system.

Capital costs and system life are only a portion of the life-cycle cost issue. These systems are very costly to operate and maintain as well. If we assume an optimistic value for system losses of 50 Btu/hr-ft (for aged systems a value of several times this is likely) and a cost of $10 per million Btu for heat energy, we find that heat losses cost the Army around $85 million per year. The FY 88 "Redbook" (U.S. Army 1988) gives annual maintenance costs of over $41 million. This, of course, does not include any significant replacement projects.

Objective and approach

The objective of DoD heat distribution research is to identify improvements in methods and systems that will prove to be less costly and problematic. This report describes a portion of the work underway in a Facilities Engineering Applications Program (FEAP) project that has this objective. This project is funded by the Army's Engineering and Housing Support Center (EHSC). The portion of the project covered by this report deals with the quantification of heat losses from operating heat distribution piping systems. This project is a joint effort between two of the U.S. Army Corps of Engineers Laboratories: CRREL and the Construction Engineering Research Laboratory (CERL). This report describes only the portion of the work for which CRREL was responsible. A joint report on the project will be available at a later date.

From the discussion presented above it is clear that heat losses are a major portion of the operations and maintenance (O&M) costs for heat distribution systems. In spite of this, little emphasis has been placed on the thermal design of these systems and the subsequent operational costs. To date heat losses have been calculated based on formulas that rely on several untested assumptions. The work described here represents one of the first efforts to measure actual heat losses from operational systems and compare these measurements with calculated results. Other efforts are currently underway to make similar types of measurements on other types of systems (Phetteplace 1990) and under closely controlled laboratory conditions (Lunardini 1990).

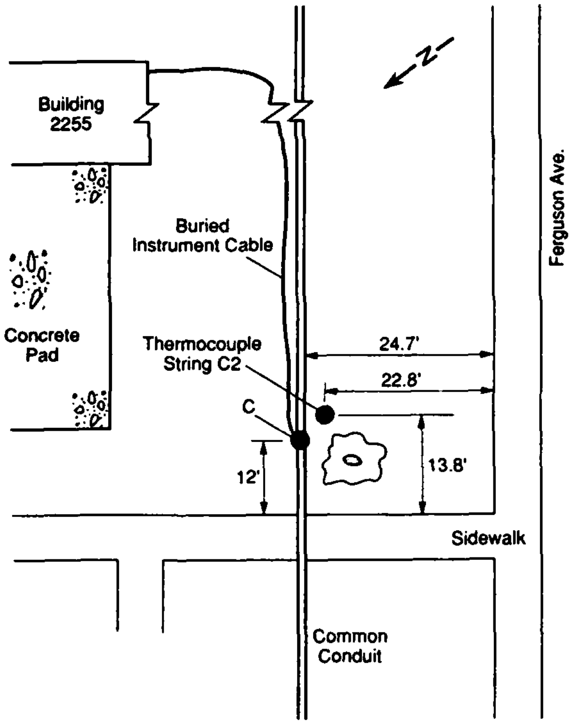
To accomplish our objective we chose to instrument an operating system on an Army facility. Ft. Jackson, South Carolina, which was selected because a large replacement project was underway there. Three types of buried heat distribution piping systems were installed:

1. Shallow concrete trench with top cover at grade level.
2. Class A steel conduit system with supply and return piping in a common conduit.
3. Class A steel conduit system with supply and return piping in individual conduits.

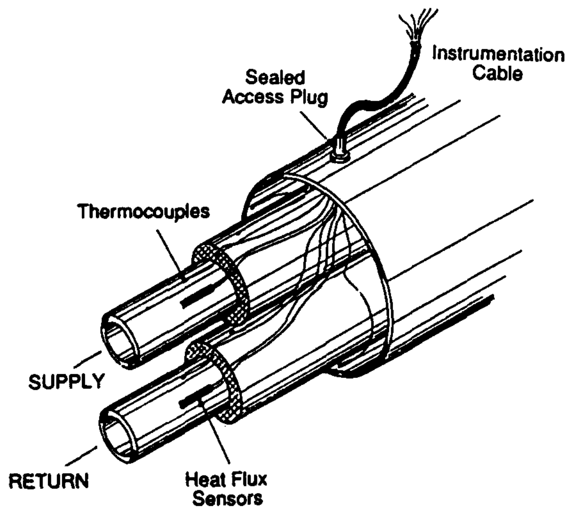
SYSTEM DESCRIPTION AND INSTRUMENTATION LAYOUT

Common conduit system

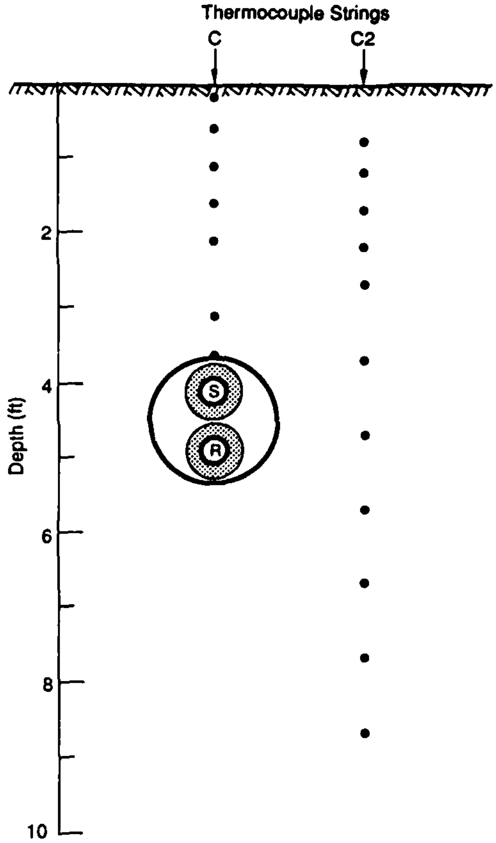
The prefabricated common conduit system, both the supply and return piping in the same steel conduit (Fig. 1), conforms to the federal agency criteria for a Class A



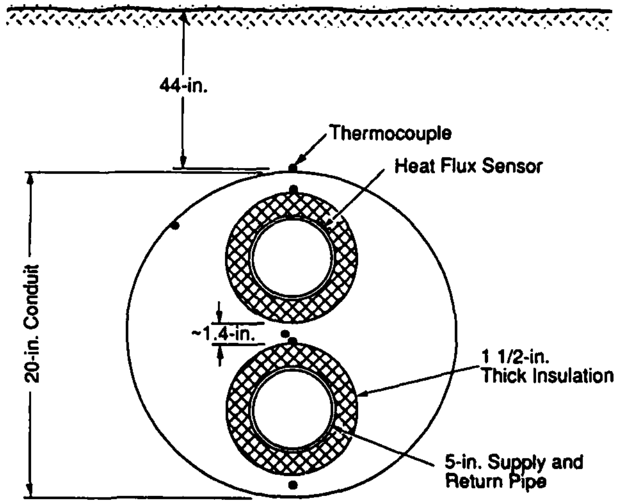
a. Instrumentation site with thermocouple strings and cable locations.



b. Isometric view of instrumented pipe and conduit.



c. Ground thermocouple locations.



d. Pipe thermocouple and sensor location.

Figure 1. Common conduit site details.

system. This type of system is designed and installed in accordance with Corps of Engineers Guide Specification (CEGS) 02695 (U.S. Army 1989).

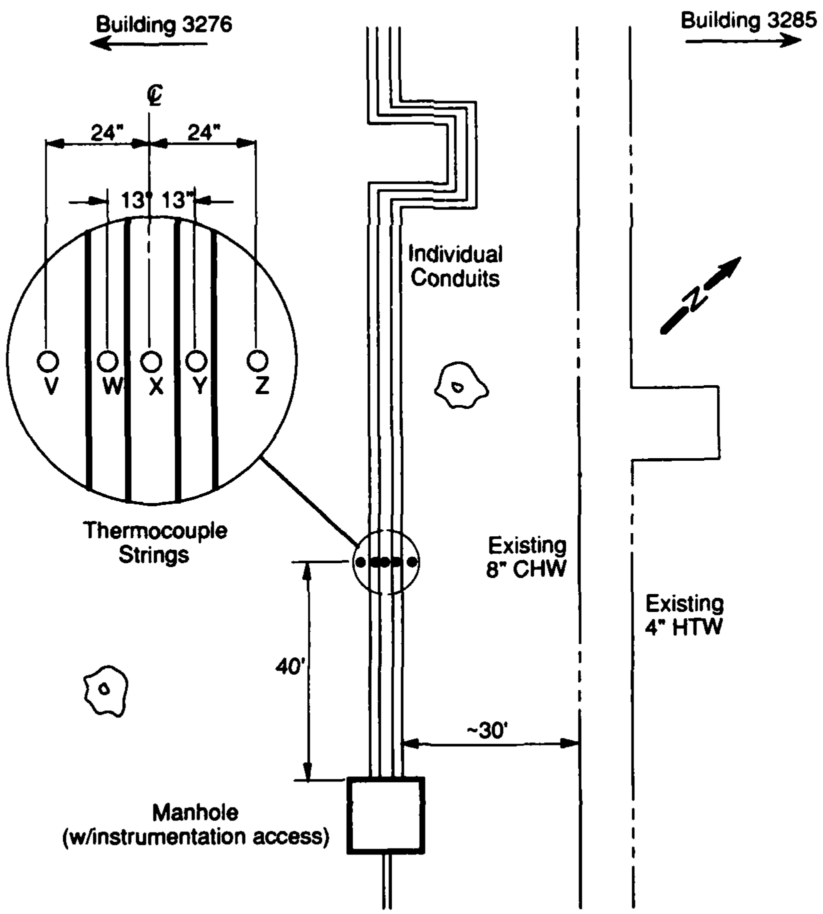
The Class A conduit system used at Ft. Jackson consists of schedule 40 steel supply and return pipes of 5-in. nominal pipe size (NPS). These pipes are insulated with a mineral wool insulation of 1.5-in. thickness. The insulated supply and return pipes are encased in a spiral-wound steel conduit that is approximately 1/8 in. thick. The supply and return pipes are oriented vertically within the conduit with the supply pipe on top of the return pipe. The conduit has an outer diameter of approximately 20 in., thus allowing for an air space between the pipe insulation and inside of the conduit. The conduit is covered with an asphalt-based corrosion-resistant coating. All field closures of the conduit are welded and coated. The interior air space between the pipe insulation and the conduit inner diameter is designed to be drainable and dryable. The integrity of the air space can be checked by pressure testing at 15 psig.

Individual conduit system

The individual conduit system employs the same construction features as the common conduit system described above. In this case the supply and return pipes are of 4-in. NPS Schedule 40 steel and each is encased in its own individual conduit of approximately 16-in. outer diameter (Fig. 2). The insulation on the pipes is 2.5-in.-thick mineral wool in each case.

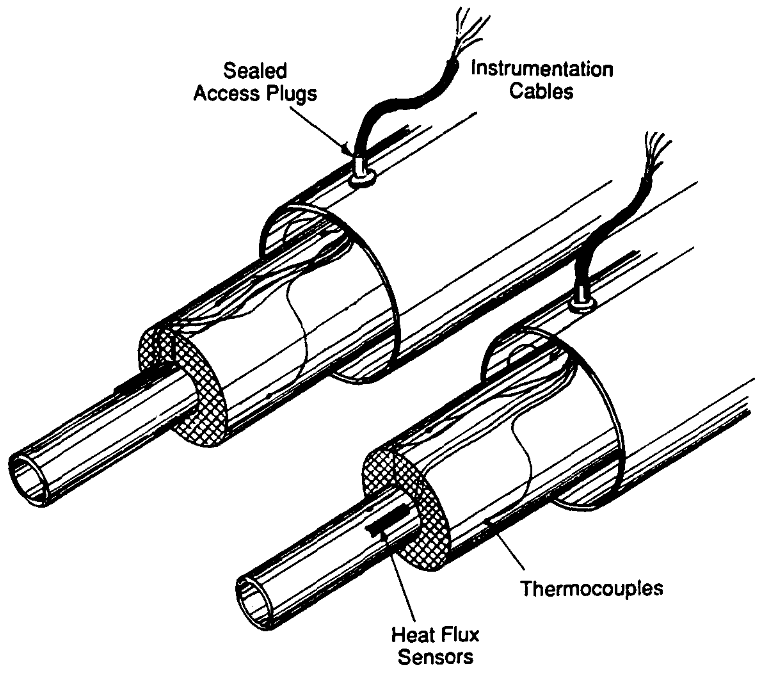
Shallow concrete trench system

The shallow concrete trench system consists of a cast-in-place concrete trench with cast-in-place concrete covers (Fig. 3). The system is designed such that the top surface of the covers is slightly above the surrounding grade level and can be used as a sidewalk.



a. Instrumentation site with thermocouple string locations.

Figure 2. Individual conduit site details.



b. Isometric view of instrumented pipe and conduit.

Figure 2. (cont'd).

The covers have lifting eyes cast into them and thus they can be removed in the event that the system must be serviced. The pipes are supported by pillars protruding from the floor. This allows any water that enters the trench to drain to the manholes where it can be removed by sump pumps or gravity drainage.

The interior dimensions of the shallow concrete trench at the Ft. Jackson test site are 40 in. wide and 21.5 in. high. The trench walls are 5.5 in. thick. The thickness of the trench covers can be varied as required for the loading expected. At our Ft. Jackson test site the trench covers are 6 in. thick and have a lip of about 1 in. at the outside edge, so that the portion resting on the trench wall is about 5 in. thick. The supply and return piping is 5-in. NPS schedule 40 steel. Each pipe is insulated with 2.5 in. of mineral wool pipe insulation.

Thermal insulation

Only two manufacturers of mineral wool insulation have a product approved for use on underground heat distribution systems. We were not able to determine which product had been used on each of the systems in this study. Since the thermal properties of the two approved insulations are somewhat different, we decided to use an average of the two for this study. The average value is within 10% of each of the two insulation thermal conductivities in every case. The thermal properties of each insulation and the average value used are given in Table 1. For the calculations an equation was fitted to the average insulation thermal conductivity data:

$$k_i = 0.0233 - (4.17 \times 10^{-3} T_i) + (8.33 \times 10^{-8} T_i^2)$$

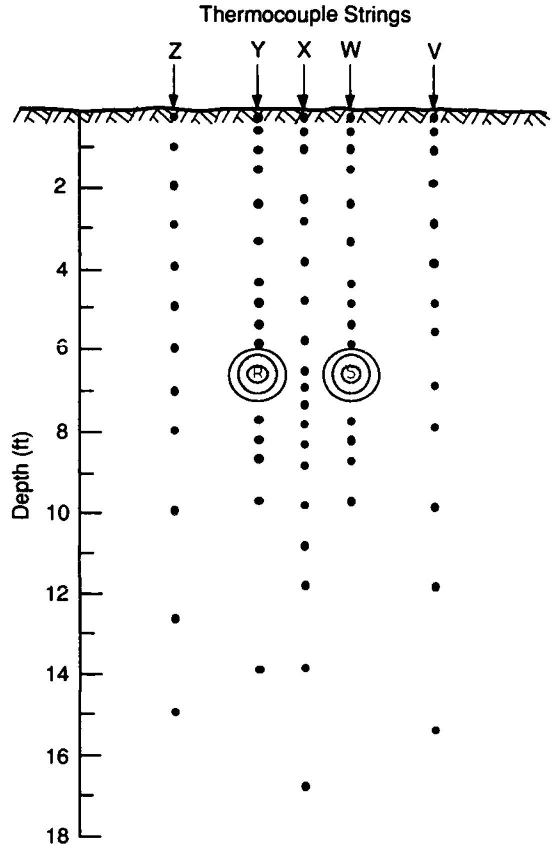
where k_i is average thermal conductivity and T_i is mean insulation temperature (°F).

Instrumentation layout

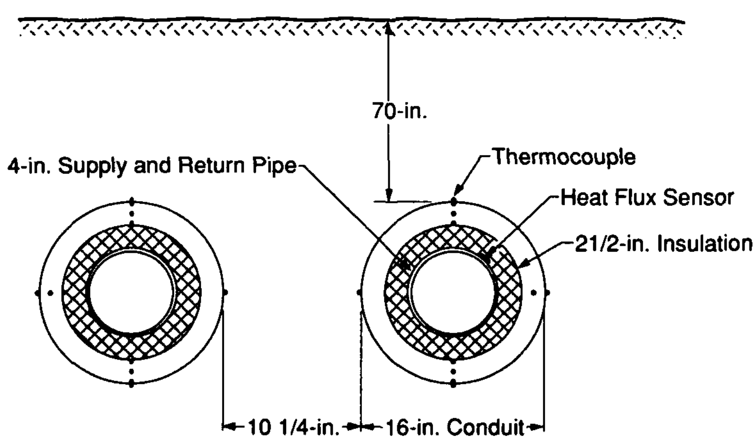
The location of the temperature and heat flux sensors as well as the approximate location of the sites themselves are shown in Figures 1, 2, and 3 for the common conduit, trench and individual conduit sites, respectively.

General description of instrumentation

Heat flow measurements were taken at each site using commercially available heat flux transducers

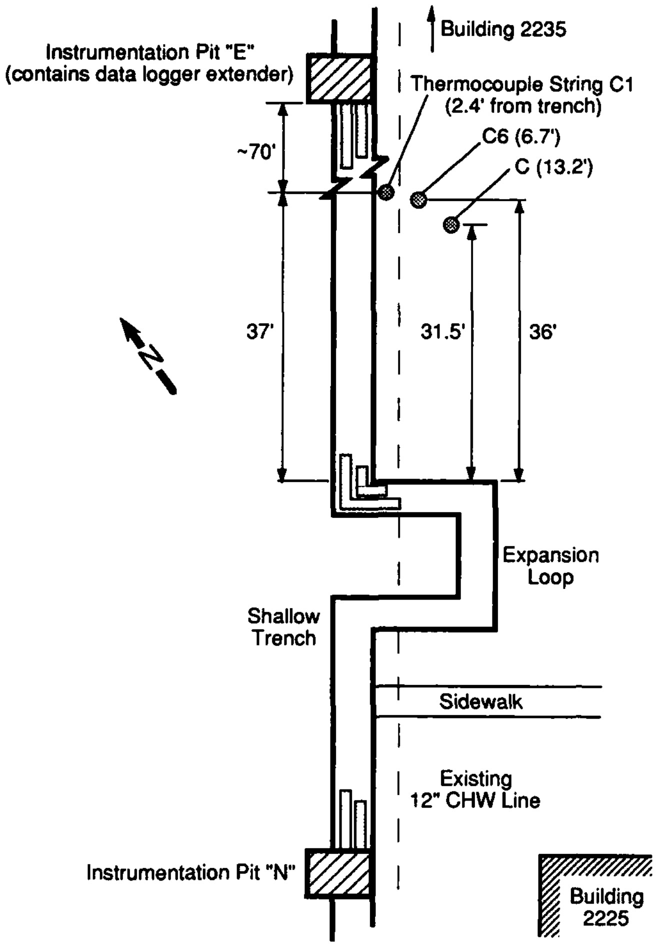


c. Ground thermocouple locations.

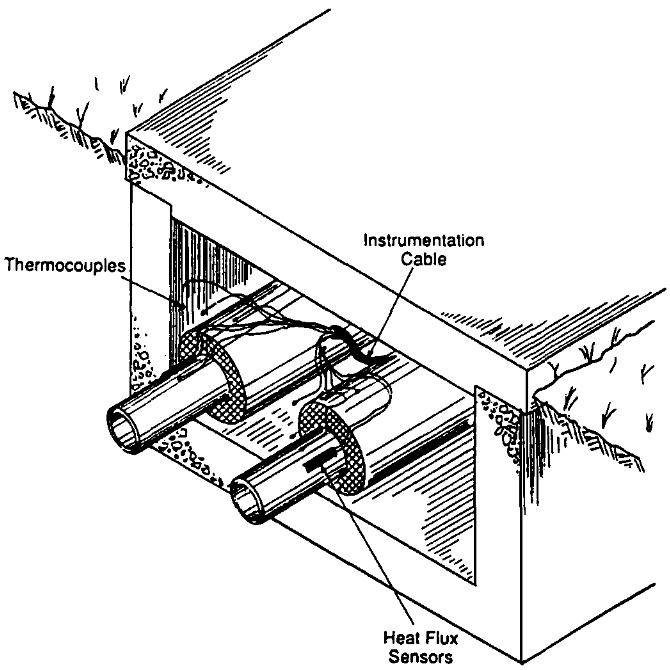


d. Pipe thermocouple and sensor locations.

Figure 2. (cont'd). Individual conduit site details.

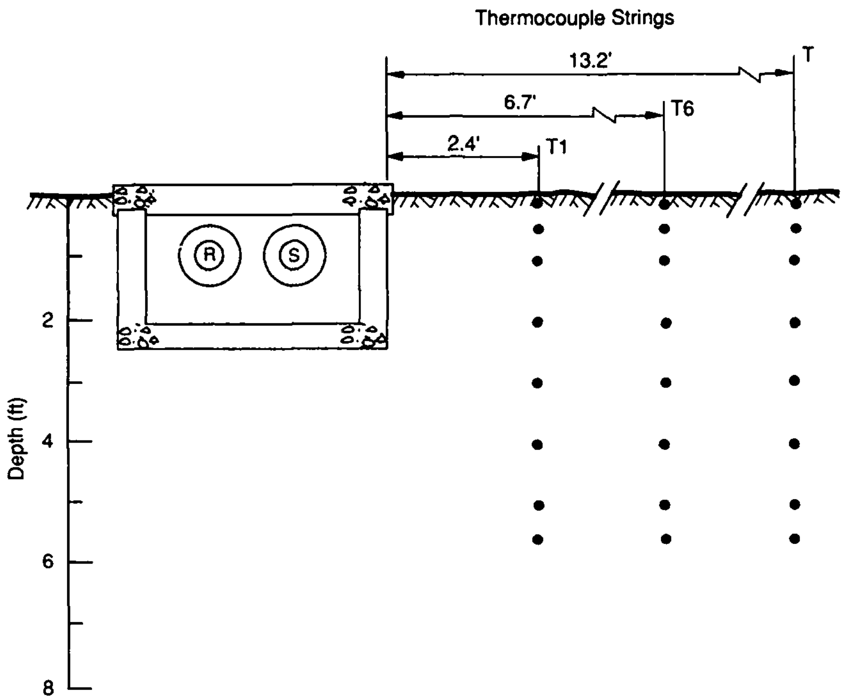


a. Instrumentation site with thermocouple string locations.

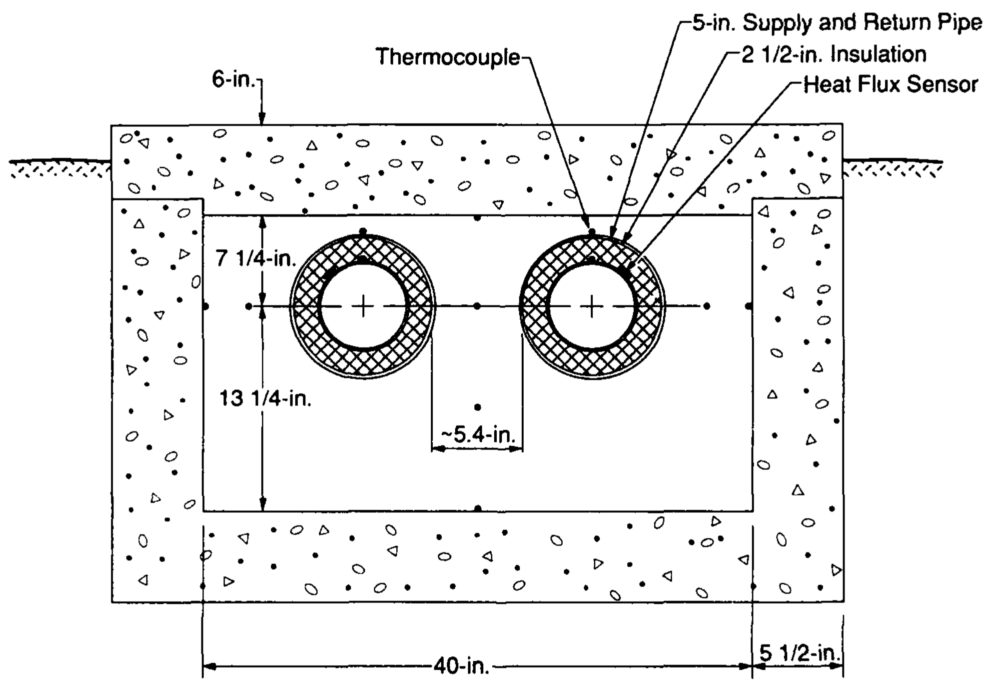


b. Isometric view of instrumented pipe and trench.

Figure 3. Trench site construction details.



c. Ground thermocouple locations.



d. Pipe thermocouple and sensor locations.

Figure 3 (Cont'd).

Table 1. Thermal properties of mineral wool pipe insulation.

Mean insulation temperature T_i, *°F*	*"Paroc" thermal conductivity Btu/hr-ft-°F*	*"Epitherm" thermal conductivity Btu/hr-ft-°F*	*Average thermal conductivity* k_i, *Btu/hr-ft-°F*
200	0.0233	0.0275	0.025
300	0.0278	0.0317	0.030
400	0.0323	0.0375	0.035

cement bonded to the outer surfaces of the carrier pipes. The heat flux transducers used are currently marketed by International Thermal Instruments (Del Mar, California) as motor efficiency meters (model MS-175). The physical dimensions of these transducers are 5/8 in. × 3-1/2 in. × 0.070 in. thick. The transducers, made of polyimide-glass, are designed to measure heat losses from any solid surface. Since the pipe has a relatively high thermal conductivity compared to the other components in the system the temperature will be fairly constant around the pipe. This constant temperature, combined with the low thermal resistance of the heat flux transducer, is small compared to that of the insulation, will ensure that the heat flux is nearly parallel through the thickness of the transducer. The flow of heat through the sensor creates a small temperature differential between its surfaces, which are in thermal contact with miniature thermopiles. The thermopiles consist of a number of thermocouples arranged in series. The difference between the EMFs produced by the thermopiles is proportional to the temperature difference across the heat flux transducer. Since the thermal conductivity of the heat flux transducer is known, this difference in EMFs can be related to the heat flux through the transducer. The manufacturer of the heat flux transducers used in this study provided a "calibration certificate" indicating that the sensitivity of the transducers was 20 Btu/hr-ft^2-mV.

Two necessary conditions for accurate measurements using heat flux transducers are that 1) the thermal resistance of the transducer itself must be negligible when compared to the other resistances in series with it, and 2) the direction of the heat flux must be nearly parallel to the thickness of the transducer. Both of these conditions are satisfied in the case of insulated pipes of relatively large diameter, such as those used in this study. Because the signal from the heat flux transducers is proportional to the heat flux through them, it is desirable to place them at a point in the system where the heat flux is greatest. On the cylindrical surfaces of the piping systems, we accomplished this by placing them on the smallest diameter available, the carrier pipe outer surface. The heat flux transducers used in this study have an operating temperature range of –400°F to 450°F, so placing them directly on the pipes poses no problems from that standpoint.

The temperature measurements in and around the pipes and conduit and in the surrounding soil were taken with the use of on-site constructed thermocouples. A thermocouple is a temperature sensor that consists of two dissimilar metals, copper and constantan (type T) which, in our case, are joined together at a junction. The junction, when connected in a certain manner to another junction, (called the reference junction), which is at a known temperature, produces a voltage output proportional to the temperature difference between the two junctions. Thermocouple thermometers or data loggers with isothermal board options that contain reference junctions can read thermocouples directly and convert the output voltage to temperature in degrees Celsius or Fahrenheit.

The thermocouples were constructed from multipair thermocouple extension cables. The cable consisted of 12-pair, 20 AWG solid copper and constantan wires with polyvinyl insulation on each conductor and on the cable overall. Each of the numbered copper/constantan pairs was separated from the cable at the desired location and trimmed to the exact length. The insulation on the individual conductors was stripped back approximately 1/4 in. and a metallic lug was crimped over both wires, bonding them together both mechanically and electrically. A cap, filled with fresh silicone rubber, was heat shrunk over the lug, protecting the thermocouple from stray electrical signals, corrosion and water. Excess extruded rubber was wiped away and the sealed thermocouple was allowed to cure.

Whenever possible, thermocouples were made directly from the thermocouple cable wires without splicing on extensions, which can cause not only slight voltage errors but can also increase the possibility of shorting or breaking of difficult-to-access wire circuits.

Data logging and communication systems

The two data loggers used in this study were Fluke 2280B series systems. These systems are capable of

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BEGIN SCAN GROUP 3    20 JUL 88  20:23:07
PIPE TEMPS/TAPE/6HR

C   1 330.16   C   2 293.34   C   3 176.10   C   4 157.01   C   5 162.43   C   6 143.56   C   7 177.55   C   8 145.72
C  18 -  8.18  C  19   4.36   C 100 134.20   C 101 110.31   C 102 332.90   C 103 140.95   C 104 132.86   C 105 261.67
C 106 146.51   C 107 127.20   C 108 102.98   C 109 109.69   C 110 128.49   C 111 128.64   C 136   1.80   C 137 -  2.94

END SCAN GROUP 3      20 JUL 88  20:23:21

BEGIN SCAN GROUP 1    20 JUL 88  22:23:01
BIHOURLY AIR TEMPS-TAPE

C   0  80.98   C  32  84.70   C 139  86.41   C 100 130.94   C 104 128.32   C 110 124.55   C 111 124.64

END SCAN GROUP 1      20 JUL 88  22:23:06

BEGIN SCAN GROUP 0    21 JUL 88  00:00:00
DAILY/EVERYTHING-TAPE

C   0  78.43   C   1 330.56   C   2 303.88   C   3 176.13   C   4 157.53   C   5 161.77   C   6 143.90   C   7 178.24
C   8 145.45   C   9  89.26   C  10  93.00   C  11  96.26   C  12  99.48   C  13 103.53   C  14 115.77   C  15 125.66
C  16 125.48   C  17 128.49   C  18 -  8.06  C  19   4.17   C  20  92.67   C  21  95.10   C  22  98.04   C  23 101.23
C  24 104.33   C  25 109.56   C  26 108.19   C  27 103.40   C  28  98.15   C  29  93.36   C  30  89.40   C  31  89.53
C  32  84.47   C 100 130.31   C 101 109.48   C 102 331.19   C 103 136.82   C 104 128.10   C 105 300.25   C 106 141.32
C 107 119.56   C 108 103.12   C 109 108.34   C 110 124.87   C 111 124.85   C 112  85.93   C 113  85.68   C 114  83.61
C 115  82.21   C 116  82.90   C 117  81.47   C 118  81.67   C 119  82.44   C 120  88.12   C 121  89.24   C 122  88.20
C 123  83.28   C 124  79.62   C 125  77.10   C 126  75.63   C 127  75.27   C 128  86.06   C 129  87.05   C 130  84.75
C 131  77.81   C 132  68.89   C 133  68.27   C 134  71.05   C 135  71.85   C 136   4.13   C 137 -  2.89  C 139  84.98

END SCAN GROUP 0      21 JUL 88  00:00:38

BEGIN SCAN GROUP 1    21 JUL 88  00:23:01
BIHOURLY AIR TEMPS-TAPE

C   0  78.02   C  32  84.48   C 139  84.51   C 100 130.11   C 104 127.75   C 110 124.19   C 111 124.38

END SCAN GROUP 1      21 JUL 88  00:23:06

BEGIN SCAN GROUP 1    21 JUL 88  02:23:01
BIHOURLY AIR TEMPS-TAPE

C   0  75.58   C  32  84.32   C 139  82.99   C 100 127.76   C 104 125.27   C 110 122.28   C 111 122.36

END SCAN GROUP 1      21 JUL 88  02:23:06

BEGIN SCAN GROUP 3    21 JUL 88  02:23:07
PIPE TEMPS/TAPE/6HR

C   1 331.30   C   2 301.89   C   3 176.64   C   4 157.97   C   5 162.42   C   6 144.39   C   7 178.77   C   8 146.14
C  18 -  8.30  C  19   5.13   C 100 127.76   C 101 108.39   C 102 332.87   C 103 133.93   C 104 125.28   C 105 299.65
C 106 138.66   C 107 115.80   C 108 102.98   C 109 107.13   C 110 122.34   C 111 122.37   C 136   4.18   C 137 -  3.02

END SCAN GROUP 3      21 JUL 88  02:23:21
```

Figure 4. Data as recorded by data logging system 1, trench and common conduit sites.

monitoring and logging up to 100 separate inputs, with expansion to 1,500 inputs using additional remote 100-channel input extenders. The individual input channels were monitored and values collected in different scan groups at different time intervals to accommodate the needs of the study. All data scans were stored on a DC 100 magnetic tape drive that recorded date, time, scan group, channel number and value. Limited data were also printed onto paper for backup purposes in the event of a problem with the magnetic tape. This also served as a quick visual check on the individual channel functions whenever we visited the test site. The data collected on magnetic tape were transferred to our personal computer at CRREL by telephone using RS-232 interfaces in the data loggers and modems. This allowed us to not only collect and process the data but to keep a close evaluation of the operation of the utility systems. This was done approximately every week.

One data logger was used to collect values from both the trench and common conduit sites and the other was used for the individual conduit site. Appendix A contains listings of monitored inputs from the three instrumented sites. These tables give the channel number, label, output unit and the sensor location. Figures 4 and 5 are samples of some typical data as collected from the data logging systems.

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BEGIN SCAN GROUP 3   28 FEB 89  14:11:06
6 HR/AIR & PIPES DATA-TAPE

C 100   47.94   C 101   54.25   C 102 -  4.08   C 103 -  2.85   C 104  337.37   C 105   93.44   C 106   93.83   C 107   87.82
C 108   82.71   C 109   84.17   C 110   78.49   C 111   78.17   C 112  230.87   C 113   82.87   C 114   79.28   C 115   80.28
C 116   76.27   C 117   77.59   C 118   78.51   C 119   74.10   C 120   77.96   C 121   75.30   C 122   77.91   C 123   74.84
C 124   75.13   C 125   71.22   C 126   71.09   C 127   74.12

END SCAN GROUP 3     28 FEB 89  14:11:20

BEGIN SCAN GROUP 3   28 FEB 89  20:11:06
6 HR/AIR & PIPES DATA-TAPE

C 100   48.20   C 101   55.42   C 102 -  3.74   C 103 -  0.85   C 104  334.78   C 105   93.40   C 106   93.75   C 107   87.67
C 108   82.67   C 109   84.13   C 110   78.51   C 111   78.13   C 112  218.48   C 113   83.13   C 114   79.49   C 115   80.72
C 116   76.38   C 117   77.79   C 118   78.77   C 119   74.19   C 120   77.92   C 121   75.30   C 122   77.85   C 123   74.81
C 124   75.15   C 125   71.27   C 126   71.08   C 127   74.19

END SCAN GROUP 3     28 FEB 89  20:11:21

BEGIN SCAN GROUP 0   01 MAR 89  00:00:00
MDNGHT DAILY/ALL DATA-TAPE

C 100   41.34   C 101   54.16   C 102 -  4.29   C 103 -  1.38   C 104  332.27   C 105   92.90   C 106   93.28   C 107   87.35
C 108   82.50   C 109   83.90   C 110   78.43   C 111   78.09   C 112  214.15   C 113   82.63   C 114   79.15   C 115   80.28
C 116   76.24   C 117   77.53   C 118   78.48   C 119   74.12   C 120   77.76   C 121   75.16   C 122   77.73   C 123   74.72
C 124   75.00   C 125   71.15   C 126   70.94   C 127   74.00   C 128   49.34   C 129   53.27   C 130   54.27   C 131   55.91
C 132   58.47   C 133   61.25   C 134   63.76   C 135   65.35   C 136   66.42   C 137   67.33   C 138   67.57   C 139   68.30
C 140   46.46   C 141   50.75   C 142   53.16   C 143   54.35   C 144   55.96   C 145   58.85   C 146   62.71   C 147   65.16
C 148   67.85   C 149   69.23   C 150   71.28   C 151   70.34   C 152   70.01   C 153   69.33   C 154   50.46   C 155   52.73
C 156   54.27   C 157   56.56   C 158   58.25   C 159   61.55   C 160   66.28   C 161   72.44   C 162   75.05   C 163   75.49
C 164   74.32   C 165   73.06   C 166   72.49   C 167   72.00   C 168   71.12   C 169   70.24   C 170   69.64   C 171   68.99
C 172   68.78   C 173   48.98   C 174   52.20   C 175   54.34   C 176   55.35   C 177   57.09   C 178   60.11   C 179   64.53
C 180   66.99   C 181   70.40   C 182   72.54   C 183   72.86   C 184   71.85   C 185   71.14   C 186   69.98   C 187   49.31
C 188   51.96   C 189   53.97   C 190   55.22   C 191   57.03   C 192   59.38   C 193   62.47   C 194   65.16   C 195   66.75
C 196   67.46   C 197   67.77   C 198   67.92   C 199   68.32

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BEGIN SCAN GROUP 3   01 MAR 89  02:11:06
6 HR/AIR & PIPES DATA-TAPE

C 100   37.67   C 101   53.38   C 102 -  3.91   C 103 -  0.94   C 104  331.95   C 105   92.92   C 106   93.30   C 107   87.51
C 108   82.54   C 109   83.89   C 110   78.46   C 111   78.05   C 112  211.92   C 113   82.49   C 114   79.08   C 115   80.05
C 116   76.15   C 117   77.43   C 118   78.31   C 119   74.06   C 120   77.75   C 121   75.17   C 122   77.69   C 123   74.70
C 124   74.93   C 125   71.08   C 126   70.88   C 127   73.93

END SCAN GROUP 3     01 MAR 89  02:11:21
```

Figure 5. Data as recorded by data logging system 2, individual conduit site.

Data acquisition schedule and coverage

The data scanning and collecting schedule varied in time interval and the particular channels sampled, depending upon the location of each sensor. All data channels were scanned and collected twice a day, but some channels associated with the air or pipe temperatures were recorded more frequently. Table 2 shows the scan frequency and the data storage location for each instrumented site. Figures 4 and 5 show the format of the data as collected by each of the two data logging systems.

Since the project started, continuous data records have been maintained on all three systems, except for data logger malfunctions, power failures and, on a few occasions, physical damage. System 1 (common conduit and trench sites) has been on line since February 1986 (54 months). System 2 (individual conduit site) has been on line since August 1987 (34 months). Table 3 summarizes the times for which data were collected by the two systems.

Soil classification and moisture content data

Soil samples were taken from sample boreholes at the common conduit site (the trench site is in close proximity) and the individual conduit site. Descriptive classifications and water content profiles of the soils surrounding these test sites are shown in Tables 4 and 5. Additional water content profiles were taken later at different times of the year to give an indication of the possible changes in in-situ water contents.

Table 2. Data scan frequencies for each site.

Site	*Scan times*	*Description*	*Channel no.*	*Storage locations*
All 3	Noon and midnight	All data	All channels	Tape
CC*	2-hour	Air temp.	0 and 32	Tape
T	2-hour	Air temp.	139	Tape
CC	6-hour	Pipe temp.	1 thru 8, 18 and 19	Tape
T	6-hour	Pipe temp.	100 thru 111 136 and 137	Tape
IC	6-hour	Air and pipe temp.	100 thru 127	Tape
All 3	4-day	All data	All channels	Printer

*CC = Common conduit site.
T = Trench site.
IC = Individual conduit site.

METHODS OF DATA ANALYSIS

Data processing

All data processing was done on an IBM-compatible personal computer. Due to the size of the data sets the machine used was equipped with an Intel 80386 microprocessor, an Intel 80387 math coprocessor, and 5 megabytes of random access memory. The data were processed using several commercial software packages. The "as logged" data from the Fluke 2280B were first processed with the *Prologger* software package available from Fluke. This transforms the data into a format suitable for use by *Lotus 1-2-3*. The remaining data analysis was done using the various capabilities of the *Lotus 1-2-3* package. Plots were produced by *Lotus 1-2-3* and other methods.

Description of calculation methods

Several different procedures are used to calculate the heat losses from the data collected at Ft. Jackson. Some of these procedures are applicable to more than one of the three system types while others are applicable only to one type of system. Each of these methods will be described here and the systems for which each is applicable will be given. More detail on heat transfer calculations appearing below, including worked examples, may be found in Phetteplace and Meyer (1990).

Insulation method

The insulation method of heat loss calculation is applicable to all system types. With the observed temperatures on the inside and outside of the pipe insulation, the heat flow through the insulation can be easily calculated. In using this method we first assume that these temperatures are reasonably uniform around the circumference of the insulation. This assumption is supported by the data of Lunardini (1989), where temperature measurements were made in each quadrant around the insulation and pipe surfaces. Of 16 temperature difference measurements made at four different test sites, the maximum that any temperature difference deviated from the mean for its set of four was 8.1%. The average variation from the individual means was only 3.4%.

To use this method, we first calculate the mean insulation temperature using the inner and outer insulation temperatures. Using the data in Table 1 we then interpolate to find the thermal conductivity of the pipe insulation. The thermal resistance of the pipe insulation is then found from

$$R_i = \frac{\ln[r_{io}/r_{ii}]}{2\pi k_i} \tag{1}$$

where R_i = thermal resistance of pipe insulation, hr-ft-°F/Btu
k_i = thermal conductivity of insulation, Btu/hr-ft-°F
r_{io} = outer radius of insulation, ft
r_{ii} = inner radius of insulation, ft.

Once the thermal resistance of the insulation is known, the heat flow is then calculated from

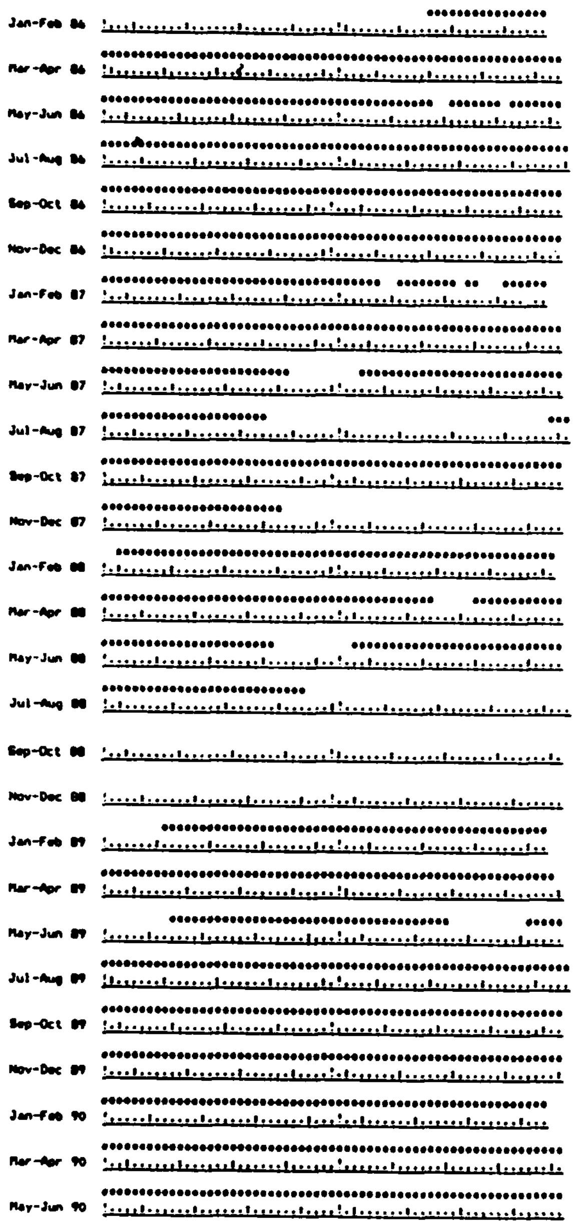
$$q_i = \frac{T_{ii} - T_{io}}{R_i} \tag{2}$$

where T_{ii} = the insulation inner surface temperature, °F
T_{io} = the insulation outer surface temperature, °F
q_i = the heat loss by the insulation method, Btu/hr-ft.

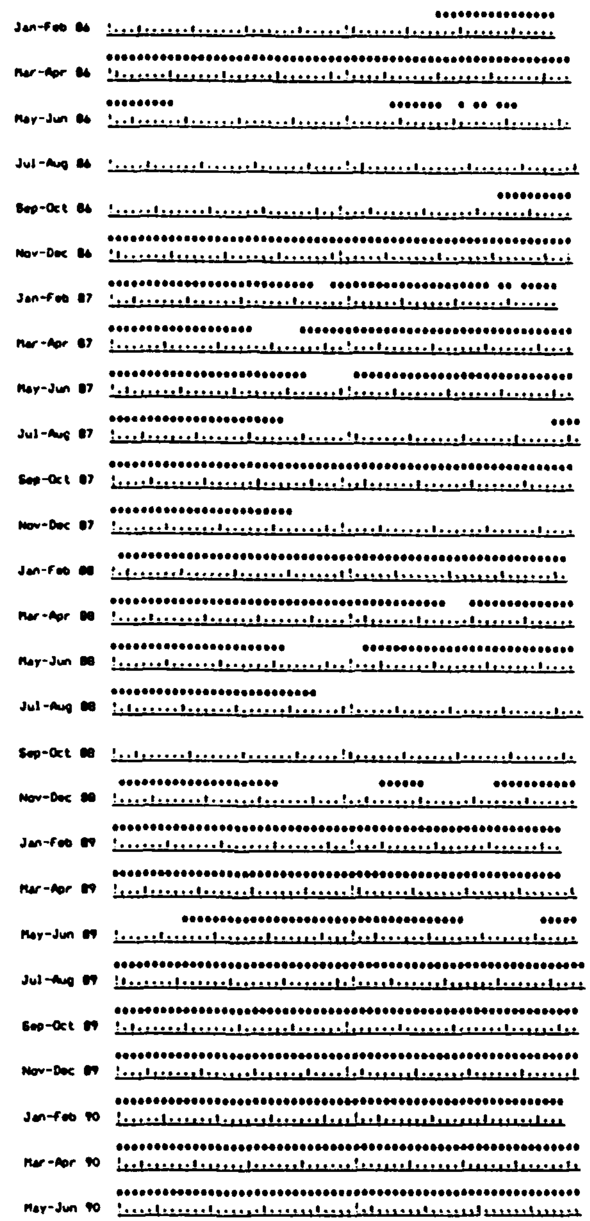
Table 3. Time periods for which data were collected.

FT. JACKSON SITE 1, TRENCH SITE

*Indicates days on which data were collected.



FT. JACKSON SITE 1, COMMON CONDUIT SITE



FT. JACKSON SITE 2, SEPARATE CONDUIT SITE

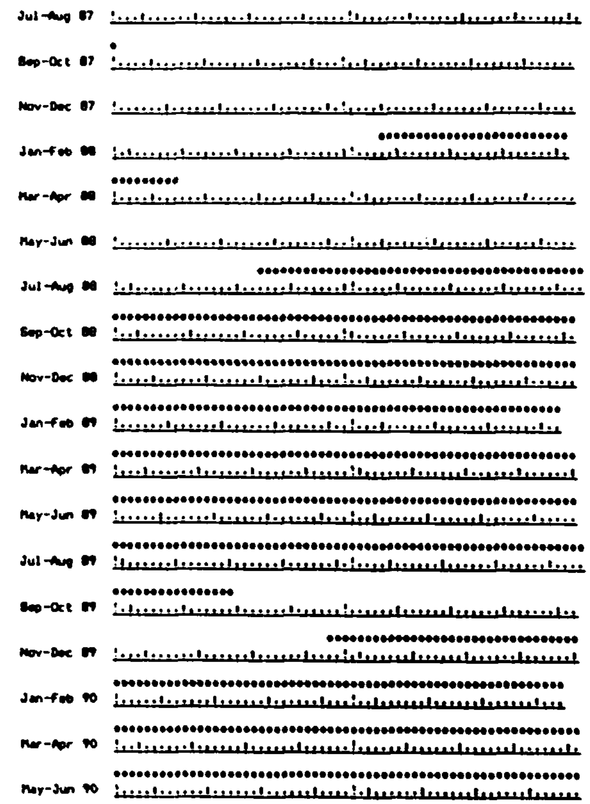


Table 4. Soil data from common conduit site. Ft. Jackson site 1, common conduit site.

Depth (ft)	*Soil description*	*Average water contents (% by weight)*		
		Apr 87	*Jul 88*	*Dec 89*
Top	Grass/sod (1 in.)			
	Brown silty sand, w/organics	11.0	8.8	6.6
1				
	Course brown sand	14.3	12.0	8.1
2				
	Clayey material w/brown	14.8	15.8	10.9
3	sand layers			
		15.9	14.9	10.8
4				
		17.9	21.7	
5				
			23.4	
6				
			23.3	
7				
	Whitish clayey material		20.6	
8	w/red varves			
			17.8	
9				
10				

Table 5. Soil data from individual conduit site. Ft. Jackson site 2, individual conduit site.

Depth (ft)	*Soil description*	*Average water contents (% by weight)*	
		Jul 88	*Dec 89*
Top	Grass/sod (1 in.)		
	Brown silty sand, loose packed	5.4	8.3
1			
	Brown silty sand	8.0	9.4
2			
		8.2	9.1
3			
		9.0	10.1
4			
		10.2	12.0
5			
	Brown silty sand	12.4	12.0
6	w/rusty colored deposits		
		11.3	11.0
7			
	Mixed light brown sand and	11.3	
8	dark brown sand w/rusty		
	colored deposits	12.6	
9			
	Light brown clayey sand	12.9	
10			
		12.6	
11			

Soil method

The soil method of heat loss calculation is applicable only to the common conduit type of system. We use the formula for a single buried uninsulated pipe, taking the pipe temperature and diameter as those of the outside of the conduit. To use this method, we first calculate the soil thermal resistance. This can be done with eq 3 below:

$$R_s = \frac{\ln[2d/r_{co}]}{2\pi k_s} \quad \text{for } d/r_{co} > 4 \qquad (3)$$

where:

R_s = thermal resistance of soil, hr-ft-°F/Btu
k_s = thermal conductivity of soil, Btu/hr-ft-°F
d = burial depth to centerline of conduit, ft
r_{co} = outer radius of conduit, ft.

From this we can calculate the heat loss using eq 4 below:

$$q_{scc} = \frac{T_{co} - T_s}{R_s} \qquad (4)$$

where

T_s = the soil temperature at the burial depth, °F
T_{co} = the outer conduit temperature, °F
q_{scc} = the heat loss by the soil method for common conduit system, Btu/hr-ft.

Soil temperatures vary with depth due primarily to changes in the air temperature. The thermal properties of the soil damp the amplitude of the temperature fluctuations at the surface and also cause a delay in the time until a temperature disturbance at the surface reaches the soil at some depth below. To accurately model the variations in heat transfer rate from a buried heat distribution system due to temperature variations at the surface requires a transient solution to the problem. Unfortunately, no closed-form transient solution is available for the case of a buried pipe. Numerical methods can be used to find very good approximate solutions to such problems, but they require much more effort than the closed-form steady-state solutions. To account for the transient nature of the problem, an approximation can be made by using the undisturbed soil temperature at burial depth instead of the ground surface temperature in the steady-state solution for a buried pipe (CSCE 1986). This substitution has been made in eq 4 above and is used for the other solutions that require soil surface temperatures as well.

Method for two buried pipes in individual conduits

This method is a combination of the two outlined above, which also accounts for the thermal resistance of the air space and the interaction of the two conduits. Other minor thermal resistances, such as those of the conduits and their coatings, are neglected. First we address the issue of the thermal resistance of the air space.

The actual heat transfer processes within the air space are far too complicated to warrant a complete treatment for the purpose of determining the heat losses from such systems. A heat transfer coefficient of 3 Btu/hr-ft-°F (based on the outer surface area of the insulation) has been assumed in the calculational procedure outlined in the Corps of Engineers Guide Specification for this system (CEGS 02695). The validity of this assumption is discussed later in the results section of this report. Using this heat transfer coefficient, we can calculate the resistance due to it from

$$R_a = 1/(3 \times 2\pi r_{io}) = 0.053/r_{io} \qquad (5)$$

where

r_{io} = the outer radius of the insulation, ft
R_a = the resistance of the air space, hr-ft-°F/Btu.

The following resistance-based formulation was developed by one of the authors and will be documented in a future report. It is much different in appearance than the conductance-based formulation presented in CEGS-02695. However, the heat transfer calculated with either will be almost identical. We feel that the resistance-based formulation is much easier to follow and thus we have chosen to present it here. The resistance-based formulation also makes it much easier to calculate intermediate temperatures within the system. In the calculations presented in the *Results*, the formulation presented in CEGS-02695 has been used where so indicated.

The case of two buried conduits may be formulated in terms of the thermal resistances that would be used for a single buried conduit and some correction factors. The total thermal resistance for each of the individual conduits if they were *not in close proximity* would be

$$R_t = R_i + R_a + R_s \qquad (6)$$

where R_t = the total thermal resistance for one conduit independent of the other conduit, hr-ft-°F/Btu.

The correction factors needed because the conduits are close to one another and interact thermally are

$$\theta_1 = (T_{ii2} - T_s)/(T_{ii1} - T_s) \qquad (7)$$

$$\theta_2 = 1/\theta_1 = (T_{ii1} - T_s)/(T_{ii2} - T_s) \qquad (8)$$

$$P_1 = \frac{\ln(\sqrt{\{[(d_1 + d_2)^2 + a^2]/[(d_1 - d_2)^2 + a^2]\}})}{2\pi k_s} \quad (9)$$

$$P_2 = \frac{\ln(\sqrt{\{[(d_2 + d_1)^2 + a^2]/[(d_2 - d_1)^2 + a^2]\}})}{2\pi k_s} \quad (10)$$

where a is the horizontal separation distance between the centerlines of the two pipes (ft).

And the effective thermal resistance for each conduit is given by

$$R_{e1} = \frac{R_{t1} - (P_1^2/R_{t2})}{1 - (P_1\theta_1/R_{t2})} \quad (11)$$

$$R_{e2} = \frac{R_{t2} - (P_2^2/R_{t1})}{1 - (P_2\theta_2/R_{t1})} \quad (12)$$

where θ = a temperature dimensionless correction factor
P = a geometric/material correction factor, hr-ft-°F/Btu
R_e = the effective thermal resistance of one pipe/conduit in the two pipe system, hr-ft-°F/Btu.

Subscripts 1 and 2, respectively, indicate quantities for each of the two conduit systems.

The heat flow from each of the conduit systems is then calculated from

$$q_{sc1} = (T_{ii1} - T_s)/R_{e1} \quad (13)$$

$$q_{sc2} = (T_{ii2} - T_s)/R_{e2} \quad (14)$$

where q_{sc} = the heat loss by the Corps of Engineers guide specification method for a individual conduit in a two conduit system (Btu/hr-ft).

Method for two pipes buried in a common conduit

This method is applicable only to the case where both the supply and return pipes are in a common conduit. Here the same assumption as above is made regarding heat transfer within the air space. The equations used are again based on resistance formulations rather than the formulation prescribed by the Corps of Engineers Guide Specification 02695 as described in the previous section. For convenience some of the thermal resistances will be added together as follows:

$$R_1 = R_{i1} + R_{a1} \quad (15)$$

$$R_2 = R_{i2} + R_{a2} \quad (16)$$

The subscripts 1 and 2 differentiate between the two pipe/insulation systems within the conduit. The combined heat loss is then given by

$$q_{cc} = \frac{[(T_{ii1} - T_s)/R_1) + ((T_{ii2} - T_s)/R_2)]}{1 + (R_s/R_1) + (R_s/R_2)} \quad (17)$$

where q_{cc} is the heat loss from both pipes within a common conduit (Btu/hr-ft).

The bulk temperature within the air space can be calculated once the combined heat flow is determined from:

$$T_a = T_s + q_{cc}R_s \quad (18)$$

where T_a is the bulk temperature of the air within the conduit air space (°F).

The heat flow from each pipe is given by

$$q_{cc1} = (T_{ii1} - T_a)/R_1 \quad (19)$$

$$q_{cc2} = (T_{ii2} - T_a)/R_2 \quad (20)$$

Heat flux transducer method

This method is used with all three types of system constructions. The heat flux transducers used are described in the previous section. In each case the heat flux transducers are attached directly to the outside surface of the carrier pipes. This location is the most desirable because the heat flux is greatest there, resulting in signals that are higher and thus less susceptible to electrical noise. To convert the heat flux transducer signals to heat losses we use eq 21 given below:

$$q_{hft} = v\, CF\, TCF\, 2\pi\, r_{ii} \quad (21)$$

where q_{hft} = the heat flow determined by the heat flux transducer, Btu/hr-ft.
CF = heat flux transducer calibration factor, Btu/ hr-ft^2-mV
TCF = temperature correction factor for the heat flux transducer, dimensionless.
v = the signal from the heat flux transducer, mV.

The calibration factor CF furnished by the manufacturer of the heat flux transducers was 20 Btu/hr-ft^2-mV. The temperature correction factor is a function of the temperature at which the heat flux transducer is operating. Based on graphical data given by the manufacturer the following equation was found for this factor over the temperature range from 75° to 400°F:

$$TCF = 1.063 - 0.0008719\, T_{ii}\,. \qquad (22)$$

After the transducers at Ft. Jackson had been installed, we contacted the manufacturer of the transducers regarding some discrepancies in the readings from identical transducers we were using on another project. At that time we were told that the calibration factor furnished with the instruments was a "nominal value" and that if an actual calibration was required we would need to request it. We had two of the meters we were using on the other project calibrated by the manufacturer and found that the calibration factor was about 10 Btu/hr-ft^2-mV in both cases rather than the value of 20 Btu/hr-ft^2-mV that had been furnished with the transducers. Thus the value of our results from the transducers used on this project is reduced because of this uncertainty in the calibration factor. The heat flux transducers provide some information about trends in heat losses even though the absolute value of their readings is of little use. The heat flux transducer results presented in the following section assume a calibration factor of 10 Btu/hr-ft^2-mV.

Heat flux transducer readings vary over an inordinately wide range of values under conditions of rapidly fluctuating temperature at either of their surfaces. We observed fluctuations in the heat flux transducer data that we attributed to this phenomenon. Because they function by measuring the relatively small temperature difference across their thickness, variations in the temperature at either surface, which may be small in an absolute sense, can result in large changes in this temperature difference and thus the resulting signal. If the temperature variations are random in nature when compared to the sampling interval, long-term averages should provide a good mean value. Because we were not able to determine an actual calibration constant for the transducers in this study, as explained above, we were unable to draw any conclusions about the accuracy of the mean value of the heat flux transducer readings.

RESULTS

Most of the results are presented in graphical form in order to present a large amount of information within a reasonable space. However, for each site we will first present a very limited sample of some of the tabular data from which the graphical information was generated. These data are only given for approximately a one-month period of time and only those sensor readings which are used to find the resulting heat loss figures are included in the tables.

Trench site

Selected instrument readings and reduced data are presented for the trench site in Table 6. The average temperature of the supply pipe was 326.4°F and for the return pipe 272.5°F, excluding the 8–10 November time period when the heat supply to the system was apparently curtailed. The average air temperatures within the trench during the same time period are also of interest. As expected the air on the supply pipe side of the trench (95.6°F) is slightly warmer than on the return side (94.8°F). Between the pipes the air is somewhat warmer at 98.0°F and below that the air is warmer yet at 99.8°F. These relative values of these two latter temperatures seem to be contrary to what we would assume due to stratification. One possible explanation would be the higher thermal resistance to heat transfer through the bottom of the trench when compared to the top. For the entire period for which we have data, the same trend is still apparent in the averages with the temperature between the pipes being 100.4°F and the the temperature below that 101.5°F. A measurement error is possible, although the 112 days for which we have data before the heating system was turned on does not support that theory. For that time period the average temperature between the pipes was 85.2°F, while the average temperature below that was 84.7°F. From Table 6 it is also of interest to note that none of the air temperatures within the trench are sufficiently different from one another to be of concern from a design standpoint. It would appear to be satisfactory to assume that the air temperature within the trench was 85°F for the purposes of conservative calculation of the heat losses.

Figure 6 shows the four air temperatures within the trench over the entire study period. These are indistinguishable from one another using the scale on this graph. This illustrates how little variation there is among them. Sometimes it is necessary to determine if the high temperature limit of any the components within the system will be exceeded. From the data in Figure 6 a temperature of 130°F would appear to be acceptable, again on the conservative side. We must caution that these values may not be applicable to systems with significantly different thermal characteristics such as insulation thickness, pipe operating temperature, and/or ambient temperature. Additional data on the air temperature within and outside of the trench as well as pipe temperatures are contained in Figure 7 for 1986–1987 and Figure 8 for 1988–1989. The close correlation

Table 6. Selected raw and reduced data for the trench site.

DATE	C 100 air center bottom (F)	C 102 supply pipe (F)	C 103 return pipe insul. (F)	C 104 air between pipes (F)	C 105 return pipe (F)	C106 supply pipe insul. (F)	C 110 air return side (F)	C 111 air supply side (F)	C 0 air amb. (F)	Insulation Thermal Conductivity supply (btu/hr-ft-F)	Insulation Thermal Conductivity return (btu/hr-ft-F)	Insulation Method Heat Loss supply (btu/hr-ft)	Insulation Method Heat Loss return (btu/hr-ft)	Insulation Method Heat Loss total (btu/hr-ft)
01-Nov-86	103.4	323.8	110.9	101.0	291.4	115.9	98.0	98.8	59.3	0.0265	0.0259	53.4	45.4	98.8
02-Nov-86	104.2	327.9	111.0	101.8	295.9	117.4	98.7	99.7	63.6	0.0265	0.0259	54.3	46.6	100.9
03-Nov-86	104.4	327.9	112.5	101.5	298.4	117.8	98.2	98.9	63.6	0.0266	0.0260	54.2	47.0	101.2
04-Nov-86	105.6	326.4	113.4	104.0	296.1	119.1	101.1	101.7	57.4	0.0266	0.0260	53.5	46.1	99.6
05-Nov-86	106.9	322.6	115.0	105.0	280.1	119.6	102.0	102.6	63.0	0.0265	0.0258	52.3	41.3	93.6
06-Nov-86	109.5	324.9	117.9	107.7	284.6	122.4	104.4	105.0	70.3	0.0266	0.0259	52.3	41.9	94.2
07-Nov-86	111.9	322.8	120.5	109.5	294.6	124.4	105.6	106.4	72.5	0.0266	0.0261	51.2	44.1	95.4
08-Nov-86	96.6	173.6	100.0	95.5	164.0	101.5	94.3	94.5	74.0	0.0243	0.0242	17.1	15.1	32.1
09-Nov-86	84.6	113.3	85.9	84.2	110.4	86.1	84.2	84.1	73.1	0.0238	0.0237	6.3	5.6	11.9
10-Nov-86	97.1	263.5	102.5	95.7	229.0	106.7	93.8	94.3	63.9	0.0254	0.0249	38.7	30.7	69.4
11-Nov-86	107.0	330.0	115.1	105.0	295.1	120.2	102.0	102.8	60.8	0.0266	0.0260	54.3	45.5	99.8
12-Nov-86	103.3	323.3	111.1	101.3	298.2	116.7	98.4	99.3	55.9	0.0265	0.0260	53.1	47.2	100.4
13-Nov-86	99.3	324.3	106.3	97.6	285.5	113.1	94.8	95.5	49.2	0.0264	0.0257	54.2	44.8	99.0
14-Nov-86	90.8	326.0	93.0	89.3	248.3	103.9	87.0	88.0	35.1	0.0263	0.0251	56.8	37.8	94.6
15-Nov-86	88.8	323.7	93.3	87.5	251.0	101.7	84.6	83.5	41.4	0.0262	0.0251	56.6	38.4	95.0
16-Nov-86	92.5	324.7	97.7	90.8	242.6	106.8	87.4	88.4	53.2	0.0263	0.0250	55.8	35.3	91.0
17-Nov-86	99.7	325.3	106.7	98.0	272.8	114.1	94.5	95.7	63.0	0.0265	0.0256	54.3	41.3	95.5
18-Nov-86	102.3	327.5	109.1	100.4	268.0	116.5	96.8	98.0	61.3	0.0265	0.0255	54.4	39.4	93.8
19-Nov-86	99.4	327.9	106.5	96.8	277.7	113.8	92.7	94.0	57.7	0.0265	0.0256	55.1	42.6	97.7
20-Nov-86	94.4	326.2	100.8	93.1	265.4	108.9	90.3	91.1	46.3	0.0264	0.0254	55.7	40.6	96.3
21-Nov-86	91.5	330.3	93.6	89.9	264.6	104.2	86.9	86.9	48.7	0.0264	0.0253	57.9	42.0	99.9
22-Nov-86	92.0	328.4	96.1	91.1	267.4	105.3	88.4	88.9	46.2	0.0264	0.0253	57.2	42.2	99.3
23-Nov-86	94.1	325.4	99.9	92.9	246.7	109.0	90.0	90.8	55.9	0.0264	0.0251	55.4	35.8	91.3
24-Nov-86	100.1	326.5	107.7	98.4	268.3	114.4	94.9	95.8	62.9	0.0265	0.0255	54.6	39.8	94.4
25-Nov-86	103.8	326.5	110.9	102.2	270.6	118.3	98.5	99.7	63.4	0.0265	0.0256	53.7	39.7	93.4
26-Nov-86	96.4	324.6	103.0	94.2	267.0	110.4	90.9	92.0	66.8	0.0264	0.0254	54.9	40.5	95.4
27-Nov-86	100.1	328.7	106.4	97.9	260.3	115.3	94.3	95.5	62.0	0.0265	0.0254	55.0	37.9	93.0
28-Nov-86	99.6	328.9	105.5	97.9	264.4	114.4	94.6	95.8	55.5	0.0265	0.0254	55.3	39.2	94.5
29-Nov-86	97.0	328.1	103.0	95.5	260.9	111.8	92.5	93.7	57.8	0.0265	0.0253	55.6	38.9	94.5
30-Nov-86	96.6	329.6	101.9	95.5	240.7	111.7	92.4	93.4	51.3	0.0265	0.0251	56.1	33.8	89.9
AVERAGES	99.1	312.1	105.2	97.4	262.0	112.0	94.4	95.2	58.5	0.026	0.025	51.3	38.9	90.2
AVERAGES EXCLUDING 8-10 Nov 86.	99.8	326.4	106.3	98.0	272.5	113.6	94.8	95.6	57.2	0.026	0.026	54.7	41.3	96.0

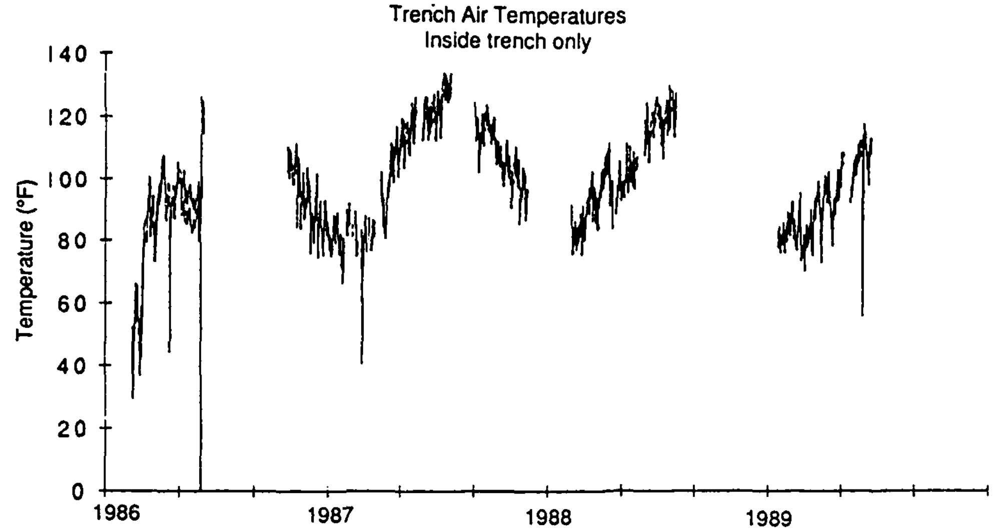


Figure 6. Trench air temperature over the study period.

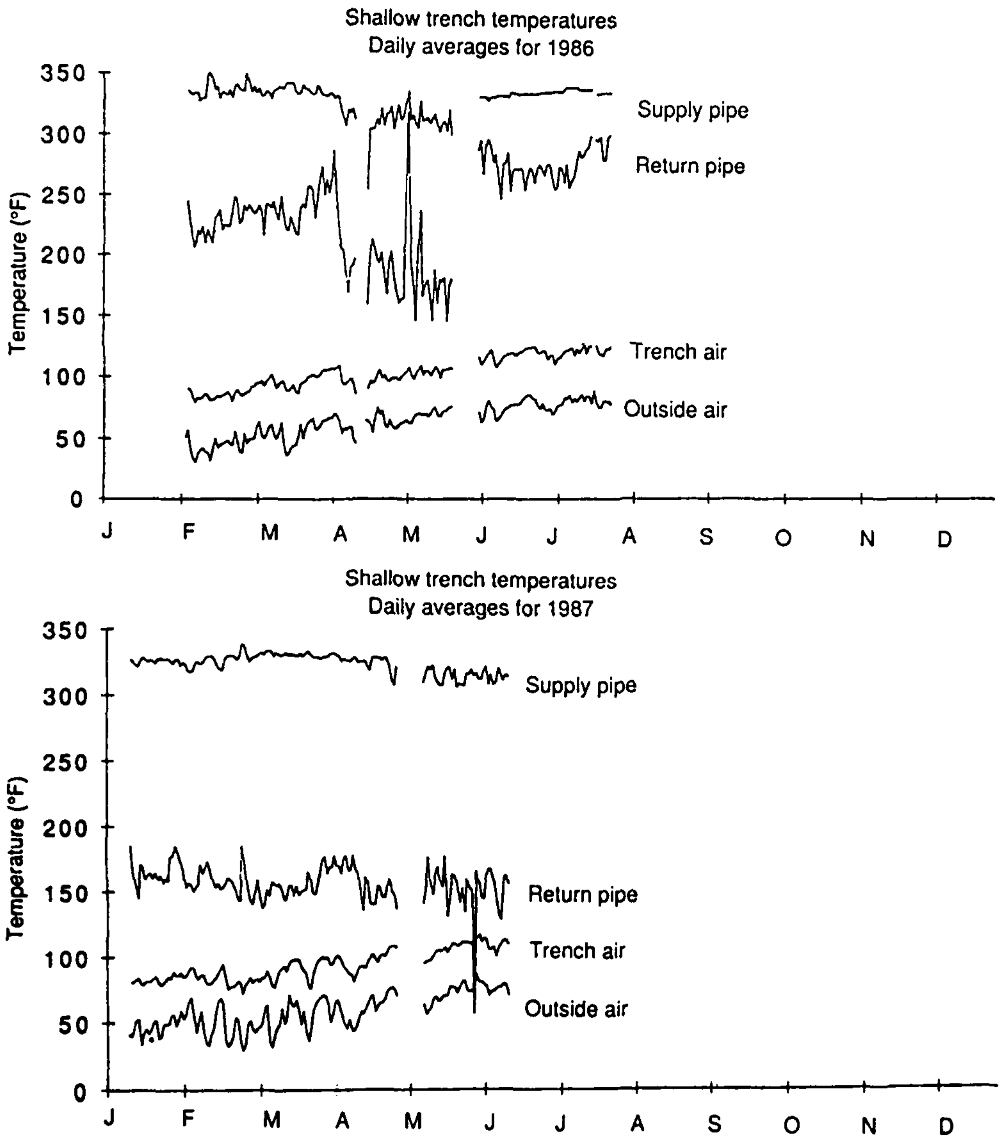


Figure 7. Trench temperatures for 1986–1987.

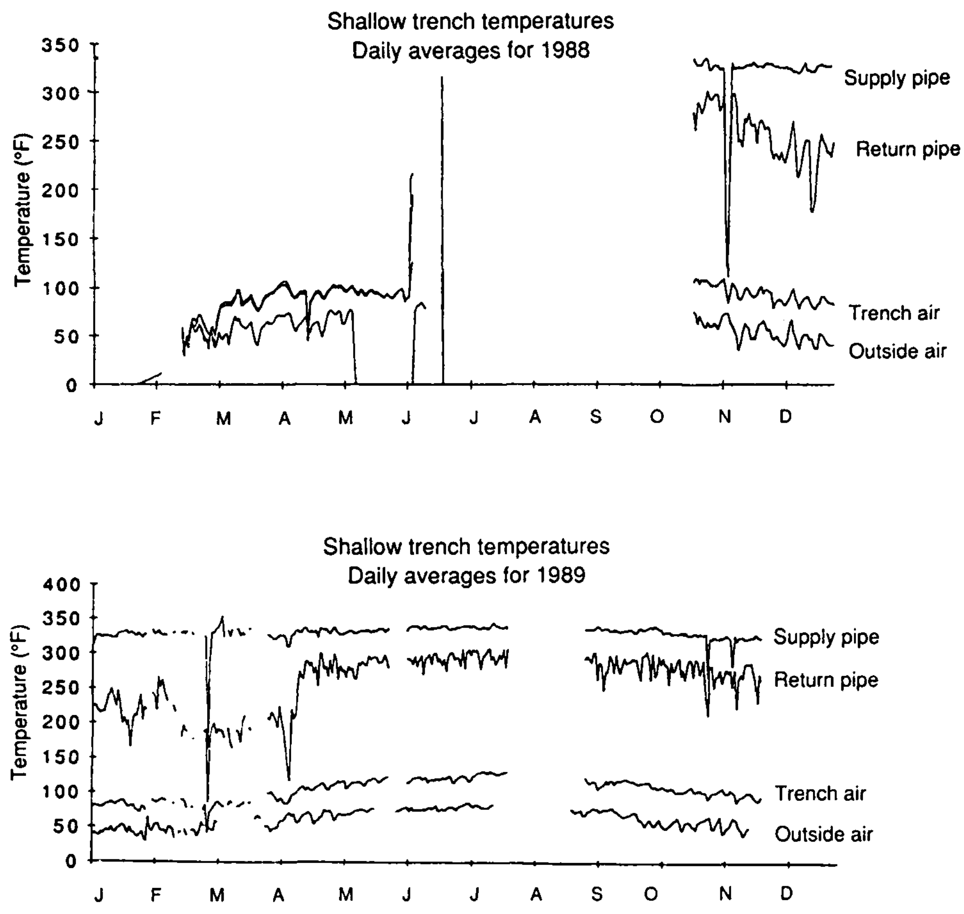


Figure 8. Trench temperatures for 1988–1989.

of trench temperature variations to ambient air temperature variations is obvious in these figures. This is a manifestation of the relatively small thermal resistance between the trench interior and the environment which the trench lid provides. In extreme cold climates subfreezing temperatures within such a system are possible. Heat tracing and/or insulation of the trench from the environment may be necessary in such cases. For additional information on such designs we refer the reader to Phetteplace et al. (1986) and Kennedy et al. (1988).

Because the heat flux transducer readings were of limited value as explained in the section above, only one method of computing the heat loss is available for this site. For the month of November 1986 the average heat loss from the trench system was 90.2 Btu/hr-ft. This is somewhat misleading since the heat supply to the system was apparently curtailed for some time during the 8–10 November period as we noted above. If we examine the average heat loss exclusive of this time period, we see that the average is slightly higher at 96.0 Btu/hr-ft. Figure 9 shows the heat loss from the shallow trench for the entire study period. The reduction in heat losses during 1988 and 1989 over the previous years is attributable to the reduced return temperature during that time period. This is a fairly significant reduction and provides a clear example of the benefits of keeping the temperature differential between supply and return as large as possible, thus resulting in lower return temperature. Not only will heat losses be reduced by lower return temperatures, but pumping costs are also reduced since less mass will need to be circulated. Of course, this assumes that the thermal load is constant and that some method of reducing pumping power input, such as

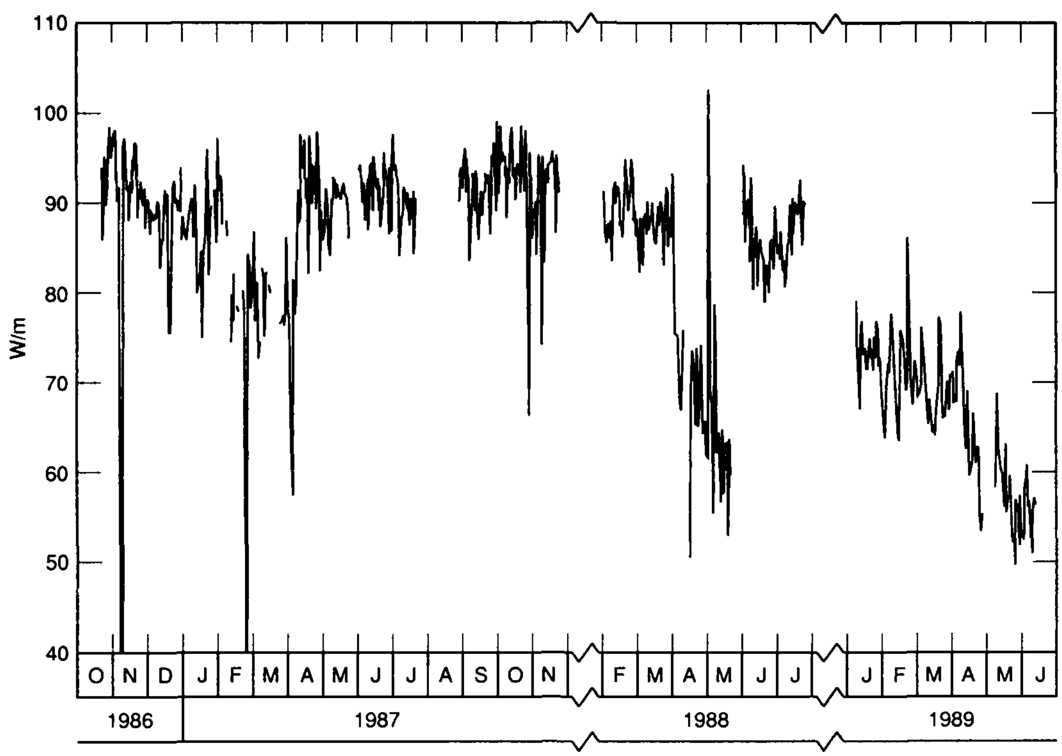


Figure 9. Heat losses for the trench site over the study period.

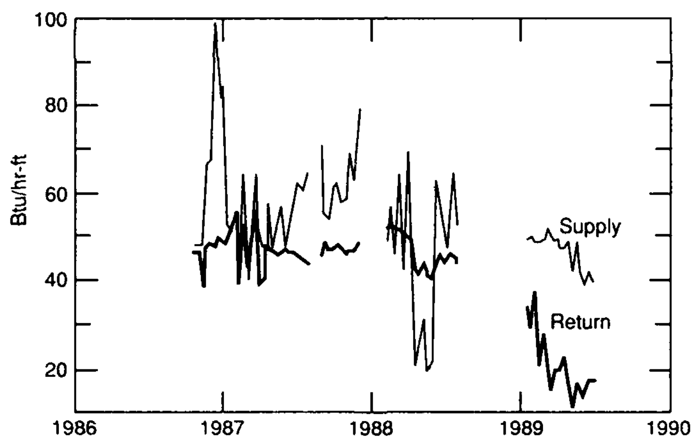


Figure 10. Heat flux sensor data for the trench site.

variable speed drives or multiple pumps, is available.

Heat flux sensor output is shown in Figure 10. Here the sensor output has been averaged over 10-day periods to attempt to eliminate the oscillations which occur in the daily average data. A calibration factor of 10 Btu/hr-ft-mV has been assumed. The general agreement between the total loss of the supply and return pipes as determined by the heat flux sensors and the insulation method (Fig. 9) is reasonable using this calibration factor.

Common conduit site

Table 7 contains selected raw and reduced data for the common conduit site. As with the data for the trench site, averages have been compiled that exclude the period of 8–10 November during which the heat supply to the system was apparently turned off. The temperature of the supply during the period summarized in Table 7 averaged 325.3°F and the return averaged 256.8°F for the same period of time. The supply tem-

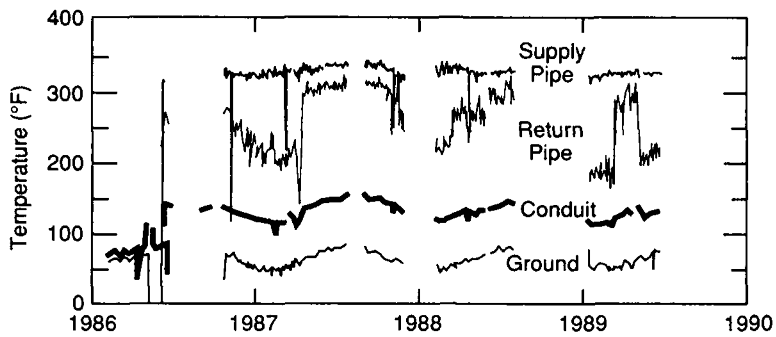


Figure 11. Common conduit site temperatures.

perature is very close to the supply temperature observed at the trench site, which is reasonably close to this site. The return temperature averaged about 16°F lower at this site when compared to the trench site. This would tend to make heat losses lower at this site if all else were equal, as of course is not the case. The temperature of the outer surface of the conduit averaged 131.7°F while the undisturbed ground temperature at approximately the same depth as the centerline of the conduit averaged 63.6°F. This illustrates the rather dramatic effect which the buried conduit has on surrounding soil temperatures. Figure 11 shows the temperatures discussed above for the entire study period.

The heat losses for the common conduit system were calculated by three of the methods described earlier, exclusive of the heat flux transducer method. The method referred to as the "soil method" uses the single buried pipe equation presented earlier and the conduit outer surface temperature to calculate the heat flow. The thermal conductivity of the soil is taken as 7.5 Btu-in./hr-ft^2-°F (0.625 Btu/hr-ft-°F) in this and the CEGS-02695 method. This is felt to be a realistic average value based on the observed soil type and moisture content and published data (Kersten 1949).

The average of the values computed by the three methods is 114.1 Btu/hr-ft. The highest of the methods (CEGS-02695) was approximately 7.3% greater than the average value and the lowest (Insulation method) was 5.8% below the average. Considering the difficulty involved in making thermal measurements of this nature, we feel this agreement is very good. This is particularly true when one considers that the CEGS-02695 method has conservative assumptions (in that they would underpredict the actual thermal resistance) regarding the heat transfer across the air space.

The heat losses for the entire study period for the common conduit site are shown in Figure 12 for 1986–1987 and Figure 13 for 1988–1989. Note that during the early spring (around March), for each of the three years that we have data during this time period, the results from the insulation method increase to a value greater than those for the soil method. Some time during the fall (about mid-September for 1987, the only year for which we have data during this time period) the trend is reversed. One possible explanation for this is the soil moisture content. The data in Table 4 suggest that the soil moisture content is higher during the spring and summer than in the winter. If the moisture content of the soil around the conduit, particularly that between the conduit and the ground surface, increases during the spring and summer months, then the thermal conductivity of the soil will increase during that time period as well. This will reduce the thermal resistance of the soil in an absolute sense as well as relative to the other thermal resistances in the system.

Presumably the other thermal resistances remain fairly constant year-round, notably the insulation thermal resistance, which is much greater than the thermal resistance of the soil or any other thermal resistance in the system. Thus, the overall thermal resistance will be reduced by a much smaller relative amount than the soil thermal resistance. With the lower thermal resistance the temperature drop across the soil from the conduit casing to the ground surface will decrease relative to the other temperature drops in the system. However, we have assumed that the thermal conductivity of the soil is constant year-round in our soil method and thus, with the lower actual resistance and relative temperature drop measured, we will underpredict the heat flow. We are continuing to take temperature data at this site and plan to take additional soil moisture data as well. Once

Table 7. Selected raw and reduced data from the common conduit site.

DATE	C 8 Conduit Temp. (F)	C 1 Supply Pipe Temp. (F)	C 2 Return Pipe Temp. (F)	C 3 Supply Insul. Temp. (F)	C 4 Return Insul. Temp. (F)	C 117 Soil Temp. @ 56" (F)	Insulation Thermal Conductivity (Btu/ft-hr-F) supply	return	CEGS-02695 Method Heat Loss (btu/hr-ft) supply	return	total	Soil Method Heat Loss total (btu/hr-ft)	Insulation Method Heat Loss (btu/hr-ft) supply	return	total
01-Nov-86	136.46	324.90	270.91	167.09	146.64	65.83	0.027	0.026	74.44	50.88	125.32	116.55	62.77	47.16	109.93
02-Nov-86	135.93	324.75	267.46	166.99	145.45	65.72	0.027	0.026	74.62	49.71	124.33	115.86	62.74	46.18	108.92
03-Nov-86	136.10	329.63	274.03	167.87	146.26	66.60	0.027	0.026	75.84	51.44	127.28	114.68	64.58	48.56	113.14
04-Nov-86	135.89	326.98	270.74	167.21	145.79	66.64	0.027	0.026	75.01	50.46	125.47	114.27	63.64	47.39	111.03
05-Nov-86	135.49	324.02	270.19	166.11	145.80	66.27	0.027	0.026	73.99	50.56	124.55	114.21	62.73	47.16	109.89
06-Nov-86	135.41	325.10	276.49	166.16	145.90	66.56	0.027	0.026	73.93	52.59	126.52	113.60	63.18	49.70	112.88
07-Nov-86	134.33	309.58	266.24	162.95	144.59	67.90	0.027	0.026	68.33	49.67	118.00	109.61	57.57	45.98	103.55
08-Nov-86	111.09	150.97	146.89	117.17	114.93	69.40	0.024	0.024	20.73	19.27	40.00	68.79	11.93	11.26	23.18
09-Nov-86	101.61	130.18	121.00	105.49	103.89	70.61	0.024	0.024	15.31	12.11	27.42	51.16	8.62	5.95	14.57
10-Nov-86	123.68	301.70	250.06	153.88	133.03	70.99	0.027	0.026	65.31	43.67	108.98	86.95	57.41	43.55	100.96
11-Nov-86	132.28	327.95	267.27	165.49	142.78	69.62	0.027	0.026	74.70	48.36	123.06	103.38	64.68	47.03	111.71
12-Nov-86	133.27	324.80	266.21	165.68	143.07	67.32	0.027	0.026	74.23	48.80	123.03	108.82	63.22	46.50	109.72
13-Nov-86	132.93	323.82	253.81	165.36	141.27	66.82	0.027	0.026	74.74	44.75	119.49	109.08	62.91	42.16	105.07
14-Nov-86	132.45	325.28	248.83	165.13	140.82	64.59	0.027	0.026	76.19	43.55	119.74	111.98	63.63	40.34	103.97
15-Nov-86	129.86	320.81	236.55	162.54	136.40	60.37	0.027	0.025	76.31	40.76	117.07	114.65	62.59	37.07	99.66
16-Nov-86	128.87	321.94	236.02	161.83	135.62	59.26	0.027	0.025	77.04	40.79	117.83	114.87	63.33	37.13	100.46
17-Nov-86	130.47	325.70	256.92	163.54	140.47	60.35	0.027	0.026	76.97	47.36	124.33	115.70	64.38	43.68	108.06
18-Nov-86	131.23	327.40	262.25	164.43	141.72	62.54	0.027	0.026	76.72	48.52	125.23	113.34	64.82	45.38	110.19
19-Nov-86	131.31	326.07	259.65	164.12	140.88	63.61	0.027	0.026	76.07	47.42	123.48	111.71	64.33	44.63	108.96
20-Nov-86	129.77	324.80	243.24	163.51	137.60	62.57	0.027	0.026	76.84	42.18	119.02	110.88	63.99	39.26	103.26
21-Nov-86	129.42	326.39	241.58	163.40	136.96	60.57	0.027	0.025	78.09	42.03	120.12	113.61	64.73	38.84	103.57
22-Nov-86	129.01	327.42	246.51	163.16	136.94	59.47	0.027	0.026	78.47	43.90	122.37	114.74	65.27	40.78	106.06
23-Nov-86	128.46	324.37	246.46	162.42	136.53	58.46	0.027	0.026	77.58	44.34	121.92	115.50	64.19	40.91	105.10
24-Nov-86	129.54	325.36	263.66	162.90	139.26	59.27	0.027	0.026	76.71	49.93	126.64	115.95	64.46	46.81	111.26
25-Nov-86	129.51	326.02	256.98	163.22	138.69	61.14	0.027	0.026	76.86	47.12	123.98	112.82	64.63	44.33	108.96
26-Nov-86	129.24	327.22	259.46	163.15	138.22	62.63	0.027	0.026	76.75	47.48	124.23	109.92	65.19	45.49	110.67
27-Nov-86	129.81	328.91	252.81	164.52	138.00	64.00	0.027	0.026	77.46	44.76	122.22	108.58	65.45	42.91	108.35
28-Nov-86	129.94	329.31	250.57	164.51	137.55	63.94	0.027	0.026	77.76	43.99	121.75	108.91	65.63	42.17	107.80
29-Nov-86	129.40	326.45	246.89	163.48	137.07	62.71	0.027	0.026	77.20	43.25	120.45	110.04	64.73	40.89	105.62
30-Nov-86	129.50	327.56	241.16	163.93	136.68	61.94	0.027	0.025	78.20	41.46	119.65	111.48	65.06	38.77	103.83
AVERAGES	129.74	312.18	248.36	160.57	138.29	64.25	0.027	0.026	71.75	44.37	116.12	108.05	60.08	41.27	101.35
AVERAGES EXCLUDING 8-10 Nov 86.	131.70	325.28	256.77	164.47	140.63	63.58	0.027	0.026	75.97	46.52	122.49	112.40	63.87	43.60	107.47

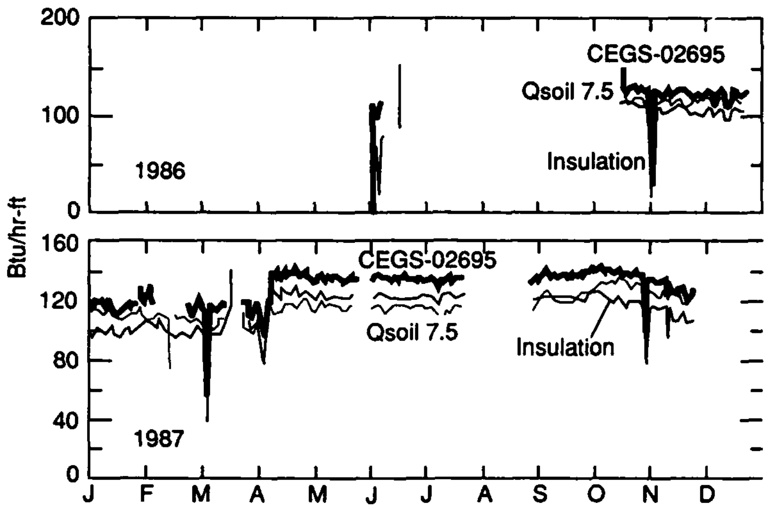


Figure 12. Common conduit site heat loss for 1986–1987.

we have more data we will attempt to adjust the soil moisture content and thermal conductivity used in our calculation on a seasonal basis to more accurately model this effect.

Study of the outer conduit temperature and the temperature for the corresponding time period for the trench interior gives some indication of the thermal resistance provided by the soil for the buried conduit, in comparison to the lesser thermal resistance provided by the trench/soil in the case of the shallow trench. It is difficult to make precise comparisons because the insulation thicknesses vary for the two sites. If, however, we compare the effective thermal resistance between the average insulation surface temperature and the ambient air temperature, we find that it is 34 % lower (0.55 hr-ft-°F/Btu) for the trench than for the common conduit (0.84 hr-ft-°F/Btu). Thus the burial depth of the conduit provides additional thermal resistance over the trench

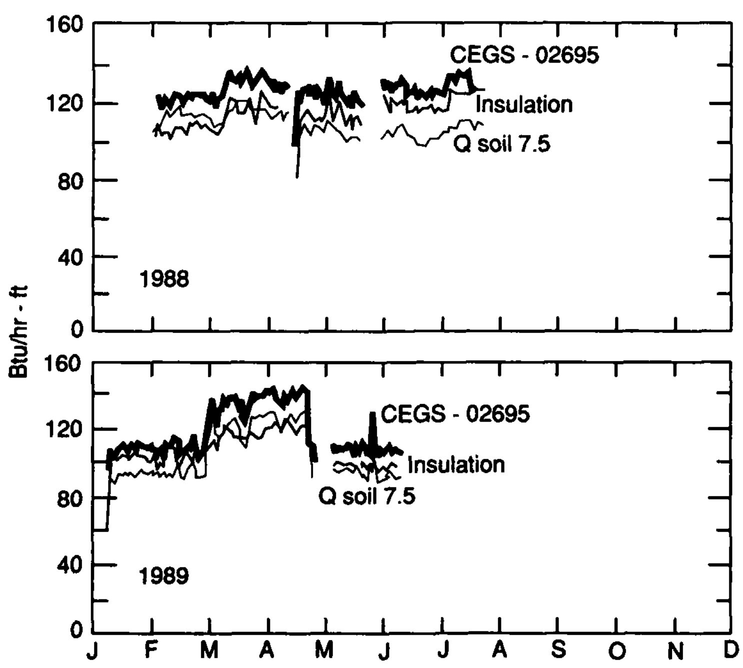


Figure 13. Common conduit heat loss for 1988-1989.

system with its top cover at grade level. The trench system, however, can accommodate incrementally thicker insulation at much lower cost than the conduit system.

Individual conduit site

Table 8 contains selected raw and reduced data for the individual conduit site. The temperature of the supply during the period summarized in Table 8 averaged 348.5°F and the return averaged 203.4°F for the same period of time. The temperature of the outer surface of the conduit averaged 73.8°F for the supply and 71.7°F for the return. The undisturbed ground temperature at approximately the same depth as the centerline of the conduit averaged 50.3°F. Here the temperature difference between the outside of the conduit and the undisturbed soil temperature at the burial depth is only 21.4°F. This can be compared to a temperature difference of nearly 60°F at the common conduit site. The primary reason for this much lower temperature difference at the individual conduit site is the increased insulation thickness at that site. Because the thermal resistance of the insulation is much larger at the individual conduit site, the thermal resistance of the soil becomes a much smaller fraction of the total and thus the corresponding temperature drop across that resistance decreases.

Figure 14 shows the temperatures discussed above for the entire study period. At the individual conduit site a data logging system separate from that used at the other two sites is used. The control string of thermocouples, which gives undisturbed ground temperatures, is connected to the data logging system for the common conduit and trench sites. This has presented an unusual difficulty in reducing the data for the individual conduit site because the data logging system at this site was operational during some periods when the data logger at the other site was not. In order to obtain the control data on undisturbed soil temperatures at the individual conduit site, we used least squares techniques to fit a sinusoidal curve to all of the control string data we had from the data logger at the other two sites. Figure 15 shows the resulting curve and the average of all available temperature data.

The heat losses for the individual conduit system were calculated by the insulation and CEGS-02695 methods described earlier. As in the calculations for the common conduit site, the thermal conductivity of the soil was taken as 7.5 Btu-in./hr-ft^2-F for the CEGS-02695 method.

The average of the heat loss values computed by the two methods is 78.8 Btu/hr-ft. The highest of the methods (Insulation Method) was approximately 9.3% greater than the lowest (CEGS-02695 method). Again, considering the difficulty involved in making thermal measurements of this nature we feel this agreement is very good. The heat losses for the entire study period for the individual conduit site are shown in Figure 16.

Figure 17 shows the heat flux sensor data for the study period at the individual conduit site. The sensor data have been averaged over 10-day periods in Figure 17 in order to eliminate the wide fluctuations that are found in the readings, as discussed earlier. The calibration factor has been assumed to be 10 Btu/hr-ft^2-mV as before. With this calibration factor the agreement between the heat losses predicted by this method and the results of the other two methods shown in Figure 16 is fairly good.

Earlier when introducing eq 5 we noted that the thermal resistance of the air space is currently based on an assumed heat transfer coefficient of 3 Btu/hr-ft^2-°F where the surface area is that of the insulation's outer surface. From our data we can calculate an observed value for this heat transfer coefficient. This can be done by combining the equation for the resistance of the air gap, eq 5, with the definition of this resistance to get the following equation:

$$h_{as} = \frac{q_i}{2\pi\, r_{io}\, (T_{io} - T_{co})} \qquad (22)$$

where h_{as} = the equivalent heat transfer coefficient of the air space based on the outer surface area of the insulation (Btu/hr-ft^2-°F).

This expression neglects the thermal resistance of the steel conduit, which is a reasonable assumption in most cases. We have also used the heat flow as measured with the insulation method described earlier, as this was felt to be the most reliable of the methods used.

Equation 22 was used to calculate h_{as} for 626 sets of daily averages for the data. For the supply conduit system the mean value of h_{as} was 1.15 Btu/hr-ft^2-°F with the standard deviation being 0.110 Btu/hr-ft^2-°F. For the return conduit system the mean value was 1.51 and the standard deviation was 0.225. These values would tend to indicate that the assumed value of 3 Btu/hr-ft^2-°F is higher than those experienced in practice, at least in this case. More data are needed from other system configurations, however, before sufficient justification for lowering this value would exist. If the results of this study are representative, the current factor is conservative in that it would underpredict the thermal resistance of the air space and thus the heat transfer would be overpredicted.

Table 8. Selected raw and reduced data from the individual conduit site.

Date	C104 Supply Pipe Temp. (F)*	C105 Supply Insul. Top (F)	C106 Supply Insul. Bottom (F)	C112 Return Pipe Temp. (F)	C113 Return Insul. Top (F)	C114 Return Insul. Bottom (F)	C127 Return Conduit Temp. (F)	C123 Supply Conduit Temp. (F)	c118 Soil Temp. @ 74" (F)	Insulation Thermal Conductivity supply (btu/hr-ft-F)	return	Insulation Method Heat Loss supply (btu/hr-ft)	return	total	CEGS-02695 Method Heat Loss supply (btu/hr-ft)	return	total
06-Feb-88	348.8	93.9	94.2	200.3	79.7	76.7	71.9	74.3	53.2	0.026	0.024	56.7	25.0	81.7	53.9	22.0	75.9
07-Feb-88	350.1	94.1	94.4	193.9	79.7	76.7	72.1	74.5	50.7	0.026	0.024	57.0	23.6	80.6	54.2	20.8	75.1
08-Feb-88	349.6	94.0	94.4	197.9	79.3	76.5	72.2	74.6	48.4	0.026	0.024	56.9	24.5	81.4	54.1	21.6	75.8
09-Feb-88	350.1	93.7	94.3	198.7	79.3	76.6	72.2	74.5	48.0	0.026	0.024	57.0	24.7	81.7	54.4	21.9	76.3
10-Feb-88	349.5	93.7	94.2	198.6	79.4	76.7	72.1	74.3	47.9	0.026	0.024	56.9	24.7	81.5	54.1	21.8	75.9
11-Feb-88	349.4	93.6	94.1	195.4	78.9	76.4	72.0	74.2	48.3	0.026	0.024	56.9	24.0	80.9	54.1	21.1	75.2
12-Feb-88	349.4	93.3	94.0	195.8	78.7	76.3	71.8	74.1	48.1	0.026	0.024	56.9	24.2	81.1	54.0	21.2	75.2
13-Feb-88	350.3	93.2	94.0	195.4	78.9	76.4	71.8	74.0	48.3	0.026	0.024	57.2	24.0	81.2	54.2	21.1	75.3
14-Feb-88	350.1	93.2	93.9	195.0	78.5	76.1	71.7	74.0	47.9	0.026	0.024	57.1	24.0	81.1	54.0	20.8	74.8
15-Feb-88	348.2	92.9	93.7	190.5	78.3	76.0	71.6	73.8	47.0	0.026	0.024	56.7	23.1	79.8	53.5	19.9	73.5
16-Feb-88	349.3	92.7	93.6	196.8	78.2	75.9	71.5	73.6	47.6	0.026	0.024	57.0	24.5	81.4	53.7	21.1	74.9
17-Feb-88	350.1	92.8	93.7	205.2	78.9	76.2	71.5	73.6	48.1	0.026	0.024	57.2	26.2	83.3	53.8	22.7	76.5
18-Feb-88	349.0	92.8	93.6	198.6	78.7	76.2	71.6	73.6	48.4	0.026	0.024	56.9	24.8	81.7	53.4	21.3	74.7
19-Feb-88	348.6	92.8	93.6	200.9	79.0	76.3	71.6	73.6	48.5	0.026	0.024	56.8	25.2	82.0	53.3	21.6	74.9
20-Feb-88	348.8	92.9	93.6	187.5	77.5	75.4	71.3	73.6	49.7	0.026	0.024	56.8	22.6	79.4	53.7	19.4	73.1
21-Feb-88	349.2	93.0	93.7	187.3	77.5	75.3	71.1	73.7	50.2	0.026	0.024	56.9	22.6	79.5	54.0	19.5	73.5
22-Feb-88	350.8	93.3	93.9	202.4	66.7	74.6	59.6	61.5	49.7	0.026	0.024	57.3	26.9	84.2	53.9	22.0	75.9
23-Feb-88	348.4	93.4	93.8	204.8	80.0	76.8	71.8	73.9	49.5	0.026	0.024	56.7	25.9	82.6	53.3	22.5	75.8
24-Feb-88	348.6	93.2	93.9	220.9	81.4	77.7	72.3	73.9	50.9	0.026	0.025	56.7	29.2	85.9	53.0	25.4	78.4
25-Feb-88	350.0	93.5	94.1	198.2	79.4	76.5	71.9	74.1	51.2	0.026	0.024	57.1	24.6	81.6	53.6	21.1	74.7
26-Feb-88	349.7	93.7	94.2	206.0	79.8	76.7	71.9	74.2	50.1	0.026	0.024	56.9	26.2	83.1	53.3	22.4	75.8
27-Feb-88	346.9	93.7	94.1	200.1	79.9	76.8	72.0	74.3	49.3	0.026	0.024	56.2	24.9	81.1	52.6	21.2	73.8
28-Feb-88	347.5	93.6	94.0	195.7	79.5	76.6	71.9	74.2	50.1	0.026	0.024	56.4	24.0	80.4	52.4	20.1	72.5
29-Feb-88	348.3	93.6	94.1	207.4	80.0	76.8	72.0	74.3	50.5	0.026	0.024	56.6	26.5	83.1	52.5	22.2	74.7
01-Mar-88	347.9	93.9	94.2	211.9	81.3	77.6	72.4	74.4	50.9	0.026	0.024	56.4	27.2	83.7	52.3	23.1	75.4
02-Mar-88	347.5	93.8	94.2	216.1	81.5	77.8	72.6	74.4	51.5	0.026	0.025	56.4	28.1	84.5	52.2	23.8	76.0
03-Mar-88	347.7	94.0	94.3	216.2	81.6	77.8	72.7	74.6	51.9	0.026	0.025	56.4	28.1	84.5	52.1	23.7	75.7
04-Mar-88	344.3	94.2	94.3	226.2	82.8	78.6	73.1	74.7	53.4	0.026	0.025	55.5	30.1	85.6	51.4	25.9	77.3
05-Mar-88	344.8	94.3	94.4	219.5	82.4	78.4	73.1	74.8	55.4	0.026	0.025	55.6	28.7	84.3	51.6	24.6	76.2
06-Mar-88	346.0	94.6	94.6	201.6	82.1	78.2	73.0	75.1	55.2	0.026	0.024	55.9	24.9	80.8	52.1	21.2	73.4
07-Mar-88	347.1	94.9	95.0	220.2	83.2	78.9	73.5	75.4	55.0	0.026	0.025	56.1	28.7	84.8	52.1	24.6	76.7
08-Mar-88	345.2	95.1	95.1	222.8	83.7	79.3	73.8	75.6	55.2	0.026	0.025	55.6	29.2	84.8	51.6	25.1	76.7
AVERAGES	348.5	93.6	94.1	203.4	79.6	76.8	71.7	73.8	50.3	0.026	0.024	56.6	25.7	82.3	53.2	22.1	75.3

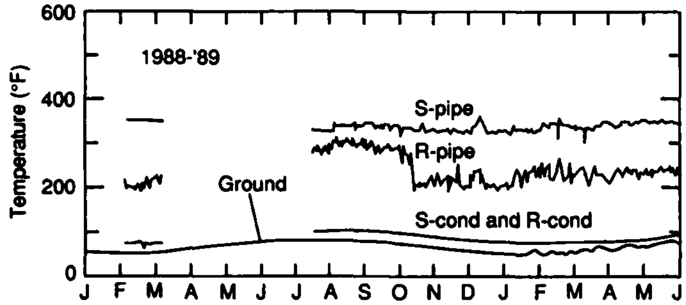


Figure 14. Individual conduit site temperatures.

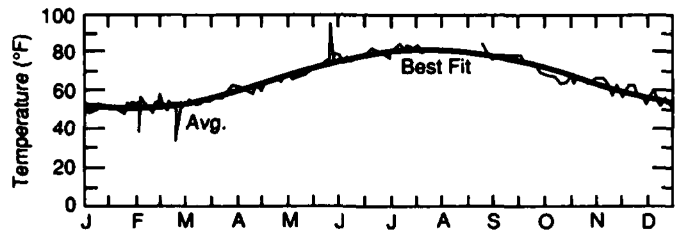


Figure 15. Average undisturbed soil temperature at 74 in. and fitted sinusoidal curve.

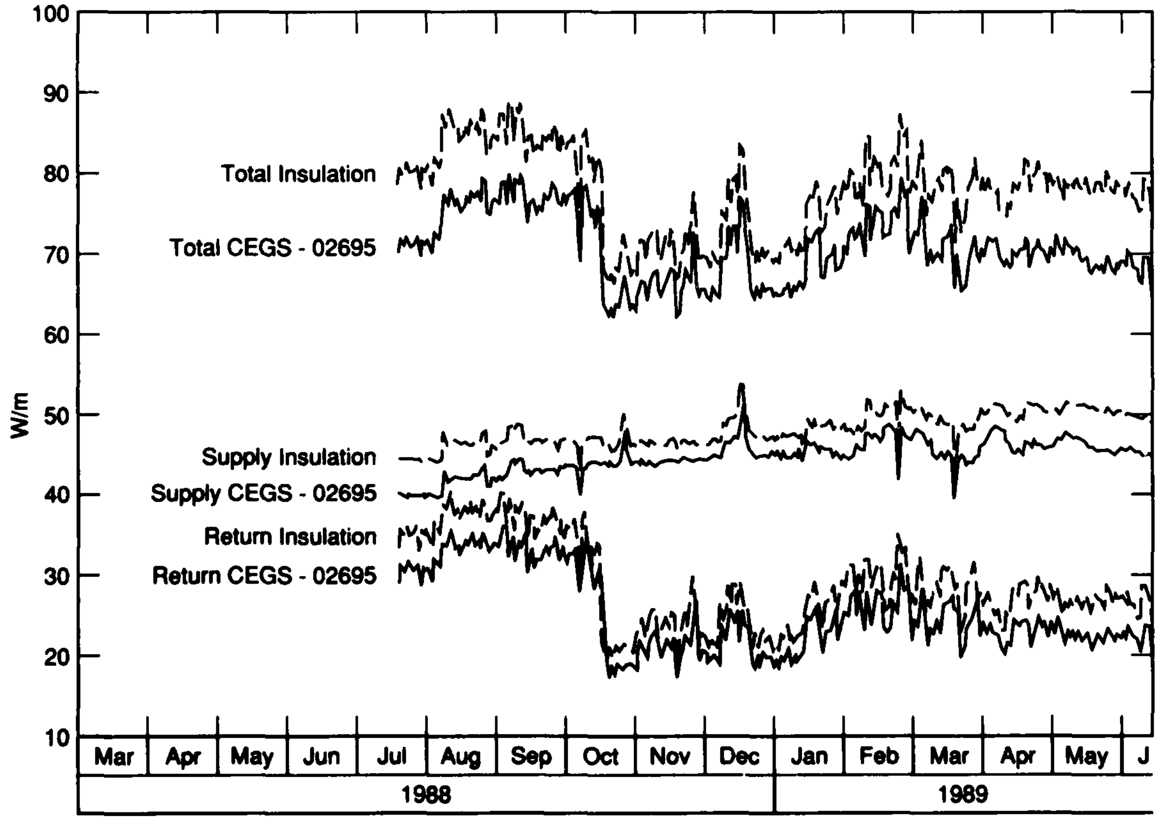


Figure 16. Individual conduit site heat losses.

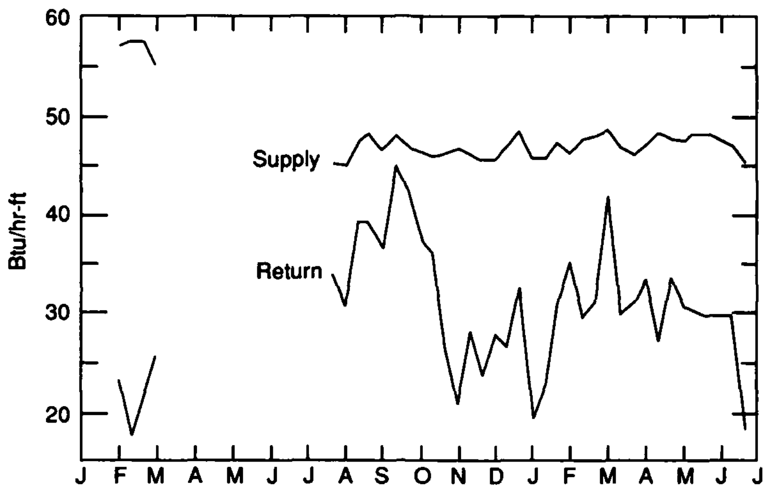


Figure 17. Heat flux sensor data for the individual conduit site, 10-day averages.

CONCLUSIONS

Much of the data taken on this project has not yet been reduced. This is particularly true of the extensive soil temperature data, which have been gathered around the three types of systems. We plan to analyze these data numerically using finite element methods. A small sample of data from this project was analyzed in this way by Fleck (1989). We plan to expand both the amount of data analyzed and the methods used.

The results from the data that have been reduced are very encouraging. We feel that two of the major objectives of the study have been accomplished:

1. We have shown that heat losses can be measured by several different methods with reliable and repeatable results.
2. We have established the level of heat losses from three types of operating heat distribution systems under field conditions.

At this point three other objectives remain:

1. To determine the long-term thermal performance of these heat distribution systems.
2. To analyze the soil temperature data more exhaustively to determine if heat losses can be accurately predicted using such information.
3. To determine if the existing calculational methods and assumptions are valid or if they are in need of modification.

In order to determine the long-term performance of the systems we would like to continue monitoring them for at least 10 more years. This would provide almost 15 years worth of data on the trench and common conduit site. The amount of data being collected could be reduced significantly for this extended monitoring period. Because the data logging systems are currently in place and operating satisfactorily we are continuing data acquisition as described earlier. We currently have approximately one year of additional data at all the sites beyond that presented here. This is information currently being reduced and will be published in a future comprehensive report on the project.

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APPENDIX A: SENSOR LOCATIONS

Two pipes, single conduit, C-site.

Channel no.	*Label*	*Output units*	*Location*
0	AIR/C-SITE TREE	F	Air temperature, located on side of tree.
1	C-SITE TOP PIPE	F	Attached to top of supply pipe.
2	C-SITE BTM PIPE	F	Attached to top of return pipe.
3	C-SITE TOP INS	F	Attached to top of supply pipe insulation.
4	C-SITE BTM INS	F	Attached to top of return pipe insulation.
5	C-SITE TOP AIR	F	Air temp. inside conduit above pipes.
6	C-SITE BTM AIR	F	Air temp. inside conduit below pipes.
7	C-SITE MID AIR	F	Air temp. inside conduit between pipes.
8	C INNER SURFACE	F	Att'd. at 45 deg. to inner surf. of conduit.
9	C CTR STR Y=2.0	F	Gnd temp. 2 in. from surf. above center of pipe.
10	C CTR STR Y=7.0	F	Gnd temp. 7 in. from surf. above center of pipe.
11	C CTR STR Y=13	F	Gnd temp. 13 in. from surf. above center of pipe.
12	C CTR STR Y=19	F	Gnd temp. 19 in. from surf. above center of pipe.
13	C CTR STR Y=25	F	Gnd temp. 25 in. from surf. above center of pipe.
14	C CTR STR Y=37	F	Gnd temp. 37 in. from surf. above center of pipe.
15	C CTR CDT TP 44	F	Top outside surf. of conduit, 44 in. from surface.
16	C CTR CDT TP 44	F	Top outside surf. of conduit, 44 in. from surface.
17	C OUTER SURFACE	F	Attached to outer surface of conduit.
18	HFS TOP PIPE	mV	Heat flow sensor attached to the top pipe.
19	HFS BOTTOM PIPE	mV	Heat flow sensor attached to bottom pipe.
20	C2 STG Y=9.0	F	Gnd temp. 9 in. from surf. 1'11 in. from ctr. cond.
21	C2 STG Y=14	F	Gnd temp. 14 in. from surf. 1'11 in. from ctr cond.
22	C2 STG Y=20	F	Gnd temp. 20 in. from surf. 1'11 in. from ctr cond.
23	C2 STG Y=26	F	Gnd temp. 26 in. from surf. 1'11 in. from ctr cond.
24	C2 STG Y=32	F	Gnd temp. 32 in. from surf. 1'11 in. from ctr cond.
25	C2 STG Y=44	F	Gnd temp. 44 in. from surf. 1'11 in. from ctr cond.
26	C2 STG Y=56	F	Gnd temp. 56 in. from surf. 1'11 in. from ctr cond.
27	C2 STG Y=68	F	Gnd temp. 68 in. from surf. 1'11 in. from ctr cond.
28	C2 STG Y=80	F	Gnd temp. 80 in. from surf. 1'11 in. from ctr cond.
29	C2 STG Y=92	F	Gnd temp. 92 in. from surf. 1'11 in. from ctr cond.
30	C2 STG Y=104	F	Gnd temp 104 in. from surf. 1.11 in. from ctr cond.
31	C2 STG Y=104	F	Gnd temp 104 in. from surf. 1.11 in. from ctr cond.
32	DATA LOGGER BOX	F	Temperature inside data logger storage box.

Two pipes, concrete trench, T-site.

Channel no.	*Label*	*Output units*	*Location*
100	T-BTM CTR AIR	F	Air temperature inside trench, lower center.
101	T-LH WALL CTR	F	Inside trench wall, return side, at mid-height.
102	T-RT PIPE	F	Attached to supply pipe.
103	T-LH PIPE INS	F	Attached to top of return pipe insulation.
104	T-CTR AIR	F	Air temp.between supply and return pipes.
105	T-LH PIPE	F	Attached to return pipe.
106	T-RH PIPE INS	F	Attached to top of supply pipe insulation.
107	T-LID UNDERSIDE	F	Attached to underside of trench cover.
108	T-FLOOR CTR	F	Attached inside trench to center of floor.
109	T-RH WALL CTR	F	Inside trench wall, supply side, at mid-height.
110	T-AIR LT OF LP	F	Air temp. inside trench, left of return pipe.
111	T-AIR RT OF RP	F	Air temp. inside trench, right of supply pipe.
112	T-CTL Y=3.0	F	Gnd temp., 3 in. from surface, 13.2' from trench.
113	T-CTL Y=8.0	F	Gnd temp., 8 in. from surface, 13.2' from trench.
114	T-CTL Y=14.0	F	Gnd temp., 14 in. from surface, 13.2' from trench.
115	T-CTL Y=26.0	F	Gnd temp., 26 in. from surface, 13.2' from trench.
116	T-CTL Y=38.0	F	Gnd temp., 38 in. from surface, 13.2' from trench.
117	T-CTL Y=56.O	F	Gnd temp., 56 in. from surface, 13.2' from trench.
118	T-CTL Y=74.0	F	Gnd temp., 74 in. from surface, 13.2' from trench.
119	T-CTL Y=98.0	F	Gnd temp., 98 in. from surface, 13.2' from trench.
120	T1 STG Y=2.0	F	Gnd temp., 2 in. from surface, 2.4' from trench.
121	T1 STG Y=7.0	F	Gnd temp., 7 in. from surface, 2.4' from trench.
122	T1 STG Y=13.0	F	Gnd temp., 13 in. from surface, 2.4' from trench.
123	T1 STG Y=25.0	F	Gnd temp., 25 in. from surface, 2.4' from trench.
124	T1 STG Y=37.0	F	Gnd temp., 37 in. from surface, 2.4' from trench.
125	T1 STG Y=49.0	F	Gnd temp., 49 in. from surface, 2.4' from trench.
126	T1 STG Y=61.0	F	Gnd temp., 61 in. from surface, 2.4' from trench.
127	T1 STG Y=68-CWP	F	Gnd temp., 68 in. from surface, 2.4' from trench.
128	T6 STG Y=2.0	F	Gnd temp., 2 in. from surface, 6.7' from trench.
129	T6 STG Y=7.0	F	Gnd temp., 7 in. from surface, 6.7' from trench.
130	T6 STG Y=13.0	F	Gnd temp., 13 in. from surface, 6.7' from trench.
131	T6 STG Y=25.0	F	Gnd temp., 25 in. from surface, 6.7' from trench.
132	T6 STG Y=37.0	F	Gnd temp., 37 in. from surface, 6.7' from trench.
133	T6 STG Y=49.0	F	Gnd temp., 49 in. from surface, 6.7' from trench.
134	T6 STG Y=61.0	F	Gnd temp., 61 in. from surface, 6.7' from trench.
135	T6 STG Y=73.0	F	Gnd temp., 73 in. from surface, 6.7' from trench.
136	T-HFS LH PIPE	mV	Heat flow sensor attached to return pipe.
137	T-HSF RH PIPE	mV	Heat flow sensor attached to supply pipe.
139	T-AIR IN MNHOLE	F	Air temperature inside man hole w/extender.

Two pipes, individual conduits, S-site.

Channel no.	*Label*	*Output units*	*Location*
100	SITE2-OUTSD AIR	F	Air temperature located on side of tree.
101	SITE2-MANHL AIR	F	Air temperature inside man hole.
102	SUPPLY(S) HFS	mV	Heat flow sensor attached to supply pipe.
103	RETURN(R) HFS	mV	Heat flow sensor attached to return pipe.
104	S-TOP CAR.PIPE	F	Attached to top of supply carrier pipe.
105	S-TOP INSUL	F	Attached to top of insulation on supply pipe.
106	S-BOT INSUL	F	Att'd to bot. of insulation on supply pipe.
107	S-TOP AIRSPACE	F	Air temp. in space above supply carrier pipe.
108	S-MID AIRSPACE	F	Air temp. in space beside supply carrier pipe.
109	S-BOT AIRSPACE	F	Air temp. in space below supply carrier pipe.
110	S-TOP INSD COND	F	Attached to top inside of supply conduit.
111	S-BOT INSD COND	F	Attached to bottom inside of supply conduit.
112	R-TOP CAR. PIPE	F	Attached to top of return carrier pipe.
113	R-TOP INSUL	F	Attached to top of insulation on return pipe.
114	R-BOT INSUL	F	Att'd to bot. of insulation on return pipe.
115	R-TOP AIRSPACE	F	Air temp. in space above return carrier pipe.
116	R-MID AIRSPACE	F	Air temp. in space beside return carrier pipe.
117	R-BOT AIRSPACE	F	Air temp. in space below return carrier pipe.
118	R-TOP INSD COND	F	Attached to top inside of return conduit.
119	R-BOT INSD COND	F	Attached to bottom inside of return conduit.
120	S-ON COND, RGHT	F	Attached outside, rightside of supply conduit.
121	S-ON COND, TOP	F	Attached outside, top of supply conduit.
122	S-ON COND, LEFT	F	Attached outside, leftside of supply conduit.
123	S-ON COND, BOT	F	Attached outside, bottom of supply conduit.
124	R-ON COND, RGHT	F	Attached outside, rightside of return conduit.
125	R-ON COND, TOP	F	Attached outside, top of return conduit.
126	R-ON COND, LEFT	F	Attached outside, leftside of return conduit.
127	R-ON COND, BOT	F	Attached outside, bottom of return conduit.
128	Z-Q CBL/2IN	F	Gnd-temp. 2 in., 30 in. rt. of return pipe center.
129	Z-Q CBL/12IN	F	Gnd-temp. 12 in., 30 in. rt. of return pipe center.
130	Z CBL/23IN	F	Gnd-temp. 23 in., 30 in. rt. of return pipe center.
131	Z CBL/35IN	F	Gnd-temp. 35 in., 30 in. rt. of return pipe center.
132	Z CBL/47IN	F	Gnd-temp. 47 in., 30 in. rt. of return pipe center.
133	Z CBL/59IN	F	Gnd-temp. 59 in., 30 in. rt. of return pipe center.
134	Z CBL/71IN	F	Gnd-temp. 71 in., 30 in. rt. of return pipe center.
135	Z CBL/83IN	F	Gnd-temp. 83 in., 30 in. rt. of return pipe center.
136	Z CBL/95IN	F	Gnd-temp. 95 in., 30 in. rt. of return pipe center.
137	Z CBL/119IN	F	Gnd-temp. 119 in.. 30 in. rt. of return pipe center.
138	Z CBL/143IN	F	Gnd-temp. 143 in., 30 in. rt. of return pipe center.
139	Z CBL/179IN	F	Gnd-temp. 179 in., 30 in. rt. of return pipe center.
140	Y-Q CBL/2IN	F	Gnd-temp. 2 in., on center line of return pipe.
141	Y-Q CBL/6IN	F	Gnd-temp. 6 in., on center line of return pipe.
142	Y CBL/12IN	F	Gnd-temp. 12 in., on center line of return pipe.
143	Y CBL/18IN	F	Gnd-temp. 18 in., on center line of return pipe.
144	Y CBL/28IN	F	Gnd-temp. 28 in., on center line of return pipe.
145	Y CBL/40IN	F	Gnd-temp. 40 in., on center line of return pipe.
146	Y CBL/52IN	F	Gnd-temp. 52 in., on center line of return pipe.
147	Y CBL/58IN	F	Gnd-temp. 58 in., on center line of return pipe.
148	Y CBL/64IN	F	Gnd-temp. 64 in., on center line of return pipe.

Two pipes, individual conduits (cont'd).

Channel no.	*Label*	*Output units*	*Location*
149	Y CBL/70IN	F	Gnd-temp. 70 in., on center line of return pipe.
150	Y-S CBL/92IN	F	Gnd-temp. 92 in., on center line of return pipe.
151	Y-S CBL/98IN	F	Gnd-temp. 98 in., on center line of return pipe.
152	Y-S CBL/104IN	F	Gnd-temp. 104 in., on center line of return pipe.
153	Y-S CBL/116IN	F	Gnd-temp. 116 in., on center line of return pipe.
154	X-Q CBL/2IN	F	Gnd-temp. 2 in., between supply and return pipes.
155	X-Q CBL/6IN	F	Gnd-temp. 6 in., between supply and return pipes.
156	XTOP CBL/12IN	F	Gnd-temp. 12 in., between supply & return pipes.
157	XTOP CBL/27IN	F	Gnd-temp. 27 in., between supply & return pipes.
158	XTOP CBL/33IN	F	Gnd-temp. 33 in., between supply & return pipes.
159	XTOP CBL/45IN	F	Gnd-temp. 45 in., between supply & return pipes.
160	XTOP CBL/57IN	F	Gnd-temp. 57 in., between supply & return pipes.
161	XTOP CBL/69IN	F	Gnd-temp. 69 in., between supply & return pipes.
162	XTOP CBL/75IN	F	Gnd-temp. 75 in., between supply & return pipes.
163	XTOP CBL/81IN	F	Gnd-temp. 81 in., between supply & return pipes.
164	XTOP CBL/87IN	F	Gnd-temp. 87 in., between supply & return pipes.
165	XBOT CBL/93IN	F	Gnd-temp. 93 in., between supply & return pipes.
166	XBOT CBL/99IN	F	Gnd-temp. 99 in., between supply & return pipes.
167	XBOT CBL/105IN	F	Gnd-temp. 105 in., between supply & return pipes.
168	XBOT CBL/117IN	F	Gnd-temp. 117 in., between supply & return pipes.
169	XBOT CBL/129IN	F	Gnd-temp. 129 in., between supply & return pipes.
170	XBOT CBL/141IN	F	Gnd-temp. 141 in., between supply & return pipes.
171	XBOT CBL/165IN	F	Gnd-temp. 165 in., between supply & return pipes.
172	XBOT SNGL/201IN	F	Gnd-temp. 201 in., between supply & return pipes.
173	W-Q CBL/2IN	F	Gnd-temp. 2 in., on center line of supply pipe.
174	W-Q CBL/6IN	F	Gnd-temp. 6 in., on center line of supply pipe.
175	W CBL/12IN	F	Gnd-temp. 12 in., on center line of supply pipe.
176	W CBL/18IN	F	Gnd-temp. 18 in., on center line of supply pipe.
177	W CBL/28IN	F	Gnd-temp. 28 in., on center line of supply pipe.
178	W CBL/40IN	F	Gnd-temp. 40 in., on center line of supply pipe.
179	W CBL/52IN	F	Gnd-temp. 52 in., on center line of supply pipe.
180	W CBL/58IN	F	Gnd-temp. 58 in., on center line of supply pipe.
181	W CBL/64IN	F	Gnd-temp. 64 in., on center line of supply pipe.
182	W CBL/70IN	F	Gnd-temp. 70 in., on center line of supply pipe.
183	W-S CBL/92IN	F	Gnd-temp. 92 in., on center line of supply pipe.
184	W-S CBL/98IN	F	Gnd-temp. 98 in., on center line of supply pipe.
185	W-S CBL/104IN	F	Gnd-temp. 104 in., on center line of supply pipe.
186	W-S CBL/116IN	F	Gnd-temp. 116 in., on center line of supply pipe.
187	V-Q CBL/2IN	F	Gnd-temp. 2 in., 29 in. rt. of supply pipe center.
188	V-Q CBL/6IN	F	Gnd-temp. 6 in., 29 in. rt. of supply pipe center.
189	V-Q CBL/12IN	F	Gnd-temp. 12 in., 29 in. rt. of supply pipe center.
190	V CBL/22IN	F	Gnd-temp. 22 in., 29 in. rt. of supply pipe center.
191	V CBL/34IN	F	Gnd-temp. 34 in., 29 in. rt. of supply pipe center.
192	V CBL/46IN	F	Gnd-temp. 46 in., 29 in. rt. of supply pipe center.
193	V CBL/58IN	F	Gnd-temp. 58 in., 29 in. rt. of supply pipe center.
194	V CBL/70IN	F	Gnd-temp. 70 in., 29 in. rt. of supply pipe center.
195	V CBL/82IN	F	Gnd-temp. 82 in., 29 in. rt. of supply pipe center.
196	V CBL/94IN	F	Gnd-temp. 94 in., 29 in. rt. of supply pipe center.

Two pipes, individual conduits (cont'd).

Channel no.	*Label*	*Output units*	*Location*
197	V CBL/118IN	F	Gnd-temp. 118 in., 29 in. rt. of supply pipe center.
198	V CBL/142IN	F	Gnd-temp. 142 in., 29 in. rt. of supply pipe center.
199	V CBL/184IN	F	Gnd-temp. 184 in., 29 in. rt. of supply pipe center.

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The actual level of heat losses from operating heat distribution systems is not well known. The effect of the type of distribution system and the length of time in service in heat losses are also not known, and methods used to calculate heat losses have not been adequately verified. This report describes a field project at Ft. Jackson, South Carolina, which addresses these needs. At Ft. Jackson three different types of systems have been instrumented: shallow concrete trench, steel conduit with supply and return in common conduit, and separate conduits for supply and return pipes. The heat losses from these systems are being monitored using several methods. Data have been collected from these sites for over four years, and some of the initial results are presented.

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