SPECIAL REPORT 94-3

CRREL

Operating Manual for Hybrid Thermosyphons at the Gakona Power Plant, Alaska

F. Donald Haynes, Frederick C. Crory, Kurt V. Knuth and William F. Quinn

March 1994

Abstract

A power plant building was constructed in 1990 at an over-the-horizon radar site in Gakona, Alaska. Since it was built on permafrost, thermal protection between the building and the underlying permafrost was included in the design, which included rigid board insulation and hybrid thermosyphons placed in the gravel fill under the building. Soil temperature is monitored with eight thermistor strings placed under and at the building perimeter. This manual describes the steps that must be taken to ensure foundation stability, including directions on when to use the thermosyphons in the active, mechanical refrigeration mode. A data acquisition system using a computer-controlled datalogger is described.

For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380-89a, *Standard Practice for Use of the International System of Units,* 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

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March 1994

Prepared for the
11TH AIR FORCE
ELMENDORF AIR FORCE BASE

PREFACE

This report was prepared by F. Donald Haynes, Mechanical Engineer, of the Ice Engineering Research Branch, and Frederick C. Crory, Civil Engineer, and William F. Quinn, Supervisory Civil Engineer, of the Civil and Geotechnical Engineering Research Branch, Experimental Engineering Division; and Kurt V. Knuth, Electronics Engineer, of the Engineering Resources Branch, Technical Resources Center, of the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL). The funding for this manual was provided by the 11th Air Force, Elmendorf AFB.

This manual was technically reviewed by Leonard Zabilanski and Donald Garfield of CRREL.

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Operating Manual For Hybrid Thermosyphons at the Gakona Power Plant, Alaska

F. DONALD HAYNES, FREDERICK C. CRORY, KURT V. KNUTH
AND WILLIAM F. QUINN

INTRODUCTION

The purpose of this manual is to instruct the plant operator on the operation of the thermosyphon installation at the Gakona Power Plant. It includes instructions on how to operate the data acquisition system that was installed to record temperature readings from eight thermistor strings. Guidelines are given for the operation of the mechanical refrigeration system so that the hybrid thermosyphons can perform their function in maintaining a stable foundation under the building. Finally, the manual includes a summary of steps that must be taken annually to ensure the integrity of the foundation. It may be necessary to update this manual after additional soil temperature analyses are made.

Background

Thermosyphons remove heat from the soil to prevent thawing of underlying permafrost. They are used throughout Alaska to stabilize foundations under buildings, roads, storage tanks, and other structures. The largest single installation is the trans-Alaska pipeline, which uses 122,000 thermosyphons.

The power plant building at Gakona, Alaska, was originally designed and constructed to support an over-the-horizon (OTH) radar site. A report on the use of thermosyphons for the OTH site was written by Haynes (1990). The OTH project was canceled, but the power plant building may be used for other projects in the future. The location of the power plant is shown in Figure 1.

The power plant building is shown in Figure 2. To the left in the photo are the hybrid thermosyphons on the northeast side of the building; at the center and to the right are the thermosyphons on the northwest side. In all, 55 thermosyphons have been placed under the building's foundation.

Locations of the thermosyphons

The locations of all 55 thermosyphons are shown in Figure 3, and thermistor well T-2, thermosyphons 1–23, and refrigeration units R1 and R2 are shown in Figure 4. Figure 5, a sectional elevation view from the southwest side of the building, shows the thermosyphons with the vertical condensers and the sloped evaporators buried in the non-frost-susceptible gravel pad. Also buried in the gravel pad is a 10-in.-thick board insulation under the building and a 4-in.-thick rigid board insulation that extends about 12 ft beyond the building. The 4-in.-thick insulation is below a sheet of geotextile and a high-density polyethylene (HDPE) liner, which keeps surface water and/or meltwater off the insulation.

THERMOSYPHON OPERATION

Passive refrigeration mode

Typically, a thermosyphon is designed to operate only in the passive mode (Figure 6). It is simply a closed metal pipe partially filled with a refrigerant such as carbon dioxide. The evaporator section is placed in the soil to be frozen, and the finned condenser section stands free in the air to dissipate the heat removed from the soil. Whenever the air

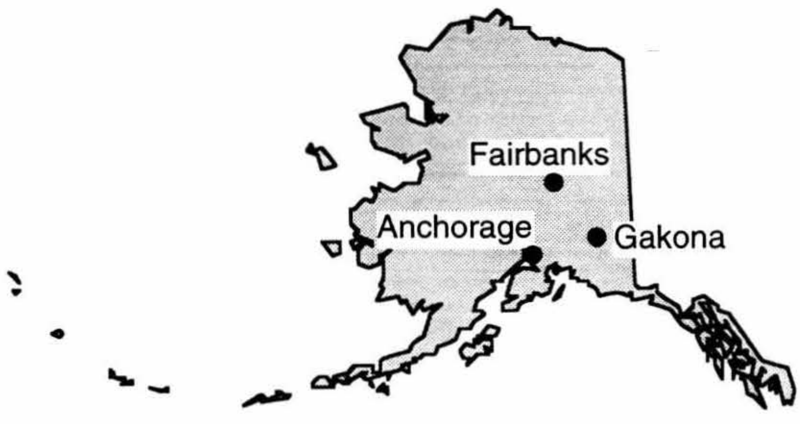

Figure 1. Location of the Gakona Power Plant.

temperature is less than the soil temperature, heat from the soil causes the liquid refrigerant to boil. This vapor rises to the condenser section where it comes in contact with the cold metal surface and condenses back into a liquid. The condensate flows to the evaporator section by gravity; this cycle continues for about 8 to 10 months of the year for most locations in Alaska. At Gakona, the thermosyphons operate in the passive mode from mid-September to mid-May.

The thermosyphons were fabricated by Arctic Foundations, Inc. of Anchorage. They are made of

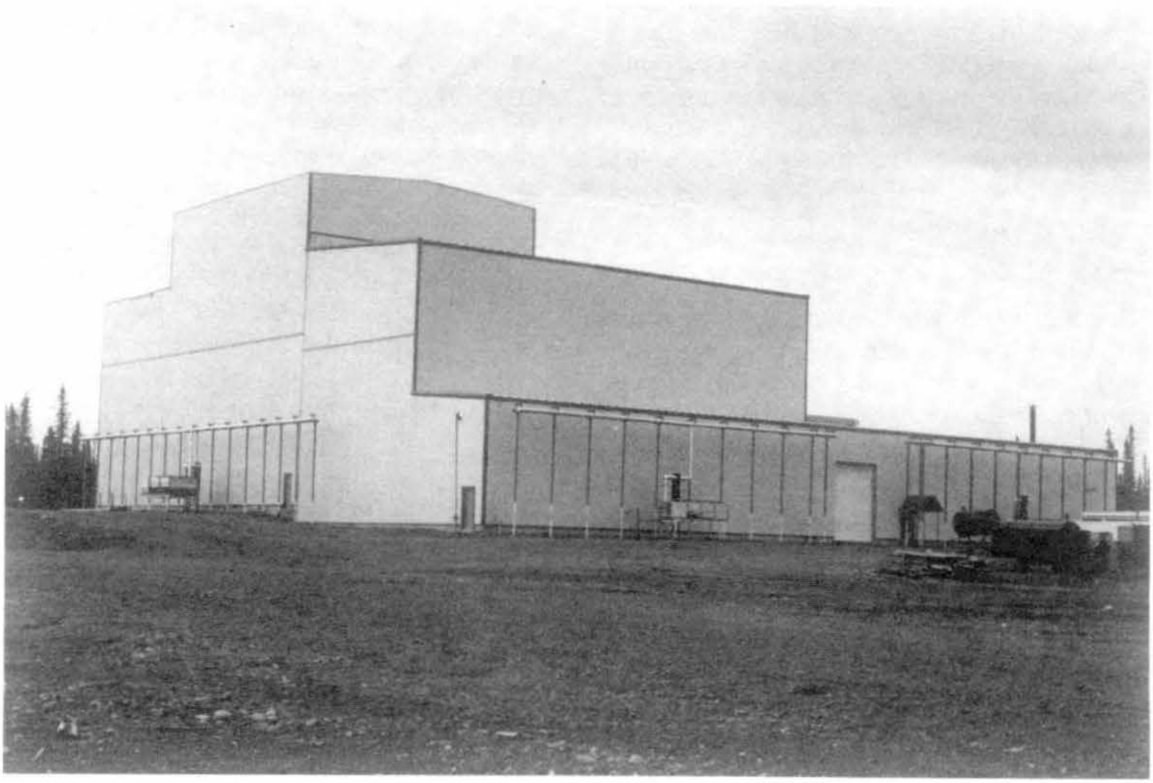

Figure 2. The Gakona Power Plant building, looking south.

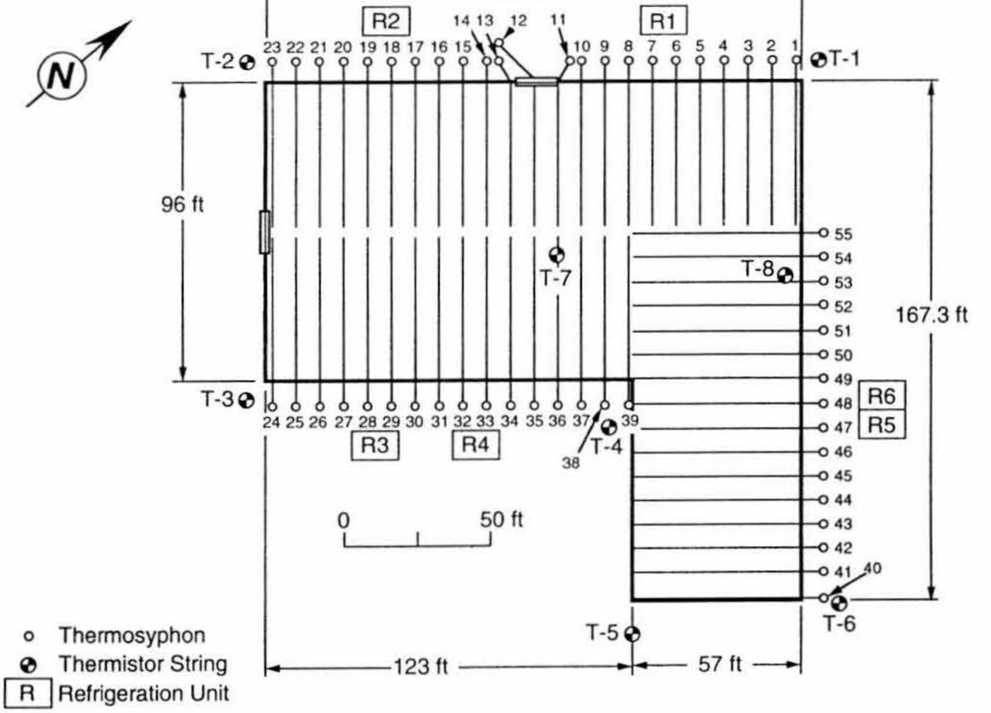

Figure 3. Plan view of the power plant building, showing the location of thermosyphons, thermistor strings, and refrigeration units.

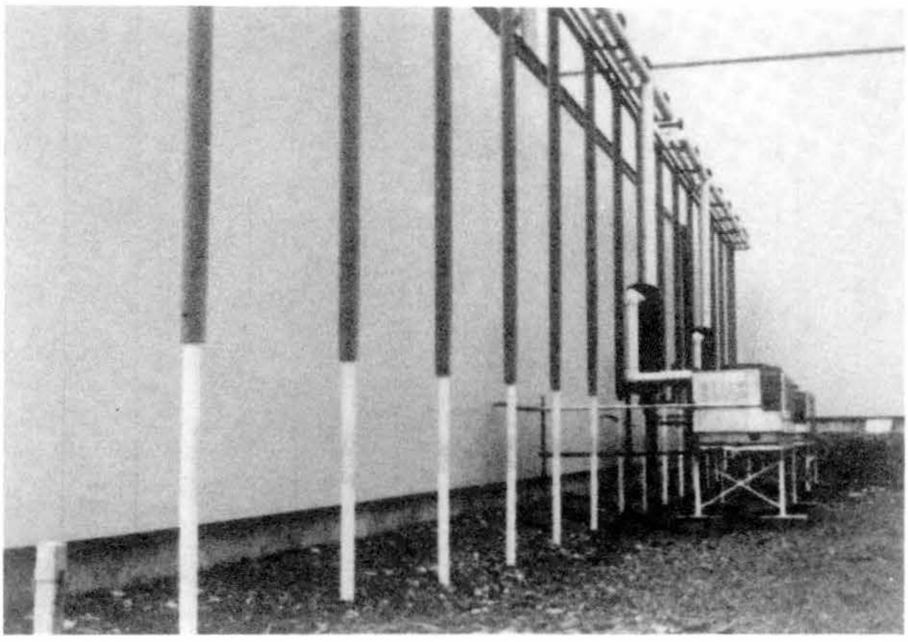

Figure 4. The northwest side of the building, showing thermistor well T-2, thermosyphons, and Larkin refrigeration units R1 and R2.

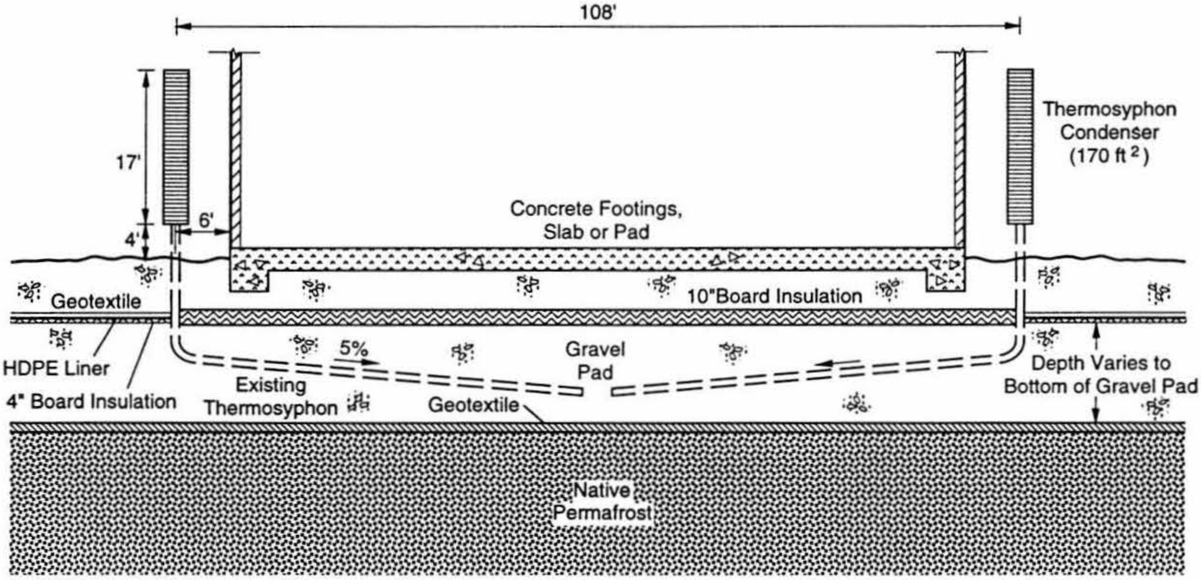

Figure 5. A sectional elevation view, looking northeast.

3-in. schedule 40 pipe and are charged with CO_2. The finned section is 17 ft long and has 170 ft^2 of fin area. The small, segmented steel fins are $1^1/_4$ in. long, $^1/_4$ in. wide, and $^1/_8$ in. thick. The 55 thermosyphons placed under the building are designed for hybrid operation, which means that they can operate in either active or passive mode.

Active refrigeration mode

In addition to passive operation, a thermosyphon can be made into a hybrid unit by providing cooling from a mechanical refrigeration system. Laboratory tests of hybrid thermosyphons have been reported by Haynes et al. (1991), who also discuss the advantages and disadvantages of

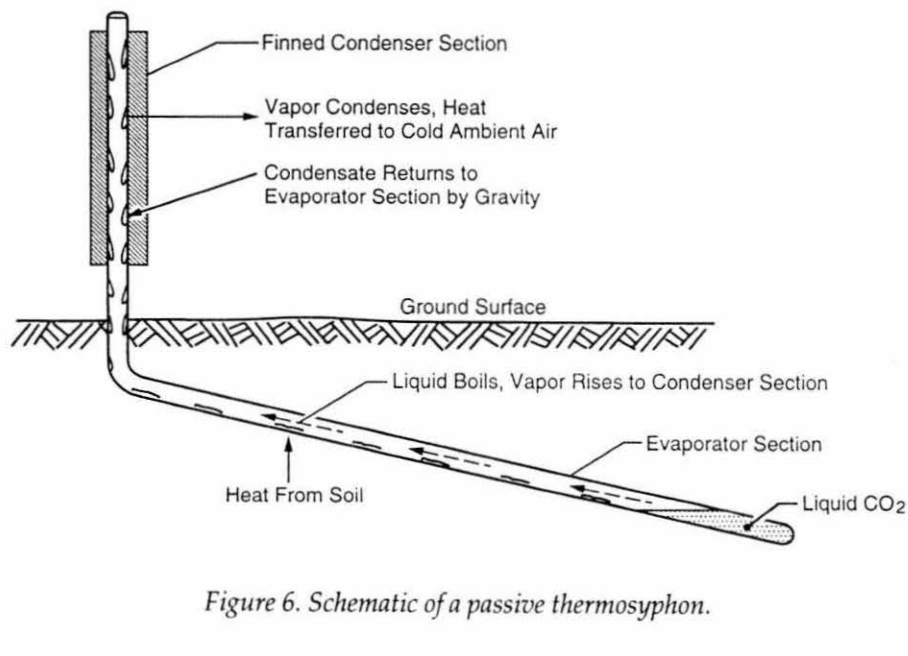

Figure 6. Schematic of a passive thermosyphon.

Table 1. Refrigeration units.

No.	*Type*	*Location*	*Connected to thermo-syphon no.**
R1	Larkin, 30 HP	Northwest side	1–11
R2	Larkin, 30 HP	Northwest side	12–23
R3	Larkin, 30 HP	South side	24–31
R4	Larkin, 30 HP	South side	32–39
R5	Larkin, 30 HP	Northeast side	40–55
R6	Larkin, 30 HP	Northeast side	48–55

* See Figure 3.

passive and active thermosyphons. The big advantage of a hybrid thermosyphon is that it can operate any time of the year. This makes it unnecessary to rely exclusively on a passive system, which can only operate about 8 months of the year. The disadvantages of a hybrid system are the capital cost and the costs of operation and maintenance.

The mechanical refrigeration units on the northeast and northwest sides of the building are shown in Figure 2. Information on the refrigeration units is given in Table 1. These units are designed to supply –40°F refrigerant to the top of the finned condenser section via a manifold. A schematic of how the hybrid thermosyphon operates in the active mode is shown in Figure 7. The cold refrigerant flows down pipe A and up the annulus between pipes A and B, creating a cold surface on the outside wall of pipe B. This condensing surface is in contact with the CO_2 vapor in the thermosyphon. The vapor condenses on the surface, which starts the heat removal cycle within the thermosyphon; the cycle continues as long as the condensing surface is kept cold.

If necessary, the thermosyphons will be operated in the active mode in summer, during August and September. The maximum depth of thaw in the gravel pad occurs in September just before the thermosyphons begin operating in the passive mode.

Maintenance

The mechanical refrigeration units must be kept in good operating condition. A shallow waterproof box should be placed over the fans on the top of each unit and sealed to the unit. Then place a plastic cover over the entire unit and tie it down. These covers should be put in place in September after the units are turned off, and they should be removed in May before the units are turned on.

The refrigeration units must be "exercised" by turning them on for at least 5 days every year. This should be done in May. The plant operator is responsible for having a refrigeration mechanic check the units before they are turned on. This check should include refrigerant fluid levels, leaks, and any damage to fan or condenser components. If there is any visible damage to a thermosyphon, contact Arctic Foundations, Inc., of Anchorage. If the system is operating properly, temperatures from thermistor strings T-7 and T-8 should decrease slightly during this 5-day exercise period.

Exercise the units in May to provide time to repair them, if necessary. After any repairs are made, in June or July, the units should be turned on for 5 days.

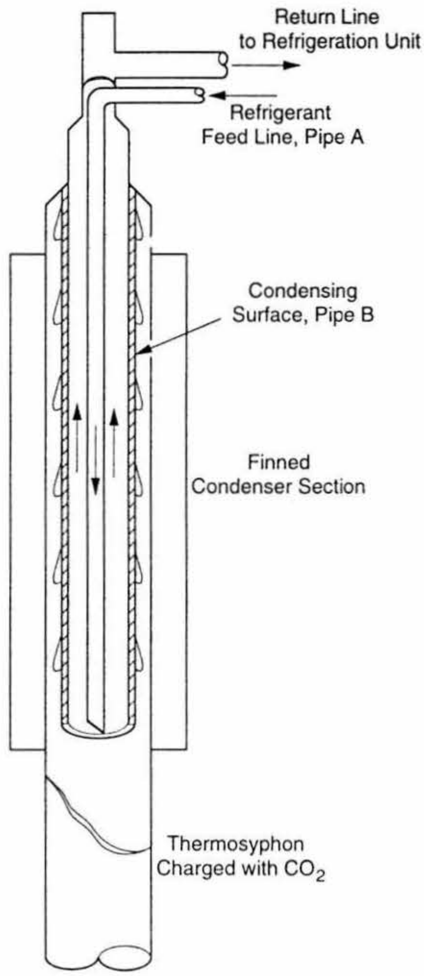

Figure 7. Cutaway schematic of the condenser section of an active thermosyphon.

DATA ACQUISITION SYSTEM

Thermistor strings

There are eight vertical thermistor strings at the building (Figure 3). Strings T-1 through T-6 are located on the outside corners of the building, and strings T-7 and T-8 are located under the building and accessed through capped holes in the floor. All of the strings have 24 thermistors, except T-8, which has 21. The thermistors on each string are spaced 2 ft apart for the upper 14 ft and 3 ft apart for the bottom 10, as shown in Table 2. The thermistors are placed inside PVC pipe. The thermistor strings were installed during the original construction. They were not installed by CRREL.

Typical sets of data for strings T-7 and T-8 are given in Table 2. A large temperature decrease is seen between thermistors 4 and 5, and between elevations 1843 and 1841, respectively. This identifies the location of the 10 in. of rigid board insulation. The temperature drop across the insulation is about 25°F for string T-8, illustrating the large thermal break provided by the insulation in separating the power plant floor above from the frozen gravel pad and permafrost below. Data from string T-8 is plotted in Figure 8. The minimum temperature of 28.15°F was measured by the thermistor closest to the thermosyphon evaporator at this location. These cold temperatures are the residual effect of the cooling provided by the thermosyphon the previous winter.

Table 2. Thermistor temperatures on 22 September 1992.

	String T-7		*String T-8*	
Thermistor number	*Elevation (ft)*	*Temp. (°F)*	*Elevation (ft)*	*Temp. (°F)*
1	1849.51	64.26	1848.75	61.02
2	1847.51	64.55	1847.58	61.22
3	1845.51	63.34	1845.58	60.31
4	1843.51	55.60	1843.58	55.28
5	1841.51	31.15	1841.58	30.87
6	1839.51	30.38	1839.58	29.83
7	1837.51	29.64	1837.58	29.39
8	1835.51	28.98	1835.58	28.74
9	1833.51	28.53	1833.58	28.38
10	1831.51	28.45	1831.58	28.20
11	1829.51	28.25	1829.58	28.15
12	1827.51	28.31	1827.58	28.42
13	1825.51	28.44	1825.58	28.45
14	1823.51	28.48	1823.58	28.67
15	1820.51	28.99	1821.58	28.77
16	1817.51	28.91	1819.58	28.81
17	1814.51	28.11	1817.58	29.07
18	1811.51	29.19	1815.58	29.08
19	1808.51	29.41	1813.58	29.17
20	1805.51	29.51	1811.58	29.33
21	1802.51	29.40	1809.58	29.38
22	1799.51	29.38		
23	1796.51	29.42		
24	1793.51	29.42		

Data acquisition equipment

CRREL was tasked to design and install a system to automatically measure and record the temperature from the eight subsurface thermistor strings that were installed during the construction of the power plant. From 1990 to September 1992 they were read manually with a multimeter.

To automate the reading of the thermistors, a system (Figure 9) was designed that consisted of a Campbell Scientific CR7 datalogger, eight multiplexers, and a Cyber Research industrial computer.

The thermistor strings were built with a 50-conductor connector on the end. CRREL supplied a 50-conductor cable with mating connector to bring the thermistor cable into the building and to the multiplexers. A hole was drilled in each of the external thermistor well enclosures and conduit was run from the well to the building. The thermistor extension cable was threaded through the conduit and into the building and wired to the multiplexer. Since each multiplexer is capable of handling 32 two-wire sensors and since the thermistor strings contain, at most, 24 sensors, a 0.01% precision 10K resistor was added to each multiplexer. This resistor allows checks of the system and, if needed, compensation for the lead resistance from the multiplexer to the datalogger. A completely wired multiplexer is shown in Figure 10.

Each multiplexer was mounted on the inside wall near the thermistor string, except for string T-7, which was mounted on a column nearest the string. The multiplexers were then connected to the datalogger by two cables, a 4-conductor 18-gauge data line and a 4-conductor 20-gauge control cable. These cables were on or under the side support beams for the walls. Several cables had to cross open spaces and were therefore suspended either from overhead beams or from lighting conduits.

The Campbell CR7 datalogger reads the thermistors once a day at midnight and stores both the thermistor resistance and the corresponding temperature. The datalogger program is included as

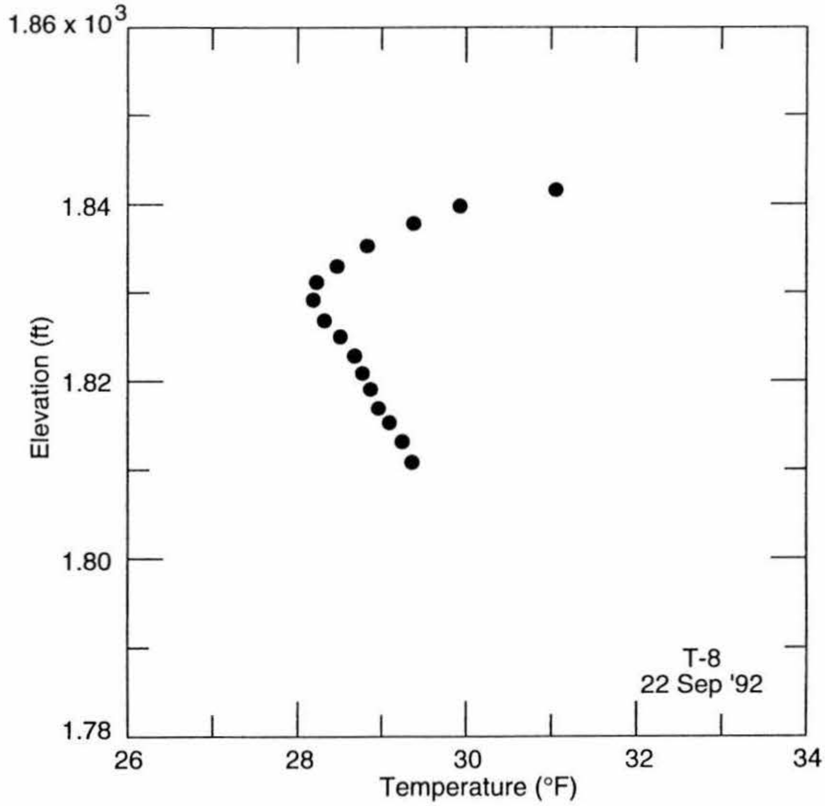

Figure 8. Temperature vs. elevation from string T-8 on 22 September 1992.

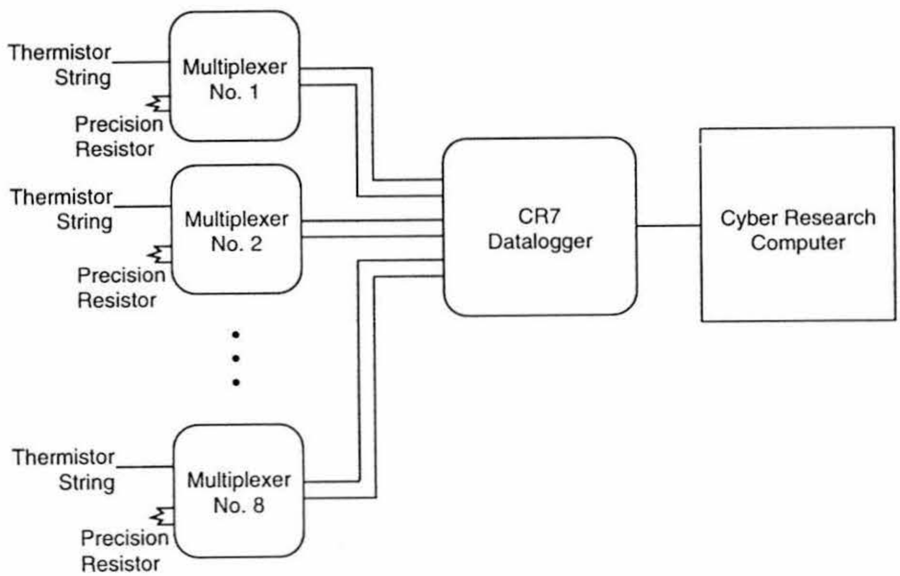

Figure 9. The data acquisition system.

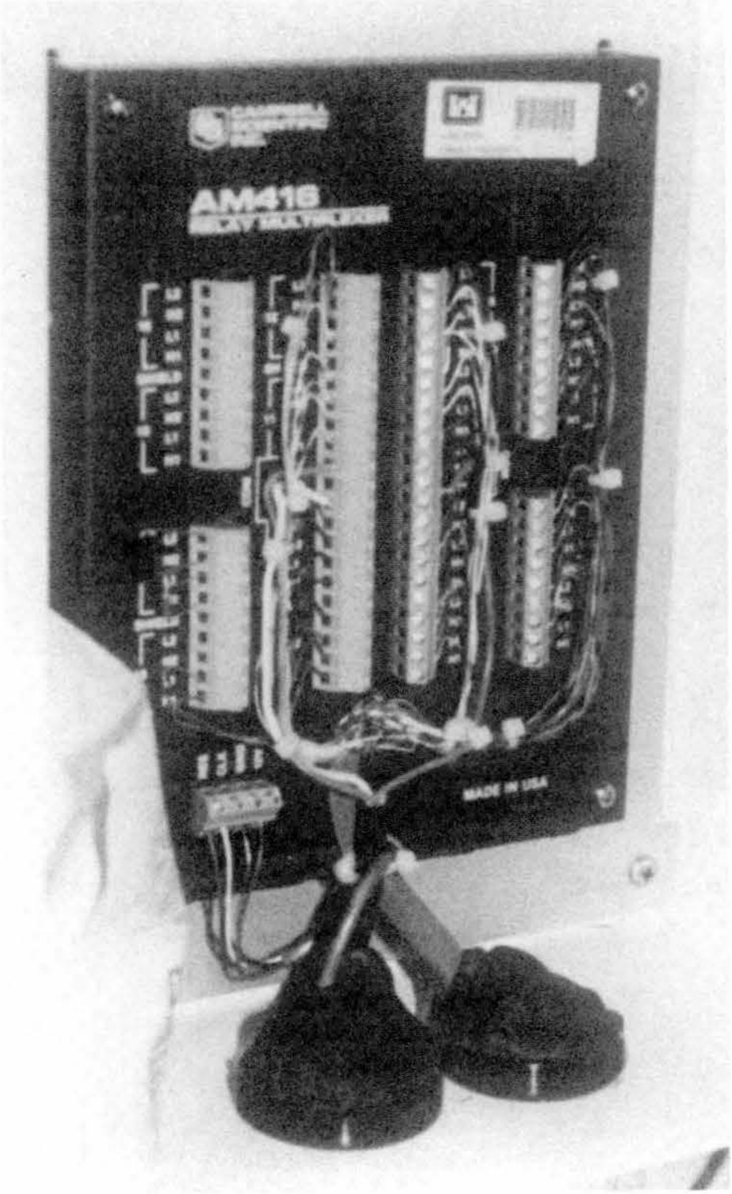

Figure 10. An installed relay multiplexer.

Appendix A to this manual; a specification sheet for the CR7 datalogger is available from the manufacturer.*

The datalogger is connected via a serial cable to the computer. The computer program (Appendix B) collects data from the datalogger and stores it, on both the internal hard disk and a removable floppy disk. The computer also displays the current readings for all eight strings in columns on the monitor. The computer system contains an analog I/O card to allow the future addition of a system to turn the active refrigeration system on automatically when it is needed.

At the present time the datalogger and computer collect data once every 24 hours. The datalogger has internal batteries in case of ac power failure. Commands in the computer's AUTOEXEC.BAT program restart the data collection program when the computer is powered up.

If the power is shut off for 6 weeks or more or if for some other reason the datalogger has been turned off, the datalogger will have to be reset. A program on the computer called TERM is used to set up the datalogger. The various command options are given in Table 3. The following steps are

*Campbell Scientific, Inc., P. O. Box 551, Logan, UT 84321.

Table 3. TERM options.

C—Call station GAKONA	M—Monitor input locations
T—Terminal emulator	R—Receive a file
D—Download program to datalogger	X—Transmit a file
S—Save program from datalogger	E—Edit station parameters
K—PC time to datalogger clock	Q—Quit
P—Create power-up Prom file	Option:

required to reset the datalogger:[*]

1. Exit the data collection program by typing

    Q

2. Type

    TERM GAKONA ¶

3. When the menu (Table 3) appears, type

    K

    to reset the datalogger clock. When asked if you want to reset the datalogger clock, type

    Y

4. After the clock is reset, type

    D

    to download the datalogger program from the computer. When asked for the file name, type

    GAKONA ¶

    The program will download; when it is finished, it will print

```
Downloading completed
```

Now press the Esc key to return to the menu. At the menu, type

    Q

5. Restart the data collection program by typing

    GAKONA ¶

    or resetting the computer.

[*]NOTE: All keystrokes are in uppercase letters and the Enter/Return key is represented by the symbol ¶.

SYSTEM OPERATION

Soil temperature observations

The data acquisition system was installed by CRREL in September 1992. It monitors soil temperatures from the eight thermistor strings as well as the inlet and outlet fluid temperatures for each Larkin refrigeration unit. The daily soil temperatures are all the data that are necessary for managing the operation of the hybrid thermosyphons.

Installation of the data acquisition system is expected to prolong the useful life of the thermistors as it makes it unnecessary to bend or twist the multiconductor cable, which would otherwise be required each time a manual reading was taken. In time, it would not be uncommon for some of the thermistors to give faulty readings or no readings at all.

Some of the thermistors are in critical locations: thermistors 5, 6, and 7 on strings T-7 and T-8 MUST provide accurate information, because their readings are used to determine when to turn the mechanical refrigeration on and off. They are located just beneath the 10-in. rigid board insulation. If these thermistors become faulty, as evidenced by an anomalous reading or no reading, THEY MUST BE REPLACED. If all three of these thermistors become faulty on one of the strings, the entire thermistor string should be replaced. New strings can be fabricated and installed by CRREL.

Alarm systems

In addition to turning the active refrigeration system on and off, the computer may also signal visual or audible alarms. For example, wires from the computer to a piezo alerting buzzer could constitute an alarm system. Buzzers could be located wherever they are needed. These buzzers can operate on 5 V dc. Such an alarm system could be easily installed in the future if it is required.

OPERATING PROCEDURES

Thermistor temperatures

The daily temperature readings from the thermistor strings should be analyzed once a month. This can be done at CRREL. The operator is responsible for sending a floppy disk of the temperature data from the computer to CRREL each month.

Particular attention should be given to the readings from July to October—this is a critical time of year when maximum thaw depths occur. If any of the readings from thermistors 5, 6, or 7 on strings T-7 and T-8 reach 32°F, the Larkin mechanical refrigeration units should be turned on. A 32°F temperature indicates that the gravel pad is thawing at that location, and the thaw depth may increase if the refrigeration is not turned on. Placing the hybrid thermosyphons in active mode will prevent an increase in the thaw depth. The mechanical refrigeration units should be kept on until all of these thermistor temperatures (5, 6, and 7 on T–7 and T–8) fall below 31.0°F.

Thermosyphon performance survey

It is important to know if each of the 55 thermosyphons is operating properly. A check should be made in the wintertime by observing that the finned condenser section is warmer than the ambient air. The surface temperature of the fins should be about 10°F warmer than the ambient air temperature for an air temperature on the order of 0°F. The fin temperature can be determined by using a thermistor or a thermocouple. A thermistor can be placed on the thermosyphon pipe just below the finned section. The operator can contact CRREL to learn how to attach and read the thermistor.

A faster and easier method of determining the fin temperature is to use an infrared thermal video camera. The resolution of these cameras is about ±4°F, which is adequate for a thermal survey. It is important that an annual thermal survey be done in the wintertime with an infrared video camera. CRREL has the equipment and the experience to perform this survey. Another easy method for measuring the temperature of the fins is to use an infrared spot radiometer.

If it is found that a thermosyphon is inoperable, the unit should be tested for leaks and recharged with refrigerant. If the thermosyphon does not pass the leak test, the unit must be "re-sleeved." This means placing a smaller-diameter (e.g., $2^1/_2$-in.) pipe in the existing 3-in. evaporator pipe, welding it to the condenser section, and charging it for normal hybrid operation. This testing and recharging could be done by Arctic Foundations, Inc. The operator can contact them by telephone at (907) 562–2741. There may also be other companies in Alaska that can do this work.

Visual inspections

It is necessary to perform monthly visual inspections of the thermosyphons, the thermistor string wells, and the refrigeration units and manifolds. These are all somewhat vulnerable to damage from snow plows, ice falling from the roof, and equipment working around the building. A comprehensive visual inspection should be done every May before exercising the refrigeration units. The operator is responsible for making sure that snow is not plowed around thermosyphons, thermistor wells, and refrigeration units.

SUMMARY

The following steps must be taken to ensure the integrity of the foundation system of the building:

- Check temperature readings from all eight thermistor strings every month.
- Send the data disk from the computer to CRREL each month.
- If thermistors 5, 6, or 7 on strings T-7 and T-8 give readings of 32°F or warmer, turn on the mechanical refrigeration units. Leave them on until these readings fall below 31°F.
- If any of thermistors 5, 6, or 7 on strings T-7 and T-8 becomes faulty, replace it.
- Visually inspect the thermosyphons, the thermistor wells, the refrigeration units, and the manifolds every month.
- Exercise the refrigeration units each year in May by turning them on for at least 5 days.
- Check all 55 thermosyphons annually to ensure that they are operating. This is easily done in the winter with an infrared thermal video camera. If an inoperable thermosyphon cannot pass a leak test, it must be re-sleeved.
- Keep all temperature data in readily accessible archives.

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Haynes, F.D. (1990) Final Report, OTH-B, An analysis of thermosyphons used for soil stabilization. U.S. Army CRREL Internal Report No. 1066.

Haynes, F.D., Zarling, J.P., Quinn, W.F. and G.E. Gooch (1991) Laboratory tests with a hybrid thermosyphon. In *Proceedings of the Offshore Mechanics and Arctic Engineering Symposium, Stavanger*, Vol. IV, p. 93–99.

APPENDIX A: GAKONA POWER PLANT DATALOGGER PROGRAM

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Program: Gakona 5©  Written 29 Sept 1992

Program to record temperatures from the Gakona Power plant.

Written by Kurt V. Knuth
U.S. Army CRREL
Copyright 1992

Program is for a Campbell CR7 Datalogger

Version 5, 29 Sept. 1992: Saves Temp and Ohms,
modified for multiple outputs

*      1     Table 1 Programs
   01:3600    Sec. Execution Interval

  01: P92      If time is
   01:0000     minutes into a
   02:1440     minute interval
   03:30       Then Do

  02: P30   Z=F
   01:2.00     F
   02:525      Z Loc:divisor for average of two readings

  03: P20   Set Port:Turn on Mux 1
   01:1        Set high
   02:1        EX Card
   03:1        Port Number

  04: P87   Beginning of Loop
   01:0000     Delay
   02:16       Loop Count

  05: P90   Step Loop Index
   01:2        Step

  06: P86   Do
   01:1        Call Subroutine 1

  07: P38   Z=X/Y
   01:520      X Loc
   02:525      Y Loc
   03:1--    Z Loc [:TS1 #1 ]

  08: P38   Z=X/Y
   01:521      X Loc
   02:525      Y Loc
   03:2--    Z Loc [:TS1 #2 ]

  09: P95   End
```

```
10: P20  Set Port:Turn off Mux 1
 01:0       Set low
 02:1       EX Card
 03:1       Port Number

11: P59  BR Transform Rf[X/(1-X)]:convert to ohms
 01:32       Reps
 02:1        Loc[:TS1 #1 ]
 03:10.0     Multiplier (Rf)

12: P34  Z=X+F
 01:28      X Loc
 02:-10.000 F
 03:526     Z Loc:

13: P87  Beginning of Loop
 01:0       Delay
 02:28      Loop Count

14: P35  Z=X-Y
 01:1--    X Loc
 02:526     Y Loc
 03:1--    Z Loc:

15: P95  End

16: P20  Set Port
 01:1       Set high
 02:1       EX Card
 03:2       Port Number

17: P87  Beginning of Loop
 01:0000    Delay
 02:16      Loop Count

18: P90  Step Loop Index
 01:2       Step

19: P86  Do
 01:1       Call Subroutine 1

20: P38  Z=X/Y
 01:520     X Loc
 02:525     Y Loc
 03:33-     Z Loc [:TS2 #1 ]

21: P38  Z=X/Y
 01:521     X Loc
 02:525     Y Loc
 03:34-     Z Loc [:TS2 #2 ]

22: P95  End
```

```
23: P20  Set Port
 01:0        Set low
 02:1        EX Card
 03:2        Port Number

24: P59  BR Transform Rf[X/(1-X)]
 01:32       Reps
 02:33       Loc[:TS2 #1 ]
 03:10.0     Multiplier (Rf)

25: P20  Set Port
 01:1        Set high
 02:1        EX Card
 03:3        Port Number

26: P87  Beginning of Loop
 01:0000     Delay
 02:16       Loop Count

27: P90  Step Loop Index
 01:2      Step

28: P86  Do
 01:1        Call Subroutine 1

29: P38  Z=X/Y
 01:520      X Loc
 02:525      Y Loc
 03:65-      Z Loc [:TS3 #1 ]

30: P38  Z=X/Y
 01:521      X Loc
 02:525      Y Loc
 03:66-      Z Loc [:TS3 #2 ]

31: P95  End

32: P20  Set Port
 01:0        Set low
 02:1        EX Card
 03:3        Port Number

33: P59  BR Transform Rf[X/(1-X)]
 01:32       Reps
 02:65       Loc[:TS3 #1 ]
 03:10.0     Multiplier (Rf)

34: P20  Set Port
 01:1        Set high
 02:1        EX Card
 03:4        Port Number

35: P87  Beginning of Loop
 01:0000     Delay
 02:16       Loop Count

36: P90  Step Loop Index
 01:2        Step

37: P86  Do
 01:1        Call Subroutine 1

38: P38  Z=X/Y
 01:520      X Loc
 02:525      Y Loc
 03:97-      Z Loc [:TS4 #1 ]

39: P38  Z=X/Y
 01:521      X Loc
 02:525      Y Loc
 03:98-      Z Loc [:TS4 #2 ]

40: P95  End

41: P20  Set Port
 01:0        Set low
 02:1        EX Card
 03:4        Port Number

42: P59  BR Transform Rf[X/(1-X)]
 01:32       Reps
 02:97       Loc[:TS4 #1 ]
 03:10.0     Multiplier (Rf)

43: P20  Set Port
 01:1        Set high
 02:1        EX Card
 03:5        Port Number

44: P87  Beginning of Loop
 01:0000     Delay
 02:16       Loop Count

45: P90  Step Loop Index
 01:2        Step

46: P86  Do
 01:1        Call Subroutine 1

47: P38  Z=X/Y
 01:521      X Loc
 02:525      Y Loc
 03:129-     Z Loc [:TS5 #1 ]
```

```
48: P38  Z=X/Y
 01:521     X Loc
 02:525     Y Loc
 03:130-    Z Loc [:TS5 #2 ]

49: P95  End

50: P20  Set Port
 01:0       Set low
 02:1       EX Card
 03:5       Port Number

51: P59  BR Transform Rf[X/(1-X)]
 01:32      Reps
 02:129     Loc[:TS5 #1 ]
 03:10.0    Multiplier (Rf)

52: P20  Set Port
 01:1       Set high
 02:1       EX Card
 03:6       Port Number

53: P87  Beginning of Loop
 01:0000    Delay
 02:16      Loop Count

54: P90  Step Loop Index
 01:2       Step

55: P86  Do
 01:1       Call Subroutine 1

56: P38  Z=X/Y
 01:520     X Loc
 02:525     Y Loc
 03:161-    Z Loc [:TS6 #1 ]

57: P38  Z=X/Y
 01:521     X Loc
 02:525     Y Loc
 03:162-    Z Loc [:TS6 #2 ]

58: P95  End

59: P20  Set Port
 01:0       Set low
 02:1       EX Card
 03:6       Port Number

60: P59  BR Transform Rf[X/(1-X)]
 01:32      Reps
 02:161     Loc[:TS6 #1 ]
 03:10.0    Multiplier (Rf)

61: P20  Set Port
 01:1       Set high
 02:1       EX Card
 03:7       Port Number

62: P87  Beginning of Loop
 01:0000    Delay
 02:16      Loop Count

63: P90  Step Loop Index
 01:2       Step

64: P86  Do
 01:1       Call Subroutine 1

65: P38  Z=X/Y
 01:520     X Loc
 02:525     Y Loc
 03:193-    Z Loc [:TS7 #1 ]

66: P38  Z=X/Y
 01:521     X Loc
 02:525     Y Loc
 03:194-    Z Loc [:TS7 #2 ]

67: P95  End

68: P20  Set Port
 01:0       Set low
 02:1       EX Card
 03:7       Port Number

69: P59  BR Transform Rf[X/(1-X)]
 01:32      Reps
 02:193     Loc[:TS7 #1 ]
 03:10.0    Multiplier (Rf)

70: P20  Set Port
 01:1       Set high
 02:1       EX Card
 03:8       Port Number

71: P87  Beginning of Loop
 01:0000    Delay
 02:16      Loop Count

72: P90  Step Loop Index
 01:2       Step

73: P86  Do
 01:1       Call Subroutine 1
```

```
74: P38  Z=X/Y
 01:520      X Loc
 02:525      Y Loc
 03:225-     Z Loc [:TS8 #1 ]

75: P38  Z=X/Y
 01:521      X Loc
 02:525      Y Loc
 03:226-     Z Loc [:TS8 #2 ]

76: P95  End

77: P20  Set Port
 01:0        Set low
 02:1        EX Card
 03:8        Port Number

78: P59  BR Transform Rf[X/(1-X)]
 01:32       Reps
 02:225      Loc[:TS8 #1 ]
 03:10.0     Multiplier (Rf)

79: P87  Beginning of Loop
 01:0        Delay
 02:256      Loop Count

80: P40  Z=LN(X)
 01:1-     X Loc TS1 #1
 02:522      Z Loc [:LN(Ohms)]

81: P55  Polynomial
 01:1        Rep
 02:522      X Loc
 03:522      F(X) Loc:[:SteinHart]
 04:29.462  C0
 05:2.5154  C1
 06:.00351  C2
 07:.00524  C3
 08:0.0000  C4
 09:-.00010 C5

82: P37  Z=X*F
 01:522      X Loc
 02:.00010   F
 03:522      Z Loc:[:Corrected value]

83: P42  Z=1/X
 01:522      X Loc
 02:522      Z Loc:[:Now T Kelvin]

84: P34  Z=X+F
 01:522      X Loc
 02:-273.15 F
 03:523      Z Loc:[Now T C]

85: P37  Z=X*F:Convert to F
 01:523      X Loc
 02:1.8      F:C * 1.8
 03:523      Z Loc:[:C * 1.8]

86: P34  Z=X+F
 01:523      X Loc
 02:32.0     F
 03:257-     Z Loc:[:Store T F]

87: P95  End

88: P17  Panel Temperature
 01:1        IN Card
 02:513      Loc:logger temp

89: P10  Battery Voltage
 01:514      Loc:Battery Voltage

90: P86  Do
 01:10       Set high Flag 0 (output)

91: P77  Real Time
 01:1110     Year,Day,Hour-Minute

92: P70  Sample
 01:24       Reps
 02:257      Loc

93: P70  Sample
 01:24       Reps
 02:289      Loc

94: P70  Sample
 01:24       Reps
 02:321      Loc

95: P70  Sample
 01:24       Reps
 02:353      Loc

96: P70  Sample
 01:24       Reps
 02:385      Loc

97: P70  Sample
 01:24       Reps
 02:417      Loc

98: P70  Sample
 01:24       Reps
 02:449      Loc
```

```
99: P70  Sample
 01:24      Reps
 02:481     Loc

100: P86 Do
 01:20      Set low Flag 0 (output)

101: P86 Do
 01:10      Set high Flag 0 (output)

102: P78 Resolution
 01:1       High Resolution

103: P70 Sample
 01:32      Reps
 02:24      Loc

104: P70 Sample
 01:24      Reps
 02:33      Loc TS2 #1

105: P70 Sample
 01:24      Reps
 02:65      Loc TS3 #1

106: P70 Sample
 01:24      Reps
 02:97      Loc TS4 #1

107: P70 Sample
 01:24      Reps
 02:129     Loc TS5 #1

108: P70 Sample
 01:24      Reps
 02:161     Loc TS6 #1

109: P70 Sample
 01:24      Reps
 02:193     Loc TS7 #1

110: P70 Sample
 01:24      Reps
 02:225     Loc TS8 #1

111: P70 Sample
 01:2       Reps
 02:513     Loc

112: P95 End

113: P   End Table 1

*      2   Table 2 Programs
 01:0.0000 Sec. Execution Interval

01: P    End Table 2

*      3   Table 3 Subroutines
01: P85 Beginning of Subroutine
 01:1       Subroutine Number

02: P22 Excitation with Delay:Clock Mux
 01:1       EX Card
 02:1       EX Chan
 03:1       Delay w/EX (units=.01sec)
 04:1       Delay after EX (units=.01sec)
 05:5000    mV Excitation

03: P4  Excite,Delay,Volt(SE):read therms
 01:2       Reps
 02:6       500 mV slow Range
 03:1       IN Card
 04:1       IN Chan
 05:1       EX Card
 06:2       EX Chan
 07:2       Meas/EX
 08:50      Delay (units .01sec)
 09:500     mV Excitation
 10:520     Loc:+readings
 11:.0020   Mult
 12:0.0000  Offset

04: P4  Excite,Delay,Volt(SE)
 01:2       Reps
 02:6       500 mV slow Range
 03:1       IN Card
 04:1       IN Chan
 05:1       EX Card
 06:2       EX Chan
 07:2       Meas/EX
 08:50      Delay (units .01sec)
 09:-500    mV Excitation
 10:522     Loc:-readings
 11:-.002   Mult
 12:0.0000  Offset

05: P33 Z=X+Y
 01:520     X Loc
 02:522     Y Loc
 03:520     Z Loc:sum the two readings

06: P33 Z=X+Y
 01:521     X Loc
 02:523     Y Loc
 03:521     Z Loc:sum the two readings
```

```
07: P95   End

08: P     End Table 3

*      4  Mode 4 Output Options
 01:00        Tape/Printer Option
 02:00        Printer Baud Option
```

```
*      A  Mode 10 Memory Allocation
   01:600     Input Locations
   02:1800    Intermediate Locations

*      C  Mode 12 Security
   01:00      Security Option
   02:0000    Security Code
```

```
Input Location Assignments (with comments):

Key:
T=Table Number   E=Entry Number   L=Location Number

T: E: L:
1: 7:  1:  Z Loc [:TS1 #1 ]
1:11:  1:  Loc [:TS1 #1 ]
1:14:  1:  Z Loc:
1: 8:  2:  Z Loc [:TS1 #2 ]
1:20: 33:  Z Loc [:TS2 #1 ]
1:24: 33:  Loc [:TS2 #1 ]
1:21: 34:  Z Loc [:TS2 #2 ]
1:29: 65:  Z Loc [:TS3 #1 ]
1:33: 65:  Loc [:TS3 #1 ]
1:30: 66:  Z Loc [:TS3 #2 ]
1:38: 97:  Z Loc [:TS4 #1 ]
1:42: 97:  Loc [:TS4 #1 ]
1:39: 98:  Z Loc [:TS4 #2 ]
1:47:129:  Z Loc [:TS5 #1 ]
1:51:129:  Loc [:TS5 #1 ]
1:48:130:  Z Loc [:TS5 #2 ]
1:56:161:  Z Loc [:TS6 #1 ]
1:60:161:  Loc [:TS6 #1 ]
1:57:162:  Z Loc [:TS6 #2 ]
1:65:193:  Z Loc [:TS7 #1 ]
1:69:193:  Loc [:TS7 #1 ]
1:66:194:  Z Loc [:TS7 #2 ]
1:74:225:  Z Loc [:TS8 #1 ]
1:78:225:  Loc [:TS8 #1 ]
1:75:226:  Z Loc [:TS8 #2 ]
1:86:257:  Z Loc [:Store T F]
1:88:513:  Loc:logger temp
1:89:514:  Loc:Battery Voltage
3: 3:520:  Loc:+readings
3: 5:520:  Z Loc:sum the two readings
3: 6:521:  Z Loc:sum the two readings
1:80:522:  Z Loc:[:LN(Ohms)]
1:81:522:  F(X) Loc:[:SteinHart]
1:82:522:  Z Loc:[:Corrected value]
1:83:522:  Z Loc:[:Now T Kelvin]
3: 4:522:  Loc:-readings
1:84:523:  Z Loc:[Now T C]
1:85:523:  Z Loc:[:C * 1.8]
1: 2:525:  Z Loc:divisor for average of two readings
1:12:526:  Z Loc:
```

APPENDIX B: GAKONA DATA ACQUISITION PROGRAM

```
'Gakona program

DECLARE SUB SCRNOUT ()
DECLARE SUB PROCESS ()
DECLARE SUB getdata ()
DIM temp(10,25)
DIM flag(10)
COMMON SHARED flag()
COMMON SHARED temp()



SCREEN 0
WIDTH 80,25

COLOR 7,0,0
CLS

FORi=0 TO 9
   flag(i)=0
NEXTi

PRINT "Starting collect data at"; TIME$,DATE$
DO
   a$=TIME$
   hr=VAL(LEFT$(a$, 2))
   min=VAL(MID$(a$, 4, 2))
   sec=VAL(RIGHT$(a$, 2))

   IF(INKEY$="Q") THEN EXIT DO

   IF flag(1)=0 AND hr=1 AND min=30 THEN
      CALL getdat
      CALL PROCESS
      CALL SCRNOUT
   END IF
   IF flag(1)=1 AND (min=45) THEN flag(1)=0

   LOOP

END

SUB getdata
   CLS
   SCREEN 0
   WIDTH 80,25
   CLS
   SHELL "TELCOM gakona/C"
   flag(1)=1
END SUB
```

```
SUB PROCESS
   CLS
   SCREEN 0
   WIDTH 80,25
   CLS
   SHELL "copy gakona.dat gakona.bak"
   SHELL "copy gakona.all d:\gakona.sav"
   SHELL "copy gakona.all+gakona.dat gakona.tst"
   SHELL "copy gakona.tst gakona.all"
   SHELL "copy gakona.all a:"
   SHELL "split gakona1/r"
   SHELL "split gakona2/r"
   SHELL "split gakona3/r"
   SHELL "split gakona4/r"
   SHELL "split gakona5/r"
   SHELL "split gakona6/r"
   SHELL "split gakona7/r"
   SHELL "split gakona8/r"
   SHELL "DEL gakona.dat"

END SUB

SUB SCRNOUT

   OPEN "string1.prn" FOR INPUT AS #1
   IF LOF(1)<100 THEN GOTO done
   INPUT #1, yr, day, time
   FORi=1 TO 24
      INPUT #1, temp(1,i)
   NEXTi
   CLOSE #1

   OPEN "string2.prn" FOR INPUT AS #1
   IF LOF(1)<100 THEN GOTO done
   INPUT #1, yr, day, time
   FORi=1 TO 24
      INPUT #1, temp(2,i)
   NEXTi
   CLOSE #1

   OPEN "string3.prn" FOR INPUT AS #1
   IF LOF(1)<100 THEN GOTO done
   INPUT #1, yr, day, time
   FORi=1 TO 24
      INPUT #1, temp(3,i)
   NEXTi
   CLOSE #1

   OPEN "string4.prn" FOR INPUT AS #1
   IF LOF(1)<100 THEN GOTO done
   INPUT #1, yr, day, time
   FORi=1 TO 24
      INPUT #1, temp(4,i)
   NEXTi
```

```
CLOSE #1

OPEN "string5.prn" FOR INPUT AS #1
IF LOF(1)<100 THEN GOTO done
INPUT #1, yr, day, time
FORi=1 TO 24
   INPUT #1, temp(5,i)
NEXTi
CLOSE #1

OPEN "string6.prn" FOR INPUT AS #1
IF LOF(1)<100 THEN GOTO done
INPUT #1, yr, day, time
FORi=1 TO 24
   INPUT #1, temp(6,i)
NEXTi
CLOSE #1

OPEN "string7.prn" FOR INPUT AS #1
IF LOF(1)<100 THEN GOTO done
INPUT #1, yr, day, time
FORi=1 TO 24
   INPUT #1, temp(7,i)
NEXTi
CLOSE #1

OPEN "string8.prn" FOR INPUT AS #1
IF LOF(1)<100 THEN GOTO done
INPUT #1, yr, day, time
FORi=1 TO 24
   INPUT #1, temp(8,i)
NEXTi
CLOSE #1

done:
CLOSE #1

CLS
SCREEN 0
WIDTH 80,43

CLS
PRINT" Temperatures at "; time; " Hours on "; DATE$

PRINT"————————————————————————————————"

FORi=1 TO 24
   IFi=6 THEN
   COLOR 9
   PRINT " 00000000000000000000000000 BLUE  BOARD
00000000000000000000000000"
   END IF
   COLOR 7
   PRINT USING "## "; i;
```

```
      FORj=1 TO 8
         COLOR 7
         IFi>7 THEN
            IF temp(j, i)>30.01 THEN COLOR 14
            IF temp(j, i)>31.2 THEN COLOR 20
         END IF
         PRINT USING "+###.#  "; temp(j, i);
      NEXTj
      PRINT
   NEXTi

END SUB
```

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A power plant building was constructed in 1990 at an over-the-horizon radar site in Gakona, Alaska. Since it was built on permafrost, thermal protection between the building and the underlying permafrost was included in the design, which included rigid board insulation and hybrid thermosyphons placed in the gravel fill under the building. Soil temperature is monitored with eight thermistor strings placed under and at the building perimeter. This manual describes the steps that must be taken to ensure foundation stability, including directions on when to use the thermosyphons in the active, mechanical refrigeration mode. A data acquisition system using a computer-controlled datalogger is described.

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