ENERGY

CONSERVATION

ORNL/Sub/85-22035/1

Field Performance Validation of an Advanced Design Earth-Coupled Heat Pump System

P. J. Hughes
R. J. Hackner

Report Prepared by

W. S. FLEMING AND ASSOCIATES, INC.
6310 Fly Road
E. Syracuse, New York 13057

under
Subcontract 86X-22035

for

NIAGARA MOHAWK POWER CORPORATION
and
OAK RIDGE NATIONAL LABORATORY
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the

U.S. DEPARTMENT OF ENERGY

OFFICE OF BUILDINGS AND COMMUNITY SYSTEMS

ORNL/Sub/85-22035/1

FIELD PERFORMANCE VALIDATION OF AN ADVANCED DESIGN EARTH-COUPLED HEAT PUMP SYSTEM

P. J. Hughes
R. J. Hackner

Date of Issue—January 1988

Report Prepared by

W. S. FLEMING AND ASSOCIATES, INC.
6310 Fly Road
E. Syracuse, New York 13057

under
Subcontract 86X-22035

for

NIAGARA MOHAWK POWER CORPORATION
and
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract DE-AC05-84OR21400

ACKNOWLEDGMENTS

The Project Manager, Richard J. Hackner, under the direction of Patrick J. Hughes, P.E., wishes to thank the cosponsors, the U.S. Department of Energy via Oak Ridge National Laboratory and Niagara Mohawk Power Corporation for their support. Niagara Mohawk provided day-to-day management via Richard A. O'Neil, P.E. Oak Ridge provided technical direction via E.A. Vineyard, and Van Baxter. Special thanks also go to Michael Hughes, Director of Engineering at Climate Master, Inc. of Utica, NY, and Mark Catan of Brookhaven National Laboratory for their cooperation at project initiation.

The contributions of W.S. Fleming staff members were as follows:

Richard J. Hackner	- Project Manager
Patrick J. Hughes	- Line Management of Engineering Analysis and Computer Services
Wayne E. Clark	- Line Management of Engineering Design and Field Services
Brad Hesse	- Field Services and Instrumentation
Mike Clarkin	- Computer Services
Betsy Hoeft	- Preparation of Reports

ABSTRACT

Oak Ridge National Laboratory, Niagara Mohawk Power Corporation, and W.S. Fleming and Associates, Inc. conducted a field-test program to evaluate prototype earth-coupled heat pump systems in two upstate New York homes. Each site utilized a prototype liquid-source heat pump designed specifically for the earth-coupled application. One-pipe and two-pipe-per-trench earth coils were used.

The results show that the prototype heat pumps provided efficient operation at source temperatures as low as 27°F, enabling significantly shorter earth loops to be installed. Earth loop cost savings were greater than the increased cost of the heat pump over standard models, resulting in a net decrease in overall system installed cost.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Background

Collaborative research has been simultaneously pursued by Niagara Mohawk Power Corporation (NMPC), and by Oak Ridge National Laboratory (ORNL) under the sponsorship of the U.S. Department of Energy, to develop, field-validate, and commercialize earth-coupled heat pump (ECHP) technology. NMPC in a series of projects from 1982 to 1987 undertook a field-test program to establish the actual performance of state-of-the-art existing ECHP technology; to develop design, materials, and installation acceptable practices; and to transfer the applications technology to the commercial sector including equipment manufacturers and installation contractors. ORNL from 1984 through 1987 undertook an earth loop model development program which supported NMPC's design development efforts.

ORNL, Brookhaven National Laboratory (BNL), and a manufacturer also developed an advanced water-source heat pump (WSHP) designed specifically for the earth-coupled application. Results of the analytical phase of this effort were sufficiently positive to warrant prototype development and follow-on laboratory and field evaluation. Laboratory testing was performed at BNL and by the manufacturer.

This report documents the results of a 12-month field-test of two advanced design ECHP systems based on the prototype WSHPs. The test sites were in the NMPC service territory near Syracuse, New York. The test was cosponsored by the U.S. Department of Energy (via ORNL), and NMPC, and was implemented by W.S. Fleming and Associates, Inc.

Objective

The objective of this project was to field-validate analytical predictions that the prototype heat pumps would provide seasonal performance similar to existing technology, while lowering the earth loop length requirement by approximately 30 percent.

The Advanced WSHP Design

The design differences between the advanced and standard WSHPs are summarized below:

- Oversized Heat Exchangers - The advanced unit uses oversized evaporator and condensor coils to provide additional heat transfer area, thus, allowing the heat pump to operate efficiently at low source temperatures.

- High-Efficiency Compressor - The high-efficiency compressor used in the advanced unit improved heat pump efficiency over the entire range of operating conditions.

- Start Assist - The advanced unit is equipped with a positive temperature coefficient varistor which provides better starting torque.

- Freeze Thermostat - Since the advanced unit operates at low source temperatures, freeze protection thermostats with a cutout temperature of 18°F are used.

Methodology

Two sites were selected based on technical requirements including house load compared to heat pump size, existence of forced air systems, sufficient room for heat pump and monitoring equipment, electrical service size, soil conditions, proximity to Syracuse, occupancy, and cooperativeness of homeowners. Application design specifications were written and the installation contractor selected. A formal Data Acquisition and Analysis Plan was developed. A Field Data Acquisition System (FDAS) was then specified and procured. Installation of the ECHP systems was closely supervised to assure proper sensor installation.

The FDAS was installed, de-bugged, and data collection began. During the 12-month monitoring period, routine data collection, analysis, and reporting functions were performed. At the end of data collection, the FDAS was removed, the prototype heat pumps were replaced by their commercial counterparts, and the sites were restored.

Monthly and seasonal data reports were produced, and all results are summarized in this final report. Analysis based on project experience and previously developed models was performed to generalize site-specific results.

Results

Heating Seasonal Coefficients of Performance (SCOPs) at the two sites were 2.74 (Site 10) and 2.90 (Site 11). The lower value at Site 10 was the result of the unit operating with low refrigerant charge for a period of time. Heating Seasonal Performance Factors (SPFs) were 2.70 and 2.71. The unit with the higher SCOP (Site 11) had a higher thermal load and higher use of auxiliary electric resistance heat causing the equalization in SPFs. Cooling Seasonal Energy Efficiency Ratios (SEERs) for the two sites were 11.92 (Site 10) and 11.32 (Site 11). Cooling hours were limited (38 hours at Site 10 and 362 hours at Site 11) due to a short cooling season in upstate New York.

These results from the field tests indicate that the project did indeed meet its stated objective. Previous tests of existing technology based systems yielded heating SPFs of 2.5 - 3.0 with earth loop sizes of 450 - 460 trench ft/ton (1 pipe/trench) (P. Hughes, 1985). The advanced systems achieved heating SPFs of about 2.7 with earth loops of 282 trench ft/ton (Site 10, 1 pipe/trench) and 183 trench ft/ton (Site 11, 2 pipe/trench). Similarily, cooling SEERs for existing technology ranged from 10.5 - 11.7 compared to 11.3 - 11.9 for the advanced systems.

Conclusions

Analysis of the field data from this project and simulations with previously developed models were performed in order to address the impact of the advanced WSHP on ECHP system design, operation and maintenance, performance, economics, and utility impact in an Upstate New York climate.

ECHP System Design. Normalized performance analyses indicated that, for equivalent minimum source temperatures, the advanced WSHP design could achieve significantly higher performance than standard WSHP designs. For example, the advanced 3-ton WSHP achieves a heating SPF of 2.8 compared to a standard 3-ton WSHP heating SPF of 2.1 at a 25°F minimum source temperature. This performance advantage can be sacrificed in favor of lower installed cost by reducing the earth loop length or by reducing the WSHP size.

For very small earth loops with minimum source temperatures below 25°F, the performance advantage of the advanced WSHP over the standard WSHP increases. However, the incremental benefit of sizing for minimum source temperatures below 25°F is small and increases the risk of experiencing soil problems.

Normalized performance analyses also indicated that, for equivalent heating SPF in a standard house in Syracuse, the advanced WSHP can be sized at 2.0-tons whereas the standard WSHP needs to be sized at 3.5-tons. Under this condition, the advanced 2.0-ton WSHP requires an earth loop only 40 percent as long as that needed by the standard 3.5-ton WSHP.

The above specific example is not a general rule for sizing earth loops to the advanced WSHP. WSHP manufacturers serving the ECHP market usually provide analytical methods for determining the minimum earth loop size required for specific applications. It is recommended that these manufacturer methods be utilized when available because they do a custom calculation for the specific site loads, conditions, and heat pump characteristics, and hence arrive at the most closely sized earth loop.

Contractor rules of thumb are often utilized locally once experience has established practical design values (P.J. Hughes, May 1986). For example, for heavy dry soil in New York State a one-pipe horizontal earth loop requires 405 trench feet/ton, and a two-pipe side-by-side horizontal earth loop requires 251 trench feet/ton to achieve SPFs of 2.5-3.0 with a standard WSHP. This project successfully demonstrated SPFs of 2.7 with advanced WSHPs with 30 percent less one-pipe loop, and 27 percent less two-pipe loop. This is the basis for the general statement that the advanced WSHP does indeed provide similar performance with 30 percent less earth loop.

Operation and Maintenance. No operation and maintenance differences were noted between the advanced and standard systems.

Performance. The normalized performance analysis showed that the advanced 3-ton ECHP system achieves heating SPFs in the range of 2.5 to 2.8 for a standard house in Syracuse, compared to 2.1 to 2.4 for standard 3-ton systems under the same design and operating conditions of which the minimum source temperature of 25°F is most critical. Similarly, the advanced ECHP achieves cooling SEERs in the range of 11 to 12, compared to 10 to 10.5 for the standard systems.

Economics. The advanced WSHP enhances the competitiveness of ECHP systems. Payback of the advanced 3-ton WSHP versus the standard 3-ton WSHP is 3.5 years at a 25°F minimum source temperature. The advanced 3-ton WSHP lowers the payback of ECHP systems versus standard 2.5-ton air source heat pumps (ASHP) from 5.9 years to 4.6 years at a 25°F minimum source temperature. These paybacks can be improved by trading away the performance advantage of advanced WSHPs relative to standard WSHPs for lower installed cost.

Utility Impact. The advanced 3-ton WSHP provides a total diversified electric demand advantage of approximately 0.9 kW/ton over the standard 3-ton WSHP. If the advanced WSHP and earth loop is downsized for improved homeowner economics, the demand advantage is traded away. Compared to standard 2.5-ton air source heat pumps (ASHP), the advanced 2.5-ton WSHP provides a total diversified electric demand advantage of approximately 1.7 kW/ton.

Recommendations

The major barrier to widespread application of earth-coupled heat pump systems remains the installed cost of the earth loop. Additional efforts recommended to reduce this cost are:

- Improved installation techniques.
- Development of specialized tools or equipment to simplify and automate the installation process.
- Evaluation of new loop configurations for their applicability in various geographic locations and geological conditions.

Section 1
INTRODUCTION

1.1 OVERVIEW

From the viewpoint of a homeowner in the northern United States climate regions, an earth-coupled heat pump (ECHP) offers the advantage of air conditioning in the cooling season and cost savings during the heating season when compared with any other electric or fossil-fuel heating system. From the viewpoint of a winter peaking electric utility such as Niagara Mohawk Power Corporation (NMPC), earth-coupled heat pumps offer the potential of increased electricity sales primarily at times not coincident with the system peak and are, therefore, good candidates for development by the utility.

Collaborative research has been simultaneously pursued by NMPC, and by Oak Ridge National Laboratory (ORNL) under the sponsorship of the U.S. Department of Energy, to develop, field-validate, and commercialize earth-coupled heat pump (ECHP) technology. NMPC in a series of projects from 1982 to 1987 undertook a field-test program to establish the actual performance of state-of-the-art existing ECHP technology: to develop design, materials, and installation acceptable practices; and to transfer the applications technology to the commercial sector including equipment manufacturers and installation contractors. ORNL from 1984 to 1987 undertook an earth loop model development program which supported NMPC's design development efforts.

ORNL, Brookhaven National Laboratory (BNL), and a manufacturer also developed an advanced water-source heat pump (WSHP) designed specifically for the earth-coupled application. Results of the analytical phase of this effort were sufficiently positive to warrant prototype development and follow-on laboratory and field evaluation. Laboratory testing was performed at BNL and by the manufacturer.

This report documents the results of a 12-month field-test of two advanced design ECHP systems based on the prototype WSHPs. The test sites were in the NMPC service territory near Syracuse, New York. The test was co-sponsored by the U.S. Department of Energy (via ORNL), and NMPC, and was implemented by W.S. Fleming and Associates, Inc.

1.2 OBJECTIVE

The objective of this project was to field-validate analytical predictions that the prototype heat pumps would provide seasonal performance similar to existing technology, while lowering the earth loop length requirement by approximately 30 percent.

1.3 SCOPE

Two sites were selected based on technical requirements including house load compared to heat pump size, existance of forced air systems, sufficient room for heat pump and monitoring equipment, electrical service size, soil conditions, proximity to Syracuse, occupancy, and cooperativeness of homeowners. Application design specifications were written and the installation contractor selected. A formal Data Acquisition and Analysis Plan was developed. A Field Data Acquisition System (FDAS) was specified and procured. Installation of the ECHP systems was closely supervised to assure proper sensor installation.

The FDAS was installed, de-bugged, and data collection begun. During the 12-month monitoring period, routine data collection, analysis, and reporting functions were performed. At the end of data collection, the FDAS was removed, the prototype heat pumps were replaced by their commercial counterparts, and the sites were restored.

Monthly and seasonal data reports were produced, and all results are summarized in this final report.

1.4 REPORT ORGANIZATION

Subsequent sections treat methodology, site and system characteristics, results, prototype vs. standard system comparisons, and conclusions and recommendations, respectively.

Section 2
METHODOLOGY

2.1 PROTOTYPE BACKGROUND

Oak Ridge National Laboratory, Brookhaven National Laboratory, and a manufacturer, under the sponsorship of the U.S. Department of Energy, undertook the development of an advanced ECHP system where the water-source heat pump (WSHP) and earth loop were designed in concert. The project consisted of separate phases for analytical work, laboratory testing of prototypes, and field-testing of prototypes. This report documents the latter activity. Brief overviews of the previous phases are provided below.

2.1.1 Analytical Phase

Elements of the analytical phase are documented in detail elsewhere (Catan and Baxter, 1985), (H.M. Hughes, 1985) and (Baxter, Catan, H.M. Hughes, P.J. Hughes, O'Neil, 1987). A brief overview is provided below.

An analytical exercise was undertaken to minimize the life-cycle cost (LCC) for an ECHP system given the freedom to design the WSHP and the earth loop in concert. In order to undertake this optimization analysis, several computer models were developed for the performance and cost analysis of ECHP systems.

The system was "optimized" by determining the values of a limited set of design variables for which the lowest LCC was predicted. The design analysis was limited to a single pipe horizontal earth loop system for a typical 3-ton house in Pittsburgh, PA. There were five WSHP design variables: (1) compressor displacement, (2) air coil characteristics, (3) water coil characteristics, (4) air flow, and (5) liquid flow. The only earth loop design variable was trench length.

The six design variables were automatically altered by a constrained function minimizing program to find the combination of parameters which yielded the lowest LCC considering both installed cost and operating costs. Then a "buildable" version of the optimized system was identified by selecting commercially-available components with characteristics matching the optimized characteristics as closely as possible. Table 2-1 summarizes the physical characteristics of the commercially-available, optimized, and "buildable" WSHPs.

The "buildable" optimized <u>system</u> consists of a heat pump with larger heat exchangers and an earth loop which is roughly 30 percent shorter than conventional systems. The improvements to the WSHP add about $110 to its construction cost, or about $275 to its installed cost. The 30 percent trench length savings is relative to the typical 400-ft/ton rule of thumb for 1 pipe-per-trench systems. Evidence exists that this thumb rule is conservative to begin with (Hackner, et.al., 1987), but assuming that 280 ft/ton is acceptable solely as a result of the WSHP redesign, at New York State prices of $2/trench foot, a savings of $720 results on a 3-ton earth loop.

Table 2-1

CHARACTERISTICS OF THE COMMERCIALLY-AVAILABLE, OPTIMIZED, AND "BUILDABLE" WATER-SOURCE HEAT PUMPS

	Commercially-Available Heat Pump	Optimized System	Buildable Optimized System
Compressor displacement, in^3 (cm^3)	3.27 (53.6)	3.419 (56.0)	3.27 (53.6)
Air Coil:			
Face area, ft^2 (m^2)	3.33 (0.309)	5.19 (0.493)	5.00 (0.465)
Tube rows	3	4	4
Circuits	4	4	4
Fin pitch, fins/in (fins/cm)	14 (5.51)	14 (5.51)	14 (5.51)
Fin thickness, in (mm)	0.0045 (0.114)	0.005 (0.140)	0.005 (0.140)
Water coil:			
Shell I.D., in (cm)	1.388 (3.53)	1.683 (4.27)	1.584 (4.01)
Length, in (m)	168 (4.27)	207.8 (5.28)	210 (5.33)
Air flow, cfm (L/s)	1250 (566)	936 (442)	1000 (452)
Liquid flow, lb/hr (kg/hr)	4700 (213)	3263 (1480)	3600 (1633)

The WSHP increase and earth loop decrease amount to a $445 decrease in installed cost on a 3-ton system. These analytical results were sufficiently positive to warrant prototype development and follow-on laboratory and field evaluations.

2.1.2 Laboratory Test Phase

Two prototypes of the "buildable" optimized nominal 3-ton WSHP were constructed by the manufacturer. The first prototype was laboratory-tested at Brookhaven National Laboratory to determine steady-state performance at several operating conditions. Results of these tests along with performance model predictions from the analytical phase of the project are given in Table 2-2 (a).

The second prototype was tested at ARI 325 standard conditions by the manufacturer. Rated performance from these tests is given in Table 2-2 (b) with the analytical phase model predictions.

In both cases, test results and analyses showed reasonably good agreement.

2.2 EXPERIMENTAL DESIGN

Both 3-ton prototypes were installed in existing residences near Syracuse, New York. A monthly bin analysis method developed previously in work sponsored by Niagara Mohawk Power Corporation, New York State Energy Research and Development Authority, and Rochester Gas and Electric Corporation (Hackner, et.al., 1987, Hughes, et.al., 1987) was utilized to size earth loops to the prototype units as applied to the two residences.

One site was designed with a one-pipe-per-trench horizontal earth loop, the other with a two-pipe-per-trench horizontal earth loop. In each case the loops were designed for a minimum source temperature of 25°F. The intent behind using 2 earth loop configurations was to verify that the prototype heat pump allows shorter single and multi-pipe earth loops.

Each site was fully instrumented as described in Section 2.4. Hourly data was collected for one heating season and one cooling season at a level of detail sufficient to establish performance factors and loads. Forcing functions (e.g., ambient temperature, far-field earth temperature, etc.) were also monitored to allow predictions of how other systems would have operated under the same conditions.

2.3 SITE SELECTION

This section outlines the methods and criteria used to select the two homes to be used in the field test. Several major pass/fail criteria for satisfaction of project objectives were established, along with considerations which would affect ease and cost of installation. A site survey form, incorporating the criteria, was developed for the collection of house and yard information. Eleven sites were surveyed and two were selected based on the survey results.

Table 2-2
PROTOTYPE HEAT PUMP LABORATORY
TEST RESULTS COMPARED WITH ANALYTICAL PREDICTIONS

a) Measured vs. Predicted Performance of the First Prototype (Brookhaven National Laboratory Tests)

Mode	Entering[a] Water Temp. °F(°C)	Entering[b] Air Temp. °F(°C)	Capacity Measured Btuh (kW)	Capacity Predicted Btuh (kW)	COP[c] Measured	COP[c] Predicte
Heating	49.5 (9.7)	78 (25.6)	40,000 (11.7)	37,900 (11.1)	3.60	3.62
	41.8 (5.4)	79 (26.1)	35,600 (10.4)	33,400 (9.8)	3.34	3.42
Cooling	88.1 (31.2)	75 (23.9)	35,300 (10.3)	36,100 (10.6)	3.07	3.30
	103.2 (3.0)	75 (23.9)	32,900 (9.6)	33,500 (9.8)	2.62	2.80

[a] 9 gpm (0.6 L/s)
[b] 1100 cfm (497 L/s)

b) Measured vs. Predicted Performance of the Second Prototype (Manufacturer Tests at ARI 325 Rating Conditions)

Mode	Entering[a] Water Temp. °F(°C)	Entering[b] Air Temp. °F(°C)	Capacity Measured Btuh (kW)	Capacity Predicted Btuh (kW)	COP[c] Measured	COP[c] Predicte
Heating	50 (10)	70 (21.1)	38,900 (11.4)	39,900 (11.7)	3.89	4.12
	70 (21.1)	70 (21.1)	49,000 (14.4)	50,100 (14.7)	4.34	4.44
Cooling	50 (10)	80 (26.7)	47,900 (14.0)	49,900 (14.6)	5.67	5.70
	70 (21.1)	80 (26.7)	44,500 (13.0)	45,100 (13.2)	4.48	4.50

[a] 9 gpm (0.6 L/s)
[b] 1200 cfm (543 L/s)
[c] Liquid-side pump watts not included

Five major selection criteria were established. In order to qualify for the field test, a site had to meet all of these five. Failure on any one meant that the site was not suitable for the study. The major criteria are as follows:

1. Applicability of Heat Pump (nominally 3-ton) to house:
   A. Design Heat Loss (DHL) of the house must be between 35,000 and 55,000 Btu per hour at design conditions.
   B. Service systems must be adequate. Forced air ducts must be adequate for a heat pump or accessible for upgrading. Adequate electrical service: as much as 100 Amps must be available for the heat pump and 15 kW electric heater.
   C. Physical suitability. Such conditions as inadequate access to mechanical area or a dirt floor in the basement would make site unacceptable.

2. Suitability of Site for Earth Loop Installation:
   A. Proper soil conditions: extremely rocky conditions or shallow soil depth to rock would make sites unacceptable. Typical soils encountered in the greater Syracuse area (clay with gravel or sand) would be acceptable.
   B. Adequate space, without underground obstructions, must be available for earth loop installation.

3. Distance from Syracuse to test site: ability to provide close supervision of work and rapid response to problems is essential. All sites to be considered for evaluation were within 40 miles of Syracuse.

4. Control of test conditions: no renovations which would change the thermal requirements of the house would be allowed during the monitoring period. Fairly constant occupancy and space usage patterns would be required. Heating contributions from sources other than the heat pump would not be allowed.

5. Receptiveness of homeowners and occupants: willingness to participate in project and cooperate as necessary.

A site survey form was designed so that auditors could visit candidate sites and return with sufficient evaluation information. A total of 14 sites were considered. Three were eliminated by telephone, 11 were surveyed, and 2 were selected based on the selection criteria.

The results of the site evaluation are summarized in Figure 2-1. A residence near DeRuyter, NY was selected and is hereafter referred to as Site #10. A residence near Lafayette, NY was selected and is hereafter referred to as Site #11.

2.4 DATA ACQUISITION AND ANALYSIS APPROACH

A plan was developed specifying all aspects of the data acquisition and analysis required to satisfy the project objectives. Sensors were installed with data collected by an on-site data acquisition system. Data was automatically transmitted over voice grade telephone lines to a central

Figure 2-1

SITE EVALUATION SUMMARY

a) Eleven sites were evaluated, with the following results:

Homeowner Name	Site Location	Remarks
Salvetti	Pompey, NY	DHL = 72,000 Btuh; too large
Kraker	Cazenovia, NY	100 Amp Service, full panel; DHL = 28,000 Btuh; Addition planned
Ryczek	Manlius, NY	Yard size barely adequate; extremely rocky conditions (large boulders)
Demers	Marcellus, NY	DHL = 25,000 Btuh
Bealer	Manlius, NY	DHL = 80,000 Btuh; Water main through backyard
Gaddis	Tully, NY	No ductwork to 2nd floor (electric baseboard heat in 2nd floor, furnace for first floor)
Clark	DeRuyter, NY	Accepted
McNamara	Scott, NY	No ductwork to second floor (no access for duct installation available)
Mentz	Lafayette, NY	Accepted
Moyer	Nelson, NY	DHL = 108,000 Btuh
Buck	Baldwinsville, NY	Inadequate Basement height (5'2"); Basement door only 24" wide (unit is 28")

b) Three other homes were eliminated by telephone interview:

Homeowner Name	Remarks
Hoo	House under construction; completion and project schedules not compatible
Fazio	DHL = 72,000 Btuh
Cosgrove	Hydronic system; no ductwork to second floor

computer facility for validation and storage on a daily basis. The central databases were used for engineering analysis in support of project reports. See Appendix A for more information about sensor selections, sensor locations, data processing procedures, report formats, etc.

Section 3
SITE AND SYSTEM CHARACTERISTICS

3.1 SITE #10

The major characteristics of the ECHP system at Site #10 are summarized in Table 3-1. The earth loop was sized with the previously validated monthly bin method (Hackner, 1987). It was determined that 815 trench feet with one pipe were necessary to maintain source temperature above 25°F. Installation of 845 trench feet was recommended, representing approximately a 30 percent decrease from the 1200 ft. (400 ft/ton) thumb rule.

The site plan is provided as Figure 3-1. The earth loop was installed in the side yard to the right of the driveway. The basement plan and piping schematic are presented in Figures 3-2(a) and 3-2(b).

3.2 SITE #11

The major characteristics of the ECHP system at Site #11 are summarized in Table 3-2. The earth loop was sized with the monthly bin method. It was determined that 549 trench feet (1100 pipe feet) of two-pipe-per-trench earth loop was necessary to maintain source temperature above 25°F. This amount was installed, representing a 27 percent decrease in trench length from the 750 ft (250 ft/ton) thumb rule.

The site plan is provided as Figure 3-3. The earth loop was installed in a long trench following a fence line off to the right hand side of the house. The basement plan and piping schematic are presented in Figures 3-4(a) and 3-4(b).

Table 3-1

MAJOR CHARACTERISTICS OF THE EARTH-COUPLED HEAT PUMP SYSTEM AT SITE #10

a) Heat pump/indoor system characteristics as installed

Size:	nominal 3-ton (See Tables 2-1, 2-2)
Air Flow:	
Liquid Flow:	
Backup/Emergency Type:	electric resistance plenum heater
Backup/Emergency Size:	5 kW supplemental, 15 kW emergency

b) Earth loop sizing assumptions

Winter design temperature:	2°F
Summer design temperature:	87°F
Design heating load:	39000 Btuh
Design cooling load:	22000 Btuh
Winter thermostat setting:	70°F
Summer thermostat setting:	74°F
Heat pump performance:	see Table 2-2
Pipes-per-trench:	one in series
Outside pipe diameter:	1.90 inch
Inside pipe diameter:	1.61 inch
Pipe thermal conductivity:	0.226 Btu/hr-ft-°F
Pipe depth:	4.0 ft
Soil thermal diffusivity:	0.025 ft^2/hr
Soil thermal conductivity:	0.75 Btu/hr-ft-°F
Soil annual mean temperature:	48.3°F
Amplitude of surface soil temperature:	24.3°F
Minimum allowable source temperature:	25°F
Maximum allowable source temperature:	95°F

c) Earth loop characteristics as installed

Configuration:	1-pipe-per-trench series
Trench Length:	845 ft
Pipe depth:	4 ft
Pipe size:	1.5 in nominal
Pipe material:	high density polyethylene
Site layout:	see Figure 3-1
Backfill:	virgin material

Table 3-2

MAJOR CHARACTERISTICS OF THE EARTH-COUPLED HEAT PUMP SYSTEM AT SITE #11

a) Heat pump/indoor system characteristics as installed

Size:	nominal 3-ton (See Tables 2-1, 2-2)
Air Flow:	
Liquid Flow:	
Backup/Emergency Type:	electric resistance plenum heater
Backup/Emergency Size:	5 kW supplemental, 15 kW emergency

b) Earth loop sizing assumptions

Winter design temperature:	2°F
Summer design temperature:	87°F
Design heating load:	52000 Btuh
Design cooling load:	27000 Btuh
Winter thermostat setting:	70°F
Summer thermostat setting:	74°F
Heat pump performance:	see Table 2-2
Pipes-per-trench:	two in series, 2 ft. spacing
Outside pipe diameter:	1.90 inch
Inside pipe diameter:	1.61 inch
Pipe thermal conductivity:	0.226 Btu/hr-ft-°F
Pipe depth:	both at 4 ft.
Soil thermal diffusivity:	0.025 ft^2/hr
Soil thermal conductivity:	0.75 Btu/hr-ft-°F
Soil annual mean temperature:	48.3°F
Amplitude of surface soil temperature:	24.3°F
Minimum allowable source temperature:	25°F
Maximum allowable source temperature:	95°F

c) Earth loop characteristics as installed

Configuration:	2-pipe series, 4 ft. depth, side-by-side
Trench Length:	549 ft.
Pipe depth:	both at 4 ft.
Pipe spacing:	2 ft. side-by-side
Pipe size:	1.5 in nominal
Pipe material:	high density polyethylene
Site layout:	see Figure 3-3
Backfill:	clay where virgin material was shale layer

Figure 3-1

SITE #10 LAYOUT

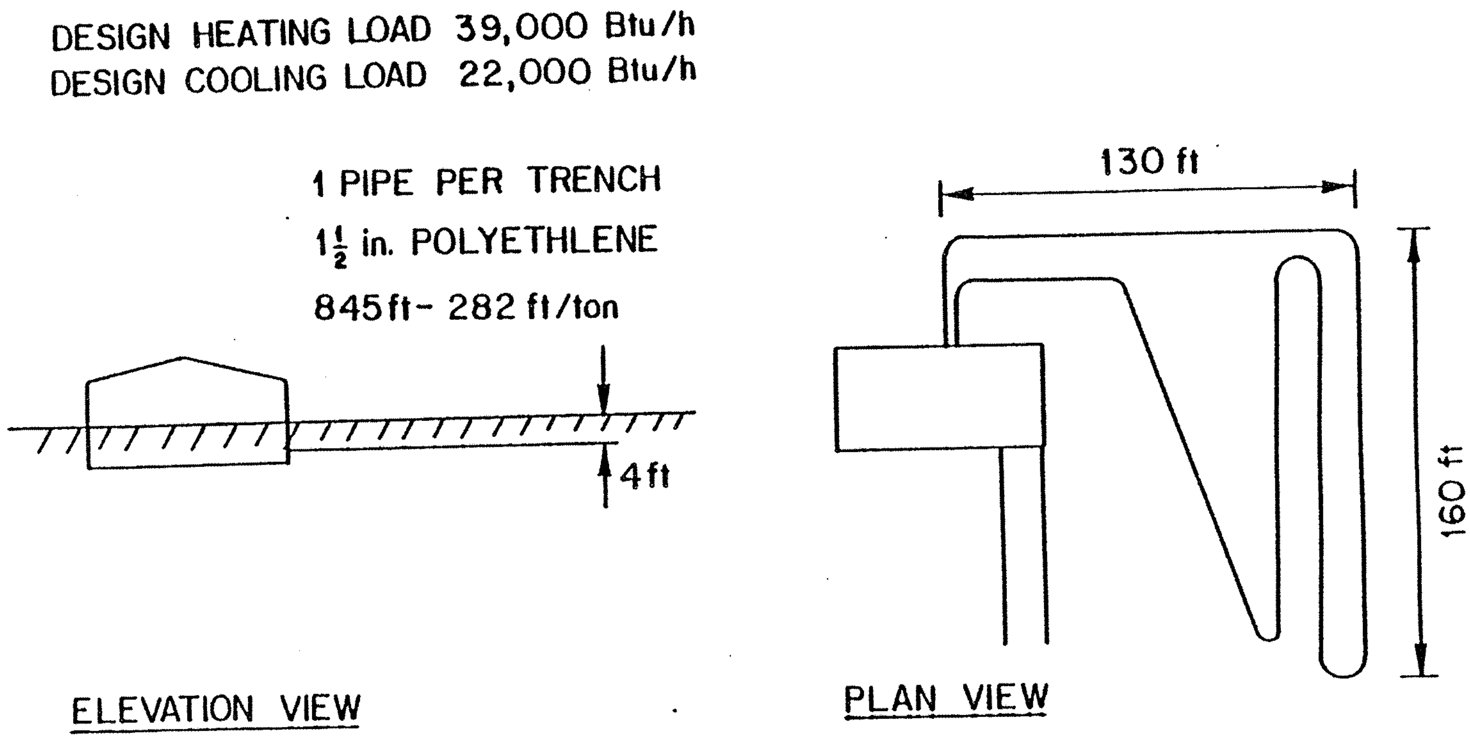
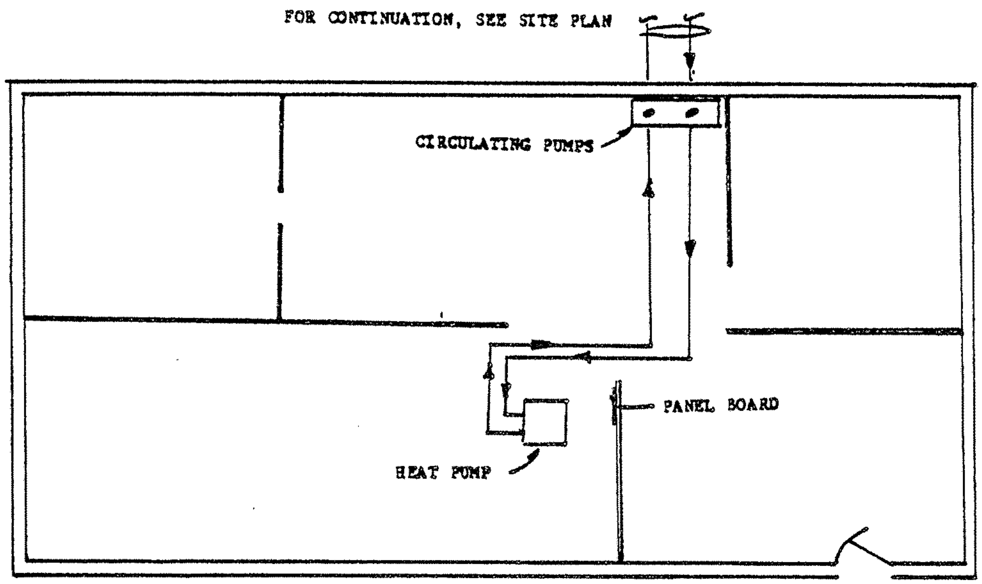


Figure 3-2

SITE #10 BASEMENT PLAN AND PIPING SCHEMATIC

a) Basement Plan



b) Piping Schematic

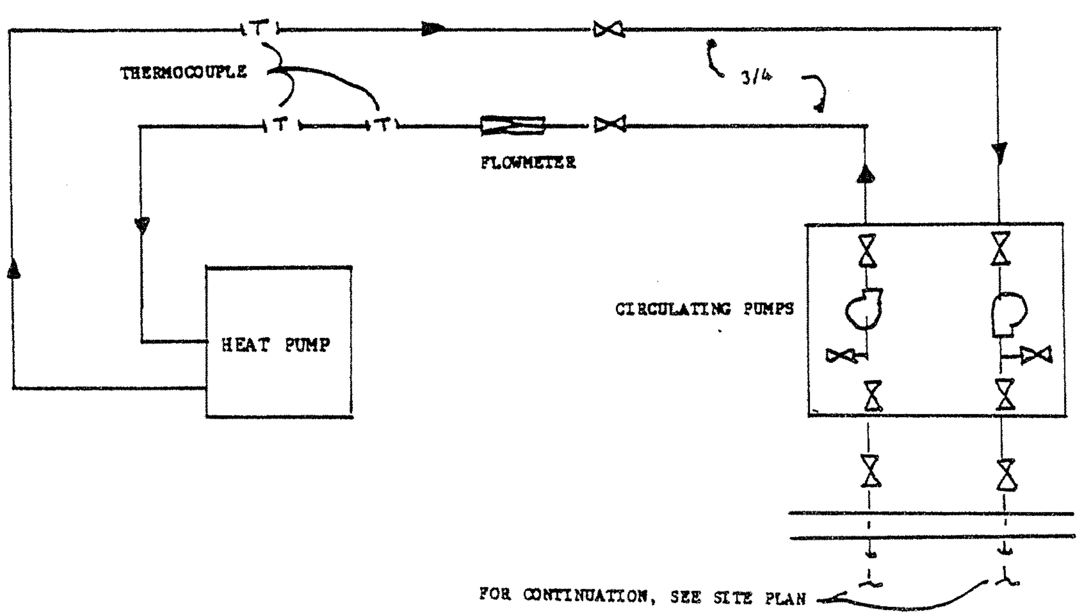


Figure 3-3

SITE #11 LAYOUT

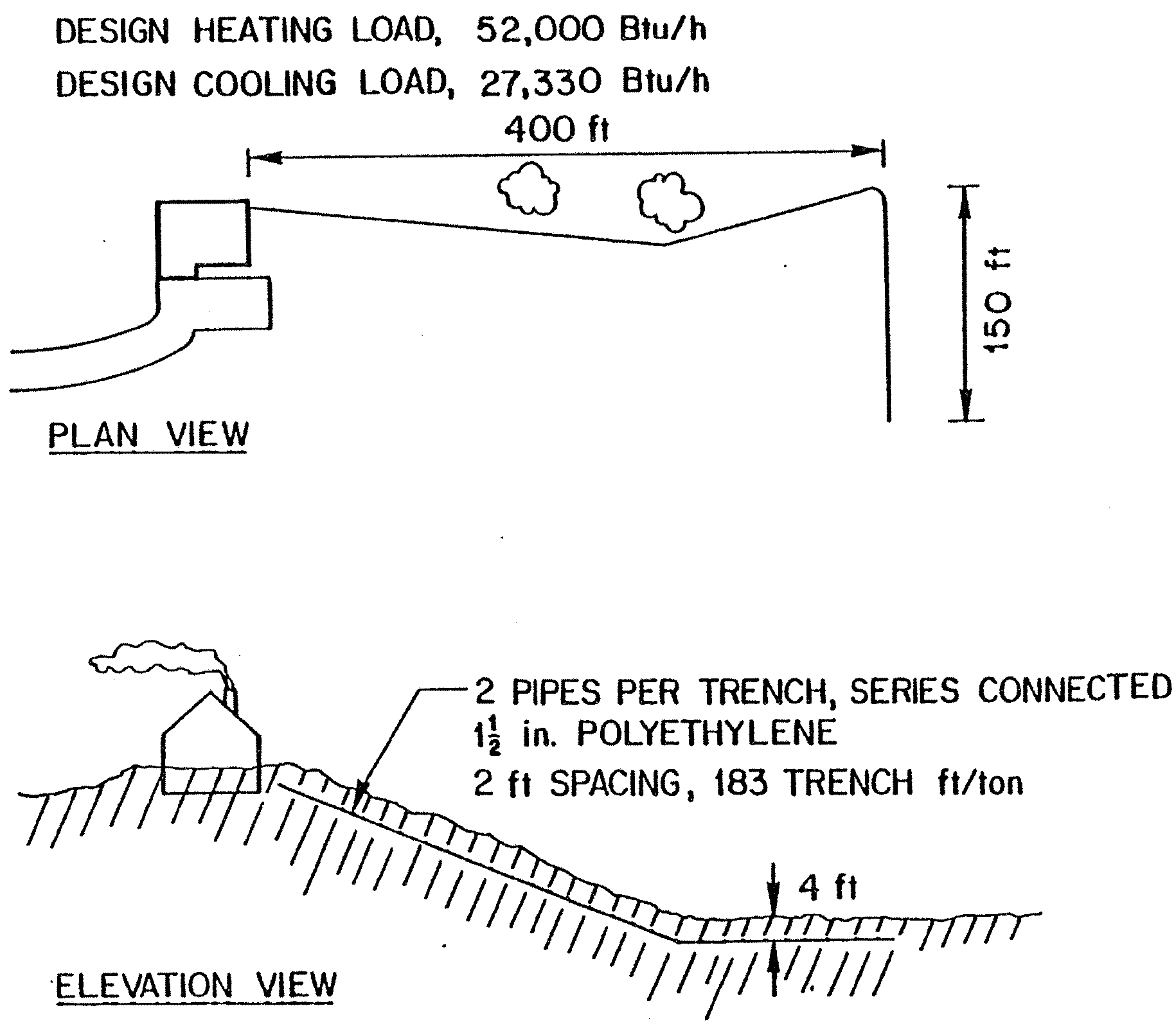
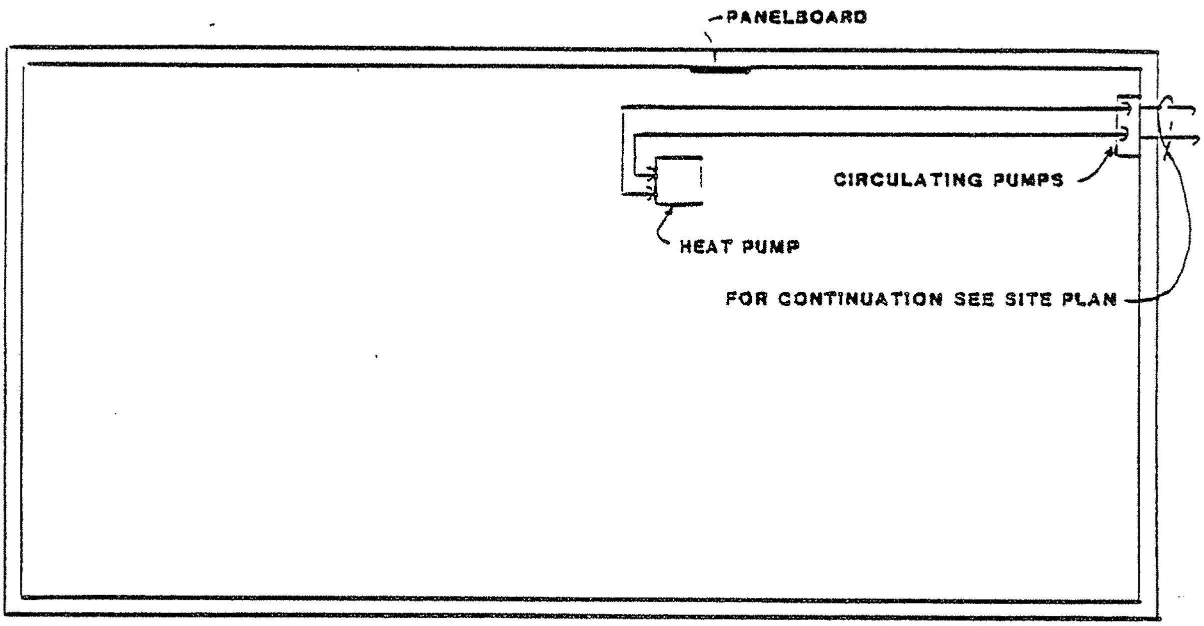


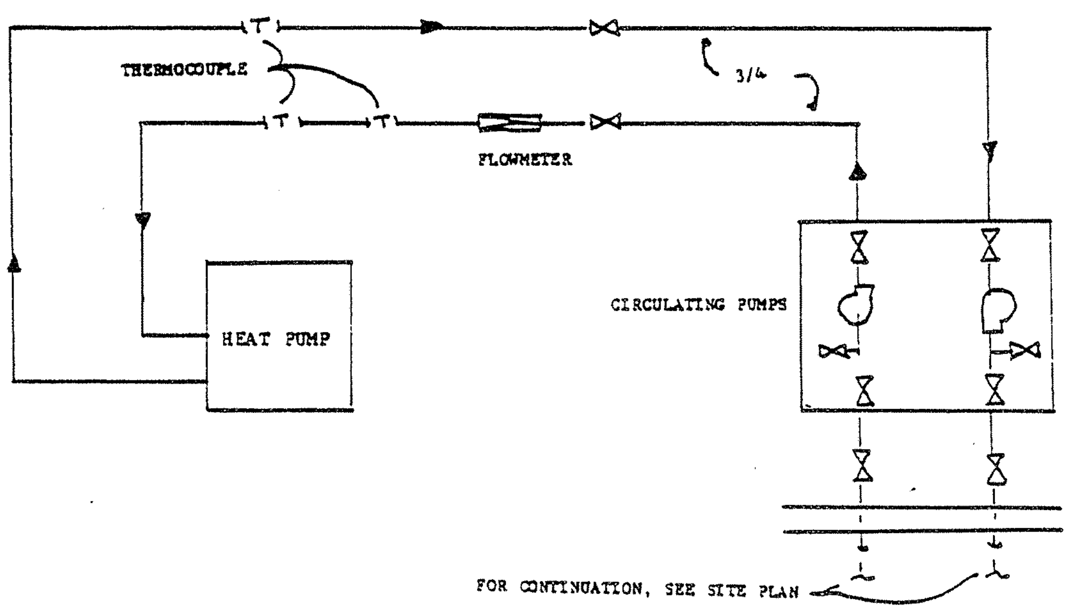
Figure 3-4

SITE #11 BASEMENT PLAN AND PIPING SCHEMATIC

a) Basement Plan



b) Piping Schematic



Section 4
RESULTS

This chapter presents the heating and cooling performance summaries for the twelve-month monitoring period. Operation and maintenance experiences are summarized in Appendix D.

4.1 HEATING PERFORMANCE SUMMARY

Tables 4-1 and 4-2 summarize the major operational characteristics for the 1985-86 heating season at Sites 10 and 11, respectively. The major points to be made regarding the Operational Summaries are:

° The minimum source temperature for Sites 10 and 11 were 28.5°F and 27.7°F, respectively.

° Due to the difference in the heating loads, Site 11 required a great deal more heat pump output and also more auxiliary heat than did Site 10.

° The heat pump Seasonal Coefficients of Performance (SCOPs) at the two sites were 2.74 (Site 10) and 2.90 (Site 11), respectively. The lower value at Site 10 was the result of the unit operating with low refrigerant charge for a period of time. System (heat pump and auxiliary) Heating Seasonal Performance Factors (SPFs) were 2.70 and 2.71. The extra auxiliary heat at Site 11 caused the equalization in SPFs.

For additional information regarding field-monitored performance during the heating season, see Appendix B.

4.2 COOLING PERFORMANCE SUMMARY

Tables 4-3 and 4-4 summarize the major operational characteristics for the 1986 cooling season at Sites 10 and 11, respectively. The major points to be made regarding the Operational Summaries are:

° Site 11 recorded 43 percent more cooling degree days than site 10 (271 versus 189, respectively),
° Site 11 cooling mode run hours were nearly 10 times more than for Site 10 indicating that the heat pump was used very sparingly for cooling at Site 10,
° The average source temperatures for the two sites were 65.7°F and 70.1°F for Sites 10 and 11, respectively.
° The maximum source temperature was much higher at Site 11, 85.9°F, than at Site 10, 76.8°F. The maximum source temperatures occurred at approximately the same time period, July 26 for Site 10 and July 24 for Site 11.
° The Seasonal Energy Efficiency Ratios (SEERs) for the two sites were very similar at 11.92 (Site 10) and 11.32 (Site 11), respectively.

For additional information regarding field-monitored performance during the cooling season, see Appendix C.

TABLE 4-1

SITE 10 - HEATING SEASON OPERATIONAL SUMMARY

DATA REPORT: ADVANCED EARTH COUPLED HEAT PUMPS - SITE #10

FROM 11/ 6/85 HOUR 00 TO 5/31/86 HOUR 23
DATABASE HOURS RECORDED: 4938 (99.4%)

MODE: HEATING
HEATING DEGREE DAYS: 6244

AVERAGE EARTH LOOP PUMP FLOW: 10.15 GPM
AVERAGE HVAC AIR FLOW: 1200. CFM

TEMPERATURES-DEG F	AVERAGE	MINIMUM	MAXIMUM
AMBIENT TEMPERATURE	34.8	-17.1	84.3
ROOM TEMPERATURE	71.8	64.1	80.4
SUPPLY AIR TEMP-HEAT PUMP	87.6	74.7	97.0
RETURN AIR TEMP-HEAT PUMP	66.0	60.1	70.1
EARTH LOOP SOURCE TEMP	35.8	28.5	51.5
EARTH LOOP RETURN TEMP	31.8	24.4	47.3
FAR FIELD TEMPERATURE	39.8	33.1	57.7

EQUIPMENT OPERATION	CYCLES	HOURS	KWH	10^6 BTU
COMPRESSOR	7858	1940.9	3958.05	13.509
BLOWER		1947.4	1184.00	4.041
LOOP PUMP		1944.7	738.99	2.520
HEAT PUMP TOTAL			5881.04	20.072
AUXILIARY ELECTRIC HEAT	85	14.7	131.99	.450
HEATING SYSTEM TOTAL			6013.03	20.522

HEAT QUANTITIES	(MILLIONS OF BTUS
EARTH LOOP EXTRACTION	34.829
TOTAL HEAT PUMP WORK INTPUT	20.072
TOTAL HEAT PUMP OUTPUT	54.901
AUXILIARY ELECTRIC HEAT OUTPUT	0.450
TOTAL AIR SIDE HEAT OUTPUT	53.788

ENERGY BALANCE PER CENT NON-CLOSURE
(AIR SIDE VS. HEAT PUMP WATER SIDE + AUX ELECTRIC): 2.8%

PERFORMANCE FACTORS

AVERAGE HEAT PUMP C.O.P.: 2.74
AVERAGE HEATING S.P.F.: 2.70

AVERAGE HEAT PUMP CAPACITY: 28286. BTU/HR

TABLE 4-2

SITE 11 - HEATING SEASON OPERATIONAL SUMMARY

DATA REPORT: ADVANCED EARTH COUPLED HEAT PUMPS - SITE #11

FROM 11/ 4/85 HOUR 00 TO 5/31/86 HOUR 23
DATABASE HOURS RECORDED: 4990 (99.5%)

MODE: HEATING
HEATING DEGREE DAYS: 6194

AVERAGE EARTH LOOP PUMP FLOW: 10.91 GPM
AVERAGE HVAC AIR FLOW: 1200. CFM

TEMPERATURES-DEG F	AVERAGE	MINIMUM	MAXIMUM
AMBIENT TEMPERATURE	35.5	-5.9	82.5
ROOM TEMPERATURE	69.9	65.8	80.4
SUPPLY AIR TEMP-HEAT PUMP	89.0	79.4	98.5
RETURN AIR TEMP-HEAT PUMP	67.2	63.8	71.6
EARTH LOOP SOURCE TEMP	33.6	27.7	53.9
EARTH LOOP RETURN TEMP	29.4	23.5	49.0
FAR FIELD TEMPERATURE	42.6	36.6	54.5

EQUIPMENT OPERATION	CYCLES	HOURS	KWH	10^6 BTU
COMPRESSOR	8327	2901.3	6144.80	20.972
BLOWER		2902.7	1764.82	6.023
LOOP PUMP		2901.2	1102.42	3.763
HEAT PUMP TOTAL			9012.04	30.758
AUXILIARY ELECTRIC HEAT	223	167.0	1004.36	3.428
HEATING SYSTEM TOTAL			10016.42	34.186

HEAT QUANTITIES (MILLIONS OF BTUS	
EARTH LOOP EXTRACTION	58.578
TOTAL HEAT PUMP WORK INTPUT	30.758
TOTAL HEAT PUMP OUTPUT	89.336
AUXILIARY ELECTRIC HEAT OUTPUT	3.428
TOTAL AIR SIDE HEAT OUTPUT	85.004

ENERGY BALANCE PER CENT NON-CLOSURE
(AIR SIDE VS. HEAT PUMP WATER SIDE + AUX ELECTRIC): 8.4%

PERFORMANCE FACTORS	
AVERAGE HEAT PUMP C.O.P.:	2.90
AVERAGE HEATING S.P.F.:	2.71

AVERAGE HEAT PUMP CAPACITY: 30792. BTU/HR

TABLE 4-3

SITE 10 - COOLING SEASON OPERATIONAL SUMMARY

DATA REPORT: ADVANCED EARTH COUPLED HEAT PUMPS - SITE #10

FROM 5/ 1/86 HOUR 00 TO 9/15/86 HOUR 23
DATABASE HOURS RECORDED: 3310 (99.9%)

MODE: COOLING
COOLING DEGREE DAYS: 189

AVERAGE EARTH LOOP PUMP FLOW: 12.16 GPM
AVERAGE HVAC AIR FLOW: 1200. CFM

TEMPERATURES-DEG F	AVERAGE	MINIMUM	MAXIMUM
AMBIENT TEMPERATURE	61.8	29.2	86.9
ROOM TEMPERATURE	73.0	62.3	85.9
SUPPLY AIR TEMP-HEAT PUMP	50.7	44.8	78.4
RETURN AIR TEMP-HEAT PUMP	69.6	65.3	75.4
EARTH LOOP SOURCE TEMP	65.7	43.7	76.8
EARTH LOOP RETURN TEMP	74.2	43.8	85.3
FAR FIELD TEMPERATURE	59.1	44.1	66.7

EQUIPMENT OPERATION	CYCLES	HOURS	KWH	10^6 BTU
COMPRESSOR	90	38.2	82.38	0.281
BLOWER		39.5	24.02	0.082
LOOP PUMP		38.2	14.52	0.050
HEAT PUMP TOTAL			120.92	0.413

HEAT QUANTITIES	MILLIONS OF BTUS
HEAT REJECTED TO EARTH LOOP	1.853
TOTAL HEAT PUMP WORK INTPUT	0.413
AIR SIDE SENSIBLE HEAT EXTRACTION	1.003
LATENT HEAT EXTRACTION FROM SPACE	0.441
TOTAL HEAT EXTRACTION FROM SPACE	1.441

PERFORMANCE FACTORS	
AVERAGE HEAT PUMP C.O.P.:	3.49
AVERAGE COOLING E.E.R.:	11.92

AVERAGE COOLING CAPACITY: 37681. BTU/HR

TABLE 4-4

SITE 11 - COOLING SEASON OPERATIONAL SUMMARY

DATA REPORT: ADVANCED EARTH COUPLED HEAT PUMPS - SITE #11

FROM 5/ 1/86 HOUR 00 TO 9/15/86 HOUR 23
DATABASE HOURS RECORDED: 3309 (99.9%)

MODE: COOLING
COOLING DEGREE DAYS: 271

AVERAGE EARTH LOOP PUMP FLOW: 11.67 GPM
AVERAGE HVAC AIR FLOW: 1200. CFM

TEMPERATURES-DEG F	AVERAGE	MINIMUM	MAXIMUM
AMBIENT TEMPERATURE	63.2	28.8	84.4
ROOM TEMPERATURE	73.1	66.3	80.6
SUPPLY AIR TEMP-HEAT PUMP	52.1	46.7	84.3
RETURN AIR TEMP-HEAT PUMP	71.4	67.2	76.6
EARTH LOOP SOURCE TEMP	70.1	46.1	85.9
EARTH LOOP RETURN TEMP	79.2	55.8	94.3
FAR FIELD TEMPERATURE	57.9	45.3	63.9

EQUIPMENT OPERATION	CYCLES	HOURS	KWH	10^6 BTU
COMPRESSOR	529	362.1	847.60	2.893
BLOWER		362.1	220.16	0.751
LOOP PUMP		362.1	137.49	0.469
HEAT PUMP TOTAL			1205.25	4.114

HEAT QUANTITIES	MILLIONS OF BTUS
HEAT REJECTED TO EARTH LOOP	17.720
TOTAL HEAT PUMP WORK INTPUT	4.114
AIR SIDE SENSIBLE HEAT EXTRACTION	9.254
LATENT HEAT EXTRACTION FROM SPACE	4.510
TOTAL HEAT EXTRACTION FROM SPACE	13.647

PERFORMANCE FACTORS	
AVERAGE HEAT PUMP C.O.P.:	3.32
AVERAGE COOLING E.E.R.:	11.32

AVERAGE COOLING CAPACITY: 37690. BTU/HR

Section 5
COMPARISON: ADVANCED VS. STANDARD SYSTEMS

The results of the field evaluation were summarized in the last chapter. Based on the field experience and appropriate analysis, the differences between the advanced and standard heat pump systems are documented here. Differences from the design, operation and maintenance, and performance standpoints are considered.

5.1 DESIGN DIFFERENCES

The design differences between the advanced and standard systems can be divided into two categories: 1) heat pump equipment/controls differences and 2) earth loop design differences. The heat pump equipment/controls differences include:

- Oversized Heat Exchangers - The advanced unit uses oversized evaporator and condensor coils to provide additional heat transfer area and, thus, allow the heat pump to operate efficiently at low source temperatures.
- High-Efficiency Compressor - A high-efficiency compressor was used in the advanced unit to improve heat pump efficiency over the entire range of operating conditions.
- Start Assist - The advanced unit is equipped with a positive temperature coefficient varistor which provides better starting torque.
- Freeze Thermostat - Since the advanced unit operates at lower source temperatures, freeze protection thermostats with a cutout temperature of 18°F are used.

The earth loop design differences are as follows. Standard one-pipe horizontal loops had been sized using a rule-of-thumb of 400 trench feet per nominal ton of heat pump. Standard two-pipe horizontal loops had been sized using a rule of 250 trench feet per nominal ton of heat pump. However, results of previous ECHP monitoring projects (Hughes, P.J., et.al., 1987, Hughes, P.J., et.al., 1985) in Upstate New York indicated that earth loops could be smaller if a heat pump was available which could retain high performance at low source temperatures. Since the advanced unit efficiently operates at source temperatures as low as 25°F, the required earth loop lengths were considerably shorter than the current design rules. For example, Site #10 was installed with one-pipe in an 845 foot trench and Site #11 was installed with two-pipes in a 549 foot trench. Standard guidelines would have called for 1200 trench feet at Site #10 and 750 trench feet at Site #11. The advanced systems therefore were installed with 27 to 30 percent less trench length than is typical for standard systems designed with standard rules of thumb.

5.2 OPERATION AND MAINTENANCE DIFFERENCES

No operation or maintenance differences were noted between the standard and advanced heat pump systems. General operation and maintenance guidelines which apply to both standard and advanced systems are presented in Appendix D.

5.3 PERFORMANCE COMPARISON

The predicted benefit of the advanced WSHP was smaller earth loops while maintaining high system performance factors, i.e., lower installed cost while maintaining the same operating cost. Sites 10 and 11 were installed with 27 to 30 percent less earth loop than standard sizing rules recommend. But previous monitored data and analysis indicated that standard sizing rules were quite conservative for northern climates. It was unclear how much of the 27 to 30 percent savings in earth loop length should be credited to the advanced WSHP versus to improved design methods.

The analysis was structured so that results would address the following research questions: (1) when both advanced and standard ECHP systems are constrained to having the same heating SPF, how much earth loop does the advanced WSHP save? and (2) when both advanced and standard ECHP systems are optimally sized without constraint, what benefit does the advanced WSHP offer?

In order to address these questions a standard residential application was defined (Table 5-1). To obtain a comparative case where both advanced and standard ECHP systems had similar SPFs, three advanced WSHPs (nominal 2, 2.5, and 3 tons) and two standard WSHPs (nominal 3 and 3.5 tons) were modeled on the same house. To assure that optimum size cases would be obtained for both advanced and standard ECHP systems, earth loops were sized at each of 3 minimum allowable source temperatures (20^{o}F, 25^{o}F, 30^{o}F). To prevent results from being obscured by secondary effects, all cases assumed a 380 watt earth loop pump.

The steady-state performance characteristics assumed for the nominal 3 and 3.5 ton standard WSHPs are presented in Tables 5-2 and 5-3. The performance characteristics assumed for the nominal 3, 2.5, and 2 ton advanced WSHPs are presented in Tables 5-4(a), (b), and (c). The power consumption in all of these tables includes that for blower, compressor, and 380 watts for the loop pump.

The steady-state heat pump performance data is also presented graphically in Figures 5-1, 5-2, and 5-3. Figure 5-1 presents COP vs. source temperature for all five heat pumps. Figure 5-2 presents capacity versus source temperature. Figure 5-3 presents power versus source temperature where power consumption includes that for the blower, compressor, and 380 watts for the loop pump.

To make the comparison as meaningful as possible, all five heat pumps represent units made by the same manufacturer. Extrapolations and approximations had to be made in order to provide performance data throughout the required source temperature ranges.

TABLE 5-1

PARAMETER VALUES ASSUMED FOR THE STANDARD RESIDENTIAL APPLICATION

Location: Syracuse, New York

Winter Design Temperature:	2°F (-17°C)
Winter Thermostat Setting:	70°F (21°C)
Design Heating Load:	47,000 Btuh (13.7 kW)
Summer Design Temperature:	87°F (31°C)
Summer Thermostat Setting:	74°F (23°C)
Design Cooling Load	22,000 Btuh (6.4 kW)
Outside Pipe Diameter:	1.9 inches (48.3 mm)
Inside Pipe Diameter:	1.6 inches (40.6 mm)
Pipe Thermal Conductivity:	0.226 Btu/hr.f.F (0.391 W/m.°C)
Earth Loop Configuration:	Two-pipe-per trench (out at 3 ft. [0.9m] return at 5 ft [1.5m])
Average Pipe Depth	4 ft (1.2 m)
Soil Annual Mean Temperature:	48.3°F (9.1°C)
Amplitude of Surface Soil Temperature:	24.3°C (13.5°C)
Soil Thermal Diffusivity	0.025 ft^2/hr (6.5 x 10^{-7} m^2/s)
Soil Thermal Conductivity:	0.75 Btu/hr.,ft.F (1.30 W/m.°C)

TABLE 5-2

STANDARD NOMINAL 3-TON HEAT PUMP PERFORMANCE VALUES

Heating Mode:

Source Temperature	Capacity	Power
25F (-3.9°C)	21.5 kBtuh (6.3 kW)	2.89 kW
35F (1.7°C)	26.1 kBtuh (7.6 kW)	3.09 kW
45F (7.2°C)	32.6 kBtuh (9.6 kW)	3.48 kW
55F (12.8°C)	37.3 kBtuh (10.9 kW)	3.66 kW
65F (18.3°C)	42.2 kBtuh (12.4 kW)	3.94 kW

Cooling Mode:

55F (12.8°)	39.2 kBtuh (11.5 kW)	2.97 kW
65F (18.3°)	37.1 kBtuh (10.9 kW)	3.15 kW
75F (23.9°)	36.2 kBtuh (10.6 kW)	3.43 kW
85F (29.4°)	35.3 kBtuh (10.3 kW)	3.51 kW
95F (35°)	34.4 kBtuh (10.1 kW)	3.59 kW

Other Conditions: Loop Flow Rate = 3 gpm per ton
Air Flow Rate = 400 cfm per ton
Loop Pump Power = 0.380 kW

TABLE 5-3

STANDARD NOMINAL 3.5-TON HEAT PUMP PERFORMANCE VALUES

Heating Mode:

Source Temperature	Capacity	Power
25F (-3.9°C)	28.7 kBtuh (8.4 kW)	3.29 kW
35F (1.7°C)	31.6 kBtuh (9.3 kW)	3.52 kW
45F (7.2°C)	38.0 kBtuh (11.1 kW)	3.88 kW
55F (12.8°C)	44.3 kBtuh (13.0 kW)	4.1 kW
65F (18.3°C)	50.4 kBtuh (14.8 kW)	4.36 kW

Cooling Mode:

55F (12.8°)	48.1 kBtuh (14.1 kW)	3.72 kW
65F (18.3°)	44.5 kBtuh (13.0 kW)	4.09 kW
75F (23.9°)	43.5 kBtuh (12.7 kW)	4.14 kW
85F (29.4°)	42.4 kBtuh (12.4 kW)	4.24 kW
95F (35°)	41.3 kBtuh (12.1 kW)	4.34 kW

Other Conditions:
Loop Flow Rate = 3 gpm per ton
Air Flow Rate = 400 cfm per ton
Loop Pump Power = 0.380 kW

TABLE 5-4a

ADVANCED NOMINAL 3-TON HEAT PUMP PERFORMANCE VALUES

Heating Mode:

Source Temperature	Capacity	Power
25F (-3.9°C)	30.9 kBtuh (9.1 kW)	2.90 kW
35F (1.7°C)	34.4 kBtuh (10.1 kW)	3.18 kW
45F (7.2°C)	38.7 kBtuh (11.3 kW)	3.40 kW
55F (12.8°C)	42.7 kBtuh (12.5 kW)	3.55 kW
65F (18.3°C)	46.7 kBtuh (13.7 kW)	3.70 kW

Cooling Mode:

55F (12.8°)	47.1 kBtuh (13.8 kW)	3.08 kW
65F (18.3°)	45.4 kBtuh (13.3 kW)	3.30 kW
75F (23.9°)	43.7 kBtuh (12.8 kW)	3.52 kW
85F (29.4°)	42.0 kBtuh (12.3 kW)	3.29 kW
95F (35°)	40.3 kBtuh (11.8 kW)	2.98 kW

Other Conditions: Loop Flow Rate = 3 gpm per ton
Air Flow Rate = 400 cfm per ton
Loop Pump Power = 0.380 kW

TABLE 5-4b

ADVANCED NOMINAL 2.5-TON HEAT PUMP PERFORMANCE VALUES[A]

	Source Temperature	Capacity	Power
Heating Mode:			
	25F (-3.9°C)	27.3 kBtuh (8.0 kW)	2.60 kW
	35F (1.7°C)	30.1 kBtuh (8.8 kW)	2.83 kW
	45F (7.2°C)	33.7 kBtuh (9.9 kW)	3.01 kW
	55F (12.8°C)	37.1 kBtuh (10.9 kW)	3.13 kW
	65F (18.3°C)	40.4 kBtuh (11.8 kW)	3.25 kW
Cooling Mode:			
	55F (12.8°)	39.5 kBtuh (11.6 kW)	2.65 kW
	65F (18.3°)	38.0 kBtuh (11.1 kW)	2.82 kW
	75F (23.9°)	36.5 kBtuh (10.7 kW)	3.00 kW
	85F (29.4°)	35.0 kBtuh (10.3 kW)	3.18 kW
	95F (35°)	33.4 kBtuh (9.8 kW)	3.35 kW

Other Conditions: Loop Flow Rate = 3 gpm per ton
Air Flow Rate = 400 cfm per ton
Loop Pump Power = 0.380 kW

A - Estimated values based in part on monitored data for advanced 3-ton unit

TABLE 5-4c

ADVANCED NOMINAL 2-TON HEAT PUMP PERFORMANCE VALUES[A]

Heating Mode:

Source Temperature	Capacity	Power
25F (-3.9°C)	23.6 kBtuh (6.9 kW)	2.31 kW
35F (1.7°C)	25.8 kBtuh (7.6 kW)	2.48 kW
45F (7.2°C)	28.8 kBtuh (8.4 kW)	2.62 kW
55F (12.8°C)	31.4 kBtuh (9.2 kW)	2.71 kW
65F (18.3°C)	34.1 kBtuh (10.0 kW)	2.80 kW

Cooling Mode:

55F (12.8°)	31.9 kBtuh (9.3 kW)	2.21 kW
65F (18.3°)	30.6 kBtuh (9.0 kW)	2.35 kW
75F (23.9°)	29.3 kBtuh (8.6 kW)	2.48 kW
85F (29.4°)	27.9 kBtuh (8.2 kW)	2.61 kW
95F (35°)	26.6 kBtuh (7.8 kW)	2.74 kW

Other Conditions: Loop Flow Rate = 3 gpm per ton
Air Flow Rate = 400 cfm per ton
Loop Pump Power = 0.380 kW

A - Estimated values based in part on monitored data for advanced 3-ton unit

Figure 5-1

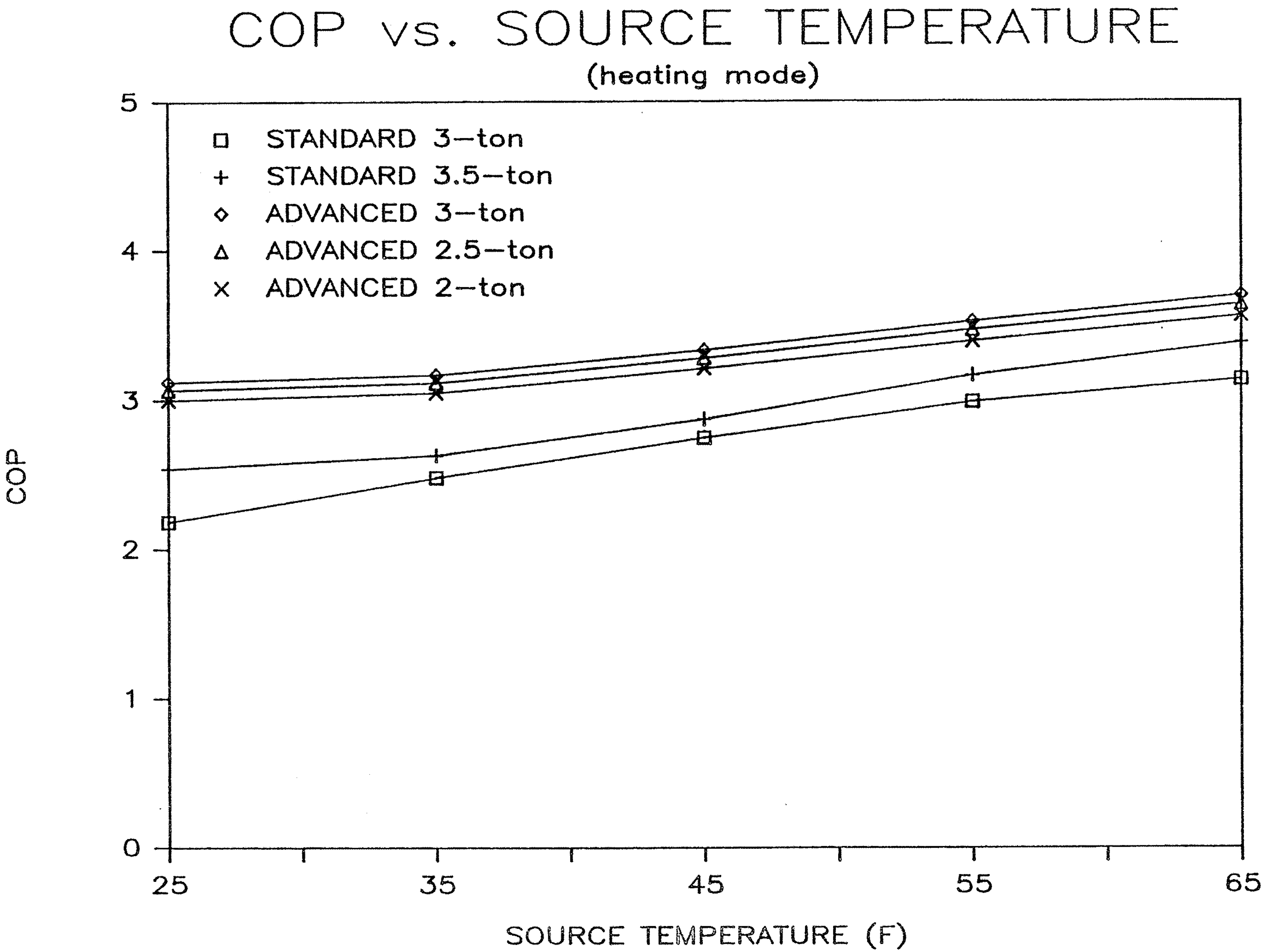

COP vs. SOURCE TEMPERATURE
(heating mode)
STANDARD 3-ton
STANDARD 3.5-ton
ADVANCED 3-ton
ADVANCED 2.5-ton
ADVANCED 2-ton
COP
0
1
2
3
4
5
25
35
45
55
65
SOURCE TEMPERATURE (F)

Figure 5-2

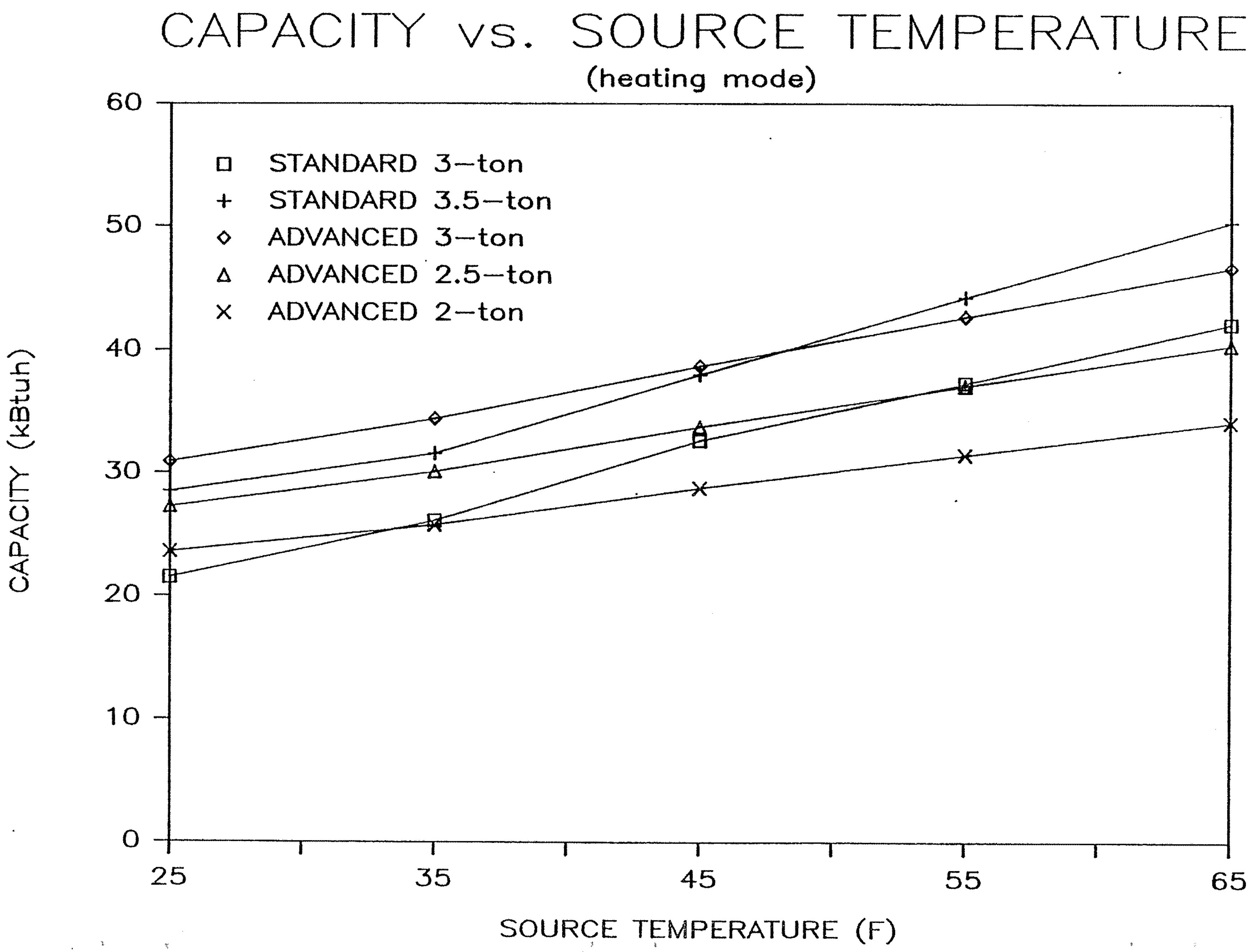
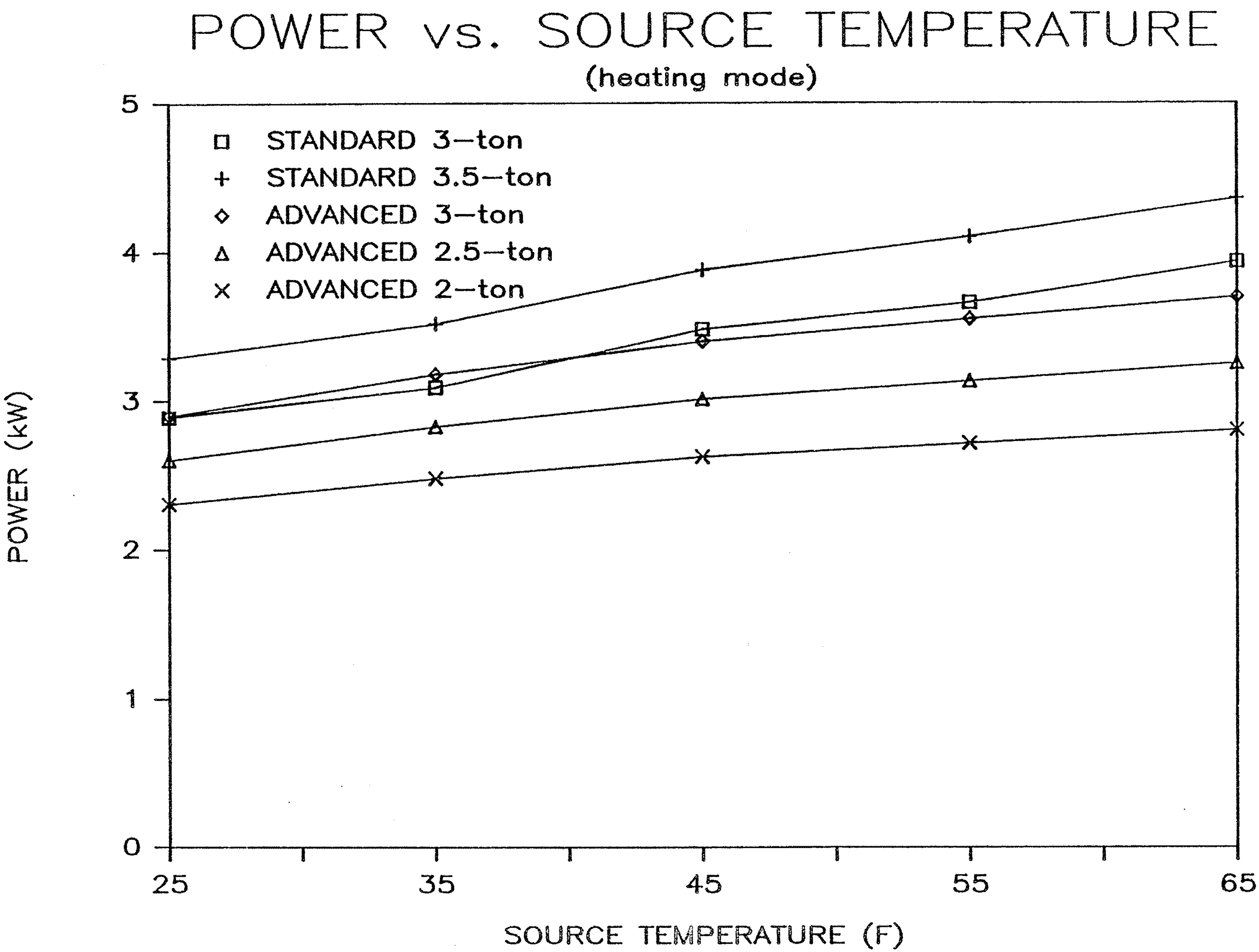

CAPACITY vs. SOURCE TEMPERATURE
(heating mode)
STANDARD 3-ton
STANDARD 3.5-ton
ADVANCED 3-ton
ADVANCED 2.5-ton
ADVANCED 2-ton
CAPACITY (kBtuh)
0
10
20
30
40
50
60
25
35
45
55
65
SOURCE TEMPERATURE (F)

Figure 5-3



POWER vs. SOURCE TEMPERATURE
(heating mode)
STANDARD 3-ton
STANDARD 3.5-ton
ADVANCED 3-ton
ADVANCED 2.5-ton
ADVANCED 2-ton
POWER (kW)
0
1
2
3
4
5
25
35
45
55
65
SOURCE TEMPERATURE (F)

The values for the 3 and 3.5 ton standard WSHPs were constructed from manufacturers data for 45°F and above, and from field-monitored data collected during a previous monitoring project (Hughes, P.J., et.al., 1986) for below 45°F.

The values for the 3-ton advanced WSHP were based on field-monitored data collected during the present monitoring project. 2.5 and 2-ton advanced WSHPs have never been built, therefore steady-state data had to be approximated from 3-ton unit data. The approach taken was to assume that COP vs. source temperature was identical for the 2, 2.5 and 3-ton units when loop pump watts were excluded. To make this happen capacity and power curves were appropriately adjusted. Then loop pump watts were added back into the power curves, and the COP curves were derived from the capacity and power curves. The resulting COP curves are slightly different for 2, 2.5, and 3-ton units because of the constant loop pump size.

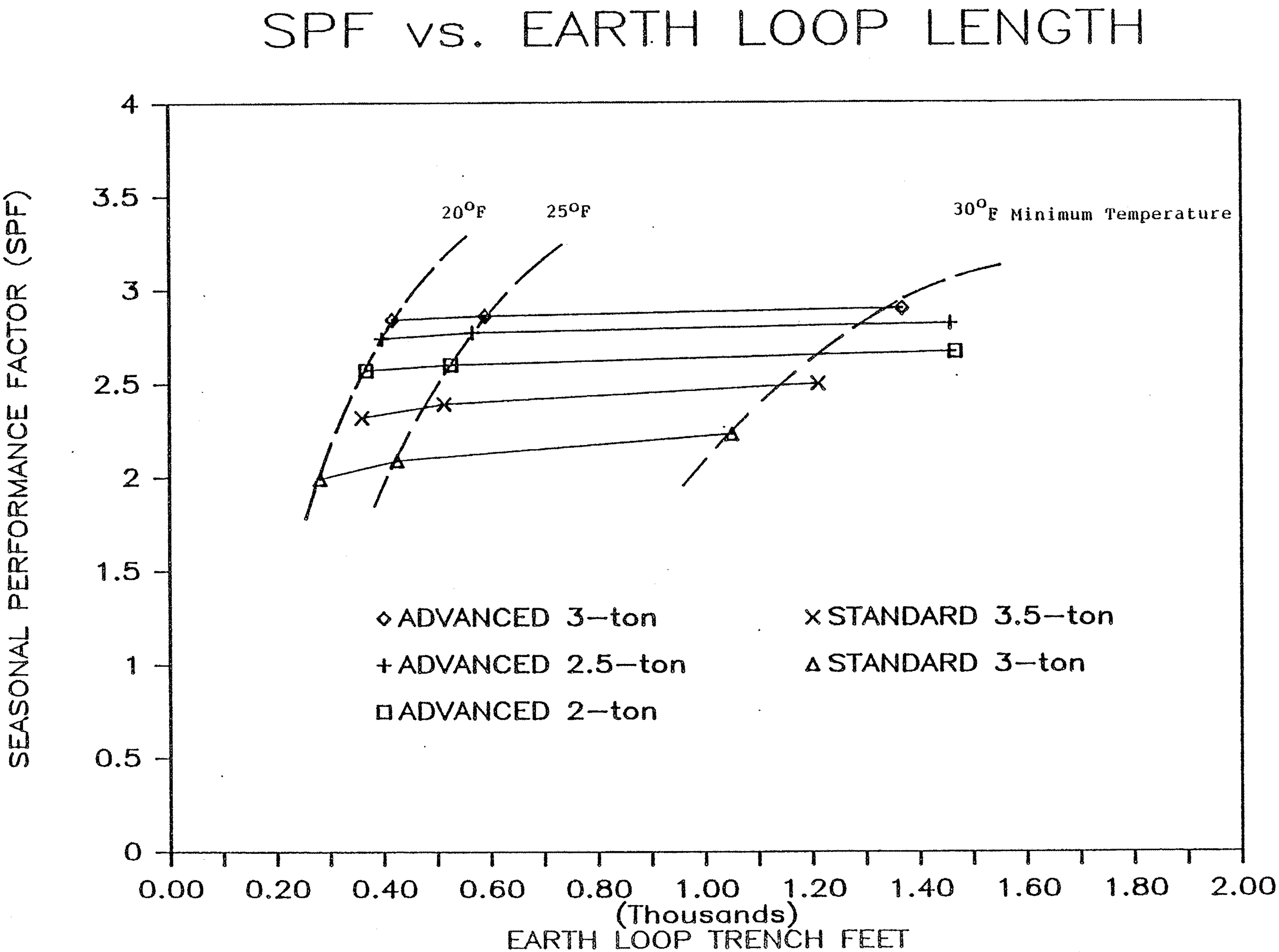
The performance comparison results are summarized in Figure 5-4. Heating SPF is plotted versus earth loop trench feet. The points are indicated for the 15 annual analyses (5 heat pumps, 3 minimum source temperatures) performed using a previously developed monthly bin model (Hackner, et.al., 1987). Solid lines connect the points for each of the five heat pumps. Dotted lines approximate the paths of constant minimum source temperature. Observations from Figure 5-4 are used to address the previously identified research questions.

The first research question was "When both advanced and standard ECHP systems are constrained to having the same heating SPF, how much earth loop does the advanced WSHP save?" The only case which nearly satisfies the requirement of equal SPF is to compare the advanced 2-ton curve to the standard 3.5-ton curve. When both units achieve an SPF of approximately 2.5, the advanced 2-ton unit requires approximately 500 trench feet whereas the standard 3.5-ton unit requires approximately 1200 trench feet. Under the conditions of an SPF constraint, the advanced WSHP demonstrates very large savings in earth loop length. Part of this large saving is due to the fact that the advanced WSHP allows the use of a smaller unit (2-ton rather than 3.5) which meets less of the load via the heat pump.

The second research question was "when both advanced and standard ECHP systems are optimally sized without constraint, what benefit does the advanced WSHP offer?" At today's earth loop installation costs, optimally sized (for heating load dominated applications) means size the earth loop for the minimum allowable source temperature. This minimum value is generally specified at 25°F in New York State. It is evident from Figure 5-4 that lowering the minimum allowable source temperature from 30°F to 25°F results in great savings in earth loop length, but further lowering the value to 20°F offers only modest additional savings and increases the risk of experiencing soil problems.

Figure 5-4 also indicates that at the same minimum source temperature, the advanced WSHP will actually require a larger earth loop than the standard WSHP. The reason is that the standard WSHP is less efficient and therefore to meet a given heating load extracts less energy from the earth loop. "Less energy extraction" takes the form of a lower extraction capacity at steady-state operation under extreme conditions. Consequently

Figure 5-4



(Horizontal 2 Pipes per Trench Over/Under Configuration) a smaller earth loop can match this steady-state heat transfer condition at the specified liquid-side minimum temperature profile.

The major benefit offered by the advanced WSHP is economic. Although a slightly larger earth loop is required (for equivalent minimum source temperatures and heat pump sizes), higher SPFs can be achieved with smaller heat pumps and correspondingly smaller earth loops. Quantification of this benefit is addressed in Section 5.4.

Other observations from Figure 5-4 are as follows. The heating SPF is surprisingly insensitive to earth loop length. The reason is that the average heating season source temperature weighted by heat pump run hours only varies from approximately 28°F in the 20°F minimum cases, to approximately 36°F in the 30°F minimum cases. It can be seen in Figure 5-1 that the COP for all 5 heat pumps has little variation in the 28 to 36°F temperature range. This flat SPF characteristic should not lead one to conclude that the smaller the earth loop the better. Below minimum temperatures of 25°F the cost of a reliable and efficient heat pump rises and in addition, soil instability problems have been observed by the Northern Europeans under such extreme operating conditions (Calm, editor, 1987).

5.4 COST IMPLICATIONS

An economic analysis was performed to determine the benefits which the advanced WSHP may provide in terms of enhancing the overall competitiveness of ECHP systems. Table 5-5 summarizes the assumptions that were used in the economic analysis. Table 5-6 presents the simple payback results.

Focusing solely on the 25°F minimum source temperature analysis, the following observations can be made:

1. The advanced WSHP enhances the competitiveness of ECHP systems. Payback of the advanced 3-ton WSHP versus the standard 3-ton WSHP is 3.5 years at a 25°F minimum source temperature. The advanced 3-ton WSHP lowers the payback of ECHP systems versus standard 2.5-ton air source heat pumps (ASHP) from 5.9 years to 4.6 years at a 25°F minimum source temperature.

2. The advanced WSHP provides an opportunity for improving homeowner economics by downsizing the heat pump and earth loop in northern climates where standard WSHPs are sized for heating but often oversized for cooling.

5.5 UTILITY IMPACT COMPARISON

NMPC is a winter peaking utility and as such the impact of the various systems were analyzed for the peak heating day.

The results of the analysis are listed in Table 5-7. The advanced 3-ton WSHP provides a total diversified electric demand advantage of approximately 0.9 kW/ton over the standard 3-ton WSHP. If the advanced WSHP and earth loop are downsized for improved homeowner economics, the demand advantage is traded away. Compared to standard 2.5-ton air source

TABLE 5-5

ECONOMIC ANALYSIS ASSUMPTIONS

SYSTEM	MIN. TEMP.	ANNUAL OPERATING COSTS HEATING	COOLING	TOTAL	INSTALLATION COSTS HEAT PUMP (Incremental)	EARTH LOOP (Total)	TOTAL
Advanced 2-ton	20	567	37	603	-450	923	473
	25	560	36	596	-450	1,315	865
	30	545	35	581	-450	3,668	3,218
Advanced 2.5-ton	20	531	36	567	-150	995	845
	25	526	35	561	-150	1,415	1,265
	30	516	35	551	-150	3,645	3,495
Advanced 3-ton	20	513	35	548	275	1,043	1,318
	25	509	35	544	275	1,475	1,750
	30	502	34	536	275	3,420	3,695
Standard 3-ton	20	732	41	773	0	705	705
	25	697	41	737	0	1,065	1,065
	30	653	39	692	0	2,628	2,628
Standard 3.5-ton	20	617	43	660	490	903	1,393
	25	609	43	652	490	1,285	1,775
	30	597	42	639	490	3,028	3,518

- Performance Factors are presented in Figure 5-4
- Earth Loop Lengths are presented in Figure 5-4
- Electric Rate - $0.065/kWh
- Earth Loop Installation Cost - $2.40/Trench Foot
- Annual Heating Load = 76.3 MMBtu (22.4 MWH)
- Annual Cooling Load = 12.9 MMBtu (3.8 MWH)
- Installed Cost of a Standard 3-ton WSHP unit is $3500, excluding ductwork and earth loop.
- Assumptions for a standard 2.5-ton ASHP are as follows:
  - a) Installation cost excluding ductwork of $3,650 (P.J. Hughes, et.al., 1985).
  - b) SPF = 1.7 (P.R. Burns, et.al., 1987, SPF of 1.83 observed for a top-of-the-line unit).
  - c) SEER = 12 (value selected so that cooling operating cost would be similar to WSHP).
  - d) Total annual operating cost equals $891 (based on b) and c) above).

TABLE 5-6

SUMMARY OF SIMPLE PAYBACK ANALYSIS

BASE CASE -- STANDARD 3-ton @ 25°F MINIMUM TEMPERATURE
ASHP -- STANDARD 2 1/2-TON AIR-SOURCE HEAT PUMP

SYSTEM	MIN. TEMP. (°F)	vs. BASECASE (years)	vs. ASHP (years)
Advanced 2-ton	20	Immediate	1.1
	25	Immediate	2.4
	30	13.8	9.9
Advanced 2.5-ton	20	Immediate	2.1
	25	1.1	3.4
	30	13.1	9.8
Advanced 3-ton	20	1.3	3.4
	25	3.5	4.6
	30	13.1	10.0
Standard 3-ton	20	(10.0)	4.7
	25	-	5.9
	30	34.9	12.5
Standard 3.5-ton	20	4.2	5.4
	25	8.3	6.8
	30	24.8	13.4

( ) - Number of years required for the total operating cost savings for the base case to equal the additional first cost of the earth loop.

TABLE 5-7

SUMMARY OF UTILITY IMPACT COMPARISONS

Assumptions

- Utility Peak Demand hour is at 7:00 PM on a winter peak day.
- House load equals the load at 7:00 PM.
- WSHP source temperature is at the minimum temperature of 25°F (-1.9°C)
- Performance values as listed in Tables 5-2 through 5-4c
- ASHP source temperature is the typical temperature at 7:00 PM on a winter peak day (5°F)

SYSTEM	LOAD @ 7:00 PM	CAPACITY @ 25°F	POWER	BACKUP REQUIRED	TOTAL DIVERSIFIED ELECTRIC DEMAND
Advanced WSHP 2-ton	33,925 Btuh (9.9 kW)	23.6 kBtuh (6.9 kW)	2.31 kW	3.04 kW	5.35 kW
Advanced WSHP 2.5-ton	33,925 Btuh (9.9 kW)	27.3 kBtuh (8.0 kW)	2.60 kW	1.94 kW	4.54 kW
Advanced WSHP 3-ton	33,925 Btuh (9.9 kW)	30.9 kBtuh (9.1 kW)	2.90 kW	0.84 kW	3.74 kW
Standard WSHP 3-ton	33,925 Btuh (9.9 kW)	21.5 kBtuh (6.3 kW)	2.89 kW	3.64 kW	6.53 kW
Standard WSHP 3.5-ton	33,925 Btuh (9.9 kW)	28.7 kBtuh (8.4 kW)	3.29 kW	1.54 kW	4.83 kW

SYSTEM	LOAD @ 7:00 PM	CAPACITY @ 5°F	POWER	BACKUP REQUIRED	TOTAL DIVERSIFIED ELECTRIC DEMAND
Standard ASHP 2.5-ton	33,925 Btuh (9.9 kW)	13.0 kBtuh (3.8 kW)	2.70 kW	6.1 kW	8.8 kW

TOTAL DIVERSIFIED ELECTRIC DEMAND ADVANTAGES:

Advanced 3-ton WSHP Over Standard 3-ton WSHP (6.53-3.74) kW/3-ton = 0.9 kW/ton
Advanced 2.5-ton WSHP Over Standard 2.5-ton WSHP (8.8-4.54) kW/2.5-ton = 1.7 kW/ton

heat pumps (ASHP) the advanced 2.5-ton WSHP provides a total diversified electric demand advantage of approximately 1.7 kW/ton.

Section 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 REVIEW OF OBJECTIVES

The objective of this project was to field-validate the analytical prediction that the prototype heat pumps would provide similar seasonal performance to existing technology while lowering the earth loop length requirement.

These results from the field tests indicate that the project did indeed meet its stated objective. Previous tests of existing technology based systems yielded heating SPFs of 2.5 - 3.0 with earth loop sizes of 450 - 460 trench ft/ton (1 pipe/trench) (P. Hughes, 1985). The advanced systems achieved heating SPFs of about 2.7 with earth loops of 282 trench ft/ton (Site 10, 1 pipe/trench) and 183 trench ft/ton (Site 11, 2 pipes/trench). Similarly, cooling SEERs for existing technology ranged from 10.5 - 11.7 compared to 11.3 - 11.9 for the advanced systems.

6.2 CONCLUSIONS

The project conclusions are divided into five categories: (1) ECHP system design, (2) operation and maintenance, (3) performance, (4) economics, and (5) utility impact.

6.2.1 ECHP System Design

Normalized performance analyses indicated that, for equivalent minimum source temperatures, the advanced WSHP design could achieve significantly higher performance than standard WSHP designs. For example, the advanced 3-ton WSHP achieves a heating SPF of 2.8 compared to a standard 3-ton WSHP heating SPF of 2.1 at a 25°F minimum source temperature. This performance advantage can be sacrificed in favor of lower installed cost by reducing the earth loop length or by reducing the WSHP size.

For very small earth loops with minimum source temperatures below 25°F, the performance advantage of the advanced WSHP over the standard WSHP increases. However, the incremental benefit of sizing for minimum source temperatures below 25°F is small and increases the risk of experiencing soil problems.

Normalized performance analyses also indicated that, for equivalent heating SPF in a standard house in Syracuse, the advanced WSHP can be sized at 2.0-tons whereas the standard WSHP needs to be sized at 3.5-tons. Under this condition, the advanced 2.0-ton WSHP requires an earth loop only 40 percent as long as that needed by the standard 3.5-ton WSHP.

The above specific example is not a general rule for sizing earth loops to the advanced WSHP. WSHP manufacturers serving the ECHP market usually provide analytical methods for determining the minimum earth loop size required for specific applications. It is recommended that these manufacturer methods be utilized when available because they do a custom calculation for the specific site loads, conditions, and heat pump characteristics, and hence arrive at the most closely sized earth loop.

Contractor rules of thumb are often utilized locally once experience has established practical design values (P.J. Hughes, May 1986). For example, for heavy dry soil in New York State a one-pipe horizontal earth loop requires 405 trench feet/ton, and a two-pipe side-by-side horizontal earth loop requires 251 trench feet/ton to achieve SPFs of 2.5-3.0 with a standard WSHP. This project successfully demonstrated SPFs of 2.7 with advanced WSHPs with 30 percent less one-pipe loop, and 27 percent less two-pipe loop. This is the basis for the general statement that the advanced WSHP does indeed provide similar performance with 30 percent less earth loop.

6.2.2 Operation and Maintenance

No operation and maintenance differences were noted between the advanced and standard systems.

6.2.3 Performance

The normalized performance analysis showed that the advanced 3-ton ECHP system achieves heating SPFs in the range of 2.5 to 2.8 for a standard house in Syracuse, compared to 2.1 to 2.4 for standard 3-ton systems under the same design and operating conditions of which the minimum source temperature of 25°F is most critical. Similarly, the advanced ECHP achieves cooling SEERs in the range of 11 to 12, compared to 10 to 10.5 for the standard systems.

6.2.4 Economics

The advanced WSHP enhances the competitiveness of ECHP systems. Payback of the advanced 3-ton WSHP versus the standard 3-ton WSHP is 3.5 years at a 25°F minimum source temperature. The advanced 3-ton WSHP lowers the payback of ECHP systems versus standard 2.5-ton air source heat pumps (ASHP) from 5.9 years to 4.6 years at a 25°F minimum source temperature. These paybacks can be improved by trading away the performance advantage of advanced WSHPs relative to standard WSHPs for lower installed cost.

6.2.5 Utility Impact

The advanced 3-ton WSHP provides a total diversified electric demand advantage of approximately 0.9 kW/ton over the standard 3-ton WSHP. If the advanced WSHP and earth loop is downsized for improved homeowner economics, the demand advantage is traded away. Compared to standard 2.5-ton air source heat pumps (ASHP), the advanced 2.5-ton WSHP provides a total diversified electric demand advantage of approximately 1.7 kW/ton.

6.3 RECOMMENDATIONS

The major barrier to widespread application of earth-coupled heat pump systems remains the installed cost of the earth loop. Additional efforts recommended to reduce this cost are:

- Improved installation techniques.
- Development of specialized tools or equipment to simplify and automate the installation process.
- Evaluation of new loop configurations for their applicability in various geographic locations and geological conditions.

Section 7
REFERENCES

Baxter, V.D., et.al., 1987, Analysis and Field Evaluation of an Advanced Ground-Coupled Heat Pump System, Proceedings of the IEA Workshop on Ground-Source Heat Pumps. Held in Albany, NY on October 27 through November 1, 1986.

Burns, P.R., et.al., 1987, Monitoring and Evaluation of Add-On Heat Pump Technologies; Phase 2 Final Report. Syracuse, NY: Prepared for Niagara Mohawk Power Corporation.

Calm, J.M. (editor), 1987, Proceedings of the IEA Workshop on Ground-Source Heat Pumps, held October 27 through November 1, 1986 in Albany, NY.

Catan, M.A. and Baxter, V.D., 1985, An Optimized Ground-Coupled Heat Pump System Design for Northern Climate Application, ASHRAE Transactions, ASHRAE 91(2B), pages 1185-1203.

Hackner, R.J., et.al., 1987, Design of ECHP Systems in Northern Climates, ASHRAE Transactions, V.93 Pt. 2, Atlanta.

Hughes, H.M., 1985, A Parameterized Cost Model for Ground-Coupled Heat Pumps, ASHRAE Transactions, 91(2B), pages 1204-1215.

Hughes, P.J., et.al., 1985, Residential Earth-Coupled Heat Pump Demonstration: Phase 1 and 2 Final Report. Albany, NY: Prepared for the New York State Energy Research and Development Authority, Niagara Mohawk Power Corporation, and Rochester Gas and Electric Corporation, by W.S. Fleming and Associates, Inc., Report No. 85-20.

Hughes, P.J., et.al., 1987. Residential Earth-Coupled Heat Pump Demonstration: Phase 3 Final Report. Albany, NY: Prepared for the New York State Energy Research and Development Authority, Niagara Mohawk Power Corporation, and Rochester Gas and Electric Corporation, by W.S. Fleming and Associates, Inc., to be published.

Hughes, P.J., May 1986. Manual of Acceptable Practices for Installation of Residential Earth-Coupled Heat Pump Systems. Prepared for Niagara Mohawk Power Corporation, the New York State Energy Research and Development Authority, and Rochester Gas and Electric Corporation by W.S. Fleming and Associates, Inc.

Appendix A

DATA ACQUISITION AND ANALYSIS

DATA ACQUISITION

This section presents the data acquisition procedures, the hourly data points, their location and their verification specifications, and the analysis constants.

Procedures

At each of the two sites, on/off status, temperatures, earth loop flow, and electrical consumption was monitored on an hourly basis.

The data acquisition units used were Campbell Scientific 21X Microloggers. The 21X Micrologger scanned sensor inputs every 30 seconds, except for on/off status which was checked at 6 second intervals. Sensor inputs were converted to engineering units and stored in memory. Every hour the appropriate analysis (sum, average, etc.) was performed for each monitored data point. Results of this analysis were placed into the final storage area where they could be accessed by peripheral devices. Enough memory existed internally to store four weeks of hourly data. When the internal storage was full, new data was written over the earliest hour still in memory. Thus, the last four weeks of data were always available.

Data transmission to the WSFA central facility was conducted daily over a voice-grade phone line installed at each site exclusively for data communication. A Campbell Scientific DC103A answer-only modem was called by an IBM PC at WSFA's central facility. The previous twenty-four hours of data was then transmitted to the IBM PC.

Data transmitted to the IBM PC was then uploaded to a minicomputer where it underwent an automated process which verified the data and loaded it into site databases. Once there, the data were available for electronic access and analysis. Two levels of verification were performed: (1) range checks, and (2) relational checks. Range checks verified that each data item had a value within minimum and maximum bounds. For every point that did not fall within these bounds a message was written to a file. In addition, relationships between sets of data points were compared to ensure that the system was performing as expected. Again, if the expected relationship did not occur, an error message was written to a file. Error messages were read daily by the Project Manager to identify data problems or system malfunctions as they occurred.

If problems were identified, service contractors or field technicians were sent to the site to remedy the situation. Error message files were checked daily except on weekends. Therefore, the longest time that a problem could go undetected was 72 hours, and less than 24 hours during the week.

Analysis Constants

In order to perform analysis, certain physical quantities in addition to the hourly data were required. These items are quantities which do not vary significantly with time and therefore did not need to be included in hourly monitoring.

AUTOMATED HOURLY DATA POINTS:
TYPICAL BOTH SITES

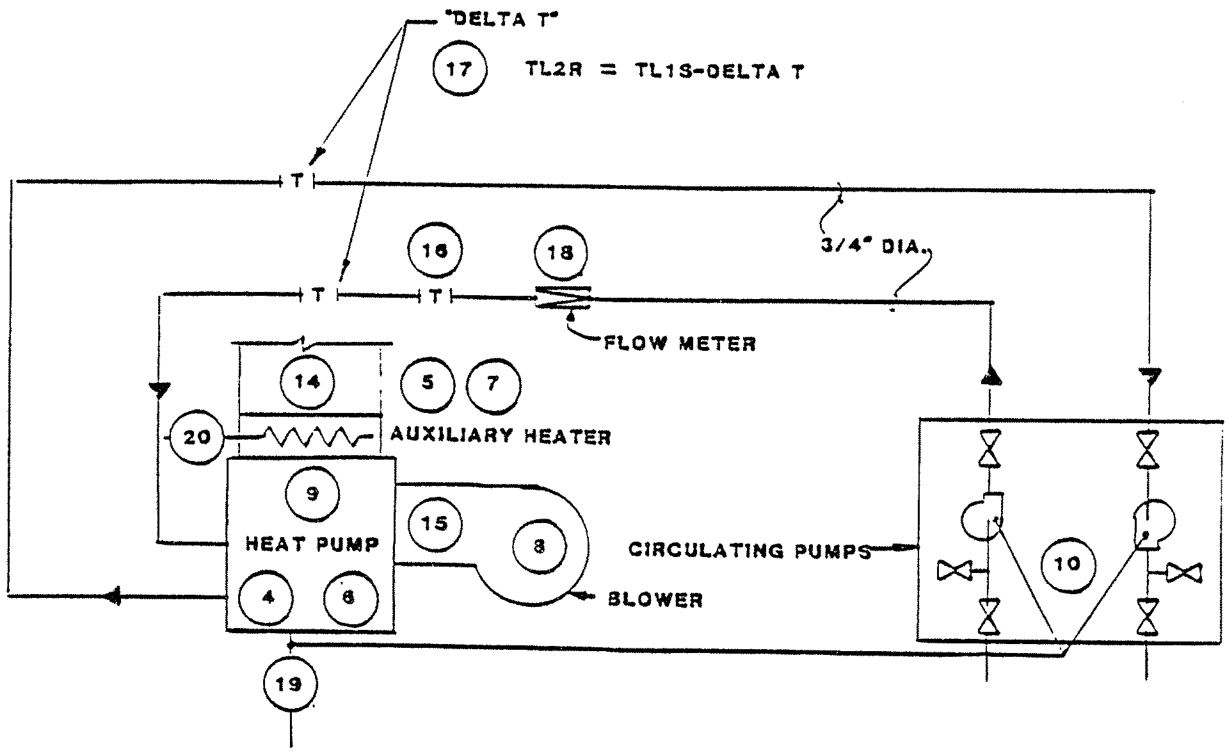
POINT NAME	OUTPUT POINT #	DESCRIPTION	DATALOGGER INPUT CHANNEL	SENSOR OUTPUT CHANNEL	ENGIN. UNITS	FILTER/ MASK	OUTPUT POINT #	LOW LIM.	HIGH LIM.
-	1	Descriptor	-	-	Integer		1		
Day	2	JULIAN DAY	-	-	Integer		2		
Hour/Min	3	HOUR (24)/MIN of Day	-	-	Integer		3		
S1Cy	4	COMPRESSOR Cycles	SE 1	RELAY	# STARTS	-	4		
S2ACy	5	AUX. HEAT Cycles	SE 2	RELAY	# STARTS	-	5		
S1Rt	6	COMPRESSOR Runtime	SE 1	RELAY	Min.	-	6		
S2ARt	7	AUX. HEAT Runtime	SE 2	RELAY	Min.	-	7		
S3FRt	8	BLOWER Runtime	SE 3	RELAY	Min.	-	8		
S4CRt	9	COOLING MODE Runtime	SE 4	RELAY	Min.	-	9		
S5PRt	10	Earth LOOP PUMP Runtime	SE 5	RELAY	Min.	-	10		
TAMB	11	AMBIENT Temp.	DE 4	T-TYPE	Deg. F	-	11		
TROOM	12	ROOM Temp (at T'STAT)	DE 5	T-TYPE	Deg. F	-	12		
TFF	13	FAR FIELD Temp (4ft deep)	DE 6	T-TYPE	Deg. F	-	13		
TA1S	14	SUPPLY Air Temp.	DE 7	T-TYPE	Deg. F	S3F ON	14		
TA2R	15	RETURN Air Temp	DE 8	T-TYPE	Deg. F	S3F ON	15		
TL1S	16	Earth Loop SOURCE Temp	DE 9	T-TYPE(I)	Deg. F	S5P ON	16		
TL2R	17	Earth Loop RETURN Temp	DIF 10	T-TYPE (I)	Deg. F	S5P ON	17		
FIEL	18	Earth Loop FLOW	P 1	PULSE	GPM	-	18		
KWH1	19	KWH HEAT PUMP	P 2	PULSE	KWH1	-			
KWH2S	20	KWH RES.HEAT	P 3	PULSE	KWH2S	-			
KWH3T	21	KWH Total House	P 4	PULSE	KWH3T	-			
KWDEM	22	Total Heating Sys. DEMAND	-	-	KWH	15 Min.			
BAT	23	Battery VOLTAGE	-	-	Volts	-		12	15

For these two sites, the analysis constants required were as follows:

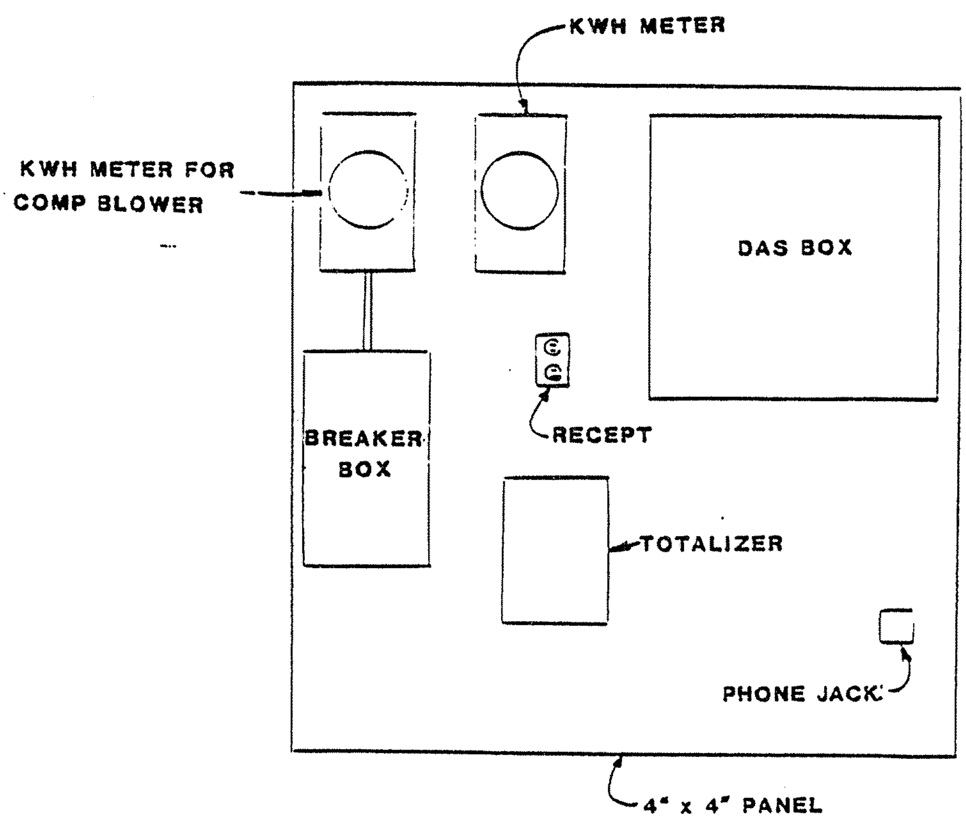
- Heating Duct Air Flow (cubic feet per minute)
  Analysis Variable Name: CFM
  This quantity is needed to calculate the heat output or extraction by the heat pump through the forced-air system.
- Specific heat (Btu/hr-^{o}F) and Density (lb/ft^3) of earth loop fluid
  Analysis Variable Names: CP and RHO respectively
  These quantities are both derived from measurements of freeze points of the ethylene glycol/water mixture in the earth loops. These quantities are necessary for calculation of the heat extracted or dumped to the earth loop by the heat pump.
- Blower Power Consumption (kW)
  Analysis Variable Name: BLKW
- Loop Pump Power Consumption (kW)
  Analysis Variable Name: LPKW

SENSOR LOCATION SCHEMATIC AND PANEL
BOARD DETAIL: TYPICAL BOTH SITES

a) Sensor Location Schematic



b) Panel Board Detail



DATA POINT VERIFICATION SPECIFICATIONS:
TYPICAL BOTH SITES

a) Range Checks

LOW LIMIT	HIGH LIMIT	PT. #	VAR. NAME	ENGG. UNITS	PT. DESCRIPTION
0.	366.	1	DAY	JULIAN	DAY NUM; JAN 1 = 1
0.	23.	2	HOUR	HR	HOUR OF DAY (0-23)
0.	61.	3	MINUTE	MIN	MINUTE
0.	10.	4	S1CCY	# IN HR	COMPRESSOR CYCLES
0.	10.	5	S2ACY	# IN HR	AUX HEAT CYCLES
0.	61.	6	S1RT	MINUTES	COMP. RUN TIME
0.	61.	7	S2ART	MINUTES	AUX. HEAT RUN TIME
0.	61.	8	S3FRT	MINUTES	BLOWER RUN TIME
0.	61.	9	S4CRT	MINUTES	COOLING MODE RUN TIME
0.	61.	10	S5PRT	MINUTES	EARTH LOOP PUMP RUN TIME
-30.	110.	11	TAMB	DEG F	AMBIENT TEMP
60.	80.	12	TROOM	DEG F	ROOM AIR TEMP AT T-STAT
32.	64.	13	TFF	DEG F	FAR FIELD TEMP DEEP
50.	120.	14	TA1S	DEG F	SUPPLY AIR TEMP
55.	85.	15	TA2R	DEG F	RETURN AIR TEMP
25.	95.	16	TL1S	DEG F	EARTH LOOP SOURCE TEMP
20.	100.	17	TL2R	DEG F	EARTH LOOP RETURN TEMP
0.	800.	18	F1EL	GALLONS	EARTH LOOP FLOW (HOURLY TOTAL)
0.	4.	19	KWH1C	KWH	KWH, HEAT PUMP SYSTEM
0.	6.	20	KWH2H	KWH	KWH, ELECTRIC HEAT
0.	20.	21	KWH3T	KWH	KWH,TOTAL HOUSE
0.	10.	22	KWDEM	KW	DEMAND, TOTAL HEATING SYSTEM

b) Relational Checks

1. HEAT PUMP RAN, BUT NO KWH REPORTED.
2. ELECTRIC HEAT RAN, BUT NO KWH REPORTED.
3. HEAT PUMP RAN, BUT NO EARTH LOOP FLOW REPORTED.
4. HEAT PUMP HEATING, BUT SOURCE TEMP. NOT GREATER THAN RETURN.
5. HEAT PUMP HEATING, BUT SUPPLY AIR TEMP. NOT GREATER THAN RETURN.
6. HEAT PUMP COOLING, BUT SUPPLY AIR NOT LESS THAN RETURN.
7. HEAT PUMP COOLING, BUT SUPPLY AIR NOT LESS THAN RETURN.
8. ELECTRIC HEAT RAN WITHOUT HEAT PUMP.
9. CAPACITY IS LESS THAN 24,000.
10. C.O.P. IS LESS THAN 2.5 OR GREATER THAN 4.0.

REPORT DESCRIPTIONS

Data analysis was performed by retrieving stored data (using the data base manager) and ran that data through analysis algorithms for various reports. The reports were tables, point plots, line plots, and histograms. Each item or result in a report is calculated from certain raw data points using specific algorithms. The reports could be output on paper or on screen for electronic access.

Below are descriptions of the tabular/graphical reports that were presented in monthly, seasonal and final reports and were made electronically accessible. Subsequent to the description were the specifications for each report.

Operational Summary

The operational summary was a one-page report of major details of conditions and equipment operation over the analysis period. It contained the following items:

- Degree days based on site outside air temperature. For each day, the average of the hourly ambient temperatures was calculated and subtracted from 65. Each day's result was summed for the data interval.
- Average earth loop fluid flow rate.
- Average duct air flow for the HVAC system.
- Averages, maximums, and minimums of various temperatures.
- Equipment operation: cycles, runtimes, and energy consumption of heating system components.
- Heat transfer quantities for the major input and output energies of the system.
- Energy balance percent non-closure. This was the percentage difference between the heat pump output as calculated from air-side and liquid-side measurements.
- Performance Factors. Average heat pump coefficient of performance, capacity, and heating system seasonal performance factor, calculated for the entire analysis period.

System and Ambient Temperature Trend Plot

For each period reported, the following temperatures in degrees Fahrenheit were plotted as a function of time:

- Indoor air temperature
- Outdoor air temperature
- Earth loop source temperature
- Earth loop return temperature
- Far-field earth temperature at the depth of the coil

These temperatures were primary indicators of system operation and external conditions.

Heating Load Line Scatter Plot

For all hours in which the blower operates, the load was calculated as the total heating output of both heat pump and supplemental electric heat. Then, the load was plotted versus the simultaneous ambient temperature to produce a scatter plot for the analysis period.

Capacity vs. Source Temperature Plot

For each hour in which the compressor operates, heat pump capacity was calculated as the energy output by the heat pump divided by compressor on-time (to get a rate in Btu/hr). Then, capacity was plotted versus the simultaneous earth loop source temperature and produced a scatter plot for the analysis period.

C.O.P vs. Source Temperature Plot

For each hour in which the compressor operates, heat pump coefficient of performance was calculated as the ratio of energy delivered to the space divided by heat pump electrical energy consumption. This was plotted versus the simultaneous earth loop source temperature.

Time of Day Electrical Usage Histogram

The heating system electrical uses were summed to obtain a total system kWh for each hour. The kWh values were divided into 24 bins based on hour of the day, and each bin was summed over the reporting period. The histogram was a graphic display of the electrical consumption of the heating system by time of day.

Electrical Demand Frequency Histogram

Each hour an electrical demand for the heating system was recorded as the maximum power usage of the total system over a 15 minute interval during that hour. These values were multiplied by four to obtain a maximum demand rate in kW over the hour. The histogram displayed the frequency with which demand existed within specified demand intervals.

CAMPBELL CR21 DATALOGGER SPECIFICATIONS

SPECIFICATIONS

The following electrical specifications are valid for an ambient temperature range of −25 deg. C to +50 deg. C unless otherwise specified.

ANALOG INPUTS

NUMBER OF CHANNELS: 8 differential or up to 16 single ended using one differential channel for each two single ended channels.

CHANNEL EXPANDABILITY: The Model AM32 Relay Scanner multiplexes 32 differential channels through a single 21X differential channel. Up to 6 AM32 scanners can be added to a 21X for 192 additional analog channels.

VOLTAGE MEASUREMENT TYPES: Single-ended or differential. A thermistor at the input terminals provides reference junction compensation for thermocouple measurements.

ACCURACY OF VOLTAGE MEASUREMENTS AND ANALOG OUTPUT VOLTAGES: 0.1% of FSR, 0.05% of FSR (0 to 40 deg. C).

RANGE AND RESOLUTION: Ranges are software selectable for any channel. Resolution for single ended measurements is twice the value shown.

Full Scale Range	Resolution
±5 volts	333. microvolts
±0.5 volts	33.3 microvolts
±50 millivolts	3.33 microvolts
±15 millivolts	1. microvolt
±5 millivolts	0.33 microvolts

INPUT SAMPLE RATES: The fast A/D conversion uses a 250us signal integration time and the slow conversion uses a 16.666ms signal integration time (one power line cycle period). Differential measurements include a second sampling with reversed input polarity to reduce thermal offset and common mode errors. The following intervals do not include the self-calibration measurement which occurs once per instruction. Input sample rates should not be confused with system data throughput rates.

Fast single-ended voltage:
2.4 milliseconds/channel
Fast differential voltage:
3.7 milliseconds/channel
Slow single-ended voltage:
18.8 milliseconds/channel
Slow differential voltage:
37.0 milliseconds/channel
Fast differential thermocouple:
7.3 milliseconds/channel

INPUT NOISE VOLTAGE:
Fast differential — 0.83 microvolts RMS
Slow differential — 0.1 microvolts RMS

COMMON MODE RANGE: ±5 volts.

COMMON MODE REJECTION: >140 dB (DC to 100 Hz).

NORMAL MODE REJECTION: 70 dB (60 Hz with slow differential measurement).

INPUT CURRENT: 2 nanoamps max.

INPUT RESISTANCE: 200 gigohms

ANALOG OUTPUTS

NUMBER OF ANALOG OUTPUTS: 4 switched, 2 continuous.

DESCRIPTION: Switched and continuous. A switched output is active only during a measurement and is switched off (high impedance) immediately following the measurement. Only one switched output can be active at any one time. The 2 continuous outputs hold a preset voltage until updated by an analog output command.

RANGE: ±5 volts.

RESOLUTION: 0.67 millivolts.

ACCURACY: Same as voltage input.

OUTPUT CURRENT: 20 mA at ±5 volts, 50 mA at ±2.5 volts.

RESISTANCE AND CONDUCTIVITY MEASUREMENTS

ACCURACY: 0.035% (0.02% 0 to 40 deg. C) of full scale bridge output provided the matching bridge resistors are not the limiting factor. The excitation voltage should be programmed to match the bridge output with a full scale input voltage range.

MEASUREMENT TYPES: 6 wire full bridge, 4 wire full bridge, 4 wire, 3 wire and 2 wire half bridge. High accuracy, low impedance bridge measurements are ratiometric with dual polarity measurements of excitation and output to eliminate thermal emfs. AC resistance and conductivity measurements use a 750us excitation pulse with the signal integration occurring over the last 250us. An equal duration pulse of opposite polarity is applied for ionic de-polarization.

PULSE COUNTERS

NUMBER OF PULSE COUNTER CHANNELS: 4 eight bit or 2 sixteen bit, software selectable.

MAXIMUM COUNT RATE: 2550 Hz, eight bit counters; 250 kHz, sixteen bit counters. Pulse counter channels are scanned at a maximum rate of 10 Hz.

MODES: Programmable modes are switch closure, high frequency pulse and low level AC.

SWITCH CLOSURE MODE
MINIMUM SWITCH CLOSED TIME:
3 milliseconds.
MINIMUM SWITCH OPEN TIME:
4 milliseconds.
MAXIMUM BOUNCE TIME:
1 millisecond open without being counted.

HIGH FREQUENCY PULSE MODE
MINIMUM PULSE WIDTH:
2 microseconds.
MAXIMUM INPUT FREQUENCY:
250 kilohertz.
VOLTAGE THRESHOLDS:
The count is incremented when the input voltage changes from below 1.5 volts to above 3.5 volts.
MAXIMUM INPUT VOLTAGE:
±20 volts.

LOW LEVEL AC MODE
This mode is used for counting frequency of AC signals from magnetic pulse flow transducers or other low voltage, sine wave outputs.

MINIMUM AC INPUT VOLTAGE:
6 millivolts RMS
INPUT HYSTERESIS:
11 millivolts.
MAXIMUM AC INPUT VOLTAGE:
20 volts RMS.
FREQUENCY RANGE:

AC Input Voltage (RMS)	Range
6 millivolts	1 Hz to 100 Hz
10 millivolts	0.5 Hz to 1000 Hz
20 millivolts to 20 volts	0.3 Hz to 2000 Hz

(consult factory if higher frequencies are desired)

DIGITAL CONTROL OUTPUTS

The 21X includes 6 digital control outputs that can be set or reset on command.

OUTPUT VOLTAGES
(no load): High — 5 volts ±.1 volt.
Low — <0.1 volt.

OUTPUT RESISTANCE:
400 ohms.

TRANSIENT PROTECTION

All input and output connections are protected using spark gaps connected directly to a heavy copper bar on the circuit card between the two input terminal strips. The 12 volt power input and charger inputs are protected with transzorbs.

CPU AND INTERFACE

PROCESSOR: HITACHI 6303 CMOS 8 bit microprocessor.

MEMORY: 16k ROM, 4k RAM, expandable in increments of 8k of RAM or ROM up to a total of 64k. Standard 21X stores 896 low resolution data points in Final Memory, 19,200 data points with fully expanded RAM.

DISPLAY: 8 digit LCD (0.5" digits).

PERIPHERAL INTERFACE: 9 pin D-type connector on the panel for connection to cassette recorder, modem, printer, or RS232 adapter. The serial interface can be programmed for baud rates of 300, 1200, 9600 and 76,800.

CLOCK ACCURACY: ±1 minute per month.

MAXIMUM PROGRAM EXECUTION RATE: The 21X Programming Table can be executed in sync with real time at a maximum rate of 80 per second. Typical throughput rates allow 1 measurement with linear scaling and transfer to tape at this rate with no interruption.

SYSTEM THROUGHPUT: Data throughput is the rate at which a signal can be measured, processed and stored in Final Memory. The rate is reduced by additional processing or when data is transferred to Cassette Tape or through the 21X serial port.

Throughput to the cassette tape is 100 data values per second. During tape transfer, 25% of the CPU's time is required. Therefore, program execution is uninterrupted if the user-entered program requires less than 75% of the CPU's time.

ASCII data values (10 characters per value) can be transmitted via the serial port at 9600 baud with a throughput of approximately 100 values per second with 15% CPU utilization. Faster throughput rates are possible if CSI's binary format is transmitted (consult factory).

Each time a new measurement instruction is specified, time for two additional measurements is required for self-calibration. Therefore, using more repetitions in fewer instructions increases throughput.

SYSTEM POWER REQUIREMENTS

VOLTAGE: 9.6 to 15 volts.

TYPICAL CURRENT DRAIN: 1.0 mA quiescent, 25 mA during processing, and 60 mA during analog measurement.

INTERNAL BATTERIES: 8 Alkaline D cells with 7 amp hour capacity. The Model 21XL includes sealed lead acid batteries with 2.5 amp hour capacity per charge.

EXTERNAL BATTERIES: Any 12 volt external battery can be connected as a primary power source with the internal batteries providing backup while changing external batteries.

OPERATION FROM OTHER SOURCES: The Model 21XL includes a battery charging circuit that can be connected to 15 to 30 VDC indefinitely to maintain a full charge on the batteries without degradation. The charging circuit includes temperature compensation for maintaining optimum charging voltage at temperature extremes. A 110 VAC to 16 VDC wall transformer is provided with the 21XL.

PHYSICAL SPECIFICATIONS

SIZE: 8.2" X 5.7" X 3.3". Input terminal strips extend 0.45" above the panel surface.

WEIGHT: 6.2 lbs.

Reprinted October 1984

MEASUREMENT:	Operational Status (Pump, Blower, Compressor, Resistance Heat)
EQUIPMENT: Specifications:	Low Voltage Relays Potter Brumfield KRPA11AG-24V Relay Contacts Rated to 10 Amps
RELATED EQUIPMENT:	Relay Base
APPLICATION NOTES:	All equipment operational status points were achieved by use of 24 VAC control voltage supplied by the equipment. Resultant time accuracy was the scan rate of the datalogger (6 seconds).

MEASUREMENT:	Temperature
EQUIPMENT: Specifications:	Thermocouple Gordon Temperature Measurement T-Type Thermocouple Wire T20-6-502 Accuracy: ±0.5°F when used individually.
APPLICATION NOTES:	For most temperatures a single junction was used. A differential junction measurement was used for the heat pump entering and leaving fluid temperature. With this method, the "delta T" across the unit was measured to an accuracy of ± 0.05°F. In effect, one junction was used as a reference junction to which the other was compared, the output signal being the difference between the two junction voltages. This accuracy was required because the temperature rise across the heat pump was typically small (about 5°F). Then, ± 0.05°F represented at 2 percent accuracy for this measurement, which translated into less than 2 percent on calculations of COP and heat output.

MEASUREMENT:	Fluid Flow
EQUIPMENT: Specifications:	Turbine Flow Meter Flow Technology, Inc. FT-16 (1" NPT) Turbine Flow Meter Range 0 to 50 USGPM Calibration Accuracy: ± 0.05% Repeatability: ± 0.04% Linearity: ± 0.5% Magnetic Pickoff Graphite Bearings
RELATED EQUIPMENT: Specifications:	PRI-3 Digital Indicator 120/240 VAC Digital display of instantaneous flow rate Analog output 0-5 VDC proportionate to flow Accuracy: ± 0.05% of reading ±1 count Resolution: 0.05% for 2000 counts Response Time: 0.35 seconds
APPLICATION NOTES:	Total system flow was continuously monitored, displayed and reported to the DAS. Union was incorporated in the system design to allow for removal of the turbine in the event of service requirements. Design of system incorporated a 10-pipe diameter up stream, 5-pipe diameter down stream straight section of pipe. Since heat output based results such as COP and capacity vary proportionally with flow rate. The possible error on these results which was due to flow measurement was 1% (± 0.05%).

MEASUREMENT:	kWh Consumption
EQUIPMENT: Specifications:	Pulse Initiating kWh Meter Westinghouse Electric Corporation Single Stator Watt Hour Meter CL 200 240V 3 Wire TA 30 Kh 7.2 Type D4S Form 2S Cyclometer Register Equipped with CDI-12B Pulse Initiator MP 25/60
APPLICATION NOTES:	The CDI-12B pulse initiator supplied mercury wetted contact closures in a ratio of 60 pulses to 25 meter revolutions. Since the meter constant was 7.2 Watt-hours per revolution, the resultant calibration factor was 3 watt-hours (0.003 kWh) per pulse. The resultant accuracy was equaled to one pulse missed or added in any one hour. However, over longer periods, the total consumption was averaged out.

APPENDIX B

FIELD MONITORED PERFORMANCE - HEATING

PHYSICAL CHARACTERISTICS - SITE #10

General Data

Location:	DeRuyter, New York
Original System:	Oil fired Hyrdonic Boiler
Design Heating Load:	39,000 Btu/hr at ASHRAE 99%
Soil Type:	Clay with gravel

Earth-Coupled Heat Exchanger

Configuration:	- single pipe in trench, 4 feet below grade
Size:	- 845 trench feet, 845 pipe feet (282 trench feet per ton)

System Data

Air Flow:	- 1200 CFM
Loop Flow:	- 10 GPM
Loop Fluid Type:	- Ethylene glycol
Heat Pump	- 3 Ton Nominal, Packaged Water-to-Air Unit of special low temperature design
Auxiliary Resistance Heat	- Available for Emergency Mode - 15 KW - Connected as Supplemental Backup - 5 KW

DATA REPORT: ADVANCED EARTH COUPLED HEAT PUMPS - SITE #10

FROM 11/ 6/85 HOUR 00 TO 5/31/86 HOUR 23
DATABASE HOURS RECORDED: 4938 (99.4%)

MODE: HEATING
HEATING DEGREE DAYS: 6244

AVERAGE EARTH LOOP PUMP FLOW: 10.15 GPM
AVERAGE HVAC AIR FLOW: 1200. CFM

TEMPERATURES-DEG F	AVERAGE	MINIMUM	MAXIMUM
AMBIENT TEMPERATURE	34.8	-17.1	84.3
ROOM TEMPERATURE	71.8	64.1	80.4
SUPPLY AIR TEMP-HEAT PUMP	87.6	74.7	97.0
RETURN AIR TEMP-HEAT PUMP	66.0	60.1	70.1
EARTH LOOP SOURCE TEMP	35.8	28.5	51.5
EARTH LOOP RETURN TEMP	31.8	24.4	47.3
FAR FIELD TEMPERATURE	39.8	33.1	57.7

EQUIPMENT OPERATION	CYCLES	HOURS	KWH	10^6 BTU
COMPRESSOR	7858	1940.9	3958.05	13.509
BLOWER		1947.4	1184.00	4.041
LOOP PUMP		1944.7	738.99	2.520
HEAT PUMP TOTAL			5881.04	20.072
AUXILIARY ELECTRIC HEAT	85	14.7	131.99	.450
HEATING SYSTEM TOTAL			6013.03	20.522

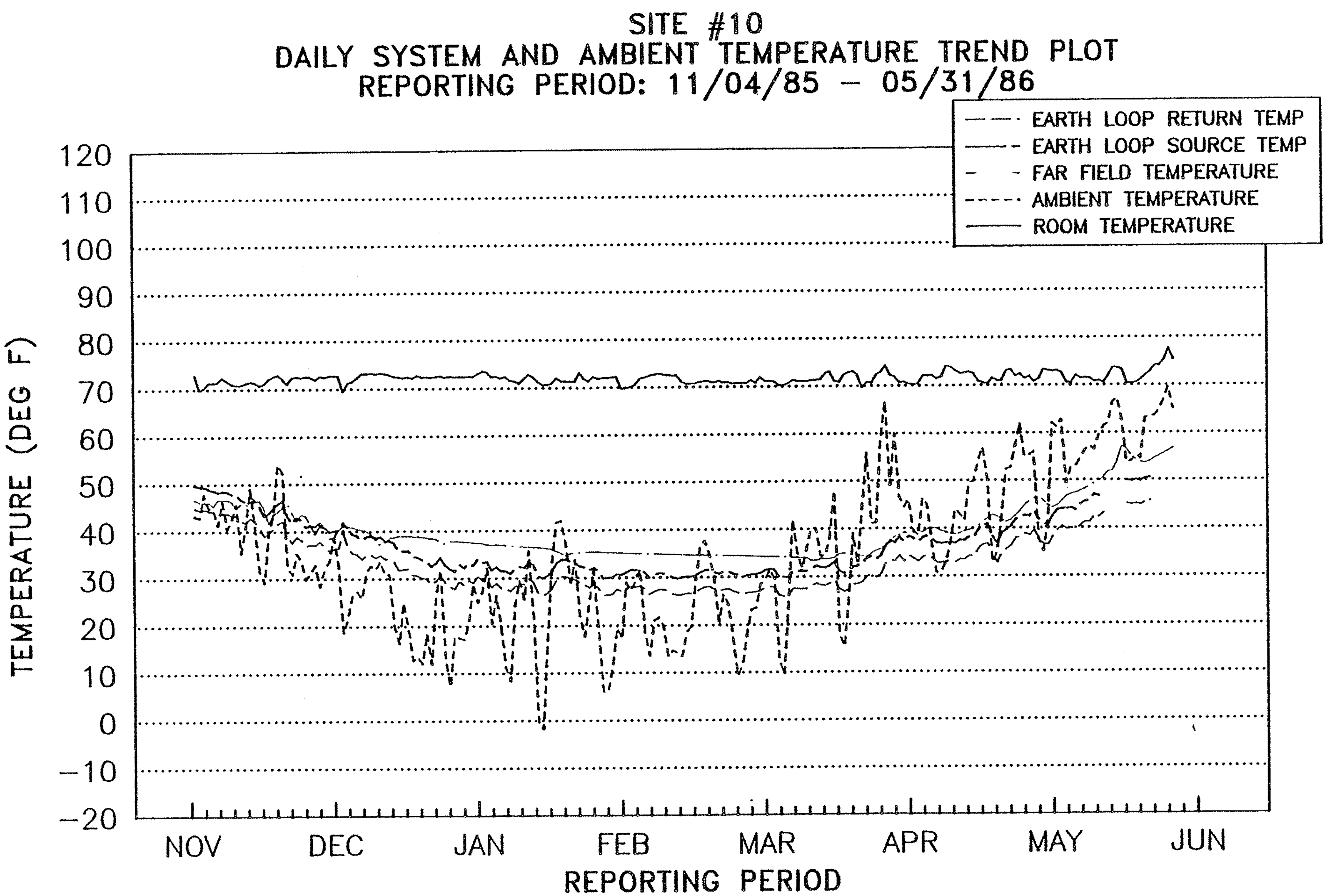
HEAT QUANTITIES	(MILLIONS OF BTUS
EARTH LOOP EXTRACTION	34.829
TOTAL HEAT PUMP WORK INTPUT	20.072
TOTAL HEAT PUMP OUTPUT	54.901
AUXILIARY ELECTRIC HEAT OUTPUT	0.450
TOTAL AIR SIDE HEAT OUTPUT	53.788

ENERGY BALANCE PER CENT NON-CLOSURE
(AIR SIDE VS. HEAT PUMP WATER SIDE + AUX ELECTRIC): 2.8%

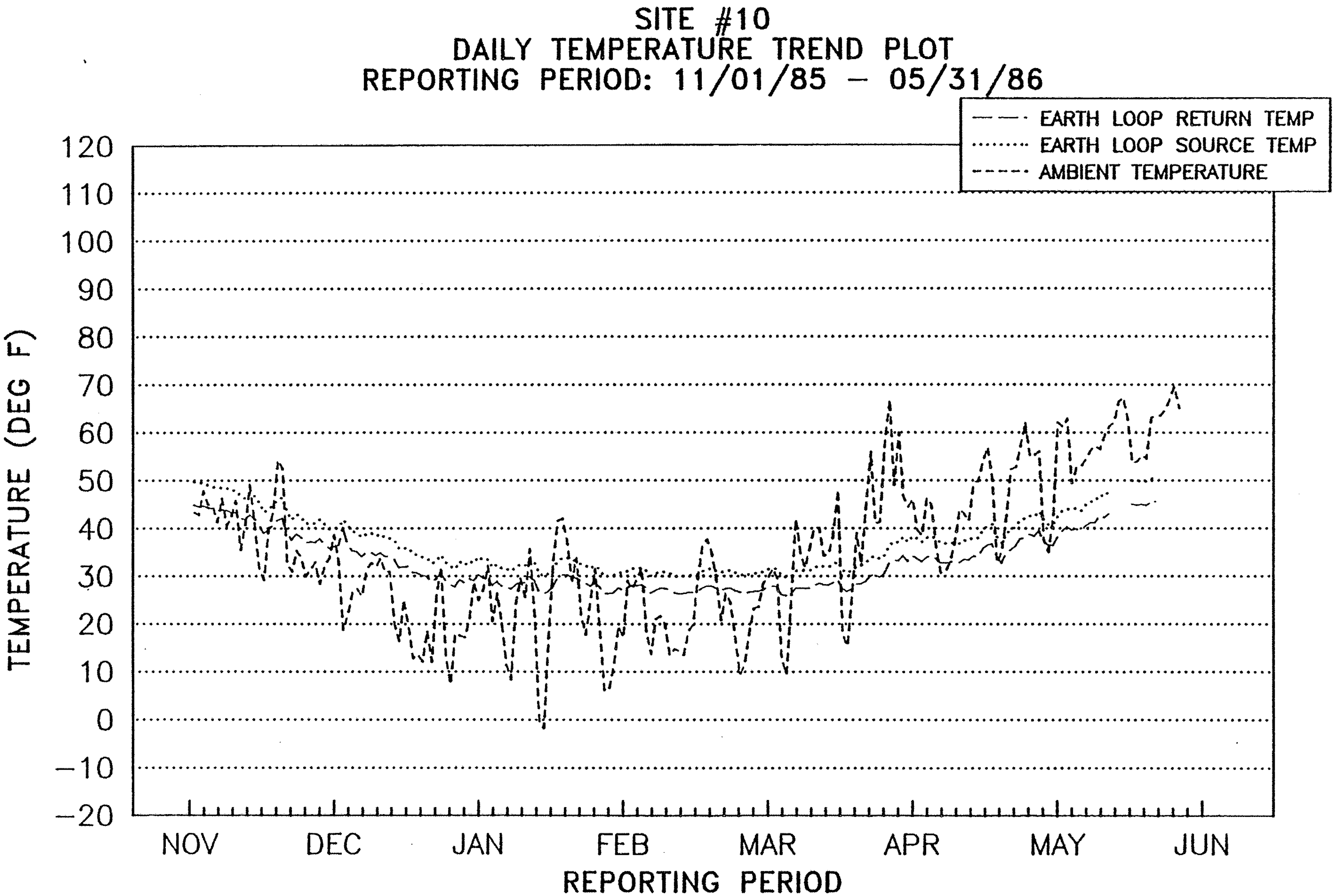
PERFORMANCE FACTORS

AVERAGE HEAT PUMP C.O.P.: 2.74
AVERAGE HEATING S.P.F.: 2.70

AVERAGE HEAT PUMP CAPACITY: 28286. BTU/HR

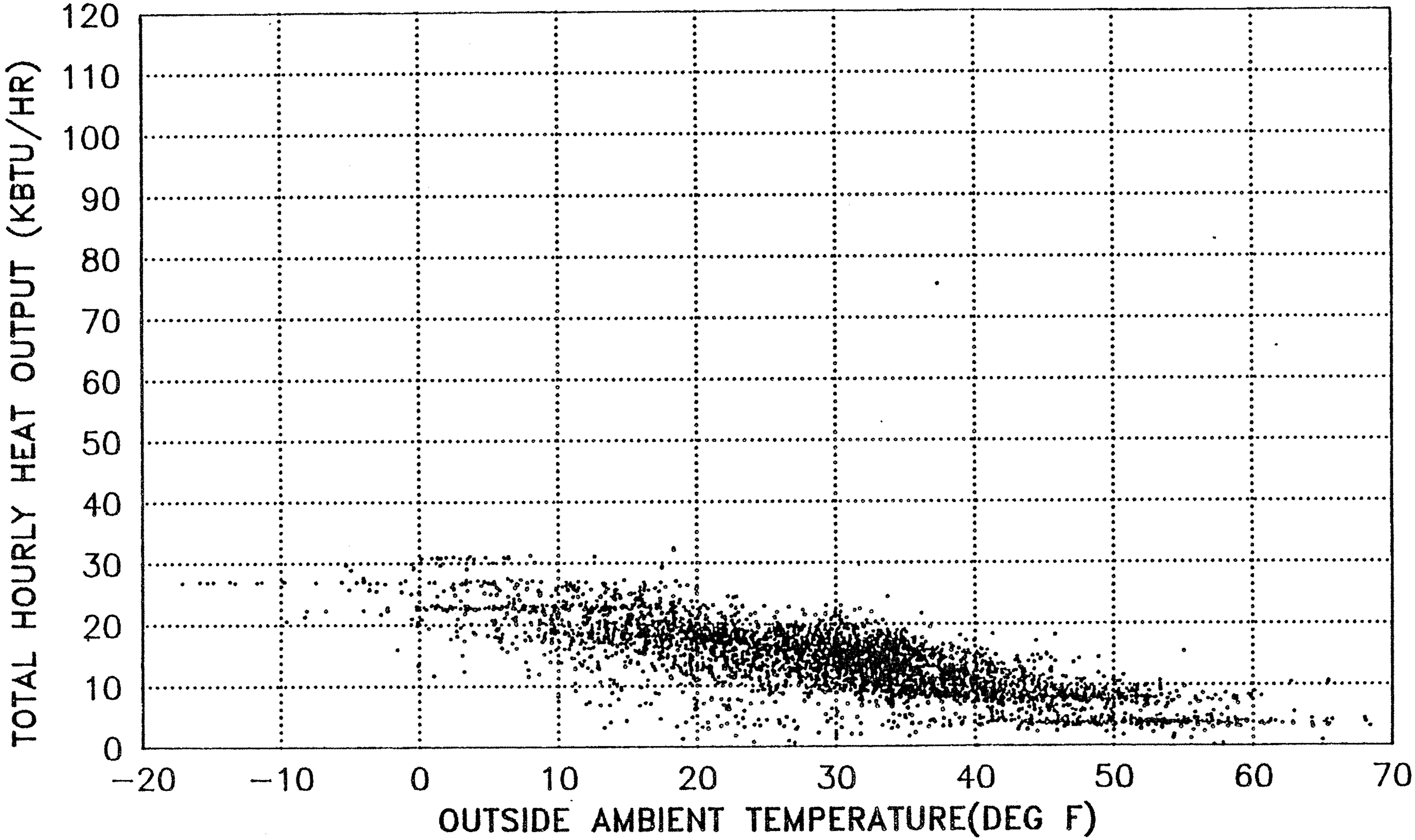


SITE #10
DAILY SYSTEM AND AMBIENT TEMPERATURE TREND PLOT
REPORTING PERIOD: 11/04/85 – 05/31/86
EARTH LOOP RETURN TEMP
EARTH LOOP SOURCE TEMP
FAR FIELD TEMPERATURE
AMBIENT TEMPERATURE
ROOM TEMPERATURE
TEMPERATURE (DEG F)
120
110
100
90
80
70
60
50
40
30
20
10
0
–10
–20
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
REPORTING PERIOD

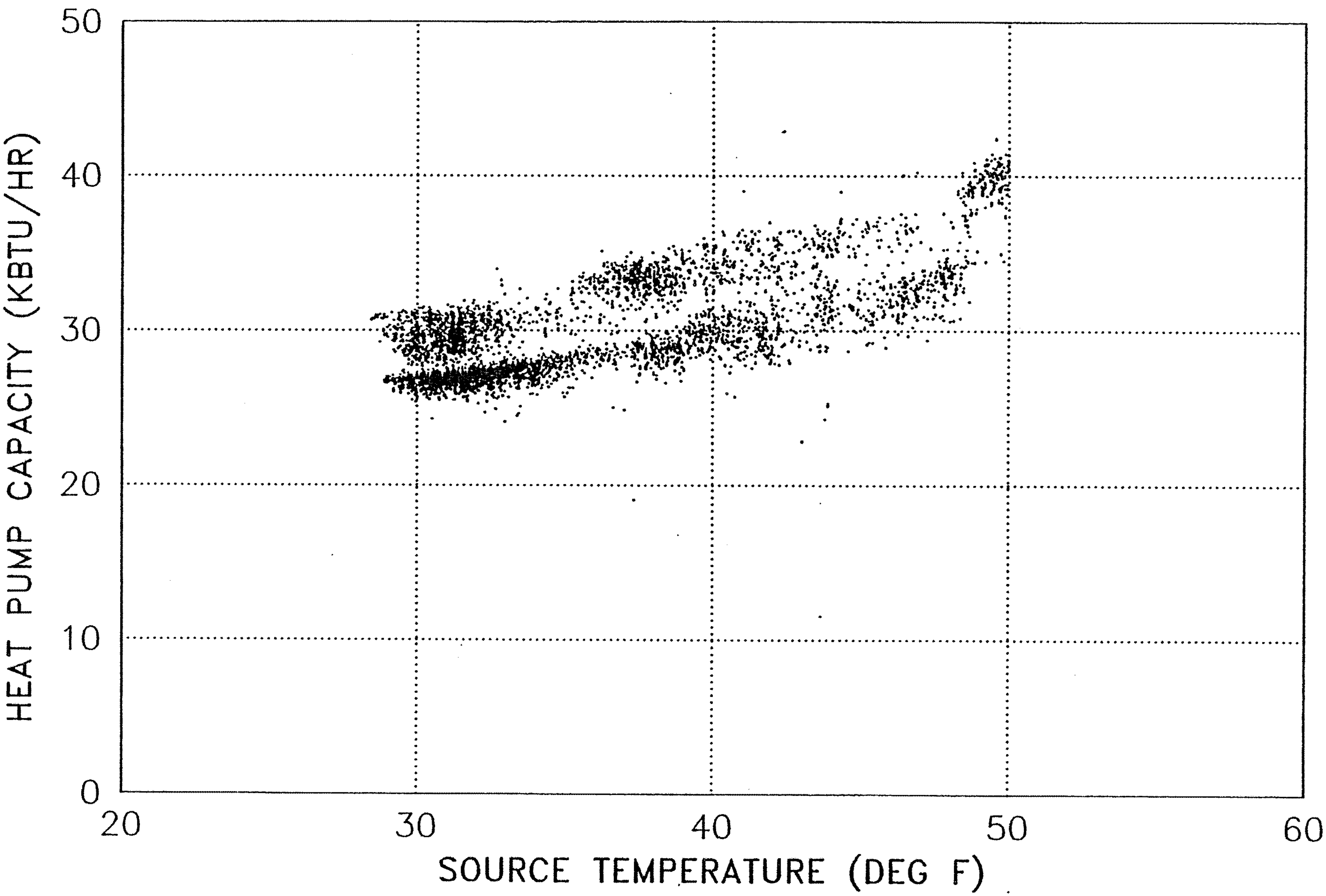


SITE #10
DAILY TEMPERATURE TREND PLOT
REPORTING PERIOD: 11/01/85 – 05/31/86
EARTH LOOP RETURN TEMP
EARTH LOOP SOURCE TEMP
AMBIENT TEMPERATURE
TEMPERATURE (DEG F)
120
110
100
90
80
70
60
50
40
30
20
10
0
–10
–20
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
REPORTING PERIOD

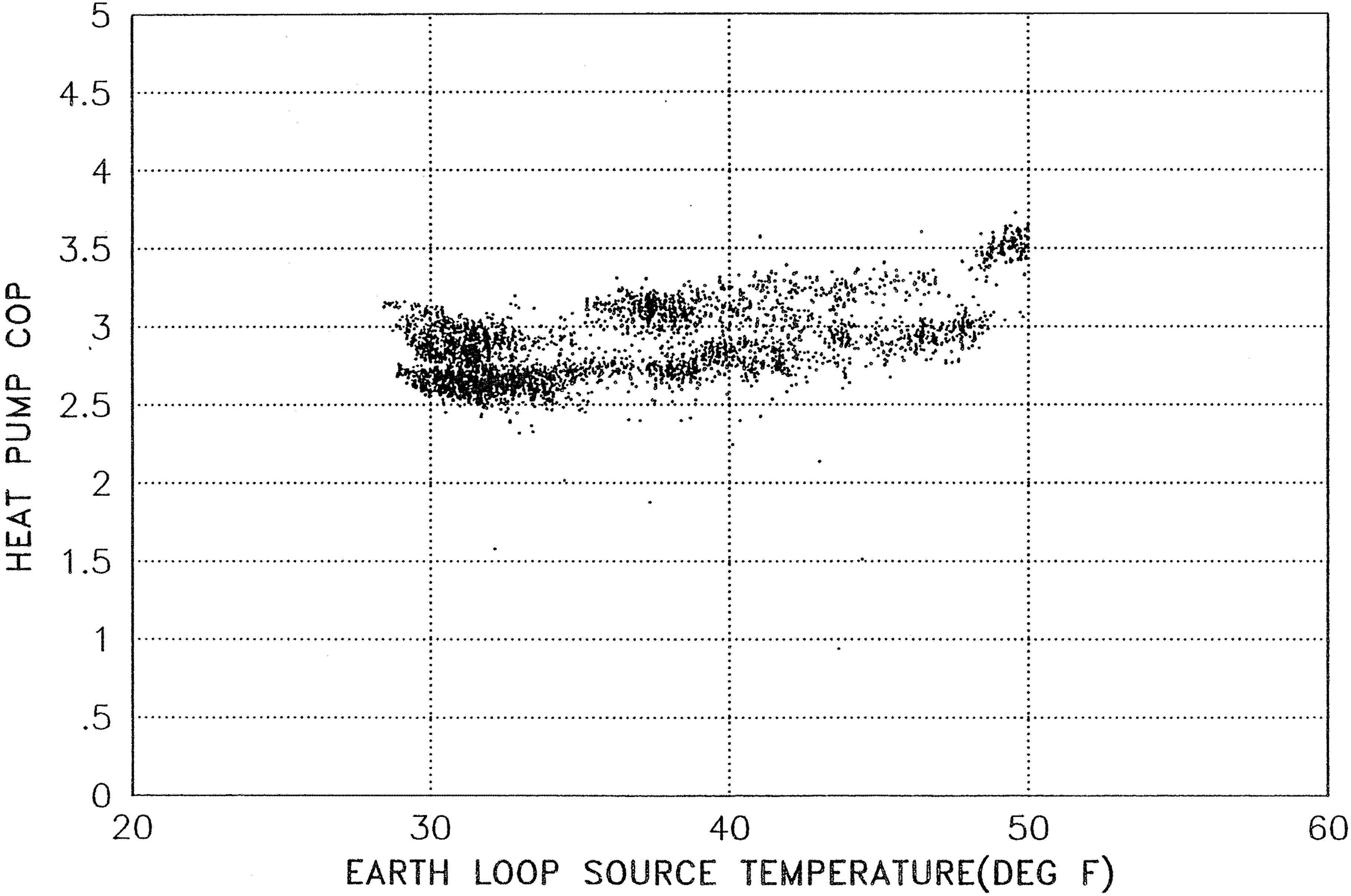
SITE #10
HEATING LOAD LINE
REPORTING PERIOD: 11/06/86-05/31/86

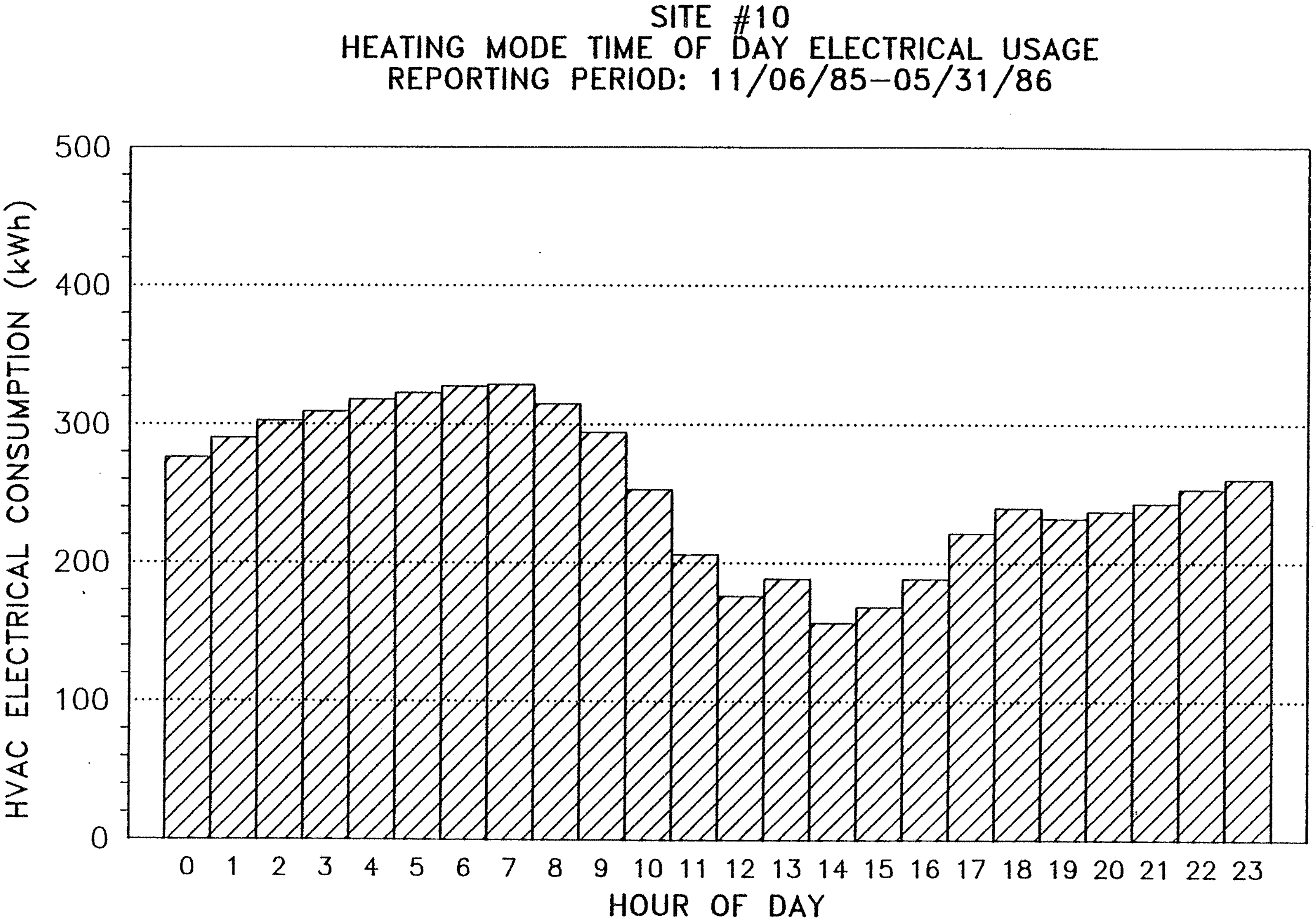


SITE #10
HEATING CAPACITY vs. SOURCE TEMPERATURE
REPORTING PERIOD: 11/06/85–05/31/86

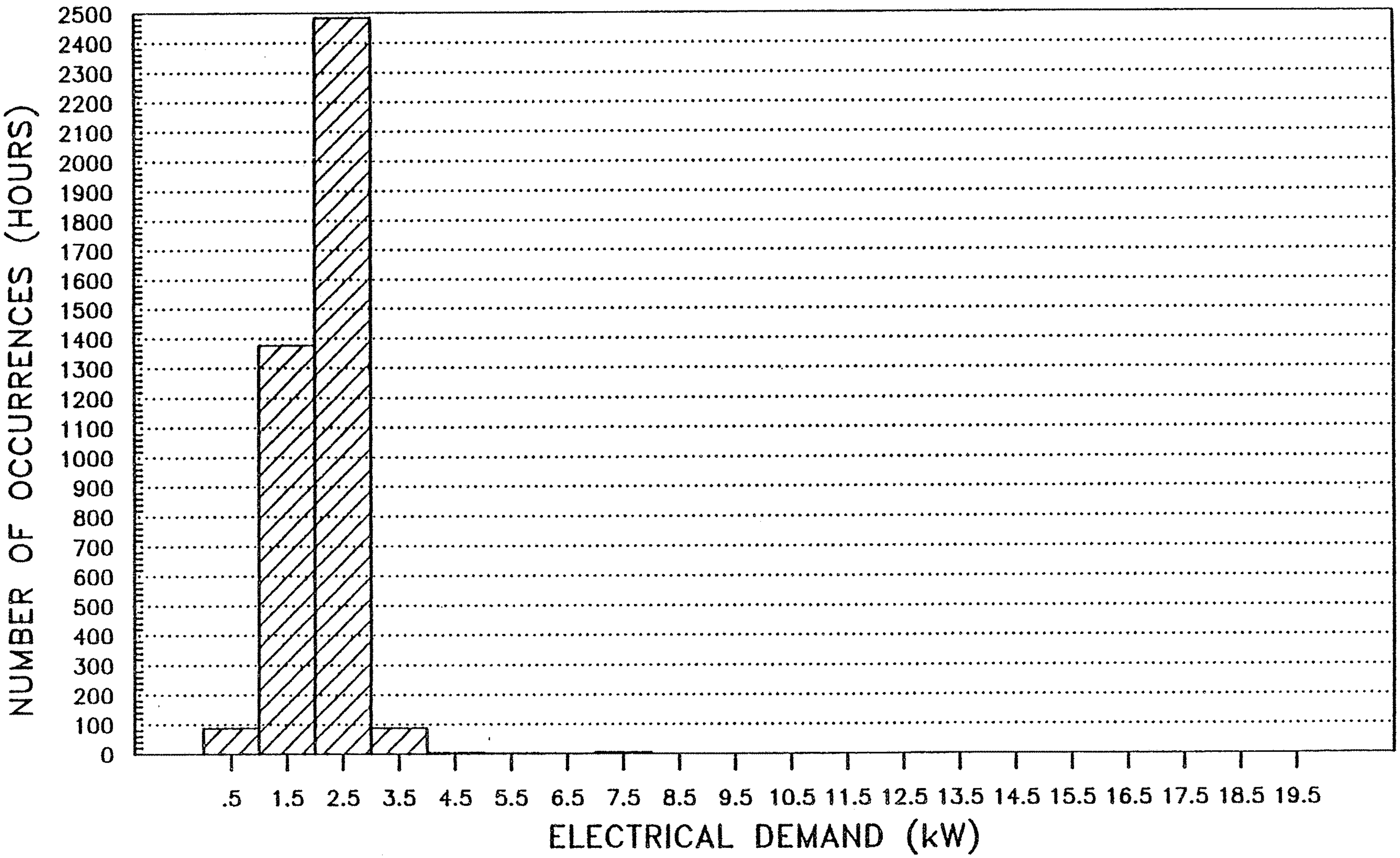


SITE #10
HEATING C.O.P. vs. SOURCE TEMPERATURE
REPORTING PERIOD: 11/06/85–05/31/86




SITE #10
HEATING MODE TIME OF DAY ELECTRICAL USAGE
REPORTING PERIOD: 11/06/85–05/31/86
HVAC ELECTRICAL CONSUMPTION (kWh)
0
100
200
300
400
500
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
HOUR OF DAY

SITE #10
HEATING MODE kW DEMAND FREQUENCY
REPORTING PERIOD: 11/06/85–05/31/86



PHYSICAL CHARACTERISTICS - SITE #11

General Data

Location:	Jamesville, New York
Original System:	Wood Fired Forced Hot Air Furnace
Design Heating Load:	52,000 Btu/hr at ASHRAE 99%
Soil Type:	Clay/Shale

Earth-Coupled Heat Exchanger

Configuration:	- Two pipes in trench, spaced 2 feet apart, 4 feet below grade
Size:	- 549 trench feet, 1100 pipe feet (183 trench feet per ton)

System Data

Air Flow:	- 1200 CFM
Loop Flow:	- 10 GPM
Loop Fluid Type:	- Ethylene glycol
Heat Pump	- 3 Ton Nominal, Packaged Water-to-Air Unit of special low temperature design
Auxiliary Resistance Heat	- Available for Emergency Mode - 15 KW - Connected as Supplemental Backup - 5 KW

SITE 11 - HEATING SEASON OPERATIONAL SUMMARY

DATA REPORT: ADVANCED EARTH COUPLED HEAT PUMPS - SITE #11

FROM 11/ 4/85 HOUR 00 TO 5/31/86 HOUR 23
DATABASE HOURS RECORDED: 4990 (99.5%)

MODE: HEATING
HEATING DEGREE DAYS: 6194

AVERAGE EARTH LOOP PUMP FLOW: 10.91 GPM
AVERAGE HVAC AIR FLOW: 1200. CFM

TEMPERATURES-DEG F	AVERAGE	MINIMUM	MAXIMUM
AMBIENT TEMPERATURE	35.5	-5.9	82.5
ROOM TEMPERATURE	69.9	65.8	80.4
SUPPLY AIR TEMP-HEAT PUMP	89.0	79.4	98.5
RETURN AIR TEMP-HEAT PUMP	67.2	63.8	71.6
EARTH LOOP SOURCE TEMP	33.6	27.7	53.9
EARTH LOOP RETURN TEMP	29.4	23.5	49.0
FAR FIELD TEMPERATURE	42.6	36.6	54.5

EQUIPMENT OPERATION	CYCLES	HOURS	KWH	10^6 BTU
COMPRESSOR	8327	2901.3	6144.80	20.972
BLOWER		2902.7	1764.82	6.023
LOOP PUMP		2901.2	1102.42	3.763
HEAT PUMP TOTAL			9012.04	30.758
AUXILIARY ELECTRIC HEAT	223	167.0	1004.36	3.428
HEATING SYSTEM TOTAL			10016.42	34.186

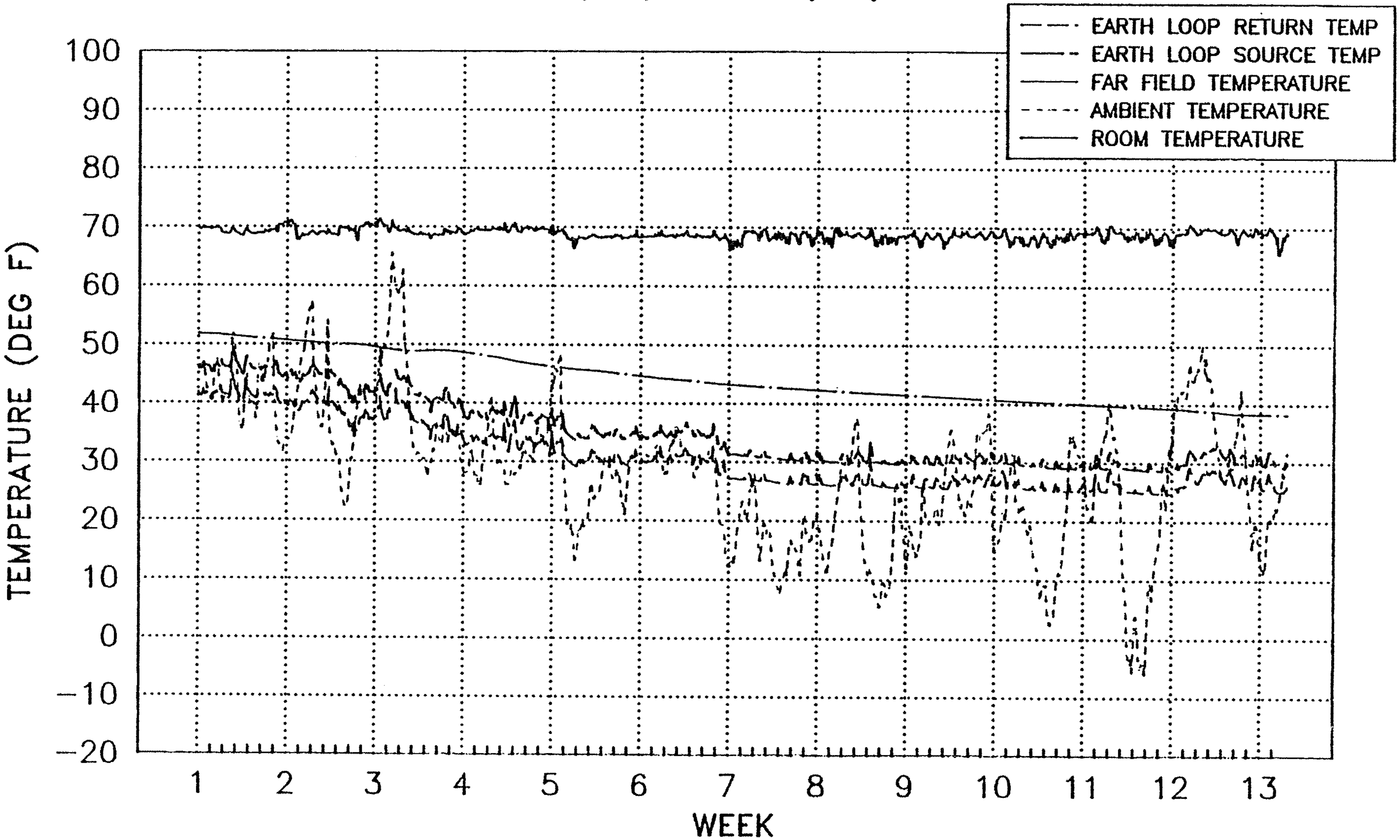
HEAT QUANTITIES	(MILLIONS OF BTUS)
EARTH LOOP EXTRACTION	58.578
TOTAL HEAT PUMP WORK INTPUT	30.758
TOTAL HEAT PUMP OUTPUT	89.336
AUXILIARY ELECTRIC HEAT OUTPUT	3.428
TOTAL AIR SIDE HEAT OUTPUT	85.004

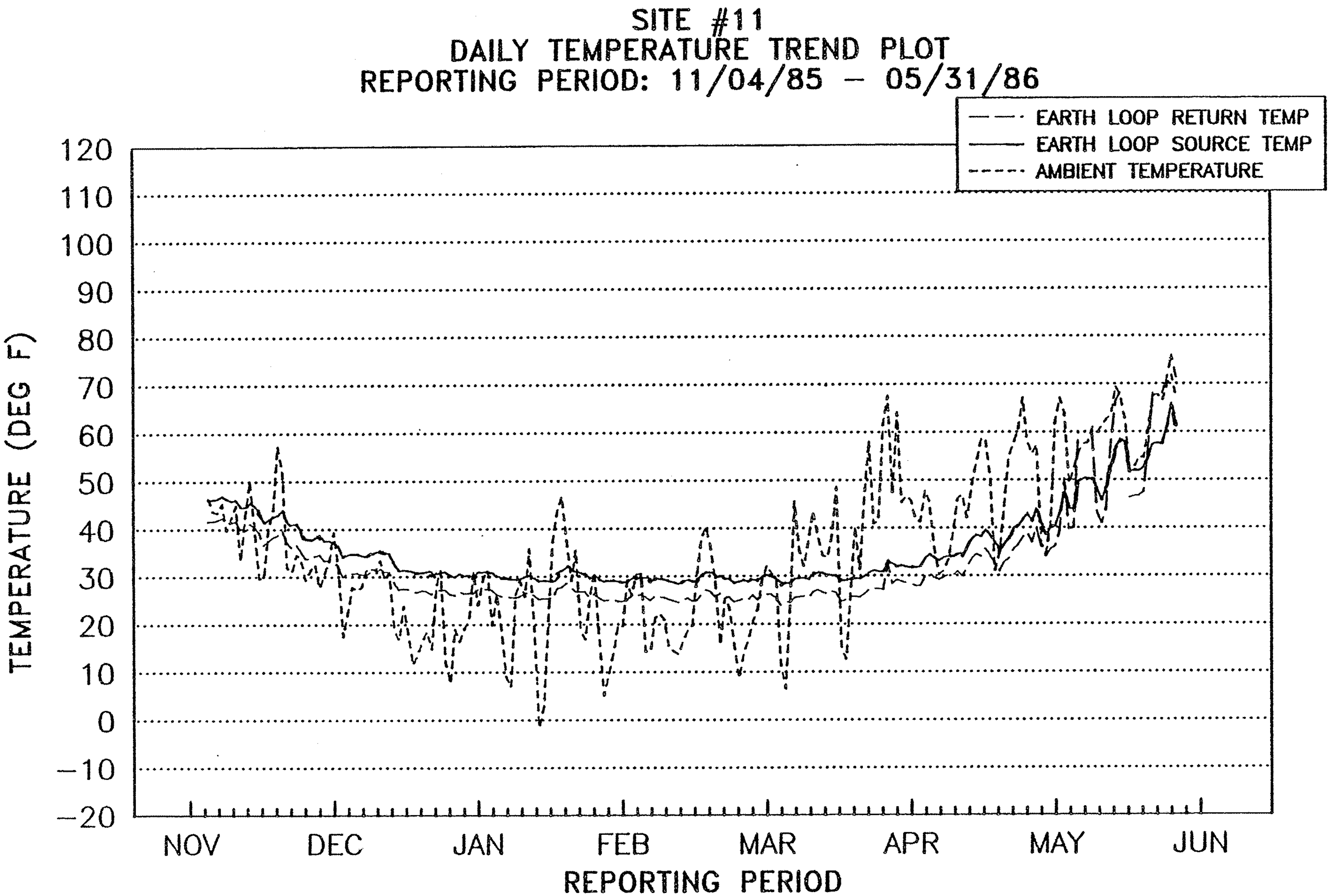
ENERGY BALANCE PER CENT NON-CLOSURE
(AIR SIDE VS. HEAT PUMP WATER SIDE + AUX ELECTRIC): 8.4%

PERFORMANCE FACTORS	
AVERAGE HEAT PUMP C.O.P.:	2.90
AVERAGE HEATING S.P.F.:	2.71

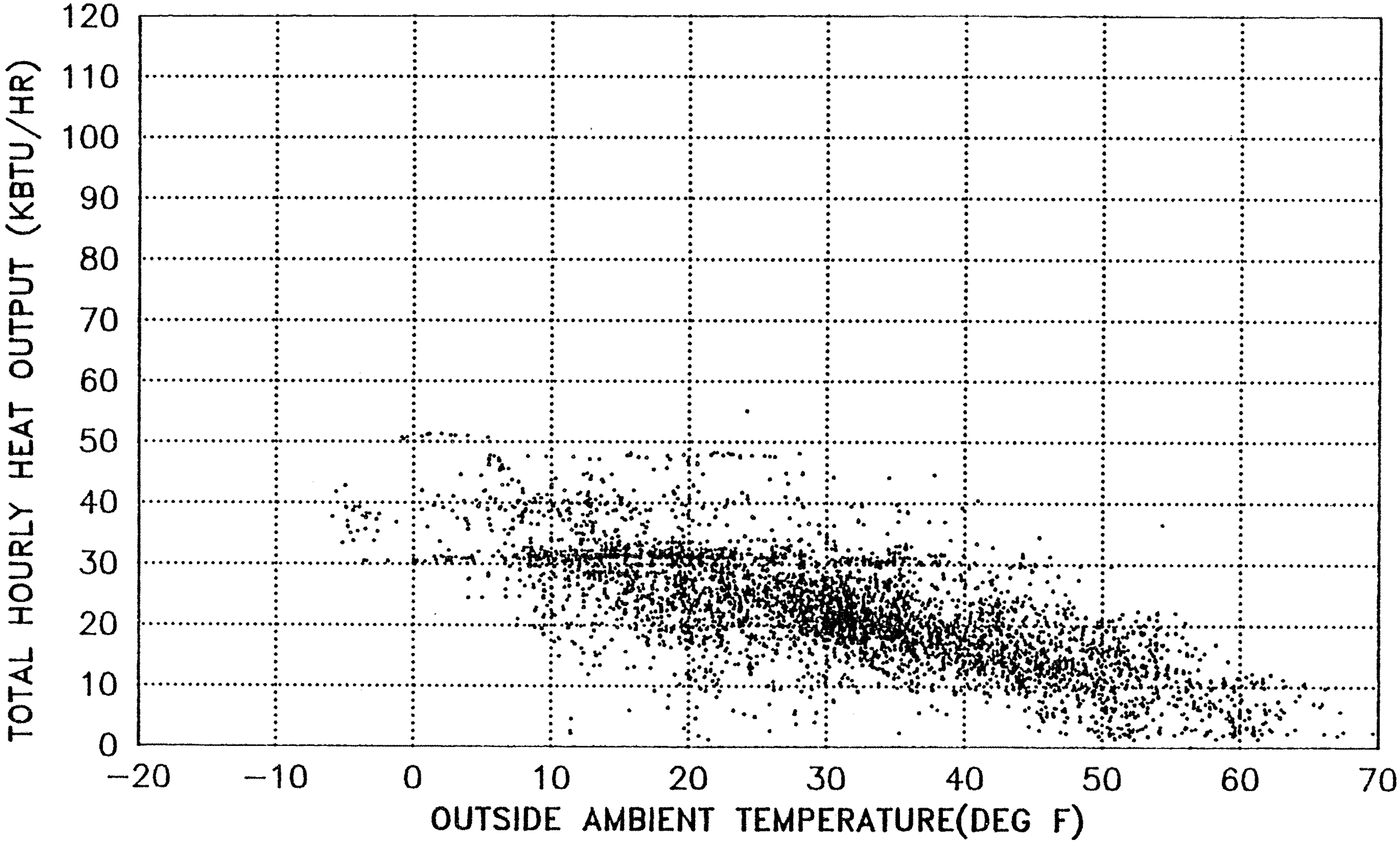
AVERAGE HEAT PUMP CAPACITY: 30792. BTU/HR

SITE #11
SYSTEM AND AMBIENT TEMPERATURE TREND PLOT
11/04/85 – 01/25/86

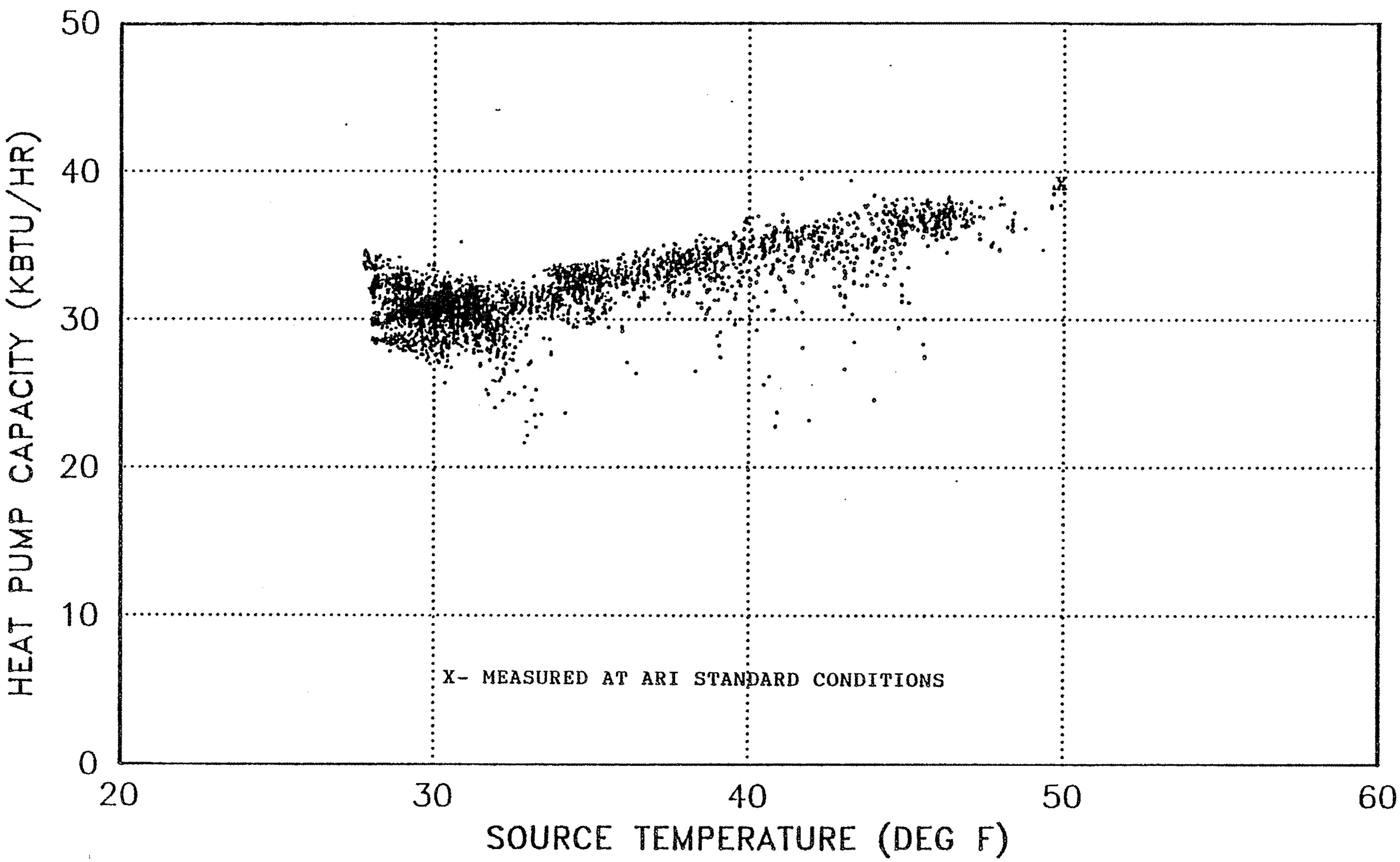



SITE #11
DAILY TEMPERATURE TREND PLOT
REPORTING PERIOD: 11/04/85 - 05/31/86
EARTH LOOP RETURN TEMP
EARTH LOOP SOURCE TEMP
AMBIENT TEMPERATURE
TEMPERATURE (DEG F)
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
REPORTING PERIOD

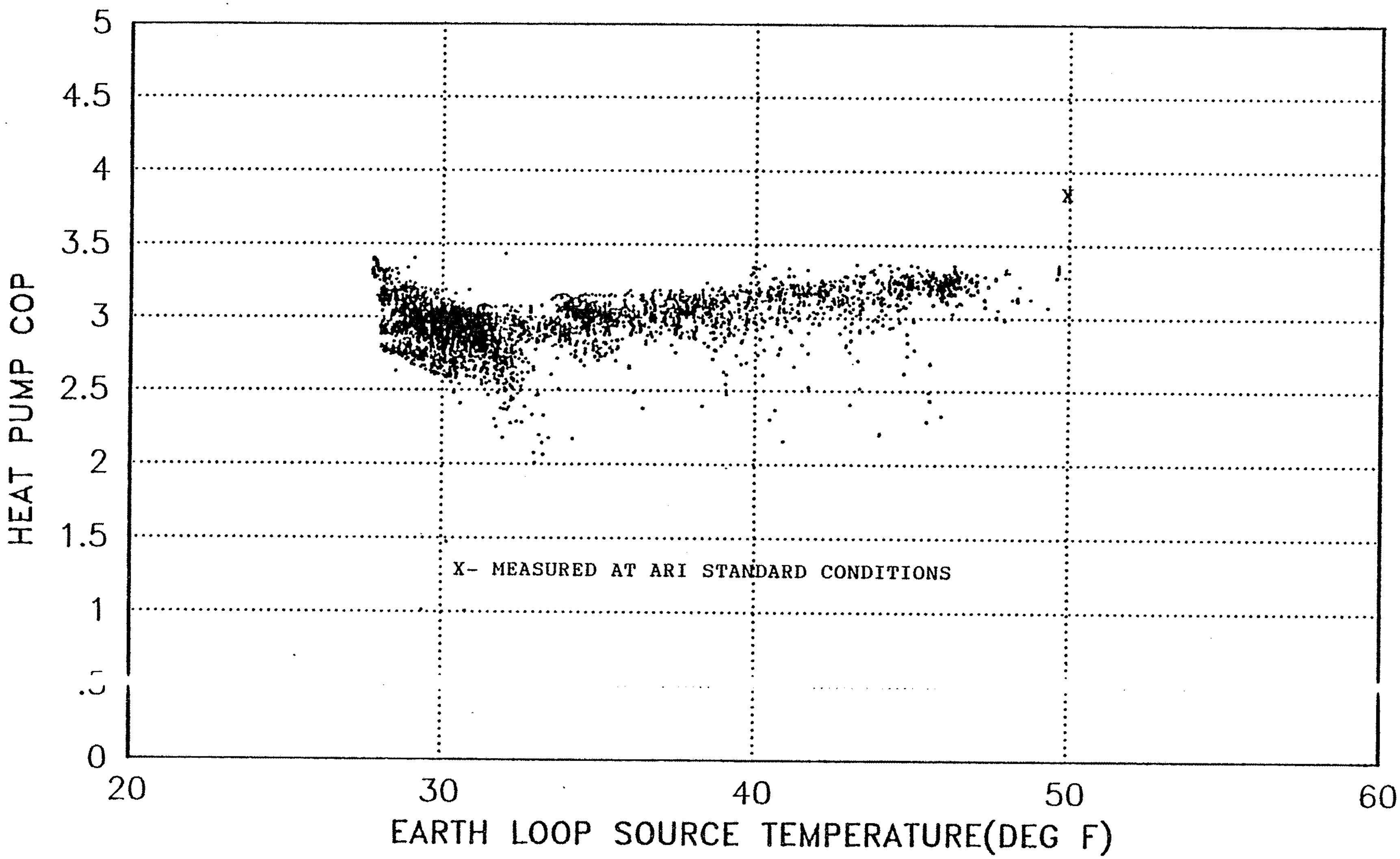
SITE #11
HEATING LOAD LINE
REPORTING PERIOD: 11/04/85–05/31/86



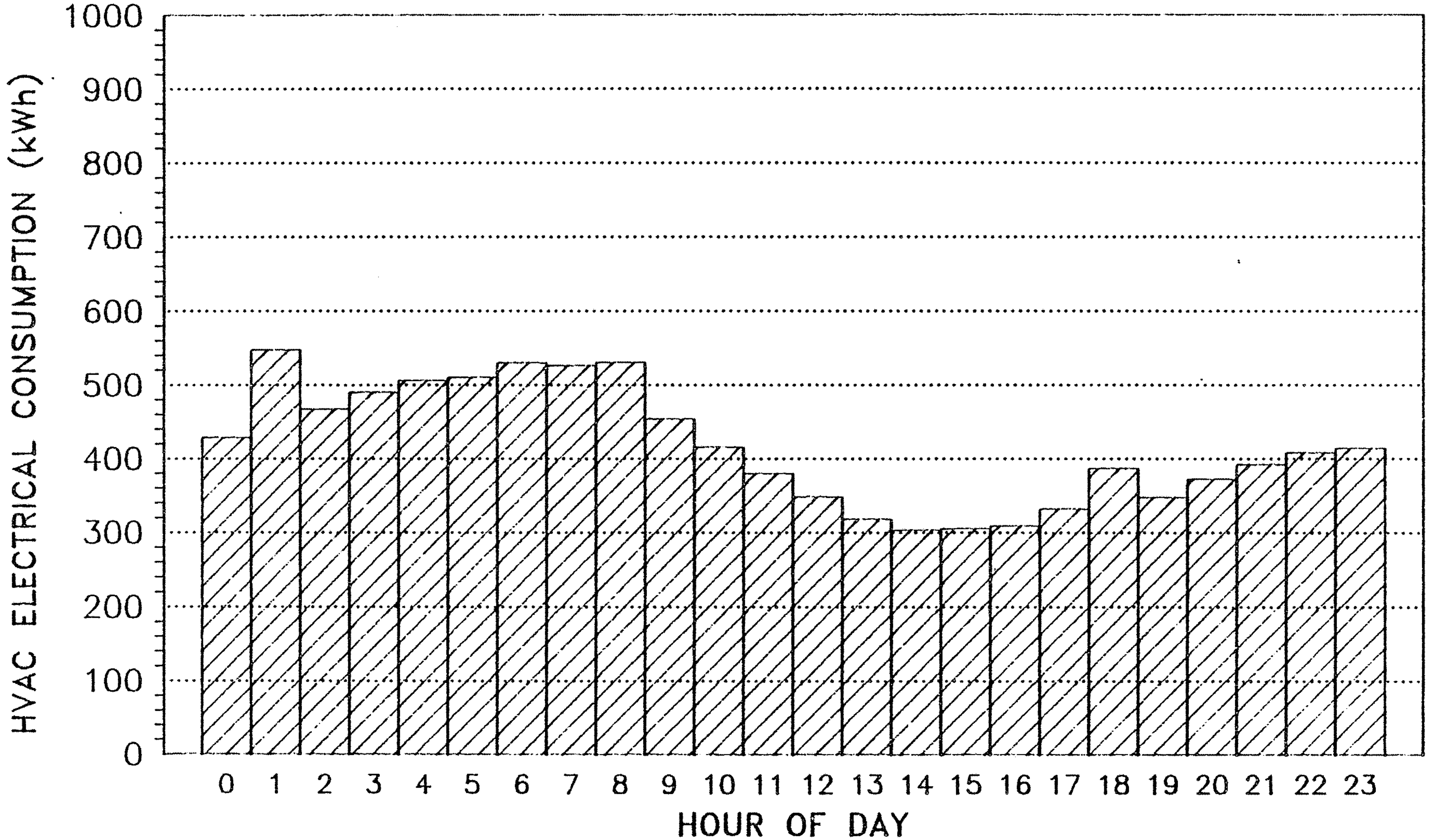
SITE #11
HEATING CAPACITY vs. SOURCE TEMPERATURE
REPORTING PERIOD: 11/04/85-05/31/86



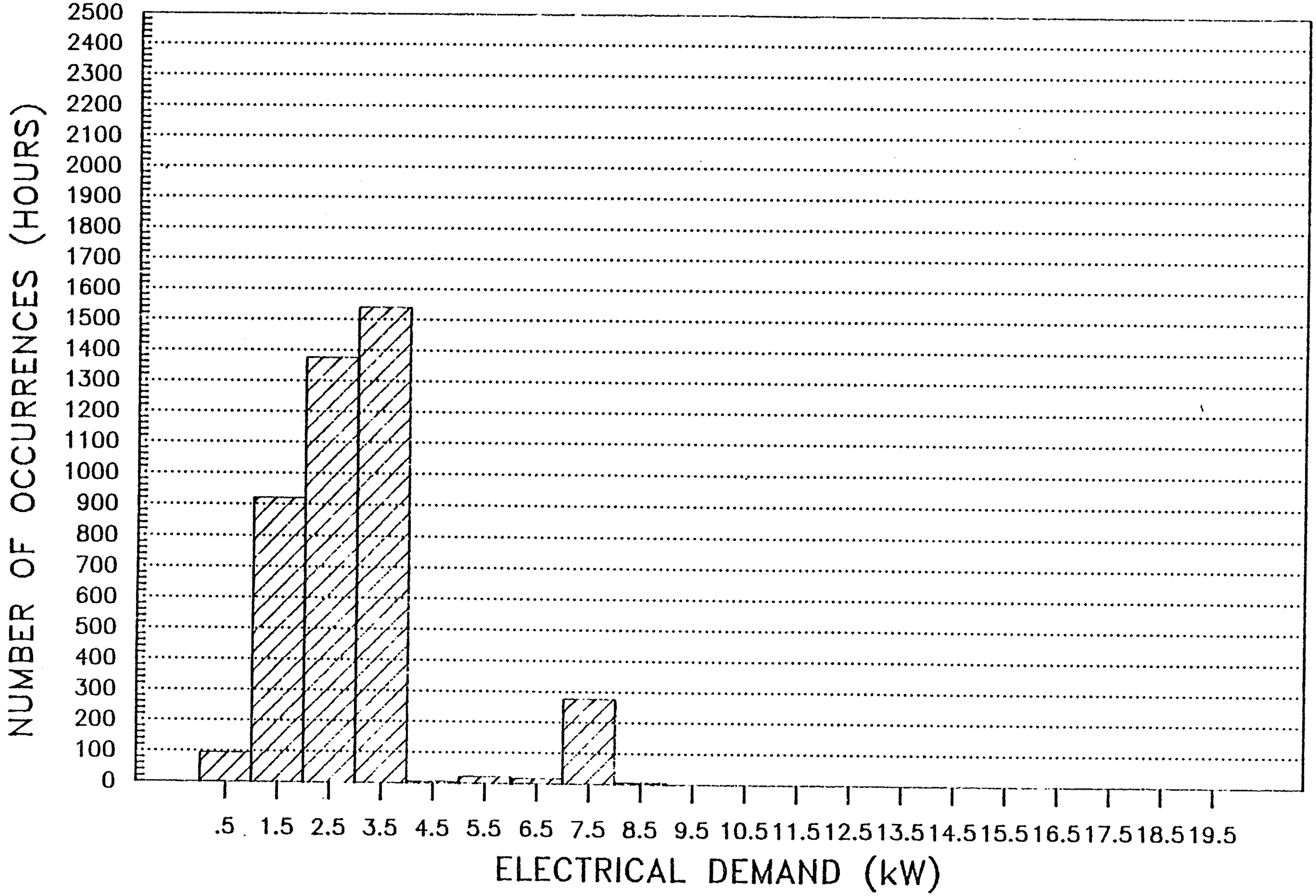
SITE #11
HEATING C.O.P. vs. SOURCE TEMPERATURE
REPORTING PERIOD: 11/04/85–05/31/86



SITE #11
HEATING MODE TIME OF DAY ELECTRICAL USAGE
REPORTING PERIOD: 11/04/85-05/31/86



SITE #11
HEATING MODE kW DEMAND FREQUENCY
REPORTING PERIOD: 11/04/85–05/31/86



APPENDIX C

FIELD MONITORED PERFORMANCE - COOLING

SITE 10 - COOLING SEASON OPERATIONAL SUMMARY

DATA REPORT: ADVANCED EARTH COUPLED HEAT PUMPS - SITE #10

FROM 5/ 1/86 HOUR 00 TO 9/15/86 HOUR 23
DATABASE HOURS RECORDED: 3310 (99.9%)

MODE: COOLING
COOLING DEGREE DAYS: 189

AVERAGE EARTH LOOP PUMP FLOW: 12.16 GPM
AVERAGE HVAC AIR FLOW: 1200. CFM

TEMPERATURES-DEG F	AVERAGE	MINIMUM	MAXIMUM
AMBIENT TEMPERATURE	61.8	29.2	86.9
ROOM TEMPERATURE	73.0	62.3	85.9
SUPPLY AIR TEMP-HEAT PUMP	50.7	44.8	78.4
RETURN AIR TEMP-HEAT PUMP	69.6	65.3	75.4
EARTH LOOP SOURCE TEMP	65.7	43.7	76.8
EARTH LOOP RETURN TEMP	74.2	43.8	85.3
FAR FIELD TEMPERATURE	59.1	44.1	66.7

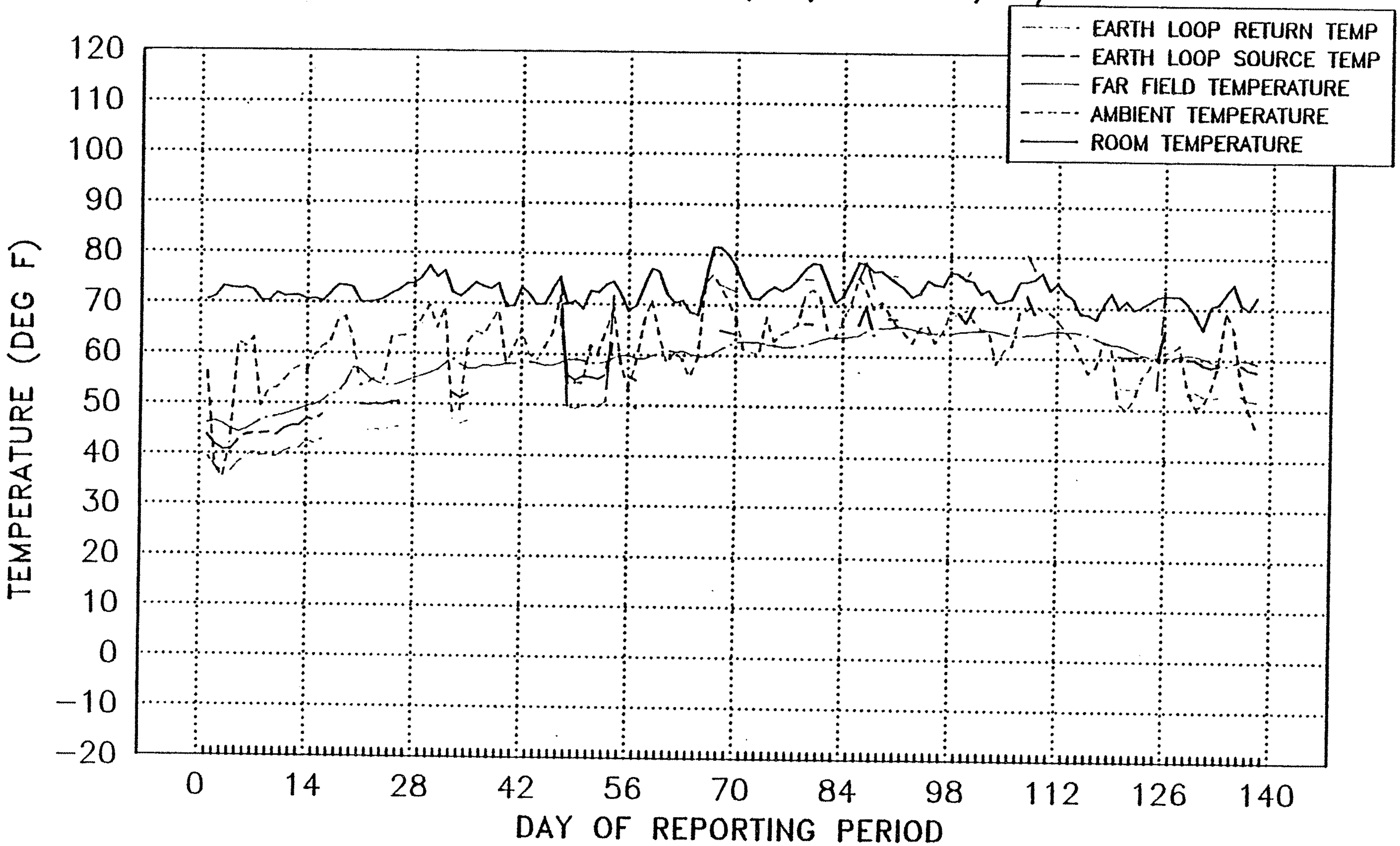
EQUIPMENT OPERATION	CYCLES	HOURS	KWH	10^6 BTU
COMPRESSOR	90	38.2	82.38	0.281
BLOWER		39.5	24.02	0.082
LOOP PUMP		38.2	14.52	0.050
HEAT PUMP TOTAL			120.92	0.413

HEAT QUANTITIES	MILLIONS OF BTUS
HEAT REJECTED TO EARTH LOOP	1.853
TOTAL HEAT PUMP WORK INTPUT	0.413
AIR SIDE SENSIBLE HEAT EXTRACTION	1.003
LATENT HEAT EXTRACTION FROM SPACE	0.441
TOTAL HEAT EXTRACTION FROM SPACE	1.441

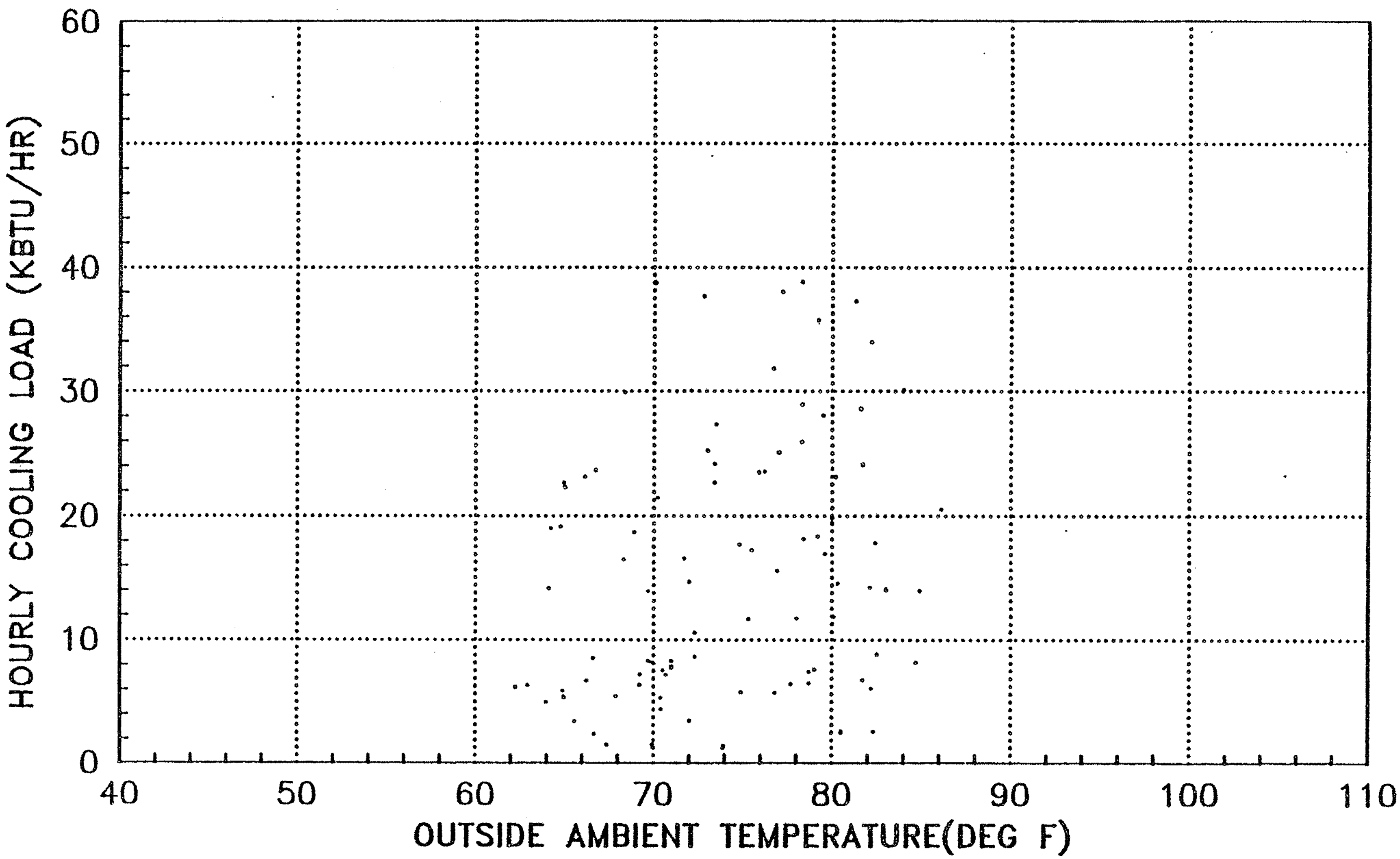
PERFORMANCE FACTORS	
AVERAGE HEAT PUMP C.O.P.:	3.49
AVERAGE COOLING E.E.R.:	11.92

AVERAGE COOLING CAPACITY: 37681. BTU/HR

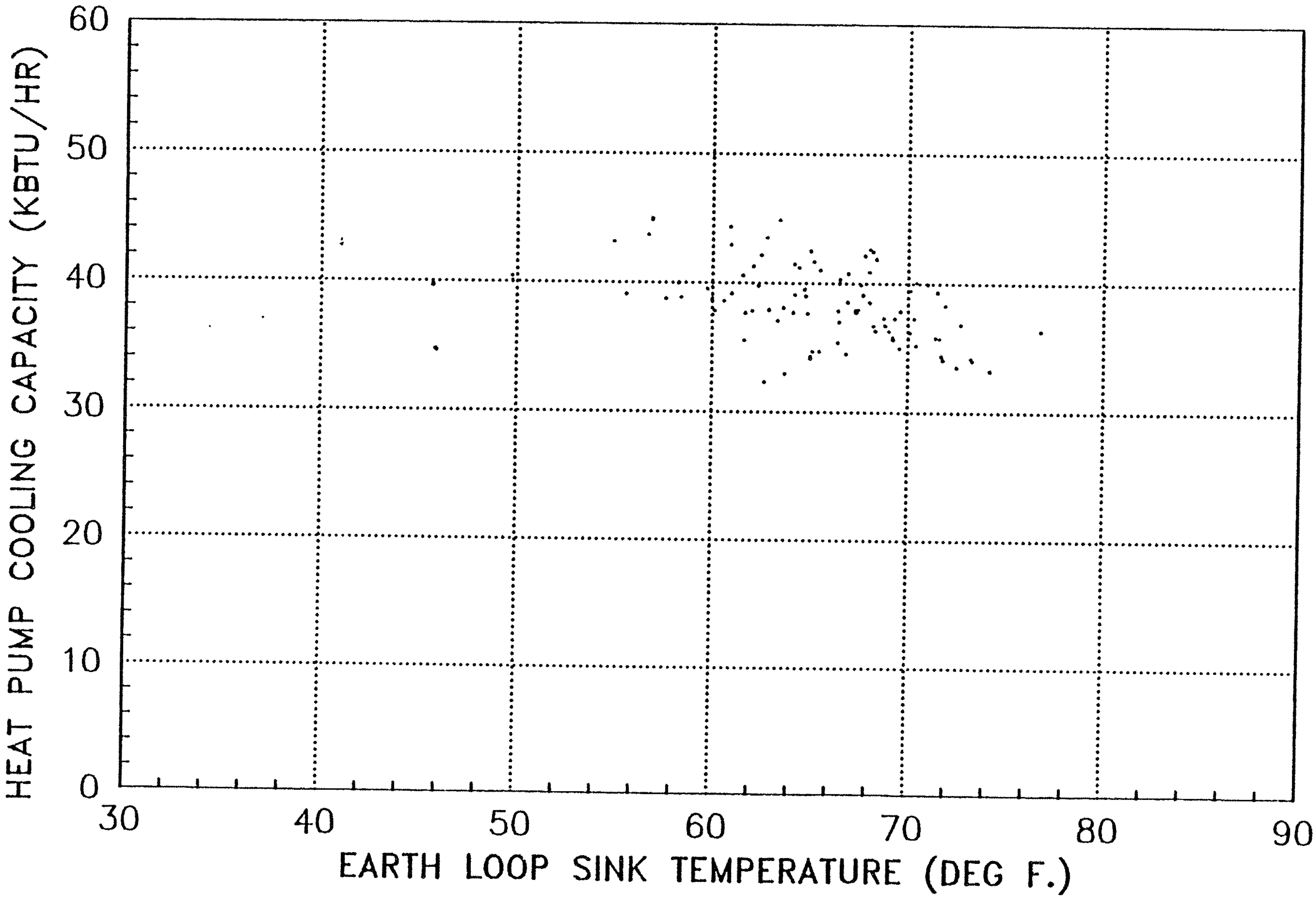
SITE #10
DAILY SYSTEM AND AMBIENT TEMPERATURE TREND PLOT
REPORTING PERIOD: 05/01/86 – 09/15/86

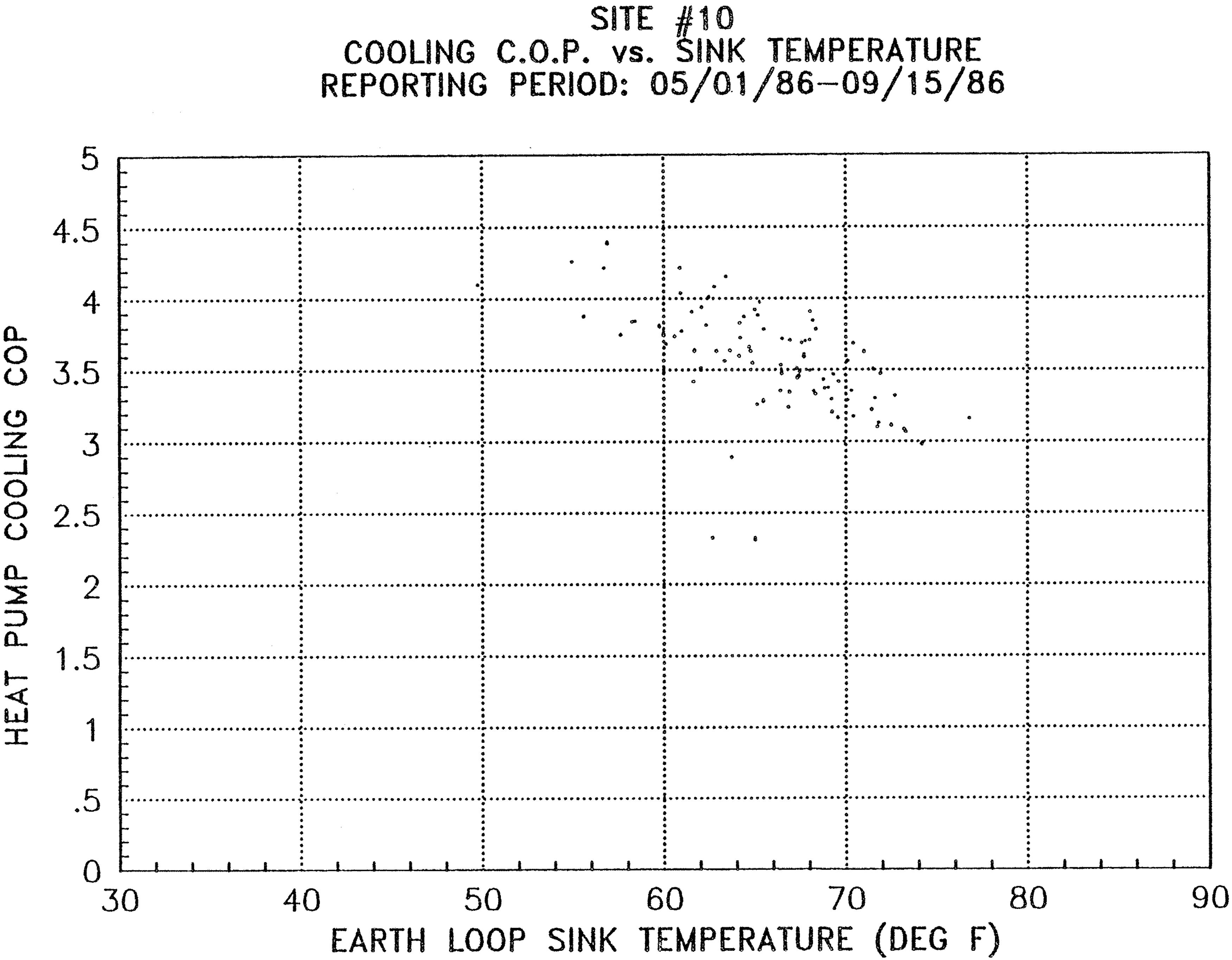


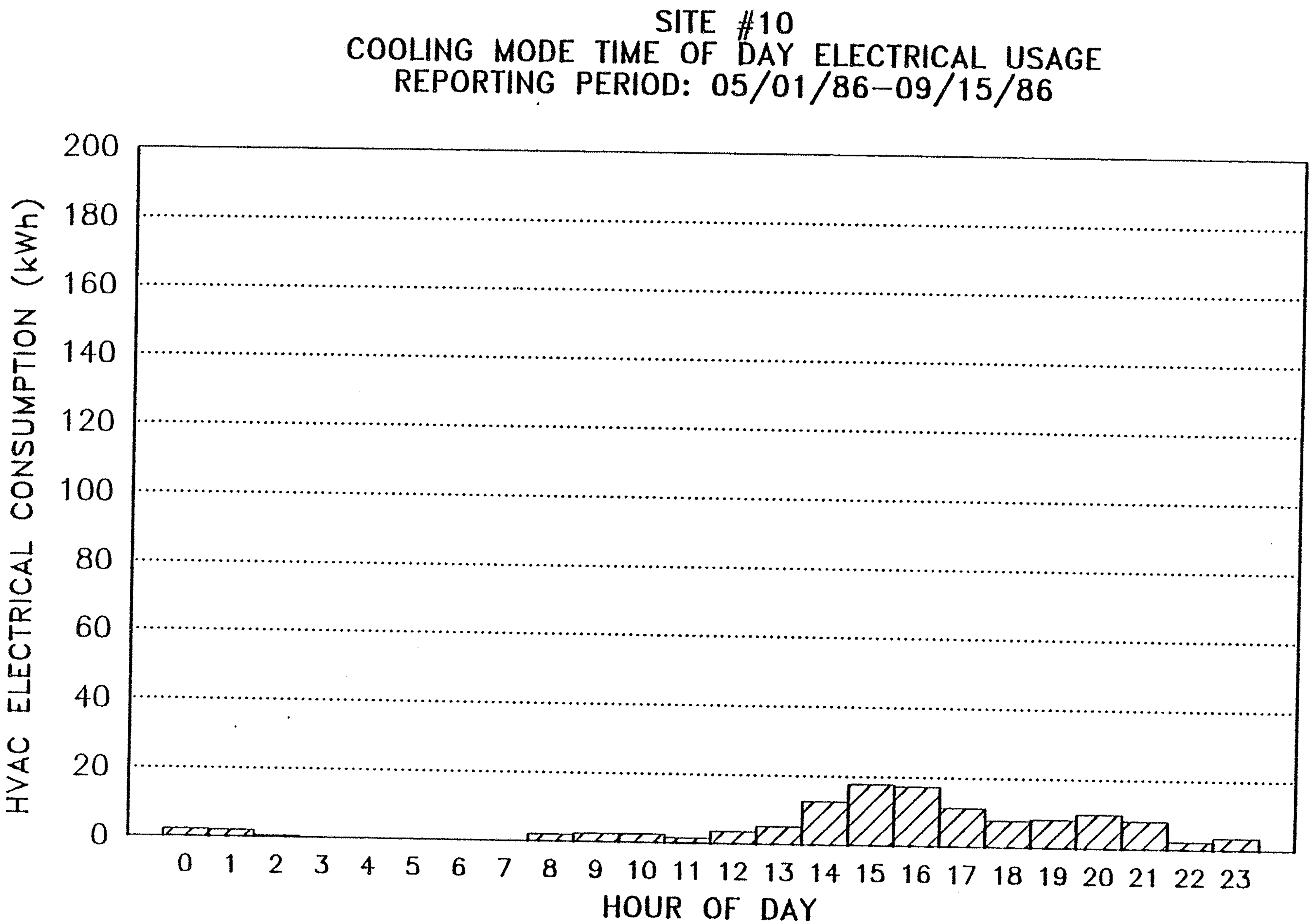
SITE #10
COOLING LOAD LINE
REPORTING PERIOD: 05/01/86-09/15/86



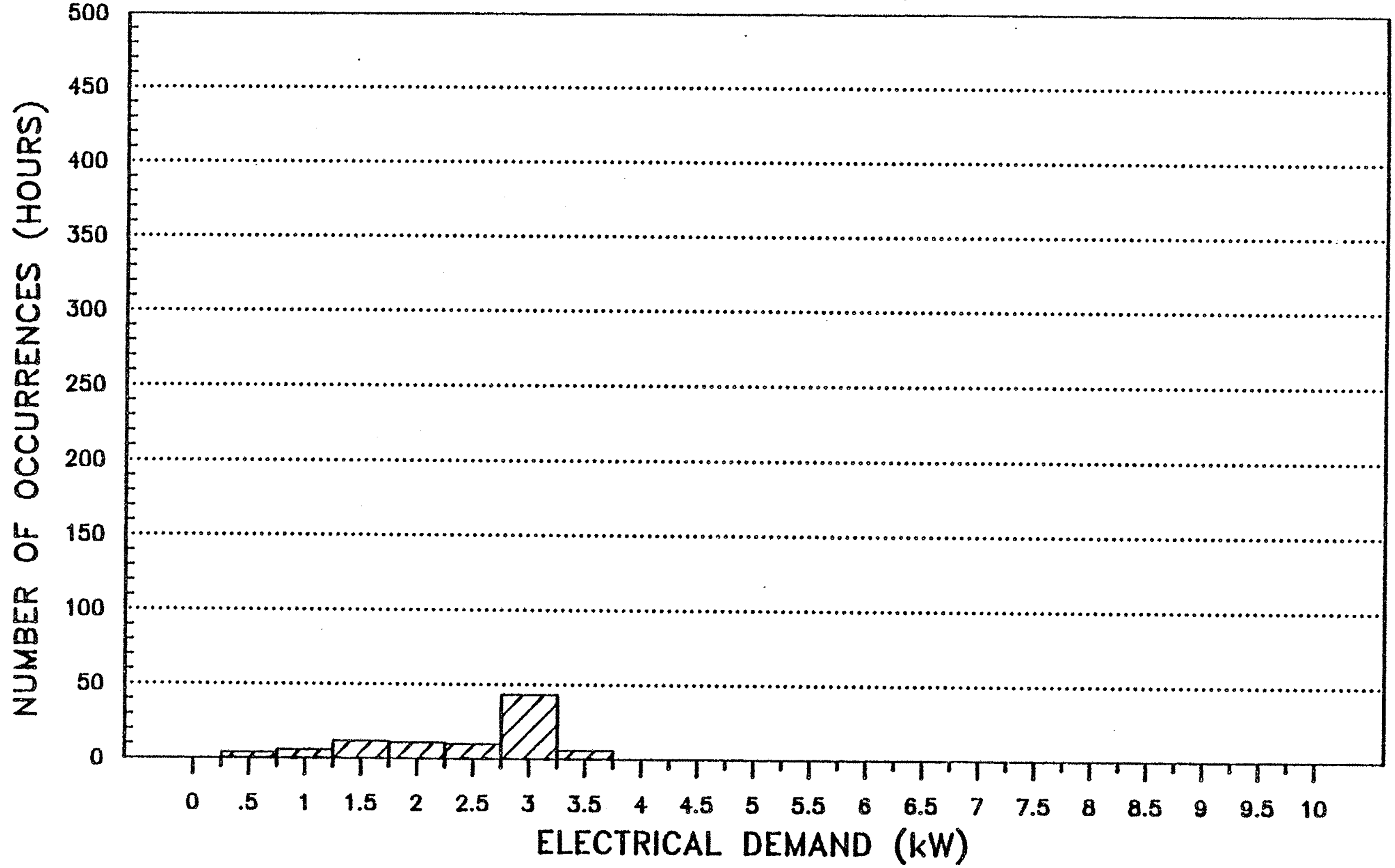
SITE #10
COOLING CAPACITY vs. SINK TEMPERATURE
REPORTING PERIOD: 05/01/86–09/15/86




SITE #10
COOLING C.O.P. vs. SINK TEMPERATURE
REPORTING PERIOD: 05/01/86-09/15/86
HEAT PUMP COOLING COP
EARTH LOOP SINK TEMPERATURE (DEG F)
0
.5
1
1.5
2
2.5
3
3.5
4
4.5
5
30
40
50
60
70
80
90


SITE #10
COOLING MODE TIME OF DAY ELECTRICAL USAGE
REPORTING PERIOD: 05/01/86-09/15/86
HVAC ELECTRICAL CONSUMPTION (kWh)
200
180
160
140
120
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
HOUR OF DAY

SITE #10
COOLING MODE kW DEMAND FREQUENCY
REPORTING PERIOD: 05/01/86-09/15/86



SITE 11 - COOLING SEASON OPERATIONAL SUMMARY

DATA REPORT: ADVANCED EARTH COUPLED HEAT PUMPS - SITE #11

FROM 5/ 1/86 HOUR 00 TO 9/15/86 HOUR 23
DATABASE HOURS RECORDED: 3309 (99.9%)

MODE: COOLING
COOLING DEGREE DAYS: 271

AVERAGE EARTH LOOP PUMP FLOW: 11.67 GPM
AVERAGE HVAC AIR FLOW: 1200. CFM

TEMPERATURES-DEG F	AVERAGE	MINIMUM	MAXIMUM
AMBIENT TEMPERATURE	63.2	28.8	84.4
ROOM TEMPERATURE	73.1	66.3	80.6
SUPPLY AIR TEMP-HEAT PUMP	52.1	46.7	84.3
RETURN AIR TEMP-HEAT PUMP	71.4	67.2	76.6
EARTH LOOP SOURCE TEMP	70.1	46.1	85.9
EARTH LOOP RETURN TEMP	79.2	55.8	94.3
FAR FIELD TEMPERATURE	57.9	45.3	63.9

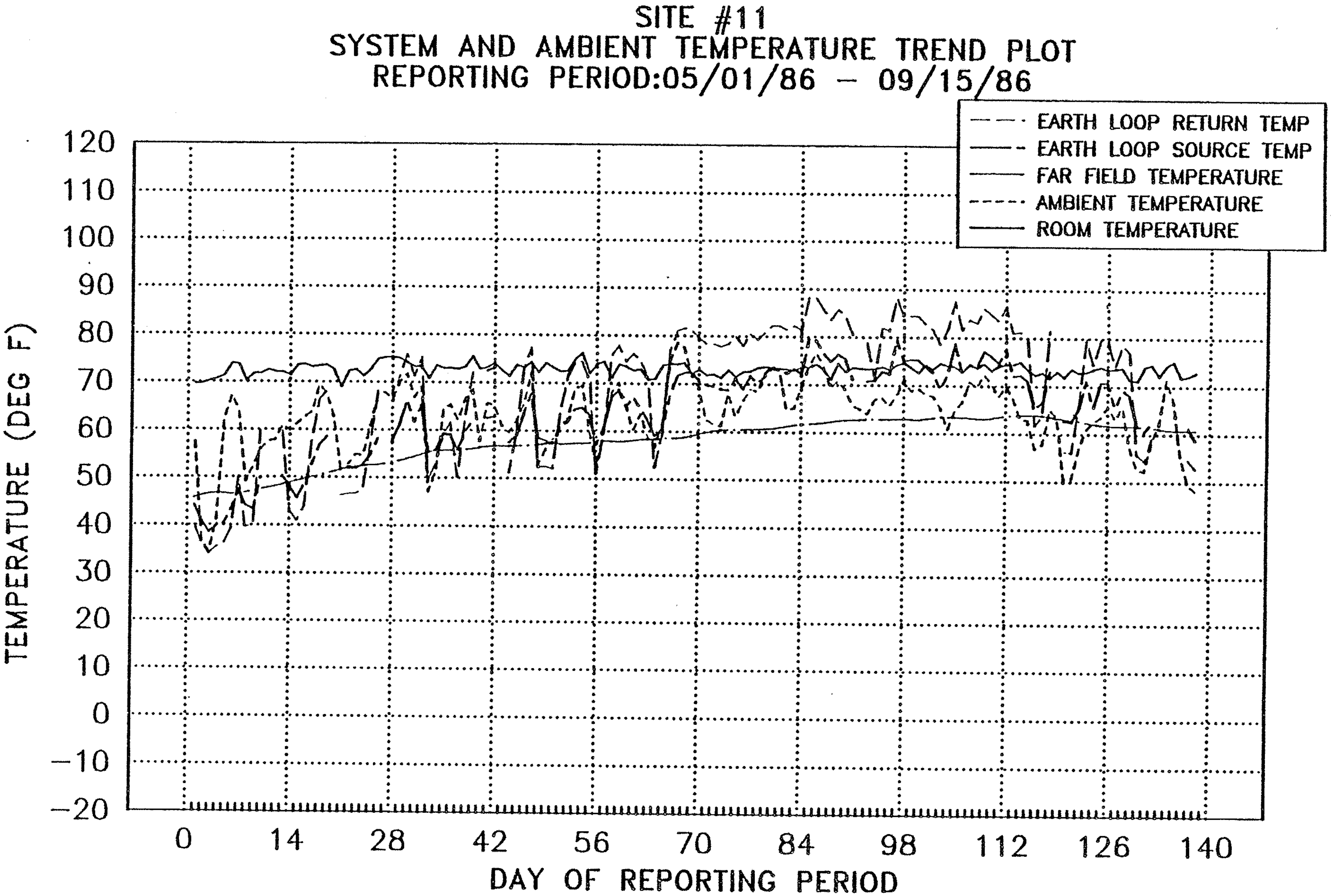
EQUIPMENT OPERATION	CYCLES	HOURS	KWH	10^6 BTU
COMPRESSOR	529	362.1	847.60	2.893
BLOWER		362.1	220.16	0.751
LOOP PUMP		362.1	137.49	0.469
HEAT PUMP TOTAL			1205.25	4.114

HEAT QUANTITIES	MILLIONS OF BTUS
HEAT REJECTED TO EARTH LOOP	17.720
TOTAL HEAT PUMP WORK INTPUT	4.114
AIR SIDE SENSIBLE HEAT EXTRACTION	9.254
LATENT HEAT EXTRACTION FROM SPACE	4.510
TOTAL HEAT EXTRACTION FROM SPACE	13.647

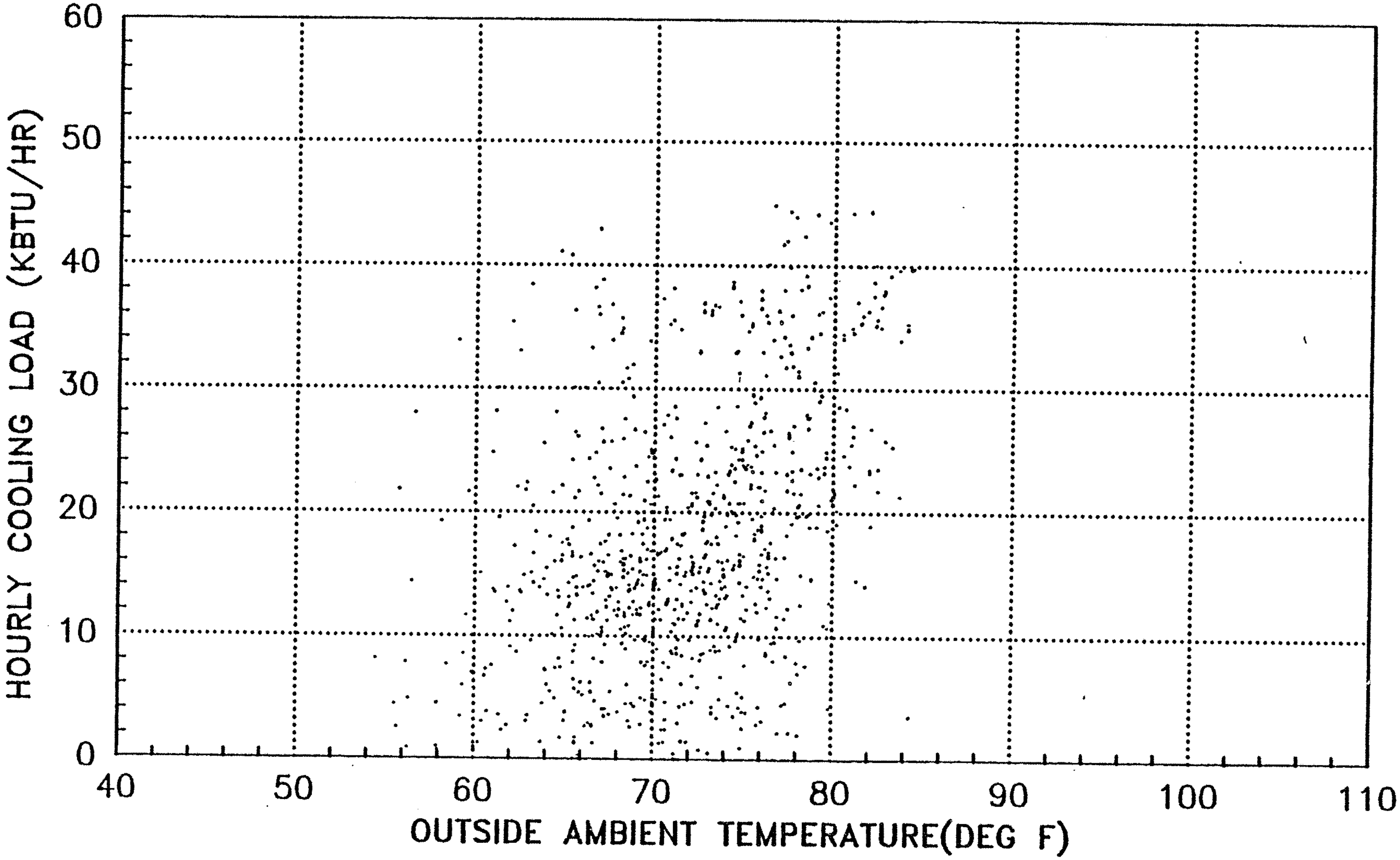
PERFORMANCE FACTORS

AVERAGE HEAT PUMP C.O.P.: 3.32
AVERAGE COOLING E.E.R.: 11.32

AVERAGE COOLING CAPACITY: 37690. BTU/HR


SITE #11
SYSTEM AND AMBIENT TEMPERATURE TREND PLOT
REPORTING PERIOD:05/01/86 - 09/15/86
EARTH LOOP RETURN TEMP
EARTH LOOP SOURCE TEMP
FAR FIELD TEMPERATURE
AMBIENT TEMPERATURE
ROOM TEMPERATURE
TEMPERATURE (DEG F)
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
0
14
28
42
56
70
84
98
112
126
140
DAY OF REPORTING PERIOD

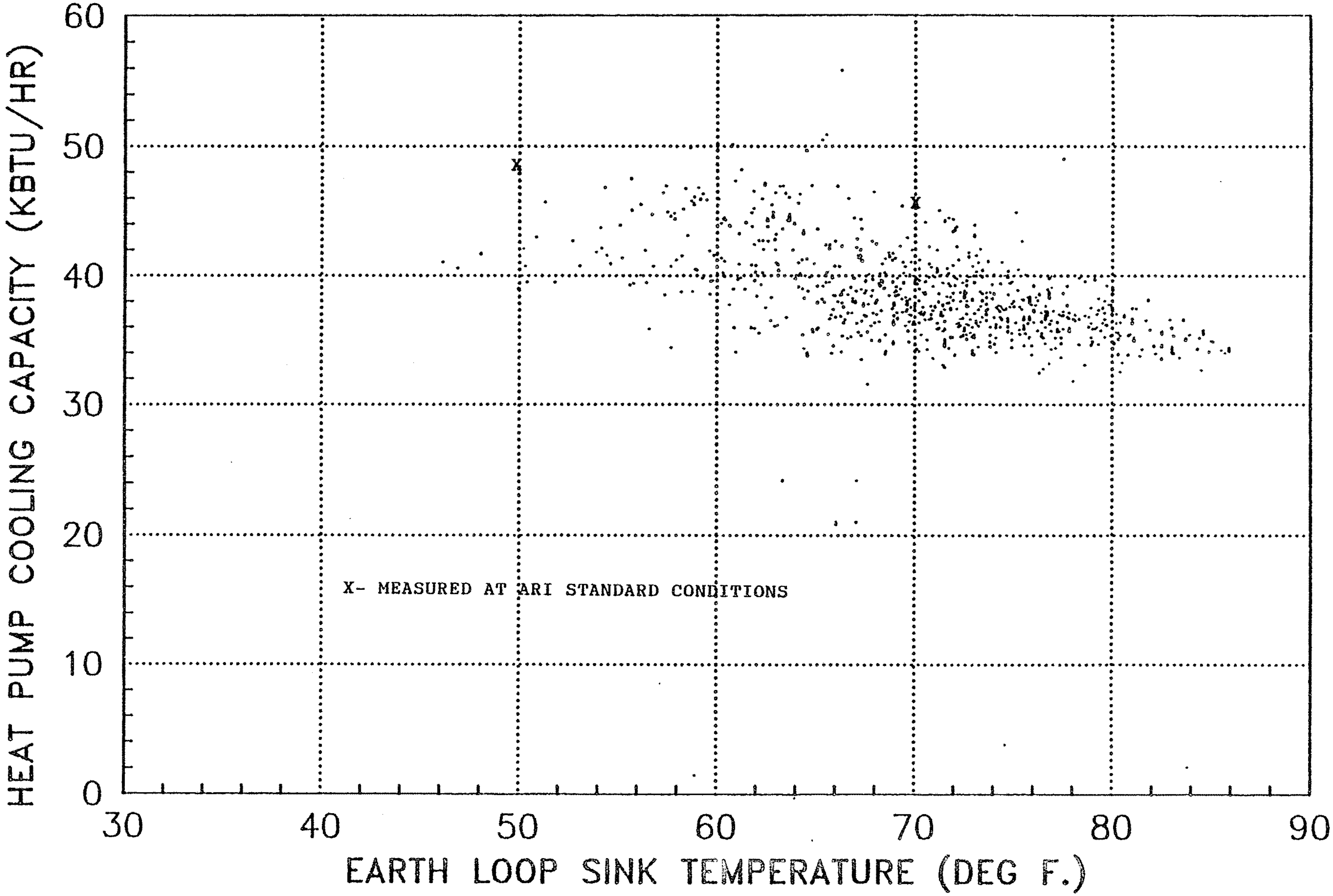
SITE #11
COOLING LOAD LINE
REPORTING PERIOD: 05/01/86-09/15/86



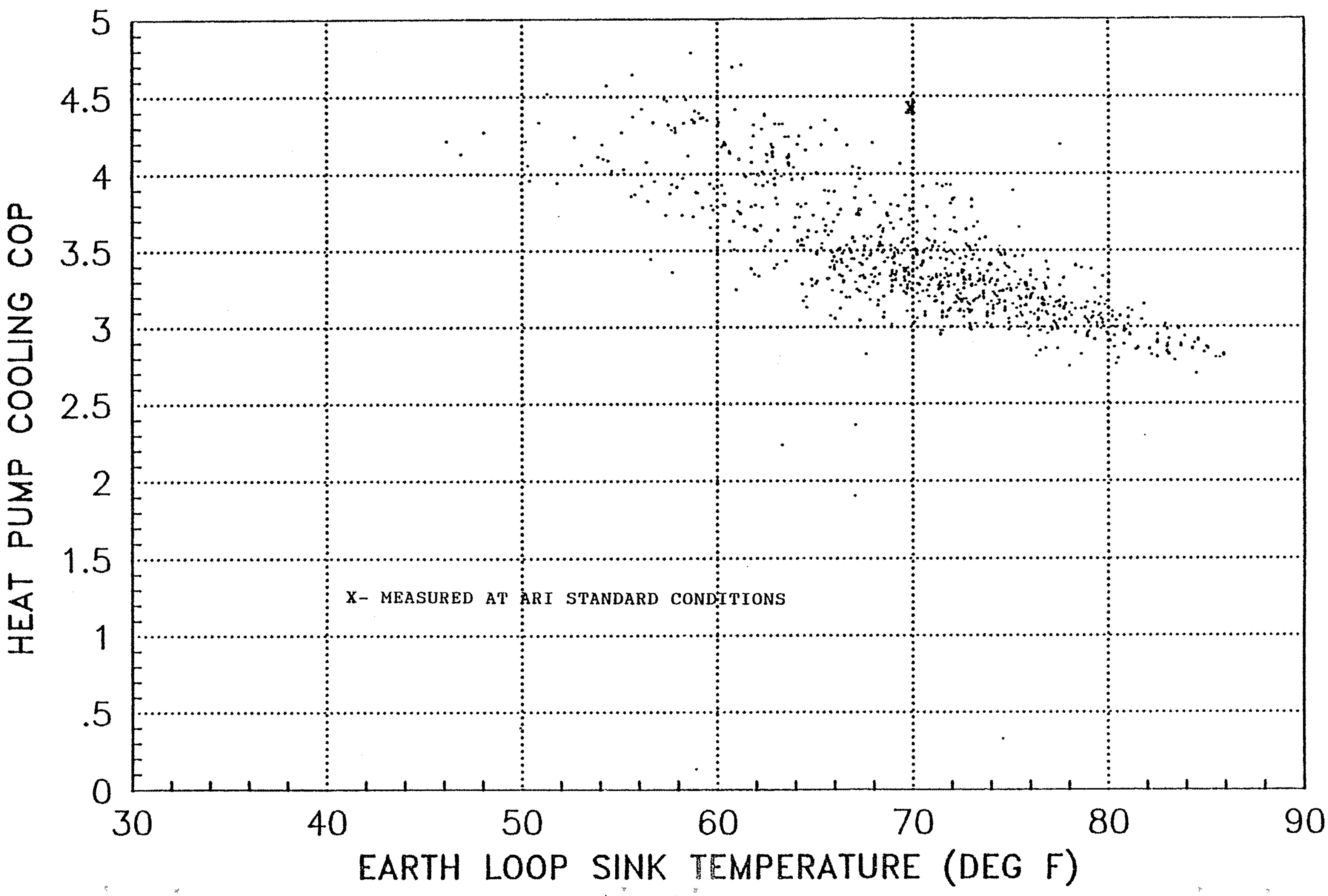
SITE #11

COOLING CAPACITY vs. SINK TEMPERATURE

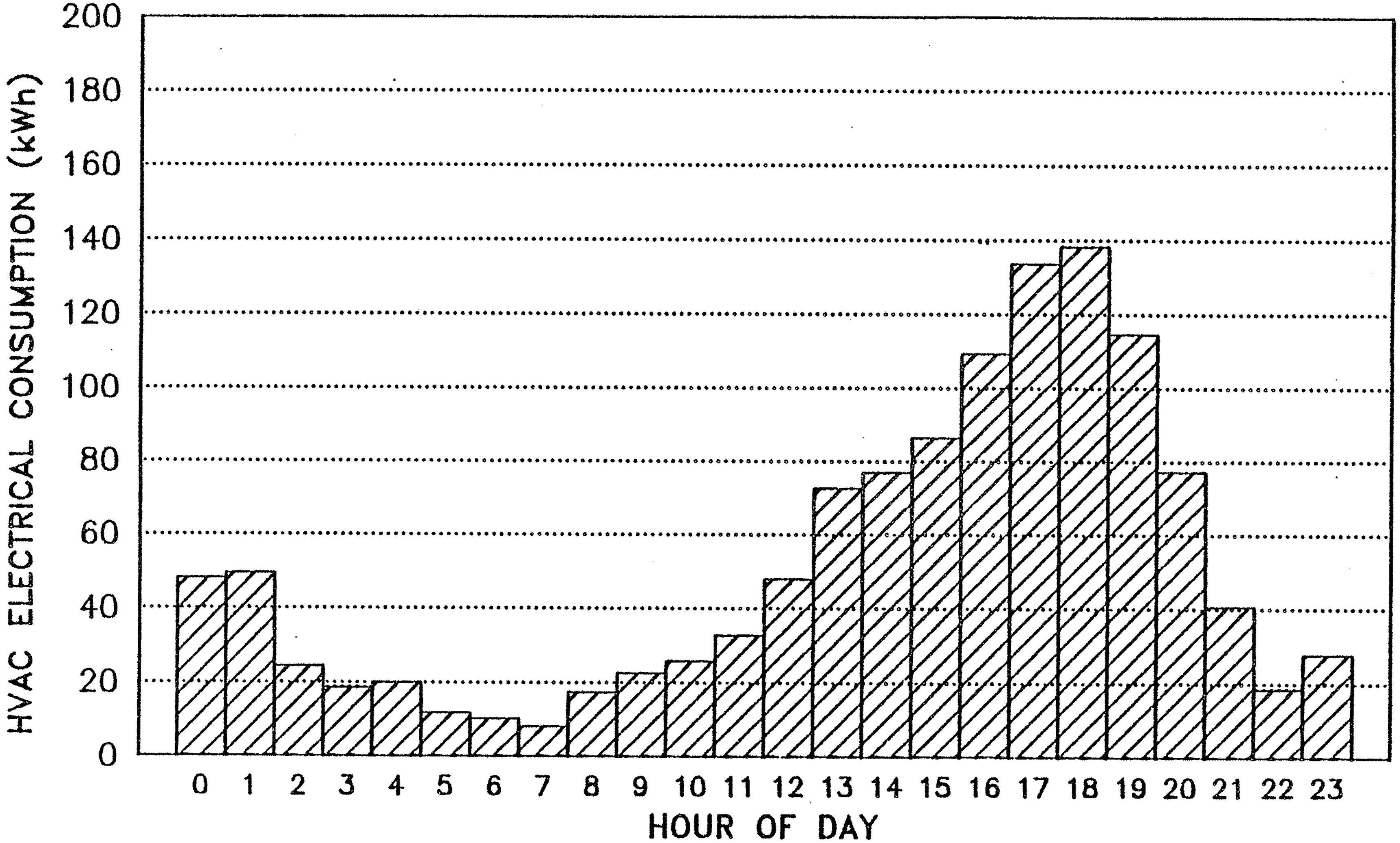
REPORTING PERIOD: 05/01/86-09/15/86

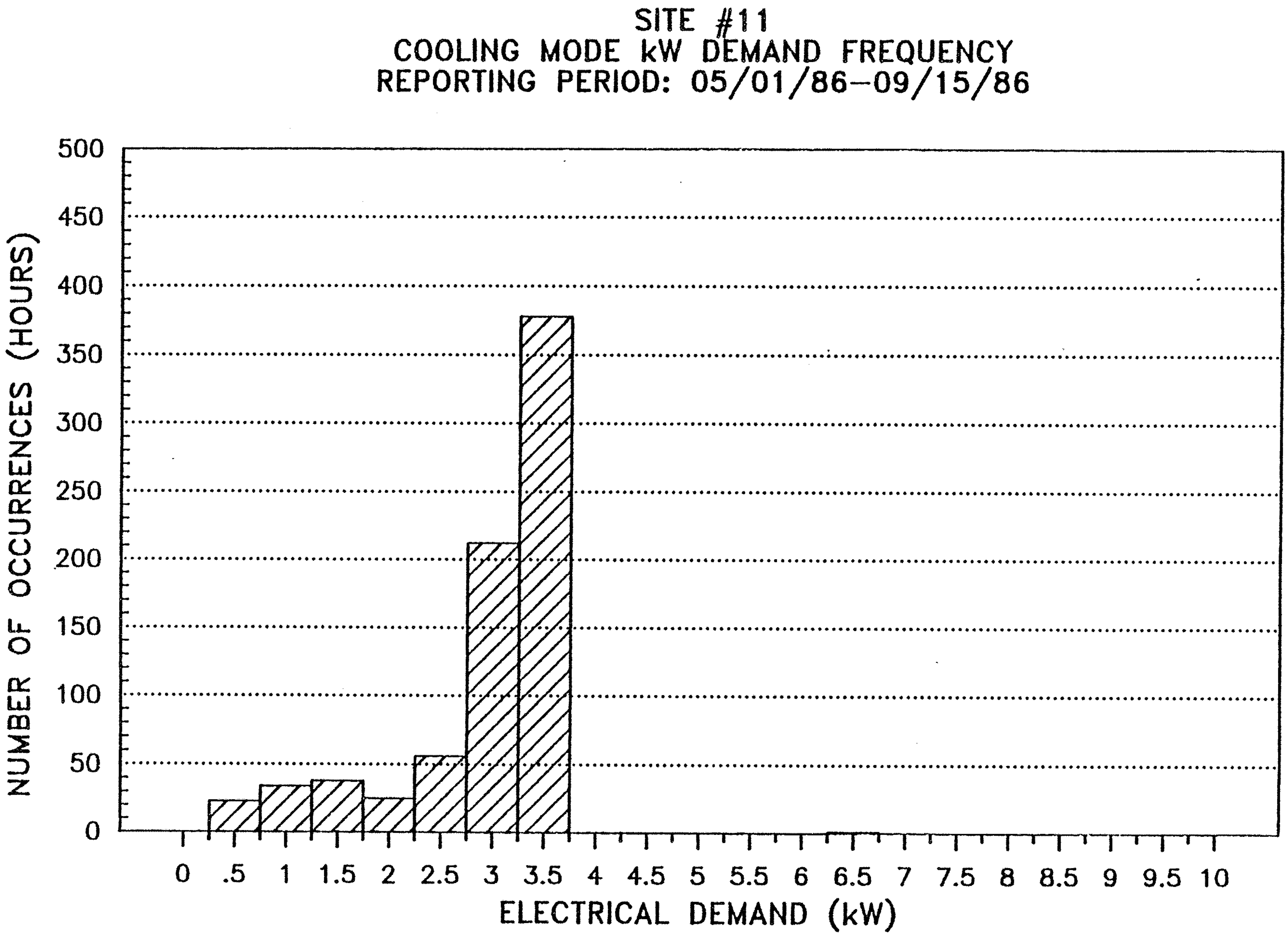


SITE #11
COOLING C.O.P. vs. SINK TEMPERATURE
REPORTING PERIOD: 05/01/86-09/15/86



SITE #11
COOLING MODE TIME OF DAY ELECTRICAL USAGE
REPORTING PERIOD: 05/01/86–09/15/86




SITE #11
COOLING MODE kW DEMAND FREQUENCY
REPORTING PERIOD: 05/01/86-09/15/86
NUMBER OF OCCURRENCES (HOURS)
500
450
400
350
300
250
200
150
100
50
0
0 .5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
ELECTRICAL DEMAND (kW)

APPENDIX D

OPERATION AND MAINTENANCE EXPERIENCE

A chronological summary of the operation and maintenance experience is given below:

December 2, 1985 - Problem: Homeowner at Site 10 reported cold air coming from supply ducts. Unit was cutout by freeze stat control. The unit was mistakenly shipped from the factory with the wrong freeze stat.

Resolution: Contractor replaced the freeze stat with another that was set for a lower cutout temperature (18°F) as was originally intended.

January 13, 1986 - Problem: Data analysis for the previous month's data indicated a significant heat pump performance difference between Site 10 (COP = 2.7) and Site 11 (COP = 3.0).

Resolution: Low freon charge at Site 10, perhaps as a result of the previous service call. The proper charge was implemented.

February 13, 1986- Problem: Routine spot check of freeze point indicated freeze protection of only 19°F at both sites. Also, the loop flow rates had dropped since the sites were brought on-line indicating possible air entrapment.

Resolution: 12 gallons of ethylene glycol were added to the loop at each site. The subsequent flushing of the systems apparently removed the entrapped air and restored flow rates to their original values.

November 10, 1986- Problem: Heat pump at site 10 had a compressor failure. In addition, the hard-start capacitor was burnt-up, probably as a result of the compressor failure.

Resolution: Since the prototype unit was due to be replaced at the conclusion of the monitoring period, the heat pump was put in emergency mode until the unit could be replaced. Unit was replaced January 2, 1987. The exact cause of the compressor failure is unknown. However, it occurred near the beginning of the second heating season at the site where cooling was seldom used. No annual tune-up was performed because the unit was schedule for removal. Perhaps normal preventative maintenance would have avoided the problem.

General Comment: both homeowners were quite pleased with their heating/cooling systems. Operation was essentially troublefree, and heating bills were pleasingly low: about $90 for the peak month at the smaller house (Site 10) and $140 for the peak month at the larger (Site 11).

General Conclusions: Key installation and maintenance guidelines include:

- Maintained antifreeze solution suitable for a low temperature of 15°F.
- Utilized antifreeze recommended by the manufacturer.
- Purged air out of the earth loop following the heat pump manufacturer's recommendations.
- Thoroughly cleaned and flushed system before adding antifreeze solution.
- Fed antifreeze to system and displaced an equal amount of water by volume, and run the earth loop pump to thoroughly mix the solution.
- Performed tests to verify the 15°F freeze point.
- The heat pump must have provision for condensate collection off of the evaporator in the cooling mode, with appropriate disposal.
- The heat pump must have provision for condensate prevention, and/or collection and disposal, off of the freon-to-liquid heat exchanger and other internal components in the heating mode.
- The heat pump supplier must provide with each unit, suitable installation, operation and maintenance manuals specifically designed for the earth-coupled heat pump application.
- The heat pump must be shipped from the factory with a time delay relay preventing compressor on-cyling prior to freon pressure equalization after the previous cycle, or a hard-start kit comprised of a start capacitor with potential relay (Field installation of factory approved components in compliance with the warranty is acceptable).
- The heat pump must be installed with a 2 stage heating, 1 stage cooling thermostat with an emergency heat switch. First stage heating is the heat pump, second stage heating is the backup source (resistance coils), and first stage cooling is the heat pump. In the emergency heat mode, the backup energy source cycles on first stage and the heat pump compressor is unused. All operational modes shall be verified at time of installation.
- Air filters must be changed at regular intervals depending upon the site conditions.

- Heat pump tuneups performed by the service contractor on an annual basis are essential to ensure continued efficient heat pump operation.