ENERGY CONSERVATION

ORNL/Sub/79-24712/4

Engineering Field Evaluation of the Westinghouse/DOE Dual-Stroke Advanced Electric Heat Pump

T. J. Fagan
R. R. Young
R. A. Lucheta
S. E. Veyo

Report Prepared by

WESTINGHOUSE ELECTRIC CORPORATION
R&D Center
1310 Beulah Road
Pittsburg, Pennsylvania 15235

Work performed for

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/79-24712/4

ENGINEERING FIELD EVALUATION OF THE WESTINGHOUSE/DOE DUAL-STROKE ADVANCED ELECTRIC HEAT PUMP

T. J. Fagan
R. R. Young
R. A. Lucheta
S. E. Veyo

Date Published-November 1986

Prepared by

WESTINGHOUSE ELECTRIC CORPORATION
R&D Center
1310 Beulah Road
Pittsburgh, Pennsylvania 15235

under
Subcontract 86X-24712C

for

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

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A11 Microfiche A01

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

CONTENTS

EXECUTIVE SUMMARY ix

ABSTRACT xiv

1. INTRODUCTION 1-1

2. SUMMARY 2-2

2.1 Objectives 2-2

2.2 Test Site 2-2

2.3 Instrumentation 2-3

2.4 Operating Status 2-8

2.5 Operating History 2-9

2.6 Thermal Energy Delivery 2-19

2.7 Electrical Energy Consumption 2-28

2.8 Electrical Demand Characteristics 2-35

2.9 Efficiency 2-43

2.10 Accomplishments 2-59

2.11 Conclusions 2-60

3. PHYSICAL INSTALLATION 3-1

3.1 Physical Installation 3-1

3.1.1 Site Considerations 3-1

3.1.2 Installation Compatibility 3-2

3.2 Heat Pump Installation 3-3

3.2.1 Site Preparation 3-3

3.2.2 Heat Pump Installation 3-6

3.2.3 Initial Operation 3-8

3.3 Weather Station Installation 3-9

3.4 Instrumentation Installation 3-13

4. INSTRUMENTATION 4-1

4.1 Delivered Heating and Cooling 4-1

4.2 Energy Consumption 4-3

4.3 Meteorological Data 4-4

4.4 Heat Pump Operating Mode 4-5

4.5 Refrigeration System State Points 4-5
4.6 Data Acquisition System Self Monitoring 4-5
4.7 Defrost Timer and Counter 4-7
5. DATA ACQUISITION HARDWARE 5-1
6. PROBLEMS AND THEIR RESOLUTION 6-1
6.1 General 6-1
6.2 Cooling Performance Ambiguity 6-1
6.3 Temperature Measurement Ambiguity 6-4
6.4 Airflow Measurement Ambiguity 6-8
6.5 Comment On Ambiguities 6-10
6.6 Data Reduction Effort 6-10
7. RESULTS 7-1
7.1 Daily Record 7-1
7.2 Temperature Bin Data 7-2
7.3 Energy Use Patterns 7-3
7.3.1 Household Energy Consumption 7-3
7.3.2 HVAC System 7-5
7.3.3 Instrumentation Power Supply 7-6
7.3.4 Water Heating 7-7
7.3.5 Clothes Dryer 7-7
7.3.6 Game Room Heater 7-7
7.3.7 Lighting and Appliance Loads 7-10
7.4 Electrical Demand Characteristics 7-11
8. ACKNOWLEDGEMENT 8-1
9. REFERENCES 9-1

A. APPENDIX A — INSTRUMENTATION A-1
B. APPENDIX B — DATA PROCESSING B-1
C. APPENDIX C — TEMPERATURE SENSOR LAG..... C-1
D. APPENDIX D — TEMPERATURE SENSOR RADIATION ERROR..... D-1
E. APPENDIX E — EFFECT OF AIR FLOW MEASUREMENT ERROR..... E-1
F. APPENDIX F — DAILY SUMMARIES AND TEMPERATURE BIN DATA..... F-1

LIST OF FIGURES

Figure	Title	Page
1.1	Preprototype Heat Pump Indoor Unit	1-2
1.2	Preprototype Heat Pump Outdoor Unit	1-3
1.3	Two-Capacity Advanced Electric Heat Pump Measured Heating Performance	1-4
1.4	Two-Capacity Advanced Electric Heat Pump Measured Cooling Performance	1-5
2.1	Host Residence for the Westinghouse/DOE Dual Stroke Advanced Electric Heat Pump	2-2
2.2	Outdoor Heat Pump Unit as Installed	2-4
2.3	Indoor Heat Pump Unit as Installed	2-5
2.4A	System Status Report — April 1, 1983 through March 31, 1984	2-10
2.4B	System Status Report — April 1, 1984 through March 31, 1985	2-11
2.5A	Hours of Temperature Occurrence — April 1, 1983, through March 31, 1984	2-12
2.5B	Hours of Temperature Occurrence — April 1, 1984 through March 31, 1985	2-13
2.6A	Heat Pump Load and Capacity — April 1, 1983 through March 31, 1984	2-14
2.6B	Building Load — April 1, 1984 through March 31, 1985	2-15
2.7A	Cooling Duty — First Cooling Season	2-17
2.7B	Cooling Duty — Second Cooling Season	2-18
2.8A	Heating Duty — First Heating Season	2-20

Figure		Page
2.8B	Heating Duty — Second Heating Season.....	2-21
2.9A	Duty Hours — April 1, 1983 through March 31, 1984.....	2-22
2.9B	Duty Hours — April 1, 1984 through March 31, 1985.....	2-23
2.10A	Operating Mode Hours — April 1, 1983 through March 31, 1984.....	2-24
2.10B	Operating Mode Hours — April 1, 1984 through March 31, 1985.....	2-25
2.11A	Thermal Energy Delivered — April 1, 1983 through March 31, 1984.....	2-26
2.11B	Thermal Energy Delivered — April 1, 1984 through March 31, 1985.....	2-27
2.12A	Delivered Heat Profile — First Heating Season....	2-29
2.12B	Delivered Heat Profile — Second Heating Season...	2-30
2.13A	Delivered Heat Profile — First Heating Season....	2-31
2.13B	Delivered Heat Profile — Second Heating Season...	2-32
2.14A	House Energy Consumption — April 1, 1983 through March 31, 1984.....	2-33
2.14B	House Energy Consumption — April 1, 1984 through March 31, 1985.....	2-34
2.15A	Heating Energy Consumption — April 1, 1983 through March 31, 1984.....	2-36
2.15B	Heating Energy Consumption — April 1, 1984 through March 31, 1985.....	2-37
2.16A	Heating Energy Consumption — April 1, 1983 through March 31, 1984.....	2-38
2.16B	Heating Energy Consumption — April 1, 1984 through March 31, 1985.....	2-39

Figure		Page
2.17	Winter Peak Electrical Demand	2-40
2.18	Summer Peak Electrical Demand	2-42
2.19A	Heating Performance — April 1, 1983 through March 31, 1984	2-45
2.19B	Heating Performance — April 1, 1984 through March 31, 1985	2-46
2.20A	Cooling Performance — April 1, 1983 through March 31, 1984	2-47
2.20B	Cooling Performance — April 1, 1984 through March 31, 1985	2-48
2.21A	Heating Cycle Length — April 1, 1983 through March 31, 1984	2-49
2.21B	Low Capacity Heating Run Cycle Length — April 1, 1984 through March 31, 1985	2-50
2.21C	High Capacity Heating Run Cycle Length — April 1, 1984 through March 31, 1985	2-51
2.22	Defrost Cycle Length — April 1, 1984 through March 31, 1985	2-52
2.23A	Resistance Heat Profile — April 1, 1983 through March 31, 1984	2-57
2.23B	Resistance Heat Profile — April 1, 1984 through March 31, 1985	2-58
3.1	Ground Floor Plan of Advanced Heat Pump Test Site	3-4
3.2	Installation of Advanced Heat Pump at Test Site	3-5
3.3	Conventional Watt-Hour Meters	3-7
3.4	East View Showing Roof Mounted Weather Station	3-11
3.5	Weather Station	3-12
3.6	Capacitance Manometer and Airflow Probe Connections	3-14

Figure		Page
3.7	Return Air Sampling Tube and Fan	3-15
3.8	Refrigeration System Pressure Transducers	3-16
3.9	Supply Air Sampling Tube and Fan	3-17
4.1	Instrumentation Locations — Preprototype #2	4-6
5.1	Data Signal Diagram	5-2
5.2	Instrumentation Cabinet Upper Portion	5-4
5.3	Instrumentation Cabinet Lower Portion	5-5
7.1	Water Heater Energy Use	7-8
7.2	Clothes Dryer Energy Use	7-9
A.1	Calibration Duct Section Schematic	A-3
A.2	Inlet Duct Details	A-4
A.3	Duct Calibration Setup	A-5
A.4	Resistance Thermometer Circuit	A-7
A.5	Calibration of Celesco Model LCVR Pressure Transducer	A-9
A.6	Heat Pump Watt/Watt Hour Transducers and Current Transformers	A-11
A.7	Line Voltage Instrument Rectifier Calibration	A-13
A.8	UPS Voltage Instrument Rectifier Calibration	A-19
C.1	Typical Supply Air Temperature History — Heating Mode	C-6
C.2	Sampling Fan Characteristics	C-9

LIST OF TABLES

Table	Title	Page
2.1	Heat Pump Performance Comparison	2-53
3.1	Estimated Heat Pump Performance at Field Test Site	3-2
4.1	Watt/Watt-Hour Transducers	4-4
4.2	Relay Functions	4-7
7.1	Distributions of Electric Consumption	7-5
7.2	HVAC System Energy Use	7-5
7.3	Typical Annual Appliance and Lighting Loads	7-10
7.4	Winter Peak Electrical Demand vs. Average Ambient Temperature	7-12
7.5	Summer Peak Electrical Demand vs. Average Ambient Temperature	7-14
A.1	Pressure Transducer Calibration Data	A-16
B.1	Thermocouple Channels	B-6
B.2	Control Relays	B-13
B.3	Watt-Hours Meters	B-18
C.1	Heat Pump Time Constants in Seconds — Heating Mode	C-7
C.2	Parameters for Average Heat Transfer Coefficient Correlation for a Cylinder	C-8
C.3	35°F High Capacity Heat — Original RTD's	C-13
C.4	35°F High Capacity Heat — Original RTD's	C-14
C.5	35°F High Capacity Heat — New RTD's	C-15

Table		Page
D.1	Thermocouple vs. RTD Temperature Reading — I^2R Heating	D-3
E.1	Refrigeration System Operating Parameters	E-2
F.1	Daily Performance Summary — April 1, 1983 to March 31, 1984	F-2
F.2	Daily Performance Summary — April 1, 1984 to March 31, 1985	F-8
F.3	Temperature Bin Data — April 1, 1983 to March 31, 1984	F-15
F.4	Temperature Bin Data — April 1, 1984 to March 31, 1985	F-30

EXECUTIVE SUMMARY

The overall objective of the advanced electric heat pump program was to design, develop, construct and demonstrate, in preprototypical form, a reliable, cost effective, electrically driven air-to-air heat pump for residential and light commercial applications with an annual energy efficiency ratio 20% higher than the most efficient units commercially available at the date of contract inception in mid 1979. The two preprototype units incorporated several advanced features including:

- A high-efficiency oil-cooled dual-stroke three cylinder reciprocating compressor located in the indoor unit.
- A high-efficiency electrically reversible two-strength single-speed electric compressor drive motor.
- A high-efficiency indoor blower with a high-efficiency two-speed drive motor.
- A high-efficiency outdoor fan with a high-efficiency two-speed drive motor.
- An indoor air-to-refrigerant heat exchanger with variable refrigerant circuitry.
- A microprocessor-based control system with extensive system protection and fault diagnosis features.

Following the successful completion of extensive laboratory testing of two preprototype units in the fall of 1982 the contract was extended to include a demonstration of the reliability and efficiency of one of the preprototype units under actual operating conditions in an occupied residence. The objectives of the field performance evaluation were to demonstrate the durability of the dual-stroke compressor and other advanced components under actual operating conditions, to verify that the thermodynamic performance of the system met the design goals and to provide a data base for evaluating methods of predicting seasonal and annual system performance.

A preprototype system test site in DOE region IV with a balance point near the optimum of 19°F was desired. A Westinghouse engineer not associated with the project agreed to host the field test in his home, a well-insulated two-story 2100 ft^2 English Tudor style single-family residence located in the outskirts of Jeannette Pa, a small industrial community about 30 miles east of Pittsburgh. The residence, which had been space conditioned for the seven years since it was constructed by a conventional 3 ton air-to-air heat pump was occupied by the engineer, his wife and two children. In exchange for hosting the field test, a state-of-the art commercial unit was installed by a HVAC contractor following completion of the test in April of 1985.

Installation of the unit was completed during the third week of November of 1982. An extensive instrumentation and data acquisition package was provided to permit determination of the major operating parameters including:

- Heating and cooling delivered by the HVAC system.
- Energy consumption of the major heat pump components, residence and other major appliances.
- Heat pump operating mode.
- Weather parameters including temperature, humidity, wind speed and direction, precipitation, barometric pressure and solar insolation.
- Instrumentation and data acquisition system status.

The data system initially recorded the output of 76 analog sensors and eight digital sensors on data cassettes. When the heat pump was idle, data was recorded every 15 minutes. When the heat pump was operating, critical channels were recorded every 140 seconds during the first year of the test. During the second year of the test software modifications reduced the time between scans to less than 60 seconds when the heat pump was operating. Data was retrieved remotely via a telephone link and stored and processed on a mainframe computer located

at the Westinghouse R&D Center. Installation of the instrumentation and data acquisition package began in mid December of 1982. The instrument package and data acquisition software and hardware were considered fully operational on April 1, 1983.

Time constraints did not permit extensive laboratory testing of the microprocessor-based control system. Several software and hardware "bugs" were uncovered early in the first year of the test. In particular the control system repeatedly shut down the heat pump due to a variety of erroneous system faults. Modifications to the microprocessor power supply and software eliminated most of these nuisance system shutdowns, but the problem was never completely eliminated.

There were no failures of the advanced system components during the 28 months when the system provided the HVAC requirements of the residence. The only components which failed were off-the-shelf compressor electrical components including a contactor, start relay and start capacitor. The indoor blower became noisy due to an undersized shaft turning in the inner bearing races and was replaced with the blower from the first preprototype late in late November of 1984.

During the first year of operation the heat pump was unavailable for 239 hours. A total of 54.9 million Btu of heat were delivered to the residence with a heating season performance factor (HSPF) of 8.13 Btu/Wh excluding emergency heat operation. During the first cooling season 21.1 million Btu of cooling was delivered at a seasonal energy efficiency ratio (SEER) of 8.35 Btu/Wh with a sensible-to-total capacity ratio of 0.64. Ambient temperatures from -12°F to 93°F were encountered and the unit operated properly during periods of sleet and freezing rain.

The efficiency of the system was lower than initial projections. This was primarily due to a building load significantly less than that

estimated from the house plans and an error in the resistance heat control logic which locked on resistance heat until the thermostat was satisfied rather than cycling the resistance heat on and off while permitting the compressor to run continuously as desired. Peak electrical demand during heating service ranged from 4.0 kW at temperatures above 42°F to 18.0 kW at -2°F. Peak electrical demand during the cooling season ranged from 2.1 to 4.6 kW.

During the second year of operation the number of stages of resistance heat were reduced from 4 to 3 and the first stage was modulated by "chopping" the power with a controller using silicon controlled rectifier (SCR) components to maintain the delivered air temperature at 90°F to 95°F during periods when resistance heat was required. The upper and lower heating balance points were lowered to reflect the lower-than-anticipated building load. The upper cooling balance point was increased for the same reason.

During the second year of operation the heat pump was unavailable for 46.5 hours. A total of 53.4 million Btu of heat was delivered to the residence with a heating season performance factor (HSPF) of 8.51 Btu/Wh. The increase in HSPF compared with the first year was due primarily to the changes in the method of applying resistance heat. During the first year 9% of the heat delivered was provided by resistance heat. During the second heating season this was reduced to 4%. During the first heating season 16% of the heat was delivered in the low capacity mode. During the second heating season this was increased to 23%. The ambient temperature distributions for the two heating seasons were very similar with 2% fewer degree hours in the second season. Low temperature heating cycle lengths were increased significantly during the second heating season. Peak electrical demand was 3.8 kw at temperatures above 38°F, less than 10 kW at temperatures above 30°F and 14.6 kW at -10°F. The changes in the resistance heat operating strategy clearly resulted in a significant reduction in low temperature peak electrical demand.

During the second cooling season 15.4 million Btu of cooling were delivered with a seasonal energy efficiency ratio (SEER) of 7.89 Btu/Wh and a sensible-to-total capacity ratio of 0.72. The decline in SEER relative to the first cooling season was due to a much milder cooling season with 28% fewer degree hours. As a consequence the heat pump was off for 81% of the hours when the cooling modes were enabled during the second cooling season compared to 75% during the first cooling season. The power consumed by the control system and crankcase heater during off periods significantly penalizes seasonal performance. Peak electrical demand characteristics were similar to the first cooling season, ranging from 2.2 to 4.2 kW.

Analysis of the results of the field evaluation of the advanced electric heat pump led to the following conclusions:

- The dual-stroke capacity modulation method is efficient and reliable.
- The advanced electric heat pump has demonstrated that it can deliver superior performance.
- Modulation of resistance heat to match the building load significantly improves low temperature energy efficiency.
- Oversizing of the heat pump significantly reduces seasonal energy efficiency, particularly in the cooling mode.
- Location of the compressor in the indoor unit air stream does not result in objectionable noise levels.

ABSTRACT

A preprototype advanced electric heat pump with a unique dual-stroke compressor was installed in an occupied residence in Jeannette, PA (near Pittsburgh). Analysis of field performance data indicates a heating performance factor (HSPF) of 8.13 Btu/Wh, and a cooling energy efficiency (SEER) of 8.35 Btu/Wh for the year April 1, 1983 through March 31, 1984. For the year April 1, 1984 through March 31, 1985 the indicated heating season performance factor (HSPF) was 8.51 Btu/Wh and the cooling season energy efficiency ratio (SEER) was 7.89 Btu/Wh. During the first heating season the peak electrical demand at temperatures above 42°F was 4.0 kW. At lower temperatures the demand reached a peak of 18.0 kW at -2°F. During the second heating season modifications to the method of controlling resistance heat and lowering of the upper and lower heating balance points reduced the peak demand to 3.8 kW at temperatures above 38°F. Maximum demand at -10°F was 14.6 kW. Peak electrical demand during cooling operation ranged from 2.1 to 4.6 kW during the first cooling season and 2.2 to 4.2 kW during the second cooling season. The heat pump was considerably oversized for the test house since the observed lower balance point was 8°F whereas 17°F was optimum. Analysis indicates that if properly sized, the system could deliver an HSPF = 8.47 Btu/Wh, (30% better than a single capacity heat pump representative of high efficiency units in the market place today) and an SEER = 9.33 Btu/Wh for the weather profile observed at the field test site during the first test year.

1. INTRODUCTION

The Westinghouse Electric Corporation has developed an advanced electric heat pump for the United States Department of Energy under contract 86X-24712C with the Oak Ridge National Laboratory. The objective of the development program was a heat pump that was at least 20% more efficient than the most efficient heat pump in the marketplace at contract inception in 1979.

Two preprototypic models were produced, each utilizing a unique dual-stroke compressor, a unique refrigerant circuit, highly efficient air movers and electric motors, and a breadboard microprocessor control system. Details of the development effort may be found in references 1-12. The indoor unit is shown in Figure 1.1, and the outdoor unit in Figure 1.2. The indoor unit is of modular construction and is unique in that the lower module contains the compressor plus all other refrigerant handling components except the outdoor heat exchanger, the center module contains the indoor air mover and controls, and the upper module contains the resistance heat package and main fuses. The outdoor unit is also of unique design in that it contains only the outdoor fan and heat exchanger in a package that can be adjusted for elevation using integral legs. Frost melt is easily shed from the inclined face, horizontal tube heat exchanger elements. The elevation of the heat exchanger above the ground provides some protection against drifting snow.

Laboratory performance data, shown in Figures 1.3 and 1.4, when compared with catalog data or the ARI directory, shows that under steady conditions the efficiency of these preprototype units exceeds by more than 20% units available in 1979. In low capacity heating at 47°F outdoor ambient, the system COP=3.83, (EER=13.1 Btu/Wh), and at 35°F, the

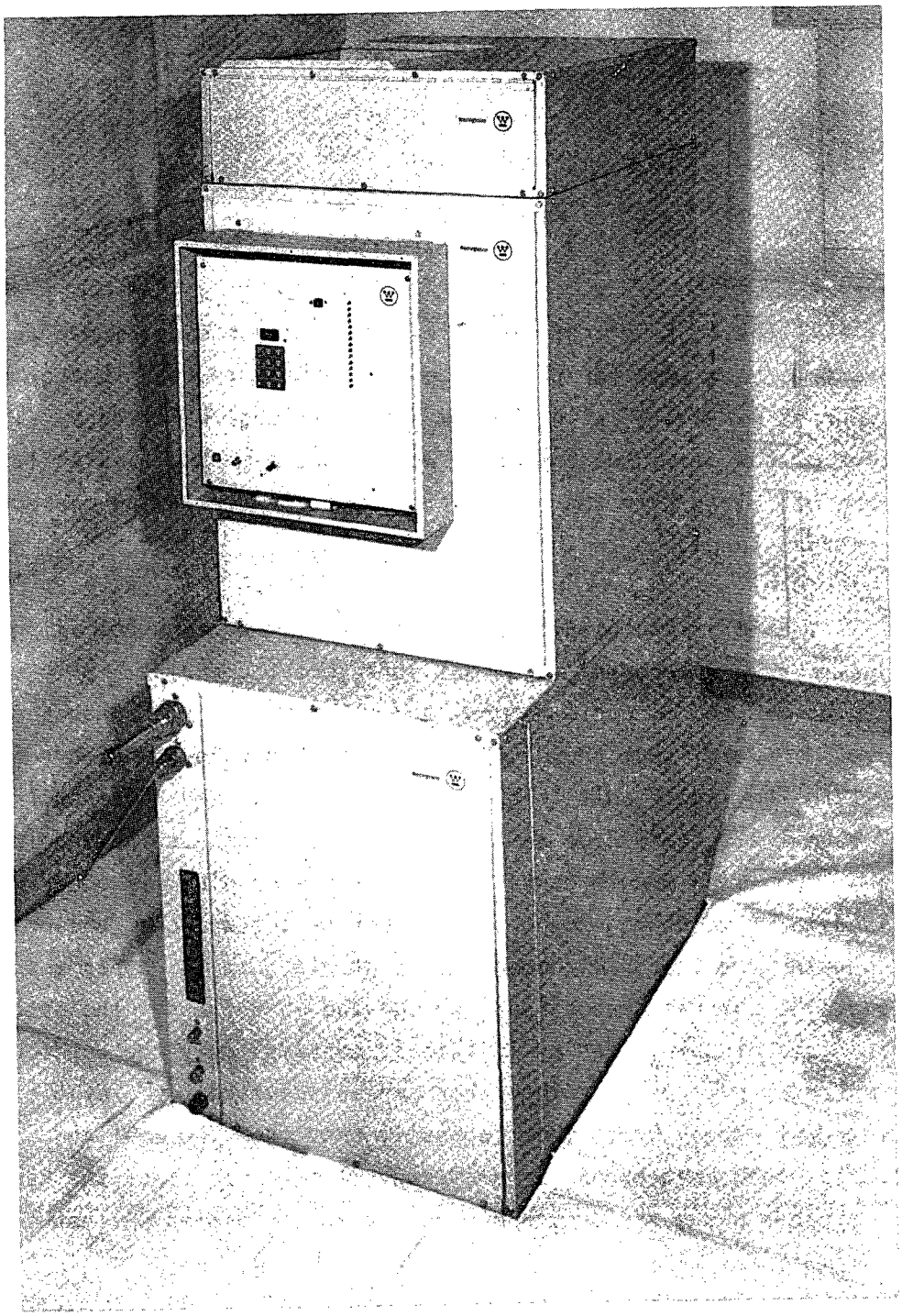

Fig. 1-1 Preprototype heat pump indoor unit

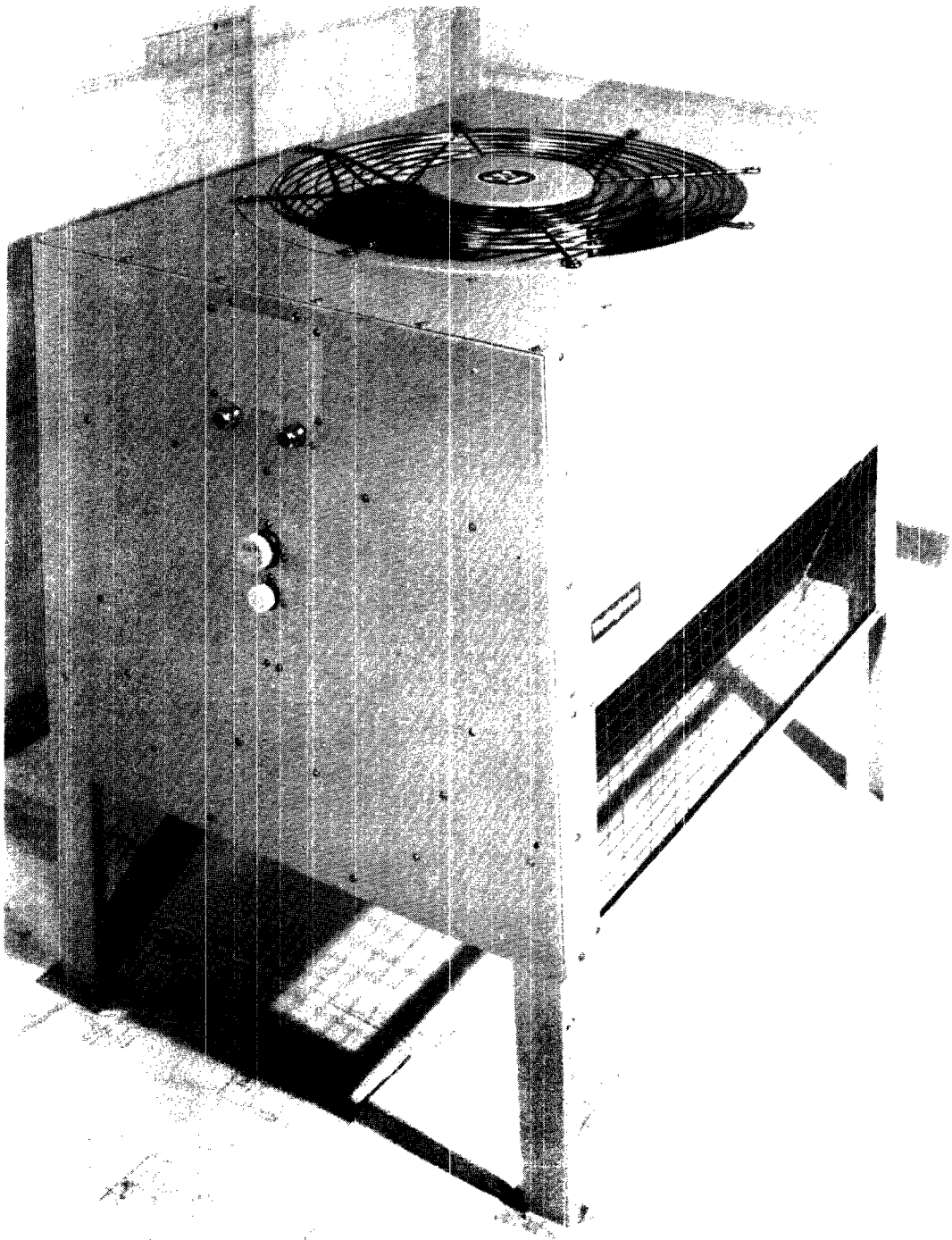

Fig. 1-2 Preprototype heat pump outdoor unit

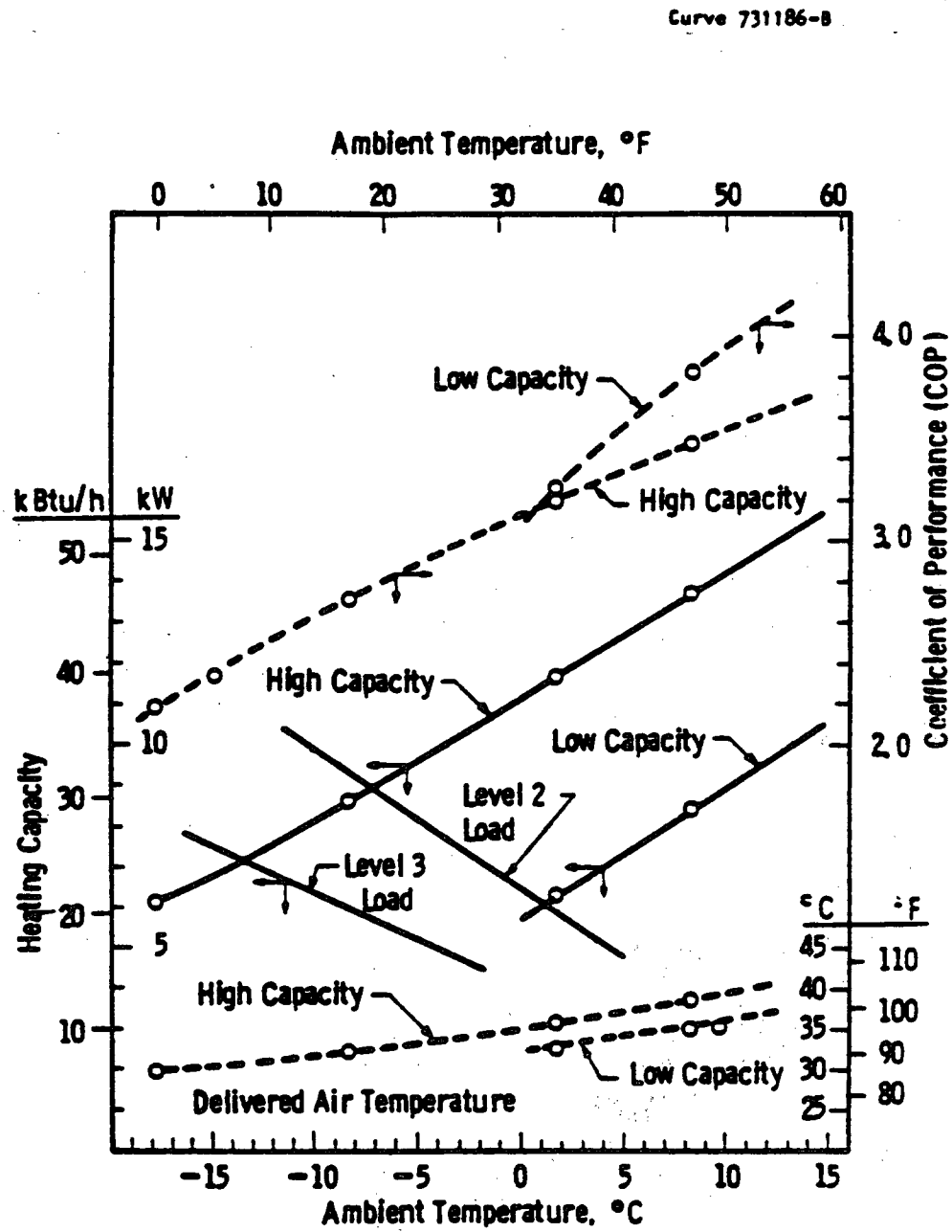

Fig. 1-3 Two-capacity advanced electric heat pump measured heating performance

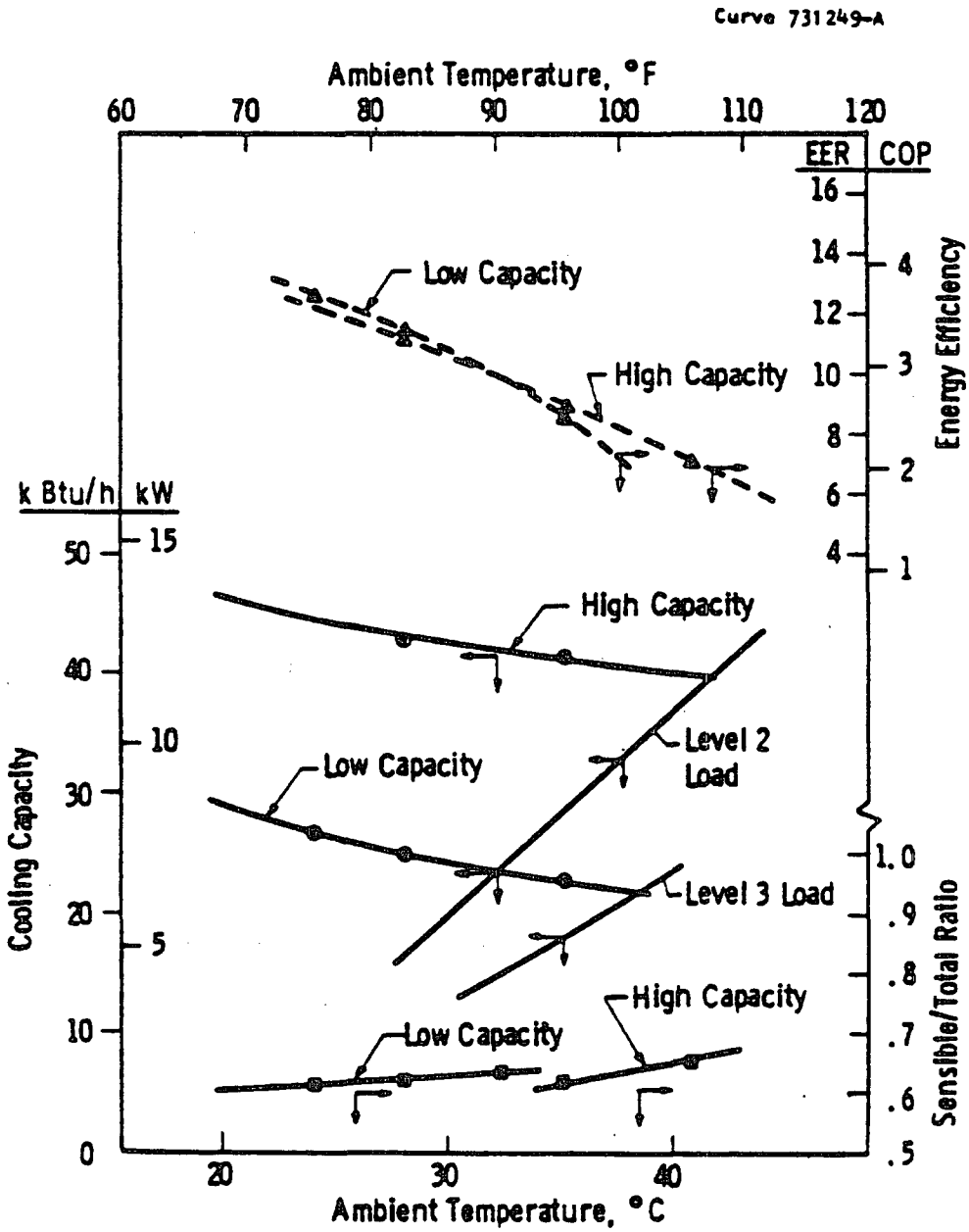

Fig. 1-4 Two-capacity advanced electric heat pump measured cooling performance

COP=3.26 (EER=11.1 Btu/Wh). The system switches to high capacity mode heating for ambient temperatures less than 35°F. In high capacity mode at 47°F outdoor ambient, the COP=3.48 (EER=11.9 Btu/Wh) and at 17°F, the COP=2.71 (EER=9.25). In low capacity cooling mode, at 95°F outdoor ambient, the COP=2.52 (EER=8.6 Btu/Wh), and at 82°F, COP=3.34 (EER=11.4 Btu/Wh). High capacity cooling is enabled at outdoor temperatures greater than 90°F, and at 95°F, high capacity cooling COP=2.67 (EER=9.1 Btu/Wh). The system was designed to provide cooling with a sensible-to-total capacity ratio not greater than 0.7. This limits the achievable cooling efficiency because it prevents evaporator temperatures greater than about 45°F.

Defrosting should not be required in low capacity heating mode, since under frosting test conditions, there was insufficient frost accumulation to degrade performance after 4.5 hours of continuous running. The defrosting penalty for high capacity operation was less than 5% at 35°F. The cyclic degradation coefficient for high capacity heating is C_d = 0.04, for low capacity heating, C_d = 0.18, for high capacity cooling C_d = 0.29, and for low capacity cooling, C_d = 0.34. The rather high cyclic degradation coefficients in cooling mode, and low coefficients in heating mode can be attributed in large part to the location of the oil cooler and compressor in the indoor air stream.

Optimally sized for residential application in a DOE Region IV northern climate, the heat pump should balance the heating load in high capacity mode at about 17°F. In Reference 1 we estimated that if optimally applied in the Pittsburgh, PA, area we should achieve a heating season performance factor or HSPF = 8.81 Btu/Wh, and a cooling season energy efficiency ratio or SEER = 10.28. This efficiency estimate was based upon optimum heat pump sizing for a house with level 2 insulation (see Reference 13), in Cleveland weather. Predicted efficiency exceeds project goals.

Before the advanced features embodied in this heat pump could be considered ready for commercialization, the system had to demonstrate its economic and technical feasibility in a residence under real world operating conditions. Considerations include the demonstration of superior seasonal performance factors; occupant comfort; proper operation under conditions of actual use including thermostat manipulation, inclement weather such as freezing rain and snow, and typical utility electrical service; and lastly, durability of the dual-stroke mechanism and other advanced features. After completion of the lab testing phase of our development project, one preprototype system was installed in an occupied residence in Jeannette, PA, (near Pittsburgh) on November 24, 1982 for an extended engineering evaluation of field performance.

2. SUMMARY

2.1 OBJECTIVES

The objectives of this field performance evaluation were threefold. First, the durability of the dual stroke compressor was to be demonstrated as part of a host heat pump system subjected to the trials of actual weather and residential application. Second, the thermodynamic performance of the system was to be monitored in detail so as to demonstrate that the system met its design goals of superior performance while providing satisfactory comfort. Third, through detailed analysis of the field performance data, the merit of the advanced concepts embodied in the system was to be evaluated, and means identified to improve system performance.

2.2 TEST SITE

A northern climate site was desired for the dual stroke heat pump field evaluation test since the system was optimized for DOE region IV. The selection of a specific site for the field evaluation test was constrained by the fact that there are but two samples of the dual stroke heat pump in existence, and no field personnel experienced with its installation and service. Since the professional and technician staff responsible for the development of the heat pump system would have to service it in the field, a test site near Pittsburgh was highly advantageous. An engineer at the Westinghouse R&D Center not associated with this project expressed an interest in hosting the test in exchange for the installation of a state-of-the-art unit at the completion of the program. His well-insulated 2100 ft^2 two-story home, shared with a wife and two children, is located near Jeannette, PA, about 30 miles east of Pittsburgh, and is shown in Figure 2.1. His home was originally space conditioned by a seven year old three ton heat pump. The building load was estimated from engineering drawings for the dwelling, and the high

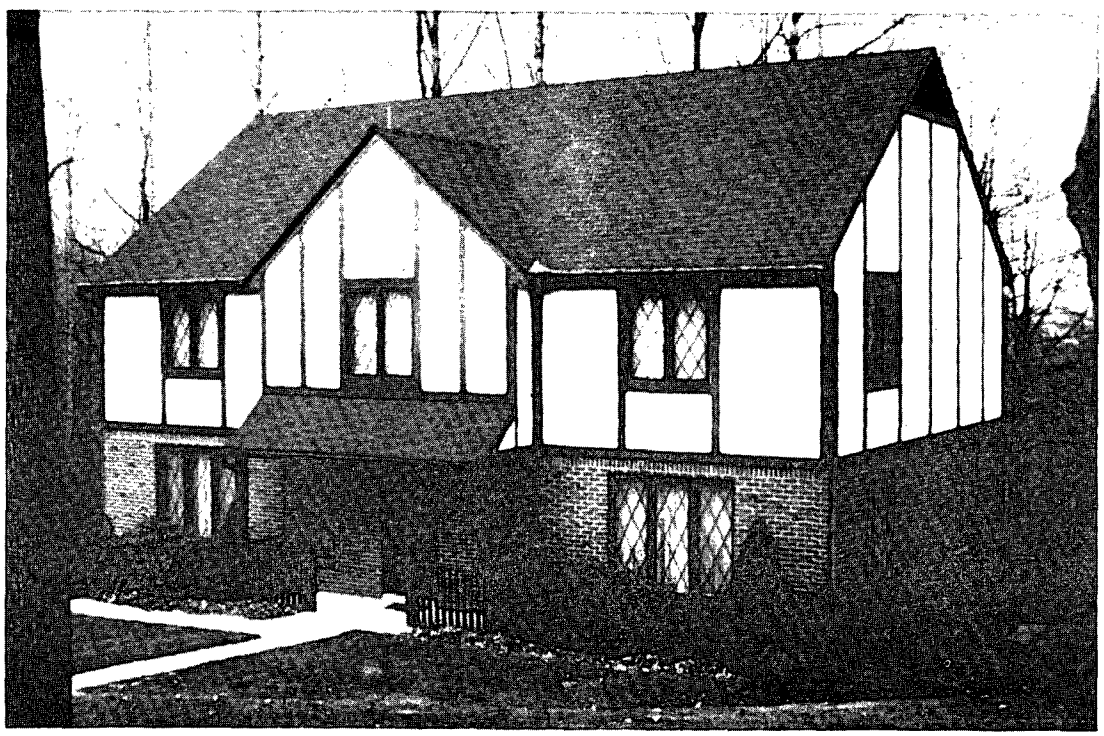

Fig. 2-1 Host residence for the Westinghouse-DOE dual-stroke advanced electric heat pump

capacity balance point for the preprototype dual stroke heat pump was estimated at 18°F, very near the analytical optimum.

The heat pump most suitable for field installation was preprototype #2, which was cycled through the laboratory performance tests in October of 1982. It was installed in the field without exhaustive laboratory testing of the fault diagnosis and system trip software (ROM based) resident in the microprocessor in order to initiate the field evaluation phase of the research and development project immediately after hardware completion and laboratory testing, but before the onset of severe winter weather. Proof testing of the control system therefore took place in the field. The heat pump was installed during the third week of November with the indoor unit in a small utility room located in the basement, between an integral two-car garage and a finished family room. Except for cramped access, the installation was straightforward, and the unit was pressed into service after installation. Figures 2.2 and 2.3 show the installation.

2.3 INSTRUMENTATION

Site weather was monitored by a commercial, roof-mounted weather station. It consisted of an anemometer, wind direction indicator, temperature sensor, solar insolation indicator, and a rain gage. Installation of the weather station took place in early December 1982, shortly after the the equipment was delivered.

Thermodynamic instrumentation was installed to measure indoor return air flow, delivery and return air temperature and relative humidity, and several temperatures and pressures within the refrigerant circuit, including compressor suction and discharge pressure and temperature. Barometric pressure in the utility room was measured using a pressure transducer. Condensate was collected and pumped to a self-emptying reservoir. The water column height in the reservoir was monitored by the data system using a pressure transducer in order to estimate delivered latent cooling.

Fig. 2-2 Outdoor heat pump unit as installed

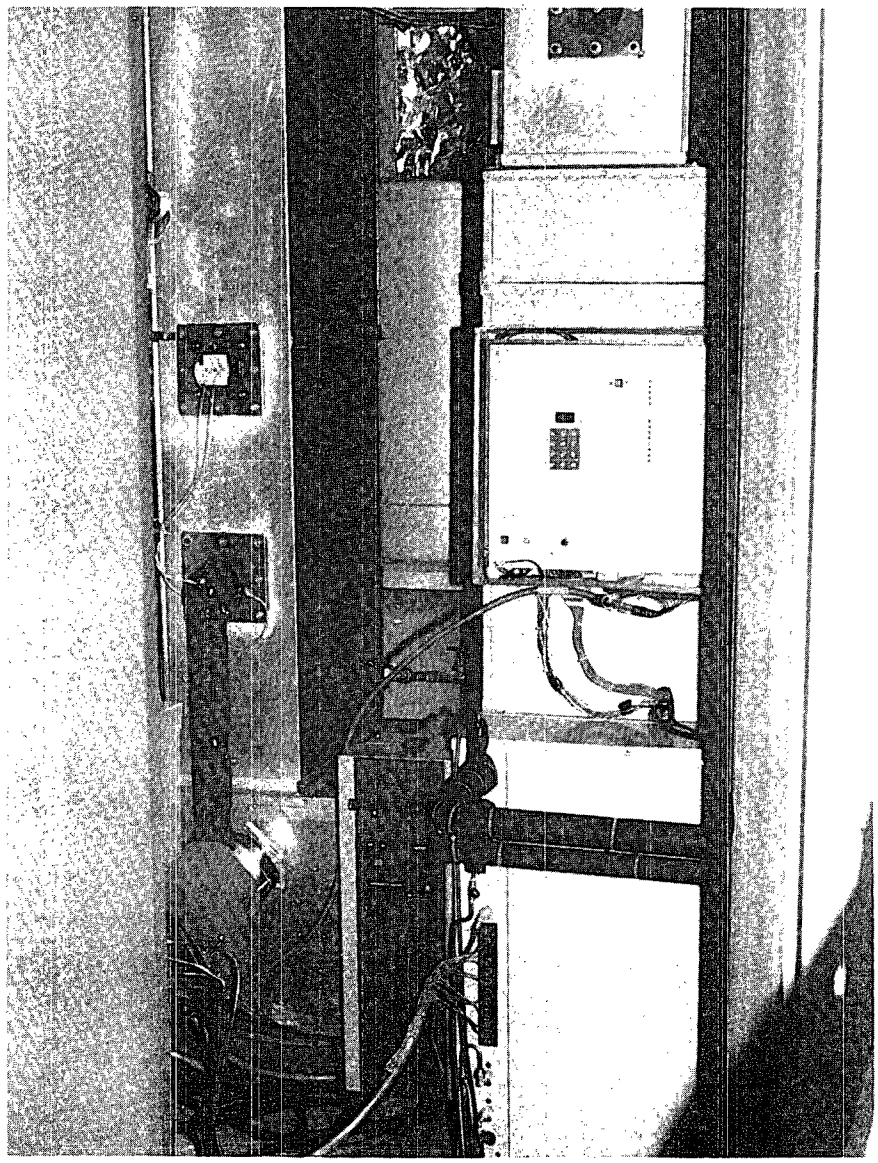

Fig. 2-3 Indoor heat pump unit as installed

All motors, the entire heat pump system, the resistance heat package and whole house energy consumption were monitored using electronic Watt/Watt-hour transducers. In addition, conventional rotating disc Watt-hour meters were used to measure the energy consumption of the hot water heater, the electric clothes dryer, an auxiliary game room heater, the heat pump system, and the resistance heaters. Line voltage was also monitored.

The control system contained 14 relays which were energized by the microprocessor's ROM based software to permit 20 distinct operating modes. The data system monitored the state of these control relays.

The data system, a Hewlett-Packard HP3497A data acquisition and control unit controlled by an HP85F computer, scanned continuously, monitoring up to 83 channels of data (60 analog voltage channels, 14 relay states, and 9 digital counters). A full scan was recorded on an on-site Quantex dual cassette tape recorder only if it immediately preceded or followed an event or was triggered by a 15 minute timer. An event was defined as the change in state of any one of the fourteen relays in the heat pump control system. A group of priority channels was recorded from every scan when the heat pump was operating. During the first year of data acquisition there were 140 seconds between successive scans in order to accommodate statistical processing, thermocouple linearization, and units conversion. Time resolution of an event was thus of the order of 140 seconds. During the second year of data acquisition, modifications to the data logger software reduced the time between scans to about 50 seconds. The on-site tape recorder was queried periodically over the telephone using an automatic answering modem and the recorded data was transferred to the mainframe computer at the R&D Center. Typically, the period was once each day, but the cassette recorder had sufficient capacity to store data over a weekend.

Although the heat pump system was installed in November of 1982, the installation of the data system and its field resident software was

not completed until March 4, 1983. Heat pump performance could be monitored at the Westinghouse R&D Center, some 30 miles distant, using a computer terminal and the telephone system, starting in mid January 1983. This monitoring process was tedious since the available data were instantaneous in nature, and for many channels the data were in voltage units. Proper unit function was relatively easy to determine, but efficiency was not. Data were archived on computer tape at the R&D Center, but those data prior to March 4, 1983 were judged to be too expensive to process because of frequent changes in the data logger software. Data were archived continuously from April 1, 1983 to March 31, 1985 and processed.

Data reduction software resident in the Univac 1108/81 computer at the R&D Center attributed each scan of the data to one of the operating modes, and to the appropriate ambient temperature bin. In order to determine operating efficiency, both the heating and cooling energy delivered, and the respective energy consumed, must be known. Energy consumption was determined without any ambiguity for the heat pump system, and the constituent components. The heating energy delivered was estimated by integrating with respect to time the instantaneous readings for the change in air enthalpy across the indoor section of the heat pump. The cooling energy delivered was estimated similarly using the amount of condensate collected as a measure of the latent heat. An effective condensate handling system was not in operation for all of the first reporting period however, and some early data was corrected using the sensible-to-total ratio as a function of temperature that was measured in the latter portion of the first cooling season. Laboratory measurements of transient heat pump behavior were used in conjunction with models for the transient behavior of the sensors to interpolate between data samples, and to extrapolate to event initiation when performing the integration. Data reduction software at the R&D Center processed approximately 34,000 data points each day and prepared a summary of performance segregated by ambient temperature bin for each day. A summation program then operated on these daily records

to provide summary reports for periods of arbitrary length, such as a week or month.

2.4 OPERATING STATUS

The dual-stroke advanced heat pump supplied the heating and cooling required by an occupied residence from November 24, 1982 through April 2, 1985 without a serious failure of any of the advanced components in the system. In particular, the oil-cooled dual-stroke compressor performed reliably with no apparent deterioration in performance. The only components to suffer failures were external compressor electrical components (contactor, start relay, and capacitor), all items of commercial hardware. The indoor blower required adjustment on several occasions to eliminate a squeak, which was determined to be the result of the drive shaft turning inside the bearing races, causing wear of the mild steel shaft. On November 30, 1984 a "ticking" noise caused by rubbing of the blower wheel on the housing could no longer be corrected by adjusting the clearance between the wheel and housing due to excessive wear of the shaft. Therefore the blower from preprototype number one was installed for the remainder of the test period. The blower shaft and bearings in the original blower were replaced to provide a spare unit.

The breadboard microprocessor control system and its resident software demonstrated that they were indeed breadboard in nature by virtue of the problems encountered. Upon installation, the microprocessor system proved to be vulnerable to line voltage fluctuations, most particularly dropouts, which occurred with regularity. We later learned from the local electrical utility that many of these dropouts were due to changes being made in the distribution system in the area. A redesigned power supply cured these problems. The first year, and in particular the first quarter, of operation was marked by repeated nuisance trips of the system, caused not by refrigeration system malfunctions, nor by electricity supply problems, but primarily by bugs in the microprocessor software. The system would mistakenly diagnose a

variety of fatal ailments, low charge most frequently, and proceed to shut the system off. The first version of the resident software did not automatically engage emergency heat, with the result that the occupants of the residence were considerably annoyed and inconvenienced. Revised software eliminated most nuisance trips and greatly reduced host dissatisfaction. However, nuisance trips were never fully eliminated. The occupants of the residence on many occasions reset the microprocessor in order to permit its continued function after a nuisance trip. Lastly, several bugs in the software were discovered, but since project resources were limited and since the bugs could be circumvented without deleterious impact upon system function, new ROM's were not prepared during the first year of service. Prior to the second year of operation new ROM's eliminating most of these bugs were prepared and installed. System trips plus necessary down time for instrumentation, maintenance and system inspection resulted in heat pump unavailability for 239 hours during the first report period of 8784 hours. The data system was down for 198.5 hours, and the dwelling was without electrical service for 12.5 hours during the first report period. System status is shown in Figure 2.4A. During the second year of operation the heat pump was unavailable for 46.5 hours, the data system was down for 643.1 hours and the residence was without electricity for 18.6 hours. System status for the second year is shown in Figure 2.4B.

2.5 OPERATING HISTORY

The histogram of hours of temperature occurrence and the mode of heat pump operation for the field test site during the first year's operation is presented in Figure 2.5A. Figure 2.5B presents equivalent data for the second year. The inferred building load and heat pump capacity are shown in Figure 2.6A for the first year. Figure 2.6B shows the inferred building load for the second test year. Note that although the zero load point was between 55°F and 57°F, the hours in heating mode and in cooling mode diffuse across this temperature. Note also that the high capacity heating balance point is approximately 8°F, considerably lower than both the 18°F expected and the 17°F that is

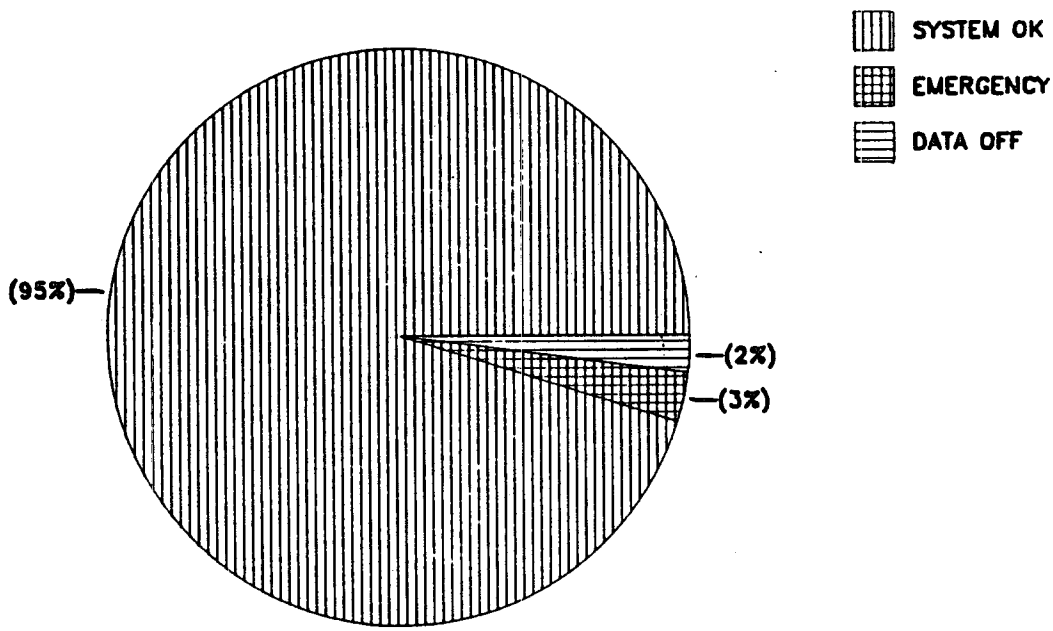

Fig. 2-4A System status report - April 1, 1983 through March 31, 1984

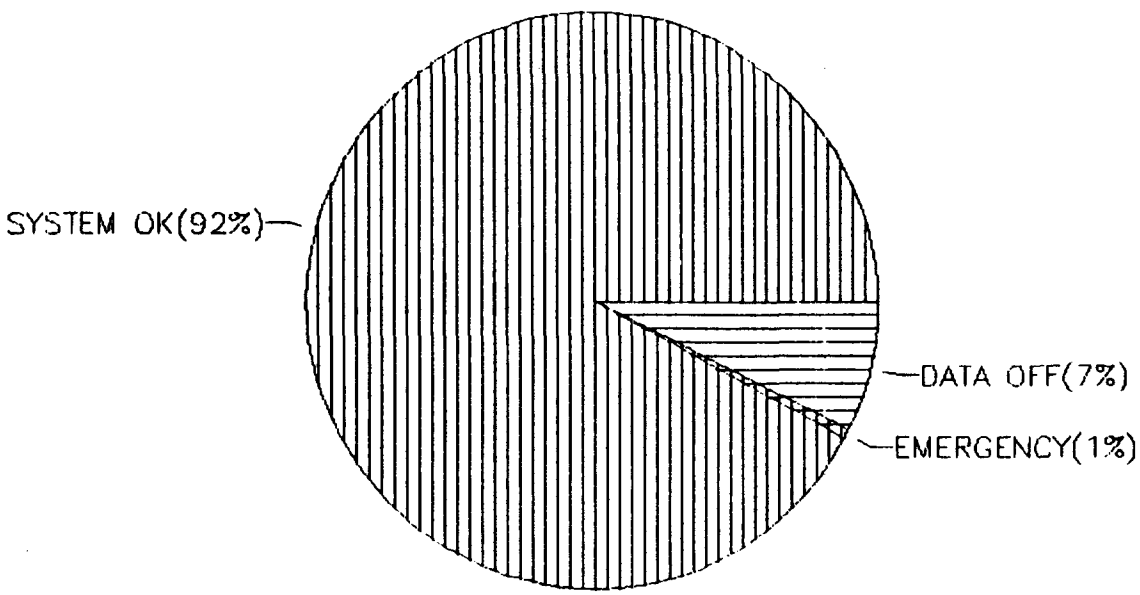

Fig. 2-4B System status report - April 1, 1984 through March 31, 1985

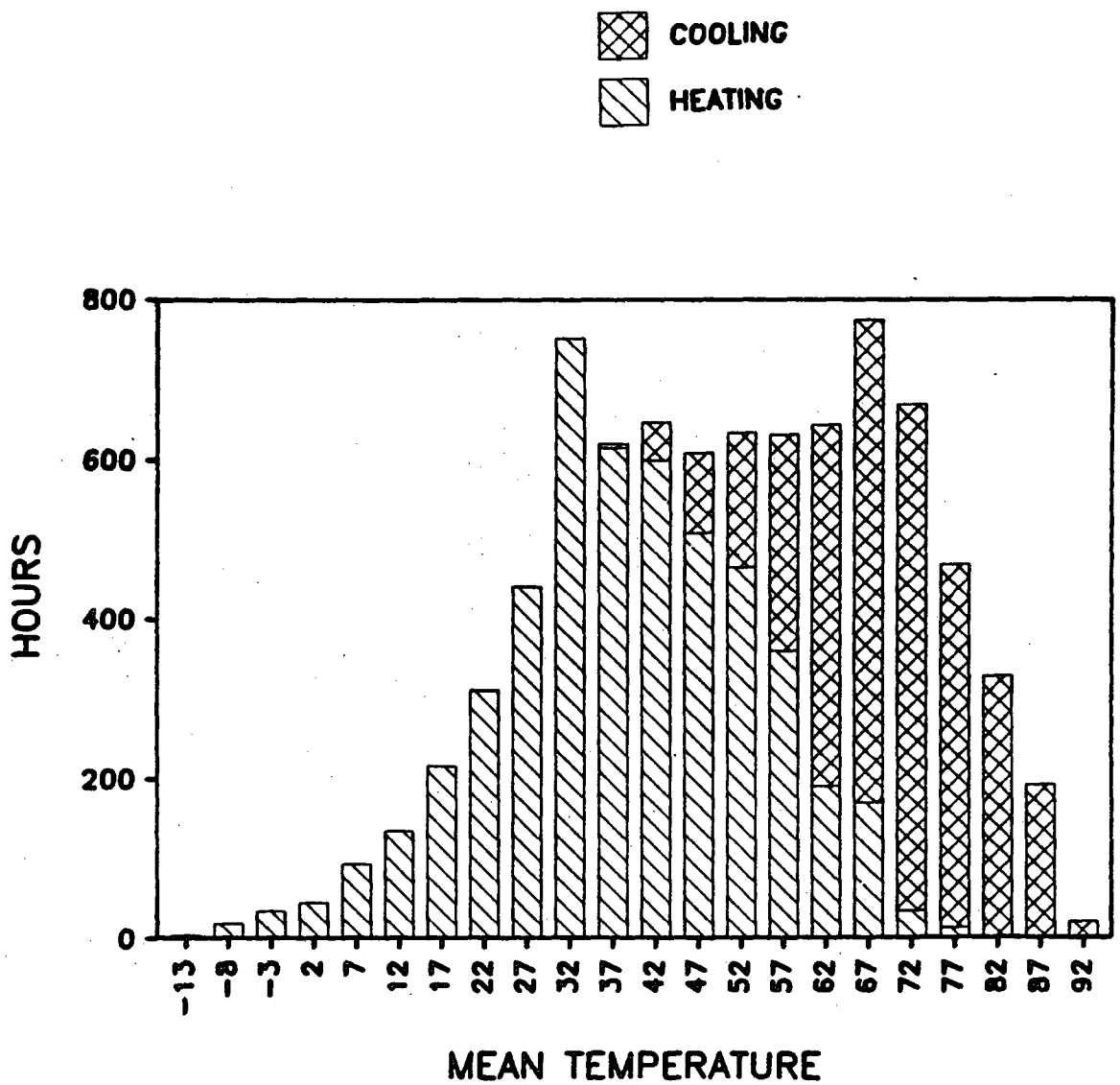

Fig. 2-5A Hours of temperature occurrence - April 1, 1983 through March 31, 1984

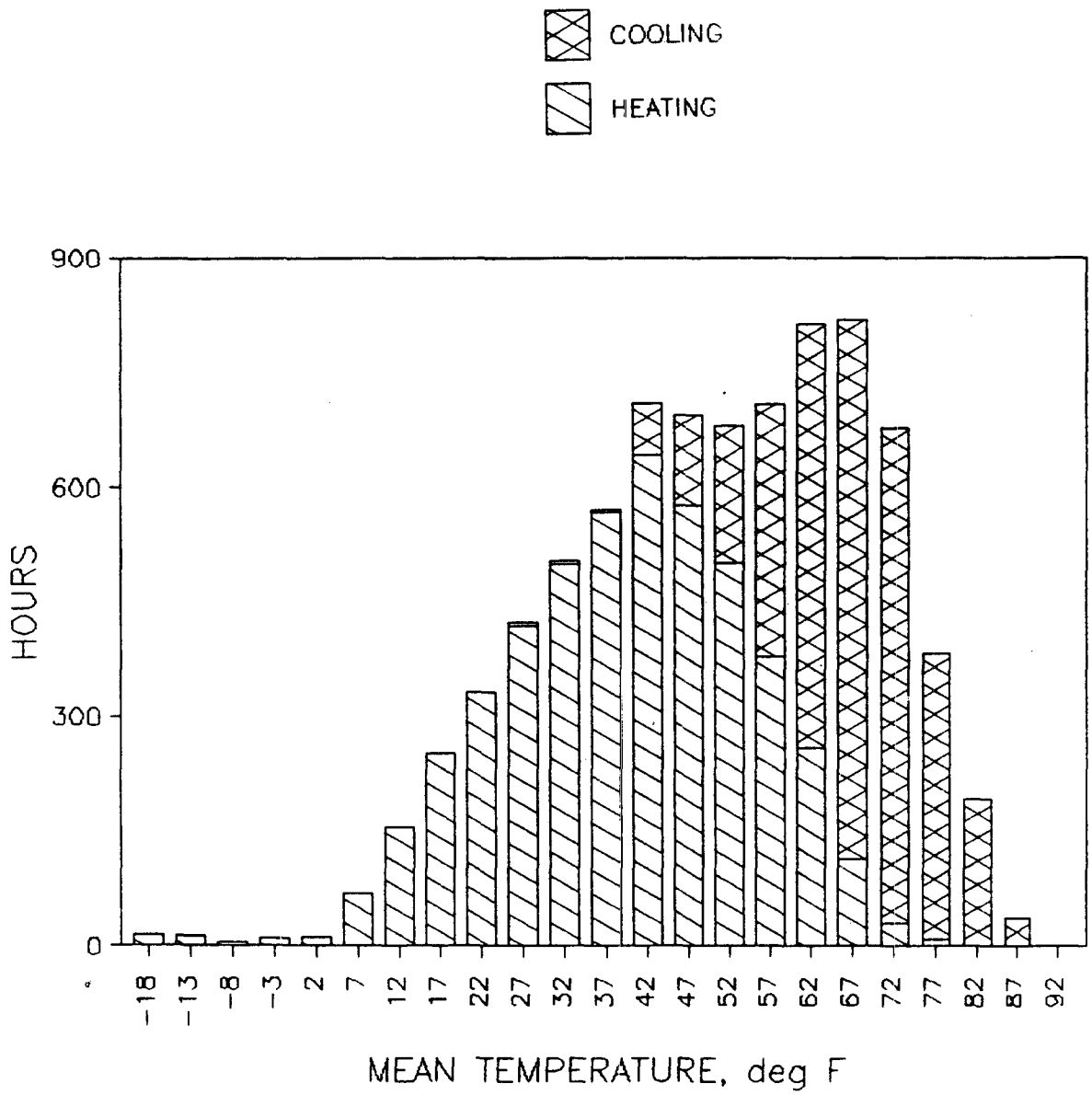

Fig. 2-5B Hours of temperature occurrence - April 1, 1984 through March 31, 1985

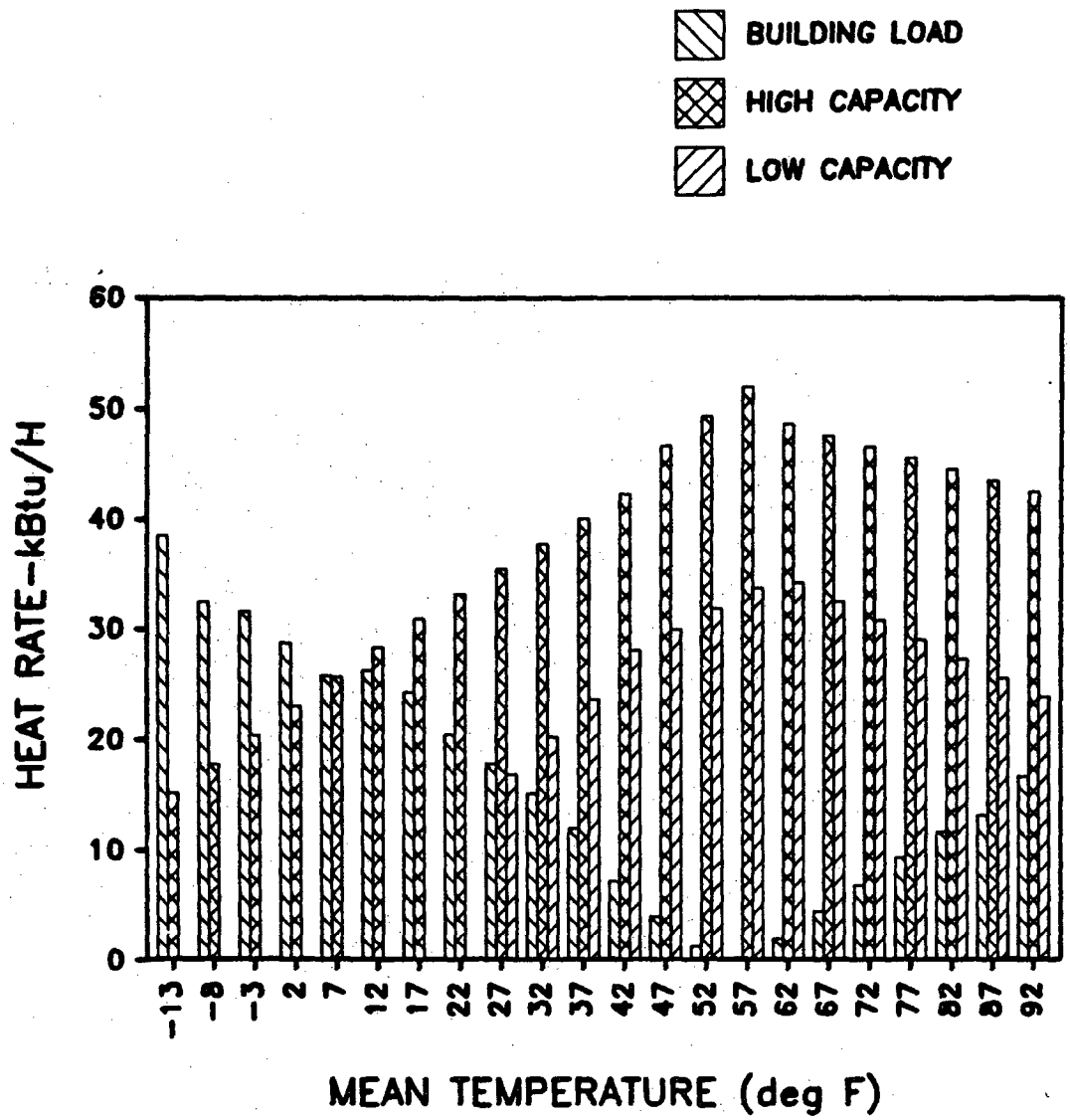

Fig. 2-6A Heat pump load and capacity - April 1, 1983 through March 31, 1984

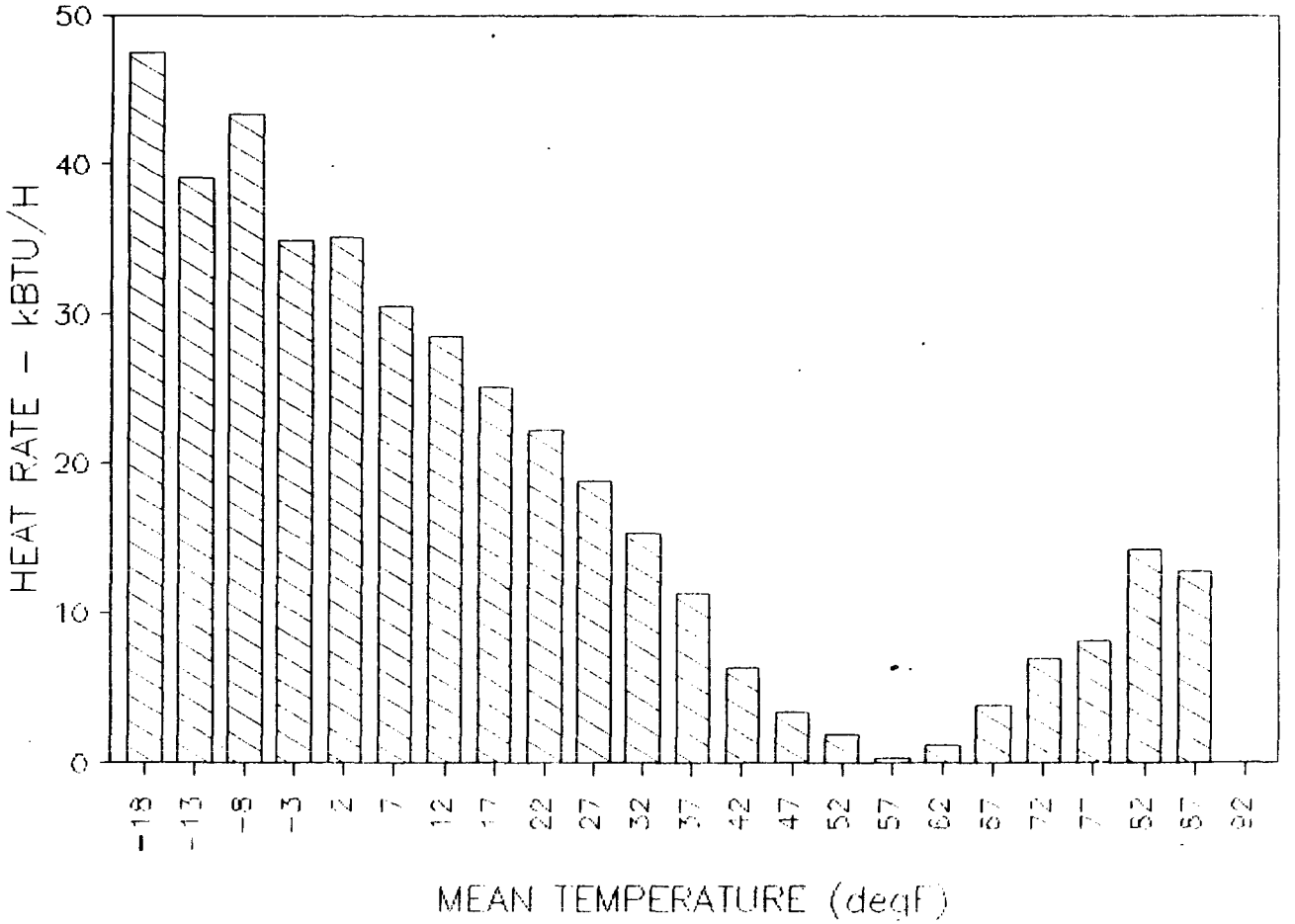

Fig. 2-6B Building load - April 1, 1984 through March 31, 1985

optimum. The low capacity heating balance point was approximately 27°F, considerably below the cutoff temperature for low capacity operation-roughly 32°F. Figures 2.6A and 2.6B indicate that high capacity cooling operation should not have been required. Figures 2.7A and 2.7B show the cooling duty for the first and second cooling seasons respectively. As expected, little high capacity cooling operation occurred, 37.0 hours in the first cooling season and 5.2 hours in the second.

The dual stroke advanced heat pump was configured for control purposes through control parameters programmed into the microprocessor. When the unit was installed the expected balance point was 18°F. Therefore, the first stage of resistance heat was enabled at 19°F. The switchover temperature between low capacity and high capacity operation was set to occur at 39°F. The second stage of resistance heat was set to come on with the compressor upon a call for heat at ambient temperatures less than 8°F, the third stage at -3°F, and the fourth stage at -14°F. The resistance heat stages were nominally 4.8 kW each. Whenever resistance heat was energized during the first heating season the control system locked it on until the system cycled off with a satisfied thermostat. During the second heating season the switch between low and high capacity operation was set at 32°F. While the unit could carry the building load in low capacity mode at lower temperatures, the pressure ratio across the compressor would be higher than the design limit. The first stage of resistance heat was enabled at 17°F, the second stage at 5°F and the third stage at -7°F. Due to the alterations to the resistance heat package to accommodate modulation of one stage, the fourth stage of resistance heat was eliminated. These set points were selected on the basis of maintaining a comfortable delivered air temperature, rather than building load considerations. During the first cooling season the unit would automatically cycle on in the high capacity cooling mode at temperatures greater than 95°F. At lower temperatures the unit would start in low capacity cooling mode and switch to high capacity mode if the load had not been met within 20 minutes of run time. During the second cooling season the switch point was raised to 97°F.

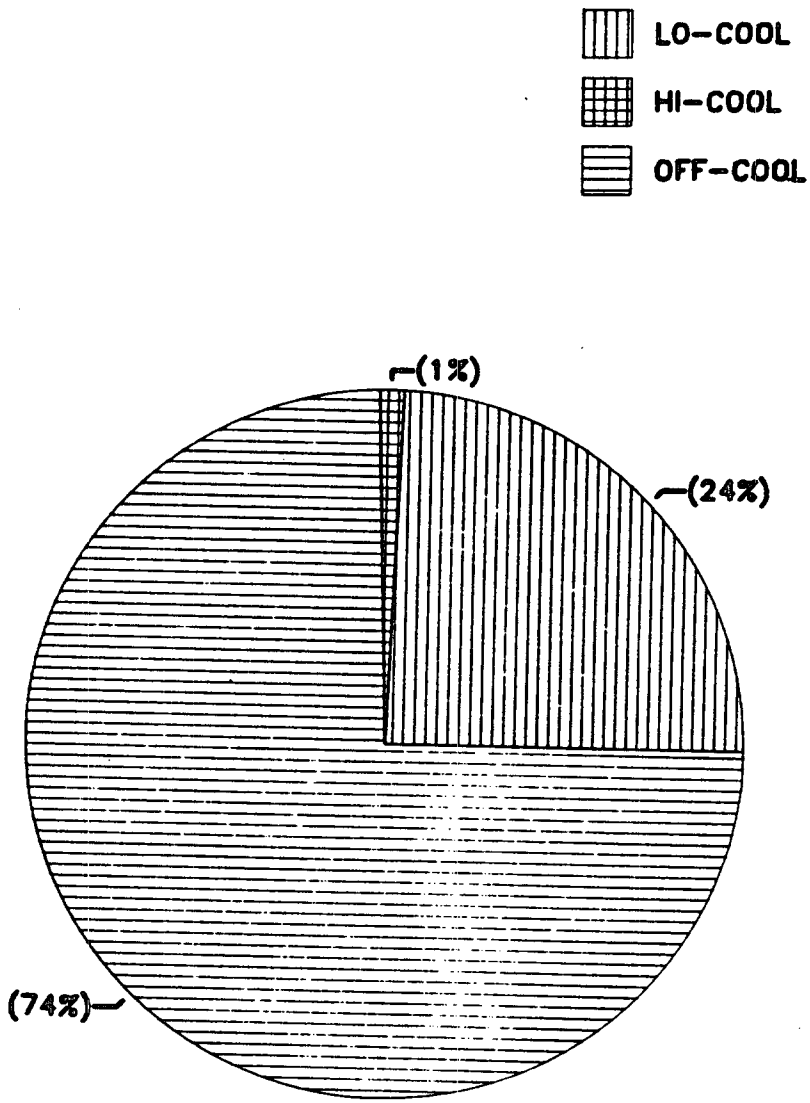

Fig. 2-7A Cooling duty - first cooling season

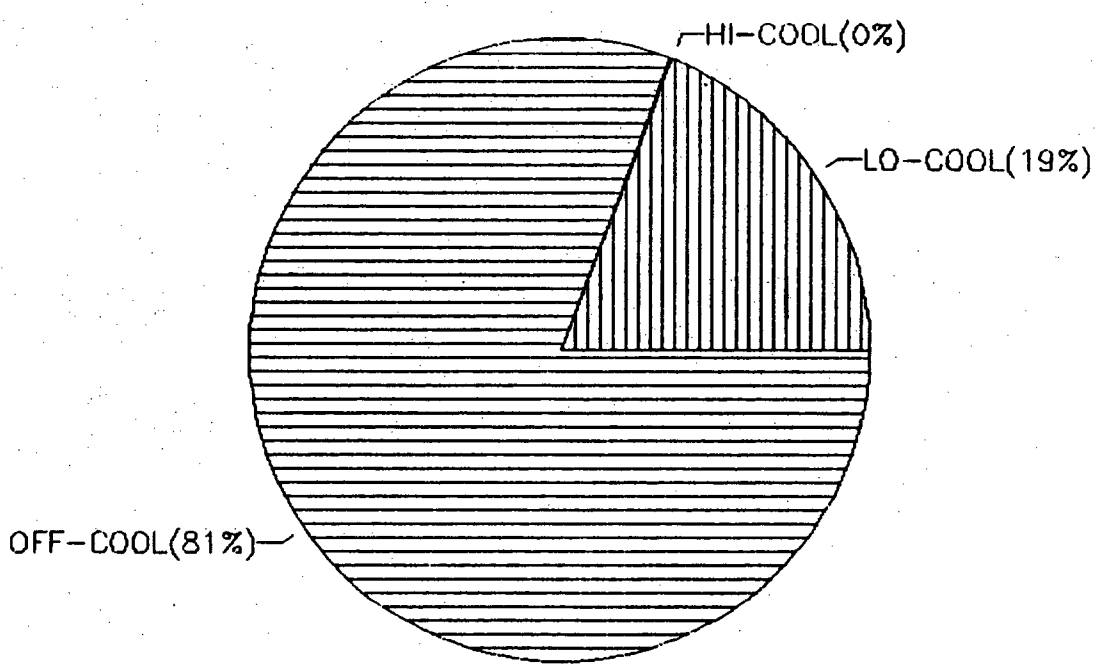

Fig. 2-7B Cooling duty - second cooling season

System status during heating operation for the first and second report periods is shown in Figures 2.4A and 2.4B. Note that the occurrence of emergency mode does not necessarily mean that the system had a fault, but could also indicate that the system was parked in this mode while some maintenance was being performed on the system, its instrumentation, the data system or its power supply. During the first heating season the owner put the unit into emergency heat mode on a few occasions to avoid nuisance trips during his absence or ensure the comfort of guests. Figure 2.7A shows that during the first cooling season the unit ran in the cooling mode for 25% of the hours during which the unit was set to cool, with only 4% of the run time (1% of the total time) occurring in high capacity mode. For the second cooling season, shown in Figure 2.7A, the unit ran in the cooling mode for 19% of the hours in which the cooling modes were enabled and in high capacity mode for than 0.8% of the operating hours (0.2% of the total time).

Figure 2.8A shows that of the time spent in heating mode during the first heating season, the unit was off 73% of the time, running in low capacity for 6% and in high capacity for 22%. For the second heating season, shown in Figure 2.8B, the unit was off 68% of the time, running in low capacity 10% of the time and in high capacity 22% of the time when the unit was configured for heating service. The distribution of duty hours for the full year is shown as a function of ambient temperature for the first year in Figure 2.9A and for the second year in Figure 2.9B. The duty factor is lower than is optimum primarily because the unit is oversized. The distributions of running hours by operating mode are shown in Figures 2.10A and 2.10B.

2.6 THERMAL ENERGY DELIVERY

The profiles of delivered space conditioning thermal energy for the first and second year's operation are shown in Figures 2.11A and 2.11B. During the first year approximately 54.9 million Btu of heat was delivered and 21.1 million Btu of cooling. For the second year, 53.4

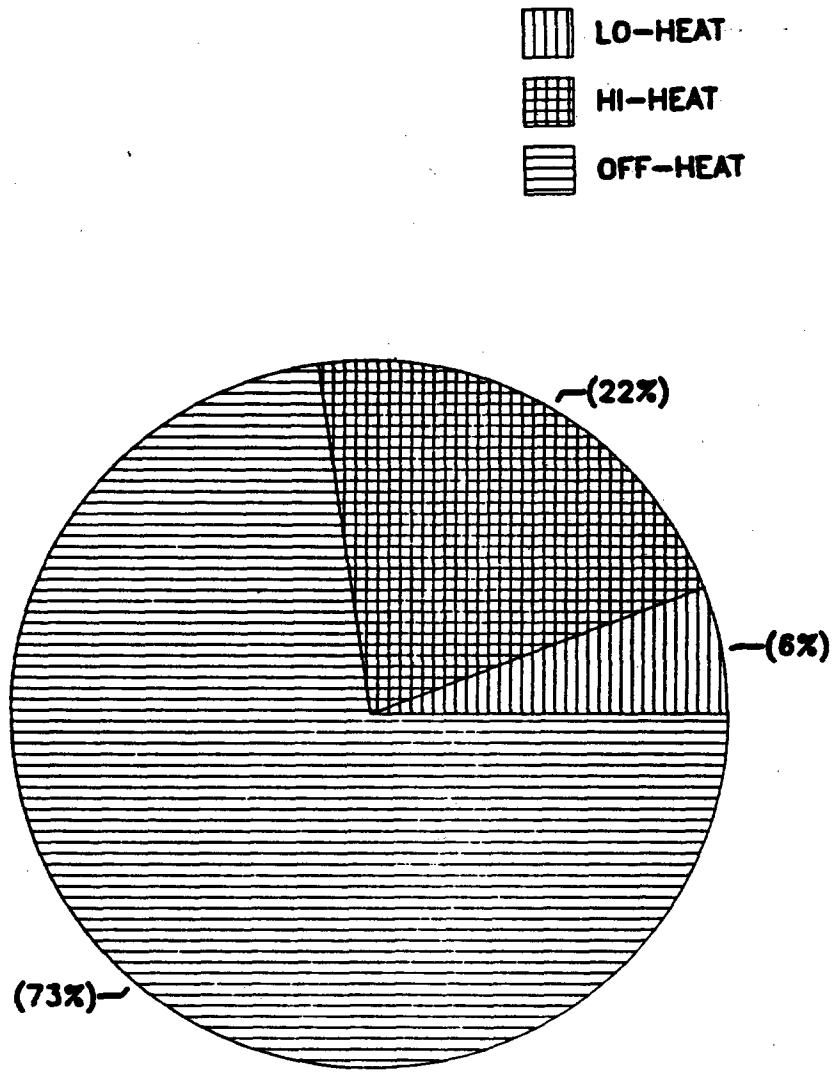

Fig. 2-8A Heating duty - first heating season

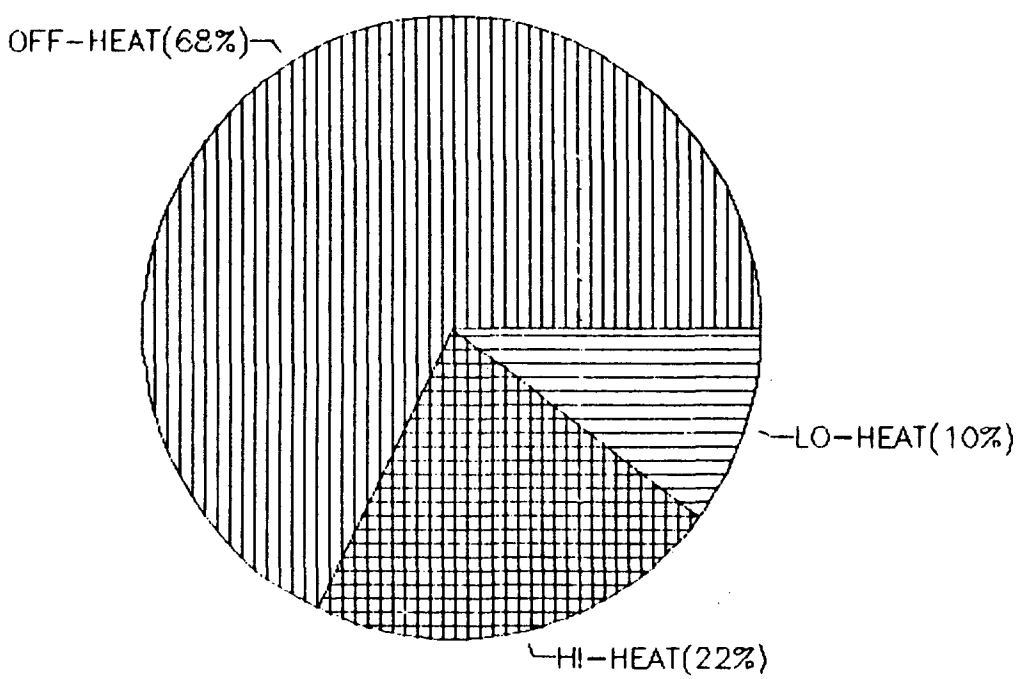

Fig. 2-8B Heating duty - second heating season

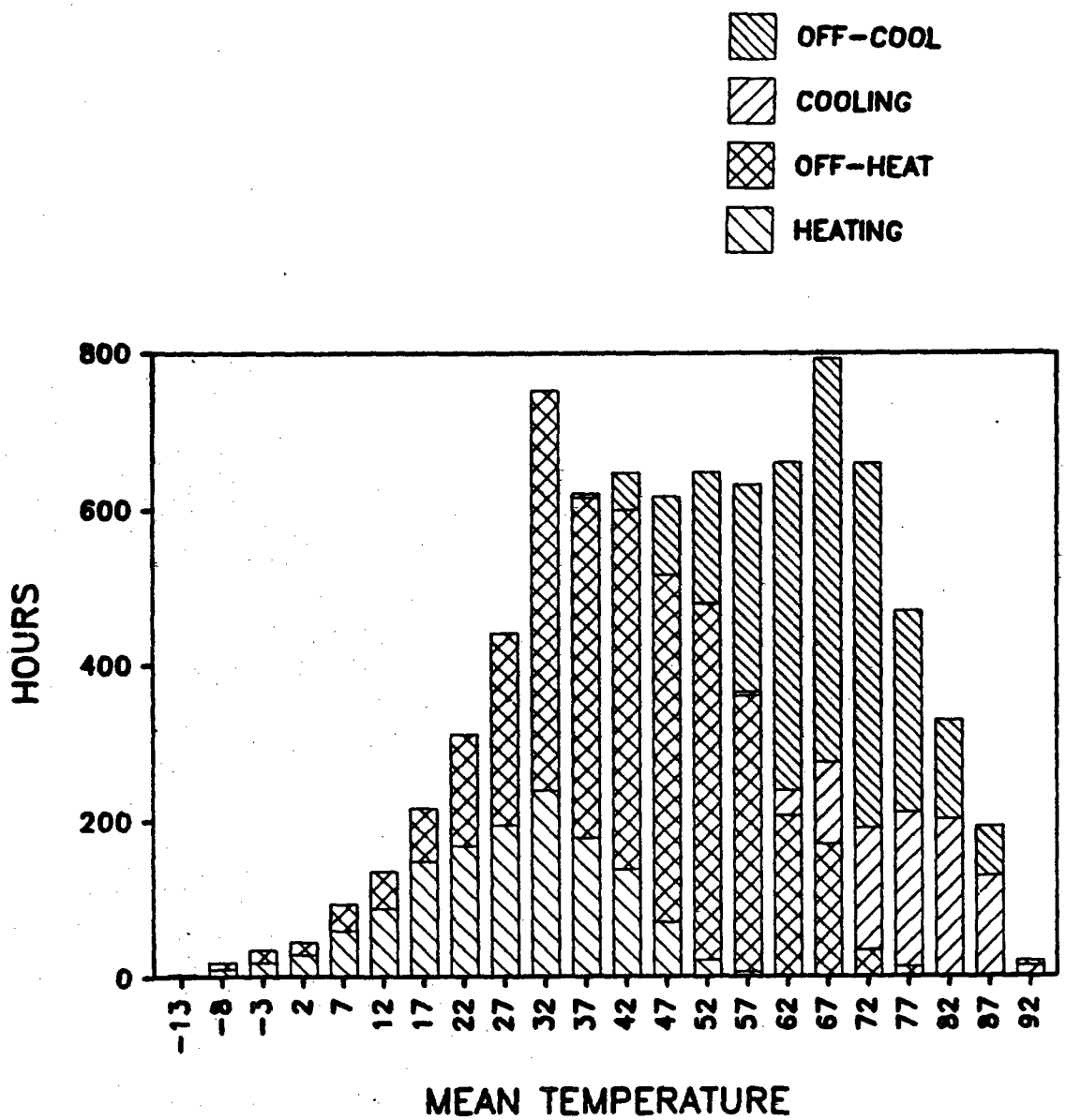

Fig. 2-9A Duty hours - April 1, 1983 through March 31, 1984

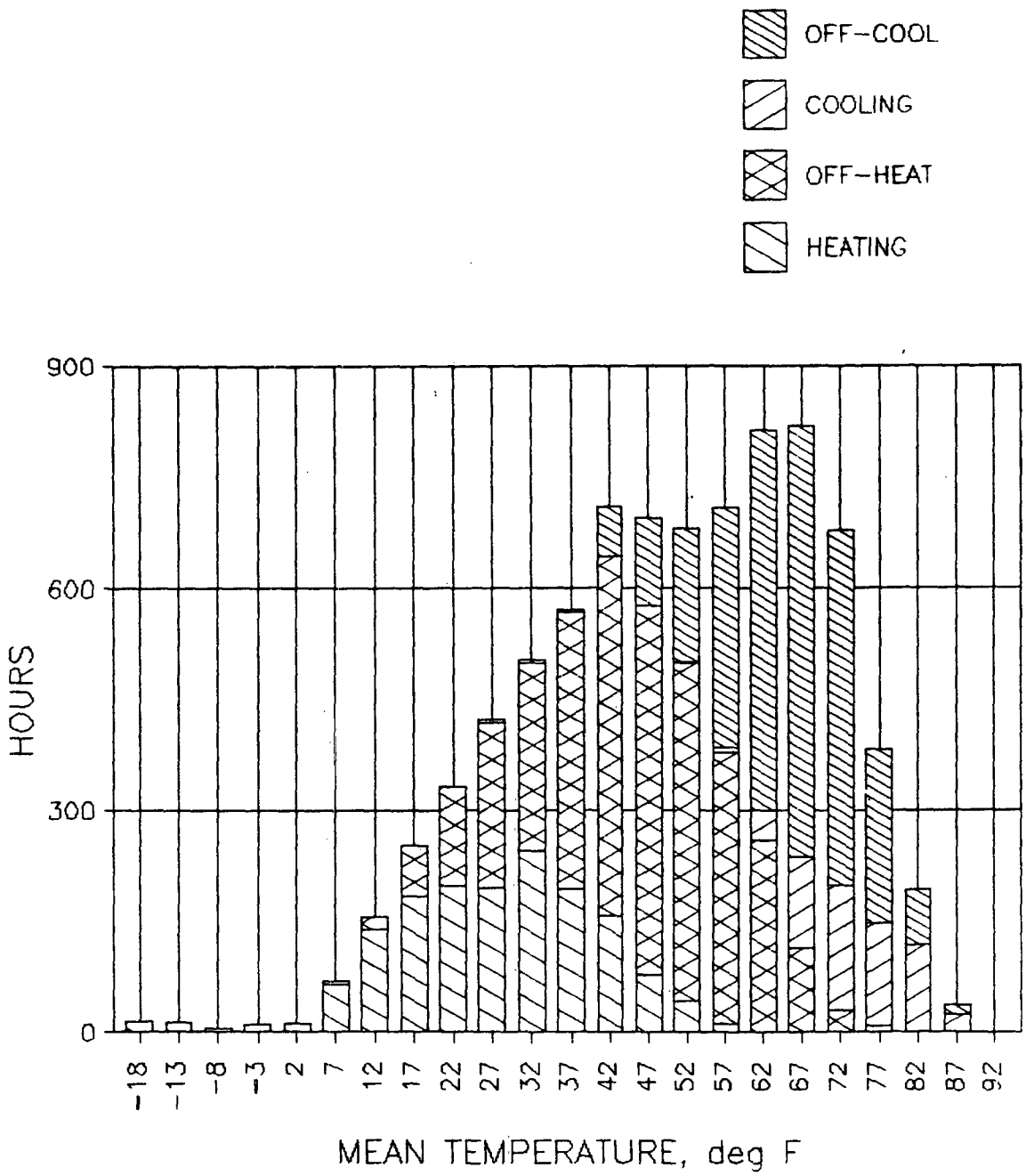

Fig. 2-9B Duty hours - April 1, 1984 through March 31, 1985

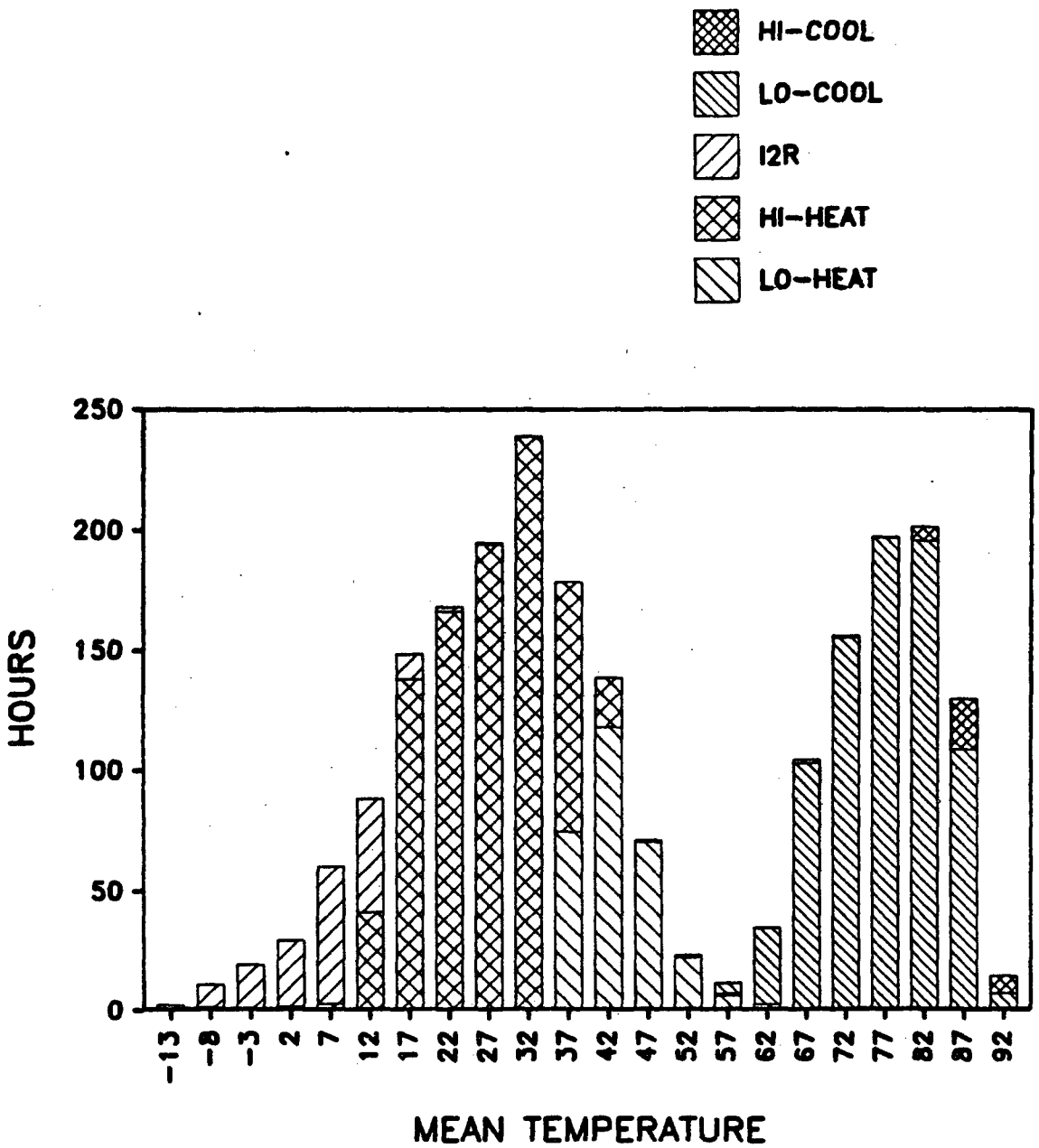

Fig. 2-10A Operating mode hours - April 1, 1983 through March 31, 1984

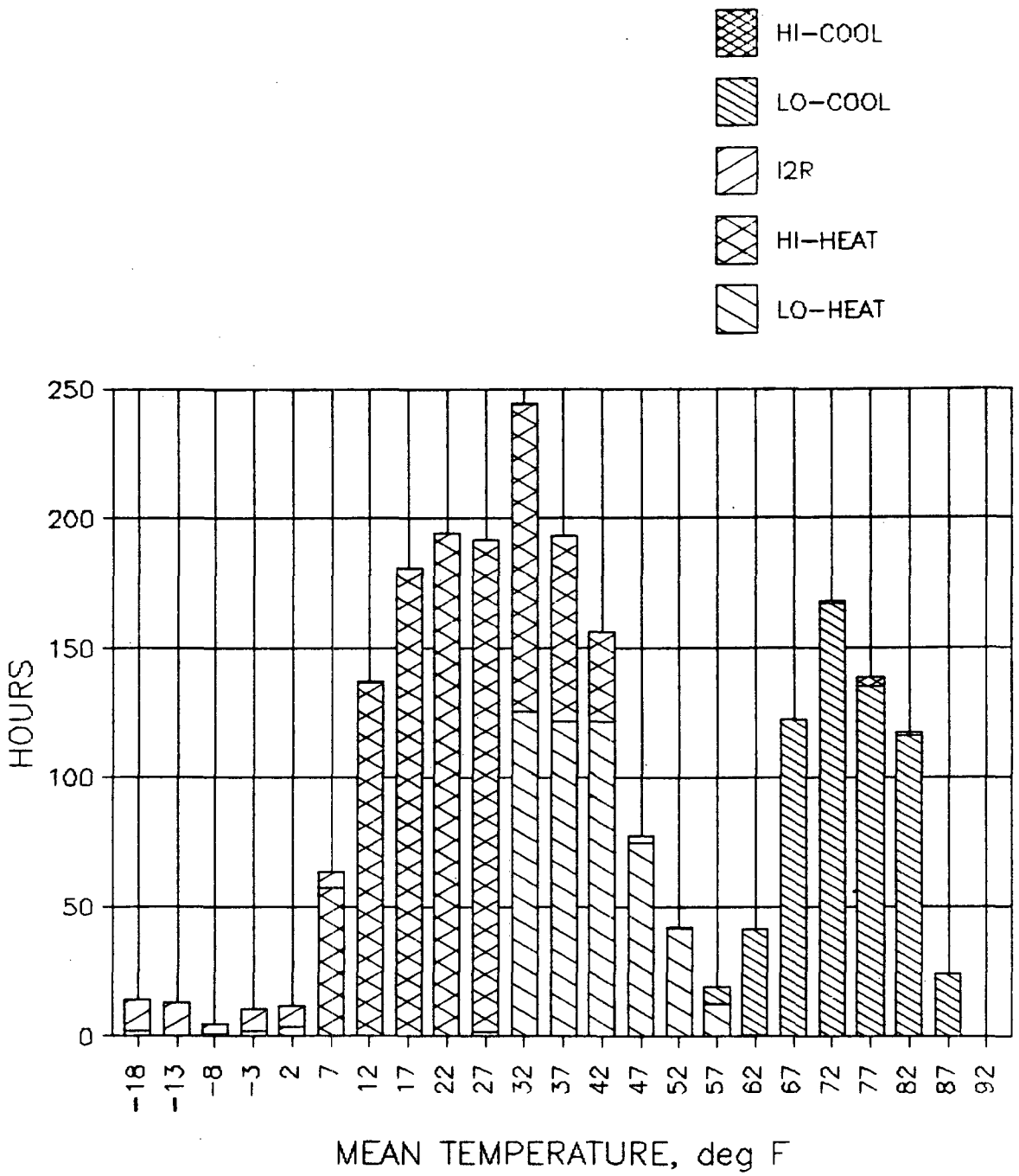

Fig. 2-10B Operating mode hours - April 1, 1984 through March 31, 1985

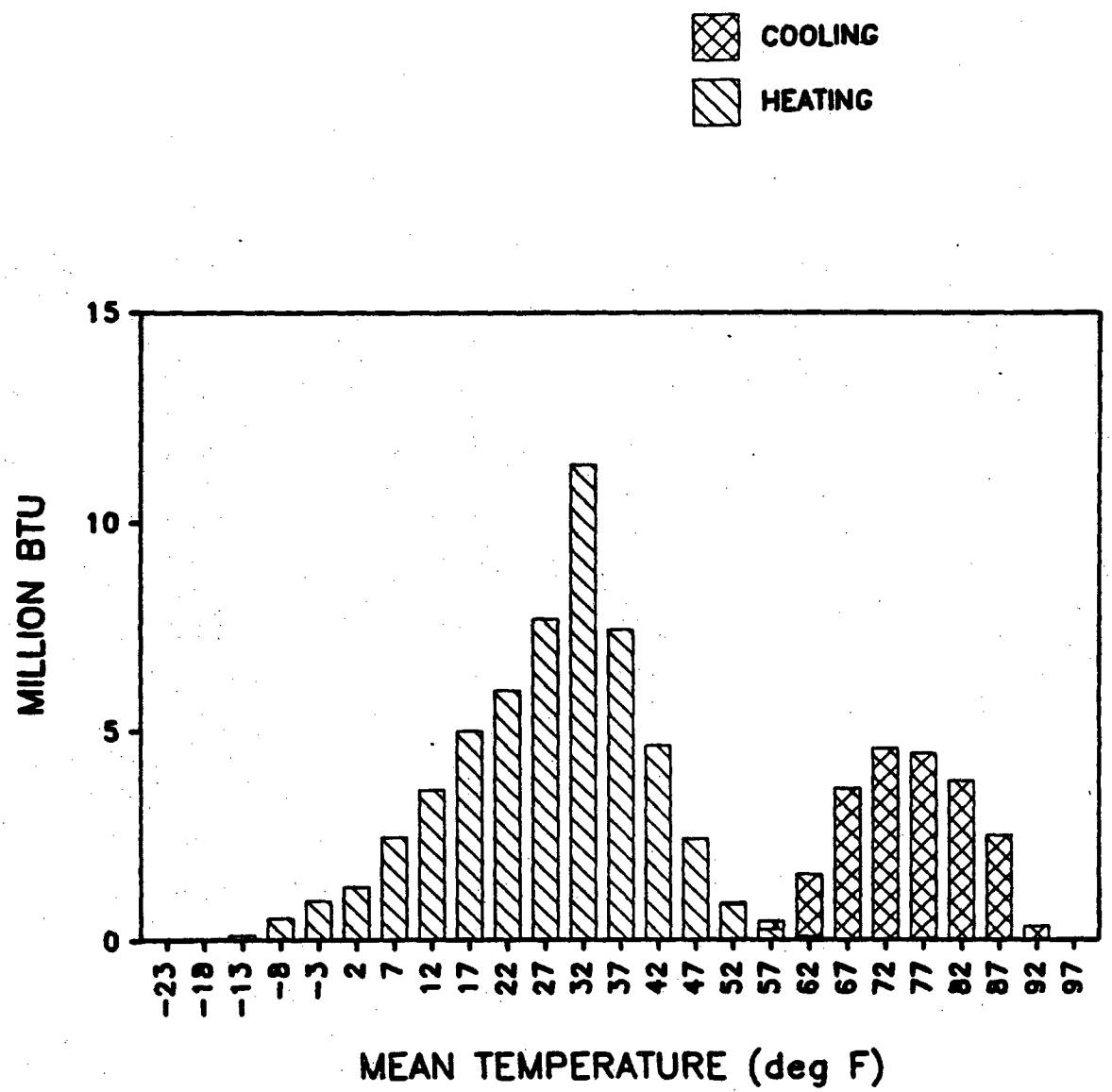

Fig. 2-11A Thermal energy delivered - April 1, 1983 through March 31, 1984

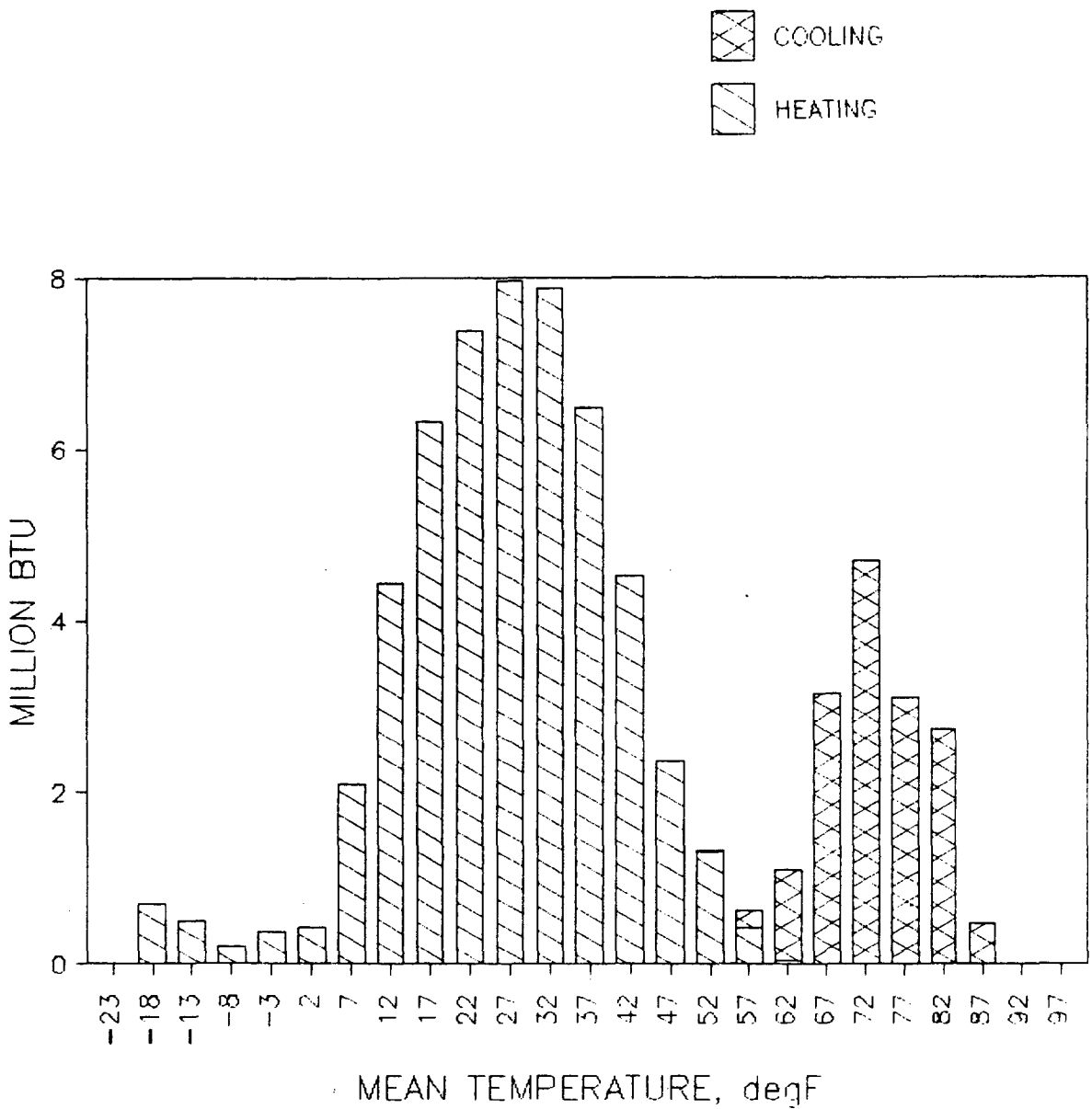

Fig. 2-11B Thermal energy delivered - April 1, 1984 through March 31, 1985

million Btu of heat and 15.4 million Btu of cooling were delivered. The relative magnitudes of the heating and cooling delivered for the first and second years are consistent with the observed temperature distributions. The heating season weather profiles were very similar for the two years, with the second year being slightly milder. Normalized to 8760 hours, the first heating season had 6245 degree hours (65°F base) and the second 6112 degree hours, about 2% less. The cooling degree hours, normalized to 8760 hours, were 1004 for the first cooling season and 725 for the second cooling season, about 28% less. Clearly the second cooling season was much milder and this is reflected in a 27% reduction in the cooling delivered.

The distributions of delivered heat between high capacity mode, low capacity mode, and resistance heat as a function of outdoor ambient temperature are shown in Figures 2.12A and 2.12B. As shown in Figure 2.13A, 72% of the heat was provided by high capacity operation, 16% by low capacity, 9% by resistance heat, and 4% was delivered under the emergency mode of operation during the first heating season. For the second season, Figure 2.13B shows that high capacity operation provided 72% of the heat delivered, low capacity operation 23%, resistance heat 4% and emergency heat mode 1%. Clearly the change in the method of applying resistance heat during the second heating season significantly reduced the amount of resistance heat required. Lowering the low capacity balance point contributed to a significant increase in the fraction of the heat provided by low capacity operation.

2.7 ELECTRICAL ENERGY CONSUMPTION

The distributions of consumed electrical energy between the HVAC system, the uninterruptable power supply for the data system, and the remainder of the building for the first and second year's operation are shown in Figures 2.14A and 2.14B as a function of the outdoor ambient temperature. Electrical energy consumption in the first year totaled 33,141 kWh, with the HVAC system consuming 9280 kWh, emergency operation 630 kWh, and the uninterruptable power supply for the data system (UPS)

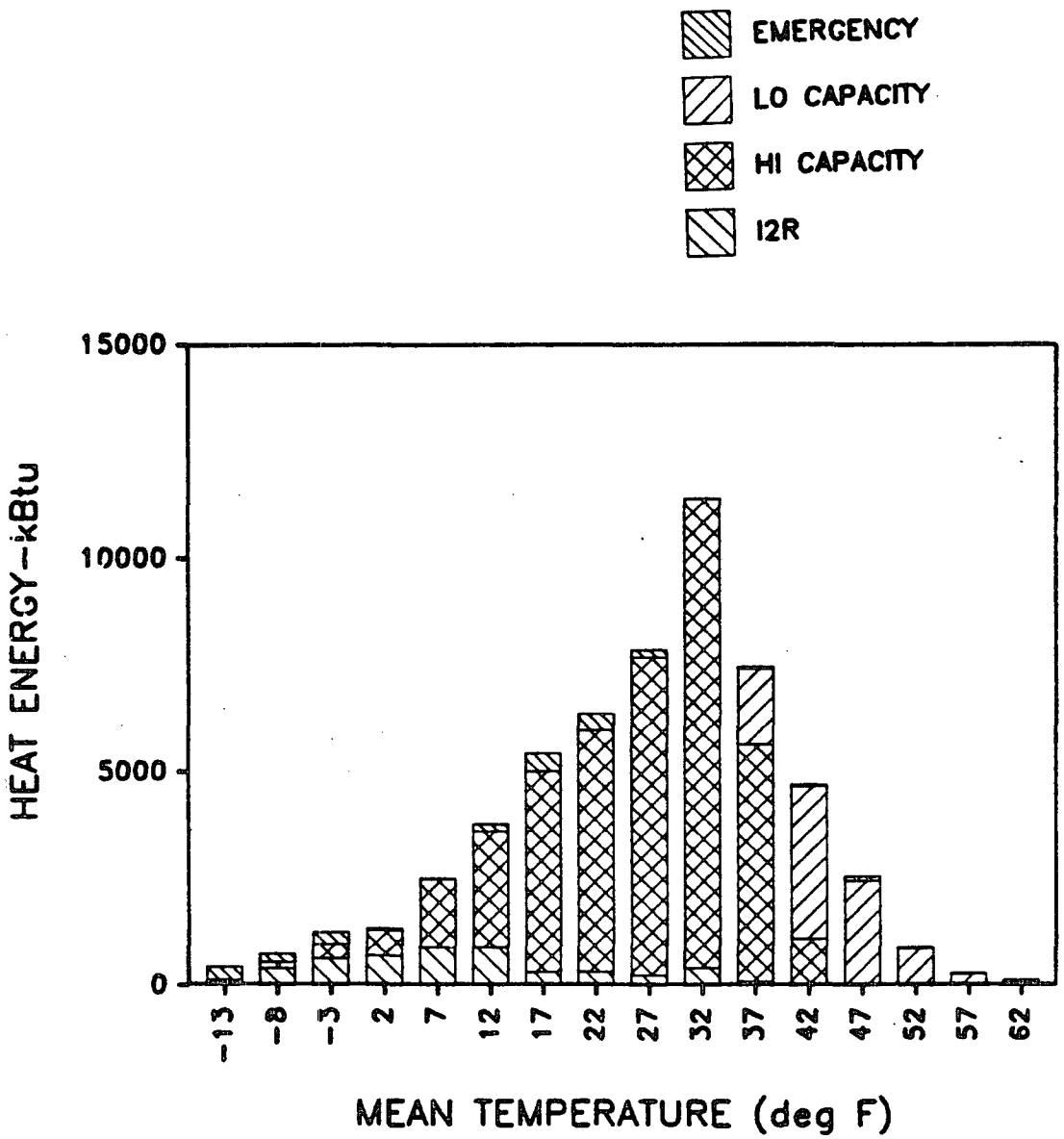

Fig. 2-12A Delivered heat profile - first heating season

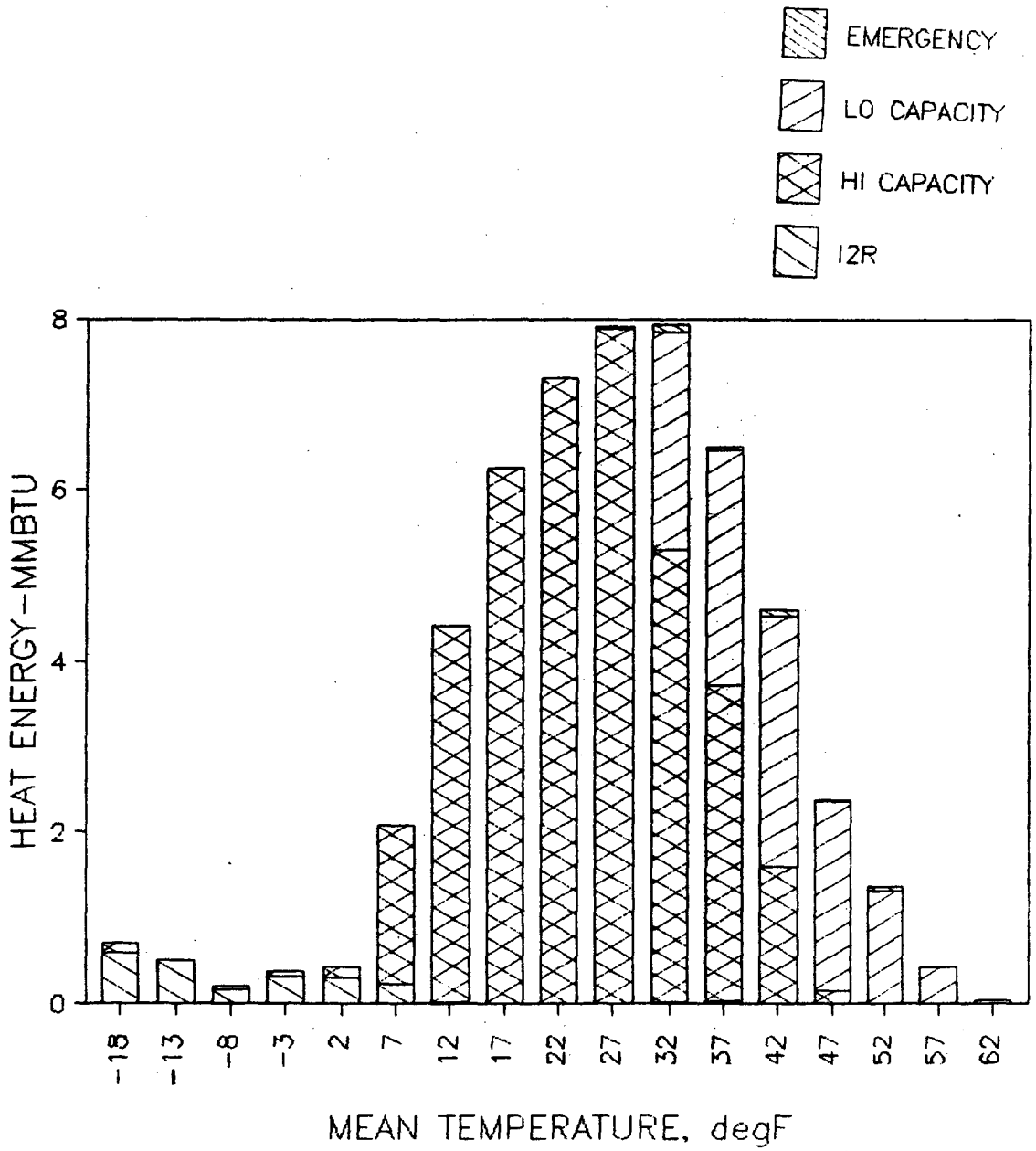

Fig. 2-12B Delivered heat profile - second heating season

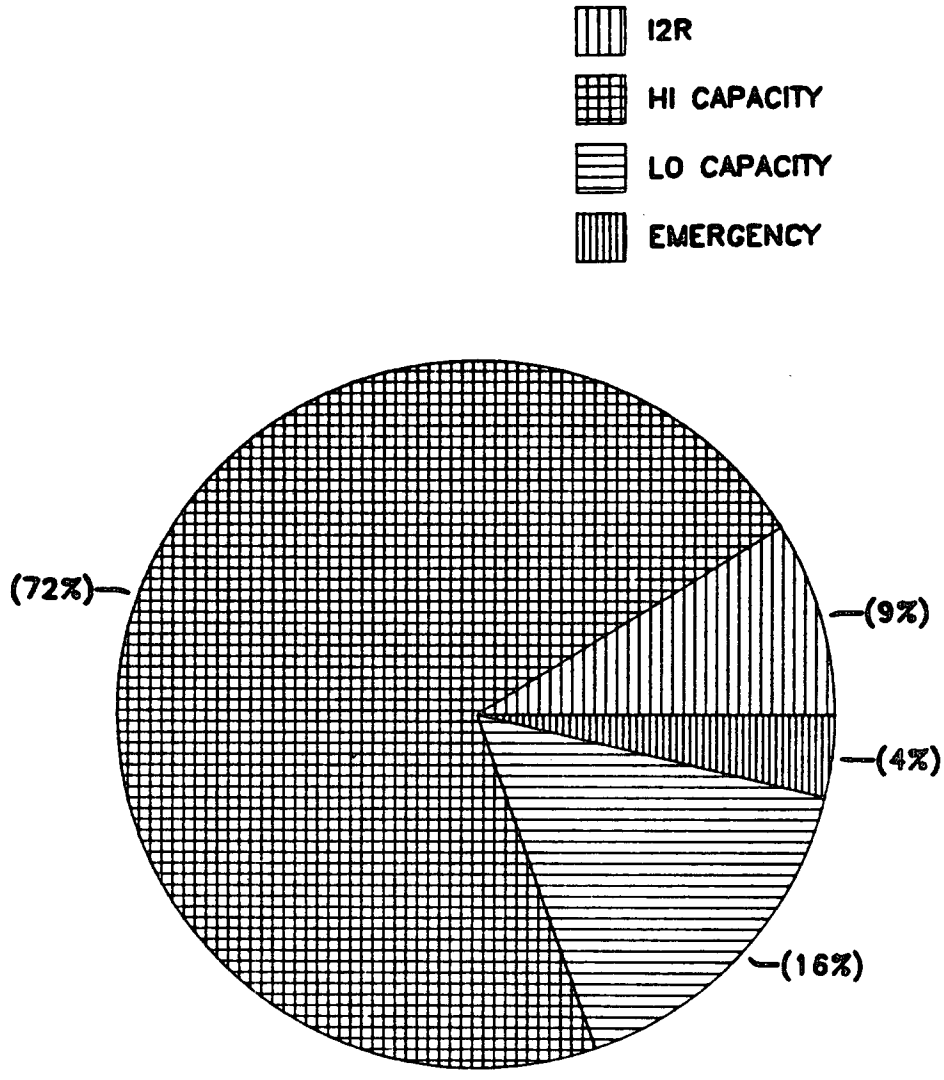

Fig. 2-13A Delivered heat profile - first heating season

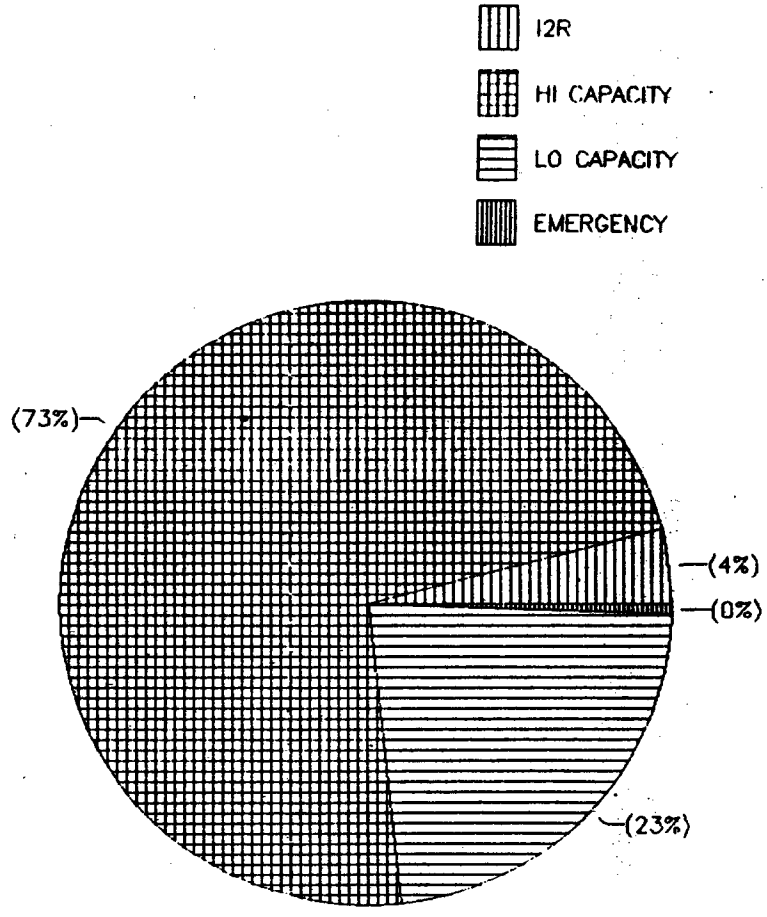

Fig. 2-13B Delivered heat profile - second heating season

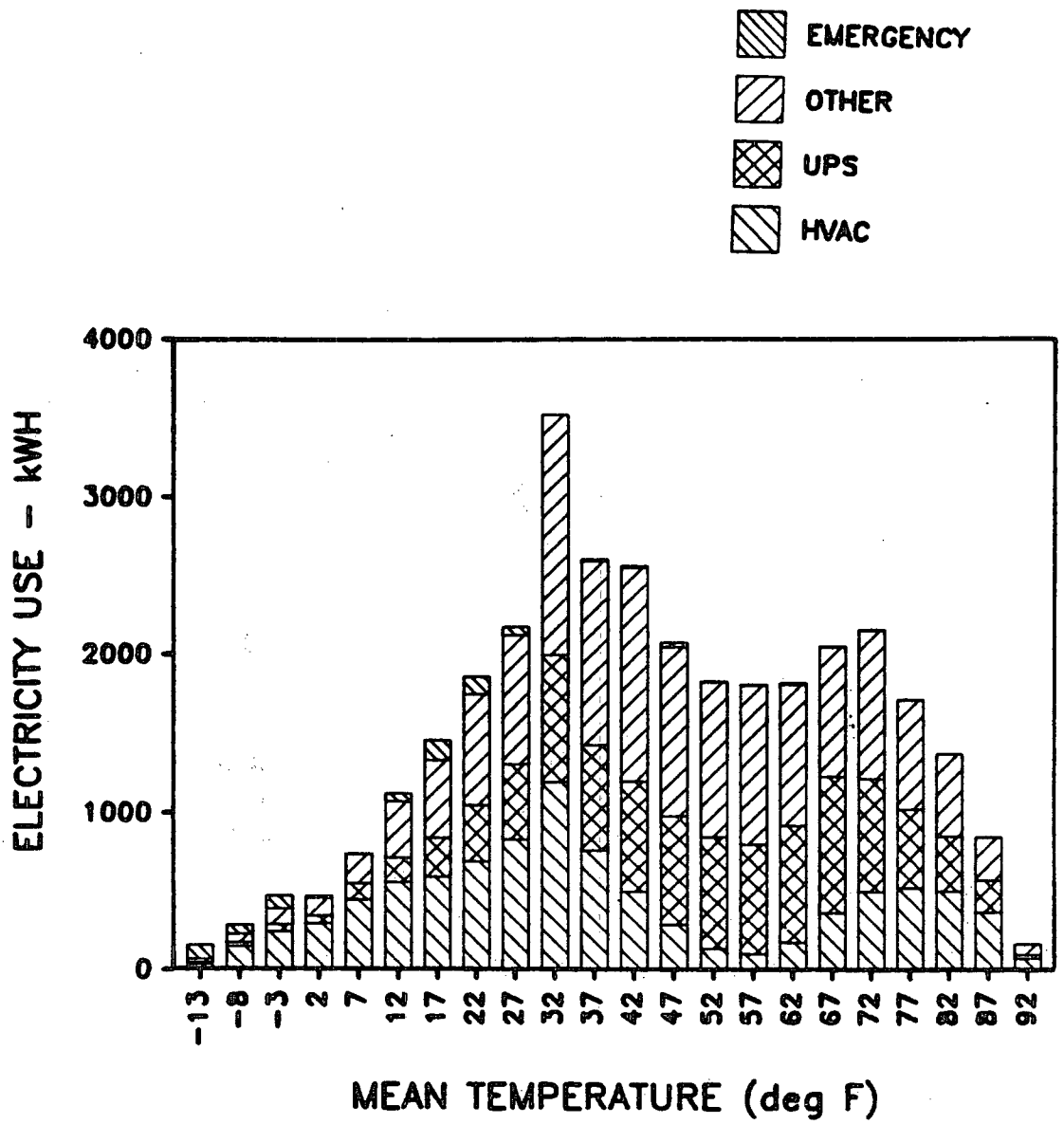

Fig. 2-14A House energy consumption - April 1, 1983 through March 31, 1984

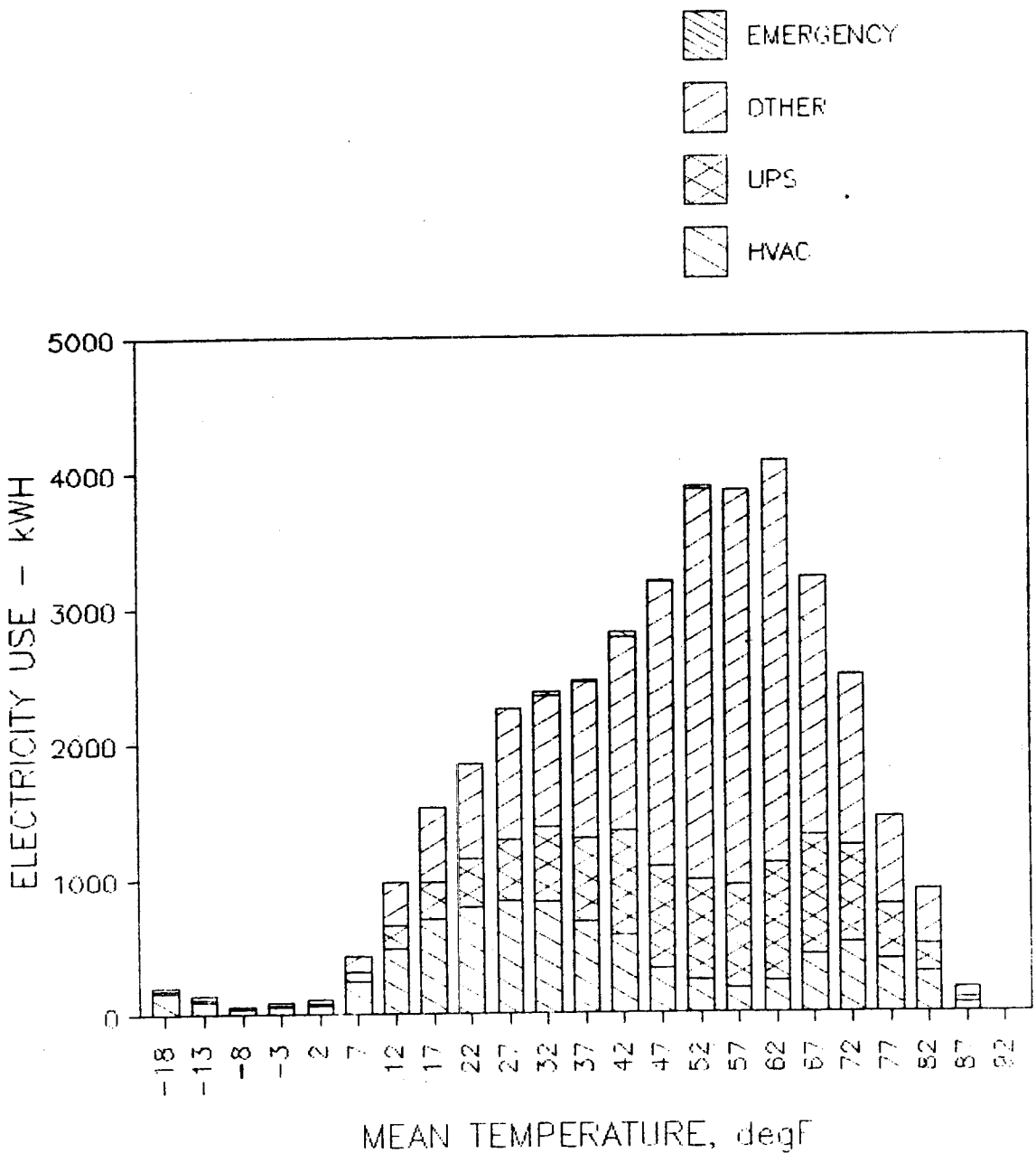

Fig. 2-14B House energy consumption - April 1, 1983 through March 31, 1985

consuming 9160 kWh. The water heater consumed approximately 6250 kWh, the electric dryer approximately 930 kWh, and the game room heater approximately 390 kWh. The lighting, cooking, and miscellaneous electrical load then totaled approximately 6500 kWh. For the second year total electric use totaled 32,163 kWh during the 8119 hours when a valid data record was obtained. This included 8088 kWh for the HVAC system, 108 kWh for emergency operation and 8671 kWh for the UPS. During the second year the water heater consumed 6741 Kwh, the clothes dryer 1006 kWh and the game room heater 243 kWh. The lighting, cooking and miscellaneous electrical load was approximately 7306 kWh.

The distributions of the energy consumed in heating service by the various components of the HVAC system are shown as a function of ambient temperature for the first year of operation in Figures 2.15A and 2.16A. Figures 2.15B and 2.16B show the distributions of heating electric consumption among the various components for the second heating season. Note that that in the heating mode, the control system and the crankcase heater represented about 4% of the total energy consumed during the first heating season and 8% during the second heating season. Note also that the modification to the method used to control resistance heat reduced the electric use for resistance heat from 16% during the first heating season to 5% during the second. The dual-stroke compressor used an external belly band heater of the self-regulating temperature type, rated at about 50 W maximum, and connected directly across the power supply. (The compressor can was well insulated in the preprototype units.)

2.8 ELECTRICAL DEMAND CHARACTERISTICS

The peak electrical demand as a function of average daily temperature for December, January and February of the 1983-1984 heating season and the 1984-1985 heating season are shown in Figure 2.17. The appearance of peak electrical demands in excess of 15 kW in the reduced data in the temperature range where defrost would normally occur indicates that defrost operation has been incorrectly identified as

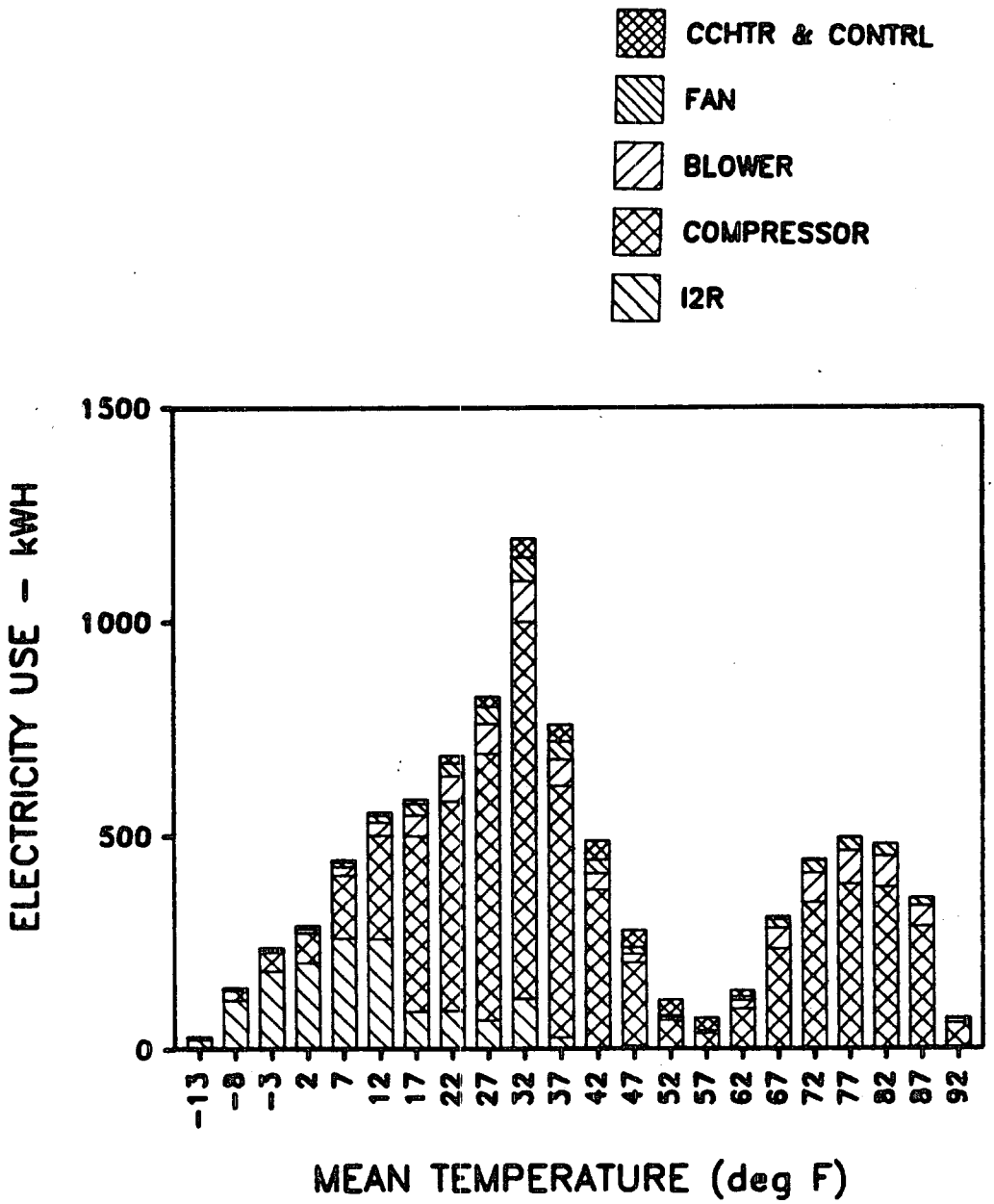

Fig. 2-15A Heating energy consumpton - April 1, 1983 through March 31, 1984

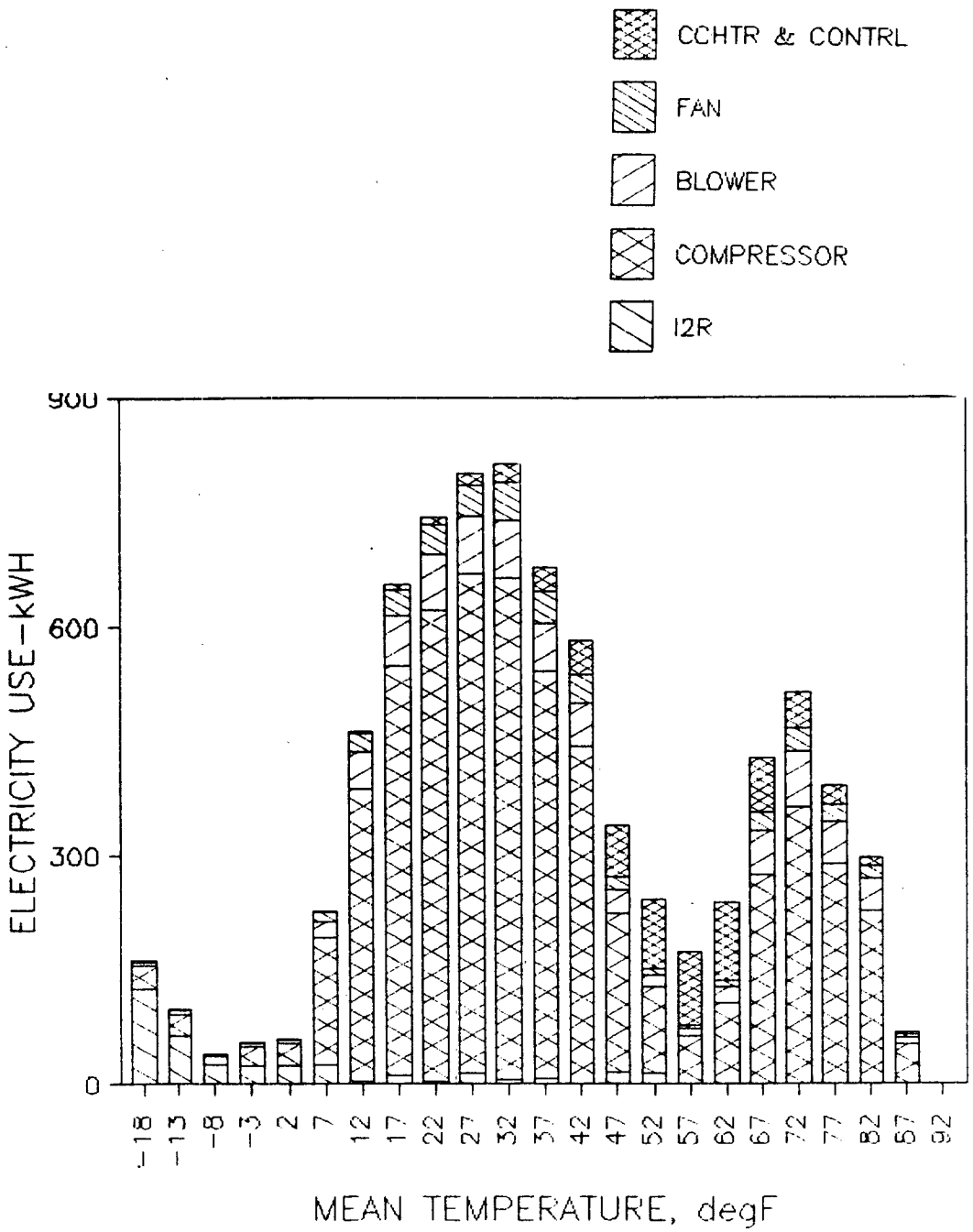

Fig. 2-15B Heating energy consumption - April 1, 1984 through March 31, 1985

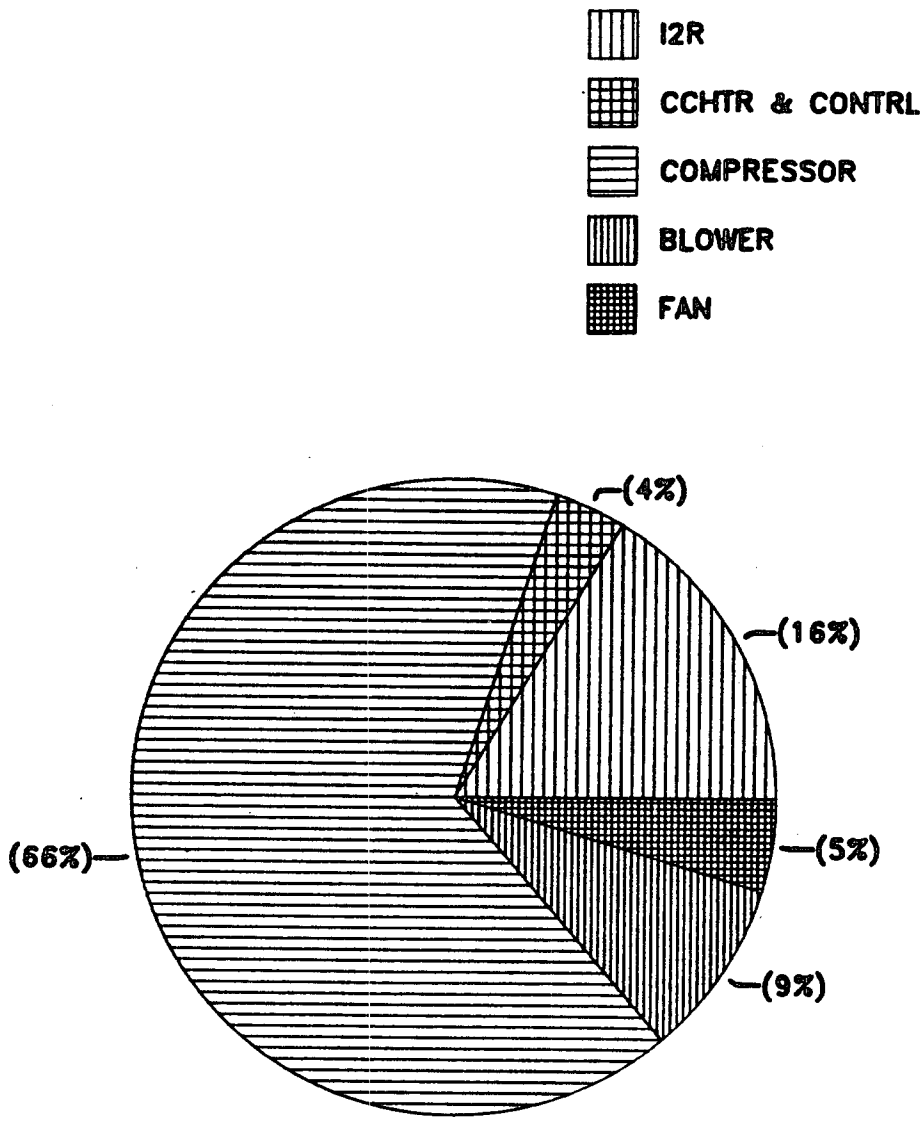

Fig. 2-16A Heating energy consumption - April 1, 1983 through March 31, 1984

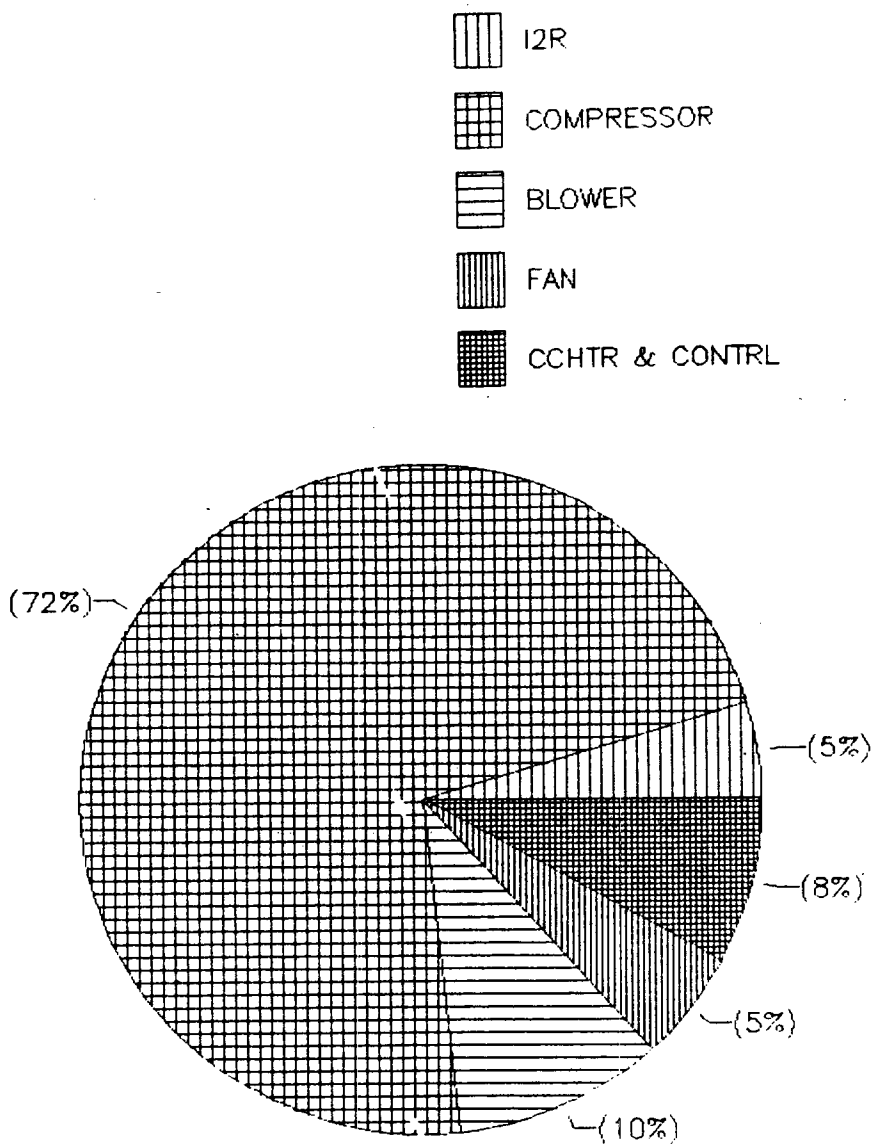

Fig. 2-16B Heating energy consumption - April 1, 1984 through March 31, 1985

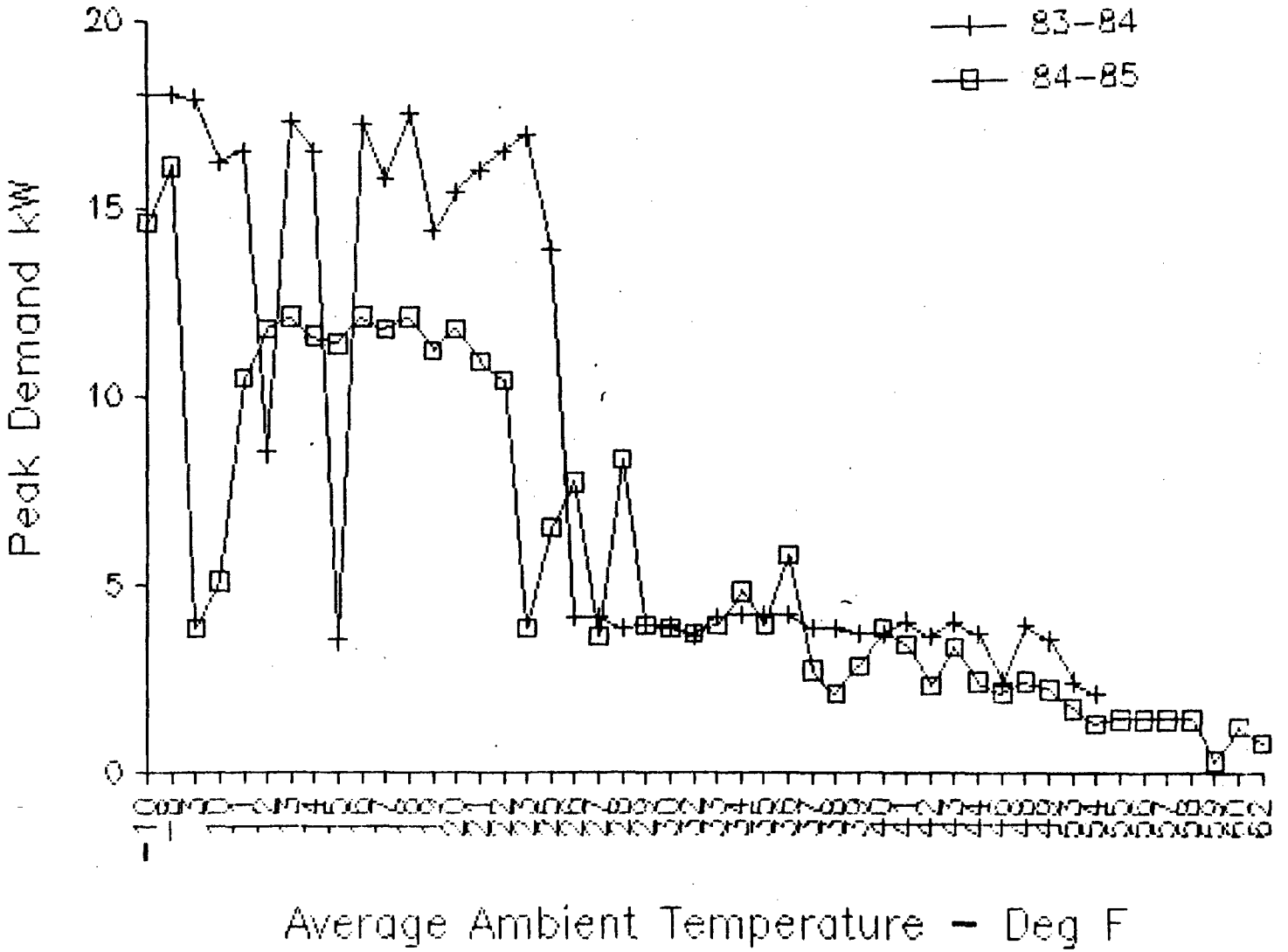

Fig. 2-17 Winter peak electrical demand

normal resistance heat operation. In normal resistance heat operation only one stage would be activated and the peak demand would be about 11 kW. Therefore peak electrical electrical demands in excess of 11 kW in the defrost temperature range have been excluded from Figure 2.17 if data for another day with the same average daily temperature and a peak demand less than 11 kW appeared in the reduced data summary. Prior to the second heating season the resistance heat package was modified to permit modulation of the first stage of resistance heat, the number of resistance heat stages was reduced from 4 to 3 and the upper and lower heating balance points were lowered to more accurately reflect the building load characteristics. These changes obviously resulted in a significant reduction in the electrical demand characteristics at temperatures below 20°F. The peak demand at temperatures below 20°F is 5 kW to 12 kW lower during the second heating season.

Since the control system did not permit resistance heat operation at temperatures above 19°F except in the defrost mode, and the maximum defrost time was limited to 10 minutes, the appearance of peak demands above 10 kW at temperatures above 19°F during the 1983-1984 heating season is unexpected. One possible explanation is that the data reduction software failed to properly recognize periods of emergency heat operation. A second possibility is that since the data scan rate during the first year did not permit resolution of events with an accuracy of better than 2.5 minutes, the total error resolving the duration of a defrost could be as much as 5 minutes. Thus 10 minutes of resistance heat operation during a defrost could have been identified as a 15 minute demand. During the second heating season, software modifications reduced the time between scans to about 50 seconds, and a normal defrost should not have been incorrectly identified as a 15 minute peak demand.

The peak electrical demand as a function of average daily ambient temperature for the months of June, July and August of 1983 and 1984 is shown in Figure 2.18. As expected the demand characteristics

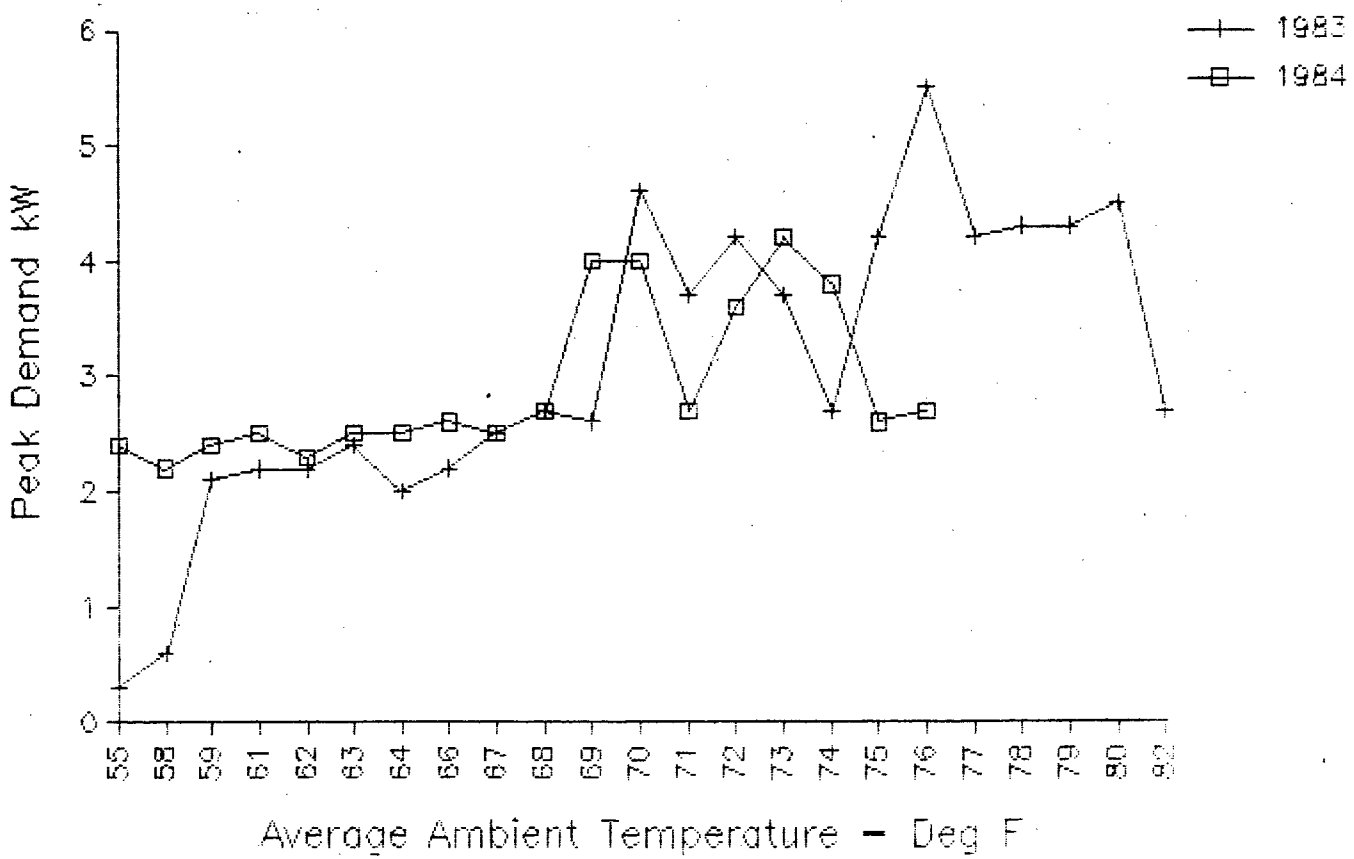

Fig. 2-18 Summer peak electrical demand

are essentially identical. The change in the upper cooling balance point from 90°F to 95°F appears to have reduced the peak demand in this temperature range. Since the data is plotted against average daily temperature and temperatures at night rarely exceed 70°F in Western Pennsylvania, a average daily temperature of 80°F or more generally indicates a maximum temperature in excess of 90°F. However, due to scatter in the data this apparent trend cannot be clearly identified.

2.9 EFFICIENCY

The observed annual heating performance factor for the system during the first heating season was HSPF = 8.13 Btu/Wh, excluding periods when the system was in the emergency heat mode. The observed cooling season energy efficiency ratio for the first cooling season was SEER = 8.35 Btu/Wh. For the season May 1 through October 15, 1983, the SEER = 8.36 Btu/Wh with a sensible-to-total ratio equal to 0.64. For the second heating season the observed annual performance factor was HSPF = 8.51 Btu/Wh, excluding emergency heating operation. The observed cooling season energy efficiency ratio for the second cooling season was SEER = 7.89 Btu/Wh with a sensible-to-total ratio of 0.72. The increase in HSPF for the second heating season may be attributed to several factors. First, a greater fraction of the heating load was provided by low capacity operation due to lowering the switchover point from 39°F to 32°F. This improved performance by reducing cycling losses and due to a slightly higher steady state COP in the low capacity mode. The portion of the heating load provided by resistance heat was greatly reduced by modulating the first resistance heat stage and by lowering the temperatures at which the respective stages were enabled. The modulation of resistance heat also significantly increased the low temperature run times, reducing cycling losses. In addition the second heating season was slightly milder than the first. The lower SEER during the second cooling season is primarily the result of significantly milder temperatures. During cooling operation at mild temperatures, the energy consumed by the control system and crankcase heater represent a large portion of the energy consumed by the heat pump and the integrated effi-

ciency is relatively low. It should be noted that during the second cooling season the total energy required for cooling was less than 2000 kWh, only 24% of the total energy consumed by the HVAC system. Figures 2.19A and 2.19B show the distributions of heating energy efficiency with outdoor ambient temperature for the first and second heating seasons. The distributions of cooling energy efficiency with outdoor ambient temperature are shown in Figures 2.20A and 2.20B.

Because the dual-stroke heat pump was oversized relative to the observed building load, excessive cycling was an expected contributor to less than expected efficiency. Figure 2.21A shows the distributions of the estimated on and off times as a function of outdoor ambient temperature for the first heating season. Figures 2.21B and 2.21C show the low and high capacity run cycle lengths in both heating and cooling modes for the second year of operation. At about 27°F, the building load was roughly half the heat pump high capacity. Note that below 17°F, during the first heating season the average length of a run cycle declined because of the way resistance heat was applied. Recall that the control system clamped resistance heat on once initiated, until the thermostat was satisfied. The amount of resistance heat used in the 17°F bin indicated that the second stage thermostat contacts closed quite regularly since they alone activated the first resistance heat stage. During the second heating season the output of the first stage of resistance heat was modulated by an SCR circuit controlled by a delivered air temperature sensor. The amount of resistance heat added was limited to that required to maintain a delivered air temperature between 90°F and 95°F. As a result, the low temperature heating cycle lengths were much longer during the second heating season and less resistance heat was required. During the second heating season software modifications permitted identification of most defrosts and defrost cycle lengths were determined. The results are shown in Figure 2.22. Defrost cycle lengths varied between 6 and 9 minutes with the longest defrosts occurring in the 12°F temperature bin.

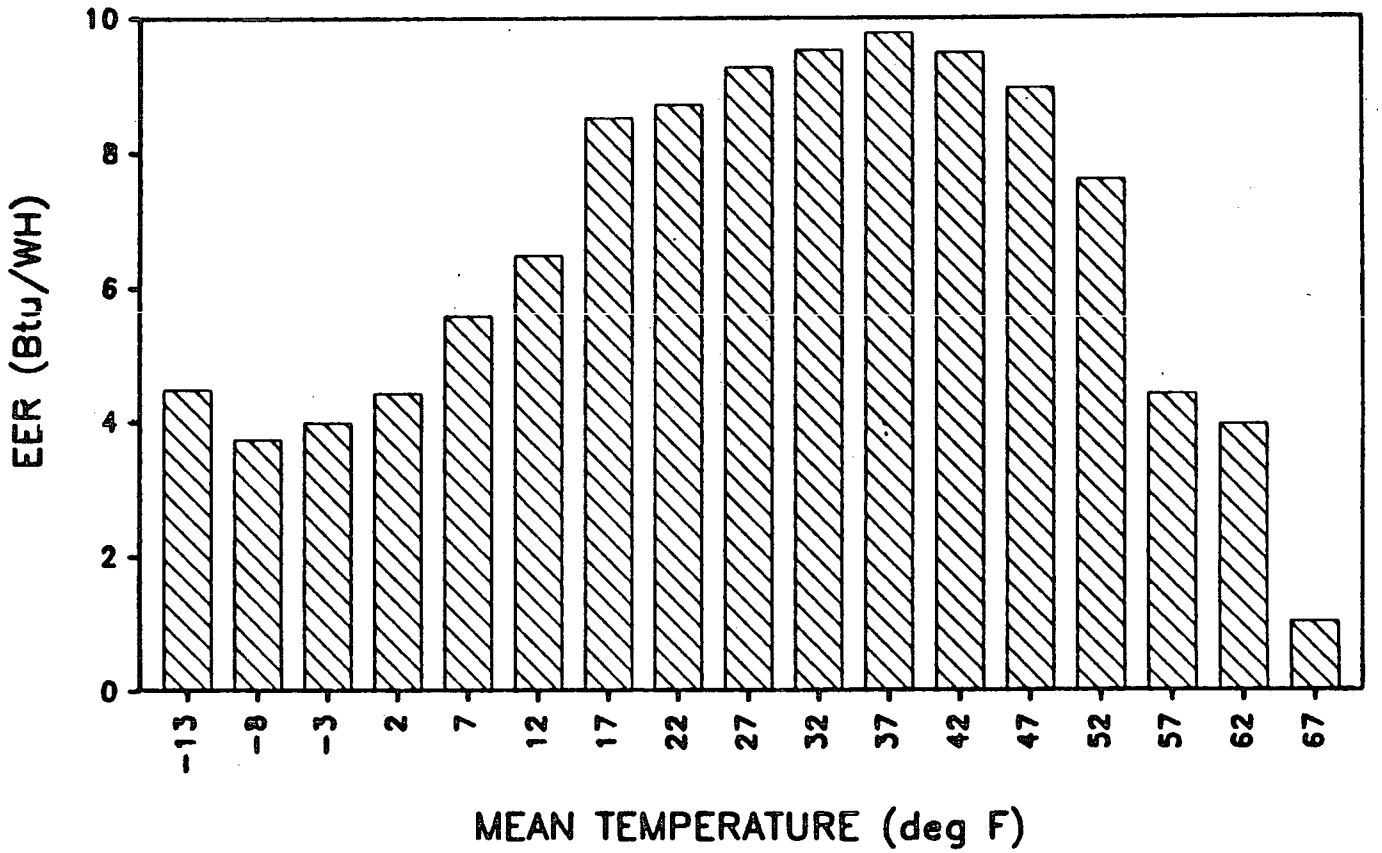

Fig. 2-19A Heating performance - April 1, 1983 through March 31, 1984

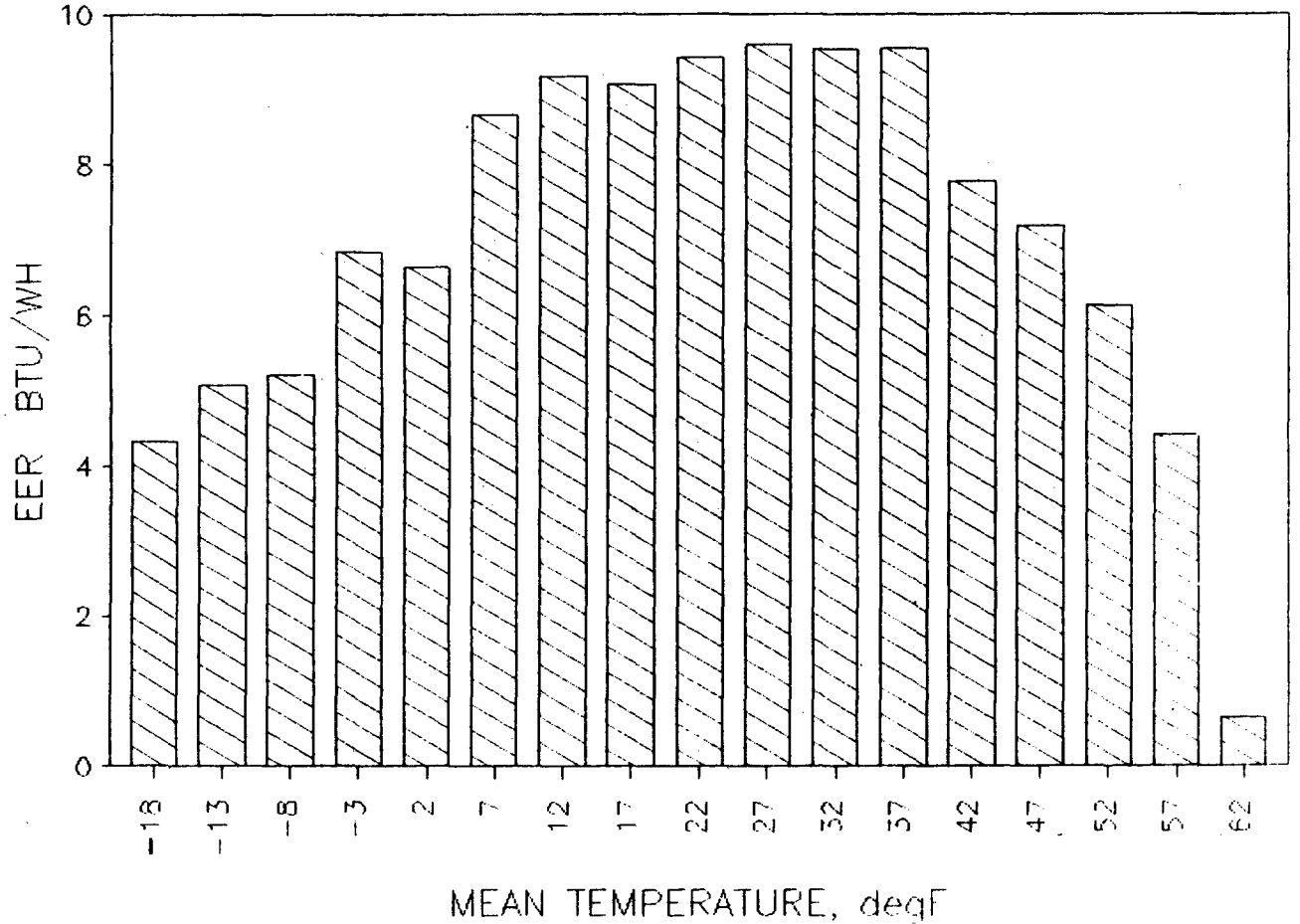

Fig. 2-19B Heating performance - April 1, 1984 through March 31, 1985

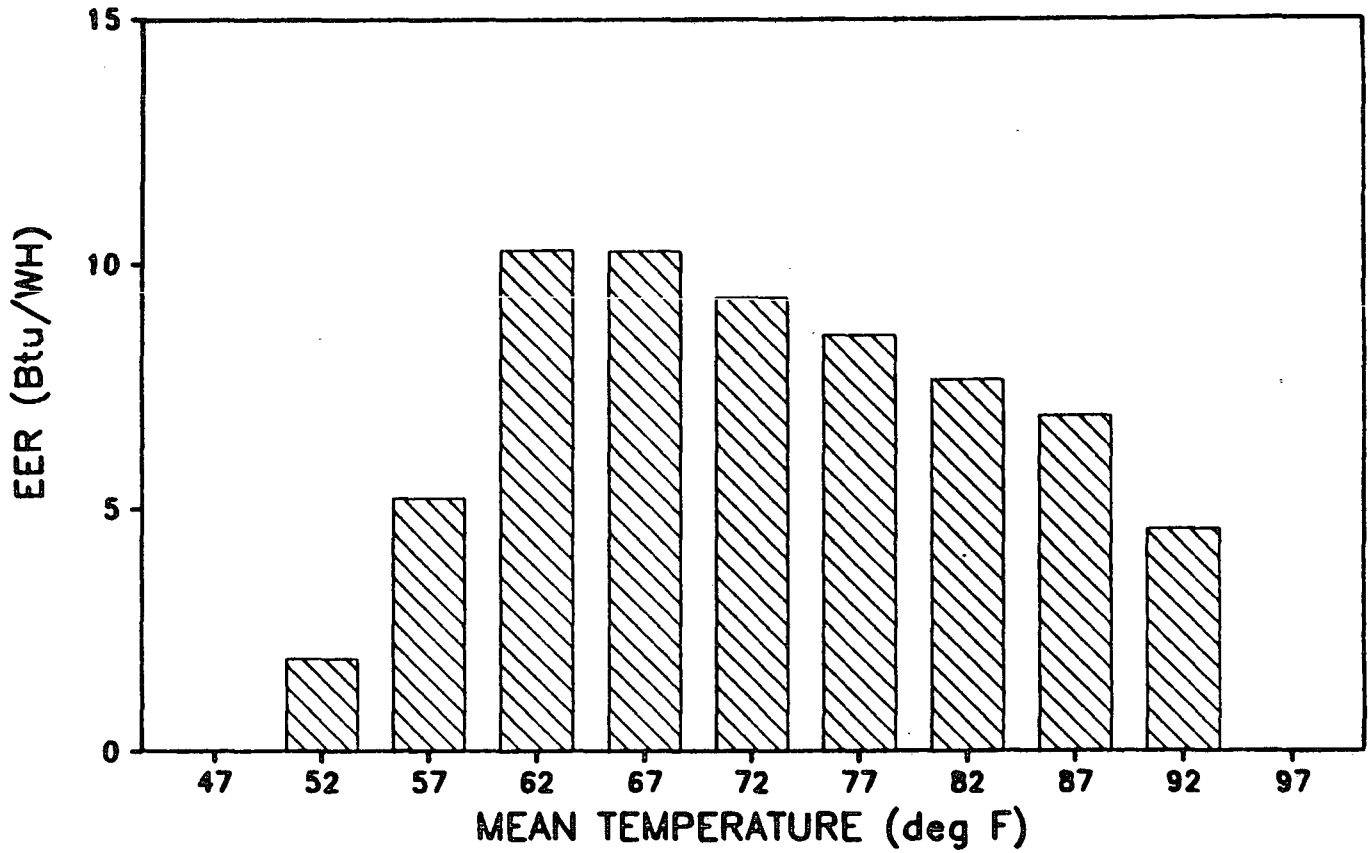

Fig. 2-20A Cooling performance - April 1, 1983 through March 31, 1984

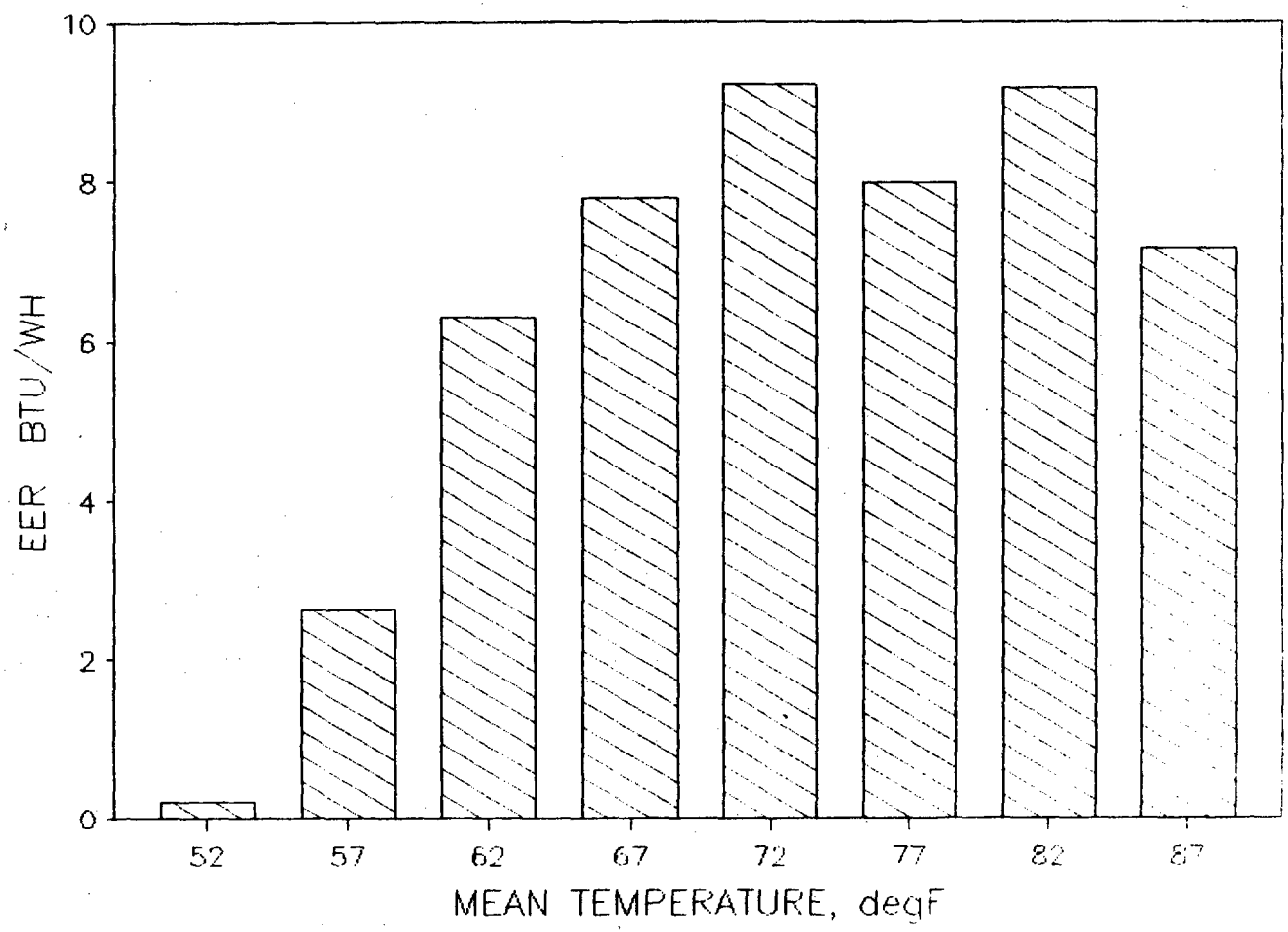

Fig. 2-20B Cooling performance - April 1, 1984 through March 31, 1985

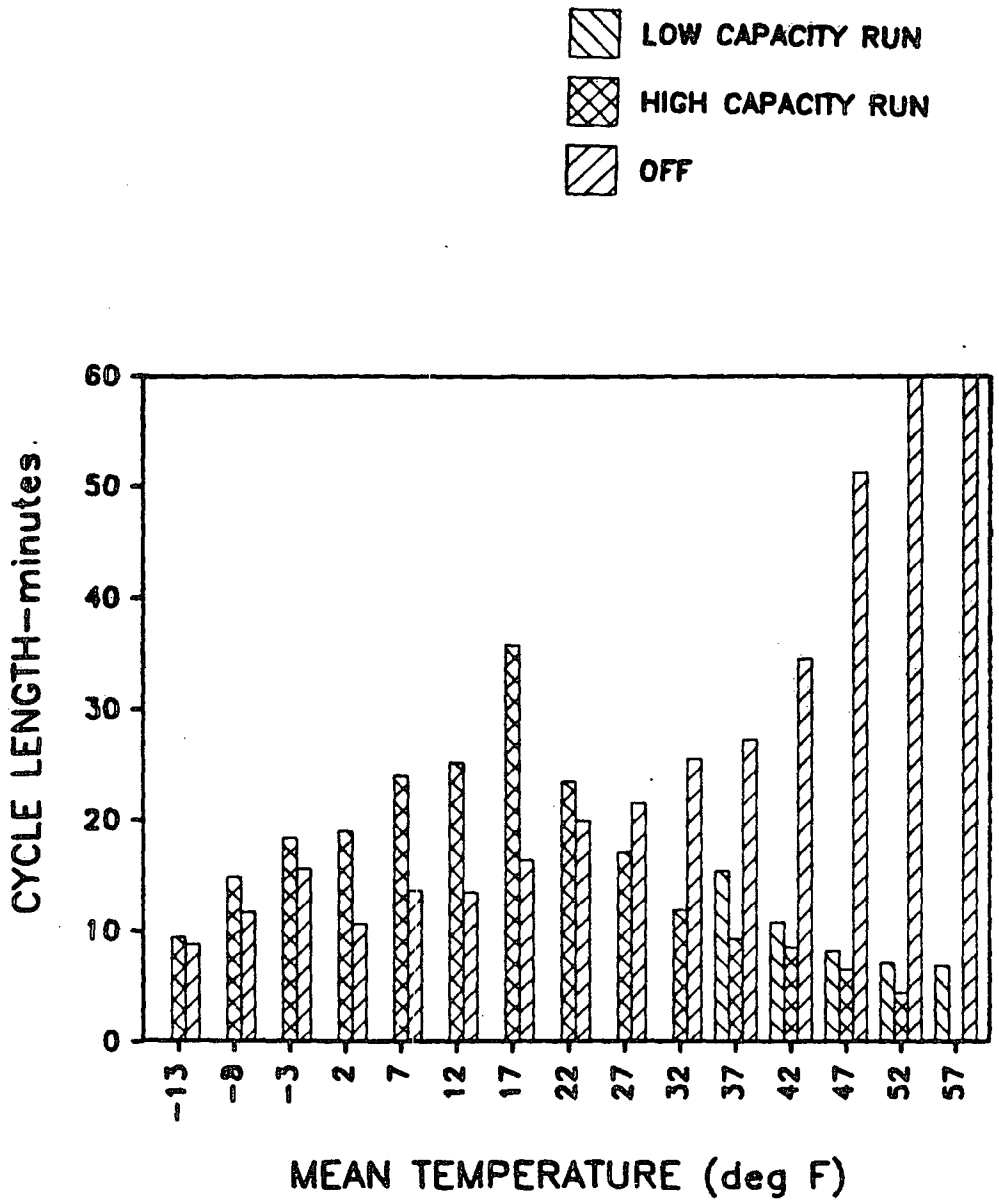

Fig. 2-21A Heating cycle length - April 1, 1983 through March 31, 1984

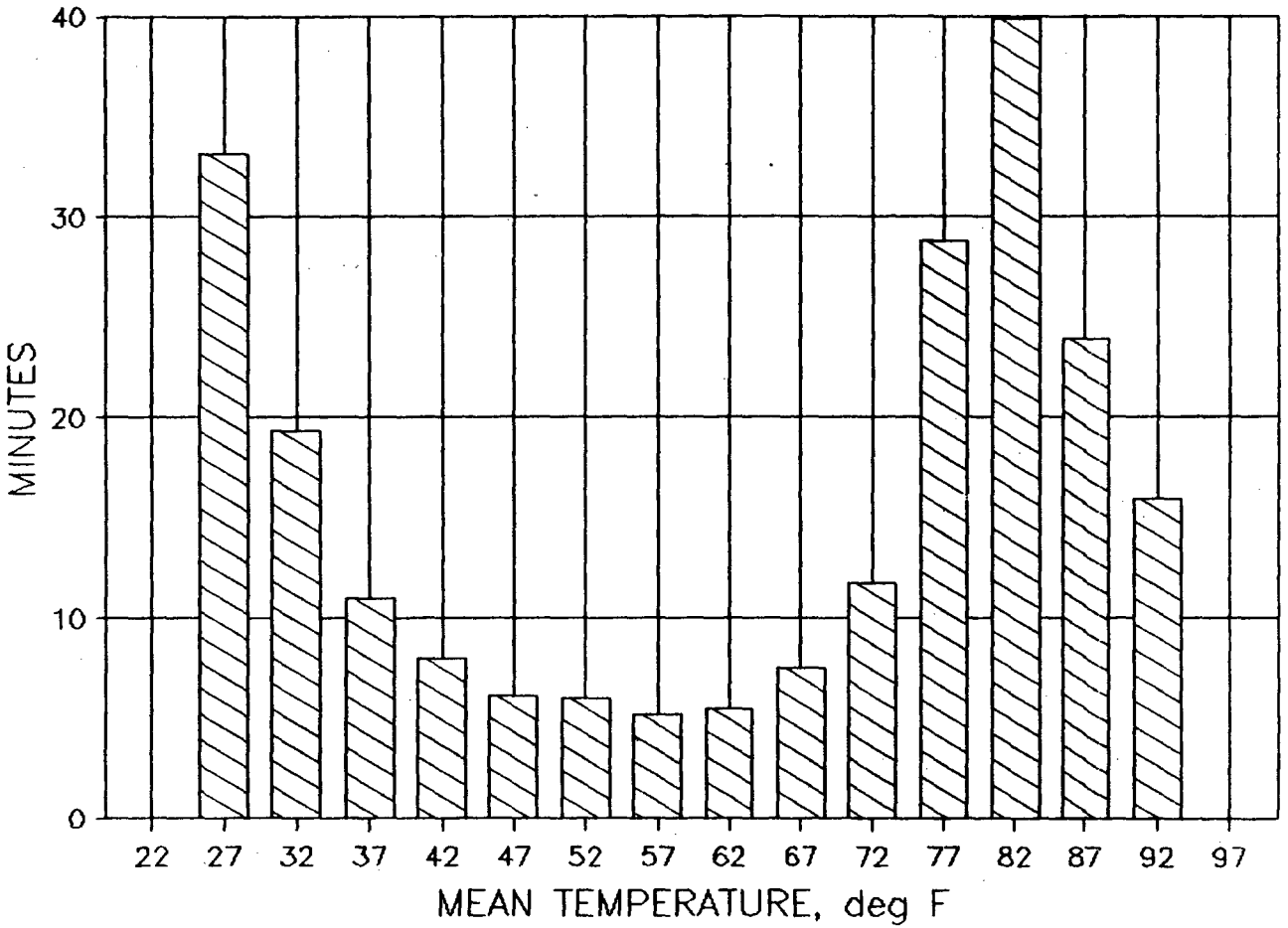

Fig. 2-21B Low capacity heating run cycle length - April 1, 1984 through March 31, 1985

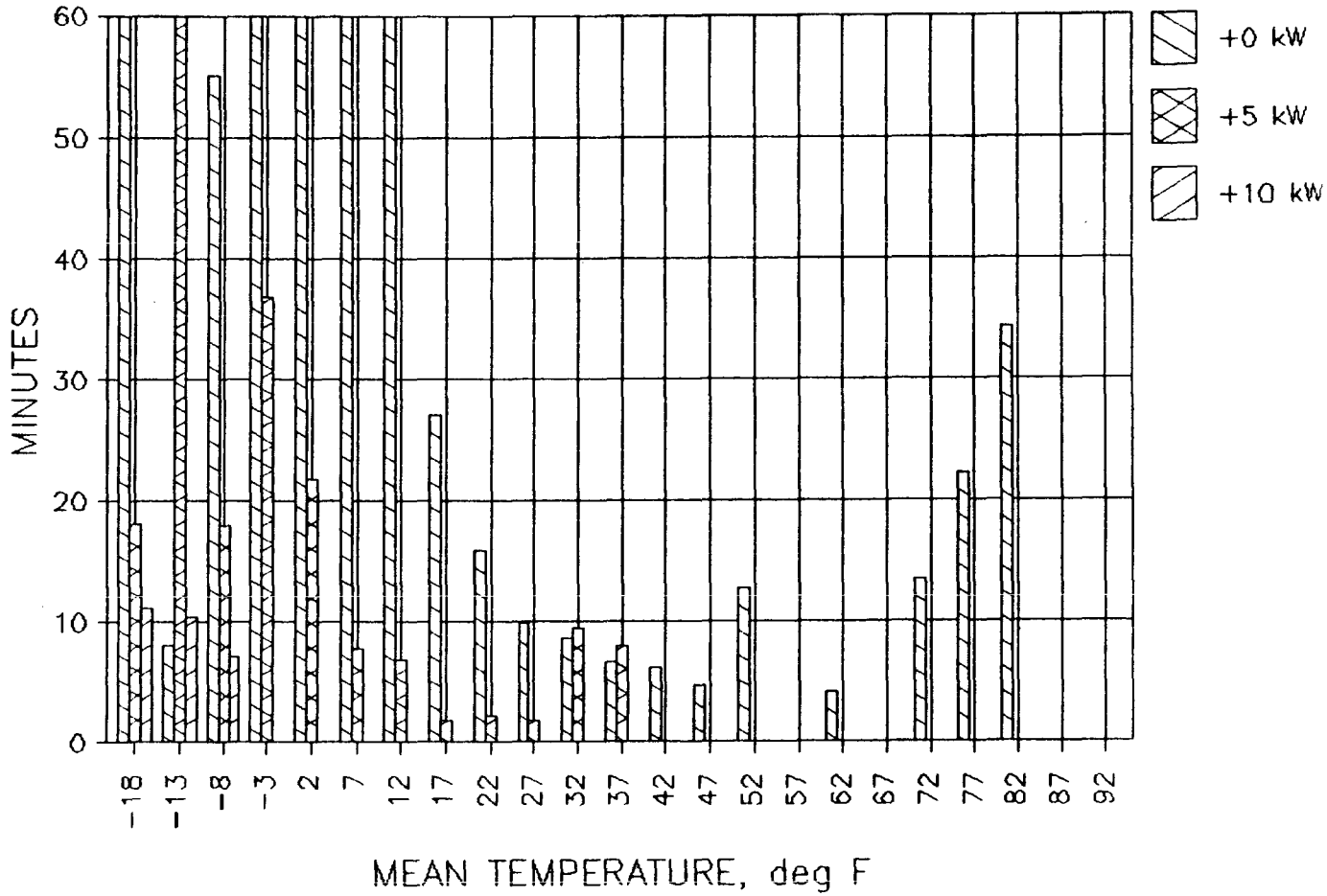

Fig. 2-21C High capacity heating run cycle length - April 1, 1984 through March 31, 1985

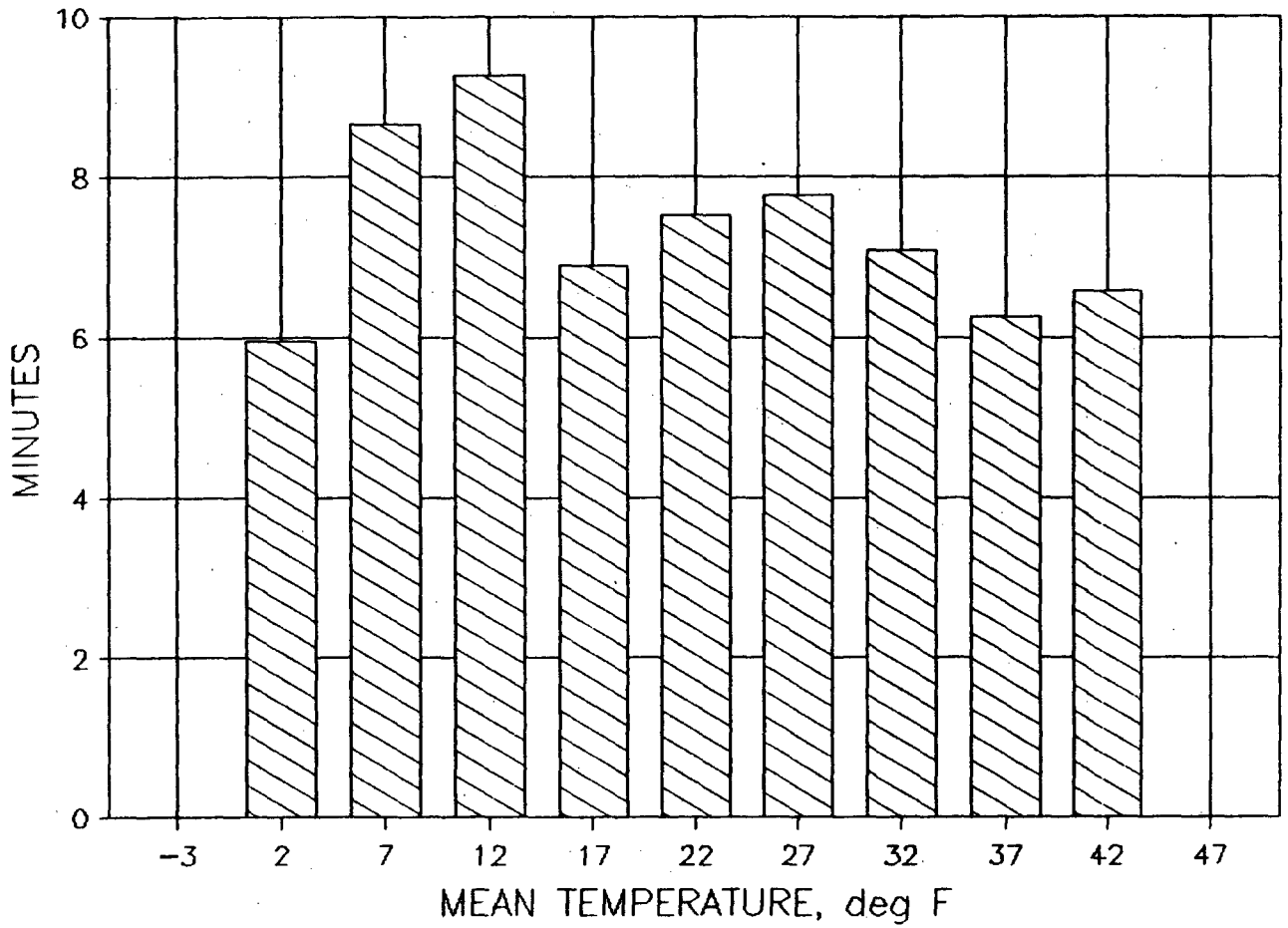

Fig. 2-22 Defrost cycle length - April 1, 1984 through March 31, 1985

The expected HSPF referenced earlier was estimated on the basis of optimum sizing (17°F high capacity heating balance point), a ten year average Cleveland weather profile, and a simple resistance heat implementation strategy that assumed that only that amount of resistance heat necessary to supply the building heat load was used. The estimated HSPF based upon the observed weather profile for the first year and the observed building load is 8.56 Btu/Wh. The estimated cooling SEER was 8.56 Btu/Wh for the first year's weather profile (by coincidence the predicted HSPF and SEER are the same).

Table 2.1 contrasts the measured and predicted performance of the dual-stroke heat pump as applied with that of the dual-stroke unit with optimum sizing, a 1979 two-speed unit, and a 1984 single-speed unit using the weather profile observed during the first year of operation. The first two cases in the "as applied" section used the observed weather profile for normal heat pump operation of 8334 hours. Emergency heat operation was excluded. The remaining "as applied" cases used the observed weather profile normalized to 8760 hours. In the third case the amount of resistance heat added was assumed to be that required to make up the difference between the building load and the heat pump capacity at all temperatures below the balance point. The fourth case represents an operating scenario in which the amount of resistance heat added between 17°F and 7°F was limited to that required to make up the difference between the building load and the heat pump capacity. Resistance heat was assumed to lock on at ambient temperatures below 7°F. For the fifth case, resistance heat was assumed to lock on with the compressor at all ambient temperatures below 17°F. We expect the actual performance to lie between the predicted values for the fourth and fifth cases.

Note that, with optimum sizing and the first year's test site weather, the dual-stroke heat pump should have an HSPF that is 29% better that a 1979 two-speed heat pump, and an SEER that is 17% better. Relative to a 1984 single-speed heat pump, the dual-stroke HSPF is 31%

Table 2.1 — HEAT PUMP PERFORMANCE COMPARISON (8760 hours except *)

(Case)	*FIELD TEST	*SIMPLE ESTIMATE	AS APPLIED SIMPLE ESTIMATE	CLAMP-ON I2R @ 7F	CLAMP-ON I2R @ 17F	OPTIMUM SIZE DUAL-STRK	2-SPEED 1979	1-SPEED 1984
HSPF	8.13(1)	8.56(2)	8.53(3)	8.22(4)	7.38(5)	8.47	6.54	6.46
HEAT-HI, KBtu	40874	34104	37685	36251	31904	35388	24045	43409
HEAT-LO	8969	16957	17290	D17290	17290	17290	27511	0
HEAT I2R	5031	5031	1631	3065	7412	3922	5050	13197
EMERGENCY	2169	0	0	0	0	0	0	0
HEAT DELIV	57043	52407	56606	56606	56606	56600	56606	56606
BAL-HI/LO	8F/26F	8F/26F	8F/26F	8F/26F	8F/26F	17F/31F	16F/27F	30F
COMP HRS HI	1086	614	718			1198	1136	1944
COMP HRS LO	293	1662	1714	1714	1714	1780	1500	0
SEER	8.35	8.56	8.56	8.56	8.56	9.33	7.96	9.35
COOL-HI	1392	0	0	0	0	413	0	23117
COOL-LO	19679	23117	23117	23117	23117	22704	23117	0
COOL DELIV	21071	23117	23117	23117	23117	23117	23117	23117
COMP HRS HI	37	0	0	0	0	16	0	1362
COMP HRS LO	804	948	940	948	940	1292	1148	0

*8334 HOURS

higher while the SEER is the same. On an annual basis, the two-speed unit was estimated to consume 22% more electricity, and the 1984 single speed unit 26% more electricity than the dual-stroke unit. Project goals for efficiency have clearly been met.

The results in Table 2.1 also show that the omission of the emergency heat hours from the weather profile does not have any significant effect upon predicted system efficiency. Figure 2.6A clearly shows that the observed system balance point in high capacity was well below that expected, and also well below the optimum value of 17°F. Note that even though the heat pump alone could carry the building load for ambient temperatures below 17°F, the delivered air temperature would drop below the constraint of 90°F. During the first heating season resistance heat was enabled at 19°F outdoor ambient, and was activated upon closure of the thermostat's second stage contacts. It is hypothesized that when the thermostat called for heat, the cold blast of air initially purged from the ductwork on many occasions caused the second stage thermostat contacts to close. The spread between stages for the thermostat in use during this report period was less than 2°F. During the first heating season the control strategy implemented locked on the mode of heat pump operation consistent with the second stage thermostat contacts (once initiated) until the thermostat was satisfied. This would explain the observation (see Figures 2.10A and 2.12A) that high capacity operation occurred when low capacity should have been sufficient, and further that resistance heat was used when high capacity operation should have been sufficient. The implementation of resistance heat in 4.8 kW stages caused the thermostat to be satisfied rapidly, with the result shown in Figure 2.21A that below 17°F outdoor ambient, the length of an operating cycle decreased. During the second heating season, when the first stage of resistance heat was modulated, operating cycle lengths increased significantly at temperatures below 17°F.

The impact of the lock on strategy for resistance heat was explored with our bin-type seasonal performance estimating code using

the first year's weather profile and the results are presented in Table 2.1. If we assumed that the resistance heat was locked on with the compressor for all ambient temperatures below 7°F, then the predicted HSPF = 8.22, very close to the observed value for the first heating season of 8.13. Clamping the resistance heat on with the compressor for ambient temperatures below 17°F leads to a predicted HSPF = 7.38, significantly lower than that observed. In Figure 2.23A the measured resistance heat delivery as a function of outdoor ambient temperature for the first report period is compared with that predicted using the simple assumption that it is used only as needed to satisfy the load, and the estimated use if it is locked on with the compressor for all temperatures in the 7 deg bin and lower. Note that a portion of the measured resistance heat shown in Figure 2.23A appears to have been associated with defrost rather than normal resistance heat operation and is felt to have been incorrectly identified by the data reduction program due to poor resolution of the initiation and termination of events. The observed heating efficiency as a function of ambient temperature was compared with the prediction based upon the simple resistance heat implementation pattern, and the steady state instantaneous efficiency of the dual-stroke heat pump in both high and low capacity. Note that for ambient temperatures less than about 32°F, low capacity operation has no steady state efficiency advantage. The drop off of measured efficiency relative to steady state for ambient temperatures greater than 42°F was the result of cycling operation. Note that the bin method tracked performance in this temperature regime fairly well. We conclude that the deviation between the observed field performance for the first report period and that estimated using a bin type analysis was due to the fact that the bin method does not consider that supplementary heat was locked on once activated, until the thermostat is satisfied. The observed resistance heat profile for the second heating season, shown in Figure 2.23B, with modulated resistance heat is far more consistent with the profile predicted by the simple bin analysis. Some of the resistance heat shown in Figure 2.23B may also include incorrectly identified defrost operation, but due to improved event resolution, the incidence

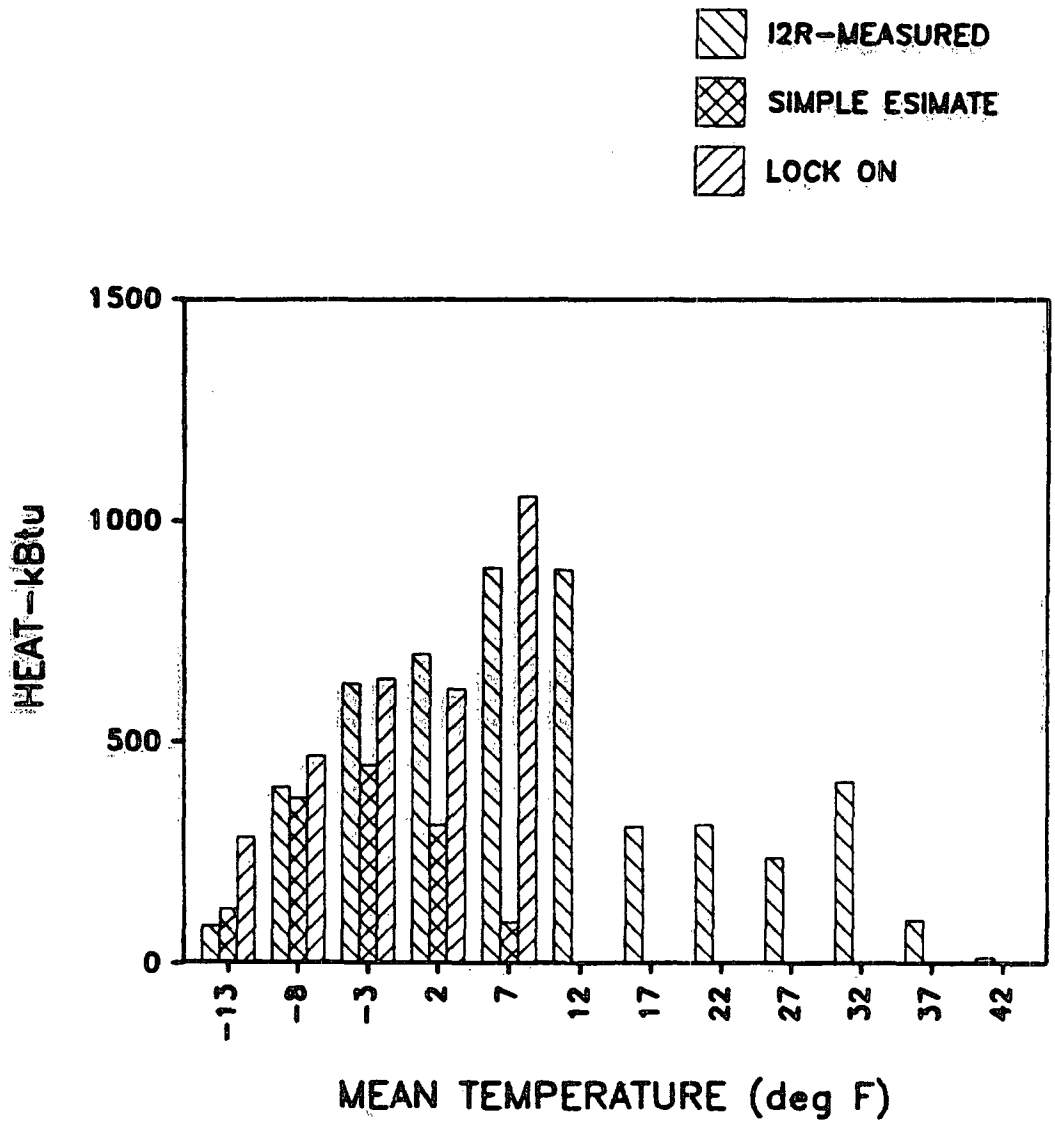

Fig. 2-23A Resistance heat profile - April 1, 1983 through March 31, 1984

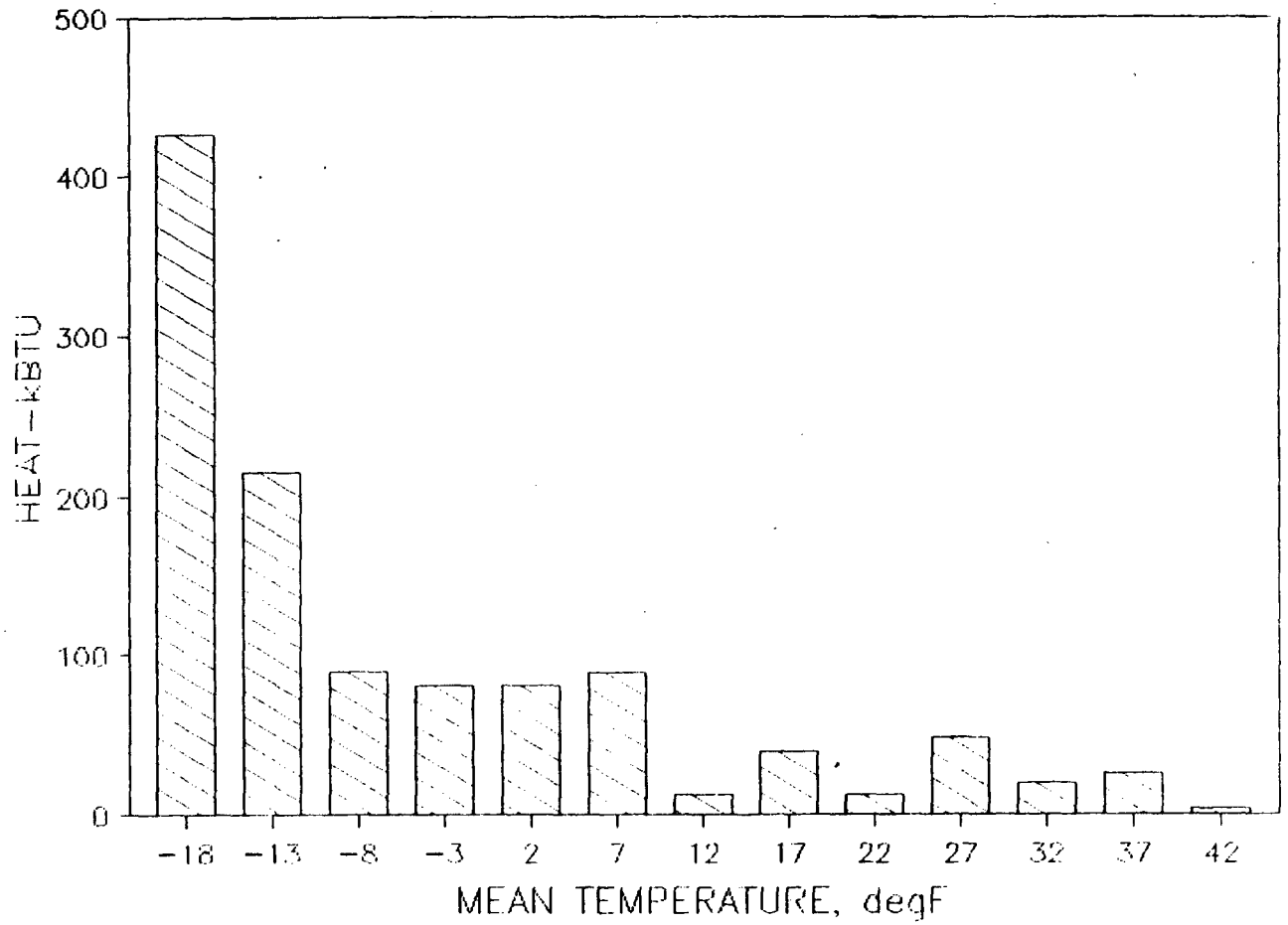

Fig. 2-23B Resistance heat profile - April 1, 1984 through March 31, 1985

of incorrect identification of the operating mode should be much less for the second year's data.

Referring to Table 2.1, it can be seen that oversizing penalizes cooling efficiency more than heating efficiency because in heating mode, an oversized heat pump can supplant resistance heat even though it suffers performance degradation due to cycling operation at warmer temperatures. Note that because the dual-stroke system has a pressure ratio limitation for the compressor, regardless of its sizing relative to the host dwelling, it must not operate in low capacity mode at ambient temperatures less that about 32°F.

2.10 ACCOMPLISHMENTS

The Westinghouse/DOE dual-stroke advanced electric heat pump in preprototypic form performed well for more than two years of use in an occupied residence, providing the space conditioning function.

There were no major failures of any of the advanced preprototypic components: dual-stroke compressor, dual-strength compressor motor, high efficiency blower, fan, blower motor, fan motor.

A low cost compressor capacity modulation concept, the dual-stroke cam and two strength hermetic motor, has been demonstrated under field conditions.

An on-line remote performance monitoring, data acquisition, data processing, and data compilation system was been developed and used to process field data.

The dual-stroke advanced electric heat pump has demonstrated that it can deliver superior performance.

The penalties associated with heat pump oversizing, and simple resistance heat management have been quantitatively demonstrated.

Heating efficiency was improved significantly during the second heating season by the use of a more sophisticated resistance heat management method.

An extensive data base for monitored heat pump performance has been assembled.

2.11 CONCLUSIONS

1. The dual-stroke capacity modulation concept is effective and reliable.

2. The heating efficiency observed during the first heating season could have been improved an additional 5% if the resistance heat were modulated so that only that amount necessary to meet load could be applied instead of a large increment being applied and locked on until the thermostat was satisfied. This mode of operation was demonstrated successfully during the second heating season and a significant improvement in low temperature heating efficiency observed.

3. Oversizing of the dual-stroke heat pump results in a greater percent decrease in cooling SEER than heating HSPF.

3. PHYSICAL INSTALLATION

3.1 PHYSICAL INSTALLATION

3.1.1 Site Considerations

To provide a realistic test, the heat pump capacity and building load characteristics should be properly matched. For the preprototype heat pump, a 17°F lower heating balance point was found to be optimum. This corresponds to a 1500 ft^2 single family residence with level 2 insulation. The heating load line would have a zero intercept at 65°F and a slope of 610 Btu/hr deg F. The cooling load was assumed to have a slope 1.4 times the slope of the heating load line to account for latent and solar loads. A level 3 construction residence with 2350 ft^2 floor area would be expected to have a similar heating load line slope and similar annual and seasonal performance.

A residence located in DOE region IV or V provides a wide range of cold ambient operating conditions. Many sites in these regions also provide moderately hot high humidity ambient conditions during the cooling season. To simplify logistics, a site in the Pittsburgh area was advantageous.

In order to quantify the building heating load as a function of outdoor ambient conditions, a structure currently using electric resistance heat was considered ideal, particularly if long term electric consumption and weather data were available for the site.

A site satisfying most of these criteria was selected. The owner of a 2100 ft^2 well-insulated residence in Jeannette, PA (30 miles east of Pittsburgh), a Westinghouse engineer, was a highly cooperative participant in this field test. The home had been previously space conditioned (for 7 years) by a Westinghouse model HL036 heat pump with

an AH012 air handling unit, which gave an estimated heating balance point of about 26.5°F. The annual and seasonal performance of an HL036/AH012 heat pump, the Westinghouse/DOE advanced dual-stroke heat pump, and a Carrier 38TQ046 two-speed heat pump, in a residence of this size and assumed insulation level, were estimated using the modified DOE procedure and region IV temperature bin data. The results are summarized in Table 3.1.

Table 3.1 — Estimated Heat Pump Performance at Field Test Site (Prior to Installation)

	Westinghouse HL036/AH012	W/DOE Advanced Dual Stroke	Carrier 38TQ046 38HQ960 Two Speed
HSPF	5.77	9.06	7.13
SEER	5.42	8.68	7.79
Annual Energy Cost, $	1105.00	703.00	878.00
Heating Balance Pt, °F	26.5	18.0	19.5
Relative Energy Consumption	1.00	0.64	0.80

Based on this analysis the selected site appeared to be near optimum in terms of application size for the advanced dual-stroke heat pump.

3.1.2 Installation Compatibility

The original heat pump indoor unit was installed in a small insulated utility room located between the integral two-car garage and a finished basement family room. The outdoor unit was mounted on the eastern side of the house on a 3 ft x 4 ft concrete pad. Access space around the indoor unit was extremely limited, and it was necessary to modify the space in order to accommodate the indoor unit of the advanced

heat pump. The existing outdoor pad was adequate for the advanced heat pump outdoor unit. The 200 amp electrical service to the house was adequate but wiring had to be modified since the advanced heat pump requires one 100 amp circuit for the resistance heat and one 50 amp circuit for the compressor indoors, and one 15 amp circuit outdoors, whereas the original unit required 100 amp service for resistance heat and 15 amp service for the blower and controls indoors and 50 amp service outdoors. The piping and wiring between the outdoor and indoor units passed through a dropped portion of the ceiling in the basement level family room which is located between the utility room and the outside east wall. The dropped portion of the ceiling was provided to enclose the supply air duct and the main support beam for the house. The thermostat for the system was located in the dining room on an indoor wall directly above the utility room. No revision of the thermostat location or the wiring was necessary for the new unit and a thermostat compatible with the control system was installed at the same location.

3.2 HEAT PUMP INSTALLATION

3.2.1 Site Preparation

Because of the limited space around the original indoor unit position it was necessary to extend the utility room by constructing a small vestibule directly to the front of the heat pump. This added space provided access for observation of the microprocessor panel board and maintenance of the indoor unit. The basement level house floor plan is shown in Figure 3.1.

The original indoor unit used bottom air entry and a horizontal mounting for the electrostatic air cleaner. The new unit was better served by side air entry and a vertical installation for the air cleaner. A new inlet elbow with turning vanes, as well as new inlet and discharge ducts with instrumentation mounting pads were fabricated and installed. Details of the installation are shown in Figure 3.2.

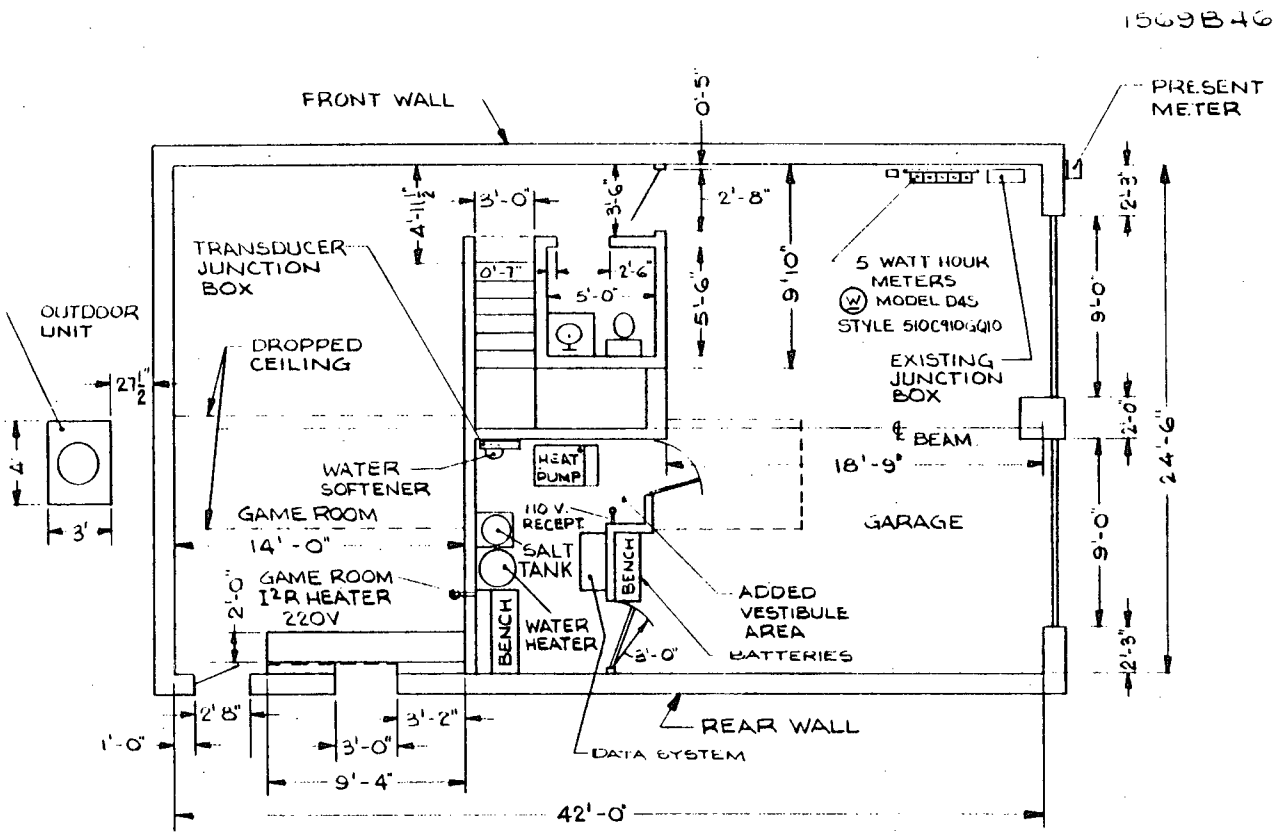

FIG. GROUND FLOOR PLAN OF ADVANCED HEAT PUMP TEST SITE

Fig. 3-1 Ground floor plan of advanced heat pump test site

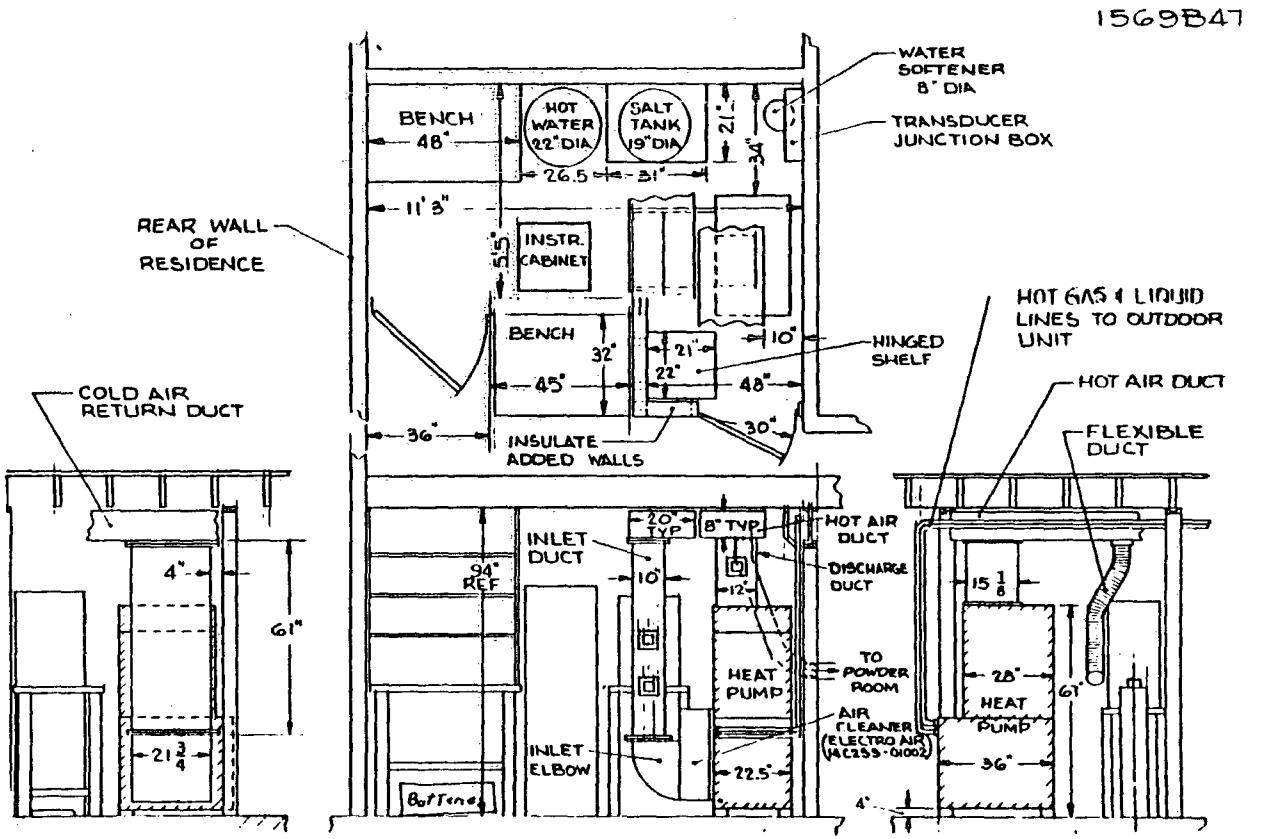

Fig. 3-2 Installation of advanced heat pump at test site

The instrumentation plan required monitoring of the various power inputs with both conventional rotating disc Watt-hour meters and electronic transducers. It was deemed advantageous to mount the conventional Watt-hour meters adjacent to the main service box of the house as indicated in Figure 3.1. These meters were installed by a registered electrician on the same day that the main circuits were revised to include a 100 amp cable for the new heat pump resistance heat package, a 15 amp circuit for an additional 120 Volt receptacle in the vestibule, and a 30 amp, 240 Volt outlet in the family room. This 240 Volt outlet was required to power a new 3 kW electric heater that replaced a catalytic kerosene heater that had previously supplied supplemental heat to the game room. Due to an air distribution problem, the family room was not adequately heated by the central HVAC system. The circuits monitored by means of conventional Watt-hour meters were:

(a) Resistance heat
(b) Heat pump system
(c) Family room heater
(d) Hot water heater
(e) Clothes dryer
(f) Total house input (existing utility meter)

A photograph of the meter installation is shown in Figure 3.3.

A telephone was installed for the purpose of voice communication between the site and the R&D Center and data retrieval and communication between site data acquisition equipment and R&D computer facilities. The phone was a standard AT&T dial-type desk model and was located in the vestibule area of the utility room.

3.2.2 Heat Pump Installation

Since the installation of the new heat pump took place the week before Thanksgiving in 1982 when the ambient temperature was beginning to drop to the 35°F range, it was necessary to equip the residence with supplemental electric heaters to maintain a comfortable interior

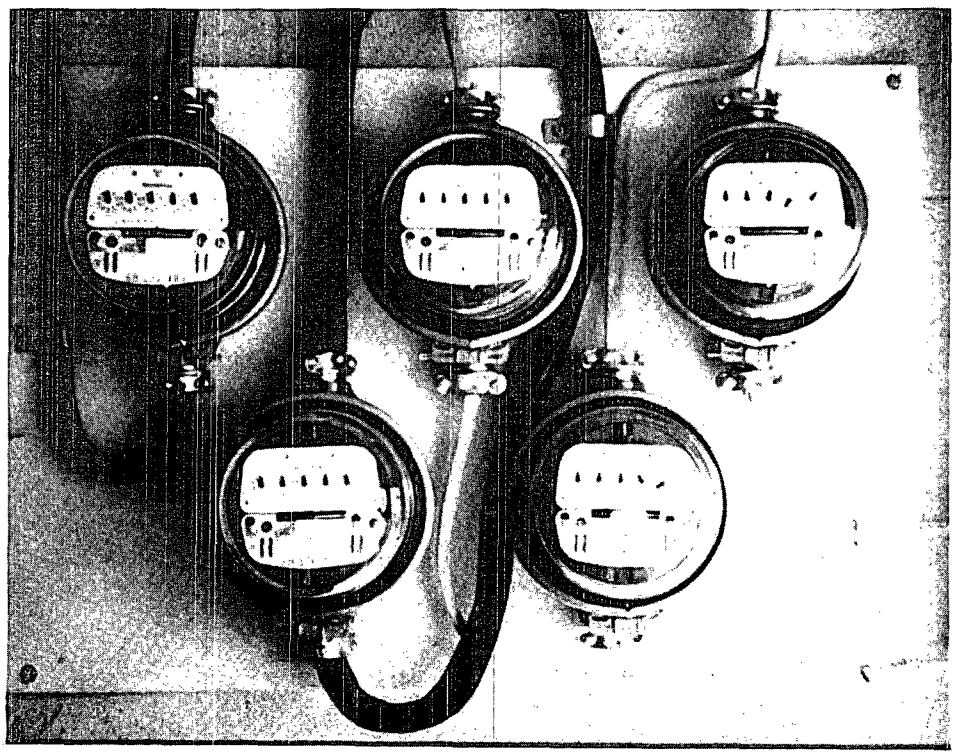

Fig. 3-3 Conventional watt hour meters

environment during the installation period and during any periods when the new central system might be inoperable. Six 120 Volt, 1500 Watt, oil filled De Longhi natural convection heaters were purchased and located within the residence as required by the owner.

3.2.3 Initial Operation

The first call for heat produced no response. After the 24 Volt auto transformer was properly grounded, the unit responded to thermostat signals, and operated normally. In emergency heat mode the resistance heaters and high speed blower operated as required, but a squeaking noise was apparent. After a series of checks including inspection of the blower clearances, it was found that the blower shaft was moving axially a small amount in the bore of the inner race of the outer bearing of the blower due to a slight "out-of-parallel" condition of the bearing mountings. Oil was introduced into the slight clearance between the shaft and bearing bore, and the noise stopped temporarily.

The system then continued to operate satisfactorily except for infrequent and apparently random cut-out signals which shut the unit off when there was no system fault. A simple reset of the microprocessor allowed the unit to function until the next erroneous fault occurred. On one occasion, however, an indicated low charge fault was correct, since charge had leaked from a defective pressure gauge connection.

Investigation of the control components and microprocessor circuitry revealed that there was a drop of about one volt across each cut out switch during normal operation. Since there are four switches in series, the total voltage drop was in the range of 2 to 4 Volts. As part of its fault detection and identification logic the microprocessor monitors the voltage between each switch and ground to determine its state. Since the normal voltage drop across the switches totaled 2 to 4 Volts, and the monitoring logic cued on a 5 Volt signal, there was the potential for a false cut-out diagnosis by the microprocessor. The

microprocessor controller was modified by increasing the reference voltage for switch state identification, and this mode for false fault diagnosis did not recur.

Heat pump indoor unit operation was smooth and quiet, particularly in the low blower speed mode. Compressor noise was unobtrusive in the utility room (about the same as a refrigerator in the kitchen) and was not noticeable in any room of the house. The transmission of compressor noise through the dwelling was a major concern during the design phase of the program when it was decided to integrate the compressor with the indoor unit in the return air stream. The success of this embodiment showed that an integrated indoor mounting for the compressor is feasible.

The noise level of the outdoor fan in the high speed mode was not objectionable outdoors. The low starting torque of the 0.2 hp drive motor combined with a heavy preprototype fan resulted a long acceleration period (15 sec.) during which laboring noises emanated from the motor. Although no apparent problems resulted from this condition, it could have been partially rectified by changing the associated capacitor.

Defrosting of the outdoor coil was accomplished normally in less than 4 minutes and the coils drained well. The reverse fan operation after defrost was not accomplished initially because of a software bug (later corrected) in the microprocessor program. Even without fan reversal after defrost, no serious ice buildup occurred at the edges of the fins.

3.3 WEATHER STATION INSTALLATION

Early in December 1982 the components procured for the monitoring of environmental conditions arrived at the R&D Center and were checked for proper operation and calibrated. The equipment consisted of an anemometer, a wind direction indicator, a humidity

indicator, a temperature indicator, a solar insolation indicator and a rain gauge. Since the manufacturer recommended that all of the above instruments, with the exception of the rain gauge, be installed six to ten feet above the top of the house, the most structurally reliable as well as the least expensive system, appeared to be the use of a television antenna tripod mast mounted on the peak of the roof straddling the ridge beam. While the rain gauge could have been mounted on the ground in an unobstructed part of the yard, it required 120 V electrical service to operate an internal electric heater provided for melting snow and ice. Therefore, if it were mounted at ground level it would have required some sort of protective barrier around it to shield it from dogs and children. The protective barrier would also have provided a definite hindrance to cutting the lawn. Therefore is was decided to mount the rain gauge on an unused chimney and combine the output wiring with the wires from the roof top weather station and route them through the dropped ceiling space in the family room along with the outdoor unit plumbing and wiring.

The wires from the tripod-mounted instruments were bundled together and routed down the fascia of the roof to the edge of the house, where they joined with the wiring from the chimney mounted rain gauge. The combined wiring was secured to the down spout from the roof gutters and routed downward to a point below the shrubbery and then horizontally to the opening provided in the wall for the outdoor unit plumbing and wiring. This resulted in an unobtrusive installation (see Figures 3.4 and 3.5). Electrical conduit (0.75 dia.) was routed through the dropped ceiling space of the game room adjacent to the other plumbing and wiring and the weather station instrument wires pulled through to the utility room. The power cable for the rain gauge was connected to electrical service in an outdoor junction box remaining from the previous heat pump. (The rain gauge heater required several amps.)

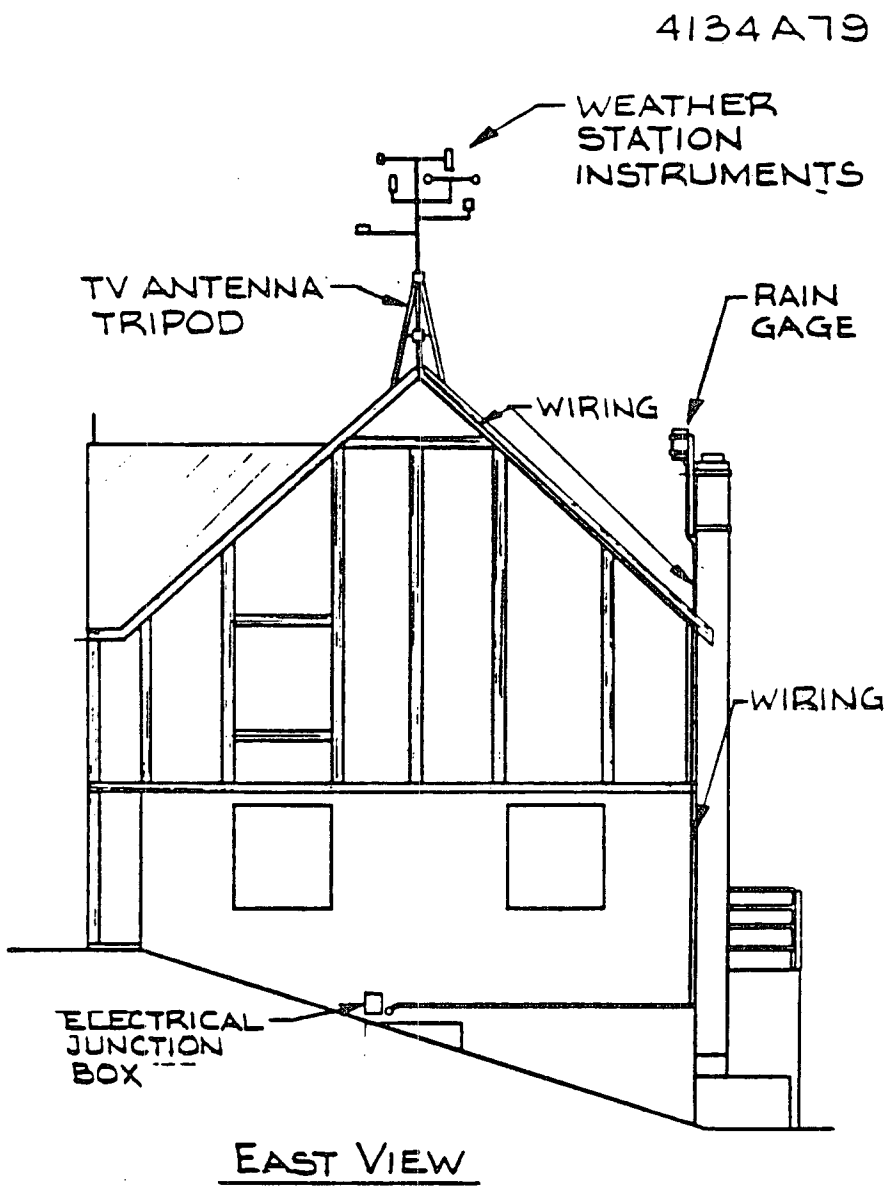

Fig. 3-4 East view showing roof mounted weather station

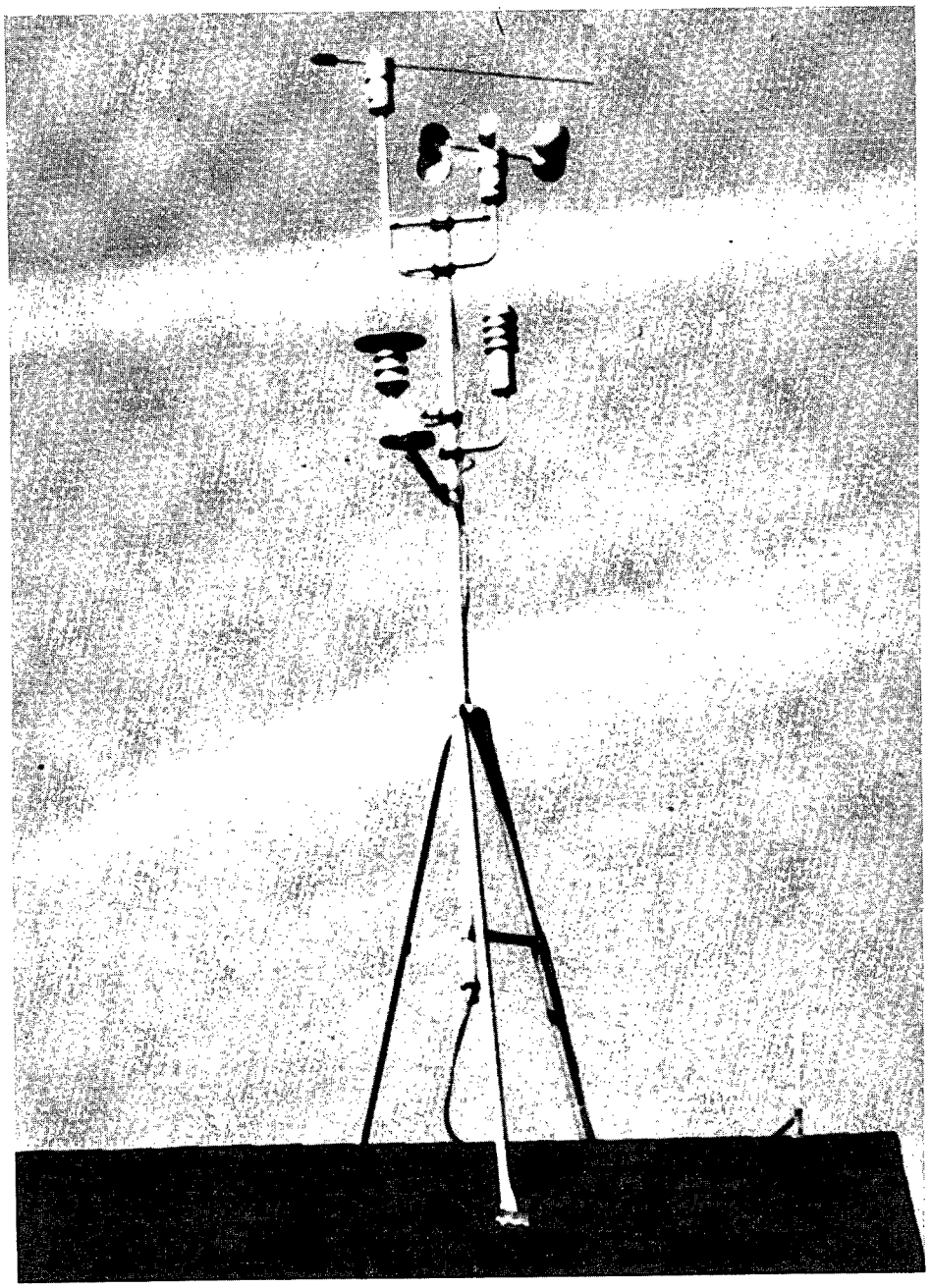

Fig. 3-5 Weather station

For protection against damage from lightning, both the T.V. antenna tripod mast and the rain gauge pipe were grounded to lightning rods already mounted on the roof and chimney.

3.4 INSTRUMENTATION INSTALLATION

Heat pump operation continued satisfactorily through January 1982 when the instrumentation arrived and installation of the various components began.

The airflow measuring equipment was calibrated on a duplicate inlet duct assembly in the R&D Laboratory, and the calibrated duct was then transported to the test site and substituted for the duct originally installed. The differential pressure transducer that was required to measure the pressure drop across the airflow measuring instrument was mounted on the wall of the vestibule part of the utility room and small flexible tubes connected between the instrument and the transducer. The airflow sampling tube was installed in the bottom pad of the return air duct and the sampling fan and connecting piping were attached to the elbow section of the inlet ducting. See Figures 3.6 and 3.7.

The power transducers and current transformers were installed in a junction box mounted on the utility room wall. See Figure A.6 in Appendix A.

The pressure transducers for measuring the various system pressures were mounted on the lower portion of the vestibule wall and copper lines were routed between the transducers and the connections on the indoor unit. See Figure 3.8. The barometric pressure transducer was also installed in this area.

The discharge airflow sampling tube was installed in the discharge duct of the unit and the sampling fan and connecting piping were attached to the ceiling mounted distribution duct. See Figure 3.9.

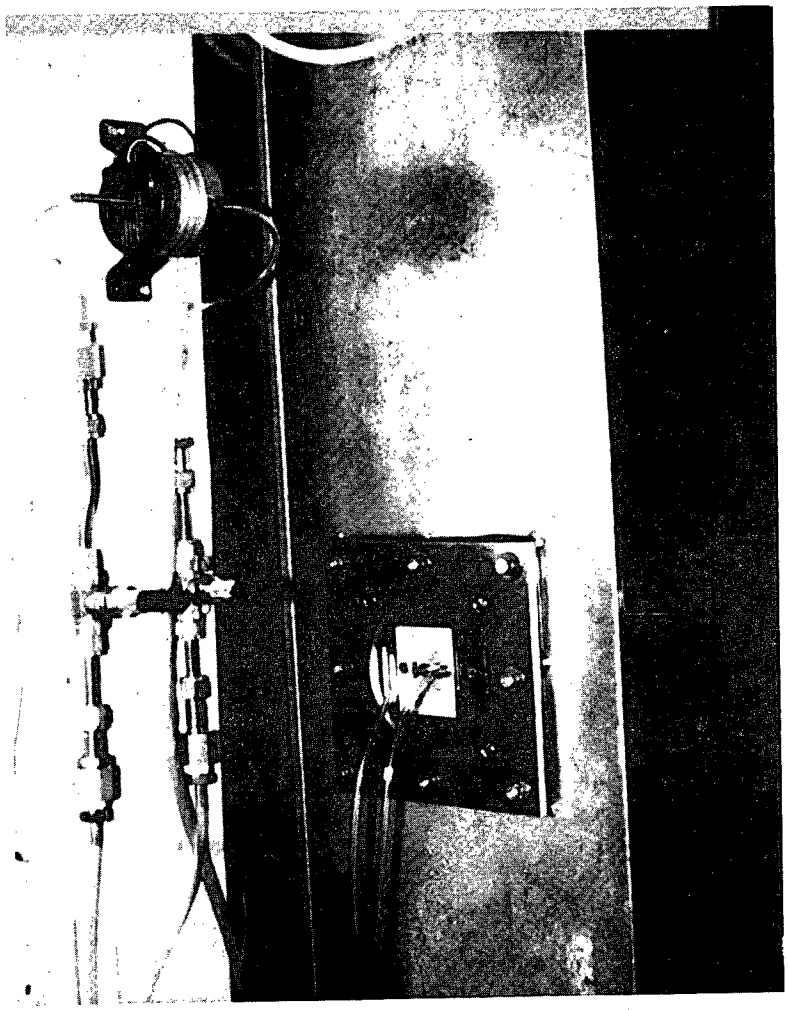

Fig. 3-6 Capacitance manometer and airflow probe connections

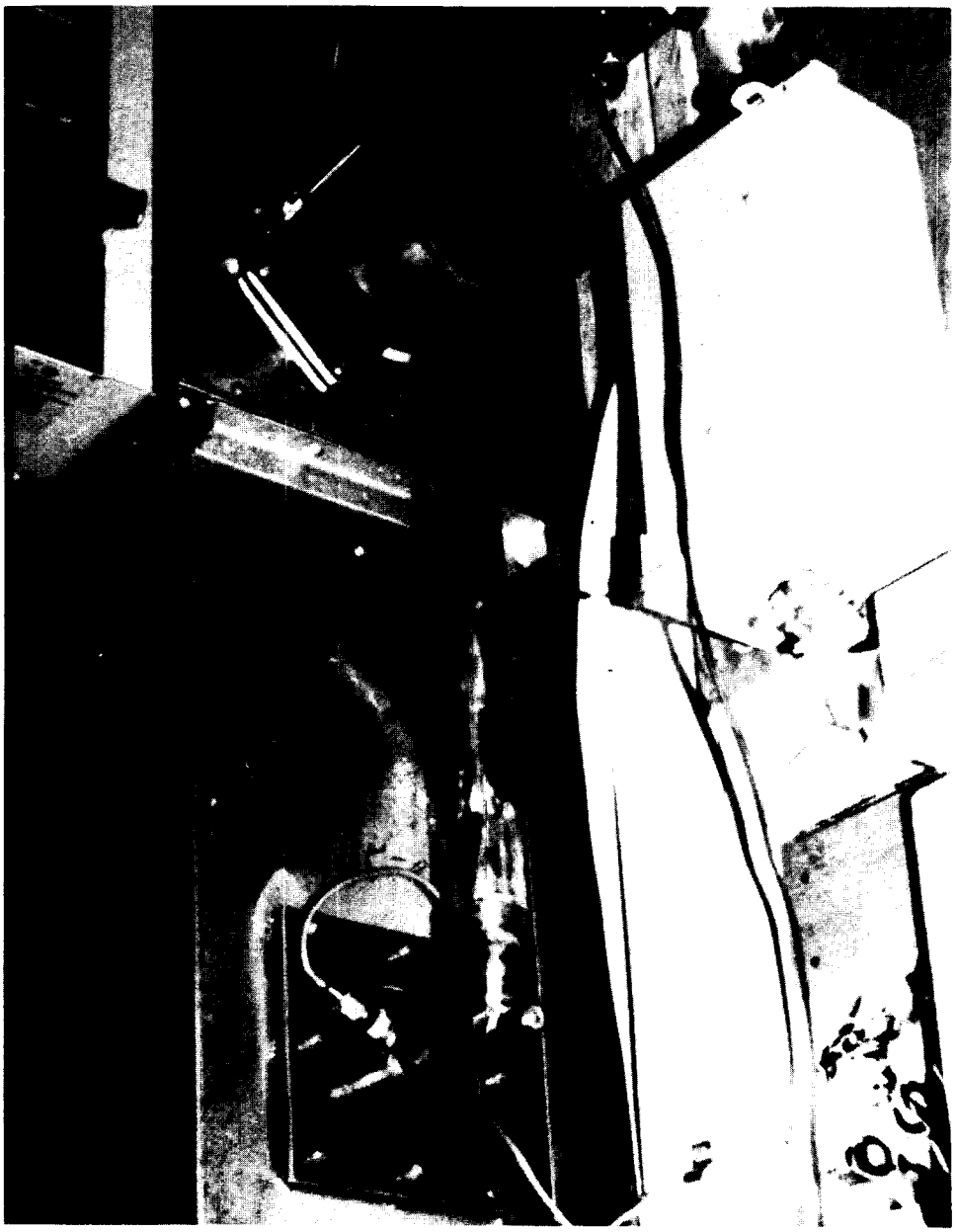

Fig. 3-7 Return air sampling tube and fan

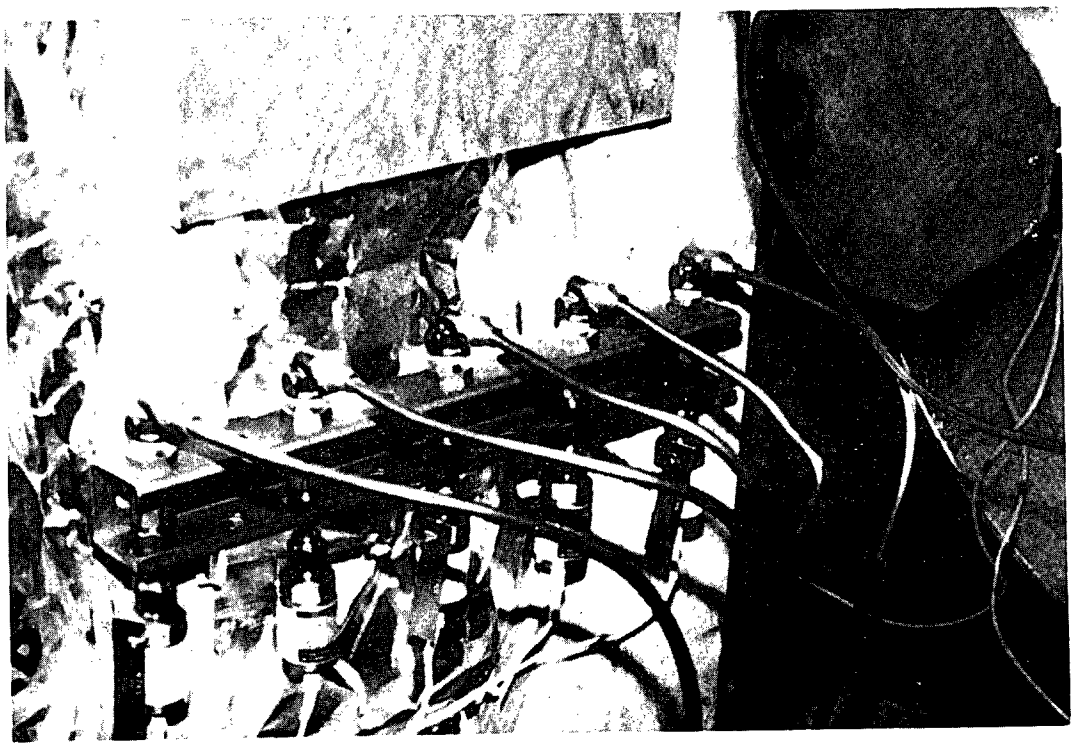

Fig. 3-8 Refrigeration system pressure transducers

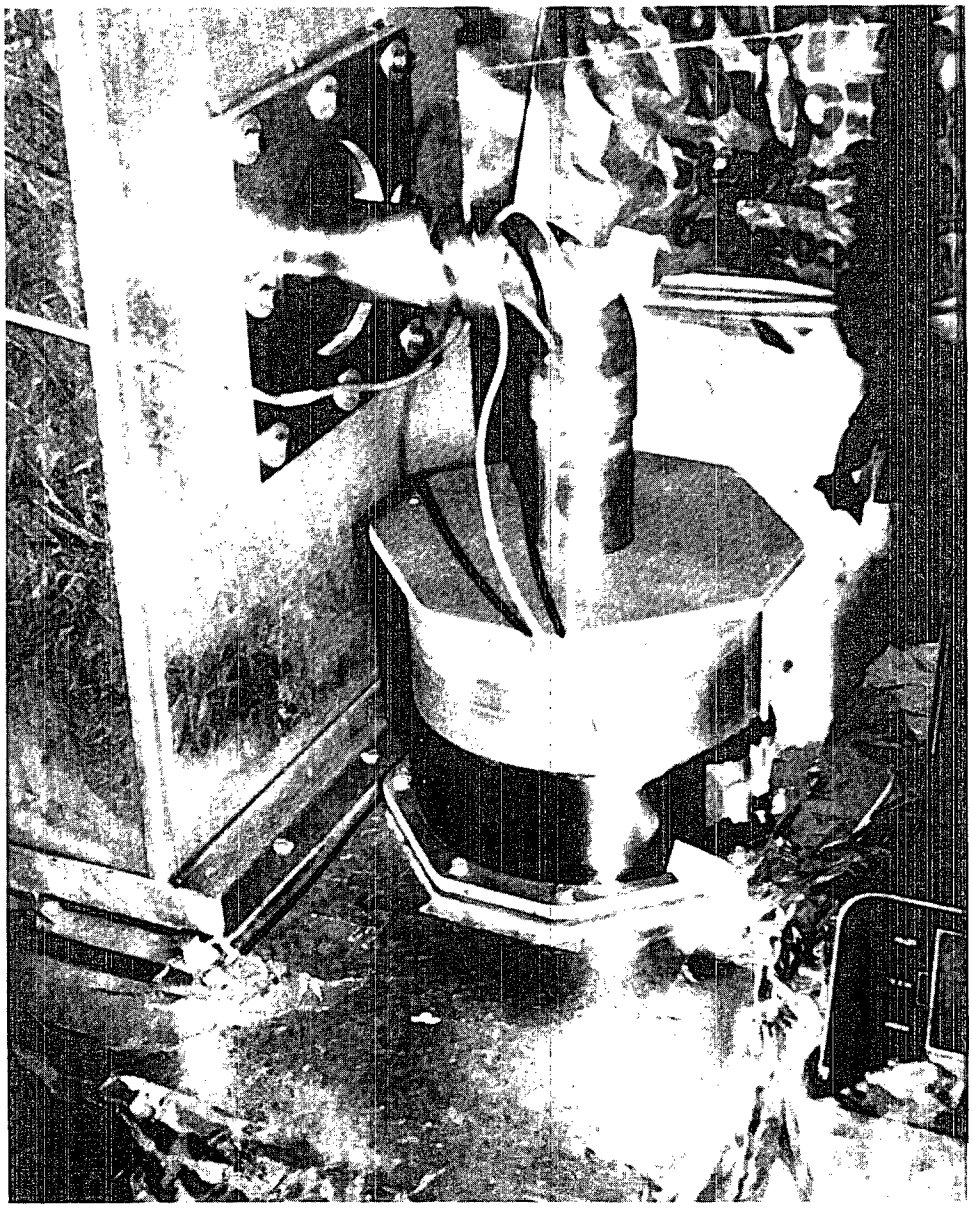

Fig. 3-9 Supply air sampling tube and fan

Note that because the unit interfaced with the main distribution duct in a short "T", no other sampling tube location was practical.

Several unsuccessful attempts were made to use pressure switches in the discharge duct to sense when the unit was running (for the purpose of turning on the sampling fans and the system humidifier). The discharge air duct static pressure in the low blower mode proved inadequate to activate the switches and it was found necessary to install small relays across the blower relay coils (in parallel with the system wiring) for this purpose. The additional power required by these relays (6 VA) did not affect system operation.

The instrumentation rack panel cabinet was located in the utility room and the data acquisition equipment plus the weather station signal conditioning electronics package, uninterruptable power supply, and cabinet cooling blower were installed in place. The tedious task of connecting all the sensor output leads to the data acquisition equipment was accomplished in two days, and the batteries for the uninterruptable power supply were installed in a plastic container in the garage under the workbench outside the utility room. It was also necessary to install a 120 V, 60 amp. circuit for the uninterruptable power supply and this was accomplished by a local registered electrician.

On March 4, 1983, the installation phase of the field evaluation was considered complete.

4. INSTRUMENTATION

An extensive instrumentation package was installed to provide inputs to the data acquisition system for monitoring the performance of the advanced dual-stroke electric heat pump under actual operating conditions. The objective was to provide the following information:

- Instantaneous and integrated values of the heating and cooling delivered to the residence.
- Instantaneous and integrated values of the energy consumed by the heat pump and the residence.
- Detailed meteorological data.
- System operating mode.
- Operating temperatures and pressures in the refrigeration system.
- Instrumentation and data acquisition system operating status.

The following describes the instrumentation used to obtain this information. More detailed descriptions of the instruments, installation and calibration data are presented in Appendix A.

4.1 DELIVERED HEATING AND COOLING

The heating and cooling delivered to the residence was determined on an instantaneous basis using the air enthalpy method. The data system scan rate and the number of connected channels determined the time interval between successive readings of the same sensor. Numerical integration was used to determine the total delivered heating and cooling. The inputs required were:

- Air Flow Rate
- Supply Air Temperature

- Supply Air Humidity
- Delivered Air Temperature
- Condensate Collected
- Compressor Run Time

The air flow rate was measured with a Dieterich-Standard model AIR-.1875-20 inch x 10 inch C06 airflow probe located in the return air duct. The air flow is a function of the pressure difference across the probe which was monitored by an MKS Barotron model 223BH-C-1CMH20 differential capacitance manometer.

Supply air and return air temperatures were measured by platinum resistance thermometers (RTD's) located in sampling tubes in the return and supply air ducts. During the second year of operation RTD's with a shorter time constant were installed and a direct measurement of air temperature change was provided by copper-constantan thermocouples located in the supply and return air ducts. The supply air and return air humidity was determined by Hygrometrics model 8501-A relative humidity sensors located in the sampling tubes.

The latent capacity during cooling operation was determined by measuring the amount of condensate draining from the indoor unit. This was accomplished by catching the condensate in a container and monitoring the depth of water in the container with a pressure transducer. During most of the first cooling season a Celesco model LCVR pressure transducer with a range of 0 to 4 cm of H_2O attached to the reservoir of a standard Teel model 1P664 condensate pump was used to determine the amount of condensate produced. It was found that when the indoor blower was operating, the portion of the indoor unit containing the condensate tray would operate at sub-atmospheric pressure. When the blower cycled off, a large quantity of condensate would flow into the condensate pump reservoir and the unit would often go through two or more cycles during one scan of the data system. As a consequence, the

amount of condensate produced was being underestimated significantly. As a result, late in the first cooling season the arrangement was altered. The output of the condensate pump was directed into a 5 gallon polyethylene demi-john placed on top of the indoor unit. The condensate level in the demi-john was monitored by a Rosemount model 115-1DP4E22 differential pressure transducer with a range of 0 to 50 inches of H_2O. A self-starting siphon drained the demi-john when it was full.

Since the heating and cooling delivered was determined by integration and the time between data scans was too long to permit accurate determination of unit running time, a compressor run time indicator was added during the second year of operation. A relay connected across the compressor contactor coil was used to activate a counter card in the data acquisition system extender chassis which registered one count per second of compressor operation.

4.2 ENERGY CONSUMPTION

The instantaneous and integrated energy consumption of the heat pump and the entire residence were monitored using electronic Watt/Watt-hour transducers. In addition conventional rotating disk Watt-hour meters were used to measure the power consumption of the heat pump, selected appliances and the residence.

The electronic Watt/Watt-hour transducers used were Rochester Instrument Systems model WWH-15 units which provided both an analog voltage output proportional to the the instantaneous power and contact closures counting the integrated Watt-hours. Current transformers were used on three of the units. The circuits monitored are shown in Table 4.1.

Five Westinghouse model D4S rotating disk Watt-hour meters mounted on a panel adjacent to the main breaker box were used to record the energy consumed by the following equipment:

Table 4.1 — Watt/Watt-Hour Transducers

Function	Model	Range
1. Whole House	WWH-15-P2-E1-C5	0-40 kW*
2. Resistance Heat	WWH-15-P2-E1-C5	0-40 kW*
3. Heat Pump (no I^2R)	WWH-15-P2-E1-C5	0-10 kW**
4. Compressor	WWH-15-P2-E1-C1	0-8 kW*
5. Indoor Blower Main Winding	WWH-15-P2-E1-C2	0-400 W
6. Indoor Blower Aux Winding	WWH-15-P2-E1-C2	0-400 W
7. Outdoor Fan Main Winding	WWH-15-P2-E1-C1	0-200 W
8. Outdoor Fan Aux Winding	WWH-15-P2-E1-C1	0-200 W

*With 40:1 current transformer
**With 10:1 current transformer

- Heat pump (excluding resistance heat)
- Resistance heat
- Game room electric heater
- Hot water heater
- Clothes dryer

The Watt-hour meter installed by the local utility (West Penn Power) provided a check on whole house energy consumption.

Line voltage was measured by an instrument rectifier providing a dc voltage proportional to the line voltage to the data system.

4.3 METEOROLOGICAL DATA

Site weather was monitored by a Texas Electronics weather station mounted on a tripod mast on the peak of the roof, a Texas Electronics tipping bucket rain guage with heater, mounted on an unused

chimney, and a Rosemount absolute pressure transducer located in the utility room. The data recorded included:

- Ambient temperature
- Relative humidity
- Barometric pressure
- Solar insolation
- Precipitation
- Wind speed
- Wind direction

4.4 HEAT PUMP OPERATING MODE

The heat pump operating mode was determined by monitoring the voltage across the contacts of the microrelays on the microprocessor board. These relays activated conventional 24 VA relays which controlled the power supplied to the heat pump components. The functions controlled by these relays are shown in Table 4.2.

4.5 REFRIGERATION SYSTEM STATE POINTS

The operating temperatures in the refrigeration system were monitored with copper-constantan thermocouples located at 12 different positions. Five critical refrigerant pressures were measured with Kulite model IPT-100 piezoelectric pressure transducers. The locations of these temperature and pressure sensors are shown in Figure 4.1.

4.6 DATA ACQUISITION SYSTEM SELF MONITORING

Several channels of data were recorded to monitor the status of the data acquisition system, the uninteruptable power supply (UPS) supporting it and the instrument power supplies. These data included:

- UPS output voltage
- UPS input ac power failure

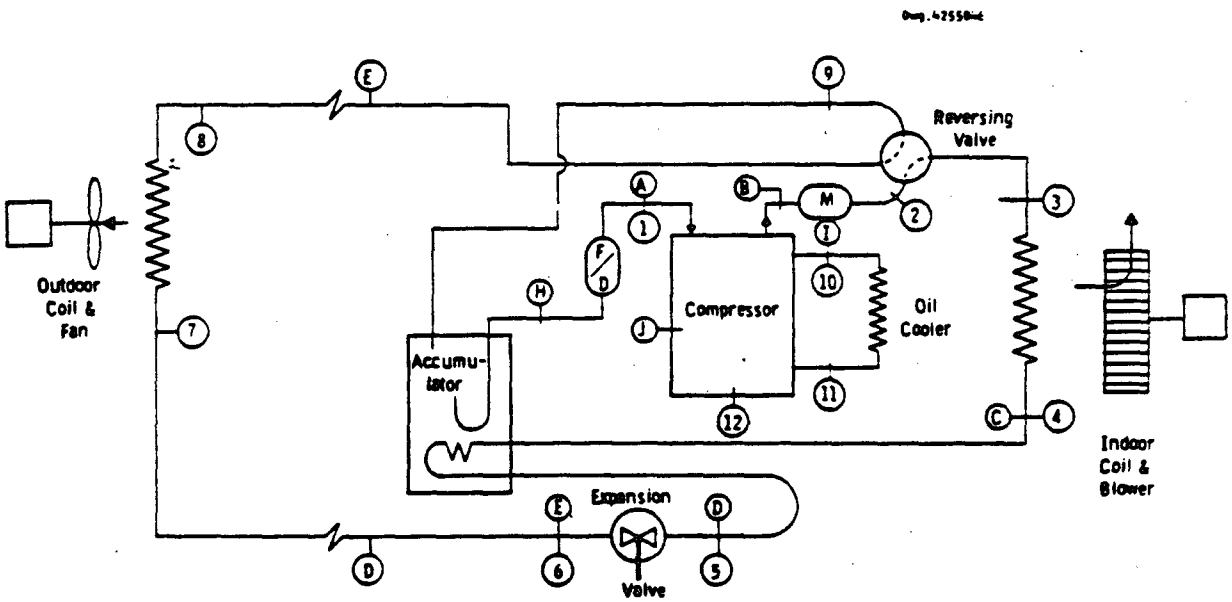

Fig. 4-1 Instrumentation locations - Preprototype #2

Table 4.2 — Relay Functions

1.	Reversing valve
2.	Auxiliary heat stage 2
3.	Outdoor fan motor trickle heat
4.	Deadman circuit*
5.	Reverse outdoor fan
6.	High-speed outdoor fan
7.	Auxiliary heat stage 3
8.	Indoor coil partitioning solenoid valve
9.	Low-speed outdoor fan
10.	Compressor
11.	Low-speed indoor blower
12.	High-speed indoor blower
13.	High-compressor capacity
14.	Auxiliary heat stage 1

*The deadman circuit automatically "rebooted" the microprocessor in the event of a power failure.

- UPS low dc bus voltage
- UPS direct dc line operation
- 24 Vdc power supply output voltage
- 10 Vdc power supply output voltage
- Utility room temperature

4.7 DEFROST TIMER AND COUNTER

Due to ambiguities encountered in determining the number of defrosts and the duration of defrosts during the first heating season, a defrost counter and timer were added. A relay across the reversing valve coil sent a pulse to a Veeder-Root type 743785-001 counter each

time the valve was energized. A Cramer type 635G elapsed time meter with 0.1 minute resolution was used to record the total time the reversing valve was activated. Since the valve was not energized during heating service and energized for defrost and cooling service this provided a measure of the number of defrosts and the total defrost time during the heating season. These counters were not connected to the data acquisition system, but were read during each visit to the site.

5. DATA ACQUISITION HARDWARE

The on-site data acquisition, storage and transmission system consisted of a Hewlett-Packard model 3054DL data logger, a Quantex model 1000 dual drive cassette recorder, a Racal-Vadic model VA3455 full duplex modem and a standard AT&T rotary dial desk telephone. This equipment was installed in a standard 66 inch high rack cabinet located in the utility room.

The 3054DL data logger consisted of a model 3797A data acquisition/control unit and a model 3498 extender chassis controlled by a model HP85F scientific computer. Four option 020 input relay multiplexer cards installed in the 3797A data acquisition/control unit provided the capability to monitor up to 80 analog signals. Nine 44426A counter cards were installed in the 3498 extender chassis to accept the inputs from the Watt-hour transducers and the compressor run time accumulator.

Data was stored on the Quantex 1000 cassette recorder and recovered remotely via the telephone and the Racal-Vadic modem at appropriate intervals (normally every 24 hours). While the Quantex recorder was being interrogated the data was stored on the integral cassette drive of the HP85F computer. When the Quantex recorder became available the data stored on the HP85F was automatically transferred to the cassette recorder. A signal diagram for the system is shown in Figure 5.1.

The entire system was supported by an Elgar model UPS-172-1 uninterruptable power supply with a static bypass switch which operated from seven Motorcraft maintenance free automotive batteries during power outages. The static bypass switch allowed the supported equipment to

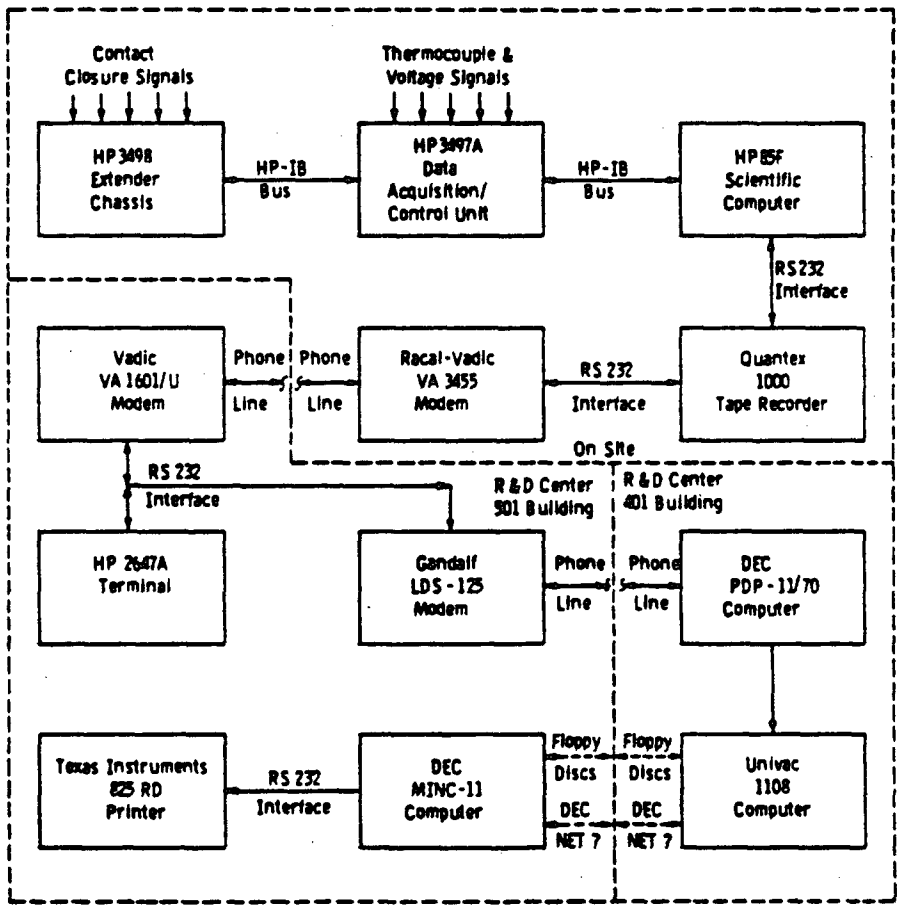

Fig. 5-1 Data signal diagram

operate directly on line power in the event of a malfunction of the UPS static inverter. The UPS and static bypass switch were mounted in the same cabinet as the data system. Photographs of the cabinet are shown in Figures 5.2 and 5.3.

At the Westinghouse R&D Center the data received via telephone was transferred to hard disk storage on a UNIVAC 1108/81 mainframe computer. A data reduction program resident on the UNIVAC was used to prepare daily summaries of the data. The raw data was then transferred to standard computer tapes for permanent storage. A second computer program resident on the UNIVAC was used to combine the daily summaries for arbitrary report periods. During the later stages of the project some of the data processing was performed on a DEC PDP-11/73 mini-computer operated by the Heat Transfer and Fluid Dynamics Department to reduce computer costs.

The data system and the methods and equations used to process the data at the Westinghouse R&D Center are described in detail in Appendix B.

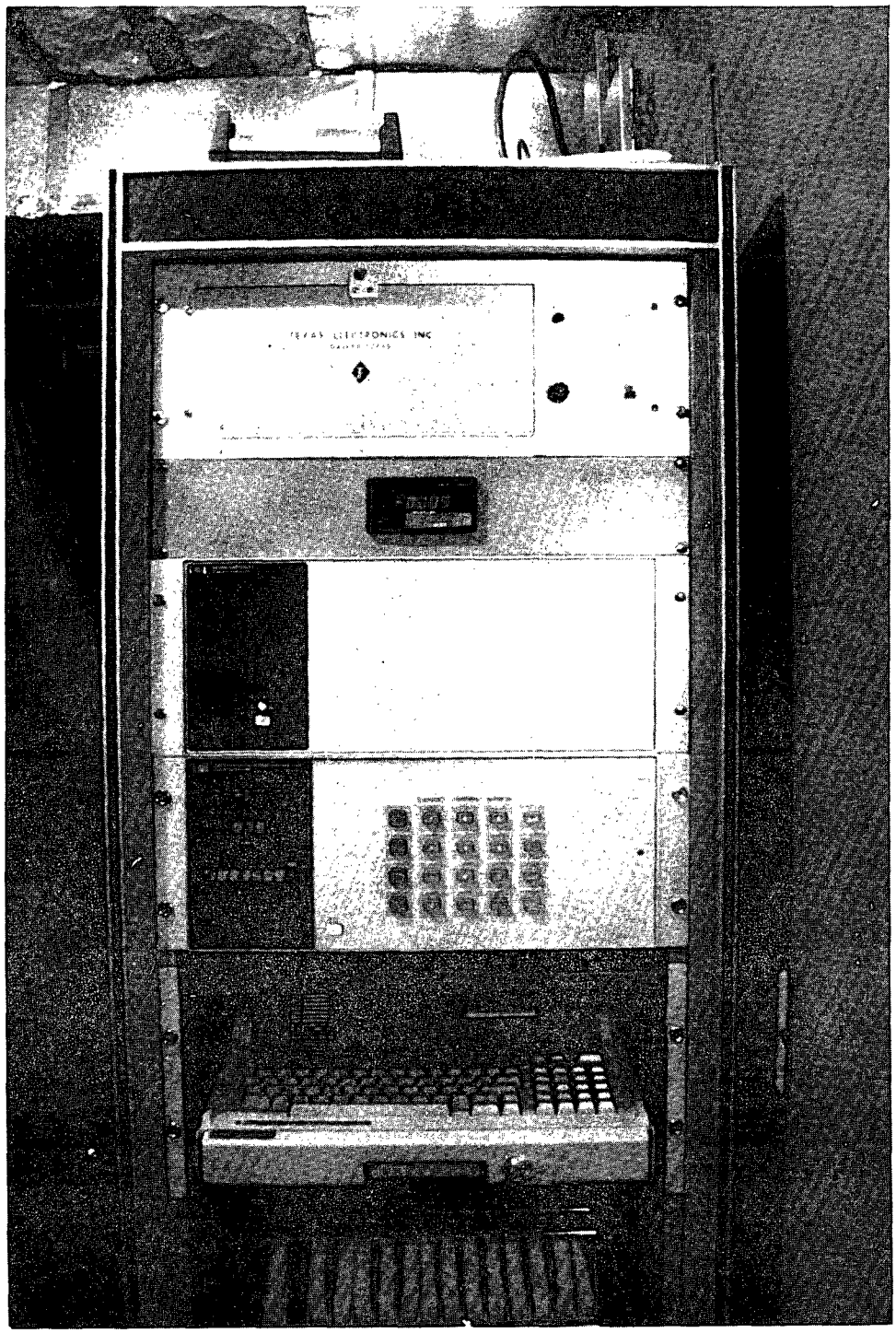

Fig. 5-2 Instrumentation cabinet upper portion

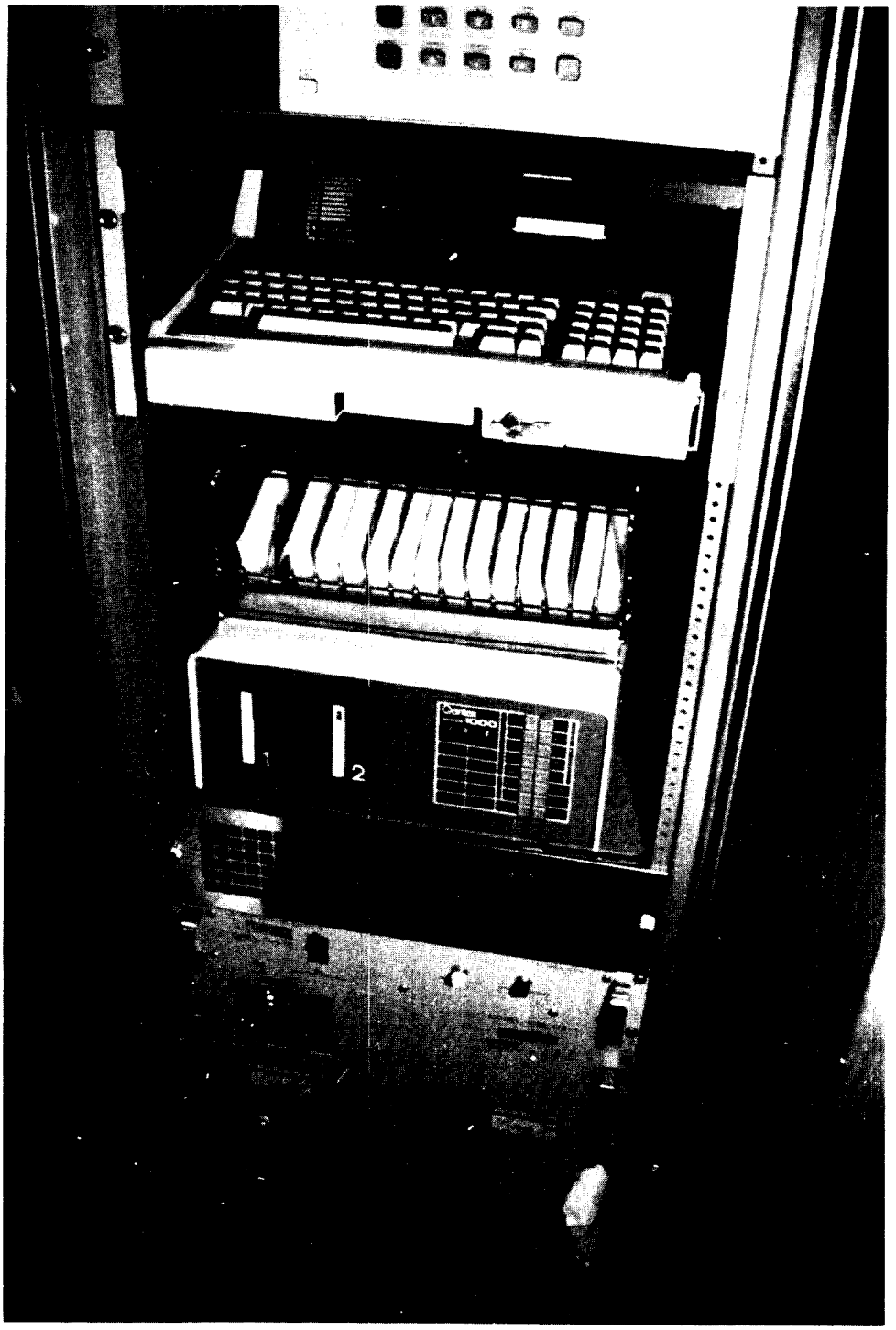

Fig. 5-3 Instrumentation cabinet lower portion

6. PROBLEMS AND THEIR RESOLUTION

6.1 GENERAL

The preceding chapter described the ideal operation and final evolution of the data system. During the course of the field test, several inadequacies were uncovered in the data system which had to be compensated for, as follows:

1) Measurement of latent cooling by relative humidity changes was unusable, due to the very slow dynamic response of the humidity sensors.

2) The original condensate collector was too small to permit an accurate measurement of liquid collected.

3) Radiant heating of the supply air RTD's during resistance heating introduced severe errors into the delivered air temperature readings.

4) The time constant of the air side RTD's was a significant fraction of typical cycle times.

5) The air flow rates inferred from the Annubar readings were obviously too low.

A discussion of each of these, with the associated analytical and hardware fixes, follows.

6.2 COOLING PERFORMANCE AMBIGUITY

There was a discrepancy between the cooling performance reported in the fall of 1983, and our more recent estimates that was the result of uncertainties associated with the measurement of latent cooling capacity. This discussion must be prefaced by a brief review of the chronological history of the field installation.

- Prior to June 21, 1983 no means of measuring condensate was available.

- Between June 21 and Sept. 9, 1983 the small condensate receiver was in place.
- The large condensate receiver became operational on Sept. 9, 1983.

When the heat pump was off during the cooling season, the utility room temperature often rose above 95°F due to the heat dissipation from the data system. As a result, the relative humidity of the air surrounding the humidity sensors was rather low. Since the sensor measuring delivered air relative humidity was near the ceiling of the utility room, when the blower was off it was at a higher temperature and consequently at a lower relative humidity than the return air sensor, which was located at waist height. When the heat pump operated in the cooling mode, the delivered air temperature fell to about 60°F with a high relative humidity near 80%. The manufacturer claims a time constant of 3 minutes for the relative humidity sensor. Thus, when the heat pump cycled on, the relative humidity in the delivered air stream was grossly underestimated for the first 6 minutes of operation (two time constants) and the latent capacity of the heat pump was overestimated.

When the blower was operating, the equipment module of the heat pump was at a negative static pressure relative to the environment. Condensate therefore tended to be retained in the drip pan. When the blower stopped, a large amount of moisture then drained out of the unit. With the small condensate receiver in place, the condensate pump often went through two or more cycles in about one minute in order to empty the receiver. Since the data reduction program estimated condensate collection by water depth in the receiver, and since the data system scanned once every 140 seconds, the additional cycles of the condensate pump were rarely recorded and condensate removal and latent capacity was underestimated.

Beginning Sept. 9, 1983 both the small condensate receiver and the large receiver were operated in series, and a comparison of cooling

capacity based upon two measures of condensate quantity showed that with the small receiver alone total capacity was underestimated by between 10 and 15%. With the large condensate receiver, the level in the receiver was measured using a pressure transducer. The large receiver was emptied automatically when full using a self priming siphon.

The cooling performance figures transmitted to ORNL in the fall of 1983 were based upon the measurement of relative humidity, not upon condensate removal measurements. At the time, this was done because it was known that the small condensate receiver was underestimating the amount of condensate removal, but the degree to which the relative humidity sensors were overestimating capacity was not known. The larger contribution of latent capacity was attributed to the fact that the indicated humidity within the residence was often significantly greater than the 51% required in lab tests. Subsequent calibration of the humidity sensors showed that the actual relative humidity was 4% to 7% less than indicated.

The subsequent analysis of heating data revealed the problem with RTD temperature lag, and also revealed that the airflow had been consistently underestimated. (See Sections 6.2 and 6.3.) When the necessary corrections were incorporated into the analysis of cooling data, reliance upon the relative humidity sensors would yield EER's greater than those obtained for steady state lab tests. The values for SEER transmitted to ORNL in the fall of 1983 were grossly in error because we had not yet uncovered some of the problems with our measurements of relative humidity, temperature, and air flow.

Our best estimate of cooling performance for the period June 21 through Sept. 29, 1983 uses the measured condensate. Thus for the period through Sept. 9, when the small condensate receiver was in place, we know that the indicated latent heat removal was conservative by about 10% compared to the results subsequently obtained with the large condensate receiver.

Data taken prior to June 20, 1983 did not include cumulative condensate measurements. In order to use this data the sensible/total capacity ratio was determined as a function of ambient temperature and capacity mode for periods when cumulative condensate measurements were available. The cooling data prior to June 20, 1983 was then adjusted by applying this sensible/total ratio to the sensible heat portion of the data.

The estimate of cooling performance given in Section 7 for the first cooling season applied the measured sensible/total capacity ratio obtained with the small condensate receiver as a function of ambient temperature and capacity mode to the entire cooling data record so that the data could be presented as a continuous record rather than segmented. Since the latent heat removal was underestimated by about ten percent, relative to later measurements with the large condensate receiver, the SEER was underestimated by about three percent.

For the second cooling season the large condensate receiver was used throughout to determine the latent capacity and the ambiguity in determining latent capacity was eliminated.

6.3 TEMPERATURE MEASUREMENT AMBIGUITY

The home owner did not use his heat pump system in the continuous fan mode. During off periods, the air in the heat pump indoor unit was not in forced motion. Because the uninterruptable power supply and the data system were located in the same utility room as the heat pump, the room tended to equilibrate at a temperature greater than the living quarters. The temperature sensors in the discharge duct tended to approach the temperature of the utility room near the ceiling, while those in the return air duct tended to approach waist level utility room temperature. When the unit turned on in the heating mode, the sensor in the return air duct initially indicated a value greater than the true return air temperature, but asymptotically approached it. The sensor in the discharge duct initially indicated a temperature near that at the

utility room ceiling, declined toward return air temperature upon startup, and then increased toward the steady state delivery air temperature for the heat pump system.

The original RTD's installed in the sampling tube had a response time in air that was much too slow, with a time constant of the order of 2 minutes in a 10 fps air stream. In order to utilize the data obtained with these RTD's an analytically derived correction curve was generated that yields the ratio of actual heat delivered to indicated heat delivered on both an instantaneous and an integrated basis. The laboratory-measured transient capacity of the heat pump upon start up for various outdoor ambient temperatures was a necessary body of experimental data. The correction factors for heat delivery were a function of outdoor ambient temperature, compressor run time, and capacity mode. For typical on cycle duration periods of the order of nine minutes, the actual integrated heat delivered was greater than the estimate of integrated heat delivered obtained using the original RTD readings by about 20%. Note that the heat delivered during the start transient is not truly measured in the field independent of lab data. The derivation of the correction is described in detail in Appendix C.

We became concerned over the slow response time of the original RTD's in the fall of 1983. On December 6, 1983 we installed thermocouples in the two branches of the delivery duct work and in the return air duct. It was not possible, without significant software revision, to include these thermocouples in the priority scans (one every 140 seconds), so their reading is available only upon a demand or time based (every 15 minutes) scan. Because of the ambiguity in resolving the actual compressor start time closer than 140 seconds, direct comparison of RTD and thermocouple reading to determine time constants was impractical. For long run times, the data can be inspected to determine the degree of discrepancy. On December 16, 1983 the holes in the sampling tubes were enlarged and additional holes drilled to increase the air flow and reduce the sensor time constant.

In January 1984, the original RTD's were replaced with new faster response sensors that had a time constant of about 20 seconds, as installed. With the new RTD's, the actual integrated heat delivered is about 3% greater than the estimate calculated from the RTD readings for a typical nine minute on cycle.

Resistance heat became necessary in about December of 1983 and it was noticed that the discharge temperature indicated by the RTD's was much higher than expected. The discharge temperature indicated by the thermocouples was in the expected range, and a heat balance indicated that the air flow was low by about 30%. It became obvious that the copper sampling tube installed in the discharge duct had an excellent thermal radiation view factor to the array of resistance heat elements. Further, the discharge air RTD was installed in an elbow at the end of the sampling tube, and had a good view of the sampling tube. Thus, the RTD readings could not be used to estimate the discharge air temperature when the unit was using resistance heat. There was no alternative to the location chosen for the sampling tube however, since the discharge duct is very short and intersected the horizontal run at a "T", with only one branch of the "T" accessible, the other branch directly entering a plastered ceiling. A radiation shield around the sampling tube was considered, but was rejected since an adequate shield would increase the blockage in the discharge duct, or require reduction of the diameter of the sampling tube.

In order to estimate the heat delivered when resistance heat was being used during the first heating season, the transient capacity of the heat pump as a function of outdoor ambient temperature, based upon lab data, was used along with the measured energy consumption of the resistance heaters. This correction is discussed in greater detail in Appendix D. Note that since the data system could not resolve the actual start of an on cycle closer than 140 seconds during the first heating season, this period was taken as the initial on period. In order to permit some future resolution of the magnitude of a radiation

correction to the sensed temperature, we performed a calibration test in the field where we monitored RTD and thermocouple readings in the resistance heat mode with various stages of resistance heat activated. Utilizing this data however, was beyond the scope of resources for this program.

Prior to the second heating season, three calibrated thermocouples equipped with radiation shields were installed in each branch of the supply air duct. Two of the thermocouples in each branch were connected in differential mode with two thermocouples in the return air sampling tube to provide a direct measurement of air temperature change. The third thermocouple in one branch was used as a sensor for the SCR controller for the first stage of resistance heat. During the second heating season the differential thermocouples were used to evaluate the air temperature change and the RTD in the return air sampling tube was used to establish the absolute temperature level. The time constants of the differential thermocouples were quite short and sensor lag was ignored in the determination of heat delivered.

In summary, an ambiguity in the measurement of return and discharge air temperature confounded our estimate of delivered heating or cooling based solely upon air side calorimetry for the first year of the field test. During the first year of the field test the return air temperature suffered only from time lag error for which an analytic correction was derived and applied, assuming the start of time for a transient, and a known initial value. Our measurement of discharge air temperature was confounded by both time lag error and radiation error when in the resistance heat mode. We incorporated into the data reduction program analytical corrections to sensed values that relied upon laboratory test data for the transient capacity of the heat pump for various outdoor ambient temperatures. For the second year of the field test, sensors with much shorter time constants were used and the radiation problem was eliminated by using shielded differential thermocouples to establish the air temperature change and an RTD to determine the

return air temperature during heating service. Corrections for sensor time lag were applied for cooling operation, but the magnitudes of the corrections were small compared to those required for reduction of the data from the first year of operation.

6.4 AIRFLOW MEASUREMENT AMBIGUITY

Reduction of heating season data for the first year uncovered a significant difference between the steady state heating capacity measured in the laboratory and that indicated by data coming from the field test site. A comparison between lab and field data for the operating state points within the refrigerant cycle, and the measured power consumption showed no significant differences. The steady state capacities calculated from the compressor map refrigerant flow and the measured refrigerant temperatures and pressures were consistently 30 to 35% higher than those indicated by air side calorimetry from field data. The RTD's were checked in the field for calibration and found to be within required accuracy. A review of the field data showed the indicated air flow to be between 1150 and 1190 cfm in high speed blower mode and between 720 and 780 cfm in low speed blower mode. The blower speed in the field was checked with a Strobetach and found to be nearly equal to lab values. The static pressure in the discharge plenum during high speed blower operation was found to be about 0.24 inches of water, compared to the 0.35 value maintained in lab tests. We would therefore expect the field airflow to be greater than that measured in the lab.

In the field, airflow was inferred from the difference in dynamic pressure across an Annubar, a commercially available flow meter. We measured the pressure difference using a MKS Barotron capacitance manometer. The calibration of this manometer was checked in the field with a micro-manometer and found to be within specifications.

When the airflow sensing system was calibrated in our lab using the setup detailed in Appendix A, the air sampling tube was in place downstream from the Annubar, but an air sample was not being withdrawn.

Since the sampling tube was in the wake of the Annubar, we hypothesized that when a sample was being withdrawn, the flow pattern behind the Annubar changed sufficiently so as to reduce the magnitude of the pressure difference across it. However, laboratory tests failed to corroborate this hypothesis. Inspection of the test unit and observation of the instrumentation in the field showed two problems. First, there were air leaks into the indoor refrigeration module due to small gaps in the case and ductwork, particularly around the electronic air cleaner unit. Second, the signal to noise ratio of the signal output by the differential pressure transducer used to measure air flow was very low. This appeared to be primarily due to vibration of the ductwork. The relatively small number of blades on the indoor blower compared to a typical "squirrel cage" blower may also have been a contributing factor. We made several attempts to improve the signal to noise ratio both by installing restrictions in the lines connecting the pressure transducer to the Annubar and by adding RC filtering to the electrical output of the pressure transducer. The attempts all proved unsuccessful.

An additional calibration based upon field data is available for those times when the unit was operated in the emergency heat mode. A comparison of air side calorimetry based upon thermocouple measurements of air temperature and measured energy consumption confirm that the airflow inferred from Annubar pressure difference and lab calibration data is low by about 27%.

In order to correct for this, we derived a correction to the lab calibration curve for the Annubar which brings the airflow measurement into agreement with the expected airflow and that required for a steady state heat balance. The magnitude of this correction factor was approximately 1.27 and was applied to both heating and cooling data for both years of the field test. The magnitude of this correction to calculated air flow is consistent with the heating and cooling capacity predicted from measured refrigerant system temperatures and pressures and the compressor performance map data. These corrections were applied

to all of the air flow data obtained during the project. Derivation of this correction is discussed in Appendix E.

6.5 COMMENT ON AMBIGUITIES

Important to note that although the heat pump was installed in the residence just before Thanksgiving weekend in 1982, the first elements of the data system were not received and installed until March 4, 1983. Thus, there was virtually no exposure of the sensor system with data acquisition in the resistance heat mode until late in 1983. Further, the software for collecting the data at the field test site and archiving it on the central computer at the research lab was not operational until Easter weekend, 1983. The first program to reduce and analyze the data was not available until July 1983. Our focus during this period was to find a solution to the numerous nuisance trips that the system kept encountering, and to ensure that the system was not deteriorating. To do this we relied mostly on our measurements of power consumption and the sensors in the refrigerant circuit, especially compressor suction and discharge pressure. In retrospect, we were not adequately concerned with the air side calorimetric measurements.

6.6 DATA REDUCTION EFFORT

Our data reduction program sought to attribute the space conditioning delivered, the energy consumed and the hours of operation and cycles of operation to each operating mode and to temperature bins. For every day of operation we created an array which was the ambient temperature bin in one index direction, and an operating parameter in the other index direction. The parameters into which we accumulated daily data were:

HOURS

- total data logging
- low capacity heating
- high capacity heating (no I^2R)
- high capacity heat with one stage of resistance heat
  - two stages
  - three stages
  - four stages

defrost
compressor off heating
low capacity cooling
high capacity cooling
compressor off cooling
emergency heat
power off

CYCLES

low capacity heat
high capacity heat (no I^2R)
high capacity heat with one stage of resistance heat
two stages
three stages
four stages
defrost
low capacity cooling
high capacity cooling

BTU's DELIVERED AND DELIVERED AIR TEMPERATURE - HEATING

low capacity
high capacity (no I^2R)
high capacity with resistance heat

BTU's DELIVERED - COOLING

high capacity
sensible
latent
low capacity
sensible
latent

SENSIBLE TO TOTAL CAPACITY RATIO

BTU's DELIVERED DURING DEFROST

BTU's DELIVERED DURING EMERGENCY HEAT

WATT HOURS CONSUMED/HIGH & LOW CAPACITY/HEATING & COOLING

whole house
compressor
blower
fan
heat pump system
crankcase heater and control system
resistance heat
defrosting
emergency heat

Our archived data then consists of the raw data plus a reduced daily record distributed into temperature bins as discussed above. A separate data summary program then operated on an arbitrary number of the daily records to produce a summary of performance for the period.

The major difficulty associated with the data reduction program was devising a scheme that would accurately attribute a particular performance parameter to the correct operating mode. There are 20 distinct operating modes possible with our control system. Consider for example the power consumed by the control system on a spring day when both heating and cooling occur. Another complication was caused by the fact that while a scan was in progress, the operation mode of the system sometimes changed. Consider for example, the fact that in heating mode the outdoor fan started before the compressor, then the compressor started, then the blower started, and if resistance heat was required, it was controlled by staged thermal relays. In addition to the software logic difficulties, there was the problem of how to handle erroneous characters in the data stream. A considerable amount of effort was expended developing screening programs to handle malformed data, or data for which counters had been reset, etc.

We believe that the final versions of the data reduction programs were sufficiently accurate and complete to satisfy the needs of this project.

7. RESULTS

7.1 DAILY RECORD

Approximately 34,000 data points per day were processed by the data reduction programs. Some data, such as that from thermocouples, was reduced to engineering units at the test site by the data acquisition software. Each recorded data scan was tagged with a date and time marker. The data reduction programs at the R&D Center converted any raw signal information to appropriate engineering units. The reduction program then attributed the data from any scan to the appropriate system operating mode, one of twenty possible, and the appropriate outdoor ambient temperature bin. The reduction program then summed or accumulated the data for each day, segregating the daily sums by temperature bin and operation mode. There exists in machine readable form, not only the raw data, but a record for each day of the year of data summarized for the day.

Another summary program operated on these daily records and prepared summaries for arbitrary numbers of days, such as the week, month, season, or year.

A one line summary of heat pump performance for each day of the year April 1, 1983 through March 31, 1984 is presented in Table F.1 in Appendix F. Similar data for the second year, April 1, 1984 through March 31, 1985 is presented in Table F.2.

In these tables, the headings are for the most part self explanatory. The average ambient temperature is the integrated average temperature over the period for which data was available during that day. Ideally "DATA HOURS" should equal 24, but there are periods where data was lost because of faults with the data acquisition and recording

system at the test site system, or irrecoverable transmission errors over the phone lines, or faults with the central computer center when attempting to record transmitted data.

7.2 TEMPERATURE BIN DATA

Table F.3 in Appendix F presents a summary of the data for the first year of operation segregated by temperature bin. Table F.4 presents a summary of the significant data elements segregated by temperature bin for the second year.

Note that duty factor is defined as the number of running hours in the designated capacity mode (hi or low) divided by the number of hours for which the system was configured to operate in that mode. In perusing these tables note that the data reduction system uses the temperature sensed at the roof top weather station as its temperature of record. The heat pump control system uses a sensor located within the outdoor unit to set the temperature dependent operating modes. There can be 2 to 3°F difference in these measures of ambient temperature.

From Table F.3 it can be seen that there were only 4 recognized calls for defrost during the first year. Obviously there were far more calls for defrost. The data reduction program logged a defrost whenever the control relay signature for defrost operation was found during a scan. The heat pump had both a demand and a timer-based defrost call system. In low capacity operation, the system should not have required defrosting based upon both laboratory data and the fact that the system was set to switch to high capacity operation at an outdoor ambient temperature of 39°F for the first heating season. The timer-based default defrost call required a defrost after the unit had operated in the frosting range (17°F to 42°F) for more that 256 minutes without a defrost. The time accumulator was reset after a defrost, or after the temperature moved out of the frosting range. Laboratory data showed that the heat pump would shed a full load of frost in about four minutes. Because of the sampling rate on the data system, if a defrost

cycle had lasted less than 140 seconds, then there is the possibility that the data system would have missed it. If we take all of the indicated resistance heat used in the 22,27,32,37 and 42°F temperature bins during the first heating season and attribute it to defrost calls, then an estimate of defrost calls can be made. There were 314 kWh of resistance heat used in these temperature bins. Upon a defrost call, 14.4 kW of resistance heat were applied. This implies 21.8 hours of defrost operation. If we assume that a missed defrost signature lasted for six minutes, then we are led to conclude that there were an additional 218 defrost cycles that were not logged by the data system. If we take the high capacity operating hours in these same bins, and divide by the 256 minute timer-based defrost call interval, we can estimate 170 timer based defrost calls as possible. The data for resistance heat kWh was not corrected for a small zero offset in the data system, so that the 218 defrost call number for the first heating season represents a somewhat conservative upper limit.

During the second heating season refinements in the data acquisition and data reduction software enhanced our ability to detect defrost cycles. As shown in Table F.4, there were 110 recognized calls for defrost during the second heating season. A comparison with visual readings of the on-site defrost counter installed on January 3, 1985 showed that the revisions to the data acquisition and reduction software had permitted detection of 70% to 80% of the actual number of calls for defrost. Therefore we conclude that the actual number of defrost cycles during the second heating season was less than 200.

7.3 ENERGY USE PATTERNS

7.3.1 Household Energy Consumption

The structure used in the engineering evaluation is a well constructed single-family all-electric two-story English Tudor style residence located in a semi-rural area near the small industrial town of Jeannette PA, about 30 miles east of Pittsburgh.

The occupants included the owner, a manager at the Westinghouse R&D Center, his spouse, a daughter who was 3 to 4 years of age during the test period and a son who was 14 to 15 years old during the test. The lady of the house was not employed outside the home during the test period and the house was occupied by at least two people at most times.

The appliances in the home are typical of a residence in its price range and include an automatic washer and dryer, a dishwasher, two refrigerators, at least two television sets, stereo equipment, two garage door openers etc.

The instrumentation installed includes electronic Watt-Watthour transducers for the heat pump components and whole-house energy use and conventional rotating disc Watt-hour meters for the heat pump, resistance heat, water heater, dryer and a portable electric heater in the basement game room. The Watt-hour meter installed by the local electric utility, West Penn Power Company, provided an additional measure of the whole house energy use.

During the 8573 hours of data (357.2 days) logged during the first year of the field test a total of 33141 kWh of electricity were consumed in the residence. During the second year the residence used 32163 kWh of electricity during the 8119 hours (338.2 days) of data logged. The electric use for the water heater, dryer and game room heater were estimated by scaling the Watt-hour meter readings for the full year to the number of hours in the data record. Table 7.1 shows the distributions of energy use. Clearly the most significant difference between the first and second years of the test was the 75% reduction in the use of resistance heat resulting primarily from modulation of the first stage and lowering of the temperatures at which the various stages were enabled. The heating degree hours below 17 for the second heating season were only slightly less than for the first heating season.

Table 7.1 — Distributions of Electric Consumption

	4/1/83 to 3/31/84	4/1/84 to 3/31/85
Heat Pump	7839 kWh	7730 kWh
Resistance Heat	2076 kWh	466 kWh
Instrument Power Supply	9156 kWh	8671 kWh
Water Heating	6248 kWh	6741 kWh
Clothes Dryer	926 kWh	1006 kWh
Game Room Heater	393 kWh	243 kWh
Appliances and Lighting	6503 kWh	7306 kWh
Total Electricity Used	33141 kWh	32163 kWh

7.3.2 HVAC System

The HVAC system consumed a total of 9915 kWh of electricity during the first year of the test which represented about 30% of the total consumption. During the second year, the 8196 kWh consumed by the HVAC system represented 26% of the total energy use of the residence. The energy use of the HVAC system may further subdivided as shown in Table 7.2.

Table 7.2 — HVAC System Energy Use

	4/1/83 to 3/31/84	4/1/84 to 3/31/85
Heat Pump - Normal Heating	5279 kWh	5768 kWh
Heat Pump - Emergency Heating	34 kWh	7 kWh
Heat Pump - Cooling	2526 kWh	1955 kWh
Resistance Heat - Normal	1475 kWh	365 kWh
Resistance Heat - Emergency	601 kWh	101 kWh
Total HVAC System	9315 kWh	8196 kWh

Note that emergency resistance heat represented about 29% of the electricity used for resistance heating during the first heating season. However, the bulk of emergency heat was used during the 1983 Christmas holiday when sub-zero temperatures were encountered and much of the heating load would have been carried by resistance heat during normal operation.

During the second heating season emergency resistance heat represented 22% of the energy used for resistance heat. All of the emergency heat operation during the second heating season occurred at temperatures above 30°F where resistance heat would not normally be required. However, emergency resistance heat represented only 1.2% of the energy consumed by the HVAC system and the impact on seasonal energy efficiency was minimal.

Note also that the electric use of the heat pump in the heating mode was 9.3% higher during the second year, in spite of a slightly milder heating season and a shorter data record. This is clearly due to the displacement of the bulk of heat delivered by resistance heat during the first year with heat supplied by the heat pump in the second year. The total electric use for normal heating was 9.2% less in the second heating season and the heat delivered was 2% less resulting in a 4.2% improvement in the heating season performance factor (HSPF). This is consistent with the 5% improvement projected.

7.3.3 Instrumentation Power Supply

In order to minimize the potential for losing data, the data acquisition, storage and transmission system was provided with an Elgar uninteruptable power supply with a peak capacity of 1500 Watts. This unit normally produced 120 Vac by inverting the 96 Vdc output from seven lead-acid storage batteries connected in series. When ac line power was available the battery charge was maintained by an independent charging circuit. Field measurements showed that the UPS had an essentially constant current draw of 8.9 Amps at 120 Volts (1068 Watts). The UPS

accounted for nearly 28% of the total electrical energy consumed during the first year and 27% during the second year. Since a large portion of the heat generated by the instrumentation package was dissipated into the occupied portions of the residence it contributed to a much lower than expected balance point.

7.3.4 Water Heating

Hot water was provided by a conventional electric storage type water heater located in the utility room. Figure 7.1 is a plot of electricity use for water heating during the entire test period. The average electricity use for water heating was 19.5 kWh per day, which is about 64% higher than the average of 11.9 kWh per day for a family of four cited in the Biddeford[14] study. The level of energy use for water heating was fairly constant. During the first year of the test it ranged from 11.8 kWh per day to 24.0 kWh per day except for the period between August 19, 1983 and September 12, 1983 where it fell to 7.8 kWh per day. This probably reflects a vacation period. For the second year daily consumption ranged from 14.0 kWh per day to 24.2 kWh per day with the highest daily energy use coinciding with periods of cold weather. This is probably the result of a combination of increased indoor activity and lower water line temperatures. Water heating represented about 20% of total energy consumption.

7.3.5 Clothes Dryer

The clothes dryer consumed an average of 2.84 kWh per day. Figure 7.2 is a plot of energy consumption vs time for the entire test period. The level was fairly constant, ranging from 1.43 kh to 3.50 kWh per day. The clothes dryer consumed about 3.0% of the total energy used.

7.3.6 Game Room Heater

Due to an air distribution problem the central HVAC system did not adequately heat the basement game room. Prior to the field test the owner used a portable catalytic heater burning 1A kerosene to provide

LEAST SQUARES FIT TO PROVIDED DATA
DATA

M	X	Y
1	61	2194
2	90	2772
3	171	4281
4	200	4690
5	224	4877
6	242	5212
7	252	5330
8	256	5384
9	273	5636
10	284	5798
11	299	6034
12	306	6132
13	322	6425
14	419	8679
15	474	10000
16	523	11076.2
17	560	11708.3
18	567	11806.2
19	580	12020.7
20	640	12940.1
21	664	13440.6
22	669	13431.6
23	698	13983.2
24	734	14736.3
25	815	16699.8
26	821	16845.2

FITTED POLYNOMIAL IS:

A(0) = 577.181848232000
A(1) = 19.483620957100

THE NUMBER OF DATA POINTS WAS = 26

STANDARD DEVIATION OF FIT = 270.539527876

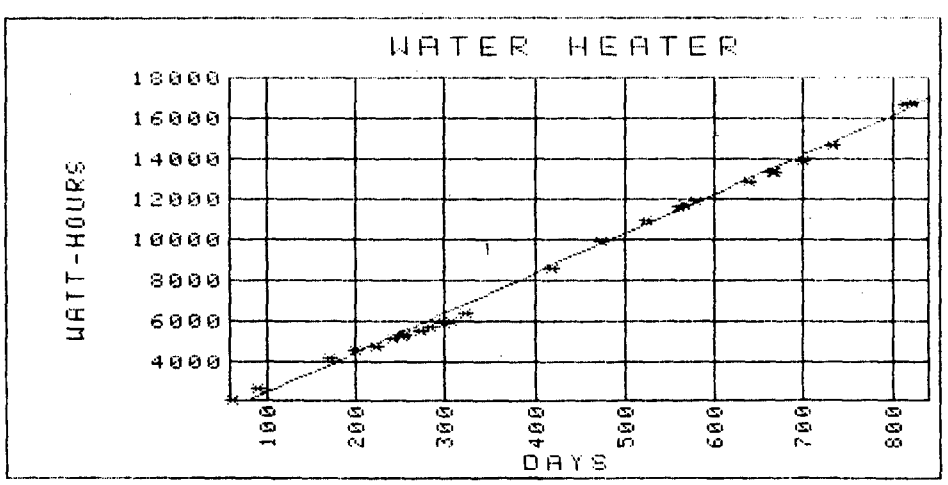

Fig. 7-1 Water heater energy use

LEAST SQUARES FIT TO PROVIDED DATA
DATA

M	X	Y
1	61	351
2	90	433
3	171	670
4	200	760
5	224	798
6	242	863
7	252	882
8	256	895
9	273	944
10	284	968
11	299	1008
12	306	1018
13	322	1074
14	419	1357
15	474	1516
16	523	1663.4
17	560	1757.2
18	567	1768.5
19	580	1803.5
20	640	1965.5
21	664	2026.4
22	669	2033.9
23	698	2130.5
24	734	2250.2
25	815	2528.7
26	821	2549.3

FITTED POLYNOMIAL IS:

A(0) = 168.207331610000
A(1) = 2.839259635510

THE NUMBER OF DATA POINTS WAS = 26

STANDARD DEVIATION OF FIT = 19.7175143344

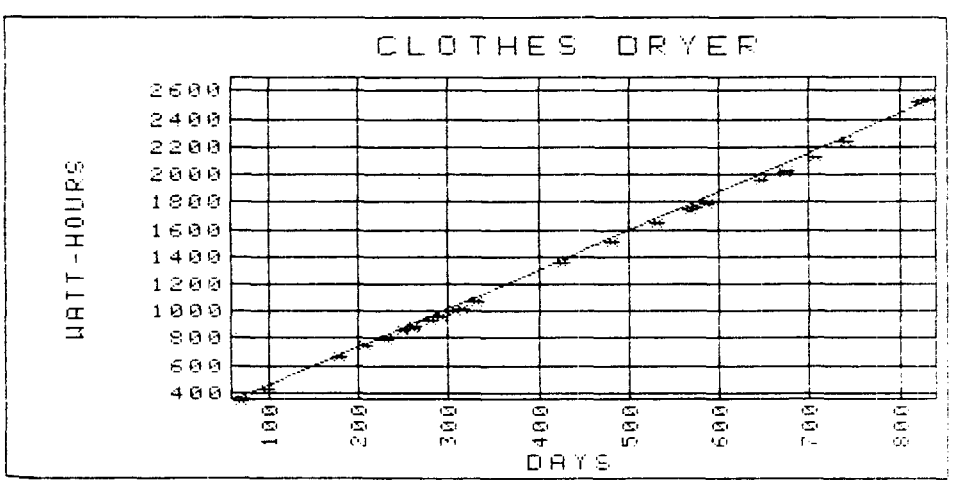

Fig. 7-2 Clothes dryer energy use

additional heating. For the duration of the field test he agreed to use an oil-filled natural convection portable electric heater. A disc type Watt-hour meter was used to monitor it's energy consumption. The average energy consumption was 0.9 kWh per day and the maximum consumption 4.8 kWh per day. As expected the electricity use is highly seasonal with no energy consumption during the late spring, summer and early fall and maximum energy use in December through March. The game room heater consumed about 1.0% of the total electricity used.

7.3.7 Lighting and Appliance Loads

The remainder of the electricity used must be attributed to appliance and lighting loads. A previous Westinghouse study[14] established the typical annual energy consumption for various appliances shown in Table 7.3. The total annual appliance and lighting load is estimated to be broken down as follows:

Table 7.3 — Typical Annual Appliance and Lighting Loads

Lighting	1200 kWh
Refrigerator	1200 kWh
Freezer	800 kWh
Coffee Maker	100 kWh
Washer	100 kWh
Iron	140 kWh
Color Television	400 kWh
Radio	90 kWh
Range	1200 kWh
Miscellaneous	900 kWh
Total	6130 kWh

The 6503 kWh appliance and lighting load deduced from the field test data for the first year. is consistent (6% higher) with typical

values. During the second year the deduced appliance and lighting load was 7306 kWh, 19% higher than the typical values.

7.4 ELECTRICAL DEMAND CHARACTERISTICS

The peak electrical demand for December 1, 1983 through February 28, 1984 and December 1, 1984 through February 28, 1985 are shown as a function of average daily ambient temperature in Table 7.4. As noted in Section 2, the modifications to the method of controlling resistance heat and the alterations to the heating balance points resulted in a significant reduction in peak electrical demand at low temperatures. Note that in the temperature range where defrost occurs, peak demands in excess of 11 kW were assumed to represent incorrect identification of defrost operation and were excluded from the demand data record if data for another day with the same average temperature indicated a peak demand below 11 kW.

The peak electrical demand for June 1, 1983 through August 31, 1983 and June 1, 1984 through August 31, 1984 is shown as a function of average daily ambient temperature are shown in Table 7.5. As expected the demand characteristics for the two cooling seasons are similar.

Table 7.4 — Winter Peak Electrical Demand vs Average Ambient Temperature

Dec. 1, 1983 - February 28, 1984		Dec. 1, 1984 - February 28, 1985	
Average Temperature Deg F	Peak Demand kW	Average Temperature Deg F	Peak Demand kW
-7	18.00	-10	14.60
-2	18.00	-8	16.10
-1	17.90	3	3.80
2	16.20	10	5.10
3	16.50	11	10.50
6	8.50	12	11.80
8	17.30	13	12.10
10	16.50	14	11.60
12	3.50	15	11.40
13	17.20	16	12.10
15	15.80	17	11.80
16	17.50	18	12.10
17	14.50	19	11.20
18	15.40	20	11.80
19	16.00	21	10.90
20	16.50	22	10.40
21	16.90	23	3.80
22	13.90	25	6.50
23	4.10	26	7.70
26	4.10	27	3.60
27	3.80	28	8.30
28	3.90	29	3.90
29	3.90	30	3.80
30	3.60	32	3.70
31	4.10	33	3.90
33	4.20	34	4.80
34	4.20	35	3.90
35	4.20	36	5.80
36	3.80	37	2.70
37	3.80	38	2.10
38	3.70	39	2.80
39	3.70	40	3.80
40	4.00	41	3.40
41	3.60	42	2.30
42	4.00	43	3.30
43	3.70	44	2.40
44	2.40	46	2.10
46	3.90	48	2.40
48	3.50	49	2.20
50	2.40	53	1.70

Table 7.4 — (Continued)

Dec. 1, 1983 - February 28, 1984		Dec. 1, 1984 - February 28, 1985	
Average Temperature Deg F	Peak Demand kW	Average Temperature Deg F	Peak Demand kW
53	2.10	54	1.30
56	2.40	55	1.40
		56	1.40
		57	1.40
		58	1.40
		59	.30
		60	1.20
		62	.80

Table 7.5 — Summer Peak Electrical Demand vs Average Ambient Temperature

June 1, 1983 - August 31, 1983		June 1, 1984 - August 31, 1984	
Average Temperature Deg F	Peak Demand kW	Average Temperature Deg F	Peak Demand kW
55	.30	58	2.40
58	.60	60	2.20
59	2.10	61	2.40
61	2.20	62	2.50
62	2.20	63	2.30
63	2.40	64	2.50
64	2.00	65	2.50
66	2.20	66	2.60
67	2.50	67	2.50
68	2.70	68	2.70
69	2.60	69	4.00
70	4.60	70	4.00
71	3.70	71	2.70
72	4.20	72	3.60
73	3.70	73	4.20
74	2.70	74	3.80
75	4.20	76	2.60
76	5.50	77	2.70
77	4.20		
78	4.30		
79	4.30		
80	4.50		
82	2.70		

8. ACKNOWLEDGEMENT

The authors wish to acknowledge the contributions of the following individuals to the work reported:

R. S. Lackey, J. C. Kastovich and R. R. Young: Installation design.

W. E. Evans, R. E. Shaffer and W. M. Urban: Heat pump installation.

N. J. Wilds and A. H. Swiss: Instrumentation and data system installation.

W. F. Evans, C. J. Kapral, A. H. Swiss, N. J. Wilds and W. M. Urban: System repair and maintenance.

R. G. Colclasser: Microprocessor control system programming and maintenance.

F. D. Snyder: Data processing consultant.

A. J. Montali: Data processing.

We would particularly like to acknowledge the patience and cooperation of the entire Taylor family, who were considerably inconvenienced on a number of occasions.

The authors acknowledge the support, guidance and encouragement given by personnel of the Oak Ridge National Laboratory in the administration of this project. In particular we recognize G. Privon, P. Fairchild and V. Baxter, Program managers and K. Rice of the Conservation and Technology Section.

9. REFERENCES

1. Young, R. R., Kastovich, J. C. and Veyo, S. E., "A High-Efficiency Dual-Stroke Compressor for Heat Pumps," Westinghouse Research Report 82-9E9-TOPIC-R1, September 30, 1982.

2. English, W. A., Young, R. R., Kastovich, J. C. and Veyo, S. E., "A Geared Dual-Speed Compressor for Heat Pumps," Westinghouse Research Report 82-9E9-TOPIC-R2, April 25, 1983.

3. Fagan, T. J., "Measured Performance of High-Efficiency Residential Heat Pump Compressors," Westinghouse Research Report 82-9E9-TOPIC-R3, December 10, 1982.

4. Chuang, M. C., Fagan, T. J. and Veyo, S. E., "An Analysis of the Boiling Thermosiphon Evaporator for Heat Pumps," Westinghouse Research Report 82-9E9-TOPIC-R4, To be published.

5. Wright, T., Krause, P. C., Lackey, R. S. and Veyo S. E., "A High-Efficiency Heat Pump Fan," Westinghouse Research Report 82-9E9-TOPIC-R5, October 29, 1982.

6. Ariewitz, D., Lackey, R. S. and Veyo, S. E., "A High-Efficiency Indoor Air Mover", Westinghouse Research Report 82-9E9-TOPIC-R6, April 22, 1983.

7. Kirschbaum, H. S. and Veyo, S. E., "Single-Phase High-Efficiency Two-Speed Air Mover Operation," Westinghouse Research Report 82-9E9-TOPIC-R7, April 26, 1983.

8. Kirschbaum, H. S., "A Two-Strength Compressor Motor," Westinghouse Research Report 82-9E9-TOPIC-R8, April 27, 1983.

9. Lee, K. H., Habron, B. F., and Veyo, S. E., "A Methodology to Estimate Seasonal Performance of Dual-Capacity Heat Pumps," Westinghouse Research Report 82-9E9-TOPIC-R9, August 31, 1983.

10. Lucheta, R. A., Fagan, T. J. and Veyo, S. E., "The Optimization of Dual-Capacity Heat Pumps," Westinghouse Research Report 82-9E9-TOPIC-R10, January 25, 1985.

11. Veyo, S. E. and Fagan, T. J., "Dual Stroke Compressor and System Development - Final Report," Oak Ridge National Laboratory, ORNL/Sub/79-24712/3, December, 1983.

12. Colclaser, R. G., Fagan, T. J. and Veyo, S. E., "Microprocessor Control System for the Dual-Stroke Advanced Electric Heat Pump," Westinghouse Research Report 82-9E9-TOPIC-R12, March 28, 1985.

13. Kirschbaum, H. S. and Veyo, S. E., "An Investigation of Methods to Improve Heat Pump Performance and Reliability in a Northern Climate," Final Report Research Project 544-1, Electric Power Research Institute EM-319, January 1977.

14. Walukas, D. J., "Assessing the Potential for Optimal Utilization of Off-Peak Power, Volume III - Biddeford Demonstration," Final Report, Federal Energy Administration Contract Number: 14-01-0001-1892, December 29, 1975.

15. Hilpert, R., "Warmeabgabe von geheizten Drahten und Rohren," Forsch. Gebiete Ingenieurw., Vol 4, p. 215, 1933.

16. Streeter, V. L., Fluid Mechanics, McGraw-Hill Book Co., New York, NY, Second Edition, 1958.

A. APPENDIX A — INSTRUMENTATION

An extensive instrumentation package was installed to provide inputs to the data acquisition system for monitoring the performance of the advanced dual-stroke electric heat pump under actual operating conditions. The objective was to provide the following information:

- Instantaneous and integrated values of the heating and cooling delivered to the residence.
- Instantaneous and integrated values of the energy consumed by the heat pump and the residence.
- Detailed meteorological data.
- System operating mode.
- Operating temperatures and pressures in the refrigeration system.
- Instrumentation and data acquisition system operating status.

The following describes the instrumentation used to obtain this information.

A.1 DELIVERED HEATING AND COOLING

The heating and cooling delivered to the residence was determined on an instantaneous basis using the air enthalpy method. The data system scan rate and the number of connected channels determined the time interval between successive readings of the same sensor. Numerical integration was used to determine the total delivered heating and cooling.

Air Flow Rate

The return air volume flow rate was obtained using a flow probe calibrated with a section of the return air duct. Return air tempera-

tures and humidity were obtained using the air sampling device shown in Figure 3.7.

The calibrated duct section (see Figures A.1 and A.2) measured 10 inches by 20.75 inches in cross section and 61 inches high. At the entrance and exit of the duct section an aluminum honeycomb material was used as a flow straightener. The honeycomb material measured 4 inches thick with hexagonal openings 0.25 inches across the flats giving an L/D of more than 10. The aluminum stock was 0.003 inches thick.

The airflow was measured with a Dieterich-Standard Corp. model AIR79-.1875-20 inch x 10 inch C06 airflow probe. This probe is a one inch square tube which completely spanned the duct and was oriented with a diagonal parallel to the airflow. The airflow rate was proportional to the square root of the pressure differential between the total pressure taps located on the leading edge of the bar and static pressure taps located on the trailing edge of the bar. The pressure differential is 2.5 times greater than that of a conventional pitot tube due to the location of the static pressure ports.

The pressure differential was monitored by a Barotron model 223BH-C-1CMH2O differential capacitance manometer manufactured by MKS Instruments Inc. This unit has a range of 0-1 cm of water. The capacitance manometer and the pressure taps of the air bar are shown in Figure 3.7. The duct and differential pressure transducers were calibrated simultaneously using the indoor code test box in the heat pump test facility as a standard. The test setup is shown schematically in Figure A.3. The code test box uses four standard 4 inch ASME short radius flow nozzles in the flow measurement section. The pressure differential across the nozzles was measured with a Rosemount model 1DP3E1282 differential pressure transducer with a range of 0-5 inches of H_2O. Immediately prior to the test the output of the Rosemount pressure transducer was compared to that of an Ellison inclined manometer with a range of 0-1.5 inches of H_2O and 0.05 inch scale divisions.

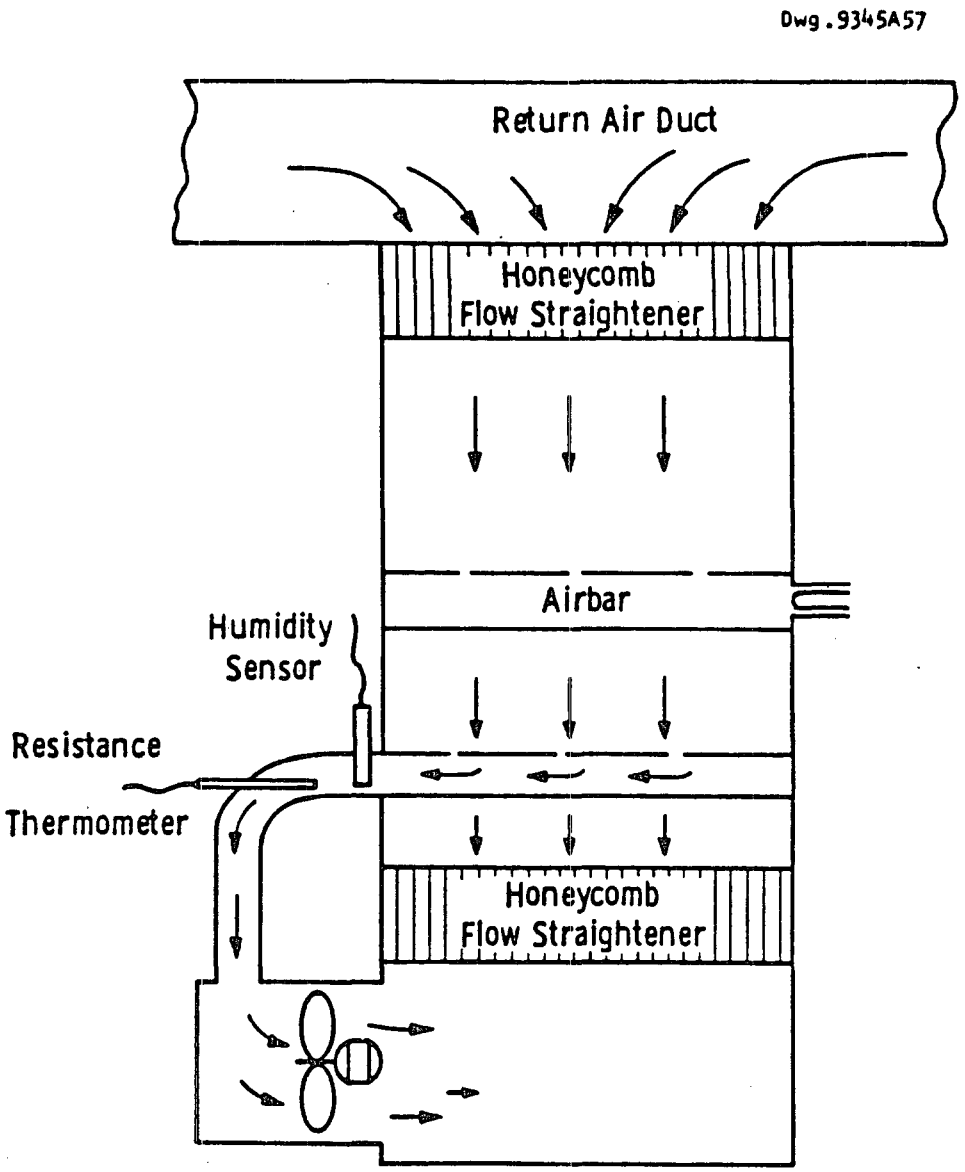

Fig. A-1 Calibrated duct section schematic

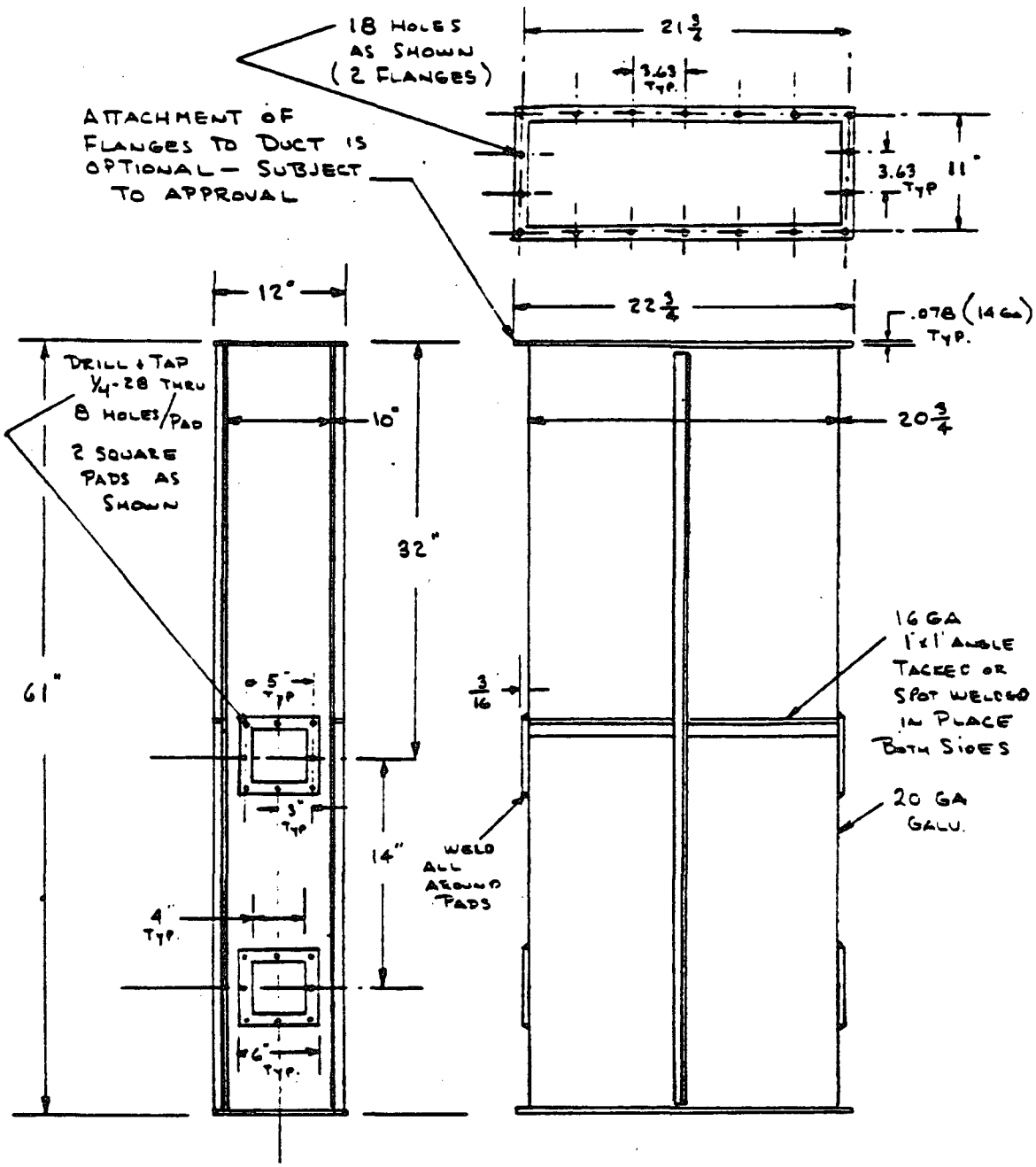

Fig. A-2 Inlet duct details

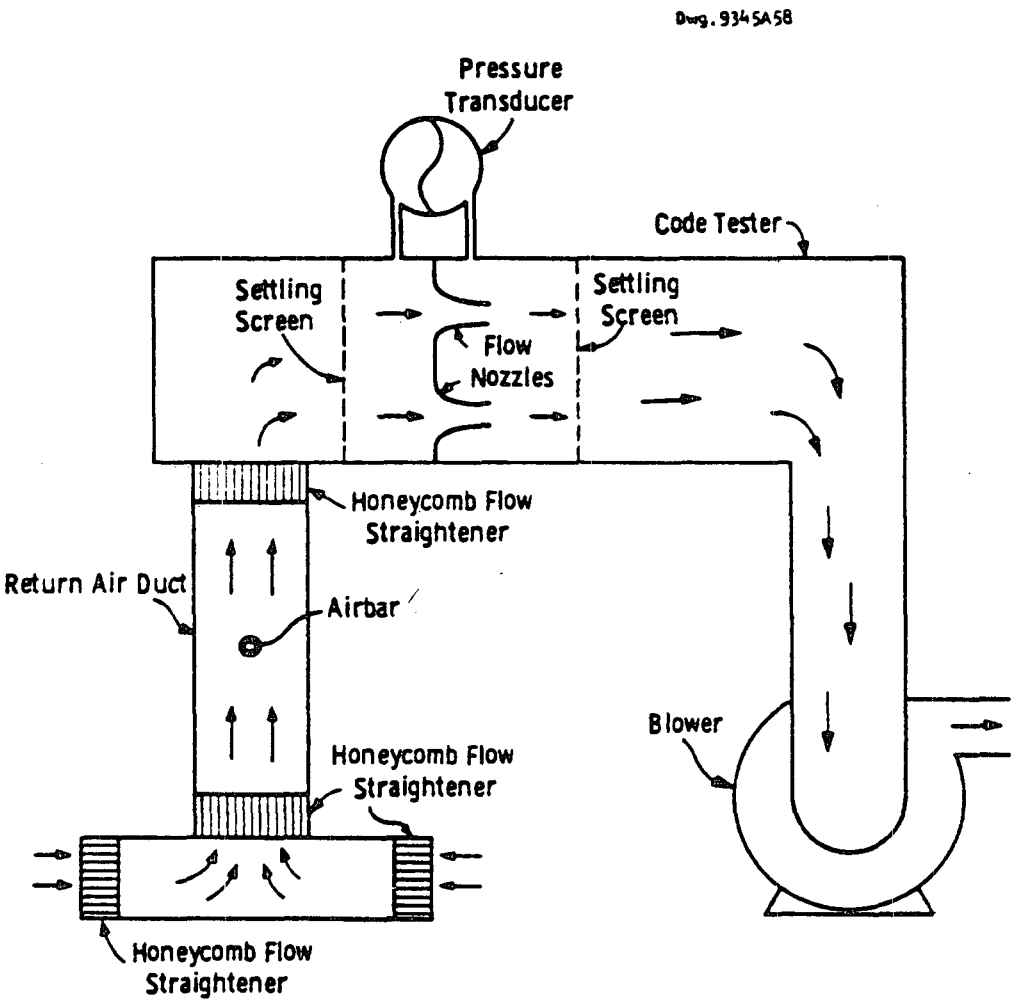

Fig. A-3 Duct calibration setup

Return Air Temperature and Humidity

Return air temperature and humidity were determined by drawing air through a sampling tube over a resistance thermometer and humidity sensor. The air sampling tube was 1.5 inch copper tubing. Eight equally spaced sampling ports were drilled into the upstream side of the tube. Air was drawn through the tubes by Pamotor Model 7600S fans which can provide an airflow of 100 cfm against a static pressure of 0.3 inches of H_2O. Unfortunately these fans were found to be noisy in service and were replaced by Pamotor Model 4600 XP fans which can provide an airflow of 50 cfm against a static pressure of 0.18 inches of water. The air sampling tube and fan are shown in Figure 3.7. The original platinum resistance thermometers were Hycal Engineering model RTS-31-A-100-C-4-3-36 three wire units. Four wire models were preferred but could not be obtained on an acceptable delivery schedule. The circuit used to operate the RTDs is shown in Figure A.4. A well-regulated 24 Vdc power supply (Elpac Model GLV-75-24) supplied power to the RTD in series with two 10000 Ohm $\pm$.01 percent resistors. The voltage across the resistors was measured to determine the current passing through the RTD, nominally 1.2 milliamps, and the voltage across the RTD was measured and divided by the current to determine the resistance. To prevent errors from radiation the RTD's were located in a position where they are were not affected by the sampling fan motor. When it was determined that the time response of the original RTD's was too slow to permit accurate integration of the sensible heating and cooling delivered, Minco Products Model S200 resistance thermometer elements were installed. These elements are embedded in a ceramic capsule 0.04 inches in diameter and 0.45 inches long and the manufacturer claims a time constant of 6 seconds in air at 3 ft/sec. The elements were attached to wire "stingers" soldered to thin wall 0.25 inch brass tubing with cotton thread. A small amount of epoxy glue was used to secure the thread.

The relative humidity was measured with a Hygrometrics Inc. Model 8501-A, "XERITRON," relative humidity sensing system. The

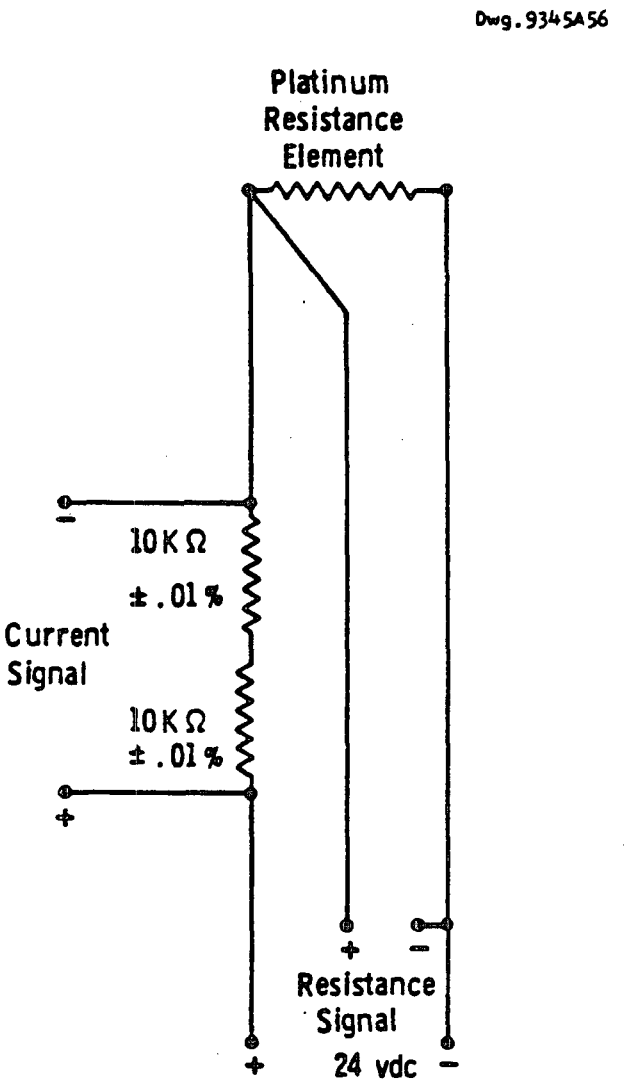

Fig. A-4 Resistance thermometer circuit

XERITRON humidity transducer is a composite of organic and inorganic crystals which sense moisture by the hygromechanical stress of small inert cellulose crystalline structures acting on a Kovar beam to which a pair of thermally matched environmentally-isolated silicon strain gauges are bonded in a half Wheatstone bridge configuration. Full range response from 0-100 percent relative humidity is obtained and the element is not damaged by immersion. The manufacturer claims ±2 percent linearity, ±1 percent repeatability, ±2 percent hysteresis and ±4 percent accuracy. The maximum time constant for a step change in humidity is 3 minutes.

Delivered Air Temperature and Humidity

The delivered air temperature and humidity were measured using an air sampling tube with 6 equally spaced ports and a fan as shown in Figure 3.9. The fan, resistance thermometer and humidity sensor were identical to those used in the return air duct.

During the cooling season the latent capacity was determined by measuring the condensate collected. Initially a Celesco Transducer Products Inc. LCVR variable reluctance differential pressure transducer with a range of 4 inches of H_2O was attached to a condensate collecting reservoir to determine the height of the condensate pool. The reservoir was drained periodically by a commercial condensate pump with a float switch. The manufacturer claims 0.25 percent full scale linearity and 0.5 percent full scale hysteresis for this unit. It was calibrated against a Meriam micromanometer with a resolution of .001 inches of water. The results shown in Figure A.5 indicate that the unit was well within specification. Experience showed that the capacity of the condensate reservoir was inadequate to give an accurate measurement of collected condensate. (See Section 6.2). On September 9, 1983, a second condensate measuring system was installed in series with the original unit. The condensate receiver consisted of a 5 gallon cubical polyethylene demi-john with a self-starting siphon which emptied it when full. The level of liquid in the container was measured with a

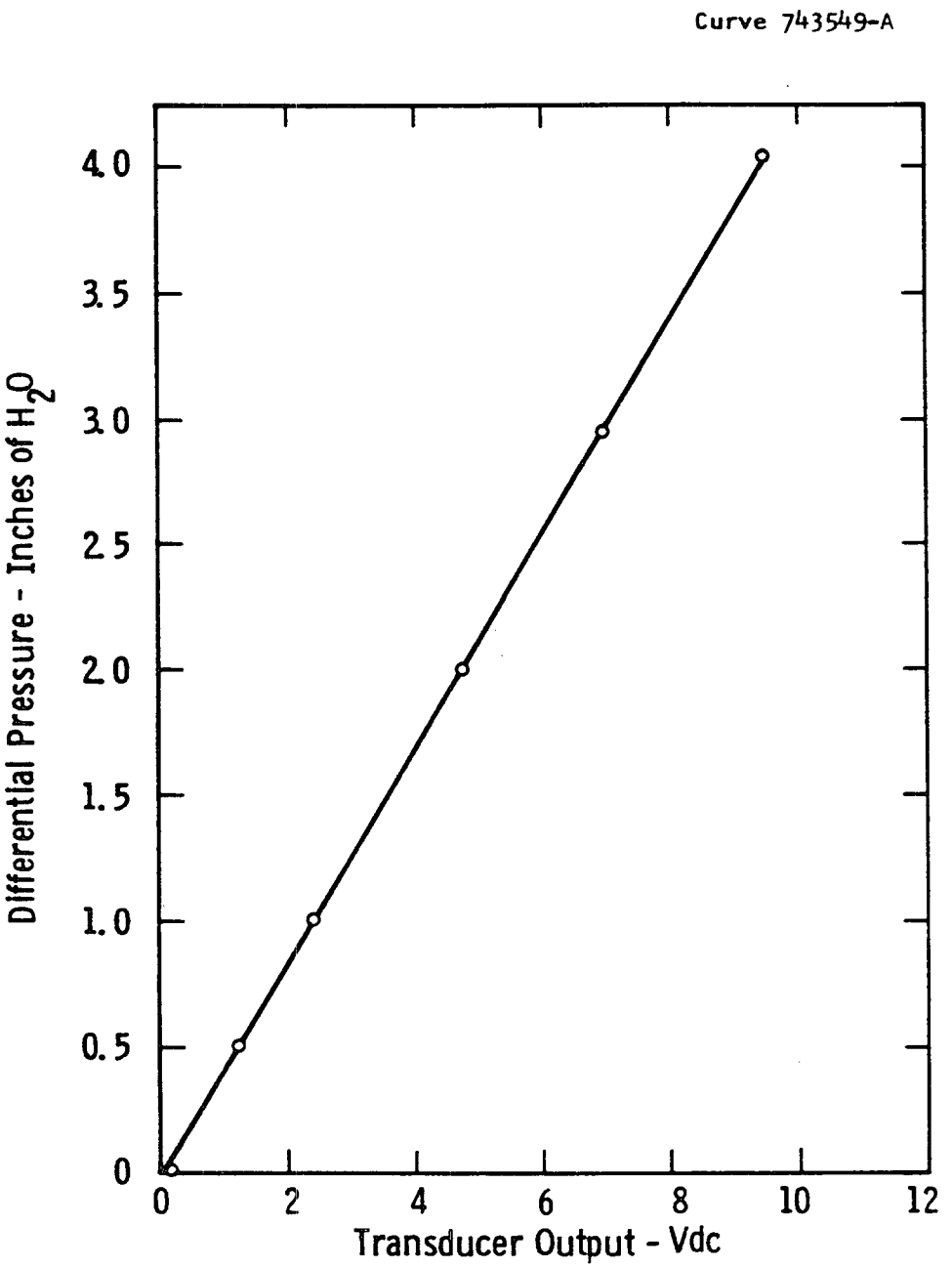

Fig. A-5 Calibration of Celesco model LCVR pressure transducer

Honeywell Model 411 differential pressure transmitter with a range of 0-50 inches of water. The 4-20 mA output of the transmitter was passed through a 100 ohm precision resistor to give an 0.4 to 2.0 Vdc signal monitored by the data acquisition system.

A.2 ENERGY CONSUMPTION

The instantaneous and integrated energy consumption of the heat pump and the entire residence were monitored using eight Rochester Instrument Systems Inc. model WWH-15 electronic Watt/Watt-hour transducers. These transducers provide a 0-1 mAdc analog current signal proportional to the instantaneous power plus a contact closure output counting the integrated Watt-hours. The circuits monitored are summarized in Table 4.1. The analog output was measured by reading the voltage across a 100 ohm ±.01 percent resistor and the contact closures were counted by eight separate Hewlett-Packard type 060100 kHz reciprocal counter modules. Due to the unique design of the indoor blower motor and outdoor fan motor the main and auxiliary windings can operate at different voltages, and two Watt/Watt-hour transducers were required for each motor. Three of the transducers used Midwest Model 6CT12B current transformers with a 200:5 ratio and 1.5 percent accuracy. A fourth transducer used a Midwest Model 6CT35B current transformer with a 50:5 ratio and 2.0% accuracy. All of the transducers had the A2 accuracy option, ±0.1 percent full scale typical accuracy and ±0.25 percent full scale worst case accuracy. These transducers are separately powered by 120 Vac and dissipate a maximum of 4 VA. The current monitoring circuits dissipate a maximum of 0.25 VA.

All of the Watt/Watt-hour transducers and current transformers associated with the heat pump were enclosed in a 24 inch by 18 inch by 8 inch metal junction box mounted on the wall of the utility room near the heat pump indoor unit, shown in Figure A.6. The whole house Watt/Watt-hour transducer was mounted in a 12 inch by 6 inch box near the main circuit breaker panel. The associated current transformer was mounted in the main breaker box.

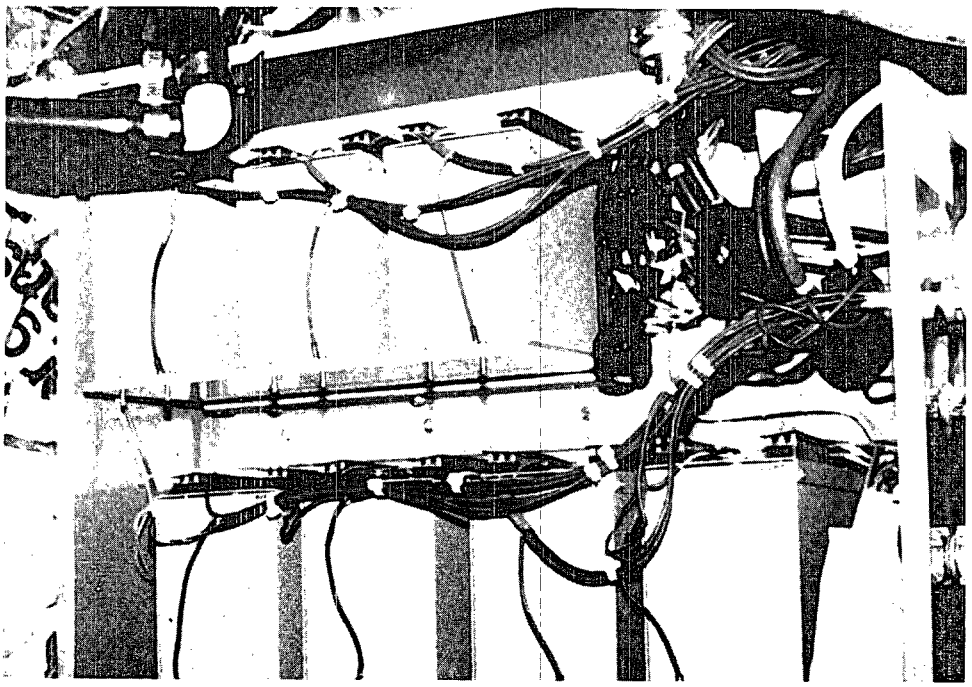

Fig. A-6 Heat pump watt/watt hour transducer and current transformers

In addition to the Watt/Watt-hour transducers five conventional Westinghouse type D4S rotating disk Watt-hour meters were mounted on a panel adjacent to the main breaker box as shown in Figure 3.3. These meters recorded the energy consumed by:

- The heat pump (excluding resistance heat)
- Resistance heat
- Game room electric heater
- Hot water heater
- Clothes dryer

The Watt-hour meter installed by the local utility (West Penn Power) provided a check on whole house energy consumption.

The actual voltage supplied to the heat pump was monitored by an instrument rectifier which provided a dc voltage proportional to the ac voltage to the data acquisition system. The calibration curve for this instrument rectifier is shown in Figure A.7.

A.3 METEOROLOGICAL DATA

A weather station manufactured by Texas Electronics Inc. was mounted on the peak of the roof using a Tandy Corporation tripod mast as shown in Figure 3.5. The following components were mounted on the mast:

- TD-104D Wind direction sensor
- TV-102S Wind speed generator
- TT-101 Temperature thermistor network
- TH-2012-2 Humidity sensing module
- TS-100 Solar radiation sensor

A model TR-6118-1L tipping bucket rainfall gauge with a heater was mounted on an unused chimney. The circuit boards supporting these sensors were mounted in a model BPC-300 rack mount chassis:

Curve 743547-A

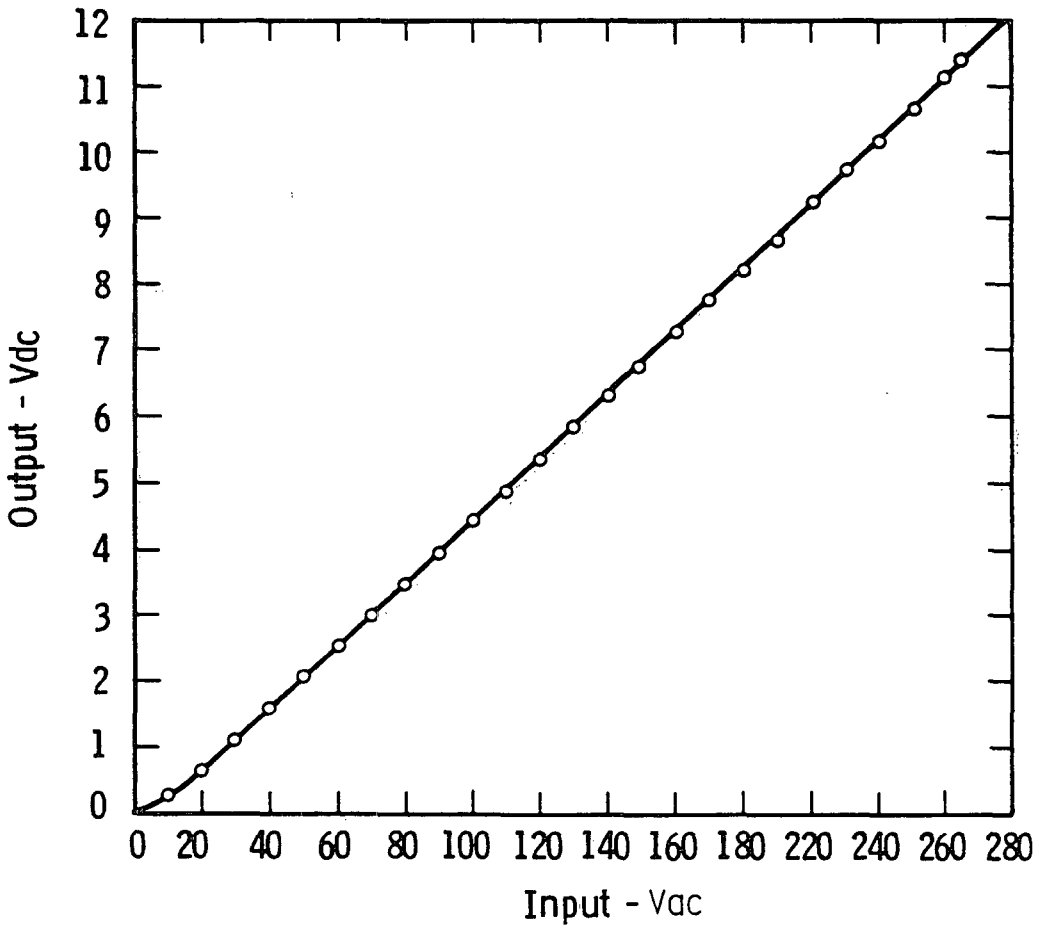

Fig. A-7 Line voltage instrument rectifier calibration

- PS-01-2 Power supply board
- SC-10-7A Wind direction board
- PA-03-1 Power amplifier boards (two)
- SC-13-3A Humidity board
- SC-14-3 Rainfall accumulator
- SC-15-5 Temperature board

The wind direction sensor output is a 0-10 Vdc signal linearly proportional to 0-360 degrees with a claimed linearity of 0.5 percent. It was mounted using an accurate compass and adjusted for the local deviation between true north and magnetic north.

The wind speed output is a 0-10 Vdc signal linearly proportional to a wind speed of 0-100 mph. An accuracy of ±2 percent full scale is claimed. The threshold response is 2 mph.

The ambient temperature sensor output is a 0-10 Vdc signal linearly proportional to a temperature range of -40°F to 120°F. Accuracy is not specified by the manufacturer. The specified response time to reach 90 percent of a step temperature change is 0.8 seconds per °F temperature change.

The relative humidity sensor uses a hygroscopic inorganic sensing element which expands and contracts with changing humidity. The sensor is attached to the moveable core of a linear variable differential transformer (LVDT). The output of the system is a 0-10 Vdc signal proportional to 0-100 percent relative humidity. Claimed accuracy is ±5 percent RH for relative humidities of 5 to 15 percent, ±2 percent RH for relative humidities of 20 percent to 90 percent and ±3 percent RH for relative humidities of 95 percent to 100 percent.

The rainfall gauge was a tipping bucket type giving one electrical impulse for each 0.01 inch of precipitation. A 120 Vac

electrical heater was provided to melt frozen precipitation. An accuracy of 1 percent is claimed for rainfall rates up to 2 inches per hour. The accumulator circuit board converts the electrical impulses into a 0 to 10 Vdc signal proportional to 0 to 1 inch of precipitation. When 1 inch of precipitation was accumulated the voltage reset to zero.

The solar radiation sensor is a photovoltaic type with a claimed accuracy of ±10 percent compared to the standard 48 junction thermopile black and white pyrometer. The output is a 0-10 Vdc signal proportional to 0-2 cal/min-cm^2 (0-442 Btu/hr-ft^2).

In addition to the sensors mounted on the roof, the barometric pressure was sensed in the utility room with a Rosemount model 1151AP-6-E-22-M1-B2 capacitive type pressure transmitter with a range of 0-17 psia. The manufacturer claims an accuracy of ±0.25 percent. The unit operated at 24 Vdc nominal voltage with a 4-20 mA output which was monitored by reading the voltage across a 1000 ohm ±.01 percent resistor in series with the pressure transmitter. The unit was calibrated at the Standards Laboratory of the Westinghouse Nuclear Technology Division. Calibration results are summarized in Table A.1.

A.4. HEAT PUMP OPERATING MODE

The operating mode was determined by monitoring the voltage across the contacts of the 14 microrelays on the microprocessor circuit board. These relays activated 14 conventional 24 Vac relays which controlled the power supplied to the heat pump components. The functions controlled by these relays are summarized in Table 4.2.

When the microrelays were deenergized the voltage across the contacts rose to the nominal supply voltage of 24 Vdc. When the microrelays were energized the voltage across the contacts dropped to 2 to 5 Vdc. This information was used by the data system to trigger the recording of data scans.

Table A-1 Pressure Transducer Calibration Data

Location	Range	Serial Number	Intercept	Slope	Positive Reference Accuracy	Negative Reference Accuracy	Hysteresis	Repeatability
A	0-250 psig	KD-319	2.87653	2.59018	+.199%	-.109%	.038%	.005%
B	0-500 psig	KE-308	-0.909601	5.07575	+.458%	-.226%	.049%	.049%
C	0-500 psig	KE-309	1.98544	5.11527	+.333%	-.238%	.114%	.104%
D	0-500 psig	KE-310	-7.14403	5.05123	+.394%	-.237%	.100%	.063%
E	0-500 psig	KE-307	-1.84530	5.09787	+.449%	-.289%	.126%	.091%
Barometric	0-17 psia	472861	-4.23660	10.6102	+.127%	-.122%	.093%	.060%

A.5 REFRIGERATION SYSTEM STATE POINTS

The operating temperatures and pressures in the refrigeration system were monitored with thermocouples and pressure transducers.

A total of 12 copper-constantan thermocouples were provided in the locations numbered from 1 to 12 in Figure 4.1. These thermocouples were lagged to the surface of the refrigerant piping and the compressor shell to minimize the number of penetrations into the hermetic system. An additional thermocouple was attached to the high temperature cut-out switch near location 2.

Five model IPT-1100 piezoelectric pressure transducers manufactured by Kulite Semiconductor Products Inc. were mounted in locations A through E on Figure 4.1. The unit mounted at position A had a range of 0 to 250 psig. The remaining units had a range of 0 to 500 psig. Transducers D and E were attached to Schraeder valves on the refrigerant line couplings at the indoor unit. The transducers were mounted on a Unistrut bracket mounted on the utility room wall near the indoor unit as shown in Figure 3.8.

The Kulite transducers operated on 10 Vdc supplied by a model WP-703A regulated power supply produced by VIZ Manufacturing Co. The supply voltage was monitored by the data acquisition system. The output of the transducers was a millivolt signal with a nominal value of 0.4 mV/psi for the 0 to 250 psig unit and 0.2 mV/psi for the 0 to 500 psig units. These units were calibrated by the Standards Laboratory of the Westinghouse Nuclear Technology Division. The results are summarized in Table A.1.

A.6 DATA ACQUISITION SYSTEM SELF MONITORING

Several channels of the data were recorded to monitor the status of the data acquisition system and the uninterruptable power supply (UPS) supporting it.

As noted previously the output voltage from the 10 Vdc power supply for the piezoelectric pressure transducers was recorded. The voltage across the precision resistors controlling the current flow through the resistance thermometers was recorded, giving an indication of the output of the 24 Vdc power supply, as well as the current passing through the RTDs. This power supply also powered the barometric pressure transducer.

The voltage supplied to the data acquisition system by the UPS was monitored via an instrument rectifier which converted the nominal 120 Vac 60 Hz signal to a dc voltage. The calibration curve for this instrument rectifier is shown in Figure A.8.

The static bypass switch on the UPS had three contact closures to indicate operating status. These contacts were wired in series with the 10 Vdc power supply. The contact closures indicated:

- Input ac power failure
- Low dc bus voltage
- Direct dc line operation

Operating temperatures in the cabinet were monitored by recording the voltage output of a resistance thermometer mounted on each of the four isothermal thermocouple blocks in the data acquisition system. These resistance thermometers gave a voltage varying linearly with temperature with an output of 2.5 Volts at 25°C and a slope of 100 mV per °C change. A shielded copper-constantan thermocouple was mounted above the instrumentation cabinet to monitor the utility room temperature.

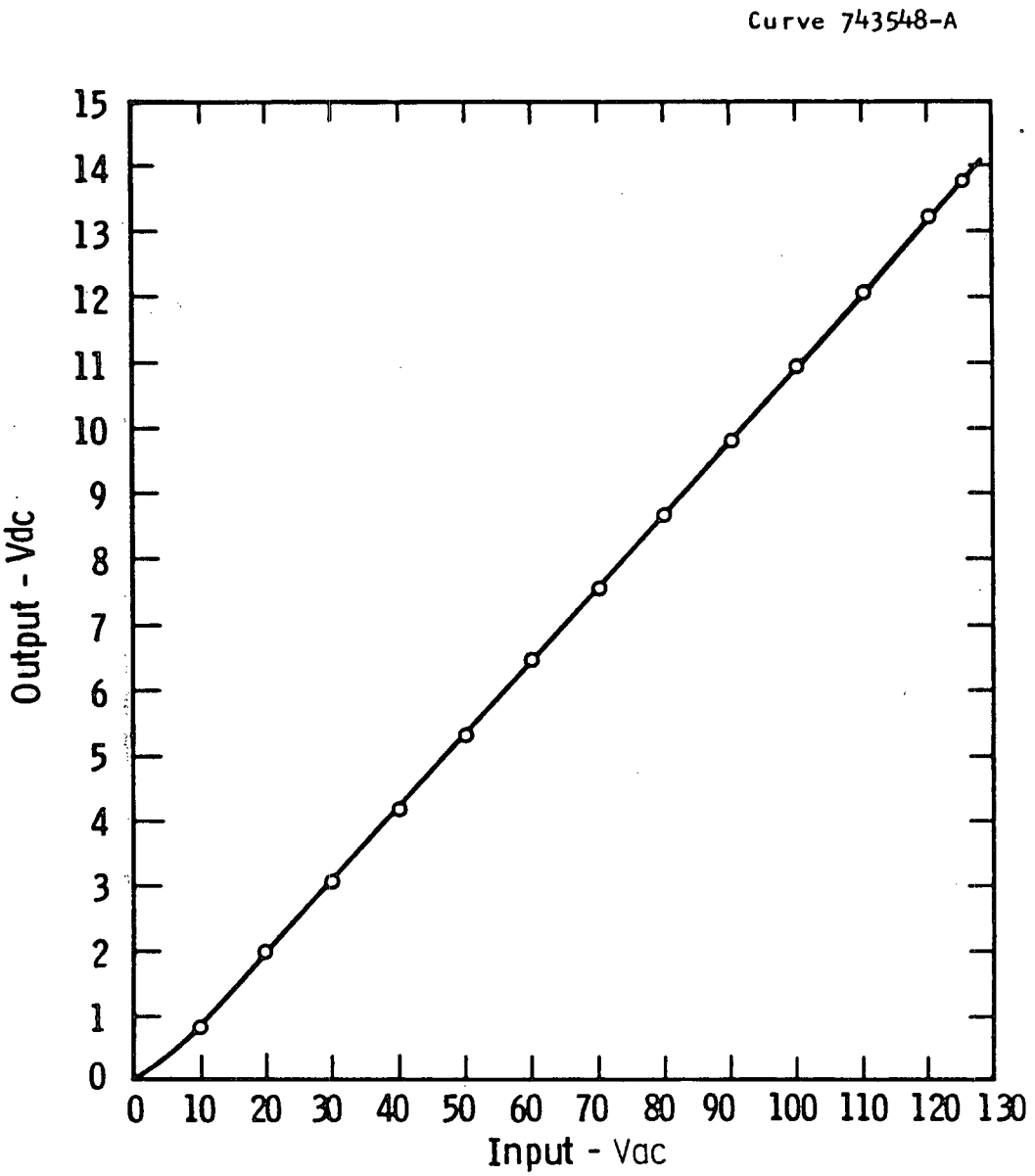

Fig. A-8 UPS voltage instrument rectifier calibration

B. APPENDIX B — DATA PROCESSING

B.1 DATA ACQUISITION HARDWARE

The on-site data acquisition system used a Hewlett-Packard model 3054DL data logger to scan data channels, measure voltages, etc., and linearize data and then record selected scans on a Quantex dual drive cassette tape recorder. A signal diagram is shown in Figure 5-1. The HP 3054DL consists of a model 3497A data acquisition/control unit and a model HP85F scientific computer. The HP85F was equipped with an 82937A HP-IB I/O card, 00085-15003 I/O ROM, 82936A ROM drawer, an 82903A 16K memory module and level 3 software which permitted utilization of user developed software.

The 3497A data acquisition/control unit is equipped with a 5-1/2 digit autoranging digital voltmeter with four ranges, 0.1 V, 1.0 V, 10.0 V and 100.0 V. Resolution ranges from 1 μV in the 0.10 V range to 1 mV in the 100 V range. The 90 day accuracy claimed is +/- .007 percent of the reading +5 counts in the 0.1 V range, +/- .006 percent of the reading +2 counts in the 10 V range and +/- .006 percent of the reading + 1 count in the remaining ranges. The input impedance is $10E^{10}$ Ohms in the lowest three ranges and $10E^{6}$ Ohms +/- 0.5 percent in the 100 V range. The maximum input voltage is 120 V high to low and 170 V low to guard and guard to chassis. The maximum reading rate in 60 Hz operation is 25 per second with auto zero on and 50 per second with auto zero off while displaying 5-1/2 digits. This can increased to 150 per second and 300 per second by displaying 3-1/2 digits.

Four option 020 guarded input relay multiplexer cards with thermocouple compensation were installed in the 3497A chassis. Each card can accept up to 19 channels of mixed dc voltage inputs or type J,

K, G, R, S or T thermocouple inputs. The claimed thermocouple junction compensation accuracy is 0.1°C.

A model 3498 extender chassis was added to accommodate nine 44426A 100 kHz reciprocal counter assemblies used to total the relay closures on the Watt/Watt-hour transducers and monitor compressor running time. These modules can also serve as totalizers, counting up to $10E^6$; can count down from a programmable start point, measure the period of input signals up to 100 kHz, measure the pulse width of input signals of 18 seconds duration or greater or output a specified number of square wave pulses (0 to 499999) at a specified frequency (0 to 1 kHz). The modules can be programmed to send an interrupt signal to the 3497A for overflow or measurement complete conditions.

The HP85F computer, 3497A data acquisition/control unit and 3498 extender chassis communicated via the HP-IB interface, Hewlett-Packard's version of the IEEE 488 interface.

The 3497A scanned continuously and software within the HP85F selected the scans to be recorded. Normally this data was directed to a Quantex Model 1000 dual drive cassette recorder via an RS232 port. When the tapes of the Quantex recorder were being read out, the data was temporarily stored on the on-board cassette drive on the HP85F and was automatically transferred to the Quantex tape drive when it was available.

The Quantex recorder uses standard high-density dual-track data cassettes with a tape length of 140 ft and capacity of about 210K bytes. When track 1 of the active drive was filled the unit switched to track 2 automatically. When the tape was full the unit switched to the second drive. All of the recorder functions could be controlled from the keyboard on the front of the unit or remotely via an RS232 interface. The output RS232 port of the Quantex tape unit was interfaced with a Racal-Vadic Model VA3455 full duplex modem operating at 1200 baud. An

independent telephone line was installed to service the modem. The operation of the data system could be monitored by telephone from any compatible terminal-modem combination.

Data stored on the cassettes was recovered via telephone from the R&D Center. Commands from a terminal switched the output of the data system to the onboard tape drive on the HP85F computer. Next commands were sent to put a file mark on the cassette tape and rewind the drive. The Quantex unit was then remotely commanded to switch to the tape drive and track where recording was initiated. The telephone modem at the R&D Center was connected to a Gandalf LDS-125 modem via a "Y" cable. The Gandalf modem was hard wired to a Digital Equipment Corporation PDP-11 Computer in the R&D Center computer room. The Gandalf modem was switched on and the command to read the stored data was sent to the Quantex unit by the terminal. As the data was received it was transferred to hard disc via the PDP-11 computer. When the data transmission was complete the Gandalf modem was switched off and the Quantex tape recorder was commanded to rewind via the terminal. When the tape was rewound, a commmand was given from the terminal to enable output from the data system to be routed to the tape recorder. Data stored on the onboard cassette drive of the HP85F was then automatically transferred to the Quantex tape recorder at that time.

B.2 HARDWARE INSTALLATION

The data acquisition system and much of the instrumentation package was housed in a standard rack panel cabinet 24 inches wide, 32 inches deep and 66 inches high. The upper section of the cabinet is shown in Figure 5.2.

The Racal-Vadic VA3455 modem was on top of the cabinet. The items mounted in the cabinet were, from top to bottom:

1. Texas Electronics BPC-300 rack mount weather instrumentation board chassis.

2. MKS Instruments PDR-D-1 power supply/readout for the 223BH-C-1 CMH20 capacitance manometer.
3. Hewlett-Packard 3498 extender chassis.
4. Hewlett-Packard 3497A data acquisition/control unit.
5. Hewlett-Packard HP85F scientific computer.

Figure 5.3 shows the lower portion of the cabinet. The components mounted were, from top to bottom:

6. Data cassette rack.
7. Quantex model 1000 dual drive cassette recorder.
8. Trans-Air model B25A cooling blower.
9. Elgar static bypass switch.
10. Elgar model UPS-172-1 uninterruptable power supply.

The Elgar uninterruptable power supply (UPS) provided 120 Vac 60 Hz power to the data acquisition system, tape recorder, dc power supplies, modem, cooling blower, weather station electronics and the return and supply air relative humidity systems.

The UPS used a static inverter to generate 120 V 60 Hz ac power from 96 Vdc provided by seven Motorcraft type MFR24 maintenance free automotive batteries wired in series. When ac power was available from the line the UPS simultaneously charged the batteries. The maximum output of the UPS is 1.75 kVA and power was sufficient for about five hours of operation during a power failure. In the event of an inverter failure, the static bypass switch would transfer the load directly to ac line power. No inverter failures were experienced during the test period.

The batteries were mounted in a rectangular polyethylene tank beneath a workbench in the integral garage adjacent to the utility room. A polyethylene cover prevented accidental contact with the batteries and was vented to prevent a buildup of hydrogen gas. Contact closures on

the static bypass switch indicated a loss of ac line power. As noted previously, these contacts were monitored by the data acquisition system.

B.3 DATA CHANNELS AND CONVERSION FACTORS

In final configuration the data system recorded 73 channels of analog data and nine channels of digital (counter) data. Analog channels 0-18 were thermocouple inputs and the conversions from millivolt readings to Fahrenheit temperatures were performed by software in the HP85F computer on site. The remaining analog channels were dc voltages converted from analog to digital form by the HP3497A data logger. This unit is autoranging and voltages less than 0.5 Vdc were displayed in millivolt form.

Thermocouple Data

The thermocouple channels are identified in Table B.1. Channels A19, A39, A59 and A79 were voltage readings indicating the temperatures of the four isothermal blocks associated with each of the 20 channel thermocouple compensated relay multiplier assemblies installed in the HP3947A chassis. The voltage readings were converted to temperatures by:

$$T_{ib} = 32.0 + 18.0\ V \qquad (B.1)$$

where T_{ib} = Isothermal block temperature - °F
V = Voltage reading

Weather Station Data

Channels A20 through A25 were the outputs from the Texas Electronics weather station. Each output was a 0-10 Vdc signal. Channel A20 was wind direction and was given by:

$$D_w = 36.0\ V(20) \qquad (B.2)$$

Table B.1 — Thermocouple Channels

A0		Outdoor coil inlet refrigerant (heating mode)
A1		Outdoor coil outlet refrigerant (heating mode)
A2		Outdoor fan motor case
A3		Compressor suction refrigerant
A4		Compressor discharge refrigerant
A5		Indoor coil inlet refrigerant (heating mode)
A6		Indoor coil outlet refrigerant (heating mode)
A7		Expansion valve inlet refrigerant (heating mode)
A8		Expansion valve outlet refrigerant (heating mode)
A9		Accumulator outlet refrigerant
A10		Oil cooler inlet oil (heating mode)
A11		Oil cooler outlet oil (heating mode)
A12		Compressor hermetic can bottom
A13	(1)	Compressor high temperature cutout switch
A13	(2)	Outdoor ambient air near outdoor unit
A14	(3)	Utility room air
A15	(4)	Outdoor ambient air 6 ft. from unit at outdoor coil level with "pagoda" radiation shield
A16	(5)	Return air
A17	(5)	Supply air - duct branch toward family room
A18	(5)	Supply air - duct branch toward garage

(1) Prior to September 15, 1983
(2) After September 15, 1983
(3) Installed March 24, 1983
(4) Installed October 19, 1983
(5) Installed December 6, 1983

where: D_w = Wind direction - degrees from North
V(20) = Voltage reading channel A20

Channel A21 was the wind velocity given by:

$$V_w = 10.0\ V(21) \tag{B.3}$$

where: V_w = Wind velocity - miles/hr
V(21) = Voltage reading channel A21

Channel A22 was the relative humidity. When the unit was functioning properly it was given by:

$$Rh = 10.0\ V(22) \tag{B.4}$$

where: Rh = Relative humidity - %
V(22) = Voltage reading channel A22

Operation of the unit was erratic and the data obtained is not considered reliable.

Channel A23 was the integrated precipitation and was given by:

$$P = 0.1\ V(23) \tag{B.5}$$

where: P = Integrated precipitation - inches
V(23) = Voltage reading channel A23

The rainfall was accumulated in increments of 0.01 inches. When a total of 1.0 inches was reached (10 volts) the integrating circuit automatically reset to zero volts. The raingage did not operate properly until June 21, 1983 due to failure of a circuit board and a defective cable connecting the weather station output to the data system.

The ambient temperature was indicated by Channel A24. The voltage reading was converted to a Fahrenheit temperature by:

$$T_{amb} = -40.0 + 16.0\ V(24) \tag{B.6}$$

where: T_{amb} = Ambient temperature - °F
$V(24)$ = Voltage reading channel A24

The intensity of solar radiation was indicated by Channel A25. The conversion from voltage to engineering units was:

$$S = 44.2\ V(25) \tag{B.7}$$

where: S = Solar radiation - Btu/hr-ft^2
$V(25)$ = Voltage reading channel A25

Channels A26 and A27 were the analog outputs from the Hygrometrix relative humidity sensors located in the return air duct and supply air duct. Calibration in our environmental test facility gave:

$$R_{hr} = -7.5339 + 20.1733\ V(26) \tag{B.8}$$

$$R_{hs} = -3.8314 + 20.1444\ V(27) \tag{B.9}$$

where: R_{hr} = Return air relative humidity - %
$V(26)$ = Voltage reading - Channel A26
R_{hs} = Supply air relative humidity - %
$V(27)$ = Voltage reading channel A27

Note that both sensors exhibited a slope within 1% of the 20% per volt claimed by the manufacturer, but an intercept significantly less than zero.

Refrigerant Pressures

Channels A28 through A34 were the outputs from the five refrigerant pressure transducers, the atmospheric pressure sensor and the capacitance manometer used to determine the air flow in the return duct. The refrigerant pressures were given by:

$$P_{oco} = 12.85070 + 5097.87\ V(28) \tag{B.10}$$

$$P_{oic} = 7.58197 + 5051.23\ V(29) \tag{B.11}$$

$$P_{ico} = 16.68144 + 5115.27\ V(30) \tag{B.12}$$

$$P_{ci} = 17.57253 + 2590.18\ V(31) \tag{B.13}$$

$$P_{cx} = 13.786399 + 5075.75\ V(32) \tag{B.14}$$

where: P_{oco} = Outdoor coil outlet pressure (heating) - psia
$V(28)$ = Voltage reading channel A28
P_{oci} = Outdoor coil inlet pressure (heating) - psia
$V(29)$ = Voltage reading channel A29
P_{ico} = Indoor coil outlet pressure (heating) - psia
$V(30)$ = Voltage reading channel A30
P_{ci} = Compressor inlet pressure - psia
$V(31)$ = Voltage reading channel A31
P_{cx} = Compressor exit pressure - psia
$V(32)$ = Voltage reading channel A32

Note that in cooling and defrost operation the direction of refrigerant flow through the refrigerant heat exchangers was reversed and channel A28 became the outdoor coil inlet, A29 became the outdoor coil outlet and A30 became indoor coil inlet.

Air Pressure

The barometric pressure in the utility room was given by:

$$P_{bar} = -4.2366 + 10.6102\ V(33) \tag{B.15}$$

where: P_{bar} = Barometric pressure - psia
$V(33)$ = Voltage reading channel A33

The air flow in the return duct was a function of the pressure drop across the air flow sensor and the return air density:

$$Q_a = (710.4106 + 95.4428\ V(34))^{*}SQR(V(34)/Rho_a) \tag{B.16}$$

where: Q_a = Air flow rate - cfm
Rho_a = Air density - lbm/ft^3
$V(34)$ = Voltage reading channel A34

The air density could be calculated from perfect gas relationships with sufficient accuracy:

$$Rho_a = 144.0\ P_{bar}/(53.35\ (T_{ra} + 459.69)) \tag{B.17}$$

where: T_{ra} = Return air temperature - °F

It was found to be necessary to apply a correction to the air flow as calculated by equation (B.16). This correction is discussed in Appendix EA.

Energy Consumption

Channels A35 through A38 and A40 through A42 were the analog outputs of the Watt transducers. The instantaneous powers and voltage outputs were related by:

$$W_{fa} = 200.0\ V(35) \tag{B.18}$$

$$W_{bm} = 400.0\ V(36) \quad (B.19)$$
$$W_{ba} = 400.0\ V(37) \quad (B.20)$$
$$W_{c} = 8000.0\ V(38) \quad (B.21)$$
$$W_{fm} = 200.0\ V(40) \quad (B.22)$$
$$W_{hp} = -18.810 + 9633.117\ V(41) \quad (B.23)$$
$$W_{rh} = -21.448 + 38997.17\ V(42) \quad (B.24)$$
$$W_{wh} = 40000.0\ V(43) \quad (B.25)$$

where: W_{fa} = Power-fan auxiliary winding - Watts
W_{bm} = Power-blower main winding - Watts
W_{ba} = Power-blower auxiliary winding - Watts
W_{c} = Power-compressor - Watts
W_{fm} = Power-fan main winding - Watts
W_{hp} = Power-heat pump (no I_2R) - Watts
W_{rh} = Power-resistance heat - Watts
W_{wh} = Power-whole house - Watts

Transducer Voltage

Channel A44 monitored the voltage delivered by the Viz WP-703A regulated dc power supply to the five refrigerant pressure transducers. The outputs of the transducers were a function of the supply voltage and they were calibrated with a supply voltage of 10.0 Vdc. The power supply voltage was well regulated and we did not observed any variations in voltage beyond the 7 mV tolerance claimed by the manufacturer.

Relay Status

Channels A45 through A58 and Channel A71 monitored the status of the relays on the microprocessor circuit board which activated the control relays in the heat pump control box. The functions which these relays controlled are described in Table B.2. The voltage drop across one pair of contacts of each relay was measured. Therefore, when the contacts were open a high voltage, typically 22 to 24 Vdc, was observed and when the contacts were closed a low voltage, typically 1.0 to 2.5 Vdc, representing the drop due to contact resistance was indicated.

Table B.2 — Control Relays

Channel	Function
A45	Reversing valve
A46	Auxiliary heat - stage 2 (10 kW)
A47	Outdoor fan motor trickle heat
A48	"Deadman" circuit (self booting)
A49	Reverse outdoor fan
A50	High-speed outdoor fan
A51	Auxiliary heat - stage 3 (15 kW)
A52	Full coil solenoid
A53	Low-speed outdoor fan
A54	Compressor
A55	Low-speed indoor blower
A56	High-speed indoor blower
A57	High compressor capacity
A58	Auxiliary heat - stage 1 (5 kW)
A71*	Auxiliary heat - stage 1 (5 kW)

* Redundant reading added October 26, 1983

In October of 1983 the data reduction program began to indicate that the first stage of resistance heat was being enabled at times when the heat pump was not running and the ambient temperature was well above the point at which resistance heat should be enabled. Further investigation showed that the voltage readings on Channel A58 were intermittently erroneous. This appeared to be the result of some malfunction of the data logging system. On October 26, 1983 a second set of voltage leads was connected from the external terminal strip on the microprocessor box to Channel A71 on the data logger to give a redundant reading of the state of the first stage resistance heat relay. Later intermittent incorrect readings were observed on several channels and the data logger was removed from service for repair on May 20, 1984 and replaced by a rental unit. Hewlett-Packard repair service was initially unable to find the problem, but when they were informed that the problem coincided with high temperatures in the utility room, they tested the unit in an environmental chamber at its maximum rated operating temperature. The problem was then found to be defective ranging resistors. The unit was returned to service on June 6, 1984 and operated properly for the remainder of the test. Earlier data was recovered by altering the data reduction software to interpret a voltage above 4.5 Vdc as indicating an open relay rather than the 13.5 Vdc used previously.

RTD Measurements

Channels A60 and A61 are the voltages across a 20,000 ohm precision resistor in series with the return air RTD and the voltage across the return air RTD respectively. The resistance of the RTD element is given by:

$$\Theta_{ra} = 20{,}000\ V(61)/V(60) \qquad (B.26)$$

where: Θ_{ra} = Resistance of the return air RTD - Ohms
V(61) = Voltage reading channel A61
V(60) = Voltage reading channel A60

The RTD's installed originally were calibrated at the Westinghouse R&D Center Standards Laboratory according to Standard IPTS-68. The resistance reading can be converted to an accurate first estimate of the temperature by:

$$T'_{rtd} = (-A + SQR(A^2+4B(0_{rtd}/0_{ro})-1)))/2B \qquad (B.27)$$

where: T'_{rtd} = First estimate of temperature - °C
A = Calibration constant
B = Calibration constant
0_{rtd} = Resistance measured - Ohms
0_{ro} = Resistance at 0°C - Ohms

The actual temperature is calculated from the first estimate by:

$$T_{rtd} = T'_{rtd} + 0.045\ (T'_{rtd}/100)\ (T'_{rtd}/100 - 1.0)\ (T'_{td}/419.58 - 1.0)\ (T'_{rtd}/630.74 - 1.0) \qquad (B.28)$$

where: T_{rtd} = Resistance thermometer temperature - °C

Note that the difference between T'_{rtd} and T_{rtd} is quite small, less than 0.01°C at 30°C, and equation B-27 is sufficiently accurate for most purposes. For the return air RTD installed initially:

0_{ro} = 100.1114 Ohms
A = 4.021269×10^{-3}
B = -2.561330×10^{-6}

On January 13, 1984 RTD's with a much shorter time constant were installed. These RTD's were calibrated in the Environmental Test Facility so that they could be installed at the earliest possible date.

For the return air RTD installed on Jan. 13, 1984:

0_{ro} = 100.0 Ohms
A = 4.118589×10^{-3}
B = -5.371320×10^{-6}

The correction of Equation B-28 should not be applied.

Channels A62 and A63 are the voltages across a 20,000 Ohm precision resistor in series with the supply air RTD and the supply air RTD, respectively. The resistance is given by:

$$0_{sa} = 20{,}000\ V(63)/V(62) \qquad (B.29)$$

where: 0_{sa} = Resistance of the supply air RTD - Ohms

V(63) = Voltage reading channel A63
V(62) = Voltage reading channel A62

Prior to Jan. 13, 1984 the temperature can be calculated from equation B.27 and B.28 using:

0_{ro} = 100.1864
A = 4.006320×10^{-3}
B = -2.512254×10^{-6}

Beginning January 13, 1983 the temperature can be calculated from equation B.27 using:

0_{ro} = 100.0 Ohms
A = 3.940041×10^{-3}
B = -1.341973×10^{-6}

Line Voltage

Channels A64 and A65 are the outputs of the instrument rectifier circuits monitoring the heat pump line voltage and the voltage output of the uninterruptible power supply (UPS). The ac voltages are related to the dc voltages monitored by:

$$V_{hp} = 50.359645 + 12.414081\ V(64) + 0.415237940\ V(64)^2 \quad (B.30)$$

$$V_{ups} = 7.1202044 + 8.1494712\ V(65) + 0.030137686\ V(65)^2 \quad (B.31)$$

where: V_{hp} = Heat pump line voltage
V_{ups} = UPS output voltage
$V(64)$ = Voltage reading channel A64
$V(65)$ = Voltage reading channel A65

UPS Status

Channels A66, A67 and A68 monitor the status of the UPS. A reading of less than 10 Volts indicates that the relay is open. If A66 reads more than 10 Vdc the ac power has been interrupted and the unit is operating on battery power. If A67 reads more than 10 Vdc the battery voltage is low and the unit cannot operate on battery power if required. This indicates that the batteries are discharged due to prolonged operation on battery power, failure of the charging circuit or inability of one or more batteries to hold a charge. If A68 reads more than 10 Vdc the static inverter has failed and the unit is operating directly on 120 Vac line voltage.

Condensate Collection

Channels A69 and A70 are the outputs from the pressure transducers monitoring the water level in the small and large condensate receivers. The large condensate receiver was installed on Sept. 9, 1983. The weights of condensate in the receivers is related to the transducer output voltages by:

$$W_{cs} = 0.00220462\ (80 + 298.1818\ V(69)) \tag{B.32}$$

$$W_{cl} = 2.20462\ (-26.05 + 65.98\ V(70)) \tag{B.33}$$

where: W_{cs} = Condensate weight - small receiver - lb
W_{cl} = Condensate weight - large receiver - lb
V(69) = Voltage reading channel A69
V(70) = Voltage reading channel A70

Digital Channels

The first eight digital channels D10 through D17 record the number of contact closures of the Watt-hour transducers. Table B.3 identifies the channels and multiplying factors. Channel D18 accumulates the number of seconds of compressor run time and became operational on January 17, 1983. When any of the counters exceed 999,999 the HP85F resets all of the counters to zero and inserts a series of "% R" strings in the data stream.

B.4 DATA REDUCTION

Inputs and Outputs

The programs for data reduction accepted as input files of data which had been collected from the HP-3054DL datalogger installed at the heat pump field test site. This data contained a large amount of time-resolved data on the operation of the heat pump and the ambient conditions, generally classified as follows:

(1) Ambient conditions, to include ambient temperature, wind, solar flux, and other meteorological variables;

(2) Heat pump operating conditions, being several pressures and temperatures within the heat pump refrigeration circuit;

Table B.3 — Watt-Hour Meters

Channel	Function	Multiplying Factor*
D10	Outdoor fan auxiliary winding	1.0
D11	Indoor blower main winding	1.0
D12	Indoor blower auxiliary winding	1.0
D13	Compressor	40.0
D14	Outdoor fan main winding	1.0
D15	Heat pump - excluding I^2R	9.63
D16	Auxiliary (I^2R) heat	39.0
D17	Whole house	40.0

*The product of the multiplying factor and the channel reading equals the Watt-hours accumulated.

(3) Energy consumption data, comprising Watt and Watt-hour measurements of the electrical energy used by the various components of the heat pump;

(4) Calorimetric data, consisting of measurements of air flow rate, air temperature, relative humidity, and condensate extracted (cooling operation only);

(5) Heat pump state data, consisting of measurements of control relay states and selected Wattmeters;

(6) UPS state, consisting of the positions of various relays in the static bypass switch;

(7) The date and time of each scan of data

Output from the data reduction program is given in Section 6 and Appendix FA. This output consists of summary tables of heat delivered and energy consumed as functions of ambient conditions and system operating mode, as well as the number of operating cycles as summarized for each season. The output also includes an abbreviated summary of daily heating and cooling data.

Heat Delivered

The heat delivered - in heating mode - is determined by

$$Q = Mdot \times C_p \times \Delta T \qquad (B.34)$$

where Mdot is the mass flow rate, C_p is the specific heat of the air, and ΔT is the temperature change of the air across the heat pump.

The basic technique used RTD's (resistance temperature detectors) to measure the air temperature and a specialized air flow pitot-static sensor marketed by the Dietrich-Standard company, called an "Annubar". The RTD voltages were recorded as often as possible, as were the Annubar readings. Calibration of the instruments was intended to allow reduction of the data with the greatest possible accuracy.

Cooling Delivered

In cooling, the removal of heat from the air flow is manifested in two ways: as a reduction in the temperature of the air ("sensible cooling"), and as a reduction in the humidity of the air ("latent cooling"). The sensible cooling is measured in the same way as is the heat delivered - as the product of the mass flow rate, air specific heat, and the temperature change of the air stream.

Latent cooling is measured by measuring the removal of humidity from the air stream. While an attempt was made to measure this humidity change indirectly by measuring the change of relative humidity of the air stream, the more direct means of simply weighing the condensate that

was draining from the refrigerant evaporator was found to be far superior, both operationally and conceptually. Operationally, the measurement of cumulative condensate in a receiver is inherently an integrating method, with the freedom from noise effects implicit in such a method; conceptually, since the total cooling delivered rather than instantaneous cooling rate is of interest, the inherently totalizing nature of the condensate measurement technique is to be preferred.

Energy Consumed

The electrical energy used by the several components of the heat pump was measured by eight Watt and Watt-hour meters. These meters measured the following loads: the whole house, the entire heat pump (exclusive of the resistance heaters), the resistance heaters, the compressor, and the main and the auxiliary windings for both the indoor and the outdoor air movers. Much like the measurement of latent heat removal by accumulated condensate, the integral nature of the Watt-hour measurements was preferred for superior noise immunity and accuracy. The superiority of the use of Watt-hours was particularly evident in the determination of crankcase heater and control power. Since the crankcase heater and control power is not directly measured, it must be determined by taking the difference between the total heat pump system power and the sum of the measured powers of the compressor and the air movers. Since this difference is a small fraction of either term, small errors in the instantaneous measurement can lead to large errors in the integrated difference. However, use of the difference of Watt-hour readings leads to quite reasonable (and verifiable) results.

Method of Mode Determination

The mode of operation of the heat pump is the type of operation it is performing; in particular, 20 modes of operation were identified for purposes of the energy analysis, as follows:

Mode 1 - Power off, no trickle heat to outdoor air mover;

Mode 2 - Power off, trickle heat to outdoor air mover;

Mode 3 - Compressor off, outdoor air mover on prior to start of heating or cooling;
Mode 4 - Low capacity heating;
Mode 5 - High capacity heating, no resistance heat;
Mode 6 - High capacity heating, 1 stage resistance heat;
Mode 7 - High capacity heating, 2 stages resistance heat;
Mode 8 - High capacity heating, 3 stages resistance heat;
Mode 9 - High capacity heating, 4 stages resistance heat;
Mode 10 - Blower on low after compressor stop, heating; (inactive)
Mode 11 - Blower on high after compressor stop, heating;
Mode 12 - Defrost, outdoor fan off;
Mode 13 - Defrost, outdoor fan reversed;
Mode 14 - Low capacity cooling;
Mode 15 - High capacity cooling;
Mode 16 - Blower on high after compressor stop, cooling;
Mode 17 - Emergency heat mode, off;
Mode 18 - Blower on, prior to emergency heat;
Mode 19 - Emergency heat mode, on;
Mode 20 - Power failure.

The modes of operation were monitored by monitoring the 14 control relays and certain selected Wattmeters. The combinations of relays corresponding to each state were tabulated in a special subprogram, which scanned the data in each scan, deciding which mode of operation was represented by that scan. If a combination of relays and/or Wattmeter readings was impossible, the mode was assumed to be the same as the mode represented by the previous scan.

Temperature Bin

The "bin analysis" of heat pump performance characterization begins by creating "bins" of temperature, each identifying a band of ambient temperature spanning 5°F, between -25°F and 100°F. The energy delivered to or from the conditioned space, and the energy consumed by the heat pump, are separately accumulated for each bin. A separate bin

analysis is performed for heating and for cooling, and, since the heat pump is a multi-capacity machine, a separate bin analysis is performed for each operating capacity as well. The bin analysis must accumulate all of the energy, and ascribe it to the proper mode of operation. A particular problem arises with the "off" modes of the heat pump. Since the unit is off, there is no way to know if heating or cooling will occur on the next cycle. Since the microprocessor control and crankcase heater use significant amounts of power, even when the heat pump is nominally off, it is important to properly ascribe energy used in the "off" states to heating or cooling. In order to do this, the following logic was adopted: if the ambient temperature was below 45°F, heating was assumed; if the ambient temperature was above 60°F, cooling was assumed; in the range 45°F to 60°F, the mode assumed was the most immediately preceeding active mode. In the case of mode 3 - outdoor air mover on prior to compressor startup - the energy accumulated during this mode of operation is accumulated and then ascribed to the following mode, be it heating or cooling. This procedure differs from the usual practice of assuming that all heat pump activity with an ambient temperature below 65°F is heating, and all activity above 65°F is cooling. This assumption is particularly invalid with a well-insulated house with a large number of appliances, in which cooling may be required (and was observed) at ambient temperatures as low as 50°F. The data reduction program was written with a large number of default options and data checks, so that obviously invalid data would not be factored into the data reduction algorithms. In general, data deemed to be invalid was replaced with the most immediately preceeding valid value of the same parameter. The sheer mass of data precluded identifying all possible erroneous inputs, nor was it necessary to do so. Since the basic evaluation of data involved integrations of the data with respect to time, the effect of an occasional rogue point would be swamped by the effect of the mass of good points. Of course, for this to work, grossly incorrect data had to be screened, and such screening was performed by the data reduction program.

C. APPENDIX C — TEMPERATURE SENSOR LAG

The theoretical response of a temperature sensor of cylindrical form to a step change in ambient temperature is a simple problem documented in most elementary heat transfer textbooks. If the radial temperature gradient in the sensor is neglected and a simple energy balance is drawn on an element of length unity:

$$c_p \, \rho\pi \, D^2/4 \; dTs = \pi D\bar{h}(T_a - T_s) \; dt \qquad (C.1)$$

where:

c_p = Specific heat of sensor - Btu/lbm - °F

ρ = Density of sensor - lbm/ft^3

D = Sensor diameter - ft

$\bar{h}$ = The average convection coefficient on the sensor surface - Btu/hr-ft^2-°F

T_s = Sensor temperature - °F

T_a = Ambient temperature - °F

dTs = Sensor temperature change during time step dt - °F

dt = Time step - hours

If the ambient temperature suddenly changes from T_o to T_f at time t = 0, the response is given by:

$$(T_s - T_f)/(T_o - T_f) = e^{-t/\alpha_s} \qquad (C.2)$$

where:

$$\alpha_s = C_p \, \rho D/(4\bar{h})$$

The quantity α_s has units of time and is called the time constant. For $t = \alpha_s$:

$$(T - T_f)/(T_o - T_f) = 1/e = 0.368$$

Thus for one time constant, 63% of the ultimate temperature change will occur, for two time constants 86% etc.

For the case of the heat pump field test, the above formulation characterized the return air temperature sensor quite accurately. When the unit was off, the sensor reached the temperature of the utility room, which due to heat from the data system and uninterruptable power supply was normally higher than the temperature in the living space. When the indoor blower came on air was drawn from the living space into the ductwork and the temperature of the air seen by the return air sensor dropped rapidly. In comparison with the time constant of the sensor this could be regarded as a step change in air temperature and Equation (C.2) could be applied directly.

$$(T_{rs} - T_{ra})/(T^*_{rs} - T_{ra}) = e^{-t/\alpha_{rs}} \qquad (C.3)$$

where:

T_{rs} = The temperature of the return air sensor - °F
T_{ra} = The return air temperature - °F
T^*_{rs} = The temperature of the return air sensor at time t = 0 - °F
α_{rs} = The time constant of the return air sensor - hr

The temperature rise of the supply air may not be considered a step function since a finite time is required for the heat pump to reach thermal equilibrium and Equation (C.2) cannot be applied to the supply air sensor. If we assume that the supply air temperature approaches steady state in an exponential manner, an assumption supported by

laboratory test data, then we can express the supply air temperature T_{sa} in terms of t by:

$$(T_{sa} - T_s)/(T^*_{sa} - T_s) = 1 - e^{-t/\alpha_{hp}} \qquad (C.4)$$

where:

T_{sa} = The supply air temperature - °F
T_s = The steady state supply air temperature - °F
T^*_{sa} = The supply air temperature at time t = 0 - °F
α_{hp} = The heat pump time constant - hrs

If we substitute Equation (C.4) into Equation (C.1) we find that the variables are no longer separable and a simple integration of Equation (C.1) is not possible. However, if we write Equation (C.1) in finite difference form and substitute Equation (C.4), numerical integration becomes straightforward.

$$C_p \rho \pi D^2/4 \quad (T'_{ss} - T_{ss}) = \pi D \bar{h} (\bar{T}_{sa} - \bar{T}_{ss}) \Delta t = \dot{q} \qquad (C.5)$$

where:

T_{ss} = The supply air sensor temperature at the start of time step Δt - °F

T'_{ss} = The supply air sensor temperature at the end of time step Δt - °F

$\bar{T}_{sa}$ = The average supply air temperature during time step Δt - °F

$\bar{T}_{ss}$ = The average supply air sensor temperature during time step Δt - °F

$\dot{q}$ = The heat transferred from the air to the sensor during time step Δt - Btu

If we define $\bar{T}_{ss}$ as $(T'_{ss} + T_{ss})/2.0$ then:

$$\bar{T}_{ss} = T_{ss} + 2\dot{q}(\pi C_p \rho D^2) \tag{C.6}$$

substituting (C.6) into (C.5) and solving for q gives:

$$\dot{q} = \pi D \bar{h} \ (\bar{T}_{sa} - T_{ss})\Delta t \ /(1 + 2\bar{h}\Delta t/(C_p \rho D)) \tag{C.7}$$

and

$$T'_{ss} = T_{ss} + 4\dot{q}/(\pi C_p \rho D^2) \tag{C.8}$$

The actual heating or sensible cooling delivered by the heat pump during time step Δt is:

$$Q_{air} = \dot{m}_a \ C_{pa} \ (\bar{T}_{sa} - \bar{T}_{ra})\Delta t \tag{C.9}$$

where:

Q_{air} = actual heating or sensible cooling during time step Δt - Btu

$\bar{T}_{ra}$ = the average return air temperature during time step Δt - °F

$\dot{m}_a$ = the air mass flow rate - lbm/hr

C_{pa} = the air specific heat - Btu/lbm - °F

The sensible heating or cooling indicated by the sensors during time step Δt is:

$$Q_{rtd} = \dot{m}_a \ C_{pa} \ (\bar{T}_{ss} - \bar{T}_{rs})\Delta t \tag{C.10}$$

where:

Q_{rtd} = the sensible heating and cooling indicated by the sensors during time step Δt - Btu

$\bar{T}_{rs}$ = the average return air sensor temperature during time step Δt - °F

The total sensible heating or cooling delivered can be obtained by using a small value of Δt and summing Q_{air} and Q_{rtd} over the desired time period. The FORTRAN 66 computer program HPTRAN was written to perform this summation. A listing is presented in Appendix CB.

The heat pump time constant α_{hp} was a function of ambient temperature and heat pump operating mode and was determined experimentally. Preprototype number one was operated in a 20 minute on/20 minute off cycle in the environmental test facility and the supply air temperature was monitored with a fast response sensor (a radiation shielded bare copper-constantan thermocouple junction of .010 inch wire) for heating and cooling operation at both capacity levels at several ambient temperatures. A typical supply air temperature history for heating operation is shown in Figure C.1.

Note that due to the heavy insulation on the code test box the air temperature indicated by the supply air sensor tended to remain high during the off cycle. When the blower came on the temperature initially dropped toward the return air temperature before rising toward the steady state supply air temperature.

Assuming that equation (C.4) applied and that T^*_{sa} equaled the return air temperature, the time constants were estimated by calculating the temperatures T_{sa} corresponding to t/α_{hp} = 1.0, 2.0 and 3.0 and finding the times corresponding to these temperatures by inspection of the data. The steady state temperatures T_s were also estimated by inspection of the data. A minimum of four on cycles were completed and α_{hp} values calculated for each on cycle. The most consistent results were obtained for t/α_{hp} = 2.0 and these values were averaged to obtain the results presented in Table C.1.

In the high capacity heating mode tests were conducted at outdoor ambient temperatures of 47, 35, 17, and 0°F. In low capacity heating tests were conducted at 62, 47 and 35°F ambient temperatures.

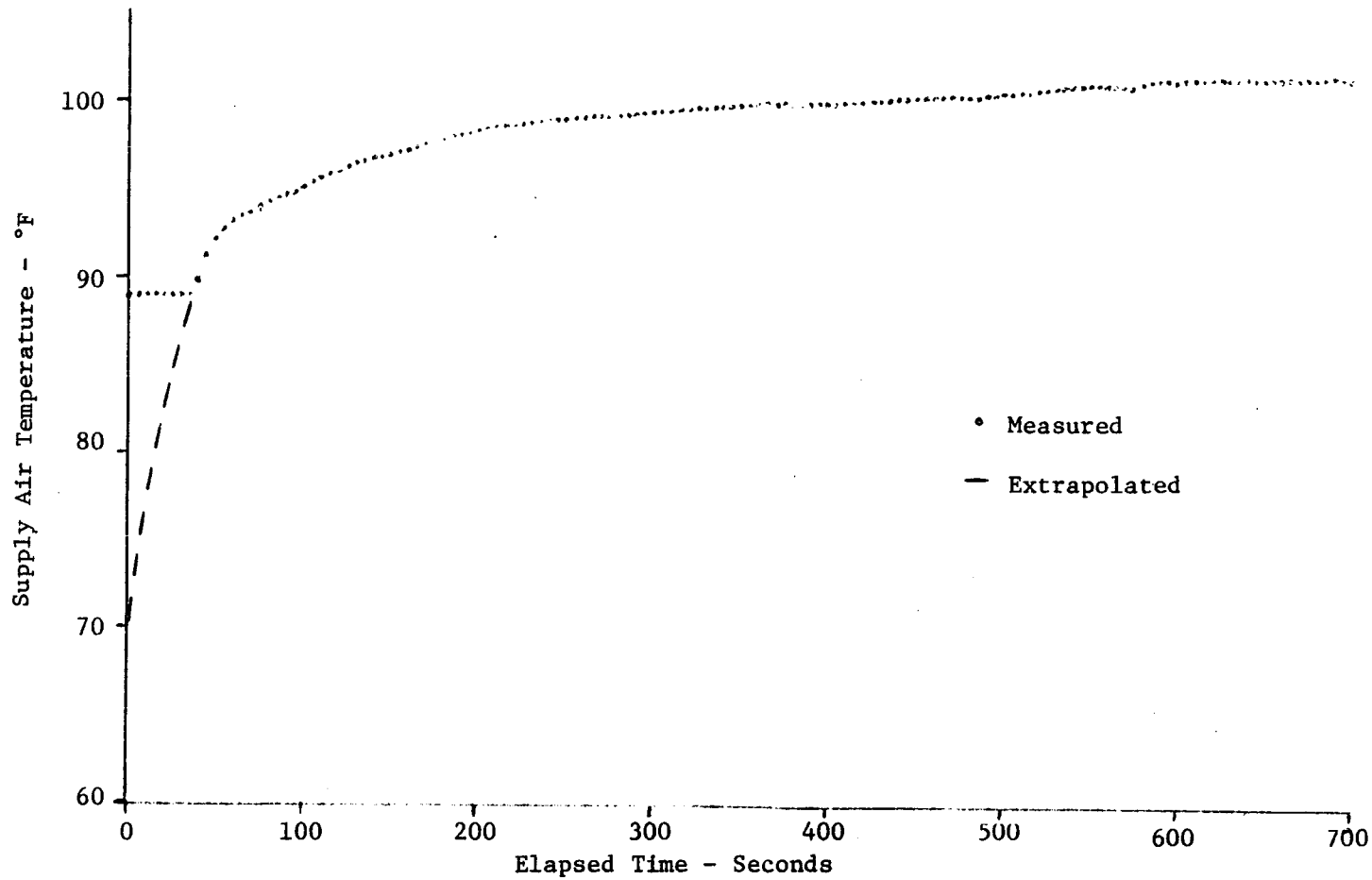

Fig. C-1 - Supply Air Temperature vs Elapsed Time, 47°F High Capacity Heating

Table C.1 — Heat Pump Time Constants in Seconds - Heating Mode

Ambient temperature	62°F	47°F	35°F	17°F	0°F
Low capacity mode	64.5	89.5	101.5	-	-
High capacity mode	-	38.0	75.0	68.0	81.0

Due to the limited resources available testing in the cooling mode was limited to 95°F and 82°F ambient temperatures in high capacity mode and 82°F in low capacity mode.

The heating data generally followed the expected pattern with longer time constants occurring at lower ambient temperatures and in low capacity mode. The calculated time constant in high capacity mode at 35°F was consistently longer than would be expected from extrapolation of the data at other ambient temperatures. This test was repeated six times with consistent results and we have concluded that the affect of moisture on the condenser coil at near freezing temperature resulted in an increase in the time constant.

In the cooling mode the limited data taken indicated that the time constant at 95°F was less than that at 82 F, a rather unexpected result. The measured time constant in low capacity cooling at 82°F was essentially equal to that in high capacity mode at 82°F, also unexpected. In general the time constants in cooling are longer than those in heating, which we would expect due to the indoor location of the oil cooler and compressor. The cooling data exhibited more scatter than the heating data, which may be due to moisture effects. Due to the limited data and the scatter, all of the data points were used in a linear regression analysis to determine the best linear approximation of the results. The function obtained was:

$$\alpha_{hp} = 292 - 2\ T_{amb} \qquad (C.11)$$

where:

α_{hp} = heat pump time constant in cooling mode - sec
T_{amb} = ambient temperature - °F

The average heat transfer coefficient for cross flow over a single cylinder is given in most basic heat transfer texts.

$$\bar{h}D/K_f = C\ (V_s D/\upsilon_f)^n \qquad (C.12)$$

where:

K_f = fluid thermal conductivity - Btu/hr-ft - °F
V_s = free stream fluid velocity - ft/hr
υ_f = fluid kinematic viscosity - ft^2/hr

The constant term C and exponent n are a function of the Reynolds number $V_s D/\upsilon_f$. Hilpert's[15] results give the relationship shown in Table C.2.

Table C.2 — Parameters for Average Heat Transfer Coefficient Correlation for a Cylinder

$V_s D/\upsilon_f$	C	n
0.4 - 4.0	.891	0.330
4.0 - 40.0	.821	0.385
40.0 - 4000.0	.615	0.466
4000.0 - 40000.0	.174	0.618
40000.0 - 400000.0	.0239	0.805

The velocity V_s was estimated by matching the system resistance of the sampling tube to the characteristics of the fan, shown in Figure C.2.

It was assumed that the sudden contraction and expansion of the air entering the sampling tubes was the dominant pressure drop. For a

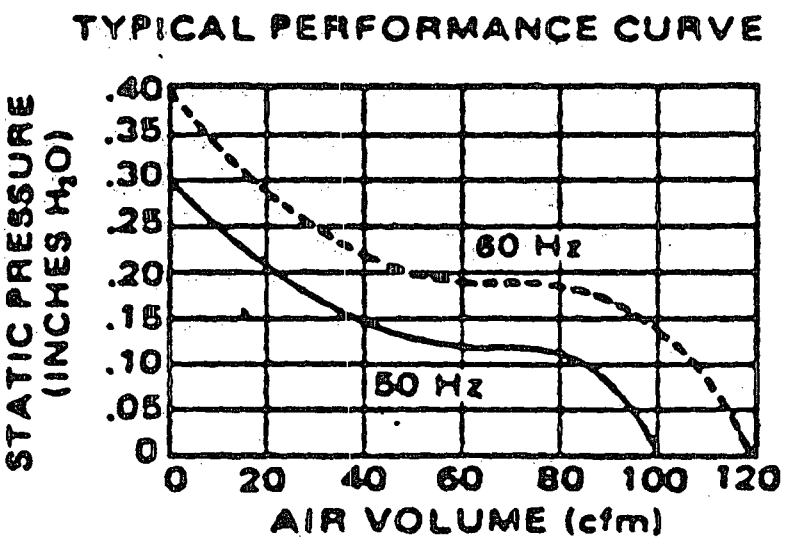

Figure C.2 — Sampling Fan Characteristics

sudden contraction from a large reservoir into a sharp edged opening is given by Streeter[16] as:

$$\Delta P_c = 0.5\ \rho_a V_o^2/(2g_c) \qquad (C.13)$$

where:

ΔP_c = contraction pressure drop - lbf/ft^3
ρ_a = air density - lbm/ft_3
V_o = air velocity in the opening - ft/sec
g_c = gravitational acceleration constant - 32.2 ft-lbm/(lbf-sec^2)

For a sudden expansion Streeter[16] gives:

$$\Delta P_E = (1-A_o/A_t)^2(\rho_a V_o^2/(2g_c)) \qquad (C.14)$$

where:

ΔP_E = expansion pressure drop - lbf/ft^2
A_o = flow area of openings - ft^2
A_t = flow area of sampling tube - ft^2

Combining (C.13) and (C.14) gives

$$\Delta P_T = \Delta P_c + \Delta P_E = (0.5+(1-A_o/A_t)^2)\ \rho_a V_o^2/(2g_c) \qquad (C.15)$$

The sampling tubes had a nominal internal diameter of 1.5 inches. The return air sampling tube was installed with 12 holes 0.1875 inches in diameter and the supply air tube was installed with 8 holes 0.1875 inches in diameter.

The velocity in the opening was estimated iteratively by selecting a value of ΔP_T from the fan curve of Figure C.2, solving Equation (C.15) for V_o, calculating the air flow from the product $A_o V_o$ and comparing it to the value corresponding to the assumed ΔP_T from

Figure C.2. Using this method the air velocity in the return air sampling tube ($V_t = A_t V_o / A_o$) was found to be approximately 7 ft/sec for the return air sampling tube and 5 ft/sec for the supply air sampling tube.

The pressure drops associated with wall friction and bends in the sampling fan inlet and the sudden expansion from the fan outlet into the duct were calculated and the assumption that the sudden contraction and expansion associated with the sampling holes is the dominant pressure drop was verified.

Substitution of the calculated velocities into Equation C.12 with a sensor diameter of 0.25 inches gave convection coefficients of 10.6 Btu/hr-ft^2-°F for the return air sensor and 9.1 Btu/hr-ft^2 for the supply air sensor. The RTD's installed initially were encased in a stainless steel sheath and using the density and specific heat for stainless steel in Equation C.2 gives time constants of 95 seconds for the return air RTD and 111 seconds for the supply air RTD.

On Jan. 13, 1983 the original RTD's were replaced with units with a significantly shorter time constant. These model S200 elements, manufactured by Minco Products Inc., were a glass coated ceramic cylinder with a diameter of 0.040 inches and a length of 0.45 inches. The manufacturer claims a time constant of 6 seconds in air at 3 ft/sec. However, to mount these elements a supporting structure was required. A stiff wire with a diameter of about 0.020 inches was soldered into the end of a piece of rigid 0.25 inch diameter thin wall brass tubing. The RTD elements were attached to the wire with cotton thread and a small amount of epoxy glue used to bond the assembly. We estimate that the time constant for the complete assembly was on the order of 18 seconds, roughly an order of magnitude less than the original RTD's.

Tables C.3 and C.4 show typical results from the HPTRAN computer program. The sample output is for the original RTD's at an ambient temperature of 35°F and the heat pump operating in the high capacity heating mode. The return air RTD was assumed to be initially at 80°F and the supply air RTD initially at 83°F. This is representative of the temperatures observed in the utility room with the heat pump off during the heating season. The return air sensor, located at about waist level, was typically cooler than the supply air sensor near the ceiling.

Note in Table C.3 that during the first few seconds of operation the temperature indicated by the supply air RTD, TRTDS, is higher than the actual supply air temperature TAIR and the heat calculated from the RTD readings, QRTD, is higher than the actual heat delivered QAIR. However, this situation reverses rapidly and after 43 seconds the supply air RTD indicates a temperature less than the actual temperature. After 43 seconds of operation the ratio of measured integrated heat delivered to actual integrated heat delivered is 0.58 and the ratio of measured instantaneous heat delivered to actual heat delivered is 0.41. Due to the uncertainty of the actual heat pump on time the first few seconds of operation are largely of academic interest. A conservative approach was used and the correction factor applied to the first data scan in which heat pump operation was observed corresponded to the maximum possible on time of 140 seconds.

Table C.4 shows that for these operating parameters the ratio of instantaneous measured capacity to actual instantaneous heat delivered was 0.60 at 140 seconds on time. Note that in the data reduction program the integration was performed internally and only the instantaneous correction was applied. After two scans, 280 seconds, the instantaneous correction was about 15% and by the third scan about 5%.

For the new RTD's and the same operating parameters (see Table C.5) the capacity for the first scan is augmented by less than 6%, and the augmentation for subsequent scans is negligible. Clearly the RTD

Table C-3 - 35°F High Capacity Heat - Original RTD's

AIR FLOW RATE	1500.00	SCFM
INLET AIR TEMP	70.00	DEG F
FINAL EXIT AIR TEMP	95.00	DEG F
HEAT PUMP TIME CONSTANT	0.02083	HOURS
DIAMETER OF RTD	0.25000	INCHES
RETURN RTD COEFFICIENT	10.600	BTU/HR-SQ FT-DEG F
SUPPLY RTD COEFFICIENT	9.100	BTU/HR-SQ FT-DEG F
NUMBER OF TIME STEPS	60	
TIME STEP SIZE	1.000	SEC

RETURN RTD TIME CONSTANT	0.02638	HOURS
SUPPLY RTD TIME CONSTANT	0.03072	HOURS
INITIAL RETURN TEMP	80.00	DEG F
INITIAL SUPPLY TEMP	83.00	DEG F

ETIME SEC	TAIR DEG.F	TRTDS DEG.F	TRTDR DEG.F	QAIR BTU	QRTD BTU	QASUM BTU	QHSUM BTU	RATIO INTEGRAL	RATIO INSTANT
1.000	70.3311	82.8845	79.8952	0.075	1.353	0.07	1.35	18.08723	18.08723
2.000	70.6579	82.7730	79.7916	0.223	1.349	0.30	2.70	9.05963	6.03706
3.000	70.9803	82.6654	79.6890	0.370	1.346	0.67	4.05	6.05677	3.63688
4.000	71.2984	82.5616	79.5875	0.515	1.344	1.18	5.39	4.55761	2.61135
5.000	71.6124	82.4617	79.4870	0.658	1.344	1.84	6.74	3.65952	2.04370
6.000	71.9221	82.3654	79.3877	0.799	1.345	2.64	8.08	3.06185	1.68409
7.000	72.2278	82.2728	79.2893	0.938	1.347	3.58	9.43	2.63581	1.43648
8.000	72.5294	82.1838	79.1920	1.075	1.350	4.65	10.78	2.31701	1.25604
9.000	72.8270	82.0982	79.0957	1.210	1.354	5.86	12.13	2.06970	1.11907
10.000	73.1207	82.0161	79.0004	1.344	1.360	7.21	13.49	1.87242	1.01184
11.000	73.4105	81.9373	78.9061	1.476	1.366	8.68	14.86	1.71153	0.92584
12.000	73.6965	81.8619	78.8128	1.606	1.374	10.29	16.23	1.57792	0.85553
13.000	73.9786	81.7896	78.7205	1.734	1.382	12.02	17.61	1.46529	0.79715
14.000	74.2571	81.7206	78.6291	1.861	1.392	13.88	19.01	1.36915	0.74804
15.000	74.5318	81.6546	78.5387	1.986	1.402	15.87	20.41	1.28620	0.70628
16.000	74.8029	81.5918	78.4493	2.109	1.414	17.98	21.82	1.21396	0.67044
17.000	75.0704	81.5319	78.3608	2.231	1.426	20.21	23.25	1.15054	0.63946
18.000	75.3344	81.4749	78.2732	2.351	1.440	22.56	24.69	1.09447	0.61249
19.000	75.5949	81.4208	78.1865	2.469	1.454	25.03	26.14	1.04459	0.58888

Table C-3 - Continued

20.000	75.8519	81.3695	78.1007	2.586	1.469	27.61	27.61	0.99996	0.56812
21.000	76.1055	81.3210	78.0159	2.702	1.485	30.32	29.10	0.95984	0.54978
22.000	76.3558	81.2752	77.9319	2.815	1.502	33.13	30.60	0.92362	0.53353
23.000	76.6027	81.2320	77.8488	2.928	1.520	36.06	32.12	0.89077	0.51908
24.000	76.8464	81.1914	77.7666	3.039	1.538	39.10	33.66	0.86088	0.50621
25.000	77.0868	81.1534	77.6852	3.148	1.557	42.25	35.22	0.83360	0.49472
26.000	77.3241	81.1179	77.6047	3.256	1.577	45.50	36.79	0.80861	0.48445
27.000	77.5582	81.0848	77.5250	3.362	1.598	48.86	38.39	0.78567	0.47526
28.000	77.7892	81.0541	77.4462	3.468	1.619	52.33	40.01	0.76456	0.46703
29.000	78.0172	81.0257	77.3682	3.571	1.642	55.90	41.65	0.74508	0.45965
30.000	78.2421	80.9997	77.2910	3.674	1.664	59.58	43.32	0.72707	0.45305
31.000	78.4641	80.9758	77.2146	3.775	1.688	63.35	45.00	0.71040	0.44713
32.000	78.6831	80.9542	77.1390	3.874	1.712	67.23	46.72	0.69492	0.44185
33.000	78.8992	80.9347	77.0642	3.972	1.736	71.20	48.45	0.68054	0.43713
34.000	79.1125	80.9174	76.9902	4.070	1.762	75.27	50.21	0.66715	0.43292
35.000	79.3229	80.9021	76.9170	4.165	1.788	79.43	52.00	0.65467	0.42919
36.000	79.5305	80.8888	76.8445	4.260	1.814	83.69	53.82	0.64303	0.42588
37.000	79.7354	80.8775	76.7728	4.353	1.841	88.05	55.66	0.63215	0.42297
38.000	79.9376	80.8681	76.7019	4.445	1.869	92.49	57.53	0.62197	0.42042
39.000	80.1371	80.8606	76.6317	4.536	1.897	97.03	59.42	0.61245	0.41820
40.000	80.3340	80.8550	76.5622	4.625	1.925	101.65	61.35	0.60352	0.41629
41.000	80.5282	80.8512	76.4934	4.714	1.954	106.36	63.30	0.59515	0.41466
42.000	80.7199	80.8492	76.4254	4.801	1.984	111.17	65.29	0.58730	0.41328
43.000	80.9090	80.8489	76.3581	4.887	2.014	116.05	67.30	0.57992	0.41216
44.000	81.0957	80.8502	76.2915	4.972	2.045	121.02	69.35	0.57299	0.41125
45.000	81.2798	80.8533	76.2256	5.055	2.076	126.08	71.42	0.56648	0.41056
46.000	81.4616	80.8579	76.1604	5.138	2.107	131.22	73.53	0.56035	0.41006
47.000	81.6409	80.8642	76.0958	5.220	2.139	136.44	75.67	0.55459	0.40974
48.000	81.8178	80.8720	76.0320	5.300	2.171	141.74	77.84	0.54917	0.40959
49.000	81.9924	80.8813	75.9688	5.380	2.203	147.12	80.04	0.54407	0.40959

Table C-3 - Continued

50.000	82.1647	80.8920	75.9062	5.458	2.236	152.57	82.28	0.53926	0.40975
51.000	82.3347	80.9043	75.8444	5.535	2.270	158.11	84.55	0.53474	0.41004
52.000	82.5025	80.9179	75.7831	5.612	2.303	163.72	86.85	0.53048	0.41046
53.000	82.6680	80.9329	75.7225	5.687	2.337	169.41	89.19	0.52647	0.41100
54.000	82.8313	80.9492	75.6626	5.761	2.372	175.17	91.56	0.52269	0.41166
55.000	82.9925	80.9669	75.6033	5.835	2.406	181.00	93.97	0.51914	0.41242
56.000	83.1516	80.9858	75.5446	5.907	2.441	186.91	96.41	0.51579	0.41328
57.000	83.3085	81.0060	75.4865	5.978	2.476	192.89	98.88	0.51264	0.41424
58.000	83.4633	81.0275	75.4290	6.049	2.512	198.94	101.40	0.50968	0.41529
59.000	83.6161	81.0501	75.3721	6.118	2.548	205.06	103.94	0.50690	0.41642
60.000	83.7669	81.0739	75.3158	6.187	2.584	211.24	106.53	0.50429	0.41763

QASUM 211.24 BTU QRSUM 106.53 BTU

Table C-4 - 35°F High Capacity Heat - Original RTD's

AIR FLOW RATE	1500.00	SCFM
INLET AIR TEMP	70.00	DEG F
FINAL EXIT AIR TEMP	95.00	DEG F
HEAT PUMP TIME CONSTANT	0.02083	HOURS
DIAMETER OF RTD	0.25000	INCHES
RETURN RTD COEFFICIENT	10.600	BTU/HR-SQ FT-DEG F
SUPPLY RTD COEFFICIENT	9.100	BTU/HR-SQ FT-DEG F
NUMBER OF TIME STEPS	1200	
TIME STEP SIZE	1.000	SEC

RETURN RTD TIME CONSTANT	0.02638	HOURS
SUPPLY RTD TIME CONSTANT	0.03072	HOURS
INITIAL RETURN TEMP	80.00	DEG F
INITIAL SUPPLY TEMP	83.00	DEG F

ETIME SEC	TAIR DEG.F	TRTDS DEG.F	TRTDR DEG.F	QAIR BTU	QRTD BTU	QASUM BTU	QMSUM BTU	RATIO INTEGRAL	RATIO INSTANT
20.000	75.8519	81.3695	78.1007	2.586	1.469	27.61	27.61	0.99996	0.56812
40.000	80.3340	80.8550	76.5622	4.625	1.925	101.65	61.35	0.60352	0.41629
60.000	83.7669	81.0739	75.3158	6.187	2.584	211.24	106.53	0.50429	0.41763
80.000	86.3963	81.7530	74.3062	7.383	3.345	348.07	166.09	0.47718	0.45311
100.000	88.4102	82.7000	73.4884	8.299	4.143	505.75	241.35	0.47721	0.49915
120.000	89.9527	83.7816	72.8258	9.001	4.931	679.42	332.53	0.48943	0.54787
140.000	91.1342	84.9074	72.2891	9.538	5.684	865.31	439.13	0.50748	0.59588
160.000	92.0391	86.0178	71.8544	9.950	6.383	1060.58	560.25	0.52824	0.64155
180.000	92.7321	87.0754	71.5022	10.265	7.022	1263.03	694.72	0.55004	0.68406
200.000	93.2630	88.0583	71.2169	10.507	7.597	1470.98	841.31	0.57194	0.72303
220.000	93.6696	88.9554	70.9857	10.692	8.108	1683.14	998.71	0.59336	0.75835
240.000	93.9810	89.7629	70.7985	10.833	8.559	1898.52	1165.70	0.61401	0.79006
260.000	94.2195	90.4819	70.6469	10.942	8.954	2116.38	1341.12	0.63369	0.81830
280.000	94.4022	91.1164	70.5240	11.025	9.297	2336.12	1523.88	0.65231	0.84329
300.000	94.5421	91.6723	70.4245	11.089	9.594	2557.32	1713.02	0.66985	0.86526
320.000	94.6493	92.1566	70.3439	11.137	9.851	2779.62	1907.66	0.68630	0.88447
340.000	94.7314	92.5762	70.2786	11.175	10.071	3002.78	2107.04	0.70170	0.90120
360.000	94.7943	92.9383	70.2256	11.203	10.259	3226.58	2310.48	0.71608	0.91571
380.000	94.8424	93.2496	70.1828	11.225	10.420	3450.89	2517.39	0.72949	0.92823

Table C-4 - Continued

400.000	94.8793	93.5164	70.1481	11.242	10.556	3675.58	2727.26	0.74199	0.93902
420.000	94.9076	93.7443	70.1199	11.255	10.673	3900.56	2939.64	0.75365	0.94827
440.000	94.9292	93.9387	70.0972	11.265	10.771	4125.76	3154.15	0.76450	0.95619
460.000	94.9458	94.1040	70.0787	11.272	10.855	4351.14	3370.47	0.77462	0.96294
480.000	94.9585	94.2444	70.0638	11.278	10.925	4576.64	3588.32	0.78405	0.96870
500.000	94.9682	94.3634	70.0517	11.282	10.984	4802.25	3807.46	0.79285	0.97360
520.000	94.9756	94.4641	70.0418	11.286	11.035	5027.94	4027.69	0.80106	0.97775
540.000	94.9813	94.5492	70.0339	11.288	11.077	5253.68	4248.84	0.80874	0.98126
560.000	94.9857	94.6211	70.0275	11.290	11.112	5479.47	4470.76	0.81591	0.98424
580.000	94.9891	94.6817	70.0222	11.292	11.142	5705.29	4693.33	0.82263	0.98675
600.000	94.9916	94.7328	70.0180	11.293	11.167	5931.15	4916.45	0.82892	0.98887
620.000	94.9936	94.7758	70.0146	11.294	11.188	6157.02	5140.02	0.83482	0.99066
640.000	94.9951	94.8120	70.0118	11.295	11.206	6382.90	5363.98	0.84037	0.99217
660.000	94.9962	94.8423	70.0096	11.295	11.221	6608.80	5588.27	0.84558	0.99343
680.000	94.9971	94.8679	70.0078	11.296	11.233	6834.71	5812.82	0.85049	0.99449
700.000	94.9978	94.8893	70.0063	11.296	11.244	7060.62	6037.60	0.85511	0.99539
720.000	94.9983	94.9073	70.0051	11.296	11.252	7286.54	6262.57	0.85947	0.99614
740.000	94.9987	94.9224	70.0041	11.296	11.260	7512.47	6487.70	0.86359	0.99677
760.000	94.9990	94.9350	70.0033	11.296	11.266	7738.40	6712.96	0.86749	0.99729
780.000	94.9992	94.9456	70.0027	11.297	11.271	7964.32	6938.33	0.87118	0.99774
800.000	94.9994	94.9545	70.0022	11.297	11.275	8190.25	7163.80	0.87467	0.99811
820.000	94.9996	94.9620	70.0018	11.297	11.279	8416.19	7389.34	0.87799	0.99842
840.000	94.9997	94.9682	70.0014	11.297	11.282	8642.13	7614.95	0.88114	0.99868
860.000	94.9997	94.9734	70.0012	11.297	11.284	8868.06	7840.61	0.88414	0.99889
880.000	94.9998	94.9778	70.0009	11.297	11.286	9094.00	8066.32	0.88699	0.99908
900.000	94.9998	94.9814	70.0008	11.297	11.288	9319.94	8292.06	0.88971	0.99923
920.000	94.9999	94.9845	70.0006	11.297	11.290	9545.88	8517.84	0.89231	0.99936
940.000	94.9999	94.9870	70.0005	11.297	11.291	9771.81	8743.64	0.89478	0.99946
960.000	94.9999	94.9892	70.0004	11.297	11.292	9997.75	8969.47	0.89715	0.99955
980.000	94.9999	94.9909	70.0003	11.297	11.293	10223.69	9195.31	0.89941	0.99962

Table C-4 - Continued

1000.000	95.0000	94.9924	70.0003	11.297	11.293	10449.63	9421.17	0.90158	0.99969
1020.000	95.0000	94.9937	70.0002	11.297	11.294	10675.56	9647.05	0.90366	0.99974
1040.000	95.0000	94.9947	70.0002	11.297	11.294	10901.50	9872.93	0.90565	0.99978
1060.000	95.0000	94.9956	70.0001	11.297	11.295	11127.44	10098.83	0.90756	0.99982
1080.000	95.0000	94.9963	70.0001	11.297	11.295	11353.38	10324.72	0.90940	0.99985
1100.000	95.0000	94.9969	70.0001	11.297	11.295	11579.31	10550.62	0.91116	0.99987
1120.000	95.0000	94.9974	70.0001	11.297	11.296	11805.25	10776.54	0.91286	0.99989
1140.000	95.0000	94.9979	70.0001	11.297	11.296	12031.19	11002.46	0.91449	0.99991
1160.000	95.0000	94.9982	70.0001	11.297	11.296	12257.13	11228.38	0.91607	0.99992
1180.000	95.0000	94.9985	70.0000	11.297	11.296	12483.06	11454.30	0.91759	0.99994
1200.000	95.0000	94.9988	70.0000	11.297	11.296	12709.00	11680.21	0.91905	0.99995

QASUM 12709.00 BTU QRSUM 11680.21 BTU

Table C-5 - 35°F High Capacity Heat - New RTD's

AIR FLOW RATE	1500.00	SCFM
INLET AIR TEMP	70.00	DEG F
FINAL EXIT AIR TEMP	95.00	DEG F
HEAT PUMP TIME CONSTANT	0.02083	HOURS
DIAMETER OF RTD	0.04000	INCHES
RETURN RTD COEFFICIENT	10.427	BTU/HR-SQ FT-DEG F
SUPPLY RTD COEFFICIENT	8.947	BTU/HR-SQ FT-DEG F
NUMBER OF TIME STEPS	1200	
TIME STEP SIZE	1.000	SEC

RETURN RTD TIME CONSTANT	0.00429	HOURS
SUPPLY RTD TIME CONSTANT	0.00500	HOURS
INITIAL RETURN TEMP	80.00	DEG F
INITIAL SUPPLY TEMP	83.00	DEG F

ETIME SEC	TAIR DEG.F	TRTDS DEG.F	TRTDR DEG.F	QAIR BTU	QRTD BTU	QASUM BTU	QMSUM BTU	RATIO INTEGRAL	RATIO INSTANT
20.000	75.8519	76.6814	72.7391	2.586	1.752	27.61	28.31	1.02536	0.67759
40.000	80.3340	77.9656	70.7503	4.625	3.220	101.65	78.02	0.76754	0.69614
60.000	83.7669	80.9644	70.2055	6.187	4.823	211.24	159.42	0.75467	0.77962
80.000	86.3963	83.9245	70.0563	7.383	6.235	348.07	271.13	0.77895	0.84447
100.000	88.4102	86.4100	70.0154	8.299	7.383	505.75	408.31	0.80733	0.88959
120.000	89.9527	88.3855	70.0042	9.001	8.286	679.42	565.83	0.83282	0.92060
140.000	91.1342	89.9222	70.0012	9.538	8.986	865.31	739.21	0.85426	0.94215
160.000	92.0391	91.1069	70.0003	9.950	9.526	1060.58	924.83	0.87200	0.95737
180.000	92.7321	92.0170	70.0001	10.265	9.940	1263.03	1119.88	0.88666	0.96830
200.000	93.2630	92.7148	70.0000	10.507	10.257	1470.98	1322.15	0.89882	0.97626
220.000	93.6696	93.2496	70.0000	10.692	10.501	1683.14	1529.96	0.90899	0.98213
240.000	93.9810	93.6592	70.0000	10.833	10.687	1898.52	1742.01	0.91756	0.98649
260.000	94.2195	93.9731	70.0000	10.942	10.830	2116.38	1957.31	0.92484	0.98975
280.000	94.4022	94.2134	70.0000	11.025	10.939	2336.12	2175.10	0.93107	0.99221
300.000	94.5421	94.3976	70.0000	11.089	11.023	2557.32	2394.80	0.93645	0.99407
320.000	94.6493	94.5386	70.0000	11.137	11.087	2779.62	2615.96	0.94112	0.99548
340.000	94.7314	94.6466	70.0000	11.175	11.136	3002.78	2838.24	0.94520	0.99655
360.000	94.7943	94.7293	70.0000	11.203	11.174	3226.58	3061.37	0.94880	0.99736
380.000	94.8424	94.7927	70.0000	11.225	11.203	3450.89	3285.16	0.95197	0.99798

Table C-5 - Continued

400.000	94.8793	94.8412	70.0000	11.242	11.225	3675.58	3509.45	0.95480	0.99846
420.000	94.9076	94.8784	70.0000	11.255	11.242	3900.56	3734.13	0.95733	0.99882
440.000	94.9292	94.9069	70.0000	11.265	11.255	4125.76	3959.10	0.95961	0.99910
460.000	94.9458	94.9286	70.0000	11.272	11.264	4351.14	4184.30	0.96166	0.99931
480.000	94.9585	94.9453	70.0000	11.278	11.272	4576.64	4409.67	0.96352	0.99947
500.000	94.9682	94.9582	70.0000	11.282	11.278	4802.25	4635.18	0.96521	0.99960
520.000	94.9756	94.9679	70.0000	11.286	11.282	5027.94	4860.78	0.96676	0.99969
540.000	94.9813	94.9754	70.0000	11.288	11.286	5253.68	5086.47	0.96817	0.99976
560.000	94.9857	94.9812	70.0000	11.290	11.288	5479.47	5312.21	0.96948	0.99982
580.000	94.9891	94.9856	70.0000	11.292	11.290	5705.29	5538.00	0.97068	0.99986
600.000	94.9916	94.9890	70.0000	11.293	11.292	5931.15	5763.82	0.97179	0.99989
620.000	94.9936	94.9915	70.0000	11.294	11.293	6157.02	5989.67	0.97282	0.99992
640.000	94.9951	94.9935	70.0000	11.295	11.294	6382.90	6215.54	0.97378	0.99994
660.000	94.9962	94.9950	70.0000	11.295	11.295	6608.80	6441.43	0.97467	0.99995
680.000	94.9971	94.9962	70.0000	11.296	11.295	6834.71	6667.33	0.97551	0.99996
700.000	94.9978	94.9971	70.0000	11.296	11.296	7060.62	6893.23	0.97629	0.99997
720.000	94.9983	94.9978	70.0000	11.296	11.296	7286.54	7119.15	0.97703	0.99998
740.000	94.9987	94.9983	70.0000	11.296	11.296	7512.47	7345.07	0.97772	0.99998
760.000	94.9990	94.9987	70.0000	11.296	11.296	7738.40	7570.99	0.97837	0.99999
780.000	94.9992	94.9990	70.0000	11.297	11.296	7964.32	7796.92	0.97898	0.99999
800.000	94.9994	94.9992	70.0000	11.297	11.297	8190.25	8022.85	0.97956	0.99999
820.000	94.9996	94.9994	70.0000	11.297	11.297	8416.19	8248.78	0.98011	0.99999
840.000	94.9997	94.9995	70.0000	11.297	11.297	8642.13	8474.72	0.98063	0.99999
860.000	94.9997	94.9997	70.0000	11.297	11.297	8868.06	8700.65	0.98112	1.00000
880.000	94.9998	94.9997	70.0000	11.297	11.297	9094.00	8926.59	0.98159	1.00000
900.000	94.9998	94.9998	70.0000	11.297	11.297	9319.94	9152.53	0.98204	1.00000
920.000	94.9999	94.9998	70.0000	11.297	11.297	9545.88	9378.47	0.98246	1.00000
940.000	94.9999	94.9998	70.0000	11.297	11.297	9771.81	9604.40	0.98287	1.00000
960.000	94.9999	94.9999	70.0000	11.297	11.297	9997.75	9830.34	0.98326	1.00000
980.000	94.9999	94.9999	70.0000	11.297	11.297	10223.69	10056.28	0.98363	1.00000

Table C-5 - Continued

1000.000	95.0000	94.9999	70.0000	11.297	11.297	10449.63	10282.22	0.98398	1.00000
1020.000	95.0000	94.9999	70.0000	11.297	11.297	10675.56	10508.15	0.98432	1.00000
1040.000	95.0000	94.9999	70.0000	11.297	11.297	10901.50	10734.09	0.98464	1.00000
1060.000	95.0000	94.9999	70.0000	11.297	11.297	11127.44	10960.03	0.98496	1.00000
1080.000	95.0000	94.9999	70.0000	11.297	11.297	11353.38	11185.97	0.98525	1.00000
1100.000	95.0000	94.9999	70.0000	11.297	11.297	11579.31	11411.90	0.98554	1.00000
1120.000	95.0000	94.9999	70.0000	11.297	11.297	11805.25	11637.84	0.98582	1.00000
1140.000	95.0000	94.9999	70.0000	11.297	11.297	12031.19	11863.78	0.98609	1.00000
1160.000	95.0000	94.9999	70.0000	11.297	11.297	12257.13	12089.72	0.98634	1.00000
1180.000	95.0000	94.9999	70.0000	11.297	11.297	12483.06	12315.65	0.98659	1.00000
1200.000	95.0000	94.9999	70.0000	11.297	11.297	12709.00	12541.59	0.98683	1.00000

QASUM 12709.00 BTU QRSUM 12541.59 BTU

lag could be neglected with the new RTD's with little effect and a precise determination of the RTD time constant is somewhat superfluous. Therefore no correction was applied for data obtained with the second set of RTD's. Results of the HPTRAN program showed that for cooling operation the correction for RTD lag was fairly small since the sensible air temperature change is comparatively small in cooling. Therefore no temperature sensor lag correction was applied to the cooling data for either set of RTD's.

Results from the HPTRAN program were used to generate the FORTRAN V subroutine QHRTD. Data for both capacity levels and the original and new RTD's was incorporated in tabular form using DATA statements. For high capacity heating operation data was input for ambient temperatures of 47, 35, 17 and 0°F for elapsed times up to 900 seconds in 60 second intervals. For low capacity heating data was input for 62, 47 and 35°F ambient temperatures at the same time intervals. For elapsed times exceeding the range of the input data no correction was applied. Both subroutines used a three point Lagrangian interpolation routine to evaluate the correction factors as a function of ambient temperature and elapsed time. Listings for QHRTD and SINTRP, a three point Lagrangian interpolation routine called by QHRTD are presented in Appendix CC.

C.1 LISTING FOR HPTRAN

```
      PROGRAM HPTRAN

C
C     ************************************************************
C     DETERMINES CORRECTION FACTOR FOR SENSIBLE HEATING OR COOLING
C     DELIVERED DUE TO TEMPERATURE SENSOR TIME LAG
C     ************************************************************
C
 1111 FORMAT(5X,'ETIME  TAIR     TRTDS   TRTDR      QAIR    QRTD',
     1     '    QASUM     QMSUM   RATIO    RATIO',/,6X,
     2     'SEC   DEG.F    DEG.F   DEG.F      BTU     BTU',
     3     '      BTU       BTU   INTEGRAL INSTANT ',//)
 2222 FORMAT(1X,F8.3,3F9.4,2F8.3,2F10.2,2F9.5,/)
 3333 FORMAT(3X,'QASUM',F10.2,' BTU  QRSUM',F10.2,' BTU',//)
 4444 FORMAT(3X,'AIR FLOW RATE             ',F8.2,' SCFM',/,3X,
     1     'INLET AIR TEMP            ',F8.2,' DEG F',/,3X,
     2     'FINAL EXIT AIR TEMP       ',F8.2,' DEG F',/,3X,
     3     'HEAT PUMP TIME CONSTANT   ',F8.5,' HOURS',/,3X,
     4     'DIAMETER OF RTD           ',F8.5,' INCHES',/,3X,
     5     'RETURN RTD COEFFICIENT    ',F8.3,' BTU/HR-SQ FT-DEG F',/,3X,
     6     'SUPPLY RTD COEFFICIENT    ',F8.3,' BTU/HR-SQ FT-DEG F',
     7     /,3X,'NUMBER OF TIME STEPS      ',I8,/,3X,
     8     'TIME STEP SIZE            ',F8.3,' SEC',//)
 4455 FORMAT(3X,'RETURN RTD TIME CONSTANT  ',F8.5,' HOURS',
     1     /,3X,'SUPPLY RTD TIME CONSTANT  ',F8.5,' HOURS',
     2     /,3X,'INITIAL RETURN TEMP       ',F8.2,' DEG F',
     3     /,3X,'INITIAL SUPPLY TEMP       ',F8.2,' DEG F',//)
      DATA CPA,CPS,RHS,PI/ 0.241,0.11,488.0,3.1415927/
      TYPE *,'GIVE AIR FLOW RATE IN SCFM'
      ACCEPT *, SCFM
      TYPE *,'      '
      TYPE *,'GIVE INLET AIR TEMP AND FINAL'
```

```
TYPE *'EXIT AIR TEMP'
ACCEPT *,TAI,TAX
TYPE *,'        '
TYPE *,'GIVE HEAT PUMP TIME CONSTANT IN HRS'
ACCEPT *,ALFA
TYPE *,'        '
TYPE *,'GIVE RTD DIAMETER IN INCHES'
TYPE *,'RETURN AIR RTD CONVECTION COEFFICIENT'
TYPE *,'AND SUPPLY AIR RTD CONVECTION COEFFICIENT IN'
TYPE *,'BTU/HR-SQ FT-DEG F'
ACCEPT *,RTDD,HRTDR,HRTDS
DRTD = RTDD/12.0
TYPE *,'        '
TYPE *,'GIVE INITIAL RETURN AIR AND'
TYPE *,'SUPPLY AIR RTD TEMPERATURES IN'
TYPE *,'DEG F'
ACCEPT *,TIRR,TIRS
TYPE *,'        '
TYPE *,'GIVE NUMBER OF TIME STEPS AND'
TYPE *,'TIME STEP SIZE IN SEC'
TYPE *,'NUMBER OF TIME STEPS BETWEEN PRINTOUTS'
ACCEPT *,NSTEP,DELT,NPRNT
WRITE(6,4444) SCFM,TAI,TAX,ALFA,RTDD,HRTDR,HRTDS,NSTEP,DELT
CONT = CPS*RHS*DRTD/(4.0*HRTDR)
CONX = CPS*RHS*DRTD/(4.0*HRTDS)
WRITE(6,4455) CONT,CONX,TIRR,TIRS
TRTD = TIRS
TRTX = TIRS
TRRX = TIRR
TAXX = TAI
QASUM = 0.0
QMSUM = 0.0
TAU = DELT/3600.0
CORF = 1.0 + (2.0*HRTDS*TAU/(DRTD*RHS*CPS))
```

```
      WRITE(6,1111)
      DO 1000 N=1,NSTEP
      JJJ = N
      ETIM = ETIM+DELT
      TIM = ETIM/3600.0
      TRR = TIRR+(TAI-TIRR)*(1-EXP(-TIM/CONT))
      TRV = 0.5*(TRR+TRRX)
      TAA = TAI+(TAX-TAI)*(1-EXP(-TIM/ALFA))
      TAV = 0.5*(TAA+TAXX)
      QRTD = PI*DRTD*HRTDS*(TAV-TRTD)*TAU/CORF
      TRTD = TRTD+QRTD/(0.25*PI*DRTD*DRTD*CPS*RHS)
      TRTV = 0.5*(TRTD+TRTX)
      QACT = 4.5*SCFM*CPA*(TAV-TAI)*DELT/3600.0
      QMES = 4.5*SCFM*CPA*(TRTV-TRV)*DELT/3600.0
      QASUM = QASUM+QACT
      QMSUM = QMSUM+QMES
      RATSUM = QMSUM/QASUM
      RATINS = QMES/QACT
      IPRNT = MOD(JJJ,NPRNT)
      IF(IPRNT.EQ.0) WRITE(6,2222) ETIM,TAA,TRTD,TRR,QACT,QMES,
     1       QASUM,QMSUM,RATSUM,RATINS
      TRRX = TRR
      TAXX = TAA
      TRTX = TRTD
 1000 CONTINUE
      WRITE(6,3333) QASUM,QMSUM
      CALL EXIT
      END
```

C.2 LISTINGS FOR QHRTD AND SINTRP

```
      FUNCTION QHRTD(NRTD,ICAP,TAMB,ONTIM)
C
C     ********************************************
C     THE RATIO OF ACTUAL HEAT PUMP CAPACITY
C     TO MEASURED HEAT PUMP CAPACITY (INSTANTANEOUS)
C     FOR THE OLD RESISTANCE THERMOMETERS
C     AS A FUNCTION OF:
C        NRTD  = RTD TYPE (1=OLD 2=NEW)
C        ICAP  = CAPACITY LEVEL (1=LOW 2=HIGH)
C        TAMB  = AMBIENT TEMPERATURE - DEG F
C        ONTIM = ON TIME - SECONDS
C     ********************************************

      DIMENSION RH47(15),RH35(15),RH17(15),RHOO(15),TIM(15),
     1          RL62(15),RL47(15),RL35(15),XHI(3),XLO(3),THI(4),TLO(3),
     2          XH47(15),XH35(15),XH17(15),XHOO(15),XL62(15),XL47(15),
     3          XL35(15)
      DATA THI/0.0,17.0,35.0,47.0/
      DATA TLO/35.0,47.0,62.0/
      DATA TIM/60.0,120.0,180.0,240.0,300.0,360.0,
     1          420.0,480.0,540.0,600.0,660.0,720.0,780.0,820.0,
     2          900.0/
      DATA RH47/0.36945,0.58114,0.74465,0.84994,
     1          0.91314,0.94999,0.97125,0.98347,0.99049,0.99453,
     2          0.99685,0.99818,0.99895,0.99940,0.99965/
      DATA RH35/0.39673,0.56849,0.72077,0.82822,
     1          0.86527,0.91572,0.94828,0.96871,0.98127,0.98888,
     2          0.99343,0.99614,0.99774,0.99686,0.99923/
      DATA RH17/0.45901,0.57622,0.70770,0.80949,
     1          0.88032,0.92671,0.95591,0.97381,0.98457,0.99097,
     2          0.99473,0.99694,0.99822,0.99897,0.99940/
```

```
 DATA RH00/0.538381,0.62036,0.72088,0.80867,
1        0.87421,0.91969,0.94984,0.96918,0.98130,0.98877,
2        0.99330,0.99603,0.99766,0.998622,0.99919/
 DATA RL62/0.37430,0.53861,0.68870,0.79996,
1        0.87566,0.92448,0.95485,0.97329,0.98431,0.99083,
2        0.99466,0.99689,0.99820,0.999895,0.99939/
 DATA RL47/0.43433,0.54237,0.66880,0.77142,
1        0.84731,0.90054,0.93651,0.96011,0.97527,0.98482,
2        0.99077,0.99442,0.996665,0.99800,0.99881/
 DATA RL35/0.44924,0.54038,0.65934,0.75876,
1        0.83427,0.88879,0.92679,0.95257,0.96968,0.98083,
2        0.98799,0.99254,0.99539,0.99717,0.99827/
 DATA XH47/0.81472,0.96111,0.99198,0.99835,
1        0.99966,0.99993,0.99999,1.0,1.0,1.0,1.0,1.0,1.0,
2        1.0,1.0/
 DATA XH35/0.79657,0.94222,0.98372,0.99466,
1        0.99047,0.99736,0.99882,0.99947,0.99976,0.99989,
2        0.99995,0.99998,0.99999,0.99999,1.0/
 DATA XH17/0.78907,0.92631,0.97237,0.98904,
1        0.99554,0.99817,0.99924,0.99969,0.99987,0.99995,
2        0.99998,0.99999,1.0,1.0,1.0/
 DATA XH00/0.76569,0.91701,0.96509,0.98433,
1        0.99274,0.99658,0.99838,0.99923,0.99963,0.99983,
2        0.99992,0.99996,0.99998,0.99999,0.99999/
 DATA XL62/0.78178,0.92905,0.97450,0.99031,
1        0.99624,0.99852,0.99942,0.99977,0.99991,0.99996,
2        0.99999,0.99999,1.0,1.0,1.0/
 DATA XL47/0.77406,0.91123,0.96088,0.98139,
1        0.99081,0.99538,0.99766,0.99881,0.99939,0.99969,
2        0.99984,0.99992,0.99996,0.99998,0.99999/

 DATA XL35/0.77117,0.90514,0.95570,0.97752,
1        0.98810,0.99357,0.99649,0.99807,0.99894,0.99941,
2        0.99968,0.99982,0.99990,0.99994,0.99997/
```

```
      QHRTD=1.0
      IF(ONTIM .GT. 900.0) GO TO 1000
      IF(NRTD .EQ. 2) GO TO 600
      IF(ICAP .EQ. 2) GO TO 500
      XLO(1)=SINTRP(TIM,RL35,ONTIM,15)
      XLO(2)=SINTRP(TIM,RL47,ONTIM,15)
      XLO(3)=SINTRP(TIM,RL62,ONTIM,15)
      QHRTD=1.0/SINTRP(TLO,XLO,TAMB,3)
      RETURN
  500 CONTINUE
      XHI(1)=SINTRP(TIM,RH00,ONTIM,15)
      XHI(2)=SINTRP(TIM,RH17,ONTIM,15)
      XHI(3)=SINTRP(TIM,RH35,ONTIM,15)
      XHI(4)=SINTRP(TIM,RH47,ONTIM,15)
      QHRTD=1.0/SINTRP(THI,XHI,TAMB,4)
      RETURN
  600 CONTINUE
      IF(ICAP .EQ. 2) GO TO 700
      XLO(1)=SINTRP(TIM,XL35,ONTIM,15)
      XLO(2)=SINTRP(TIM,XL47,ONTIM,15)
      XLO(3)=SINTRP(TIM,XL62,ONTIM,15)
      QHRTD=1.0/SINTRP(TLO,XLO,TAMB,3)
      RETURN
  700 CONTINUE
      XHI(1)=SINTRP(TIM,XH00,ONTIM,15)
      XHI(2)=SINTRP(TIM,XH17,ONTIM,15)
      XHI(3)=SINTRP(TIM,XH35,ONTIM,15)
      XHI(4)=SINTRP(TIM,XH47,ONTIM,15)
      QHRTD=1.0/SINTRP(THI,XHI,TAMB,4)
      RETURN
 1000 CONTINUE
      RETURN
      END
```

```
      FUNCTION SINTRP(XT,YT,X,N)
      DIMENSION XT(6),YT(6)
C
C     ***************************************************
C     SINGLE VARIABLE INTERPOLATION USING THE THREE POINT
C     LAGRANGE METHOD
C             XT = ARRAY OF INDEPENDENT VARIABLES
C             YT = ARRAY OF DEPENDENT VARIABLES
C             X  = DESIRED VALUE OF INDEPENDENT VARIABLE
C             N  = NUMBER OF ITEMS IN XT AND YT ARRAYS
C     ***************************************************
C
      NM1 = N - 1
      K = 2
      IF(XT(2) .GT. X) GO TO 40
      K = NM1
      IF(XT(K) .LE. X) GO TO 40
      K = 3
10    CONTINUE
      IF(X .GT. XT(K)) GO TO 11
      GO TO 40
11    CONTINUE
      K = K + 1
      GO TO 10
40    CONTINUE
      Y1 = YT(K-1)
      Y2 = YT(K)
      Y3 = YT(K+1)
      X1 = XT(K-1)
      X2 = XT(K)
      X3 = XT(K+1)
      Z1 = X - X1
```

D. APPENDIX D — TEMPERATURE SENSOR RADIATION ERROR

In the week preceding the 1983 Christmas holiday the microprocessor shut the system down several times due to high and low compressor run current. The data obtained during this period gave no indication of unusual operation so malfunctions of the microprocessor control system seemed to be the cause. Consequently the backup microprocessor board was installed on December 21, 1983. Due to sub-zero temperatures the owner was understandably concerned that a system outage could result in plumbing damage and switched the unit to emergency heat mode at night.

Inspection of the data obtained during emergency heat operation showed extremely high supply air temperatures as indicated by the RTD. The thermocouples in the duct, which are in substantial agreement with the RTD during normal heat pump operation, indicated significantly lower temperatures. Therefore we concluded that radiation from the bare wire resistance heat elements was causing the RTD to read a temperature higher than the actual supply air temperature. The copper air sampling tube is located directly above the resistance heat elements with a high "view factor" and the RTD is located in an elbow and has a good "view" of that portion of the sampling tube located directly above the resistance heat elements. When the sampling tube was installed we were aware that the location directly above the resistance heat elements was less than ideal, but it was the only location available and since the RTD could not "see" the resistance heat elements we did not anticipate a significant radiation error.

Inspection of data obtained during normal heat pump operation with resistance heat supplement also showed that the temperature indicated by the RTD was significantly higher than that indicated by the

duct thermocouples. In order to obtain a more complete understanding of the nature of this phenomenon, on April 18, 1984 the heat pump was operated in the emergency heat mode and data taken for 15 minute intervals. Fuses were removed so that the unit operated with one stage of resistance heat for the first test, two stages for the second test and three stages for the third test. The temperatures indicated by the thermocouples and the RTD during the final data scan before shutdown are summarized in Table D.1. Also shown in Table D.1 are RTD and thermocouple readings for normal high capacity heating operation with I^2R supplement obtained on Jan. 20-21, 1984 when ambient temperatures below -10°F were observed. It is interesting to note that with one stage of I^2R heat the left branch thermocouple reads slightly less than the right branch thermocouple and with two or more stages of I^2R this situation is reversed. This may be due to non-uniformities in the delivered air temperature or radiation from the resistance heat elements to the thermocouples. Due to space limitations the right branch thermocouple was placed near the top of the vertical supply duct and may be able to "see" the I^2R elements to a limited extent.

In the data reduction program this inconsistency was accommodated by limiting the supply air temperature to that calculated from the air mass flow, return air temperature, resistance heat input as determined by the Watthour transducer and the heat pump capacity as determined from laboratory measurements and adjusted for on-time.

Table D.1 — Comparison of RTD and Thermocouple Readings with Resistance Heat

Operating Mode	RTD #49 °F	Left Branch Thermocouple °F	Right Branch Thermocouple °F
One Stage I^2R	87.58	80.24	80.03
Two Stages I^2R	102.15	86.39	89.79
Three Stages I^2R	117.51	95.95	99.06
High Capacity Heat + One Stage I^2R	99.95	94.42	93.64
High Capacity Heat + Two Stages I^2R	110.23	95.98	97.14
High Capacity Heat + Three Stages I^2R	125.47	120.83	105.27

E. APPENDIX E — EFFECT OF AIR FLOW MEASUREMENT ERROR

Initial reductions of the data using laboratory calibrations of the Annubar revealed a significant discrepancy between the computed air flow rate and the expected flow rate. An in-situ calorimetric calibration was then performed on the Annubar, which verified that the original laboratory calibration was, indeed, incorrect. The calorimetric calibration was then used to reduce the remaining data.

Typical results are represented by data taken at 12:27 on April 6, 1984. The unit was running in the high capacity heating mode at an ambient temperature of 37°F. The unit had been operating for about 12 minutes and should be at steady state. Table E.1 compares the field test data with lab test results for both prototypes at 35°F.

If we draw an energy balance around the compressor, oil cooler and condenser we can estimate the heat delivered. The compressor suction conditions give an enthalpy of 107.02 Btu/lbm and the condenser exit temperature gives a liquid enthalpy of 38.59 Btu/lbm. Using the map compressor Watts (the compressor Wattmeter had not been calibrated)

$$Q = 3264 \times 3.41276 + 448.5 \times (107.02 - 38.59) = 41830.1 \text{ Btu/hr}$$

If we add the fan power of 337.7 Watts

$$Q = 41830.1 + 337.7 \times 3.41276 = 42982.6 \text{ Btu/hr}$$

Allowing 2% for heat leakage in the reversing valve we get a net capacity of 42123 Btu/hr - consistent with the rated capacity of 42477 Btu/hr at 37°F for unit #2 (Note that since the refrigerant lines in the

Table E.1 — Refrigeration System Operating Parameters

	Field #2	Laboratory #1	Laboratory #2
Compressor Suction Pressure - psi	58.3	59.2	57.5
Compressor Suction Temperature - °F	24.0	22.6	20.00
Compressor Suction Superheat - °F	3.5	1.3	0.20
Compressor Discharge Pressure - psia	225.3	221.7	218.0
Compressor Discharge Temperature - °F	155.5	158.2	166.8
Compressor Discharge Superheat - °F	50.5	54.4	64.3
Condenser Exit Temperature - °F	97.9	99.5	95.1
Map Refrigerant Flow lb/hr - °F	448.5	462.4	447.7
Compressor Power - Watts measured	3354	3190	3164
Compressor Power - Watts map	3264	3262	3197
Supply Air Temperature - °F	71.6	70.6	69.8
Delivered Air Temperature - °F	97.9	95.2	95.9

Note that the temperatures and pressures measured in the field are in good agreement with the lab test results.

field test were longer than in the lab, slightly lower suction pressure and capacities are expected). The COP based on a capacity of 42123 Btu/hr and the field measured power consumption of 3877 Watts is 3.18 compared to a COP of 3.22 for the unit #2 laboratory test, if crankcase heat and control power are included, giving a power consumption of 3863 Watts.

If the indicated capacity of 30,713 Btu/hr based on an actual air flow of 1143 actual cfm were accepted, the COP would be 2.32, clearly grossly inconsistent with the laboratory value of 3.19. Thus we conclude that the actual air flow is: (allowing 3% for RTD lag)

$$\frac{42123 \times .97}{30713} \times 1143 = 1520 \text{ acfm.}$$

This is consistent with the air flows measured in the lab of 1420-1500 acfm and 33% higher than the indicated value. Field measurements show that the duct static pressure in the field was less than the 0.35 inches of H_2O maintained in the lab. Thus slightly higher air flows are reasonable.

In the emergency heat mode, data on Feb. 24 at 4:14 also indicates air flows significantly higher than the values calculated from the Annubar readings. The measured heat pump power input is 16037 Watts (I^2R + blower) or 54730 Btu/hr. With a return air temperature of 103.8°F as indicated by the duct thermocouple, the heat delivered would be 39193 Btu/hr if the 1163 acfm indicated were correct. Thus the calorimetric air flow is about 39% more than the indicated air flow. Since the emergency heat was on for more than 25 minutes when this measurement was made and the I^2R Wattmeter was field calibrated against a Yokagawa laboratory Wattmeter, this measurement is considered accurate.

F. APPENDIX F — DAILY SUMMARIES AND TEMPERATURE BIN DATA

Table F-1 - Daily Summary April 1, 1983 through March 31, 1984

DATE	AVERAGE AMBIENT TEMPERATURE DATA HOURS	COMPRESSOR RUNNING HOURS (STATE/ COUNTER)	"ON" CYCLES	NORMAL HEATING DELIVERED BTU	NORMAL HEATING WATTHOURS CONSUMED	EMERGENCY WATTHOURS	COOLING ABSORBED BTU	COOLING WATTHOURS CONSUMED	COOLING SENSIBLE/ TOTAL HEAT	PEAK K.W.	EER HEATING	EER COOLING	WHOLE HOUSE WH
APR 1	58/ 1.7	.08/ .00	3	6408.	809.	0.	0.	0.	.0000	2.3	7.92	.00	8760.
APR 2	48/21.8	3.27/ .00	21	119849.	14682.	0.	0.	0.	.0000	2.5	8.16	.00	85800.
APR 3	42/26.0	.81/ .00	4	21163.	16716.	0.	0.	0.	.0000	2.3	1.27	.00	115720.
APR 4	40/21.6	11.04/ .00	33	258730.	26704.	0.	0.	0.	.0000	2.4	9.69	.00	117600.
APR 5	47/24.0	6.94/ .00	17	162655.	18102.	0.	0.	0.	.0000	2.4	8.99	.00	99920.
APR 6	53/24.0	1.87/ .00	18	98251.	8904.	0.	0.	0.	.0000	2.3	11.03	.00	93640.
APR 7	58/21.6	.90/ .00	10	59206.	4876.	0.	0.	0.	.0000	2.3	11.94	.00	45920.
APR 8	49/24.0	2.69/ .00	23	120815.	11092.	0.	0.	0.	.0000	2.4	10.89	.00	82800.
APR 9	49/24.0	3.98/ .00	25	150829.	13653.	0.	0.	0.	.0000	2.4	11.05	.00	94400.
APR 10	48/24.0	3.35/ .00	18	110868.	11371.	0.	0.	0.	.0000	2.4	9.75	.00	103520.
APR 11	41/24.0	7.63/ .00	41	241280.	22949.	0.	0.	0.	.0000	3.1	10.51	.00	91720.
APR 12	43/24.0	7.44/ .00	21	158573.	19239.	0.	0.	0.	.0000	2.3	8.24	.00	109360.
APR 13	50/24.0	5.43/ .00	16	127217.	15213.	0.	0.	0.	.0000	2.3	8.36	.00	98480.
APR 14	55/24.0	.72/ .00	10	51721.	5794.	0.	0.	0.	.0000	2.3	8.93	.00	87480.
APR 15	45/24.0	3.30/ .00	8	76141.	9964.	0.	0.	0.	.0000	2.4	7.64	.00	94120.
APR 16	38/24.0	5.92/ .00	33	254238.	23777.	0.	0.	0.	.0000	4.0	10.69	.00	102360.
APR 17	33/24.1	6.23/ .00	28	231873.	27976.	0.	0.	0.	.0000	3.8	8.29	.00	136480.
APR 18	29/23.9	7.74/ .00	33	311789.	35240.	0.	0.	0.	.0000	3.8	8.85	.00	105440.
APR 19	26/23.5	9.64/ .00	29	323710.	43253.	0.	0.	0.	.0000	15.4	7.47	.00	123320.
APR 20	34/23.9	7.79/ .00	32	225833.	31675.	0.	0.	0.	.0000	3.7	9.02	.00	139760.
APR 21	43/24.0	3.63/ .00	18	150757.	17477.	0.	0.	0.	.0000	3.9	8.63	.00	86200.
APR 22	53/24.0	2.43/ .00	11	59187.	9540.	0.	0.	0.	.0000	2.3	6.20	.00	77600.
APR 23	54/24.1	1.24/ .00	8	43741.	6919.	0.	0.	0.	.0000	2.2	6.32	.00	85440.
APR 24	43/23.9	5.18/ .00	24	133839.	15444.	0.	0.	0.	.0000	2.2	8.67	.00	100760.
APR 25	40/24.2	5.52/ .00	25	223890.	23141.	0.	0.	0.	.0000	3.8	9.68	.00	115320.
APR 26	53/23.9	2.02/ .00	11	85946.	12921.	0.	0.	0.	.0000	3.6	7.66	.00	114600.
APR 27	67/24.1	.00/ .00	0	3025.	2538.	0.	0.	0.	.0000	.2	1.19	.00	76080.
APR 28	68/23.8	.12/ .00	1	5359.	2962.	0.	0.	0.	.0000	1.6	3.16	.00	86640.
APR 29	58/24.1	.00/ .00	0	30465.	4782.	0.	0.	0.	.0000	.6	6.37	.00	99160.
APR 30	65/24.1	.00/ .00	0	8952.	1225.	1403.	0.	0.	.0000	.6	7.31	.00	72080.
MAY 1	62/24.0	.00/ .00	0	0.	0.	2145.	0.	0.	.0000	.2	.00	.00	85280.
MAY 2	65/24.0	.00/ .00	0	0.	0.	2145.	0.	0.	.0000	.2	.00	.00	105600.
MAY 3	58/24.0	.00/ .00	0	0.	0.	2103.	0.	0.	.0000	.3	.00	.00	77400.
MAY 4	51/24.0	.00/ .00	0	0.	0.	2164.	0.	0.	.0000	.2	.00	.00	73960.
MAY 5	49/ 5.5	.00/ .00	0	0.	0.	537.	0.	0.	.0000	.2	.00	.00	18080.
MAY 9	42/ 8.0	1.15/ .00	8	32988.	4481.	0.	0.	0.	.0000	3.3	7.36	.00	88400.
MAY 10	47/24.0	2.50/ .00	11	82814.	13953.	0.	0.	0.	.0000	3.7	5.94	.00	97080.
MAY 11	56/23.7	1.65/ .00	10	36667.	6986.	0.	12546.	2331.	.4835	2.4	5.24	5.38	73640.
MAY 12	62/24.1	.00/ .00	0	0.	0.	0.	0.	2187.	.0000	.2	.00	.00	67520.
MAY 13	65/24.1	.00/ .00	0	0.	0.	0.	0.	2193.	.0000	.2	.00	.00	67000.
MAY 14	66/24.0	.00/ .00	0	0.	0.	0.	102842.	9431.	.4952	2.5	.00	10.88	72840.
MAY 15	57/24.0	.00/ .00	0	0.	0.	0.	43128.	5260.	.4952	2.2	.00	8.20	86040.
MAY 16	46/23.9	.00/ .00	0	0.	0.	0.	0.	2167.	.0000	.2	.00	.00	90320.
MAY 17	49/24.1	1.51/ .00	6	48568.	7046.	0.	0.	164.	.0000	3.1	6.89	.00	83160.
MAY 18	58/24.0	.78/ .00	4	22385.	4429.	0.	0.	0.	.0000	2.0	5.06	.00	76320.
MAY 19	56/23.5	.00/ .00	0	2545.	1589.	0.	0.	0.	.0000	.3	1.60	.00	60280.
MAY 20	61/11.0	.00/ .00	0	0.	1496.	0.	0.	0.	.0000	1.1	.00	.00	36320.
MAY 23	68/85.2	.00/ .00	0	2308.	780.	0.	0.	0.	.0000	.3	2.95	.00	31800.
MAY 24	56/24.1	.44/ .00	3	0.	0.	0.	15686.	3314.	.3936	2.1	.00	4.70	88080.
MAY 25	59/23.9	.29/ .00	3	0.	0.	0.	8118.	3295.	.4472	1.7	.00	1.55	75920.
MAY 26	52/24.1	.00/ .00	0	0.	0.	0.	0.	2216.	.0000	.3	.00	.00	78120.
MAY 27	49/23.8	.00/ .00	0	0.	0.	0.	0.	2187.	.0000	.3	.00	.00	63680.
MAY 28	54/24.2	.66/ .00	6	15514.	5177.	0.	0.	250.	.0000	2.1	3.00	.00	68720.
MAY 29	61/24.1	.55/ .00	2	6703.	3589.	0.	0.	0.	.0000	1.8	1.87	.00	73960.
MAY 30	62/24.0	.00/ .00	0	132.	2645.	0.	0.	0.	.0000	.3	.05	.00	100600.
MAY 31	58/23.9	.00/ .00	0	3268.	2703.	0.	0.	0.	.0000	.3	1.21	.00	62560.
JUN 1	55/24.1	.00/ .00	0	2542.	2752.	0.	0.	0.	.0000	.3	.96	.00	90680.
JUN 2	59/23.8	.00/ .00	0	0.	0.	0.	0.	0.	.0000	.6	.00	.00	72600.
JUN 3	59/24.1	.00/ .00	0	0.	0.	0.	0.	0.	.0000	.3	.00	.00	72040.
JUN 4	63/24.1	.94/ .00	3	0.	0.	0.	25904.	3988.	.4310	2.4	.00	6.50	65520.
JUN 5	68/24.0	.00/ .00	0	0.	0.	0.	0.	2206.	.0000	.3	.00	.00	74920.
JUN 6	68/24.1	5.03/ .00	17	0.	0.	0.	125133.	15577.	.5743	2.7	.00	8.03	73840.
JUN 7	62/23.8	1.66/ .00	16	0.	0.	0.	45719.	9007.	.4796	2.2	.00	5.08	101240.
JUN 8	62/24.0	2.29/ .00	16	0.	0.	0.	82858.	9180.	.5127	2.1	.00	5.74	78440.

Table F-1 - Continued

JUN 9	64/24.0	1.99/	.00	14	0.	0.	0.	41107.	8390.	.6071	2.0	.00	4.90	70440.
JUN 10	71/24.1	4.85/	.00	19	0.	0.	0.	108503.	15896.	.6538	2.7	.00	6.96	84360.
JUN 11	74/23.8	6.64/	.00	20	0.	0.	0.	182591.	19642.	.6919	2.7	.00	7.11	87880.
JUN 12	76/24.1	9.03/	.00	18	0.	0.	0.	199554.	24758.	.7204	5.5	.00	8.06	119660.
JUN 13	77/23.9	8.98/	.00	23	0.	0.	0.	183302.	25393.	.7194	2.7	.00	7.22	83040.
JUN 14	75/24.2	7.58/	.00	23	0.	0.	0.	187710.	26838.	.6436	2.7	.00	6.99	94680.
JUN 15	75/23.8	8.15/	.00	20	0.	0.	0.	180041.	23320.	.6803	2.7	.00	7.70	88600.
JUN 16	76/24.1	9.09/	.00	24	0.	0.	0.	207051.	26539.	.6940	4.2	.00	7.80	98240.
JUN 17	70/24.0	7.40/	.00	25	0.	0.	0.	188911.	22050.	.6004	2.6	.00	8.57	88400.
JUN 18	71/23.5	4.40/	.00	28	0.	0.	0.	115930.	16058.	.6210	2.6	.00	7.22	84400.
JUN 19	70/24.0	7.45/	.00	30	0.	0.	0.	201599.	19440.	.5691	4.6	.00	10.37	87560.
JUN 20	67/24.0	4.55/	.00	36	0.	0.	0.	161475.	15404.	.4935	2.4	.00	10.48	113400.
JUN 21	66/22.3	2.11/	.00	24	0.	0.	0.	85034.	7745.	.4407	2.2	.00	12.27	54760.
JUN 22	70/24.0	5.78/	.00	28	0.	0.	0.	147613.	17715.	.6012	2.7	.00	8.33	84240.
JUN 23	74/24.0	6.18/	.00	21	0.	0.	0.	171608.	22860.	.7578	2.7	.00	7.52	87920.
JUN 24	71/11.5	3.37/	.00	12	0.	0.	0.	79112.	6791.	.6480	2.6	.00	11.65	32800.
JUN 24	77/12.5	5.33/	.00	17	0.	0.	0.	144602.	49002.	.6855	130.6	.00	8.02	160760.
JUN 25	70/24.0	5.76/	.00	32	0.	0.	0.	166547.	18862.	.6127	2.5	.00	8.83	83240.
JUN 26	74/19.0	5.12/	.00	12	0.	0.	0.	92578.	13503.	.7438	2.7	.00	6.65	59800.
JUN 27	82/28.9	25.21/	.00	9	0.	0.	0.	429948.	35022.	.9511	2.7	.00	11.31	119960.
JUN 28	71/23.9	7.58/	.00	42	0.	0.	0.	232997.	23476.	.5690	2.6	.00	9.92	115760.
JUN 29	67/24.0	4.44/	.00	34	0.	0.	0.	186172.	14536.	.5022	2.3	.00	9.37	77800.
JUN 30	72/24.0	6.43/	.00	29	0.	0.	0.	167089.	20355.	.6067	4.1	.00	9.21	83400.
JUL 1	75/23.9	7.00/	.00	34	0.	0.	0.	183834.	22012.	.6098	4.1	.00	8.35	87080.
JUL 2	78/24.0	10.08/	.00	27	0.	0.	0.	204758.	28042.	.7235	2.7	.00	7.30	83680.
JUL 3	77/24.0	12.23/	.00	29	0.	0.	0.	283102.	33331.	.7317	2.8	.00	7.89	98120.
JUL 4	75/24.0	8.44/	.00	31	0.	0.	0.	202294.	24816.	.6474	2.7	.00	8.25	111720.
JUL 5	70/24.0	6.07/	.00	40	0.	0.	0.	204084.	20834.	.5584	2.6	.00	9.89	91960.
JUL 6	59/24.0	3.11/	.00	28	0.	0.	0.	112569.	11078.	.4940	2.1	.00	10.16	61640.
JUL 7	61/24.0	2.76/	.00	24	0.	0.	0.	89810.	10134.	.4869	2.2	.00	8.74	77240.
JUL 8	68/24.0	3.92/	.00	29	0.	0.	0.	127089.	14238.	.5436	2.5	.00	8.93	78820.
JUL 9	68/24.0	3.58/	.00	28	0.	0.	0.	116377.	12851.	.4956	2.5	.00	9.06	71400.
JUL 10	67/24.0	4.53/	.00	30	0.	0.	0.	142400.	15577.	.5589	2.5	.00	9.14	101800.
JUL 11	71/24.0	6.06/	.00	22	0.	0.	0.	150574.	18148.	.6817	2.7	.00	8.30	112800.
JUL 12	77/24.0	10.71/	.00	22	0.	0.	0.	209785.	29093.	.7716	2.7	.00	7.21	97920.
JUL 13	77/24.0	10.97/	.00	30	0.	0.	0.	267562.	31722.	.7258	4.1	.00	8.43	95640.
JUL 14	75/24.0	10.48/	.00	24	0.	0.	0.	233155.	23851.	.7417	2.7	.00	8.08	103400.
JUL 15	80/24.0	12.30/	.00	28	0.	0.	0.	272713.	34978.	.7504	2.7	.00	7.80	108320.
JUL 16	80/24.0	8.55/	.00	19	0.	0.	0.	178082.	23909.	.7728	2.7	.00	7.45	83760.
JUL 17	68/23.9	12.55/	.00	26	0.	0.	0.	282607.	15702.	.7648	.0	.00	18.00	89560.
JUL 18	74/24.0	9.08/	.00	30	0.	0.	0.	208449.	25431.	.6919	2.7	.00	8.12	117560.
JUL 19	72/20.0	5.44/	.00	32	0.	0.	0.	154969.	16030.	.5259	2.5	.00	9.66	61840.
JUL 20	75/12.2	6.93/	.00	16	0.	0.	0.	141149.	18579.	.7283	4.2	.00	7.60	61640.
JUL 21	76/24.0	9.51/	.00	36	0.	0.	0.	248713.	29545.	.6327	4.4	.00	8.42	92760.
JUL 22	70/24.0	8.59/	.00	33	0.	0.	0.	198752.	22116.	.6178	3.3	.00	8.99	80040.
JUL 23	69/24.0	4.25/	.00	35	0.	0.	0.	143142.	14748.	.4687	2.5	.00	9.71	76560.
JUL 24	73/23.8	8.23/	.00	37	0.	0.	0.	195520.	23004.	.6104	2.7	.00	8.50	88360.
JUL 25	69/24.0	6.80/	.00	33	0.	0.	0.	169869.	18882.	.5882	2.6	.00	9.01	98120.
JUL 26	72/24.0	6.95/	.00	34	0.	0.	0.	182569.	20509.	.5738	2.7	.00	8.90	80040.
JUL 27	75/24.0	10.70/	.00	28	0.	0.	0.	215616.	26896.	.7009	2.7	.00	8.02	101160.
JUL 28	78/24.0	11.21/	.00	37	0.	0.	0.	278283.	32964.	.6483	4.3	.00	8.44	95480.
JUL 29	78/24.0	12.34/	.00	37	0.	0.	0.	289294.	32531.	.6786	2.7	.00	8.28	102680.
JUL 30	79/23.9	12.23/	.00	33	0.	0.	0.	283712.	35016.	.6865	4.3	.00	8.10	95640.
JUL 31	78/24.0	12.55/	.00	31	0.	0.	0.	268296.	34159.	.7237	2.7	.00	7.85	109880.
AUG 1	71/24.0	8.03/	.00	40	0.	0.	0.	240194.	25133.	.5890	3.7	.00	9.56	114520.
AUG 2	72/24.0	7.81/	.00	31	0.	0.	0.	180452.	21877.	.6398	2.6	.00	8.25	81480.
AUG 3	76/24.0	9.99/	.00	34	0.	0.	0.	249235.	29169.	.6578	4.1	.00	8.54	91200.
AUG 4	72/24.0	6.53/	.00	36	0.	0.	0.	169209.	19684.	.5847	2.6	.00	8.64	80200.
AUG 5	74/24.0	10.01/	.00	33	0.	0.	0.	210260.	25567.	.6403	2.6	.00	8.24	94080.
AUG 6	73/24.0	8.16/	.00	42	0.	0.	0.	208389.	23466.	.5728	2.5	.00	8.80	80600.
AUG 7	74/24.0	9.96/	.00	41	0.	0.	0.	245487.	28198.	.6229	2.8	.00	8.71	88240.
AUG 8	77/24.0	10.77/	.00	42	0.	0.	0.	282780.	31510.	.6385	4.2	.00	8.34	99040.
AUG 9	73/23.8	9.77/	.00	37	0.	0.	0.	230751.	26279.	.6406	3.7	.00	8.78	97840.
AUG 10	70/23.9	7.44/	.00	37	0.	0.	0.	214235.	22518.	.5875	4.0	.00	9.52	97960.
AUG 11	70/24.0	6.24/	.00	41	0.	0.	0.	186923.	20008.	.5246	2.5	.00	9.34	89280.
AUG 12	63/24.0	3.83/	.00	37	0.	0.	0.	133822.	13833.	.4914	2.4	.00	9.67	98360.
AUG 13	63/24.0	2.56/	.00	16	0.	0.	0.	61582.	8834.	.5334	2.4	.00	6.97	58840.
AUG 14	66/24.0	2.02/	.00	19	0.	0.	0.	60799.	8323.	.4542	2.2	.00	7.30	53600.
AUG 15	70/24.0	5.79/	.00	27	0.	0.	0.	183727.	16378.	.6032	2.5	.00	8.17	77680.
AUG 16	73/24.0	8.15/	.00	32	0.	0.	0.	195784.	22282.	.6207	2.7	.00	8.79	109040.
AUG 17	75/24.0	10.05/	.00	34	0.	0.	0.	228712.	27503.	.6583	4.2	.00	8.24	105520.
AUG 18	75/24.0	8.46/	.00	44	0.	0.	0.	213210.	24140.	.5614	2.6	.00	8.83	88720.
AUG 19	77/24.0	10.51/	.00	37	0.	0.	0.	244102.	29102.	.6508	2.7	.00	8.39	88640.
AUG 20	80/24.0	10.83/	.00	42	0.	0.	0.	306360.	37714.	.6556	4.5	.00	8.12	95000.
AUG 21	73/24.0	8.70/	.00	40	0.	0.	0.	238735.	26431.	.5894	2.6	.00	9.39	93480.
AUG 22	80/24.0	11.02/	.00	38	0.	0.	0.	292770.	35893.	.6504	4.5	.00	8.16	111400.

Table F-1 - Continued

AUG 23	75/24.0	8.62/	.00	41	0.	0.	0.	214269.	24266.	.5869	2.6	.00	8.83	81720.
AUG 24	76/24.0	5.94/	.00	44	0.	0.	0.	212392.	23254.	.5252	4.2	.00	9.13	72000.
AUG 25	77/24.0	5.58/	.00	25	0.	0.	0.	160798.	20027.	.6214	4.2	.00	8.03	85360.
AUG 26	79/24.0	14.48/	.00	12	0.	0.	0.	243236.	36404.	.8820	2.7	.00	6.68	96480.
AUG 27	76/24.0	9.75/	.00	42	0.	0.	0.	278713.	30171.	.6119	4.2	.00	9.07	101880.
AUG 28	72/24.0	7.55/	.00	35	0.	0.	0.	198129.	21424.	.6015	2.6	.00	9.15	98600.
AUG 29	72/24.0	6.73/	.00	46	0.	0.	0.	225414.	22224.	.5125	3.0	.00	10.14	102080.
AUG 30	72/24.0	7.70/	.00	37	0.	0.	0.	231910.	26077.	.6053	4.2	.00	8.99	89240.
AUG 31	67/24.0	4.27/	.00	39	0.	0.	0.	150518.	14517.	.4556	2.5	.00	10.37	76880.
SEP 1	69/24.0	4.71/	.00	30	0.	0.	0.	128355.	14931.	.5435	2.5	.00	8.63	76720.
SEP 2	72/24.0	7.08/	.00	34	0.	0.	0.	189259.	21087.	.5864	4.2	.00	8.97	87880.
SEP 3	73/24.0	7.18/	.00	39	0.	0.	0.	193442.	21491.	.5613	2.7	.00	9.28	80480.
SEP 4	74/24.0	9.02/	.00	35	0.	0.	0.	187420.	23370.	.6234	2.6	.00	8.45	89040.
SEP 5	74/24.0	8.85/	.00	29	0.	0.	0.	190306.	24767.	.6648	2.6	.00	7.70	89040.
SEP 6	78/24.0	12.45/	.00	32	0.	0.	0.	287784.	34082.	.7237	4.3	.00	7.98	184240.
SEP 7	73/24.0	10.70/	.00	32	0.	0.	0.	288520.	27688.	.7009	2.6	.00	8.43	91080.
SEP 8	68/24.0	5.11/	.00	20	0.	0.	0.	120189.	15375.	.6779	3.5	.00	7.92	74040.
SEP 9	72/24.0	7.07/	.00	2	0.	0.	0.	125028.	19141.	.9303	2.7	.00	6.53	92640.
SEP 10	77/24.0	12.07/	.00	30	0.	0.	0.	271729.	33332.	.7429	4.3	.00	8.08	97480.
SEP 11	76/23.8	12.72/	.00	28	0.	0.	0.	255047.	34563.	.8106	2.6	.00	7.87	118840.
SEP 12	68/24.0	7.61/	.00	30	0.	0.	0.	146932.	17860.	.5760	2.5	.00	8.22	91560.
SEP 13	60/22.5	1.71/	.00	19	0.	0.	0.	63680.	9227.	.4803	2.0	.00	7.72	74760.
SEP 14	56/24.0	1.22/	.00	11	0.	0.	0.	42589.	5529.	.3995	2.0	.00	7.72	64840.
SEP 15	58/24.0	1.03/	.00	8	0.	0.	0.	41593.	5491.	.4695	2.4	.00	7.59	83360.
SEP 16	58/24.0	.00/	.00	0	0.	0.	0.	1746.	2225.	.0000	.2	.00	.78	65880.
SEP 17	62/24.0	3.11/	.00	22	0.	0.	0.	108024.	10857.	.4964	2.5	.00	9.77	88240.
SEP 18	69/24.0	5.70/	.00	19	0.	0.	0.	147227.	16935.	.5541	2.7	.00	8.69	95240.
SEP 19	76/23.8	9.38/	.00	23	0.	0.	0.	282041.	27792.	.6448	4.1	.00	9.07	129400.
SEP 20	75/21.0	9.79/	.00	23	0.	0.	0.	257282.	27907.	.6430	4.1	.00	9.22	99000.
SEP 21	59/24.0	2.43/	.00	24	0.	0.	0.	116252.	9970.	.4236	2.3	.00	11.66	79480.
SEP 22	47/24.0	.00/	.00	0	0.	0.	0.	0.	2245.	.0000	.2	.00	.00	67680.
SEP 23	46/24.0	2.59/	.00	14	67802.	9225.	0.	0.	19.	.0000	2.4	7.35	.00	93760.
SEP 24	49/24.0	1.92/	.00	13	55152.	8020.	0.	0.	0.	.0000	2.2	6.88	.00	97160.
SEP 25	56/24.0	.80/	.00	4	19114.	4581.	0.	0.	0.	.0000	2.2	4.17	.00	80560.
SEP 26	59/24.0	.00/	.00	0	0.	2723.	0.	0.	0.	.0000	.3	.00	.00	87400.
SEP 27	61/24.0	.00/	.00	0	0.	2752.	0.	0.	0.	.0000	.3	.00	.00	82380.
SEP 28	60/24.0	.00/	.00	0	0.	2829.	0.	0.	0.	.0000	.2	.00	.00	84040.
SEP 29	60/24.0	9.53/	.00	6	29740.	4107.	0.	166846.	20884.	.9304	2.6	7.24	7.98	129600.
SEP 30	56/23.8	.00/	.00	0	1419.	2816.	0.	0.	0.	.0000	.3	.54	.00	74280.
OCT 1	63/24.2	.00/	.00	0	0.	2751.	0.	0.	0.	.0000	.2	.00	.00	84920.
OCT 2	61/24.0	2.68/	.00	9	116.	1767.	0.	86831.	7408.	.5618	2.4	.07	11.69	82800.
OCT 3	66/24.0	4.28/	.00	18	0.	0.	0.	124359.	13621.	.6022	2.6	.00	9.13	81680.
OCT 4	67/24.0	3.18/	.00	23	0.	0.	0.	102912.	11743.	.5727	2.6	.00	8.76	83600.
OCT 5	62/24.0	1.23/	.00	7	0.	0.	0.	61741.	5664.	.4660	2.5	.00	10.90	72120.
OCT 6	56/24.0	1.40/	.00	16	0.	0.	0.	152640.	7138.	.2203	2.4	.00	21.38	77720.
OCT 7	55/24.0	.75/	.00	7	0.	0.	0.	51226.	4441.	.2368	2.1	.00	11.53	87000.
OCT 8	61/24.0	2.11/	.00	8	0.	0.	0.	96570.	7032.	.3315	2.4	.00	13.73	71400.
OCT 9	54/24.0	.00/	.00	0	0.	0.	0.	0.	2193.	.0000	.2	.00	.00	84320.
OCT 10	55/24.0	.00/	.00	0	0.	0.	0.	0.	2225.	.0000	.2	.00	.00	95760.
OCT 11	57/24.0	.00/	.00	0	0.	0.	0.	0.	2216.	.0000	.2	.00	.00	70320.
OCT 12	66/24.0	.30/	.00	1	0.	0.	0.	17189.	2851.	.4174	2.5	.00	6.01	72440.
OCT 13	64/24.0	1.16/	.00	1	0.	0.	0.	40305.	4961.	.5085	2.6	.00	8.12	81280.
OCT 14	48/24.0	.00/	.00	0	0.	0.	0.	0.	2203.	.0000	.2	.00	.00	80920.
OCT 15	51/24.0	.00/	.00	0	0.	0.	0.	0.	2225.	.0000	.2	.00	.00	70880.
OCT 16	57/24.0	.00/	.00	0	0.	0.	0.	996.	2187.	1.0000	.2	.00	.45	80960.
OCT 17	58/24.0	.00/	.00	0	0.	0.	0.	0.	2216.	.0000	.2	.00	.00	92720.
OCT 18	48/24.0	.14/	.00	1	7750.	678.	0.	409.	1946.	1.0000	1.7	11.48	.21	82960.
OCT 19	49/24.0	.97/	.00	2	26814.	5197.	0.	0.	0.	.0000	3.7	5.13	.00	79160.
OCT 20	48/24.0	1.13/	.00	10	38583.	5224.	9222.	0.	0.	.0000	15.4	7.39	.00	83120.
OCT 21	47/24.0	1.67/	.00	14	54359.	6954.	16682.	0.	0.	.0000	15.6	9.13	.00	101800.
OCT 22	46/24.0	5.05/	.00	39	185664.	18280.	0.	0.	0.	.0000	2.4	10.15	.00	88600.
OCT 23	52/24.0	1.97/	.00	12	64697.	8103.	0.	0.	0.	.0000	2.4	7.87	.00	96760.
OCT 24	53/24.0	1.90/	.00	14	60381.	8116.	0.	0.	0.	.0000	2.2	7.44	.00	85200.
OCT 25	49/21.9	1.07/	.00	13	44810.	6150.	0.	0.	0.	.0000	2.3	7.29	.00	82680.
OCT 26	43/22.8	2.86/	.00	21	92229.	11457.	0.	0.	0.	.0000	3.5	8.05	.00	90520.
OCT 27	41/24.0	5.74/	.00	28	185824.	20194.	0.	0.	0.	.0000	3.9	9.20	.00	84560.
OCT 28	58/24.0	3.75/	.00	15	88557.	11400.	0.	0.	0.	.0000	2.4	7.77	.00	78160.
OCT 29	45/23.9	1.45/	.00	10	40635.	7027.	0.	0.	0.	.0000	3.5	5.78	.00	76560.
OCT 30	39/24.0	3.87/	.00	23	161539.	17882.	0.	0.	0.	.0000	3.7	9.03	.00	104080.
OCT 31	48/24.0	4.00/	.00	19	125033.	15089.	0.	0.	0.	.0000	3.9	8.29	.00	81280.
NOV 1	54/24.0	1.83/	.00	16	63397.	8449.	0.	0.	0.	.0000	2.4	7.51	.00	69800.
NOV 2	59/24.0	.99/	.00	9	29412.	5524.	0.	0.	0.	.0000	2.1	5.32	.00	91120.
NOV 3	50/24.0	.42/	.00	5	16378.	4388.	0.	0.	0.	.0000	3.3	3.73	.00	89160.
NOV 4	33/24.0	5.98/	.00	44	311209.	31456.	0.	0.	0.	.0000	3.8	9.89	.00	102960.
NOV 5	36/24.0	6.40/	.00	37	270003.	30235.	0.	0.	0.	.0000	16.1	8.93	.00	103680.
NOV 6	41/24.0	6.81/	.00	33	167039.	18970.	0.	0.	0.	.0000	3.3	8.81	.00	105040.

Table F-1 - Continued

NOV	7	44/24.0	7.08/	.00	41	198181.	21340.	0.	0.	0.	.0000	2.4	9.29	.00	96400.
NOV	8	52/24.0	3.50/	.00	18	90927.	11458.	0.	0.	0.	.0000	3.6	7.94	.00	96360.
NOV	9	56/24.0	1.11/	.00	13	42156.	6593.	0.	0.	0.	.0000	2.2	6.39	.00	80320.
NOV	10	52/24.0	.00/	.00	0	0.	2577.	0.	0.	0.	.0000	.2	.00	.00	76400.
NOV	11	37/24.0	4.50/	.00	41	217849.	22882.	0.	0.	0.	.0000	3.8	9.52	.00	107200.
NOV	12	29/24.0	8.35/	.00	46	412770.	49095.	0.	0.	0.	.0000	14.5	8.41	.00	120520.
NOV	13	29/24.0	8.10/	.00	36	346371.	41314.	0.	0.	0.	.0000	15.6	8.46	.00	128240.
NOV	14	33/24.0	6.33/	.00	29	278111.	33270.	0.	0.	0.	.0000	13.9	8.36	.00	136600.
NOV	15	39/24.0	7.47/	.00	39	265339.	26676.	0.	0.	0.	.0000	3.9	9.96	.00	118920.
NOV	16	36/24.0	7.37/	.00	42	304017.	28902.	0.	0.	0.	.0000	3.9	10.52	.00	112600.
NOV	17	34/24.0	6.69/	.00	47	394311.	38449.	0.	0.	0.	.0000	16.0	10.26	.00	111040.
NOV	18	43/24.0	5.09/	.00	18	192586.	22969.	0.	0.	0.	.0000	16.6	8.39	.00	92600.
NOV	19	50/24.0	2.77/	.00	19	87566.	10116.	0.	0.	0.	.0000	2.4	8.66	.00	102880.
NOV	20	55/23.8	2.72/	.00	27	118609.	12238.	0.	0.	0.	.0000	2.8	9.29	.00	60840.
NOV	21	49/24.0	3.60/	.00	32	147029.	14781.	0.	0.	0.	.0000	2.3	9.95	.00	60280.
NOV	22	54/24.0	2.98/	.00	22	111846.	11746.	0.	0.	0.	.0000	2.4	9.52	.00	56880.
NOV	23	58/23.4	2.04/	.00	20	68928.	9281.	1422.	0.	0.	.0000	5.5	9.39	.00	55920.
NOV	24	49/23.9	3.74/	.00	32	193337.	15715.	0.	0.	0.	.0000	3.6	12.32	.00	78200.
NOV	25	33/24.0	5.70/	.00	37	297572.	30873.	0.	0.	0.	.0000	14.7	9.64	.00	124960.
NOV	26	44/24.0	4.24/	.00	27	195853.	18902.	0.	0.	0.	.0000	3.9	10.37	.00	104200.
NOV	27	48/24.0	3.35/	.00	24	120578.	12497.	0.	0.	0.	.0000	2.4	9.66	.00	98960.
NOV	28	49/24.0	2.68/	.00	24	111542.	11226.	0.	0.	0.	.0000	2.4	9.94	.00	91320.
NOV	29	35/24.0	4.53/	.00	20	192939.	19230.	0.	0.	0.	.0000	3.9	10.03	.00	112600.
NOV	30	35/24.0	10.20/	.00	38	399821.	35962.	0.	0.	0.	.0000	3.9	11.12	.00	110320.
DEC	1	27/24.0	9.05/	.00	42	409465.	38244.	0.	0.	0.	.0000	3.7	10.68	.00	122040.
DEC	2	27/24.0	11.62/	.00	45	505750.	52268.	0.	0.	0.	.0000	13.0	9.68	.00	126640.
DEC	3	33/24.0	8.04/	.00	39	390264.	39268.	0.	0.	0.	.0000	13.2	9.94	.00	112680.
DEC	4	38/24.0	6.20/	.00	46	324729.	31419.	0.	0.	0.	.0000	17.1	10.34	.00	118560.
DEC	5	41/24.0	6.99/	.00	45	255378.	23505.	0.	0.	0.	.0000	3.6	10.88	.00	103120.
DEC	6	43/20.4	5.02/	.00	31	193388.	17234.	0.	0.	0.	.0000	3.5	11.22	.00	102880.
DEC	7	28/24.0	10.78/	.00	39	417617.	39949.	0.	0.	0.	.0000	3.7	10.45	.00	129280.
DEC	8	29/24.0	10.01/	.00	43	467750.	45061.	0.	6982.	173.	.3050	14.9	10.38	39.57	160960.
DEC	9	33/24.0	8.50/	.00	39	478079.	42255.	0.	0.	0.	.0000	15.7	11.31	.00	114360.
DEC	10	36/24.0	5.61/	.00	41	357875.	30850.	0.	0.	0.	.0000	16.8	11.60	.00	118440.
DEC	11	39/24.0	5.58/	.00	38	295979.	26847.	0.	0.	0.	.0000	18.5	11.06	.00	112160.
DEC	12	43/24.0	7.00/	.00	35	241090.	19970.	0.	0.	0.	.0000	2.4	12.07	.00	129380.
DEC	13	41/24.0	7.21/	.00	44	250861.	21093.	0.	0.	0.	.0000	2.4	11.89	.00	121400.
DEC	14	43/24.0	6.46/	.00	27	189127.	17138.	0.	0.	0.	.0000	2.3	11.04	.00	99920.
DEC	15	40/22.4	6.26/	.00	37	213981.	19489.	0.	0.	0.	.0000	3.7	10.93	.00	98000.
DEC	16	29/23.9	9.02/	.00	43	477933.	42097.	0.	0.	0.	.0000	14.1	11.35	.00	116120.
DEC	17	23/24.0	14.93/	.00	36	585210.	54340.	0.	0.	0.	.0000	15.4	10.77	.00	130120.
DEC	18	21/16.8	7.73/	.00	18	303855.	30555.	0.	0.	0.	.0000	15.2	9.94	.00	93160.
DEC	18	25/ 7.1	.00/	.00	0	631.	193.	50588.	0.	0.	.0000	15.8	8.27	.00	76560.
DEC	19	15/23.9	8.09/	.00	11	270875.	29427.	63444.	0.	0.	.0000	18.9	9.21	.00	193680.
DEC	20	15/24.0	6.67/	.00	8	233574.	33442.	47885.	0.	0.	.0000	15.7	6.98	.00	199720.
DEC	21	23/24.0	3.63/	.00	14	188895.	15654.	112389.	0.	0.	.0000	15.9	12.07	.00	220680.
DEC	22	33/24.0	6.78/	.00	28	334894.	28611.	0.	0.	0.	.0000	4.2	11.71	.00	120240.
DEC	23	12/24.0	19.02/	.00	25	941217.	62519.	0.	0.	0.	.0000	3.5	15.05	.00	151880.
DEC	24	-1/24.0	9.86/	.00	37	498147.	111830.	49937.	0.	0.	.0000	17.9	4.45	.00	255480.
DEC	25	-7/24.0	4.86/	.00	28	309747.	75088.	88638.	0.	0.	.0000	18.0	4.13	.00	282520.
DEC	26	2/24.0	7.74/	.00	27	325698.	69184.	100528.	0.	0.	.0000	16.2	4.71	.00	276840.
DEC	27	18/24.0	17.03/	.00	32	606280.	82070.	0.	0.	0.	.0000	14.6	7.39	.00	190600.
DEC	28	35/23.9	10.48/	.00	40	501826.	42307.	0.	11885.	185.	.2500	12.4	11.86	65.90	128840.
DEC	29	17/24.0	11.13/	.00	25	452482.	69403.	0.	0.	0.	.0000	14.4	6.52	.00	164880.
DEC	30	6/24.0	15.78/	.00	39	594870.	125225.	0.	0.	0.	.0000	8.5	4.75	.00	206000.
DEC	31	13/24.0	13.53/	.00	34	547914.	90222.	0.	0.	0.	.0000	17.2	6.07	.00	187240.
JAN	1	27/24.0	10.76/	.00	40	523723.	43274.	0.	0.	0.	.0000	3.8	12.10	.00	132720.
JAN	2	30/24.0	10.20/	.00	40	512350.	44630.	0.	0.	0.	.0000	12.3	11.48	.00	121440.
JAN	3	31/24.0	9.16/	.00	25	463110.	45418.	0.	0.	0.	.0000	13.6	10.20	.00	149000.
JAN	4	35/23.9	6.91/	.00	12	325850.	31114.	0.	0.	0.	.0000	15.3	10.47	.00	117440.
JAN	5	34/21.4	7.28/	.00	41	440220.	41987.	0.	0.	0.	.0000	15.2	10.48	.00	114720.
JAN	6	35/24.0	7.76/	.00	42	472138.	39922.	0.	0.	0.	.0000	16.1	11.83	.00	109440.
JAN	7	23/24.0	12.57/	.00	29	531804.	53429.	0.	0.	0.	.0000	14.5	9.95	.00	121400.
JAN	8	26/24.0	14.09/	.00	34	588560.	54400.	0.	0.	0.	.0000	16.3	10.62	.00	150600.
JAN	9	28/24.0	13.50/	.00	36	565303.	48639.	0.	0.	0.	.0000	3.9	11.62	.00	136200.
JAN	10	28/24.0	11.25/	.00	39	484867.	46023.	0.	7391.	173.	.2767	13.3	10.54	42.62	162560.
JAN	11	10/24.0	13.09/	.00	39	542680.	68989.	0.	0.	0.	.0000	16.5	6.10	.00	189160.
JAN	12	13/24.0	13.64/	.00	32	540512.	92648.	0.	0.	0.	.0000	13.2	5.83	.00	176120.
JAN	13	27/15.7	8.15/	.00	17	309841.	35492.	0.	0.	0.	.0000	8.8	8.49	.00	91400.
JAN	14	28/24.0	10.97/	.00	41	417982.	49472.	0.	0.	0.	.0000	15.3	8.45	.00	142320.
JAN	15	13/24.0	16.80/	.00	31	551884.	70284.	0.	0.	0.	.0000	16.0	7.85	.00	151480.
JAN	16	19/24.0	15.21/	.00	13	502136.	56650.	9819.	0.	0.	.0000	15.7	8.86	.00	156800.
JAN	17	23/24.0	4.25/	4.07	11	133010.	58247.	55379.	0.	0.	.0000	15.8	2.28	.00	206080.
JAN	18	21/24.0	16.79/16.00		33	550612.	68561.	0.	0.	0.	.0000	16.9	8.03	.00	159640.
JAN	19	8/24.0	13.34/13.60		47	600990.	126911.	0.	0.	0.	.0000	17.3	4.74	.00	241120.
JAN	20	3/24.0	15.41/14.41		40	683340.	161509.	0.	0.	0.	.0000	17.5	4.23	.00	250880.

Table F-1 - Continued

JAN 21	-2/24.0	14.32/13.50	52	731608.	171832.	0.	0.	0.	.0000	18.0	4.26	.00	281000.
JAN 22	13/24.0	13.44/13.30	47	559785.	106498.	0.	0.	0.	.0000	16.3	5.26	.00	187880.
JAN 23	30/24.0	11.70/11.71	31	428047.	48038.	0.	0.	0.	.0000	8.6	8.01	.00	134920.
JAN 24	42/24.0	7.07/ 7.93	37	262139.	26944.	0.	0.	0.	.0000	4.0	9.73	.00	121120.
JAN 25	37/24.0	4.46/ 6.15	39	249097.	26108.	0.	0.	0.	.0000	3.8	9.54	.00	108360.
JAN 26	39/24.0	5.69/ 6.17	27	229278.	27408.	0.	0.	0.	.0000	12.6	8.37	.00	113760.
JAN 27	36/24.0	5.24/ 5.82	30	227097.	24276.	0.	0.	0.	.0000	3.8	9.35	.00	116160.
JAN 28	23/24.0	12.50/12.02	32	410054.	44881.	0.	0.	0.	.0000	4.1	9.14	.00	120160.
JAN 29	31/24.0	8.98/10.19	41	391610.	46929.	0.	0.	0.	.0000	13.8	8.34	.00	132480.
JAN 30	30/24.0	10.96/11.12	37	418621.	50777.	0.	0.	0.	.0000	15.8	8.24	.00	163400.
JAN 31	19/24.0	16.98/15.49	34	511970.	61652.	0.	0.	0.	.0000	16.0	8.30	.00	135560.
FEB 1	22/24.0	12.38/12.37	39	508225.	76852.	0.	0.	0.	.0000	13.9	6.61	.00	146480.
FEB 2	38/24.0	8.93/ 9.30	31	297749.	32416.	0.	0.	0.	.0000	3.7	9.19	.00	98160.
FEB 3	42/24.0	8.43/ 9.27	36	246707.	26279.	0.	0.	0.	.0000	3.9	9.39	.00	97520.
FEB 4	37/24.0	6.24/ 7.11	34	254367.	30481.	0.	0.	0.	.0000	16.0	8.35	.00	114760.
FEB 5	30/23.9	7.46/ 8.46	37	320860.	36364.	0.	0.	0.	.0000	15.0	8.93	.00	148200.
FEB 6	21/24.0	14.51/14.01	34	485001.	55061.	0.	0.	0.	.0000	16.0	8.81	.00	175760.
FEB 7	16/24.0	18.18/17.62	32	606032.	82148.	0.	0.	0.	.0000	17.5	7.38	.00	164760.
FEB 8	20/24.0	15.96/15.70	29	519747.	64897.	0.	0.	0.	.0000	16.5	8.01	.00	142080.
FEB 9	35/24.0	8.89/ 9.14	31	319314.	33899.	0.	0.	0.	.0000	3.7	9.42	.00	125880.
FEB 10	46/24.0	4.55/ 5.10	28	178004.	19363.	0.	0.	0.	.0000	3.9	9.19	.00	114480.
FEB 11	48/18.9	3.81/*****	32	133625.	14586.	0.	0.	0.	.0000	2.4	9.16	.00	75440.
FEB 12	53/ 1.7	.00/*****	0	0.	145.	0.	0.	0.	.0000	.1	.00	.00	7960.
FEB 13	53/23.2	.18/ .00	1	4863.	2698.	0.	0.	0.	.0000	2.1	1.80	.00	119620.
FEB 14	48/24.0	3.36/ 4.35	29	116766.	13642.	0.	0.	0.	.0000	3.5	8.56	.00	110160.
FEB 15	43/24.0	2.68/ 4.13	30	152286.	17120.	0.	0.	0.	.0000	3.7	8.30	.00	94120.
FEB 16	46/24.0	2.00/ 2.66	15	102801.	12579.	0.	0.	0.	.0000	3.8	8.16	.00	102000.
FEB 17	48/24.0	3.05/ 4.08	25	98054.	12043.	0.	0.	0.	.0000	2.4	7.98	.00	94880.
FEB 18	44/24.0	7.24/ 8.04	39	184128.	21283.	0.	0.	0.	.0000	2.4	8.66	.00	98960.
FEB 19	50/24.0	4.90/ 5.41	25	132337.	15251.	0.	0.	0.	.0000	2.4	8.68	.00	101640.
FEB 20	36/24.0	5.11/ 6.57	45	255582.	28082.	0.	0.	0.	.0000	3.6	9.10	.00	111400.
FEB 21	33/24.0	8.70/ 9.42	41	363529.	41390.	0.	0.	0.	.0000	17.3	8.78	.00	148920.
FEB 22	40/24.0	7.20/ 7.56	26	248105.	33419.	0.	0.	0.	.0000	17.8	7.42	.00	111000.
FEB 23	47/24.0	3.04/ 3.48	15	103344.	10895.	690.	0.	0.	.0000	4.0	9.49	.00	110360.
FEB 24	49/24.0	.28/ .28	3	6086.	2168.	16907.	0.	0.	.0000	16.3	2.81	.00	102720.
FEB 25	33/24.0	6.44/ 7.58	38	262341.	32123.	0.	0.	0.	.0000	14.2	8.17	.00	110040.
FEB 26	27/24.0	10.62/10.81	35	359157.	43227.	0.	0.	0.	.0000	16.3	8.31	.00	138840.
FEB 27	27/24.0	11.84/12.09	38	434498.	48432.	0.	0.	0.	.0000	9.4	8.97	.00	145240.
FEB 28	30/24.0	10.68/10.48	37	391971.	50132.	0.	0.	0.	.0000	14.3	7.82	.00	135160.
FEB 29	18/24.0	16.06/15.06	33	504480.	58933.	0.	0.	0.	.0000	15.4	8.56	.00	158840.
MAR 1	19/23.9	14.58/14.46	35	522128.	70298.	0.	0.	0.	.0000	17.3	7.43	.00	168440.
MAR 2	22/24.0	14.14/13.61	31	453647.	48512.	0.	0.	0.	.0000	3.6	9.35	.00	151640.
MAR 3	22/24.0	10.84/10.83	37	411587.	50706.	0.	0.	0.	.0000	9.0	6.78	.00	142120.
MAR 4	27/24.0	8.95/ 9.76	35	357857.	42784.	0.	0.	0.	.0000	3.9	8.36	.00	145360.
MAR 5	43/24.0	5.83/ 7.82	45	259943.	26241.	0.	0.	0.	.0000	4.0	9.91	.00	120960.
MAR 6	30/24.0	7.71/ 8.86	40	318890.	34989.	0.	0.	0.	.0000	3.7	9.12	.00	118560.
MAR 7	25/24.0	10.54/10.79	41	379282.	44497.	0.	0.	0.	.0000	16.1	9.52	.00	126160.
MAR 8	21/24.0	16.33/15.30	37	527986.	60875.	0.	0.	0.	.0000	11.6	8.67	.00	145040.
MAR 9	12/24.0	11.85/11.70	41	475168.	87386.	0.	0.	0.	.0000	10.0	5.44	.00	171320.
MAR 10	17/24.0	12.95/12.67	35	470621.	76711.	0.	0.	0.	.0000	10.3	6.13	.00	155120.
MAR 11	23/24.0	11.20/11.07	38	403863.	50785.	0.	0.	0.	.0000	8.9	7.95	.00	132960.
MAR 12	21/24.0	9.40/10.96	42	445284.	66491.	0.	0.	0.	.0000	8.7	6.70	.00	181200.
MAR 13	33/23.9	9.18/10.15	45	395973.	45364.	0.	0.	0.	.0000	13.5	8.73	.00	140960.
MAR 14	34/24.0	7.93/ 8.97	41	358350.	45493.	0.	0.	0.	.0000	16.2	7.88	.00	133040.
MAR 15	47/24.0	4.33/ 4.48	19	166673.	20698.	0.	0.	0.	.0000	13.7	7.98	.00	119160.
MAR 16	45/21.4	2.80/*****	26	125885.	14393.	0.	0.	0.	.0000	3.4	8.75	.00	100640.
MAR 17	32/23.9	5.80/ 7.59	45	285898.	33636.	0.	0.	0.	.0000	14.3	8.50	.00	111840.
MAR 18	40/24.0	4.84/ 6.27	38	216097.	23400.	0.	0.	0.	.0000	3.8	9.23	.00	115800.
MAR 19	39/23.9	4.31/ 6.25	48	230748.	26466.	0.	0.	0.	.0000	13.5	8.72	.00	105120.
MAR 20	56/24.0	3.21/ 3.70	14	84779.	10549.	0.	0.	0.	.0000	2.4	8.04	.00	124160.
MAR 21	40/24.0	2.89/ 4.05	30	146198.	16995.	0.	0.	0.	.0000	3.5	8.60	.00	103600.
MAR 22	33/24.0	7.10/ 8.86	50	351928.	42720.	0.	0.	0.	.0000	16.9	8.24	.00	117600.
MAR 23	31/24.0	8.03/ 9.07	43	335690.	38571.	0.	0.	0.	.0000	15.3	8.70	.00	115520.
MAR 24	34/24.0	6.72/ 9.33	38	365706.	36982.	0.	0.	0.	.0000	3.9	9.99	.00	120840.
MAR 25	42/24.0	4.51/ 4.81	22	197942.	19643.	0.	0.	0.	.0000	3.8	10.08	.00	106120.
MAR 26	42/24.0	2.12/ 2.82	16	97531.	12158.	0.	0.	0.	.0000	3.8	8.02	.00	90480.
MAR 27	43/24.0	3.13/ 4.53	27	156080.	17861.	0.	0.	0.	.0000	3.8	8.74	.00	119960.
MAR 28	39/24.0	5.56/ 7.29	44	260117.	27910.	0.	0.	0.	.0000	3.9	9.32	.00	117360.
MAR 29	33/24.0	7.91/ 8.87	40	337286.	41787.	0.	0.	0.	.0000	15.6	8.07	.00	127240.
MAR 30	35/24.0	7.49/ 8.25	41	341824.	38185.	0.	0.	0.	.0000	16.2	8.95	.00	113560.
MAR 31	37/24.0	6.50/ 6.81	28	294953.	28588.	0.	3173.	154.	.8280	17.8	10.32	20.59	97000.

SUMMATIONS - HEATING:

DELIVERED HEAT =	54389944.	BTU
POWER USED =	6754.2986	KWH

Table F-1 - Continued

NORMAL HPF =	8.1267	
DEGREE-HOURS BELOW 72 DEG. F =	192742.08	
DEGREE-HOURS BELOW 65 DEG. F =	.00000000	
EMERGENCY POWER USED =	633.86948	KWH
SUMMATIONS - COOLING:		
ABSORBED TOTAL HEAT =	21099770.	BTU
ABSORBED LATENT HEAT =	7681152.1	BTU
COOLING ENERGY USED =	2528.8048	KWH
EER =	8.3537	
DEGREE-HOURS ABOVE 78 DEG. F =	3549.9967	
DEGREE-HOURS ABOVE 65 DEG. F =	.00000000	
SUMMATIONS - ENTIRE PERIOD:		
NUMBER OF OPERATING CYCLES =	8892	
COMPRESSOR HOURS	2219.7209	(FROM RELAY STATES)
COMPRESSOR HOURS =	375.72878	(FROM COUNTER)
TOTAL HOURS =	6573.2498	
AVERAGE TEMPERATURE =	50.64	DEGREES F

Table F-2 - Daily Summary April 1, 1984 through March 31, 1985

3/09/1986
DAILY SUMMARY OF FIELD TEST DATA--corrected for air flow
WESTINGHOUSE / DOE ADVANCED DUAL STROKE ELECTRIC HEAT PUMP
JEANNETTE SITE, APR 1, 1984 thru MAR 31, 1985

MON	DAY	AVG AMB TEMP degF	DATA HRS	COMP RUN HRS timer	COMP RUN HRS counter	CYC	NORMAL HEATING DELIVER BTU	NORMAL HEATING CONSUME WH	EMER WH	ABSORB BTU	COOLING CONSUME WH	S/T	PEAK kW	HEAT EER	COOL EER	WHOLE HOUSE WH	SEQ DAY
APR	1	41	23.9	4.18	4.63	17	225064	17777	0	0	0	0.00	3.8	12.66	0.00	84422	1
APR	2	44	24.0	2.66	2.95	14	137927	12467	0	0	0	0.00	3.8	11.06	0.00	84254	2
APR	3	47	24.0	2.21	2.59	14	119590	10636	0	0	0	0.00	3.8	11.24	0.00	118119	3
APR	4	45	24.0	4.64	5.47	30	170349	14740	0	0	0	0.00	2.3	11.56	0.00	86125	4
APR	5	47	24.0	2.86	3.97	26	141016	12409	0	0	0	0.00	3.4	11.36	0.00	87860	5
APR	6	36	24.0	6.18	7.46	43	398358	34380	0	0	0	0.00	17.1	11.59	0.00	91407	6
APR	7	36	24.0	6.86	8.14	42	417259	32880	0	0	0	0.00	15.7	12.69	0.00	102176	7
APR	8	44	24.0	2.69	3.13	14	165580	13873	0	0	0	0.00	3.9	11.94	0.00	95022	8
APR	9	47	24.0	1.65	2.02	11	92235	9018	0	0	0	0.00	3.7	10.23	0.00	79375	9
APR	10	47	24.0	1.73	1.98	11	98569	9528	0	0	0	0.00	3.6	10.35	0.00	110942	10
APR	11	49	24.0	1.61	1.75	9	87532	8594	0	0	0	0.00	3.6	10.19	0.00	88164	11
APR	12	47	9.4	0.31	0.44	3	13399	1750	0	0	0	0.00	2.1	7.66	0.00	25935	12
APR	13	56	24.0	0.00	0.00	0	16812	3029	0	0	0	0.00	0.5	5.55	0.00	92391	13
APR	14	53	24.0	0.00	0.00	0	0	1841	0	0	0	0.00	0.3	0.00	0.00	69778	14
APR	15	52	24.0	0.18	0.21	1	5861	2323	0	0	0	0.00	2.1	2.52	0.00	65427	15
APR	16	48	24.0	1.27	1.47	9	45615	5387	0	0	0	0.00	2.2	8.47	0.00	69715	16
APR	17	44	9.2	2.11	2.77	18	90170	7235	0	0	0	0.00	2.3	12.46	0.00	29671	17
APR	18	41	13.9	1.03	1.27	9	2945	5567	4304	0	0	0.00	5.7	0.53	0.00	57643	18
APR	19	40	24.0	4.92	5.96	33	14700	23477	0	0	0	0.00	4.2	0.63	0.00	93453	19
APR	20	45	24.0	2.66	3.48	23	6654	14297	0	0	0	0.00	3.8	0.64	0.00	84712	20
APR	21	48	24.0	1.51	2.15	15	5516	9404	0	0	0	0.00	3.5	0.59	0.00	98731	21
APR	22	40	24.0	2.32	2.49	13	6358	13709	0	0	0	0.00	3.4	0.46	0.00	126413	22
APR	23	46	24.0	3.07	4.19	25	10859	12765	0	0	0	0.00	3.5	0.85	0.00	92128	23
APR	24	41	24.0	5.42	6.41	37	15602	22071	0	0	0	0.00	3.5	0.71	0.00	120981	24
APR	25	52	24.0	2.69	3.47	18	8957	12313	0	0	0	0.00	3.9	0.73	0.00	79672	25
APR	26	53	10.1	0.80	1.03	7	1924	3230	0	0	0	0.00	2.1	0.60	0.00	23483	26
APR	27	68	37.9	3.78	4.78	24	118	2458	0	27232	12852	0.15	2.6	0.05	2.12	119311	27
APR	28	70	24.0	5.24	5.76	21	0	0	0	14675	15838	0.28	2.6	0.00	0.93	86952	28
APR	29	67	24.0	4.78	5.30	17	0	0	0	4981	14577	0.67	2.6	0.00	0.34	75743	29
APR	30	67	24.0	3.32	3.49	11	0	0	0	3301	10241	1.00	2.6	0.00	0.32	62556	30
MAY	1	51	24.0	0.00	0.00	0	0	0	0	0	1841	0.00	0.3	0.00	0.00	72842	31
MAY	2	45	6.8	0.00	0.00	0	0	0	0	0	518	0.00	0.3	0.00	0.00	13200	32
MAY	3	48	41.2	0.53	0.86	6	2221	2639	0	4	3170	1.00	2.6	0.84	0.00	161912	33
MAY	4	50	23.9	1.94	2.77	20	7984	9599	0	0	0	0.00	2.2	0.83	0.00	72662	34
MAY	5	48	23.7	2.03	3.00	22	102804	8995	0	0	0	0.00	2.3	11.43	0.00	83283	35
MAY	6	52	24.0	2.16	2.56	15	84375	7938	0	0	0	0.00	2.4	10.63	0.00	69369	36
MAY	7	58	24.0	0.65	1.01	8	38448	4375	0	0	0	0.00	2.2	8.79	0.00	104281	37
MAY	8	54	24.0	0.00	0.00	0	0	1861	0	0	0	0.00	0.3	0.00	0.00	69237	38
MAY	9	43	24.0	5.68	6.47	31	277631	21377	0	0	0	0.00	4.2	12.99	0.00	77261	39
MAY	10	51	24.0	2.66	3.25	17	116515	9442	0	0	0	0.00	2.4	12.34	0.00	80804	40
MAY	11	54	24.0	0.92	1.22	9	43557	4856	0	0	0	0.00	2.1	8.97	0.00	71930	41
MAY	12	62	24.0	0.00	0.00	0	0	1851	0	0	0	0.00	0.3	0.00	0.00	62129	42
MAY	13	56	24.0	0.00	0.00	0	0	1832	0	0	0	0.00	0.3	0.00	0.00	62836	43
MAY	14	46	24.0	0.84	1.27	7	37454	5251	0	0	0	0.00	2.1	7.13	0.00	102548	44
MAY	15	43	24.0	3.87	5.51	38	227086	18757	0	0	0	0.00	3.6	12.11	0.00	77856	45
MAY	16	44	24.0	2.43	2.93	17	149628	12659	0	0	0	0.00	3.8	11.82	0.00	77072	46
MAY	17	50	23.8	1.88	2.19	12	121675	10246	0	0	0	0.00	3.6	11.88	0.00	58555	47
MAY	18	6	24.0	0.67	0.80	5	47973	4519	0	0	0	0.00	2.1	10.62	0.00	85855	48

Table F-2 - Continued

MON	DAY	AVG AMB TEMP degF	DATA HRS	COMP RUN HRS timer	COMP RUN HRS counter	CYC	NORMAL HEATING DELIVER BTU	NORMAL HEATING CONSUME WH	EMER WH	COOLING ABSORB BTU	COOLING CONSUME WH	S/T	PEAK kW	HEAT EER	COOL EER	WHOLE HOUSE WH	SEQ DAY
MAY	19	65	24.0	0.17	0.37	4	32614	3547	0	0	135	0.00	2.1	9.19	0.00	52457	49
MAY	20	64	23.3	4.73	4.84	8	79	807	0	117550	12530	0.76	2.5	0.10	9.38	79373	50
MAY	21	67	24.0	1.24	1.77	13	0	0	0	35322	6301	0.64	2.2	0.00	5.61	81493	51
MAY	22	69	4.9	0.00	0.00	0	0	0	0	0	390	0.00	0.2	0.00	0.00	7701	52
MAY	23																53
MAY	24	57	22.4	1.37	1.79	11	0	0	0	66088	5656	0.93	2.2	0.00	11.68	57178	54
MAY	*25	66	23.0	4.08	4.64	12	0	0	0	104618	11849	0.24	2.6	0.00	8.83	67328	55
MAY	26																56
MAY	27																57
MAY	28	60	24.0	0.84	0.86	4	0	0	0	718	3778	1.00	2.3	0.00	0.19	78369	58
MAY	29	55	23.4	0.51	0.50	2	0	0	0	902	2931	1.00	2.3	0.00	0.31	89639	59
MAY	*30	46	23.8	1.12	1.30	7	41381	4879	0				2.2	8.48	0.00	63368	60
MAY	31	53	24.0	2.09	2.85	17	7159	9037	0	0	0	0.00	2.4	0.79	0.00	66249	61
JUN	1	58	24.0	4.59	4.73	16	3744	4829	0	33210	8206	0.53	2.4	0.78	4.05	71458	62
JUN	2	62	23.7	1.89	1.81	8	0	0	0	98712	6123	0.35	2.5	0.00	16.12	61121	63
JUN	3	67	23.9	5.34	5.31	12	0	0	0	202664	14126	0.11	2.5	0.00	14.35	80900	64
JUN	*4	66	23.7	4.74	4.76	13	0	0	0	97132	13224	0.16	2.6	0.00	7.35	66762	65
JUN	5	73	24.0	7.14	7.12	10	0	0	0	28452	20693	0.12	4.2	0.00	1.37	109413	66
JUN	6	74	23.5	9.52	9.84	24	0	0	0	154962	25337	0.59	2.7	0.00	6.12	76812	67
JUN	7	74	22.9	10.63	11.42	20	0	0	0	194210	28507	0.67	2.7	0.00	6.81	90663	68
JUN	8																69
JUN	9																70
JUN	10																71
JUN	11																72
JUN	12																73
JUN	13																74
JUN	14	72	8.9	1.56	1.58	8	0	0	0	7852	4429	0.31	2.0	0.00	1.77	21800	75
JUN	15																76
JUN	16																77
JUN	17																78
JUN	18																79
JUN	19																80
JUN	20	74	10.3	3.62	4.00	14	0	0	0	112322	11030	0.71	3.8	0.00	10.18	59645	81
JUN	21	70	24.0	6.21	6.66	21	0	0	0	162975	17948	0.75	2.6	0.00	9.08	87037	82
JUN	22	70	24.0	6.43	6.62	17	0	0	0	164458	17996	0.76	2.6	0.00	9.14	84633	83
JUN	23	73	24.0	6.01	6.82	30	0	0	0	149614	18642	0.78	2.6	0.00	8.03	69897	84
JUN	24	69	23.9	5.55	6.51	29	0	0	0	161773	17997	0.71	4.0	0.00	8.99	71769	85
JUN	25	65	24.0	3.45	3.88	17	0	0	0	81882	11108	0.75	2.5	0.00	7.37	78915	86
JUN	26	66	24.0	3.76	4.30	19	0	0	0	91763	12158	0.73	2.5	0.00	7.55	74829	87
JUN	27	67	24.0	4.83	5.40	23	0	0	0	113119	14673	0.79	2.5	0.00	7.71	76796	88
JUN	28	70	23.9	5.24	5.76	22	0	0	0	133314	16244	0.74	3.9	0.00	8.21	67177	89
JUN	29	68	23.9	6.14	6.24	24	0	0	0	152683	16687	0.70	2.6	0.00	9.15	76083	90
JUN	30	65	24.1	3.57	4.48	27	0	0	0	94778	12387	0.59	2.4	0.00	7.65	75012	91
JUL	1	68	24.0	4.45	4.92	19	0	0	0	109959	13680	0.67	2.5	0.00	8.04	65298	92
JUL	2	70	23.8	7.49	7.78	13	0	0	0	197808	20764	0.77	2.6	0.00	9.53	89065	93
JUL	3	71	24.0	6.77	7.36	28	0	0	0	181773	19527	0.71	2.6	0.00	9.31	77835	94
JUL	4	67	24.0	5.51	6.20	32	0	0	0	140502	16474	0.69	2.4	0.00	8.53	103859	95
JUL	5	66	24.0	4.22	4.76	23	0	0	0	121543	13189	0.66	2.5	0.00	9.22	74171	96
JUL	6	61	24.0	1.53	2.49	19	0	0	0	64683	7592	0.70	2.3	0.00	8.52	65849	97
JUL	7	60	24.0	1.60	2.20	19	0	0	0	50003	6995	0.73	2.2	0.00	7.15	68139	98
JUL	8	66	24.0	1.63	2.54	23	0	0	0	43970	7987	0.71	2.1	0.00	5.51	54217	99
JUL	9	69	24.0	3.43	4.03	29	0	0	0	78133	11570	0.63	2.5	0.00	6.75	90274	100
JUL	10	73	24.0	6.61	6.97	27	0	0	0	149520	18950	0.70	2.6	0.00	7.89	77073	101
JUL	11	70	24.0	6.31	6.91	22	0	0	0	53049	18565	0.19	2.6	0.00	2.86	84886	102
JUL	12	74	24.0	6.20	6.70	30	0	0	0	148421	18295	0.73	2.6	0.00	8.11	57633	103
JUL	13	71	9.8	0.97	1.26	10	0	0	0	30413	3832	0.76	2.2	0.00	7.94	18081	104

Table F-2 - Continued

MON	DAY	AVG AMB TEMP degF	DATA HRS	COMP RUN HRS timer	COMP RUN HRS counter	CYC	NORMAL HEATING DELIVER BTU	NORMAL HEATING CONSUME WH	EMER WH	ABSORB BTU	COOLING CONSUME WH	S/T	PEAK kW	HEAT EER	COOL EER	WHOLE HOUSE WH	SEQ DAY
JUL	14	77	24.0	6.81	7.18	30	0	0	0	178124	19691	0.80	2.6	0.00	9.05	53840	105
JUL	15	76	24.0	9.65	9.67	29	0	0	0	267292	25732	0.77	2.6	0.00	10.39	78213	106
JUL	16	74	24.0	9.90	10.46	28	0	0	0	287311	27369	0.79	2.6	0.00	10.50	108523	107
JUL	17	72	23.9	8.62	9.01	19	0	0	0	249072	23710	0.78	2.6	0.00	10.50	81976	108
JUL	18	66	24.0	5.34	6.26	29	0	0	0	179147	16570	0.76	2.5	0.00	10.81	79368	109
JUL	19	65	24.0	4.57	5.11	19	0	0	0	145180	13951	0.76	2.5	0.00	10.41	69751	110
JUL	20	70	23.7	6.97	6.91	13	0	0	33	198034	19391	0.81	4.0	0.00	10.21	98548	111
JUL	21	71	23.9	6.55	7.33	25	0	0	0	208541	19540	0.78	2.6	0.00	10.67	68537	112
JUL	22	70	24.0	6.64	7.09	21	0	0	0	199046	20067	0.82	4.0	0.00	9.92	74163	113
JUL	23	76	24.0	10.23	10.45	22	0	0	0	285178	27610	0.79	2.6	0.00	10.33	104827	114
JUL	24	72	24.0	7.34	8.38	33	0	0	0	233409	22167	0.80	2.6	0.00	10.53	79034	115
JUL	25	66	24.0	4.13	5.05	26	0	0	0	137085	13921	0.78	2.5	0.00	9.85	60785	116
JUL	26	68	24.0	5.45	5.60	12	0	0	0	151685	15165	0.82	2.7	0.00	10.00	85596	117
JUL	27	64	24.0	3.43	4.09	26	0	0	0	113758	11445	0.73	2.4	0.00	9.94	75924	118
JUL	28	66	24.0	5.41	5.48	16	0	0	0	150740	14903	0.77	2.5	0.00	10.11	71219	119
JUL	29	67	24.0	5.42	5.64	20	0	0	0	154096	15308	0.78	2.5	0.00	10.07	68205	120
JUL	30	69	24.0	6.07	6.55	22	0	0	0	179625	18160	0.81	4.0	0.00	9.89	95545	121
JUL	31	74	24.0	8.95	9.26	17	0	0	0	263876	24508	0.79	2.6	0.00	10.77	88120	122
AUG	1	76	24.0	10.04	9.95	26	0	0	0	241303	26242	0.76	2.6	0.00	9.20	80369	123
AUG	2	74	24.0	7.06	7.50	26	0	0	0	153795	20030	0.80	2.6	0.00	7.68	59693	124
AUG	3	70	24.0	5.64	6.62	35	0	0	0	119519	17756	0.77	2.5	0.00	6.73	70853	125
AUG	4	69	23.9	4.53	5.46	39	0	0	0	104922	14953	0.65	2.5	0.00	7.02	65574	126
AUG	5	71	24.0	6.32	6.90	22	0	0	0	147652	18536	0.66	2.6	0.00	7.97	72328	127
AUG	6	73	23.9	7.70	8.45	24	0	0	0	190925	22448	0.67	2.6	0.00	8.51	89739	128
AUG	7	74	24.0	9.36	9.46	24	0	0	0	213200	24971	0.69	2.6	0.00	8.54	127338	129
AUG	8	74	19.7	4.08	5.36	38	0	0	5	109870	14743	0.50	2.6	0.00	7.45	83849	130
AUG	9	77	24.0	10.30	10.86	41	0	0	0	206232	29421	0.66	2.7	0.00	7.01	92718	131
AUG	10	77	24.0	9.84	10.33	39	0	0	0	206519	28024	0.68	2.7	0.00	7.37	79132	132
AUG	11	68	24.0	5.95	6.43	39	0	0	0	131540	17448	0.65	2.5	0.00	7.54	71427	133
AUG	12	70	24.0	6.10	6.02	32	0	0	0	126562	16532	0.63	2.5	0.00	7.66	71898	134
AUG	13	72	24.0	6.05	6.44	36	0	0	0	134125	18400	0.64	3.6	0.00	7.29	81575	135
AUG	14	73	24.0	7.19	7.71	31	0	0	0	161566	20809	0.69	2.6	0.00	7.76	102353	136
AUG	15	72	24.0	6.36	6.76	38	0	0	0	137326	18622	0.66	2.6	0.00	7.37	67269	137
AUG	16	72	24.0	8.05	8.42	31	0	0	0	180523	22697	0.70	2.6	0.00	7.95	89344	138
AUG	17	71	24.0	7.45	7.89	30	0	0	0	174894	21194	0.70	2.7	0.00	8.25	75311	139
AUG	18	71	24.0	6.41	6.57	32	0	0	0	145474	17986	0.71	2.6	0.00	8.09	74165	140
AUG	19	66	24.0	4.94	5.34	38	0	0	0	116780	14749	0.69	2.5	0.00	7.92	71372	141
AUG	20	63	24.0	2.71	3.04	32	0	0	0	62209	9124	0.68	2.3	0.00	6.82	84728	142
AUG	21	66	24.0	2.99	3.21	27	0	0	0	51624	9827	0.74	2.5	0.00	5.25	50877	143
AUG	22	71	24.0	6.13	6.00	35	0	0	0	127939	16676	0.71	2.6	0.00	7.67	76209	144
AUG	23	66	24.0	5.88	6.67	36	0	0	0	155357	17871	0.67	2.5	0.00	8.69	75438	145
AUG	24	61	24.0	3.26	3.31	26	0	0	0	63910	9750	0.76	2.4	0.00	6.55	72051	146
AUG	25	64	24.0	3.60	3.84	25	0	0	0	91216	11128	0.71	2.5	0.00	8.20	64876	147
AUG	26	68	24.0	4.35	4.30	26	0	0	0	97971	12389	0.77	2.5	0.00	7.91	64439	148
AUG	27	71	24.0	0.59	5.92	20	0	0	0	126239	16426	0.72	2.6	0.00	7.69	67903	149
AUG	28	73	24.0	8.26	8.61	33	0	0	0	204708	23698	0.70	3.9	0.00	8.64	119130	150
AUG	29	72	23.8	5.98	6.18	31	0	0	0	121810	17133	0.71	2.6	0.00	7.11	67717	151
AUG	30	70	24.0	5.51	5.87	47	0	0	0	110381	16281	0.69	2.6	0.00	6.78	66156	152
AUG	31																153
SEP	1	62	24.0	2.03	2.11	25	0	0	0	30867	6975	0.83	2.2	0.00	4.43	63535	154
SEP	2	74	24.0	7.43	8.03	32	0	0	0	170914	21965	0.71	2.7	0.00	7.78	89655	155
SEP	3	69	24.0	5.37	5.91	37	0	0	0	120160	16474	0.68	2.7	0.00	7.29	66293	156
SEP	4	59	24.0	2.51	2.73	33	0	0	0	58061	8286	0.64	1.6	0.00	7.01	88287	157
SEP	5	55	24.0	0.00	0.00	0	0	0	0	1714	1870	0.00	0.3	0.00	0.92	62603	158
SEP	6	55	24.0	0.00	0.00	0	0	0	0	0	1889	0.00	0.3	0.00	0.00	44723	159
SEP	7	61	24.0	1.46	1.39	13	0	0	0	23111	5194	0.75	2.3	0.00	4.45	88949	160

Table F-2 - Continued

MON	DAY	AVG AMB TEMP degF	DATA HRS	COMP RUN HRS timer	COMP RUN HRS counter	CYC	NORMAL HEATING DELIVER BTU	NORMAL HEATING CONSUME WH	EMER WH	ABSORB BTU	COOLING CONSUME WH	S/T	PEAK kW	HEAT EER	COOL EER	WHOLE HOUSE WH	SEQ DAY
SEP	8	65	24.0	3.71	4.12	26	0	0	0	84088	12457	0.79	4.2	0.00	6.75	59232	161
SEP	9	66	24.0	0.94	0.90	7	0	0	0	13527	4047	0.73	2.3	0.00	3.34	62435	162
SEP	10	68	24.0	4.89	5.26	26	0	0	0	104147	14538	0.69	2.5	0.00	7.16	70600	163
SEP	11	70	24.0	6.83	6.98	27	0	0	0	153877	19028	0.70	2.6	0.00	8.09	103114	164
SEP	12	66	24.0	4.37	5.21	32	0	0	0	109503	14402	0.64	2.5	0.00	7.60	72975	165
SEP	13	72	24.0	6.96	7.45	29	0	0	0	163100	20385	0.73	2.6	0.00	8.00	78402	166
SEP	14	67	24.0	4.23	4.82	41	0	0	0	84638	13498	0.68	2.5	0.00	6.27	61828	167
SEP	15	53	24.0	0.05	0.07	1	0	0	0	2098	2072	0.17	0.8	0.00	1.01	62358	168
SEP	16	49	24.0	0.00	0.00	0	0	0	0	0	1880	0.00	0.3	0.00	0.00	47911	169
SEP	17	54	24.0	0.00	0.00	0	0	0	0	0	1908	0.00	0.3	0.00	0.00	65134	170
SEP	18	58	24.0	0.93	1.01	13	0	0	0	11833	4327	1.00	1.3	0.00	2.73	90717	171
SEP	19	62	24.0	0.53	0.43	7	0	0	0	6920	2959	0.71	0.9	0.00	2.34	59391	172
SEP	20	68	24.0	4.14	4.14	10	0	0	0	86037	12082	0.77	2.6	0.00	7.12	69468	173
SEP	21	66	24.0	4.82	5.30	35	0	0	0	111612	14557	0.74	2.5	0.00	7.67	79921	174
SEP	22	66	14.7	2.81	3.05	9	0	0	0	90558	8615	0.67	2.7	0.00	10.51	49298	175
SEP	23	70	24.0	5.45	5.66	23	0	0	0	126722	15501	0.65	2.6	0.00	8.18	79539	176
SEP	24	69	24.0	5.66	5.77	34	0	0	0	116848	15934	0.65	2.5	0.00	7.33	78073	177
SEP	25	72	24.0	6.41	6.32	29	0	0	0	128065	17496	0.69	2.6	0.00	7.32	84494	178
SEP	26	54	24.0	55.00	0.75	10	0	0	0	12750	3720	0.52	1.6	0.00	3.43	90280	179
SEP	27	43	11.7	0.00	0.00	0	0	0	0	0	917	0.00	0.3	0.00	0.00	24014	180
SEP	28	47	8.3	1.17	1.30	14	29291	3832	0	0	0	0.00	1.1	7.64	0.00	25223	181
SEP	29	49	24.0	4.07	4.39	42	94856	12399	0	0	0	0.00	5.2	7.65	0.00	65686	182
SEP	30	48	24.0	2.71	2.86	32	65033	8759	0	0	0	0.00	1.5	7.42	0.00	71986	183
OCT	1	47	23.7	2.93	3.44	37	83944	10396	1667	0	0	0.00	3.5	8.07	0.00	98377	184
OCT	2	47	24.0	3.90	3.86	26	0	49298	0	0	0	0.00	8.9	0.00	0.00	686719	185
OCT	3	53	23.9	2.88	2.95	19	0	49113	0	0	0	0.00	10.5	0.00	0.00	786593	186
OCT	4	53	23.9	0.72	0.77	4	0	39710	0	0	0	0.00	12.3	0.00	0.00	924382	187
OCT	5	56	24.1	57.00	0.62	7	0	34386	0	0	0	0.00	4.6	0.00	0.00	959660	188
OCT	6	55	23.9	0.21	0.25	3	0	35003	0	0	0	0.00	6.4	0.00	0.00	906686	189
OCT	7	58	24.1	0.10	0.07	1	2319	18760	0	0	0	0.00	1.8	0.12	0.00	494619	190
OCT	8	59	24.1	0.00	0.00	0	0	19541	0	0	0	0.00	1.8	0.00	0.00	541810	191
OCT	9	63	23.3	0.00	0.00	0	0	18668	0	0	0	0.00	1.8	0.00	0.00	517170	192
OCT	10	63	24.0	3.63	3.56	16	0	11039	0	79451	33743	0.84	20.9	0.00	2.35	437342	193
OCT	11	61	23.9	1.04	1.03	10	0	0	0	25468	17718	0.58	2.9	0.00	1.44	480235	194
OCT	12	61	24.1	0.91	1.42	12	0	0	0	35565	20393	0.61	5.7	0.00	1.74	429235	195
OCT	13	53	23.9	0.11	0.12	1	0	0	0	2931	15600	0.97	2.8	0.00	0.19	448097	196
OCT	14	54	24.0	0.36	0.39	4	11172	2233	0	764	701	1.00	1.2	5.00	1.09	65773	197
OCT	15	62	24.0	1.11	1.17	13	31246	4873	0	0	0	0.00	1.2	6.41	0.00	59336	198
OCT	16	65	24.0	3.30	3.54	19	110	885	0	77903	9543	0.81	2.6	0.12	8.16	58286	199
OCT	17	65	24.0	3.33	3.85	21	0	0	0	78376	11080	0.92	2.5	0.00	7.07	106877	200
OCT	18	62	22.0	2.62	8.92	28	0	0	0	63050	28360	0.91	81.2	0.00	2.22	235747	201
OCT	19																202
OCT	20																203
OCT	21	67	19.2	4.49	4.44	25	0	0	0	86843	11766	0.95	2.4	0.00	7.38	61428	204
OCT	22	58	24.0	0.00	0.02	0	0	0	0	0	1909	0.00	0.2	0.00	0.00	90053	205
OCT	23	51	24.0	0.00	0.00	0	0	0	0	0	1860	0.00	0.2	0.00	0.00	77064	206
OCT	24	49	24.0	0.10	1.84	2	3181	549	0	608	6161	1.00	1.0	5.79	0.10	70429	207
OCT	25	57	24.0	1.63	1.66	17	39544	5758	0	0	0	0.00	1.5	6.87	0.00	70479	208
OCT	26	68	24.0	4.14	3.35	21	77	1061	0	71196	9064	0.88	2.5	0.07	7.85	71859	209
OCT	27	71	24.0	7.32	7.73	29	0	0	0	154288	20559	0.92	2.5	0.00	7.50	82646	210
OCT	28	66	24.0	4.12	4.12	26	0	0	0	81591	11686	0.94	2.5	0.00	6.98	79497	211
OCT	29	59	24.0	1.02	0.78	8	0	0	0	13141	3720	0.91	1.2	0.00	3.53	66123	212
OCT	30	56	24.0	1.26	1.26	12	0	0	0	31816	4820	0.64	2.2	0.00	6.60	86482	213
OCT	31	59	24.0	1.44	1.36	15	0	0	0	38265	5059	0.61	2.1	0.00	7.56	75458	214
NOV	1	64	24.0	3.78	4.30	22	0	0	0	104422	12120	0.74	2.5	0.00	8.62	75582	215
NOV	2	42	24.0	0.00	0.00	0	0	0	0	0	1909	0.00	0.3	0.00	0.00	65579	216

Table F-2 - Continued

MON	DAY	AVG AMB TEMP degF	DATA HRS	COMP RUN HRS timer	COMP RUN HRS counter	CYC	NORMAL HEATING DELIVER BTU	NORMAL HEATING CONSUME WH	EMER WH	ABSORB BTU	COOLING CONSUME WH	S/T	PEAK kW	HEAT EER	COOL EER	WHOLE HOUSE WH	SEQ DAY
NOV	3	37	24.0	5.27	5.13	27	170129	18397	0	808	295	1.00	3.7	9.25	2.74	82596	217
NOV	4	48	24.0	5.84	5.82	61	153162	15860	0	0	0	0.00	1.8	9.66	0.00	70409	218
NOV	5	51	24.0	1.15	1.14	13	32619	4859	0	0	0	0.00	1.2	6.71	0.00	103131	219
NOV	6	38	23.9	7.34	7.44	77	169612	18515	0	0	0	0.00	1.8	9.16	0.00	81356	220
NOV	7	38	24.0	10.36	10.24	73	258281	26355	0	0	0	0.00	3.6	9.80	0.00	86630	221
NOV	8	42	24.0	8.10	8.46	44	180859	20488	0	0	0	0.00	2.3	8.83	0.00	91691	222
NOV	9	49	24.0	6.31	5.43	55	153618	15089	0	0	0	0.00	1.5	10.18	0.00	69974	223
NOV	10	54	24.0	1.82	1.83	21	54754	6604	0	0	0	0.00	1.1	8.29	0.00	65171	224
NOV	11	43	24.0	5.97	5.53	57	119280	14761	0	0	0	0.00	1.7	8.08	0.00	79632	225
NOV	12	30	24.0	12.93	13.15	70	380948	40162	0	0	0	0.00	4.0	9.49	0.00	125716	226
NOV	13	35	23.9	11.94	12.48	78	281870	33351	0	0	0	0.00	14.9	8.45	0.00	111833	227
NOV	14	36	24.0	7.73	8.35	67	266591	29253	0	0	0	0.00	11.2	9.11	0.00	98521	228
NOV	15	48	23.8	7.73	7.78	62	205340	20035	0	0	0	0.00	2.3	10.25	0.00	86984	229
NOV	16	35	24.0	13.86	14.08	74	372043	37829	0	0	0	0.00	3.7	9.83	0.00	110066	230
NOV	17	33	24.0	15.79	15.62	64	447053	45201	0	0	0	0.00	3.7	9.89	0.00	78892	231
NOV	18	34	23.8	19.78	20.53	31	420091	45812	0	0	0	0.00	2.6	9.17	0.00	90466	232
NOV	19	31	23.9	16.13	16.99	59	389137	45847	0	0	0	0.00	15.9	8.49	0.00	110038	233
NOV	20	24	24.0	13.59	13.94	64	529819	54953	0	0	0	0.00	12.5	9.64	0.00	145394	234
NOV	21	28	24.0	10.76	11.92	93	423257	43789	0	0	0	0.00	13.8	9.67	0.00	115445	235
NOV	22	27	24.0	11.12	12.44	72	467192	49127	0	0	0	0.00	12.0	9.51	0.00	109344	236
NOV	23	34	24.0	10.24	12.77	93	393187	37552	0	0	0	0.00	3.6	10.47	0.00	93084	237
NOV	24	39	24.0	7.49	8.71	65	255567	25461	0	0	0	0.00	3.6	10.04	0.00	92544	238
NOV	25	43	24.0	7.82	8.21	29	181997	19872	1461	0	0	0.00	6.0	9.16	0.00	81108	239
NOV	26	49	24.0	0.00	0.40	0	390	2169	35847	0	0	0.00	7.3	0.18	0.00	102877	240
NOV	27	57	24.0	0.00	0.00	0	0	867	25858	0	0	0.00	6.5	0.00	0.00	128347	241
NOV	28	49	23.7	3.06	3.47	28	70556	10485	1773	0	0	0.00	9.3	6.73	0.00	72816	242
NOV	29	36	24.0	12.26	12.26	55	244199	28852	436	0	0	0.00	3.8	8.46	0.00	98589	243
NOV	30	41	24.0	3.85	3.89	19	92956	9675	36865	0	0	0.00	8.0	9.61	0.00	111072	244
DEC	1	40	24.0	10.10	11.21	89	234097	27224	0	0	0	0.00	2.3	8.60	0.00	99380	245
DEC	2	40	24.0	10.39	10.46	49	215696	25500	0	0	0	0.00	3.8	8.46	0.00	91373	246
DEC	3	39	24.0	9.92	9.91	92	250262	28005	0	0	0	0.00	2.8	8.94	0.00	91456	247
DEC	4	27	24.0	12.35	12.96	79	436523	48158	0	0	0	0.00	3.6	9.06	0.00	104398	248
DEC	5	28	24.0	13.48	14.23	75	422375	47618	0	0	0	0.00	3.7	8.87	0.00	148539	249
DEC	6	25	23.8	11.63	14.07	101	484321	58908	0	0	0	0.00	9.1	8.22	0.00	140819	250
DEC	7	14	24.0	20.36	20.61	30	628259	73379	0	0	0	0.00	11.6	8.56	0.00	156423	251
DEC	8	30	24.0	13.53	14.24	64	473639	48361	0	0	0	0.00	3.8	9.79	0.00	104372	252
DEC	9	38	24.0	7.00	7.67	63	262669	28950	0	0	0	0.00	9.4	9.07	0.00	98707	253
DEC	10	42	23.9	10.46	11.62	90	271037	28208	0	0	0	0.00	2.3	9.61	0.00	109418	254
DEC	11	42	24.0	11.64	12.74	105	290412	30443	0	0	0	0.00	2.3	9.54	0.00	108969	255
DEC	12	48	24.0	10.09	10.20	45	231818	25067	0	0	0	0.00	2.4	9.25	0.00	100801	256
DEC	13	54	23.8	2.23	2.46	25	67771	8300	0	0	0	0.00	1.3	8.17	0.00	84108	257
DEC	14	53	23.9	4.47	4.40	46	114555	13019	0	0	0	0.00	1.7	8.80	0.00	85256	258
DEC	15	55	24.0	1.62	1.76	17	44524	6514	0	0	0	0.00	1.4	6.84	0.00	63710	259
DEC	16	57	24.0	2.74	2.26	22	58818	7552	0	0	0	0.00	1.4	7.79	0.00	83075	260
DEC	17	59	24.0	0.00	0.00	0	0	1991	0	0	0	0.00	0.3	0.00	0.00	102938	261
DEC	18	46	16.7	2.38	2.55	14	49787	6851	0	0	0	0.00	2.1	7.27	0.00	45385	262
DEC	19	41	24.0	11.18	11.42	46	252713	27494	0	0	0	0.00	2.3	9.19	0.00	98906	263
DEC	20	36	21.8	12.98	12.76	36	272110	30242	0	0	0	0.00	2.6	9.00	0.00	92165	264
DEC	21	41	24.0	13.37	14.03	45	314865	33226	0	0	0	0.00	3.4	9.48	0.00	100517	265
DEC	22	43	24.0	7.81	8.26	53	225453	22948	0	0	0	0.00	3.3	9.82	0.00	86872	266
DEC	23	33	24.0	11.08	11.09	50	342287	35212	0	0	0	0.00	3.9	9.72	0.00	97480	267
DEC	24	43	24.0	9.41	9.96	32	237396	26154	0	0	0	0.00	2.4	9.08	0.00	101501	268
DEC	25	23	24.0	13.98	14.77	48	467876	52127	0	0	0	0.00	3.8	8.98	0.00	103261	269
DEC	26	28	24.0	17.30	17.57	39	505579	54490	0	0	0	0.00	5.6	9.28	0.00	133492	270
DEC	27	44	22.4	11.10	11.75	44	292128	28555	0	0	0	0.00	2.4	10.23	0.00	112003	271
DEC	28																272

Table F-2 - Continued

MON	DAY	AVG AMB TEMP degF	DATA HRS	COMP RUN HRS timer	COMP RUN HRS counter	CYC	NORMAL HEATING DELIVER BTU	NORMAL HEATING CONSUME WH	EMER WH	COOLING ABSORB BTU	COOLING CONSUME WH	S/T	PEAK kW	HEAT EER	COOL EER	WHOLE HOUSE WH	SEQ DAY
DEC	29	62	24.1	0.11	0.15	2	12496	2882	0	0	0	0.00	0.8	4.34	0.00	79392	273
DEC	30	42	24.0	2.99	3.45	23	115576	13636	0	0	0	0.00	1.8	8.48	0.00	87165	274
DEC	31	43	24.0	8.24	8.98	26	222331	24692	0	0	0	0.00	2.4	9.00	0.00	96485	275
JAN	1	56	24.0	1.88	2.31	21	78715	8768	0	0	0	0.00	1.4	8.98	0.00	88516	276
JAN	2	3	24.0	10.52	11.60	57	353507	37330	0	0	0	0.00	3.8	9.47	0.00	100705	277
JAN	3	28	23.0	11.62	11.30	40	359641	44947	0	0	0	0.00	8.3	8.00	0.00	105188	278
JAN	4	34	17.4	9.59	10.32	36	232899	32274	0	0	0	0.00	4.8	7.22	0.00	87248	279
JAN	5	29	24.0	11.12	12.32	70	380658	52776	0	0	0	0.00	10.8	7.21	0.00	156535	280
JAN	6	32	24.0	11.71	12.82	66	312685	40494	0	0	0	0.00	3.5	7.72	0.00	132101	281
JAN	7	33	24.1	15.44	16.10	53	345154	46138	0	1592	189	0.78	9.8	7.48	8.42	124950	282
JAN	8	22	24.0	15.56	16.34	50	469160	61679	0	0	0	0.00	10.4	7.61	0.00	145840	283
JAN	9	15	24.0	18.83	19.42	28	488472	68685	0	0	0	0.00	9.2	7.11	0.00	158038	284
JAN	10	19	23.6	18.89	19.30	35	545178	74806	0	0	0	0.00	11.2	7.29	0.00	153616	285
JAN	11	19	24.0	17.75	18.34	52	541636	76961	0	0	0	0.00	9.7	7.04	0.00	154229	286
JAN	12	17	24.0	19.18	19.85	17	548001	75675	0	0	0	0.00	11.8	7.24	0.00	150661	287
JAN	13	20	24.0	17.25	17.95	31	516820	67122	0	984	0	0.70	11.8	7.70	0.00	152668	288
JAN	14	27	23.9	11.73	12.84	60	422976	50294	0	0	0	0.00	7.9	8.41	0.00	120730	289
JAN	15	14	24.0	18.88	19.60	36	671096	68936	0	0	0	0.00	11.0	9.74	0.00	145878	290
JAN	16	14	24.0	20.04	20.54	40	702434	76197	0	694	86	1.00	9.3	9.22	8.07	165209	291
JAN	17	27	24.0	13.34	14.20	65	558706	59990	0	0	0	0.00	9.7	9.31	0.00	151602	292
JAN	18	25	18.0	9.52	10.43	52	381318	45876	0	0	0	0.00	10.2	8.31	0.00	111926	293
JAN	19	16	24.0	16.33	17.00	47	564239	63151	0	241	0	1.00	10.9	8.93	0.00	128632	294
JAN	20	-10	24.0	23.78	23.81	59	944248	188130	0	0	0	0.00	14.6	5.02	0.00	263384	295
JAN	21	-8	24.0	23.51	23.58	58	1017186	197349	0	0	0	0.00	16.1	5.15	0.00	274993	296
JAN	22	12	24.0	23.35	23.39	17	848711	94312	0	0	0	0.00	10.2	9.00	0.00	196336	297
JAN	23	19	24.0	16.65	16.97	16	623880	63844	0	0	0	0.00	11.2	9.77	0.00	136117	298
JAN	24	27	24.0	13.56	13.89	59	555151	55680	0	0	0	0.00	10.6	9.97	0.00	128172	299
JAN	25	23	24.0	13.31	13.91	61	522559	55314	0	0	0	0.00	10.5	9.45	0.00	137355	300
JAN	26	13	24.0	20.12	20.12	27	673388	70229	0	0	0	0.00	10.7	9.59	0.00	130551	301
JAN	27	19	24.0	16.61	17.02	45	610853	61250	0	0	0	0.00	8.8	9.97	0.00	142976	302
JAN	28	25	24.0	11.47	12.80	62	506909	49211	0	0	0	0.00	9.3	10.30	0.00	119101	303
JAN	29	21	24.0	14.42	15.46	61	561025	60455	0	0	0	0.00	10.3	9.28	0.00	169682	304
JAN	30	25	23.9	11.84	12.76	58	479181	47785	0	0	0	0.00	6.5	10.03	0.00	122763	305
JAN	31	36	23.8	13.05	14.36	66	408325	40305	0	0	0	0.00	5.8	10.13	0.00	121853	306
FEB	1	27	24.0	11.94	12.72	73	477406	55111	0	0	0	0.00	9.6	8.66	0.00	140323	307
FEB	2	17	24.1	15.82	16.24	51	569385	63620	0	0	0	0.00	10.3	8.95	0.00	140014	308
FEB	3	11	24.0	19.19	19.40	29	610791	66712	0	0	0	0.00	10.5	9.16	0.00	138137	309
FEB	4	14	24.0	17.63	18.23	50	618232	70170	0	0	0	0.00	10.9	8.81	0.00	137603	310
FEB	5	26	24.0	14.02	15.04	55	546311	53139	0	0	0	0.00	7.7	10.28	0.00	160600	311
FEB	6	29	24.0	12.23	12.75	66	470715	49781	0	0	0	0.00	10.3	9.46	0.00	125983	312
FEB	7	14	24.0	17.43	17.96	41	613940	64135	0	0	0	0.00	11.4	9.57	0.00	141998	313
FEB	8	10	24.0	20.64	20.73	7	700152	67815	0	0	0	0.00	5.1	10.32	0.00	155918	314
FEB	9	12	24.0	20.27	20.53	35	712141	78686	0	0	0	0.00	11.8	9.05	0.00	146678	315
FEB	10	17	24.0	15.74	15.97	37	546172	58290	0	0	0	0.00	8.7	9.37	0.00	128418	316
FEB	11	35	24.0	9.08	10.09	50	365698	33718	0	0	0	0.00	3.9	10.85	0.00	109455	317
FEB	12	37	24.0	6.35	7.35	57	324968	29440	0	0	0	0.00	2.7	11.04	0.00	141135	318
FEB	13	23	24.0	13.65	13.89	55	513113	56262	0	0	0	0.00	11.1	9.12	0.00	127567	319
FEB	14	21	23.9	14.46	15.21	51	557676	56093	0	0	0	0.00	10.9	9.94	0.00	129059	320
FEB	15	16	24.0	16.97	17.14	39	590648	61115	0	0	0	0.00	12.1	9.66	0.00	152778	321
FEB	16	18	24.0	16.77	18.40	40	691424	71166	0	0	0	0.00	12.1	9.72	0.00	136472	322
FEB	17	33	24.0	8.41	9.25	57	402582	36328	0	0	0	0.00	3.8	11.08	0.00	109376	323
FEB	18	32	24.0	7.03	7.77	44	316903	29886	0	0	0	0.00	3.7	10.60	0.00	136674	324
FEB	19	32	24.0	5.60	6.66	51	280807	26800	0	0	0	0.00	2.5	10.48	0.00	101215	325
FEB	20	32	24.0	6.90	7.98	47	320233	30462	0	0	0	0.00	3.7	10.51	0.00	106431	326
FEB	21	43	24.0	5.16	5.90	43	228567	21954	0	0	0	0.00	3.3	10.41	0.00	106335	327
FEB	22	49	24.0	5.62	6.75	62	204189	19816	0	0	0	0.00	2.2	10.30	0.00	87092	328

Table F-2 - Continued

MON	DAY	AVG AMB TEMP degF	DATA HRS	COMP RUN HRS timer	COMP RUN HRS counter	CYC	NORMAL HEATING DELIVER BTU	NORMAL HEATING CONSUME WH	EMER WH	COOLING ABSORB BTU	COOLING CONSUME WH	S/T	PEAK kW	HEAT EER	COOL EER	WHOLE HOUSE WH	SEQ DAY
FEB	23	58	23.9	1.96	2.37	22	74487	8068	0	0	0	0.00	1.4	9.23	0.00	75365	329
FEB	24	60	24.1	0.40	0.48	6	15062	3149	0	0	0	0.00	1.2	4.78	0.00	84929	330
FEB	25	38	23.9	3.59	4.44	46	197655	19375	0	0	0	0.00	2.1	10.20	0.00	97263	331
FEB	26	43	23.9	5.20	6.50	62	248351	24307	0	0	0	0.00	2.3	10.22	0.00	116267	332
FEB	27	33	24.1	6.47	7.93	68	329531	31884	0	0	0	0.00	3.2	10.34	0.00	129852	333
FEB	28	29	24.0	10.18	10.73	47	405629	40201	0	0	0	0.00	3.8	10.09	0.00	112301	334
MAR	1	45	24.0	5.63	6.62	53	246583	23737	0	0	0	0.00	2.9	10.39	0.00	98064	335
MAR	2	40	24.0	5.36	6.61	61	234446	23218	0	0	0	0.00	2.2	10.10	0.00	87320	336
MAR	3	35	24.0	5.95	7.33	49	292571	27863	0	0	0	0.00	7.5	10.50	0.00	108886	337
MAR	4	50	24.0	3.77	4.53	38	191747	18127	0	0	0	0.00	2.4	10.58	0.00	88675	338
MAR	5	35	24.0	5.93	6.84	62	269155	26150	0	0	0	0.00	2.2	10.29	0.00	120209	339
MAR	6	25	24.0	9.45	10.37	62	402800	38832	0	0	0	0.00	3.7	10.37	0.00	120228	340
MAR	7	39	23.9	8.99	10.10	62	379155	35520	0	0	0	0.00	3.7	10.67	0.00	115843	341
MAR	8	50	24.1	5.99	6.78	49	234128	21844	0	0	0	0.00	1.9	10.72	0.00	97027	342
MAR	9	42	23.9	3.51	4.00	34	170550	17079	0	0	0	0.00	2.1	9.99	0.00	86018	343
MAR	10	45	24.1	2.20	2.75	26	113502	12585	0	0	0	0.00	2.2	9.02	0.00	89020	344
MAR	11	48	24.0	3.36	4.03	38	132959	14532	0	0	0	0.00	2.0	9.15	0.00	113467	345
MAR	12	42	24.0	4.47	5.38	39	237896	23157	0	0	0	0.00	4.2	10.27	0.00	96464	346
MAR	13	39	23.9	4.85	5.74	42	246653	23719	0	0	0	0.00	2.5	10.40	0.00	93093	347
MAR	14	40	24.0	3.83	4.65	48	200701	19865	0	0	0	0.00	2.2	10.10	0.00	103619	348
MAR	15	34	24.1	5.44	6.75	58	279197	27483	0	0	0	0.00	2.3	10.16	0.00	106833	349
MAR	16	40	23.9	6.08	7.02	49	244540	24257	0	0	0	0.00	3.3	10.08	0.00	93486	350
MAR	17	32	24.1	6.58	7.73	62	319626	30393	0	0	0	0.00	2.4	10.52	0.00	99704	351
MAR	18	23	23.9	11.09	12.26	56	458530	44441	0	0	0	0.00	3.6	10.32	0.00	122509	352
MAR	19	38	24.0	9.65	10.68	54	373451	34950	0	0	0	0.00	3.7	10.69	0.00	103759	353
MAR	20	46	23.8	1.03	1.47	10	36490	5052	0	0	0	0.00	1.4	7.22	0.00	131249	354
MAR	21	34	24.1	7.34	8.01	36	312872	30141	0	0	0	0.00	3.9	10.38	0.00	97899	355
MAR	22	37	24.0	7.04	7.82	61	352944	32389	0	0	0	0.00	2.6	10.90	0.00	96421	356
MAR	23	41	24.0	5.80	7.03	62	290995	30836	0	0	0	0.00	12.4	9.44	0.00	103159	357
MAR	24	49	12.3	3.31	3.86	30	127123	11059	0	0	0	0.00	1.9	11.49	0.00	38584	358
MAR	25	40	13.3	0.92	1.26	14	45099	5559	0	0	0	0.00	1.8	8.11	0.00	80965	359
MAR	26	42	23.8	4.53	5.20	36	204324	20234	0	0	0	0.00	2.7	10.10	0.00	87569	360
MAR	27	58	24.0	2.31	2.67	21	86121	9442	0	0	0	0.00	2.0	9.12	0.00	78994	361
MAR	28	61	24.0	0.23	0.23	3	9412	2487	0	0	0	0.00	1.1	3.78	0.00	69333	362
MAR	29	66	23.9	0.00	0.00	0	0	1833	0	0	0	0.00	0.3	0.00	0.00	77172	363
MAR	30	45	24.2	2.13	2.55	27	95302	10238	0	0	0	0.00	2.1	9.31	0.00	65276	364
MAR	31	46	24.0	4.01	4.81	46	177366	17573	0	0	0	0.00	2.2	10.09	0.00	84966	365
			8118.8	2286.59	2344.0	10724	53440471	6307684	108249	14539477	1953931			8.47	7.44	38530898	

Table F-3 - Temperature Bin Data April 1, 1983 through March 31, 1984

	A	B	C	D	E	F
1	BIN	TOT-HRS	LO-HT HRS	HI-HT-HRS	1-I2R-HRS	2-I2R-HRS
2	-25 TO -20	.41	.00	.00	.00	.00
3	-20 TO -15	.18	.00	.00	.00	.00
4	-15 TO -10	12.60	.00	.67	.00	.35
5	-10 TO -5	24.28	.00	1.19	.00	8.18
6	-5 TO 0	41.68	.00	.10	.00	18.90
7	0 TO 5	46.93	.00	1.45	18.43	9.32
8	5 TO 10	96.92	.00	2.74	56.27	1.10
9	10 TO 15	146.85	.00	41.18	46.25	.87
10	15 TO 20	232.43	.00	138.01	10.44	.00
11	20 TO 25	336.71	.00	166.18	1.93	.00
12	25 TO 30	446.77	.00	194.09	.57	.00
13	30 TO 35	751.30	.24	238.35	.23	.00
14	35 TO 40	624.06	74.48	104.04	.00	.00
15	40 TO 45	655.93	117.74	20.65	.00	.00
16	45 TO 50	648.10	70.14	.76	.00	.00
17	50 TO 55	666.50	21.80	.39	.05	.00
18	55 TO 60	652.28	5.86	.97	.00	.00
19	60 TO 65	696.53	2.30	.00	.00	.00
20	65 TO 70	810.47	.04	.00	.00	.00
21	70 TO 75	671.43	.00	.00	.00	.00
22	75 TO 80	469.45	.12	.00	.00	.00
23	80 TO 85	328.28	.00	.00	.00	.00
24	85 TO 90	192.47	.00	.00	.00	.00
25	90 TO 95	20.70	.00	.00	.00	.00
26	95 TO 100	.00	.00	.00	.00	.00
27						
28	TOTALS	8573.24	292.73	910.79	134.17	38.71

Table F-3 - Continued

	G	H	I	J	K	L
1	3-I2R-HRS	4-I2R-HRS	DEFR-HRS	COMP/HT/OFF	LOCOOL-HRS	HICOOL-HRS
2	.00	.00	.00	.28	.00	.00
3	.00	.00	.00	.18	.00	.00
4	1.05	.13	.00	2.05	.00	.00
5	1.29	.00	.00	8.40	.00	.00
6	.00	.00	.00	16.16	.00	.00
7	.00	.00	.00	16.29	.00	.00
8	.00	.00	.00	34.13	.00	.00
9	.00	.00	.00	46.92	.00	.00
10	.00	.00	.05	67.98	.00	.00
11	.00	.00	.00	142.18	.00	.05
12	.00	.00	.05	244.29	.00	.17
13	.00	.00	.09	512.11	.00	.10
14	.00	.00	.00	435.97	.00	.00
15	.00	.00	.00	459.13	.00	.00
16	.00	.00	.00	435.14	.00	.00
17	.00	.00	.00	438.65	.75	.00
18	.00	.00	.00	352.74	4.39	.09
19	.00	.00	.00	188.35	32.16	.04
20	.00	.00	.00	170.37	102.88	1.43
21	.00	.00	.00	34.91	155.54	.59
22	.00	.00	.00	13.28	196.93	.29
23	.00	.00	.00	.56	195.70	5.82
24	.00	.00	.00	.00	108.37	21.07
25	.00	.00	.00	.00	6.95	7.33
26	.00	.00	.00	.00	.00	.00
27						
28	2.34	.13	.19	3620.07	803.68	36.97

Table F-3 - Continued

	M	N	O	P	Q	R
1	COMP/CL/OFF	LO-HT-HZ	HI-HT-HZ	1-I2R-HZ	2-I2R-HZ	3-I2R-HZ
2	.12	0	0	0	0	0
3	.00	0	0	0	0	0
4	.00	0	2	0	3	7
5	.00	0	5	0	27	11
6	.00	0	2	0	60	0
7	.00	0	11	32	49	0
8	.00	0	4	140	6	0
9	.00	0	28	180	2	0
10	.00	0	194	55	0	0
11	.30	0	422	7	0	0
12	.13	0	682	2	0	0
13	.00	0	1201	1	0	0
14	4.89	289	671	0	0	0
15	46.89	656	145	0	0	0
16	100.13	514	7	0	0	0
17	167.66	183	5	1	0	0
18	266.58	51	2	0	0	0
19	420.27	26	0	0	0	0
20	499.01	1	0	0	0	0
21	477.02	0	0	0	0	0
22	258.20	1	0	0	0	0
23	126.21	0	0	0	0	0
24	63.03	0	0	0	0	0
25	6.41	0	0	0	0	0
26	.00	0	0	0	0	0
27						
28	2436.85	1721	3381	418	147	18

Table F-3 - Continued

	S	T	U	V	W	X
1	4-I2R-HZ	DEFR-HZ	LO-COOL-HZ	HI-COOL-HZ	LO-HT-kBTU	LO-HT-TEMP
2	0	0	0	0	.000	.00
3	0	0	0	0	.000	.00
4	2	0	0	0	.000	.00
5	0	0	0	0	.000	.00
6	0	0	0	0	.000	.00
7	0	0	0	0	.000	.00
8	0	0	0	0	.000	.00
9	0	0	0	0	.000	.00
10	0	1	0	0	.000	.00
11	0	0	0	0	.000	.00
12	0	1	0	0	.000	.00
13	0	2	0	0	2.198	83.46
14	0	0	0	0	1781.120	89.66
15	0	0	0	0	3581.360	92.23
16	0	0	0	0	2407.840	95.10
17	0	0	9	0	842.608	96.15
18	0	0	44	1	238.019	94.09
19	0	0	305	1	107.613	97.95
20	0	0	795	17	8.207	33.05
21	0	0	911	3	.000	.00
22	0	0	609	0	44.846	92.50
23	0	0	316	11	.000	.00
24	0	0	104	56	.000	.00
25	0	0	3	16	.000	.00
26	0	0	0	0	.000	.00
27						
28	2	4	3096	105	9013.810	

Table F-3 - Continued

	Y	Z	AA	AB	AC	AD
1	HI-HT-kBTU	HI-HT-TEMP	I2R-kBTU	I2R-TEMP	LOCOOL-kBTU	LOLAT-kBTU
2	.000	.00	.000	.00	.000	.000
3	.000	.00	.000	.00	.000	.000
4	40.835	107.30	96.122	114.69	.000	.000
5	70.966	107.35	475.664	101.75	.000	.000
6	3.021	98.97	957.121	100.45	.000	.000
7	87.014	104.85	1209.590	96.72	.000	.000
8	112.881	93.11	2374.920	94.22	.000	.000
9	1324.410	88.26	2280.210	95.51	.000	.000
10	4520.580	89.01	486.218	95.74	.000	.000
11	5887.870	90.43	79.137	97.67	.000	.000
12	7632.360	92.56	41.180	110.72	.000	.000
13	11327.000	94.88	22.739	114.50	.000	.000
14	5643.170	96.01	.000	.00	.000	.000
15	1085.900	96.00	.000	.00	.000	.000
16	43.582	97.85	.000	.00	.000	.000
17	24.474	84.11	5.761	92.22	35.189	19.780
18	33.780	93.47	.000	.00	199.184	127.547
19	.000	.00	.000	.00	1334.880	772.719
20	.000	.00	.000	.00	3527.150	1869.270
21	.000	.00	.000	.00	4571.340	2041.190
22	.000	.00	.000	.00	4429.970	1414.930
23	.000	.00	.000	.00	3640.850	742.159
24	.000	.00	.000	.00	1826.480	228.989
25	.000	.00	.000	.00	1137.220	7.278
26	.000	.00	.000	.00	.000	.000
27						
28	37837.843		8028.662		20702.263	7223.862

Table F-3 - Continued

	AE LO-SEN/TOT	AF HICOOL-kBTU	AG HILAT-kBTU	AH HI-SEN/TOT	AI HOUSE-kWH	AJ LOCHT-kWH
1						
2	.00	.000	.000	.00	1.520	.000
3	.00	.000	.000	.00	.480	.000
4	.00	.000	.000	.00	165.760	.000
5	.00	.000	.000	.00	300.600	.000
6	.00	.000	.000	.00	500.320	.000
7	.00	.000	.000	.00	499.360	.000
8	.00	.000	.000	.00	799.360	.000
9	.00	.000	.000	.00	1215.080	.000
10	.00	.000	.000	.00	1598.760	.000
11	.00	7.391	5.346	.28	2057.320	.000
12	.00	6.862	4.769	.30	2433.160	.000
13	.00	14.758	9.235	.37	3952.120	.480
14	.00	.000	.000	.00	2955.600	150.760
15	.00	.000	.000	.00	2924.720	282.000
16	.00	.000	.000	.00	2426.440	191.480
17	.44	.000	.000	.00	2182.920	61.440
18	.36	2.751	1.536	.44	2154.200	18.960
19	.42	155.563	78.524	.50	2186.600	7.840
20	.47	103.645	56.655	.45	2477.960	.200
21	.55	20.861	8.799	.58	2519.360	.000
22	.68	2.158	.376	.83	1972.200	.800
23	.80	178.729	45.006	.75	1557.480	.000
24	.87	697.231	189.590	.73	954.360	.000
25	.94	231.059	57.454	.75	179.720	.000
26	.00	.000	.000	.00	.000	.000
27						
28		1421.008	457.290		38015.400	713.960

Table F-3 - Continued

	AK	AL	AM	AN	AO	AP
1	HICHT-kWH	LOBHT-kWH	HIBHT-kWH	LOFHT-kWH	HIFHT-kWH	HP-kWH
2	.000	.000	.000	.000	.000	.019
3	.000	.000	.000	.000	.000	.019
4	4.560	.000	.701	.000	.428	5.905
5	22.920	.000	3.517	.000	2.038	29.680
6	43.800	.000	6.468	.000	3.522	55.959
7	70.440	.000	9.975	.000	5.379	88.404
8	147.600	.000	19.840	.000	10.996	183.897
9	241.840	.000	30.575	.000	16.316	295.874
10	410.440	.000	48.742	.000	26.121	497.380
11	489.640	.000	57.995	.000	30.679	594.222
12	622.320	.000	69.849	.000	39.209	758.940
13	880.120	.048	95.067	.075	55.153	1073.050
14	437.400	15.751	45.608	14.647	27.177	731.284
15	89.360	29.241	8.970	25.349	5.846	488.430
16	3.520	19.143	.313	15.246	.320	264.248
17	2.400	5.892	.211	4.753	.160	111.966
18	2.160	1.633	.227	1.383	.106	57.028
19	.000	.794	.000	.626	.023	26.809
20	.000	.019	.000	.037	.005	8.063
21	.000	.000	.000	.016	.001	3.410
22	.000	2.605	.000	.027	.000	1.609
23	.000	.000	.000	.000	.000	.048
24	.000	.000	.000	.000	.000	.000
25	.000	.000	.000	.000	.000	.000
26	.000	.000	.000	.000	.000	.000
27						
28	3468.520	75.126	398.058	62.159	223.479	5276.245

Table F-3 - Continued

	AQ CC+CTR-kWH	AR I2R-kWH	AS LOCCL-kWH	AT HICCL-kWH	AU HIBCL-kWH	AV LOFCL-kWH
1						
2	.019	.000	.000	.000	.000	.001
3	.019	.000	.000	.000	.000	.000
4	.258	24.647	.000	.000	.000	.000
5	1.205	116.601	.000	.000	.000	.000
6	2.209	184.730	.000	.000	.000	.000
7	2.745	204.385	.000	.000	.000	.000
8	5.310	261.828	.000	.000	.000	.000
9	7.108	260.307	.000	.000	.000	.000
10	10.626	90.278	.000	.000	.000	.000
11	17.112	91.683	.000	.120	.017	.000
12	24.526	69.610	.000	.120	.015	.000
13	44.740	119.955	.000	.240	.032	.000
14	39.868	28.741	.000	.000	.000	.026
15	44.856	4.095	.000	.000	.000	.016
16	40.278	9.632	.000	.000	.000	.041
17	36.556	2.925	2.080	.000	.417	.244
18	29.382	4.602	12.600	.240	2.300	1.051
19	15.698	.390	79.040	8.960	19.083	6.963
20	7.120	.000	229.440	7.080	48.271	19.780
21	3.195	.000	343.280	1.960	68.870	28.345
22	1.075	.624	385.520	.840	74.679	30.228
23	.048	.000	360.600	20.200	72.113	27.398
24	.000	.000	214.160	74.480	47.000	16.230
25	.000	.000	30.800	30.760	8.756	2.311
26	.000	.000	.000	.000	.000	.000
27						
28	333.954	1475.032	1657.520	145.000	341.553	132.634

Table F-3 - Continued

	AW HIFCL-kWH	AX HP-COOL-kWH	AY CTR-CL-kWH	AZ DEFR-kBTU	BA DEFR-kWH	BB EM-HRS
2	.000	.029	.028	.000	.000	.00
3	.000	.000	.000	.000	.000	.00
4	.000	.000	.000	.000	.000	8.34
5	.000	.000	.000	.000	.000	5.22
6	.000	.000	.000	.000	.000	6.52
7	.000	.000	.000	.000	.000	1.44
8	.000	.000	.000	.000	.000	2.70
9	.000	.000	.000	.000	.000	11.39
10	.000	.000	.000	2.291	.728	15.91
11	.014	.173	.022	.000	.000	26.07
12	.013	.173	.025	2.689	.687	5.77
13	.012	.289	.011	4.650	1.610	.00
14	.007	.462	.389	.000	.000	4.13
15	.013	4.374	3.903	.000	.000	9.57
16	.010	9.238	8.307	.000	.000	31.92
17	.024	18.236	14.248	.000	.000	19.30
18	.024	38.639	22.974	.000	.000	21.14
19	.338	144.863	36.414	.000	.000	37.26
20	.408	353.768	48.294	.000	.000	18.55
21	.096	493.228	49.505	.000	.000	13.58
22	.175	519.400	34.121	.000	.000	.36
23	.842	501.068	25.989	.000	.000	.00
24	3.081	366.465	13.078	.000	.000	.00
25	1.204	75.399	2.563	.000	.000	.00
26	.000	.000	.000	.000	.000	.00
28	6.261	2525.805	259.872	9.630	3.025	239.17

Table F-3 - Continued

	BC EM-kBTU	BD EM-I2R-kWH	BE EM-B-kWH	BF EM-CTR-kWH	BG EM-HP-kWH	BH PWR-OFF-HRS
1						
2	.000	.000	.000	.000	.000	.00
3	.000	.000	.000	.000	.000	.00
4	348.850	85.287	1.969	.707	2.717	.00
5	242.276	55.064	1.282	.440	1.763	.00
6	356.200	80.061	1.866	.530	2.437	.00
7	51.906	9.944	.508	.128	.636	.00
8	12.197	.000	.955	.249	1.204	.00
9	249.438	47.498	1.140	.870	2.090	.23
10	633.790	120.735	2.873	1.342	4.219	.05
11	902.451	107.983	2.563	1.331	4.017	.00
12	288.540	51.398	1.225	.497	1.724	1.70
13	.000	.000	.000	.000	.000	.19
14	36.318	10.802	.238	.328	.607	.54
15	45.327	5.187	.120	.739	.944	1.95
16	123.502	23.359	.906	2.486	3.603	2.03
17	14.267	.429	.008	1.310	1.570	4.24
18	15.680	.351	.000	1.617	1.744	.49
19	39.509	1.872	.109	2.739	3.189	.31
20	18.393	.273	.000	1.286	1.493	.04
21	9.649	.234	.000	1.031	1.156	.74
22	.647	.000	.000	.000	.000	.00
23	.000	.000	.000	.000	.000	.00
24	.000	.000	.000	.000	.000	.00
25	.000	.000	.000	.000	.000	.00
26	.000	.000	.000	.000	.000	.00
27						
28	3388.940	600.477	15.762	17.630	35.113	12.51

Table F-3 - Continued

	BI HRS DISTR	BJ NORM HRS
1		
2	.0000472400	.41
3	.0000209302	.18
4	.0014693391	12.87
5	.0028318341	24.81
6	.0048612879	42.58
7	.0054735417	47.95
8	.0113054076	99.04
9	.0171288752	150.05
10	.0271110961	237.49
11	.0392745221	344.04
12	.0521121388	456.50
13	.0876331219	767.67
14	.0727915960	637.65
15	.0765089760	670.22
16	.0755956693	662.22
17	.0777418818	681.02
18	.0760832328	666.49
19	.0812446405	711.70
20	.0945348281	828.13
21	.0783169267	686.06
22	.0547575790	479.68
23	.0382912302	335.43
24	.0224500825	196.66
25	.0024140225	21.15
26	0	.00
27	---	
28	1	8760.00

Table F.3 — Nomenclature

Column	Title	Meaning
A	BIN	Range of temperatures in the bin - °F
B	TOT-HRS	Total hours of data accumulated in the bin
C	LO-HT-HRS	Operating hours in low capacity heating mode
D	HI-HT-HRS	Operating hours in high capacity heating mode
E	1-I2R-HRS	Operating hours in high capacity heating mode with one stage of resistance heat
F	2-I2R-HRS	Operating hours in high capacity heating mode with two stages of resistance heat
G	3-I2R-HRS	Operating hours in high capacity heating mode with three stages of resistance heat
H	4-I2R-HRS	Operating hours in high capacity heating mode with four stages of resistance heat
I	DEFR-HRS	Operating hours in defrost mode
J	COMP/HT/OFF	Hours during heating mode with compressor off
K	LOCOOL-HRS	Operating hours in low capacity cooling mode
L	HICOOL-HRS	Operating hours in high capacity cooling mode
M	COMP/CL/OFF	Hours during cooling mode with compressor off
N	LO-HT-HZ	Compressor operating cycles in low capacity heating mode
O	HI-HT-HZ	Compressor operating cycles in high capacity heating mode
P	1-I2R-HZ	First stage resistance heat operating cycles in normal heating operation
Q	2-I2R-HZ	Second stage resistance heat operating cycles in normal heating operation
R	3-I2R-HZ	Third stage resistance heat operating cycles in normal heating operation
S	4-I2R-HZ	Fourth stage resistance heat operating cycles in normal heating operation

T	DEFR-HZ	Defrost cycles
U	LO-COOL-HZ	Compressor operating cycles in low capacity cooling mode
V	HI-COOL-HZ	Compressor operating cycles in high capacity cooling mode
W	LO-HT-kBTU	Heat delivered in low capacity heating mode - kBtu
X	LO-HT-TEMP	Delivered air temperature in low capacity heating mode - °F
Y	HI-HT-kBTU	Heat delivered in high capacity heating mode - kBtu
Z	HI-HT-TEMP	Delivered air temperature in high capacity heating mode - °F
AA	I2R-kBTU	Heat delivered in high capacity heating mode with resistance heat on - kBtu
AB	I2R-TEMP	Delivered air temperature in high capacity heating mode with resistance heat on - °F
AC	LOCOOL-kBTU	Total cooling delivered in low capacity cooling mode - kBtu
AD	LOLAT-kBTU	Latent cooling delivered in low capacity cooling mode - kBtu
AE	LO-SEN/TOT	Sensible to total capacity ratio in low capacity cooling mode
AF	HICOOL-kBTU	Total cooling delivered in high capacity cooling mode - kBtu
AG	HILAT-kBTU	Latent cooling delivered in high capacity cooling mode - kBtu
AH	HI-SEN/TOT	Sensible to total capacity ratio in high capacity cooling mode - kBtu
AI	HOUSE-kWH	Whole house electric use - kWh
AJ	LOCHT-kWH	Compressor electric use in low capacity heating mode - kWh
AK	HICHT-kWH	Compressor electric use in high capacity heating mode - kWh

AL	LOBHT-kWH	Indoor blower electric use in low capacity heating mode (low blower speed) - kWh
AM	HIBHT-kWH	Indoor blower electric use in high capacity heating mode (high blower speed) - kWh
AN	LOFHT-kWH	Outdoor Fan electric use in low capacity heating mode (high fan speed) - kWh
AO	HIFHT-kWH	Outdoor fan electric use in high capacity heating mode (high fan speed) - kWh
AP	HP-kWH	Heat pump system electric use in heating mode not including resistance heat (difference between heat pump system electric use and sum of other components) - kWh
AQ	CC+CTR-kWH	Crankcase heat and control electric use in heating mode - kWh
AR	I2R-kWH	Resistance heat electric use not including defrost - kWh
AS	LOCCL-kWH	Compressor electric use in low capacity cooling mode - kWh
AT	HICCL-kWH	Compressor electric use in high capacity cooling mode - kWh
AU	HIBCL-kWH	Indoor blower electric use in cooling mode (high speed at all times) - kWh
AV	LOFCL-kWH	Outdoor fan electric use in low capacity cooling mode (high speed at all times as applied) - kWh
AW	HIFCL-kWH	Outdoor fan electric use in high capacity cooling mode (high speed) - kWh
AX	HP-COOL-kWH	Heat pump system electric use in cooling mode - kWh
AY	CTR-CL-kWH	Crankcase heat and control electric use in cooling mode - kWh
AZ	DEFR-kBTU	Heat delivered in defrost mode - kBtu

BA	DEFR-kWH	Heat pump system electric use in defrost mode - kWh
BB	EM-HRS	Operating hours in emergency heat mode
BC	EM-kBTU	Heat delivered in emergency heat mode - kBtu
BD	EM-I2R-kWH	Resistance heat electric use in emergency heat mode - kWh
BE	EM-B-KWH	Blower electric use in emergency heat mode - kWh
BF	EM-CTR-kWH	Crankcase heat and control electric use in emergency heat mode - kWh
BG	EM-HP-kWH	Heat pump system energy use in emergency heat mode not including resistance heat - kWh
BH	PWR-OFF-HRS	Hours of electric power outage
BI	HRS-DISTR	Ratio of hours in bin to total hours in data record
BJ	NORM HRS	Observed hours in bin normalized to a full year of 8760 hours

Table F-4. - Temperature Bin Data April 1, 1984 through March 31, 1985

DISTRIBUTION OF ENERGY, W / DOE DUAL STRK HP, JEANNETTE, 4/1/84 thru 3/31/85

TEMPERATURE BIN degF	LOCAP HTG DELIVERED MMBTU	LOCAP HTG DEL AIR degF	HICAP HTG DELIVERED MMBTU	HICAP HTG+O DEL AIR degF	I2R HTG DELIVERED MMBTU	HICAP HTG+R DEL AIR degF	DEFROST Q DELIVERED MMBTU	LOCAP CLG DELIVERED MMBTU
-25 TO -20	.000	.00	.000	.00	.000	.00	.000	.000
-20 TO -15	.000	.00	.123	100.87	.583	96.86	.000	.000
-15 TO -10	.000	.00	.001	87.67	.501	92.12	.000	.000
-10 TO -5	.000	.00	.040	94.64	.168	94.35	.000	.000
-5 TO 0	.000	.00	.063	84.83	.314	89.64	.000	.000
0 TO 5	.000	.00	.116	87.10	.309	90.55	.007	.000
5 TO 10	.000	.00	1.850	87.65	.226	91.63	.018	.000
10 TO 15	.000	.00	4.392	89.42	.019	95.17	.030	.000
15 TO 20	.000	.00	6.247	91.44	.006	82.25	.070	.000
20 TO 25	.000	.00	7.311	93.13	.004	87.44	.063	.000
25 TO 30	.031	85.33	7.881	94.20	.002	87.17	.041	.000
30 TO 35	2.546	87.95	5.279	96.32	.018	92.71	.023	.000
35 TO 40	2.748	89.21	3.692	100.47	.033	112.33	.002	.000
40 TO 45	2.935	87.85	1.594	100.82	.000	.00	.004	.000
45 TO 50	2.213	92.29	.152	102.89	.000	.00	.000	.000
50 TO 55	1.309	96.37	.004	88.14	.000	.00	.000	.005
55 TO 60	.423	96.44	.000	.00	.000	.00	.000	.204
60 TO 65	.037	97.38	.009	94.31	.000	.00	.000	1.049
65 TO 70	.000	.00	.000	.00	.000	.00	.000	3.152
70 TO 75	.000	.00	.000	.00	.000	.00	.000	4.682
75 TO 80	.000	.00	.000	.00	.000	.00	.000	2.983
80 TO 85	.000	.00	.000	.00	.000	.00	.000	2.708
85 TO 90	.000	.00	.000	.00	.000	.00	.000	.482
90 TO 95	.000	.00	.000	.00	.000	.00	.000	.000
95 TO 100	.000	.00	.000	.00	.000	.00	.000	.000
	12.242		38.753		2.182		.258	15.264

Table F-4 - Continued

LOCAP CLG CONDNSATE MMBTU	LOCAP CLG SEN/TOTAL RATIO	HICAP CLG DELIVERED MMBTU	HICAP CLG CONDNSATE MMBTU	HICAP CLG SEN/TOTAL RATIO	WHOLE HOUSE kWH	LOCAP HTG COMPR kWH	HICAP HTG COMPR kWH	LOCAP HTG BLOWER kWH
.000	.000	.000	.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	203.494	.000	30.400	.000
.000	.000	.000	.000	.000	146.580	.000	28.920	.000
.000	.000	.000	.000	.000	53.934	.000	11.080	.000
.000	.000	.000	.000	.000	86.207	.000	25.640	.000
.000	.000	.000	.000	.000	110.482	.000	29.600	.000
.000	.000	.000	.000	.000	428.407	.000	165.560	.000
.000	.000	.000	.000	.000	977.595	.000	383.200	.000
.000	.000	.000	.000	.000	1529.260	.000	536.800	.000
.000	.000	.000	.000	.000	1843.430	.000	617.000	.000
.000	.000	.000	.000	.000	2251.490	3.400	651.040	.390
.000	.000	.000	.000	.000	2375.890	231.960	426.040	27.254
.000	.000	.000	.000	.000	2457.080	235.080	299.680	28.961
.000	.000	.000	.000	.000	2816.280	291.840	150.080	40.980
.000	.000	.000	.000	.000	3197.470	196.880	11.920	30.048
.003	.371	.000	.000	.000	3887.290	112.520	.280	14.152
.084	.589	.000	.000	.000	3853.390	34.200	.000	4.311
.301	.713	.000	.000	.000	4072.350	9.530	1.080	.694
.864	.726	.000	.000	.000	3221.170	.000	.000	.000
1.651	.647	.020	.000	1.000	2490.480	.000	.000	.000
.655	.780	.121	.018	.848	1436.860	.000	.000	.000
.576	.787	.018	.006	.653	907.647	.000	.000	.000
.090	.814	.000	.000	.000	183.735	.000	.000	.000
.000	.000	.000	.000	.000	.371	.000	.000	.000
.000	.000	.000	.000	.000	.000	.000	.000	.000
4.224	.723	.159	.025	.844	38530.892	1115.410	3368.320	146.790

Table F-4 - Continued

HICAP HTG FAN kWH	HTPMP HTG SYSTEM kWH	HTPMP HTG HTR+CTRL kWH	I2R kWH	LOCAP CLG COMPR kWH	HICAP CLG COMPR kWH	HICAP CLG BLWR kWH	LOCAP CLG FAN kWH	HICAP CLG FAN kWH
.000	.000	.000	.000	.000	.000	.000	.000	.000
2.343	38.388	.572	124.979	.000	.000	.000	.000	.000
2.091	35.922	.355	63.025	.000	.000	.000	.000	.000
765	13.647	.118	26.218	.000	.000	.000	.000	.000
1.686	31.365	.312	23.688	.000	.000	.000	.000	.000
1.918	37.039	.267	23.682	.000	.000	.000	.000	.000
11.310	203.553	1.609	26.010	.000	.000	.000	.000	.000
24.270	462.811	3.296	3.635	.000	.000	.000	.000	.000
33.567	651.412	6.826	11.488	.000	.000	.000	.000	.000
38.202	747.264	11.088	3.676	.000	.000	.000	.000	.000
40.793	792.568	15.576	14.013	.000	.000	.000	.000	.000
27.012	808.613	24.007	5.658	.000	.000	.000	.000	.000
19.981	671.138	30.540	7.506	.000	.000	.000	.000	.000
10.070	572.966	42.997	1.017	.000	.000	.000	.019	.000
.763	303.845	57.179	15.291	.000	.000	.000	.061	.000
.048	194.079	63.751	14.855	.840	.000	.064	.586	.000
.012	104.555	54.519	.087	28.800	.000	5.496	1.792	.000
.053	72.316	59.074	.194	95.680	.000	20.234	8.547	.000
.004	25.897	22.007	.000	274.040	.000	57.295	23.880	.000
.000	.000	3.035	.000	361.320	1.880	72.781	30.049	.093
.000	.710	.621	.000	276.120	12.800	54.638	21.599	.578
.000	.000	.000	.000	223.240	3.400	42.280	16.994	.140
.000	.000	.000	.000	51.640	.000	9.530	3.865	.002
.000	.000	.000	.000	.120	.000	.018	.018	.000
.000	.000	.000	.000	.000	.000	.000	.000	.000
214.888	5768.088	397.750	365.022	1311.800	18.080	262.336	107.410	.813

Table F-4 - Continued

HTPMP CLG SYSTEM kWH	HTPMP CLG HTR+CTRL kWH	DEFROST kWH	EMERGENCY Q DELIVERED MMBTU	EMERGENCY RESISTANCE kWH	EMERGENCY BLOWER kWH	EMERGENCY CONTROLLER kWH	EMERGENCY HEAT PUMP kWH	emergency in error kwh
.000	.000	.000	.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000	.000	.000	.000
.000	.000	5.552	.000	.000	.000	.000	.000	.000
.000	.000	4.883	.000	.000	.000	.000	.000	.000
.000	.000	1.249	.000	.000	.000	.000	.000	.000
.000	.000	2.826	.000	.000	.000	.000	.000	.000
.000	.000	9.527	.000	.000	.000	.000	.000	.000
.259	.259	9.202	.000	.000	.000	.000	.000	.000
.262	.262	3.024	.092	29.125	1.078	.523	1.685	.084
.155	.155	1.125	.029	10.490	.297	.191	.490	.002
2.979	2.680	2.736	.076	34.718	1.042	.600	1.723	.081
10.697	9.357	.000	.017	7.594	.583	.400	1.026	.043
33.776	26.056	.000	.052	19.483	.526	.707	1.276	.043
77.598	41.563	.000	.001	.414	.016	.132	.148	.000
161.190	41.943	.000	.000	.028	.000	.220	.262	.042
401.118	49.878	.000	.000	.000	.000	.044	.044	.000
511.826	44.470	.000	.000	.000	.000	.000	.000	.000
389.828	23.876	.000	.000	.000	.000	.000	.000	.000
297.719	11.541	.000	.000	.000	.000	.000	.000	.000
67.215	2.234	.000	.000	.000	.000	.005	.005	.000
.242	.000	.000	.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000	.000	.000	.000
1954.863	254.273	170.125	.267	101.852	3.542	2.822	6.659	

Table F-4 - Continued

emergency nrg LOSS kwh	DELIVERED HEAT MMBTU	DELIVERED COOL MMBTU	MEAN TEMP degF	COMPRESSOR ENERGY kWH	BLOWER ENERGY kWH	FAN ENERGY kWH	CHTR & CTRL ENERGY kWH	HEATING EER BTU/WH	COOLING EER BTU/WH
.000	.000	.000	-23.00	.000	.000	.000	.000	.000	.000
.000	.706	.000	-18.00	30.400	5.073	2.343	.572	4.322	.000
.000	.502	.000	-13.00	28.920	4.556	2.091	.355	5.069	.000
.000	.208	.000	-8.00	11.080	1.684	.765	.118	5.215	.000
.000	.377	.000	-3.00	25.640	3.727	1.686	.312	6.842	.000
.000	.432	.000	2.00	29.600	4.081	1.918	.267	6.633	.000
.000	2.093	.000	7.00	165.560	22.195	11.310	1.609	8.665	.000
.000	4.441	.000	12.00	383.200	48.168	24.270	3.296	9.179	.000
.000	6.322	.000	17.00	536.800	65.705	33.567	6.826	9.068	.000
.000	7.378	.000	22.00	617.000	73.672	38.202	11.088	9.420	.000
.000	7.955	.000	27.00	654.440	75.287	41.108	15.835	9.589	.000
3.920	7.867	.000	32.00	658.000	74.885	50.073	24.269	9.528	.000
2.474	6.474	.000	37.00	534.760	62.329	42.254	30.695	9.542	.000
14.183	4.533	.000	42.00	441.920	57.261	36.751	45.677	7.780	.000
3.620	2.366	.000	47.00	208.800	31.274	16.953	66.536	7.181	.000
5.628	1.313	.005	52.00	113.640	14.244	9.416	89.807	6.122	.197
.161	.423	.204	57.00	63.000	9.807	4.833	96.082	4.396	2.622
.290	.046	1.049	62.00	106.290	21.011	9.171	101.017	.646	6.302
.044	.000	3.152	67.00	274.040	57.295	24.010	71.885	.000	7.780
.000	.000	4.702	72.00	363.200	72.781	30.182	47.505	.000	9.208
.000	.000	3.104	77.00	288.920	54.638	22.181	24.497	.000	7.966
.000	.000	2.727	82.00	226.640	42.280	17.134	11.541	.000	9.163
.005	.000	.482	87.00	51.640	9.530	3.867	2.234	.000	7.162
.000	.000	.000	92.00	.120	.018	.018	.000	.000	.000
.000	.000	.000	97.00	.000	.000	.000	.000	.000	.000
	53.434	15.423		5813.610	811.501	424.103	652.023	8.506	7.890

Table F.4 — Nomenclature

Title	Meaning
TEMPERATURE BIN	Range of temperatures in the bin - °F
LOCAP HTG DELIVERED MMBTU	Heating delivered in low capacity heating mode - Btu X 10^6
LOCAP HTG DEL AIR deg F	Delivered air temperature in low capacity heating mode - °F
HICAP HTG DELIVERED MMBTU	Heating delivered in high capacity heating mode with no resistance heat - Btu X 10^6
HICAP HTG+O DEL AIR deg F	Delivered air temperature in high capacity heating mode with no resistance heat - °F
I^2R HTG DELIVERED MMBTU	Heating delivered in high capacity heating mode with resistance heat - Btu X 10^6
HICAP HTG+R DEL AIR deg F	Delivered air temperature in high capacity heating mode with resistance heat - °F
DEFROST Q DELIVERED MMBTU	Heating delivered in defrost mode - Btu X 10^6
LOCAP CLG DELIVERED MMBTU	Total cooling delivered in low capacity cooling mode - Btu X 10^6
LOCAP CLG CONDNSATE MMBTU	Latent cooling delivered in low capacity cooling mode - Btu X 10^6

LOCAP CLG SEN/TOTAL RATIO	Ratio of sensible cooling delivered to latent cooling delivered in low capacity cooling mode
HICAP CLG DELIVERED MMBTU	Total cooling delivered in high capacity cooling mode - Btu X 10^6
HICAP CLG CONDNSATE MMBTU	Latent cooling delivered in high capacity cooling mode - Btu X 10^6
HICAP CLG SEN/TOTAL RATIO	Ratio of sensible cooling delivered to latent cooling delivered in high capacity cooling mode
WHOLE HOUSE kWH	Whole house electric use - kWh
LOCAP HTG COMPR kWH	Compressor electric use in low capacity heating mode - kWh
HICAP HTG COMPR kWH	Compressor electric use in high capacity heating mode - kWh
LOCAP HTG BLOWER kWH	Indoor blower electric use in low capacity heating mode (low speed) - kWh
HICAP HTG BLOWER kWH	Indoor blower electric use in high capacity heating mode (high speed) - kWh
LOCAP HTG FAN kWH	Outdoor fan electic use in low capacity heating mode (high speed as applied) - kWh
HICAP HTG FAN kWH	Outdoor fan electric use in high capacity heating mode (high speed) - kWh

HTPMP HTG SYSTEM kWH	Heat pump system electric use in normal operation excluding resistance heat - kWh
HTPMP HTG HTR+CTRL kWH	Crankcase heat and control system electric use during heating operation (difference (between heat pump system electric use and sum of other components) - kWh
I^2R kWH	Resistance heat electric use during normal heating operation excluding defrost - kWh
LOCAP CLG COMPR kWH	Compressor electric use in low capacity cooling mode - kWh
HICAP CLG COMPR kWH	Compressor electric use in high capacity cooling mode - kWh
HICAP CLG BLWR kWH	Indoor blower electric use during cooling operation (high speed at all times) - kWh
LOCAP CLG FAN kWH	Outdoor fan electric use in low capacity cooling mode (high speed as applied) - kWh
HICAP CLG FAN kWH	Outdoor fan electric use in high capacity cooling mode (high speed) - kWh
HTPMP CLG SYSTEM kWH	Heat pump system electric use during cooling operation - kWh
HTPMP CLG HTR+CTRL kWH	Crankcase heat and control system electric use during cooling operation (difference between heat pump system electric use and sum of other components) - kWh

DEFROST kWH	Heat pump system electric use during defrost operation excluding resistance heat - kWh
EMERGENCY Q DELIVERED MMBTU	Heat delivered during emergency heat operation - Btu X 10^6
EMERGENCY RESISTANCE kWH	Resistance heat electric use during emergency operation - kWh
EMERGENCY BLOWER kWH	Indoor blower electric use during emergency operation (high speed) - kWh
EMERGENCY CONTROLLER kWH	Control system electric use during emergency operation (difference between heat pump system electric use and sum of other components) - kWh
EMERGENCY HEAT PUMP kWH	Heat pump system electric use during emergency operation excluding resistance heat - kWh
emergency in error kwh	Difference between heat pump system electric use and sum of emergency blower and emergency controller electric use - kWh
emergency nrg LOSS kWh	Difference between sum of emergency heat pump electric use and emergency resistance heat electric use and electrical equivalent of emergency heat delivered - kWh
DELIVERED HEAT MMBTU	Total heat delivered during normal heating operation - Btu X 10^6
DELIVERED COOL MMBTU	Total cooling delivered - Btu X 10^6

MEAN TEMP deg F	Mean temperature in the bin - °F
COMPRESSOR ENERGY kWH	Total compressor electric use - kWh
BLOWER ENERGY kWH	Total indoor blower electric use excluding emergency operation - kWh
FAN ENERGY kWH	Total outdoor fan electric use - kWh
CHTR & CTRL ENERGY kWH	Total crankcase heat and control system electric use excluding emergency operation (difference between heat pump system electric use and sum of other components) - kWh
HEATING EER BTU/WH	Heating energy efficiency ratio during normal operation - Btu/Wh
COOLING EER BTU/WH	Cooling energy efficiency ratio - Btu/Wh

ORNL/Sub/79-24712/4
Dist. Category UC-95d

INTERNAL DISTRIBUTION

1. V. D. Baxter
2. J. G. Carbonell, Consultant
3. R. S. Carlsmith
4. F. C. Chen
5. N. Domingo
6. P. D. Fairchild
7. S. K. Fischer
8. W. Fulkerson
9. S. M. Gillis, Consultant
10. W. R. Huntley
11. L. Jung
12. F. R. Kalhammer, Consultant
13. R. E. Kasperson, Consultant
14. M. A. Kuliasha
15. M. Lessen, Consultant
16. W. P. Levins
17. F. C. Maienschein
18. J. F. Martin
19. S. H. McConathy
20. H. A. McLain
21. V. C. Mei
22. J. W. Michel
23. R. W. Murphy
24. H. Perez-Blanco
25. G. T. Privon
26. C. K. Rice
27. M. W. Rosenthal
28. R. A. Stevens
29. M. P. Stulberg
30. K. H. Zimmerman

31–200. Energy Conservation Distribution, Bldg. 9102-2, Room 218
201–202. Laboratory Records Department
203. Laboratory Records—RC
204. ORNL Patent Office
205–206. Central Research Library
207. Document Reference Section

EXTERNAL DISTRIBUTION

208. T. J. Fagan, Westinghouse Electric Corporation, R&D Center, 1310 Beulah Road, Pittsburgh, PA 15235
209. R. J. Fiskum, Energy Conversion Equipment Branch, CE-132, GH-068 Department of Energy, 1000 Independence Avenue SW, Washington, DC 20585
210. T. Kapus, Department of Energy, 1000 Independence Avenue, Washington, DC 20585
211. R. A. Lucheta, Westinghouse Electric Corporation, R&D Center, 1310 Beulah Road, Pittsburgh, PA 15235
212. J. P. Millhone, Director, Office of Buildings and Community Systems, Department of Energy, 1000 Independence Avenue SW, Washington, DC 20585
213. J. D. Ryan, Energy Conversion Equipment Branch, CE-132, U.S. Department of Energy, 1000 Independence Avenue SW, Washington, DC 20585

214–243. T. G. Statt, Energy Conversion Equipment Branch, CE-132, Department of Energy, 1000 Independence Avenue SW, Washington, DC 20585

244. S. E. Vego, Westinghouse Electric Corporation, R&D Center, 1310 Beulah Road, Pittsburgh, PA 15235
245. R. R. Young, Westinghouse Electric Corporation, R&D Center, 1310 Beulah Road, Pittsburgh, PA 15235
246. Congressional Information Service, Research Building 83, Kodak Park, Rochester, NY 14050
247. Edison Electric Institute, Eighth Floor, 1111 19th Street NW, Washington, DC 20036
248. National Energy Information Center, Library, Room 1404, 12th and Pennsylvania Avenue NW, Washington, DC 20461
249. Office of the Assistant Manager for Energy R&D, U.S. Department of Energy, Oak Ridge Operations, Oak Ridge, TN 37831
250–500. Given distribution as shown in TIC-4500 (Rev. 73) under Energy Conservation—Buildings and Community Systems (25 copies, NTIS)