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Monitoring of Residential Groundwater-Source Heat Pumps in the Northeast

Final Report

Report Prepared by

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212 Locust Street
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under
Subcontract 7985

for

OAK RIDGE NATIONAL LABORATORY
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the

U.S. DEPARTMENT OF ENERGY

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Date of Issue—March 1986

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Palo Alto, California 94304

ABSTRACT

Two rural Pennsylvania single-family residences in a 6,000 heating degree-day climate, were retrofitted with add-on groundwater-source heat pumps. Performance data were collected over a two-year period. Data were collected manually and by microcomputer, and included weather, energy use of the heat pump and house, water flow and temperature.

Compared to oil, at 1984 prices, a payback of 4 to 6 years is possible. One unit operated at a COP in heating of nearly 3.0, including an allowance for pumping energy. The COP of the second unit was lower, still better than oil heating but not cost-effective at today's rates. Some initial reliability problems were also encountered with one unit. This emphasizes the need for astute buying and use of comparative ratings on models at conditions consistent with the application. As water-source heat pump performance is affected by water supply temperatures, the rating must be for temperatures similar to groundwater temperatures in the region where the heat pump will be installed, typically 50 to 55°F in Pennsylvania. A substantial quantity of water is required and proper disposal is a consideration. Ponds were used to receive processed water in both test applications. The source groundwater was obtained from wells of more than 50 feet in depth, which are common at rural residences.

The units tested required no significant supplemental heat. Although oversizing may effect performance slightly, undersizing the unit would increase supplemental heat usage. The resulting aggregated demand on a winter-peaking utility could be deleterious. A properly-sized groundwater heat pump should have a load profile similar to resistance heat.

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CONTENTS

Section		Page
1.	**INTRODUCTION**	
	1.1 Background	1-1
	1.2 Current Project	1-1
2.	**METHODS**	
	2.1 Sites	2-1
	2.1.1 Location	2-1
	2.1.2 Climate	2-1
	2.1.3 Groundwater Availability	2-1
	2.2 Equipment	2-1
	2.2.1 Reversible Heat Pump	2-6
	2.2.2 Heating-only Heat Pump	2-6
	2.2.3 Thermostats	2-11
	2.2.4 Water Flow	2-11
	2.2.5 Operational Problems	2-11
	2.3 Measurements	2-14
	2.3.1 Manual Metering	2-15
	2.3.2 Automated Data Acquisition	2-16
	2.3.3 Sensors	2-16
	2.3.4 Data Logger	2-16
	2.3.5 Microcomputer Control Unit	2-18
3.	**TECHNICAL PERFORMANCE RESULTS**	
	3.1 General Results	3-1
	3.2 Overall Performance	3-3
	3.2.1 East Freedom Site	3-3
	3.2.2 Bedford Site	3-4

Section		Page
	3.3 Typical Daily Performance	3-8
	3.3.1 East Freedom Site	3-10
	3.3.2 Bedford Site	3-15
	3.4 Typical Cycle Performance	3-19
	3.4.1 East Freedom Site	3-19
	3.4.2 Bedford Site	3-19
	3.4.3 Cycling Losses	3-24
	3.5 Electrical Load Characteristics	3-24
	3.6 Summary Performance Results	3-29
4.	**CONCLUSIONS**	
	4.1 Introduction	4-1
	4.2 Technical Feasibility & Performance Over Time	4-1
	4.3 Effects on Utility Loads	4-2
	4.4 Economic Performance	4-3
Appendix A	Additional Data	A-1
Appendix B	Glossary	B-1

ILLUSTRATIONS

Figure		Page
1-1	House load and Heating	1-2
2-1	Extremes of Outdoor Temperature Heating Season 82-83 (East Freedom)	2-5
2-2	1982-1983 Heating Season (East Freedom)	2-5
2-3	Water Temperature at 1 a.m. Heating Season 1982-1983 (East Freedom)	2-5
2-4a	Reversible Heat Pump (East Freedom)	2-9
2-4b	Reversible Heat Pump (East Freedom)	2-9
2-5	Heating only Heat Pump with Direct Well-Water Air Conditioning (Bedford)	2-10
2-6	Groundwater Heat Pump Water Processing	2-12
2-7	Data Handling Residence	2-20
2-8	Data Handling University of Pittsburgh	2-20
3-1	Daily Electrical Energy Consumption Heating Season 1982-1983 (East Freedom)	3-5
3-2	Daily System Energy Consumption Heating Season 1982-1983 (East Freedom)	3-5
3-3	Daily Water Consumption of Heat Pump Heating Season 1982-1983 (East Freedom	3-5
3-4	Daily Run Time of Pumps Heating Season 1982-1983 (East Freedom)	3-5
3-5	Daily Heat Pump Cycles Heating Season 1982-1983 (East Freedom)	3-6
3-6	Daily Water Pump Cycles Heating Season 1982-1983 (East Freedom)	3-6
3-7	Fractional Run Time History of Pumps Heating Season 1982-1983 (East Freedom)	3-6
3-8	Components of Heating Energy and Heating Degree Days January 1983 (East Freedom)	3-6
3-9	Total Energy Input (water + fan + compressor) Heating Season 1982-1983 (East Freedom)	3-7
3-10	Daily Electrical Energy Consumption Heating Season 1982-1983 (Bedford)	3-7

Figure		Page
3-11	Daily System Energy Consumption Heating Season 1982-1983 (Bedford)	3-7
3-12	Daily Run Time of Pumps Heating Season 1982-1983 (Bedford)	3-7
3-13	Daily Heat and Water Pump Cycles Heating Season 1982-1983 (Bedford)	3-9
3-14	Fractional Run Time History of Pumps February 1983 thru May 1983 (3rd ht. pump)(Bedford)	3-9
3-15	Component of Heating Energy and Heating Degree Days February 1983 (Bedford)	3-9
3-16	Total Energy Input (water + fan + compressor Heating Season 1982-1983 (Bedford)	3-9
3-17	Hourly Outdoor Temperature, January 20, 1983 (East Freedom)	3-13
3-18	Hourly Electrical Energy Consumption, January 20, 1983 (East Freedom)	3-13
3-19	Hourly System Energy Consumption, January 20, 1983 (East Freedom)	3-13
3-20	Hourly Water Consumption of Heat Pump January 20, 1983 (East Freedom)	3-13
3-21	System Operation on January 20, 1983 (East Freedom)	3-14
3-22	15 Minute Demand for House January 20, 1983 (East Freedom)	3-14
3-23	15 Minute Demand of System (fan + compressor + water Pump January 20, 1983 (East Freedom)	3-14
3-24	Hourly Outdoor Temperature, February 12, 1983 (Bedford)	3-14
3-25	Hourly Electrical Energy Consumption, February 12, 1983 (Bedford)	3-18
3-26	Hourly System Energy Consumption, February 12, 1983 (Bedford)	3-18
3-27	System Operation on February 12, 1983 (Bedford)	3-18
3-28	15 Minute Demand for House, February 12, 1983 (Bedford)	3-18
3-29	15 Minute Demand of System (fan + compressor + water Pump) February 12, 1983 (Bedford)	3-20
3-30	Air and Water Flow for a Cycle at East Freedom	3-20

Figure		Page
3-31	Capacity of Unit for a Cycle at East Freedom	3-20
3-32	COP of Unit for a Cycle at East Freedom	3-20
3-33	Typical Demand for a Cycle at East Freedom	3-23
3-34	Differential Temperatures of Flows at East Freedom	3-23
3-35	Return Air and Water Inlet Temperatures for a Cycle at East Freedom	3-23
3-36	Air and Water Flow for a Cycle at Bedford	3-23
3-37	Capacity of Unit for a Cycle at Bedford	3-25
3-38	COP of Unit for a Cycle at Bedford	3-25
3-39	Typical Demand for Cycle at Bedford	3-25
3-40	Differential Temperatures of Flows at Bedford	3-25
3-41	Return Air and Water Inlet Temperatures for a Cycle at Bedford	3-28
3-42	15 Minute Compressor Demand Heating Season 1982-1983 (East Freedom)	3-28
3-43	15 Minute Compressor Demand Heating Season 1982-1983 (Bedford)	3-28
4-1	15 Minute Demand for Total House (Bedford)	4-2
4-2	Annual Sales	4-4
4-3	Revenue Productivity Potential	4-4

TABLES

Table		Page
2-1	East Freedom Home	2-2
2-2	Bedford Home	2-3
2-3	Weather Information for 1982-83 Heating Season	2-4
2-4	Equipment - Groundwater Source Heat Pumps	2-7
2-4m	Equipment - Groundwater Source Heat Pumps (Metric)	2-8
2-5	Automated Instrumentation	2-17
3-1	Results 1982-83 Heating Season	3-2
3-2	Hourly Data File - East Freedom	3-11
3-3	15-Minute Demand File - East Freedom	3-12
3-4	Hourly Data File - Bedford	3-16
3-5	15-Minute Demand File - Bedford	3-17
3-6	Cycle Data	3-21
3-7	Cycle Data Summary	3-22
3-8	Electrical Demand	3-26
3-8m	Electrical Demand - Metric	3-27

SUMMARY

Many existing residences, especially in the rural areas of the Northern United States, are heated by oil. Currently, oil is readily available and the dismaying price increases of the 1970's are a bad memory. But in the long-term we can expect an inexorable cost escalation exceeding inflation and decreasing availability. Electric-driven heat pumps promise a reliable, economic alternative.

The objectives of the current project were to determine the technical feasibility of groundwater-source heat pumps in the northeast U. S. region, evaluate their coefficient of performance and capacity, analyze the impact of these devices on utility load shape, and compare economics of the units to alternate heating systems - principally oil.

Two groundwater heat pumps were installed in existing residences in central Pennsylvania in climates of more than 6,000 heating degree days. Both heat pumps remove heat from supply water via a vapor compression refrigeration cycle to heat air in a forced-air distribution system. Both units were retrofit into forced-air fossil-fuel-fired heating systems. Electric furnace units were installed to conveniently measure backup heat requirements and for calibration.

One heat pump is reversible and supplies air conditioning via the refrigeration cycle. The other system includes a water-to-air coil or heat exchanger for direct cooling.

Water was obtained from on-property conventional wells of greater than 50' (15m) depth. Groundwater temperature was about 54 deg F (12 deg C) year-round.

Sensors necessary to measure heat pump performance and weather were connected to micro-computers in the homes. Detailed high speed and hourly average data were recorded on magnetic tape and mailed weekly to the University of Pittsburgh which provided data reduction. The test period was two heating and cooling seasons, 1981-83.

RESULTS:

Two complete systems and an extra compressor were necessary to finally achieve reliable performance of the non-reversing system. The reversible system operated reliably through the two-year test period. The systems had adequate capacity even during some of the coldest weather of the century.

As shown below both units exhibited heating season coefficients of performance (COPs) less than published by the manufacturers. No significant supplemental heat was required by either system. The COPs shown below include a penalty for pumping the water required by the heat pump with a common head of 100 feet (300m), at a wire-to-water efficiency of 29%.

It can be seen that the capacity of the nonreversible unit was very close to its published value, but the capacity of the reversible unit was 20% less than its corresponding published value.

Unit		Measured	Published
Nonreversible			
	COP	3.0	3.2
	Capacity-MBTUH (kW)	45.2 (13.2)	46.9 (13.7)

Reversible		
COP	1.8	2.9
Capacity-MBTUH (kW)	32.6 (9.6)	41.5 (12.2)

While the reversible unit exhibited a disappointing COP in the heating mode, it offered other desirable attributes: it operated reliably during the entire two-year test period; and its more-than-adequate mechanical refrigeration permitted the owner to use the system for air conditioning. Water consumption for air conditioning was only one third of that required for the direct cooling coil of the nonreversing system.

The reversible unit was probably designed for the southern U. S. market: the low heating COP suggests it was optimized for cooling, with the heating mode an added feature.

In the installation of these units, special attention must be given to the existing ducting and adequate air flow. Air flow in the typical fossil-fuel, forced-air system produces a temperature rise of about 60 deg F (16 deg C). This volume may not be adequate to keep condenser pressure down to design conditions, and it may be impractical or require additional expense to increase the air flow. If air flow is less than that recommended by the heat pump manufacturer, the result will be reduced COP in heating and reduced capacity. And if air flow is increased, the resulting high velocity, low temperature discharge may be objectionable to occupants.

Based on the above data, at current rates for electricity and oil, if well-drilling and water disposition costs are neglected, payback will range from 4 to 6 years using the nonreversible system.

An adequate quantity of supply water and its disposition are important. The units require a volume in a heating season that would fill the house: a half- to three-quarter million gallons (1,900-2,800 M3). If well water is to be used, the well production rate should be tested by pumping continuously at the heat pump manufacturer's recommendations for several days.

Both units operated satisfactorily in cooling, but because of the limited amount of cooling required in this climate, no conclusions on efficiency are possible. With cooling available, the owners of the reversible unit opted to use the capability, even at significant operating expense. The owners of the nonreversible system used the cooling capability liberally the first summer of the test period. But a drought developed during the second year. And aware of the higher water use of the unit in cooling, and concerned for the reliability of their potable water supply, the owners did not use air conditioning during the summer of 1983.

The installation and failures of units involved in the testing punctuate the need for qualified, available service in a rural setting. Unlike the oil heating industry, there was no cadre of qualified mechanics readily available in the Allegheny service areas.

As the price of fossil fuels escalates, groundwater heat pumps show promise to make a significant penetration into existing oil-fired residential markets in rural areas. In addition to reducing the nation's dependence on oil, this translates to increasing loads on electrical systems.

Load management implications are that an adequately-sized groundwater heat pump, i.e. one with no backup heat, will have a profile of electric energy consumption vs. outside air temperature very similar to resistance heat. This is different from the case of an air-source heat pump where supplemental electric resistance energy is normally required at low temperatures.

Section 1

INTRODUCTION

1.1 BACKGROUND

Since the 1973 Arab oil embargo, energy conservation has been a national priority. The availability and cost of all forms of energy - but particularly oil - has had a major impact on all sectors of American society. This has been particularly true in the rural northeast areas where relatively cold weather and overwhelming dependence on oil heating systems has caused many residents to look elsewhere for affordable heating alternatives. The homeowner, in many cases, has done all he/she can, practically, to weatherize their structure. Unfortunately, in many old rural homes, heating costs are still quite high. Many of these consumers are considering air source (ASHP) and groundwater source (GWHP) heat pumps for such conversions. And the new-home buyer must take a long, hard look at the various space heating options open to him/her. They realize the wrong decision can cost them many thousands of dollars in excess heating costs over the 40 years plus life of their home. They may also sense that in this world of no absolutes, and in light of dwindling oil reserves, electric rates, which depend on a variety of primary fuels, should be more stable than oil.

Acceptance and application of heat pumps by a great number of consumers will have a substantial impact on electric utility load characteristics. Increasing use in homes otherwise heated by oil or other fossil fuels promises increased sales to an electric utility industry currently plagued with little growth. But demand during peak periods must be controlled to produce high load factor. Effect on load factor of various backup heating methods, such as resistance heat, must be explored. See Figure 1-1. Unlike air-source heat pumps, as space heating load increases with decreasing outside air temperature, capacity and efficiency of groundwater heat pumps should remain relatively constant. Consequently, the seasonal performance factor should be better than an air-source heat pump. In rural areas where groundwater is available in adequate quantities, the efficient add-on groundwater heat pump appears to be a viable concept. Sales of such heat pumps could occur even in regions of the country experiencing little growth by replacing oil units in existing residences.

1.2 CURRENT PROJECT

Compared to air-source heat pumps there has been little published on the results of field testing of water-source heat pumps.

Recognizing these concerns, as well as the potential for enhanced energy conservation, Allegheny Electric Cooperative, the wholesale power supplier to 14 member distribution cooperatives in Pennsylvania and New Jersey, embarked on a research program to evaluate the technical and economic effectiveness of groundwater source heat pumps in rural residential applications. The project was begun in November of 1980 and data collection was completed in August 1983. The Electric Power Research Institute selected the project for funding on a cost-sharing basis because of the national implications of the technology and its potential impact on utility loads in the future.

The University of Pittsburgh (Pitt) provided Allegheny support for the project in the form of data collection, reduction, and interpretation. The Pittsburgh work was funded by U.S. Department of Energy subcontract 7985 from Oak Ridge National Laboratory. The Pitt principal investigator was Dr. Richard Dougall in the Department of Mechanical Engineering. Much of the project field work was performed by the staffs of the host Pennsylvania rural electric distribution cooperatives, Bedford Rural

Electric Cooperative and Valley Rural Electric Cooperative.

The objectives of the project were to:

- Prove technical feasibility of groundwater source heat pumps in the northeast region.
- Evaluate seasonal performance of units.
- Analyze impact of units on utility load shapes.
- Compare economics of the units to alternate heating systems - principally oil.

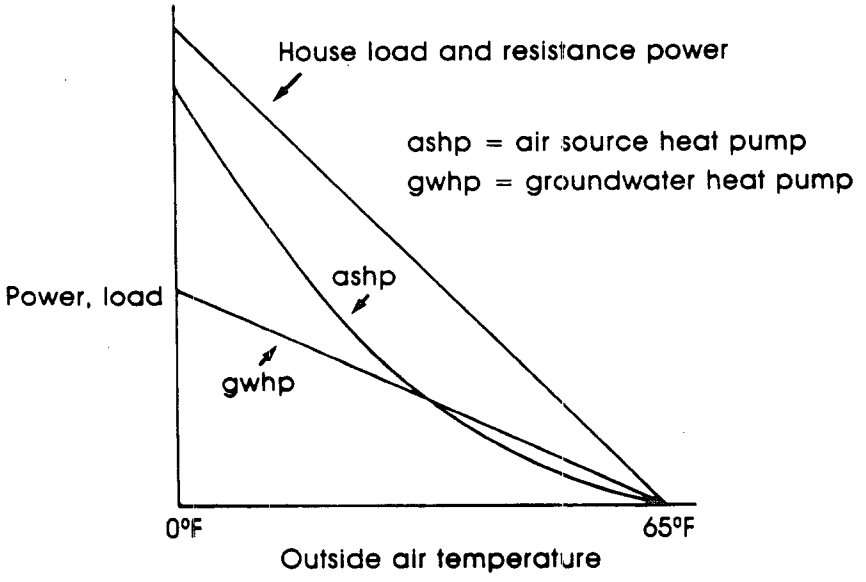


Figure 1-1

Section 2

METHODS

2.1 SITES

Two test sites were used in obtaining field performance data.

The selected residences are described in Tables 2-1 and 2-2 entitled "East Freedom Home" and "Bedford Home". The following sections will give further information about the sites.

2.1.1 Location

Both field test sites are located in the south central mountains of Pennsylvania and are approximately 30 miles (45 km) apart. The East Freedom site is located in a pronounced valley while the Bedford site is on the eastern edge of a gentle ridge bordering on a valley of farmlands.

2.1.2 Climate

The weather conditions are approximately the same for the two sites. Temperatures and heating degree days for the two sites are shown in Table 2-3.

Wind was monitored at both sites for the second year. At the gable height of about 12 feet (3.7 m), wind of significant magnitude was rarely observed, i.e. wind of more than the 3 mph (1.3 m/s) threshold of sensitivity of the anemometer was not observed for more than five hours of each month.

Figure 2-1 shows a plot of daily maximum and minimum temperatures recorded at the East Freedom site. A plot of the Bedford site would be very similar. Figure 2-2 shows a month-by-month plot of heating degree days for East Freedom and the "region." This plot shows that the test site experienced weather colder than normal for the region. NOAA data (1) indicates that the general region experienced near normal to slightly higher temperatures during the colder part of the season and an abnormally cold spring.

2.1.3 Groundwater Availability

The water used by the heat pumps at both sites was drawn from deep wells. Measurements showed very little variation in well water temperature over the complete season at both sites. Figure 2-3 for the East Freedom site shows that this temperature is about 55 deg F. (13 deg C.). The gaps in the data in early October, late April, and May are for days when the heat pump was not running at 1 a.m. and thus the temperature in the water lines was not sampled.

At the Bedford site, drought conditions prevailed through the latter part of the two-year test period. The NOAA station closest to the site reported a 28% deficiency in precipitation in 1982, and only near-normal or extremely dry months for January through August 1983 (1).

2.2 EQUIPMENT

Different types of water-source heat pumps were installed at the two test sites. The heat pump at the East Freedom site was reversible so that the refrigeration cycle of the heat pump could perform both heating and cooling. The heat pump at the Bedford site was not reversible and thus the refrigeration cycle was limited to just supply-

Table 2-1

EAST FREEDOM HOME

LOCATION:	Central Pennsylvania, 1,200' (366m) elevation
DESCRIPTION:	Modern (constructed in 1952), 2-story, vinyl-sided house with finished basement, constructed by owner. 1,900 sq. ft. (176 sq. m) living area.
INSULATION & LOAD:	6" (15 cm) fiberglas in attic, 3/8" (1 cm) styro-foam and 3 1/2" (9 cm) fiberglas wall insulation. Storm windows and doors. 6,000+ degree days Design heat loss (Manual J) 43,500 BTUH (13.1kW) at about a 70 deg F (21 deg C) temperature difference.
THERMOSTAT SETTING:	70 deg F (21 deg C)
WATER SOURCE, SINK:	120' (37m) well, 20+gpm (1.31/s) Supply temperature at heat pump: 55 deg F (13 deg C) prior: 57' (17m) well; could not sustain 10 gpm (0.6 l/s) Reject to 17' (5.2m) hand-dug well and surface percolation. (During 1981-1982 season). Reject to pond (1982-83 season). Langelier Index at 52 deg F (11 deg C): -0.155 (i.e., neither significantly corrosive or scale-forming)
SPACE HEAT:	Original: Coal-fired forced air Converted in May 1981 to: Century Heat Pump WPH-44 with electric furnace (15 kW) backup. Estimated installed value: $3,100 in 1981

Table 2-2

BEDFORD HOME

LOCATION:	Central Pennsylvania, 1,395' (425m) elevation
DESCRIPTION:	75-year old, 2-story brick farmhouse with basement
	2,200 sq. ft (204 sq. m) living area
INSULATION & LOAD:	6"-10" (15-25 cm) blown fiberglass in attic, some wall insulation in kitchen add-on, storm windows and doors.
	6,000 + degree days
	Design heat loss (Manual J) 83,100 BTUH (25.3 kW) at about a 70 deg temperature difference.
THERMOSTAT SETTING:	70-72 deg F (21-22 deg C)
WATER SOURCE, SINK:	300' (91m) well, 60 gpm+ (3.8 l/s) when drilled.
	Supply temperature at heat pump: 54 deg F (12 deg C).
	Reject to pond.
	Langelier Index at 52 deg F (11 deg, C): +0.(i.e., neither significantly corrosive or scale-forming).
SPACE HEAT:	Original: Oil-fired forced air.
	4-year average: 1,370 gal. (5.19m^3).
	Converted in 1980 to: Tetco heater HECWE-50 with electric (15 KW), and oil-fired furnace backup.
	Estimated installed value: $3,830 including cooling coil.

Table 2-3

WEATHER INFORMATION
FOR
1982-1983 HEATING SEASON

MONTH

East Freedom	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	TOTAL
Max. temp., deg F (deg C)	77 (25)	79 (26)	66 (19)	37 (3)	46 (8)	67 (19)	78 (26)	73 (23)	
Min. temp., deg F (deg C)	23 (-5)	7 (-14)	0 (-18)	-9 (-23)	9 (-23)	4 (-16)	18 (-8)	17 (-8)	
Heating Degree-Days(1)	456	829	1110	1397	1261	1036	733	462	7284

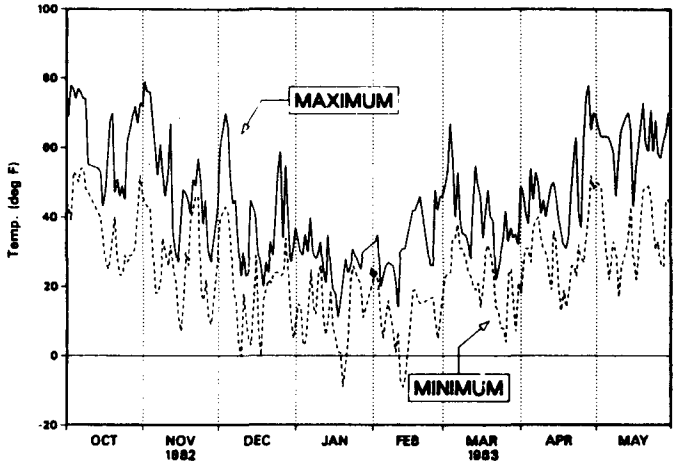
(Regional Averages from NOAA)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	TOTAL
Heating Degree-days	589	720	1080	1150	1000	860	470	180	6049

Bedford	FEB	MAR	APR	MAY	TOTAL
Max. temp., deg F (deg C)	56(13)	69(21)	77(25)	79(26)	
Min. temp., deg F (deg C)	-4(-20)	10(-12)	17(-8)	21(-6)	
Heating Degree-days (2)	1132	653	753	362	2900

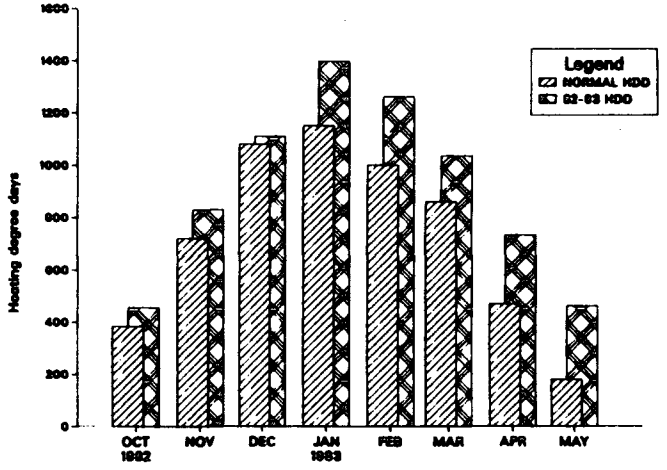
(1) Here the degree-day is the sum of the hourly difference between 65 deg F (18 deg C) and the average outside air temperature, divided by 24 hours per day.

(2) Note: Four days of data missing from March.



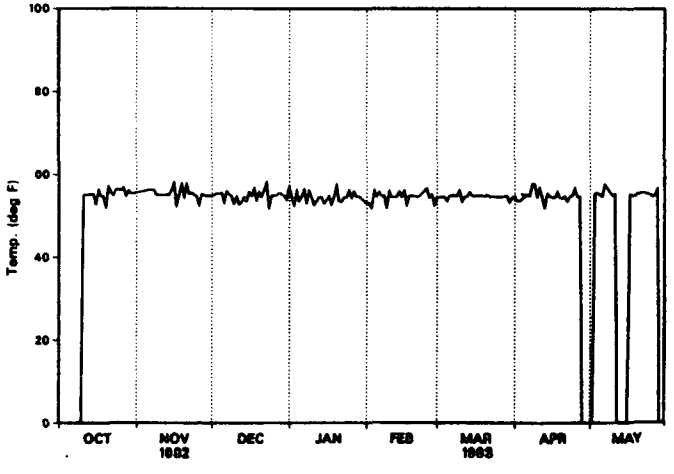
Extremes of outdoor temperature
heating season 82-83 East Freedom

Figure 2-1



1982-83 heating season
East Freedom

Figure 2-2



Water temperature at 1 a.m.
heating season 82-83 East Freedom

Figure 2-3

ing heat. Cooling was supplied by a separate water coil in the air ducting. The details of each of these systems are shown in Tables 2-4 and 2-4m as well as in the following sections.

2.2.1 Reversible Heat Pump

The heat pump unit installed in 1981 at the East Freedom site was the reversible unit with compression cooling capacity. The manufacturer's literature for this unit indicated a required groundwater flow of 9-10 gpm (0.03-0.04 m^3/s).(See Figures 2-4a, 2-4b.) The existing 57-foot (17 m) well could not sustain this flow and another well was drilled which produced adequate water. The water temperature remained very nearly constant throughout the year and water quality was good. Water from the heat pump was discharged into a small pond constructed by the homeowner.

The original anthracite coal-fired furnace was disconnected from the system when the heat pump was installed. An electric furnace was installed as a convenient measurement of backup heating needs and air flow calibration.

2.2.2 Heating-Only Heat Pump

A heating-only (nonreversible) heat pump was installed in the Bedford home in 1980. It was added ahead of the existing furnace in an oil-fired forced air system, an "add-on" configuration. (See Figure 2-5.) The heating unit is designed for heating, but also has a separate water coil for cooling in summer. During the testing period, the oil-fired furnace was disconnected and an electric furnace was installed as the backup system. Again, this was done as a convenient means of measuring backup heating needs and so that air flow calibration could be performed.

The Bedford water source was a 300-foot (91 m) well whose production was measured in excess of 60 gpm (3.8 l/s) at the time of construction, more than sufficient to meet the flow requirements for the value unit, i.e. 5 gpm (0.3 l/s) for heating and 8 gpm (0.5 l/s) for cooling. Once through the heat pump, the water is rejected to a nearby pond. The water temperature remained very nearly constant throughout the year. The water was good except that there was substantial flocculation due to a bacteria infection in the well. The homeowner solved this problem by treating with a chlorine solution every few months.

Tables 2-4 and 2-4m summarize the heat pumps and their operating characteristics. While the literature for the reversible unit indicated the ratings were established at ARI conditions, neither company displayed the ARI seal at that time. Unlike much other HVAC equipment, while a standard has been developed by ARI, there was no certification program in effect at the time of selection. Such a program would make an array of useful information available to the buyer, and could contribute to a more cost-effective choice of units. In any event, the ARI standard conditions in effect at that time specified a water supply of 70 deg F (21 deg C)., much higher than deep groundwater temperatures in areas of the country requiring significant space heating.

As mentioned, the Bedford unit refrigerant loop is for heating only. The evaporator is of a large shell-and-tube design with end plates removable for water-side inspection and cleaning. A separate coil, using well water for straight-through cooling, provides heat and moisture removal from the air during the summer. The water requirement in heating is greater for the reversible unit, and in cooling, the heating-only water coil requires more water.

Table 2-4

EQUIPMENT
GROUNDWATER SOURCE HEAT PUMPS

	EAST FREEDOM	BEDFORD
UNIT-type	Reversible	Nonreversible(2)
-installed as	Integral (1)	Add-on
CAPACITY	@ 1,100 CFM	@ 1,000 CFM
-heating	41.5 MBTUH	46.9 MBTUH
-cooling	45.9 MBTUH	31.4 MBTUH
WATER REQUIRED	@ 55 deg F	@ 55 deg F
-heating	9 gpm	5 gpm
-cooling	5 gpm	8 gpm
Published COP (3)		
-heating	2.9	3.2
-cooling	3.0	10.6

(1) Has own fan.

(2) Vapor-compression heater with direct water cooling.

(3) At capacity rating conditions, per the manufacturers' literature available at the time of purchase.
Nonreversible heating rating is from interpolation of published information at 52 deg F and 57 deg F water temperature.
Allowance made for fan energy, for both units, but only heater (nonreversible) manufacturer accounted for some pumping energy.

TABLE 2-4m

EQUIPMENT
(METRIC)
GROUNDWATER SOURCE HEAT PUMPS

	EAST FREEDOM	BEDFORD
UNIT-type	Reversible	Nonreversible(2)
-installed as	Integral (1)	Add-on
CAPACITY	@ 1,100 CFM (0.52m3/s)	@ 1,000 CFM (0.47m3/s)
-heating	41.5 MBTUH (12.2kW)	46.9 MBTUH (13.7kW)
-cooling	45.9 MBTUH (13.5kW)	31.4 MBTUH (9.2kW)
WATER REQUIRED	@ 55 deg F (13 deg C)	@ 55 deg F (13 deg C)
-heating	9 gpm (0.6 l/s)	5 gpm (0.3 l/s)
-cooling	5 gpm (0.3 l/s)	8 gpm (0.5 l/s)
Published COP (3)		
-heating	2.9	3.2
-cooling	3.0	10.6

(1) Has own fan.

(2) Vapor-compression heater with direct water cooling.

(3) At capacity rating conditions, per the manufacturers' literature available at the time of purchase.

Nonreversible heating rating is from interpolation of published information at 52 deg F (11 deg C) and 57 deg F (14 deg C) water temperature. Allowance made for fan energy, for both units, but only heater (nonreversible) manufacturer accounted for some pumping energy.

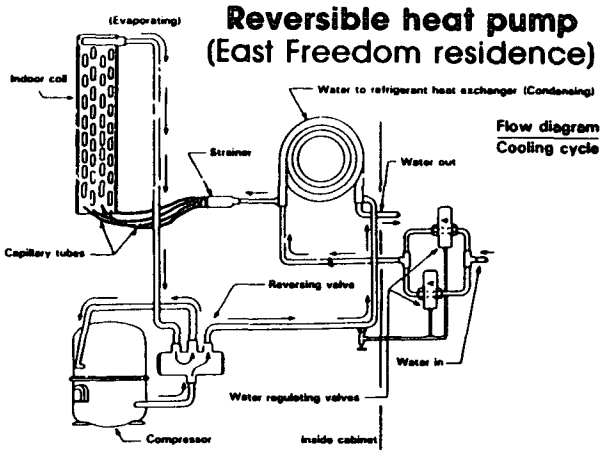


Figure 2-4a

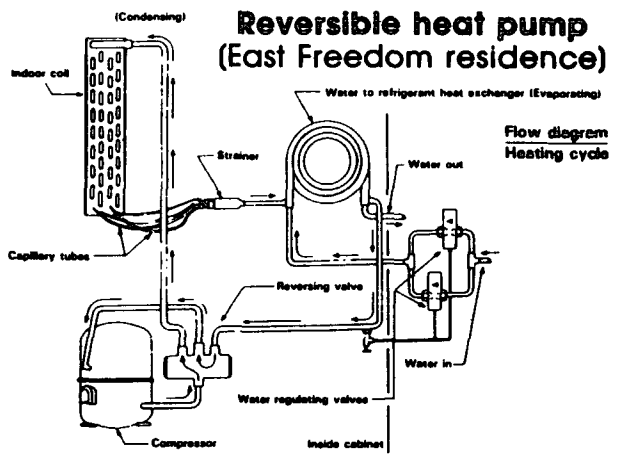


Figure 2-4b

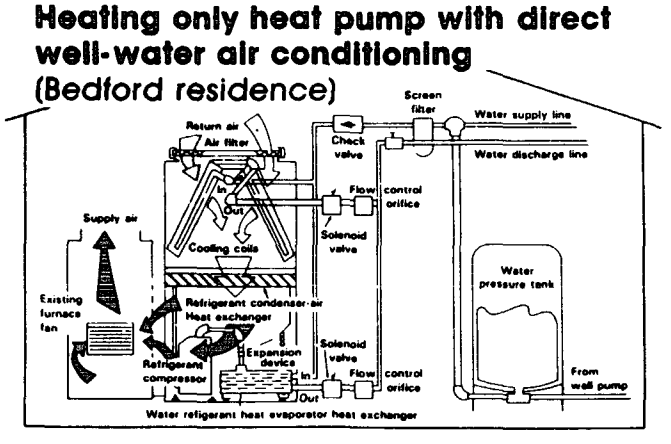


Figure 2-5

2.2.3 Thermostats

In heating, the units are controlled by conventional two-position, two-stage thermostats. When the room temperature drops below the set point, the first stage (the heat pump) operates. Should the room temperature continue to drop, when it is approximately two deg F (one deg C) below the set point, the backup electric furnace comes on and remains on until space temperature equals the set point. The heat pump continues to operate and will only shut down when the space temperature reaches about two deg F (one deg C) above the set point. In normal operation, space temperature should modulate around the set point. Occupants were asked to set thermostats at a temperature comfortable to themselves and in no case lower than 70 deg F (21 deg C), per manufacturer's recommendations.

At the Bedford thermostat, the occupant can select dual operation as described above, or either system alone. The East Freedom thermostat provides for dual operation, or backup only. Heating-cooling-off is controlled at the thermostat by the occupant. Both units have safety switches to protect the machines from excessively low water temperatures or high refrigerant pressures. (Low water temperatures can lead to ice formation, expansion and damage on the water side of the evaporator. High refrigerant pressures can damage the compressor, cause loss of charge or cause condenser damage.)

2.2.4 Water Flow

Water flow is controlled as follows: A variable area orifice is installed in the water line from the Bedford unit. In addition, a solenoid valve provides positive cutoff when the unit is off. A second orifice is needed for cooling. The East Freedom unit controls water flow by the setting of a pressure-regulating valve (PRV) that has evaporator pressure as an input. For cooling, a second PRV takes the same signal, coming from what is then the condenser, and meters at a lower rate. The orifices were selected and PRV settings were made in accordance with the manufacturers' recommendations. A filter in the water line just before the East Freedom unit provides particulate filtration.

2.2.5 Operational Problems

It was hoped that data for two full heating seasons could be obtained. However, this was not possible. Data acquisition at the East Freedom site was delayed because of water availability problems. Complete data collection began at this site in February 1982 and continued without any major interruption until data gathering terminated at the end of August 1983. Thus, a nearly complete set of data was obtained for the East Freedom site for the 1982-83 heating season and the last half of the 1981-82 heating season.

Data collection began at the Bedford site in August 1981. The months of August through September were used for debugging the automated data acquisition system, and valid data collection began in October 1981. During the colder part of the 1981-82 heating season, the heat pump at this site experienced many trips due to what appeared to be low evaporator pressure. Extensive efforts by Allegheny Electric Cooperative, Bedford REC, and the manufacturer of the heat pump were only partially successful in resolving all the problems with the unit. In addition, the nuisance tripping of the heat pump and the subsequent startup of the electrical resistance heating coils resulted in voltage fluctuations which caused trips in the data acquisition system. Installing a transient suppressor eliminated the problem.

In August 1982, Allegheny and Bedford REC personnel cleaned the evaporator heat exchanger and found that one of the 36 tubes of this heat exchanger was plugged but no significant fouling was seen on the surface of the tubes. This unit was to have

continued in operation for the full 1982-83 heating season. It operated during the month of October (which was taken as the start of the heating season). However, the COP was low for the unit, below 2.8 as compared to previous values around 3.0 or above. On November 10, 1982, the homeowner noticed a slow refrigerant leak. Complete loss of refrigerant was noted on November 15. The heat pump was turned off and heating was provided by the oil furnace.

In mid-December, a replacement unit for the original heat pump was installed. This unit also experienced great sensitivity to temperature conditions at the site and would trip out very easily. This condition worsened until on January 17, 1983, the homeowner considered the operation so unsatisfactory that the system was turned completely off and heating was again obtained from the oil furnace. Finally, on January 27, 1983, a new heat pump unit was installed at the Bedford site. This unit has operated quite satisfactorily since that time.

There has been no significant problem with the reversible unit at East Freedom.

Because of the equipment problems with the heat pump at the Bedford site, the only truly reliable data for a normally-operating unit at this site for heating operation were the data from February through May of 1983. Nevertheless, the house and heat pump were subjected to very nearly 3,000 heating degree days, or about half the typical annual load and to a profile that is a "mirror image" of the first half of the season: a mix of extremely cold days graduating to milder. The remainder of the data reflect operation of a unit which is not performing to its full capabilities.

In addition to the substantial data bank established, some qualitative observations are in order. These include water considerations, reliability of operation of the mechanical systems and reaction of occupants.

Availability of an adequate supply of water is a very real concern with groundwater source heat pumps. As Figure 2-6 entitled "Water Processing" implies, a tremendous amount of water is required annually for heating, roughly equal to the volume of the house being heated. (On the other hand, in the climate of the northeast more rain falls on just an acre in the same time.)

Groundwater Heat Pump
WATER PROCESSING

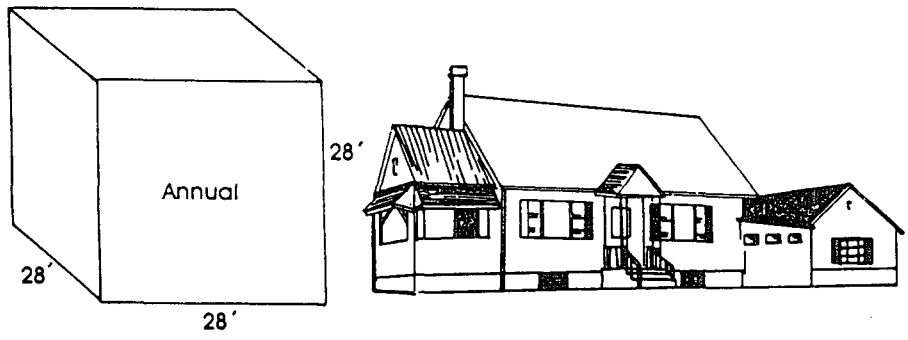


Figure 2-6

Spent water disposition is sometimes a problem, especially if one is concerned with replenishing the groundwater reservoir. Both supply and rejection well service are difficult to predict in geologically complex areas such as those found in Pennsylvania. Originally the East Freedom site owner had planned to dispose of processed water via a 30-foot (9 m) hand-dug well, but he soon observed overflow. He subsequently had a pond of about 25 feet (7 m) in diameter built; this has proven to be an acceptable disposal technique.

Both units operated reliably through some of the coldest weather of the century in early 1982. However, the compressor in the Bedford home had to be replaced in March of 1981, prior to commencement of monitoring. This was quickly effected under warranty. (This failure was in addition to the ones mentioned above.) The heat pump at the Bedford home has also been interrupted several times for factors outside the scope of this experiment. In the one case, the water line to the milk parlor of the resident's dairy operation froze and ruptured, starving the heat pump. In another case, faulty pressure switch contactors on the control to the well pump failed open. In a third case, operation was interrupted for preventive maintenance so the owner could replace the belt on the forced-air fan. This would be a consideration with oil-fired forced-air as well.

The occupants were basically satisfied-to-pleased with the economics and reliability of their units during the period covered by this report. Noise has not been a complaint. As mentioned above in the summary section, both units operated satisfactorily in cooling, but because of the limited amount of cooling required in this climate, no conclusions on efficiency are possible. With cooling available, the owners of the reversible unit opted to use the capability, even at significant operating expense.

There have been design and balancing problems on the air side: both upstairs tended to overheat in summer. The Bedford house had inadequate air supply upstairs and the East Freedom site had no ducting there. Consequently, with discharge air temperatures lower than with fossil fuel, natural convection was inadequate to deliver much heating to upper floors. And in cooling, what mixing existed apparently did not overcome warm air stratification in the upper floors.

As an add-on, the Bedford system relied on the capacity of the installed fan. This air flow was below that recommended by the manufacturer for optimum performance. In the case of the East Freedom unit, an integral fan is provided. But again, with duct work sized for fossil-fuel heating, resulting air volume was significantly less than optimal. As will be seen below, the reversible unit's performance was more sensitive to this air flow deficiency than the nonreversing.

Duct air leakage appeared to be on the order of 10-20%. Losses of this magnitude into an unused space, such as the basement of the Bedford home, are significant. Not only is heating energy lost, but fan energy is also wasted. However, since it was desired to approach a "typical" rural residential installation as closely as possible, no heroic attempts were made to improve air flow by enlarging or tightening ducting.

During the cooling cycle, saturated conditions are produced at discharge from the units. This air then passes through the furnace in the add-on configuration, and there was some concern for accelerated corrosion of the furnace. Corrosion test strips were installed at key spots in the ducting of both units and control specimens were installed in the basements outside the units. The strips were carbon-steel scrap from the production line of a major furnace manufacturer. No significant effects were seen after exposure for over a year.

2.3 MEASUREMENTS

The objective of the measuring system at the sites was to supply information which could be used to evaluate the performance of the water-source heat pumps over a range of time scales. The primary parameter of interest was the seasonal coefficient of performance (COPs). This parameter is the ratio of heat delivered to the air divided by the electrical energy used by the compressor and fan (plus any electrical resistance heating if used). Other parameters of interest were information on energy usage over periods of fifteen minutes to an hour, and performance of the heat pumps for some typical cycles of operation.

In addition, parameters which might affect heat pump performance such as outside weather conditions, water inlet temperature, return air temperature from the house, and various room temperatures were also desired on an hourly basis.

In order to achieve the objectives of the program, the collection system was designed to provide the following data:

- Date and hour
- Heat and water pump run times
- Number of heat and water pump cycles
- Average power (kilowatts) for the house for the hour
- Average power (kilowatts) for the fan, compressor, water pump, and resistance heaters when operating
- Average water flow rate through the heat pump when the fan was operating
- Average water inlet temperature when the fan was operating
- Average return air temperature when the fan was operating
- Estimate of air speed in the ducting as measured by a hot film anemometer when the compressor was operating
- Average temperature differences of water and air passing through the heat pump, when the fan was operating
- Average humidity of the return air entering the heat pump when the fan was operating
- Average temperatures, of various rooms in the house
- Average outdoor air temperature, humidity, and wind speed

There were three types of instrumentation installed at the two field test sites: Manual meters, an automated data acquisition system, and a magnetic tape record unit for 15 minute total house electrical energy usage.

2.3.1 Manual Metering

Manual meters were used to measure long-term usage and to backup the automated system. (See the table below.) The primary manual meters were watt-hour meters which measured total electrical usage of the residences as well as separate meters to record electrical usage of the fan, compressor, water pump, and electric resistance backup heaters. A commercial positive displacement water meter was connected to the feed lines of both heat pumps and measured cumulative water flow through each heat pump unit.

Counters were also connected to the heat pump so that the number of cycles of operation could be determined over various period of time. Two counters were used at the Bedford site. One recorded the number of times the compressor started; the other recorded the number of times water passed through the independent coil which provided cooling. Only one counter was used at the East Freedom site. Since this is a reversible heat pump, the counter recorded compressor cycles, but did not distinguish whether the cycle was heating or cooling

During the second heating season, it was felt that a manual meter which was able to give an indication of heat extraction from the water would be desirable: the weekly coefficient of performance could be calculated with this additional information. (See Appendix B for the derivation.) Therefore, a BTU meter was installed at the East Freedom site in early November 1982, and while some problems with grounding were experienced at the Bedford site, a second meter was operational there by early January 1983.

The readings from the manual meters at the two sites were recorded approximately once a week.

MANUAL METERS

Measured Item	Type
Electrical Energy	
house total	kilowatt-hour
compressor	kilowatt-hour
fan	kilowatt-hour
water pump	kilowatt-hour
resistance heat	kilowatt-hour
Flow Rates	
water	nutating disk
Energy	
water	BTU meter
Cycles	
heating/cooling	counter

2.3.2 Automated Data Acquisition

The automated data acquisition system was made up of three main components: 1) the sensors, 2) the data logger unit, and 3) the microcomputer which controlled the operation and stored the data obtained. Each of these components will now be summarized.

2.3.3 Sensors

The individual sensors used are listed in Table 2-5. These sensor types can be conveniently broken down into two groups: (1) those directly related to the measurement of heat pump performance and (2) those related to monitoring conditions inside or outside the residences. One set of instruments related to monitoring system performance were electric power sensors. This group included meters to monitor the fan, compressor, water pump, and resistance heaters. These took instantaneous readings of rate of energy consumption which had to be integrated to give cumulative energy usage of the individual components.

Flow measuring instruments were installed to monitor the rate of water and air flow. A target flow-meter was used for the water rate; a hot film anemometer was used to give an indication of air flow. The water meter proved to be able to provide an accurate measure of the flowrate in the pipe. On the other hand, the anemometer measured the flow air velocity at only a single point in a rather large air duct. Pitot probe measurements suggested air flow highly varying in both time and position across the duct. Thus, air velocity measurements could only be considered as qualitatively indicating the air flowrate.

Platinum resistance temperature devices (RTDs) were inserted in the inlet water line and return air duct to monitor temperatures of the fluids entering the heat pump. Thermopiles made of type T (copper-constantan) thermocouple junctions were used to measure the temperature differences of the fluids after they passed through the heat pump. Finally, a humidity sensor was placed in the return air duct.

The second set of sensors monitored conditions pertaining to the residence itself. These included a number of room temperature sensors, nine sensors at the Bedford site and six at the smaller East Freedom site. A wattmeter monitored the total electrical consumption at each site. The Cooperative backed the house wattmeter with a magnetic tape recording unit attached to the kilowatthour meter supplying electrical energy to the house.

A weather station was installed at each site to monitor outside air parameters. Initially, this station only monitored temperature and humidity. However, in August 1982, wind speed anemometers of the rotating cup type were installed to give some indication of wind conditions at the sites.

2.3.4 Data Logger

The readings from the sensors were fed into a Hewlett-Packard Model 3497A data logger. This unit converted the analog current and voltage signals from the sensors into digital form and sent them to the microcomputer which controlled the data gathering effort. Two plug-in cards were used in the data logger which gave a data gathering capability of 40 channels. However, only 28 channels were needed to monitor the installed sensors.

The data logger responded to commands from the microcomputer to initiate a scan of channels. Early in the project the instrumentation related to the heat pump was kept distinct from that related to parameters concerning the residence. Scans of the heat pump channels were only initiated when the system was running. Scans of the resi-

Table 2-5

AUTOMATED INSTRUMENTATION

MEASURED ITEM	SENSOR TYPE	SENSOR MODEL	ACCURACY (1)
Temperatures			
Indoor Space	7-Thermistors	Hy Cal CT850-B	0.75°F
Water Inlet	Platinum RTD	Hy Cal RTS-34/ CT-865-DC transmitter	0.5%
Supply Air	Platinum RTD	Hy Cal RTS-4250/ CT-865-DC transmitter	"
Outdoor Air #1	Platinum RTD	Hy Cal RTS-36/ CT-865-DC transmitter	"
Outdoor Air #2	Thermocouple	Type T	
Temperature Difference			
Water	Custom-made	Type T	
Air	Thermopiles		
Flow Rate			
Supply Air	Hot Film Anemom.	TSI 1610-12-10	
Water	Target Flowmeter	Ramapo Mark V-3/4-J02/SGA-8401B transmitter	
Wind Speed	Rotating Cup	Natural Power A70-104	
Humidity			
Supply Air	(2)	Hy Cal H5-3552-B/ CT-822-H transmitter	2%
Outdoor Air	(2)	"	"

(1) Published sensor-transmitter accuracy
(2) hygro-mechanical strain gauge using orthogonally-oriented cellulose crystallite strips

dence sensors were scheduled over longer intervals (i.e. approximately every five minutes). However, this complicated the monitoring program in the microcomputer to a very large degree and resulted in some decrease in scan speed when the heat pump was running. Then the program was modified to include all sensors whenever a scan was requested by the microcomputer. This simplified the monitoring program, actually reduced the time between scans to about seven seconds, and gave finer resolution of all the data being gathered.

2.3.5 Microcomputer Control Unit

The automatic control of the data gathering process was the responsibility of a Hewlett-Packard Model HP-85 microcomputer. Details of the monitoring program can be found in the thesis by R. Browell (2). Figures 2-7, 2-8 are a schematic representation of the data gathering procedure. The microcomputer would send a command to the data logger to initiate a scan and receive the digitized data. For parameters relating to the residence (i.e. room temperatures, house wattmeter, etc.) it kept a running numerical integration of these values. If the heat pump was not running, the data from the heat pump sensors was basically zero and was discarded. When the heat pump unit turned on, the time the unit started was noted. Then, running averages of heat pump parameters were kept while the unit was running.

The data recording device for the HP-85 computer was a built-in cassette tape unit. Since the storage capability of the cassette tapes used is large (210K bytes) but finite, some screening of the data had to be done. The data to be stored on the cassette tapes was divided into three different types. These types were: (1) hourly data, (2) fifteen minute demand data, and (3) detailed data.

The hourly data consisted of time-weighted averages of the sensor readings over one hour periods of time. In addition to averages of sensor readings, the run times of the heat pump and water pump during the hour were recorded as well as the number of times each unit turned on in a given hour. This was the primary set of data that was obtained for this project.

The fifteen minute wattmeter demand data was similar to the hourly data, but included average readings over fifteen minute time intervals.

Finally, samples of system performance parameters were recorded at selected time periods. The detailed data files contained a selected set of raw sensor readings versus time while the heat pump system was running. Since this data accumulates at a rapid rate with a scanning period of less than 10 seconds only about 45 minutes of accumulated run-time data was obtained on an individual cassette tape.

The cassette tape had enough storage capability for approximately eight days of hourly and fifteen minute demand data as well as 45 minutes of detailed data. It also had storage capability of two additional days of hourly and fifteen minute demand data in power failure files. These error files were only used for data storage if a power failure occurred at the site or the tape was not changed on time and the normal file filled to overflow. The data tapes were removed approximately once weekly and a new tape inserted into the computer. The tape containing recorded data was then shipped by mail to the University of Pittsburgh for processing. Samples of data files after processing are given in Appendix A.

REFERENCES

1. Climatological Data, Pennsylvania, October 1982 - May 1983, v. 87, no. 10-12, and v. 88, no. 1-5 . Asheville, N.C.: National Climatic Data Center.

2. R. L. Browell. "Computer Method for Field Monitoring of Residential Energy Use." M.S. Thesis, Mechanical Engineering Department, the University of Pittsburgh, 1983.

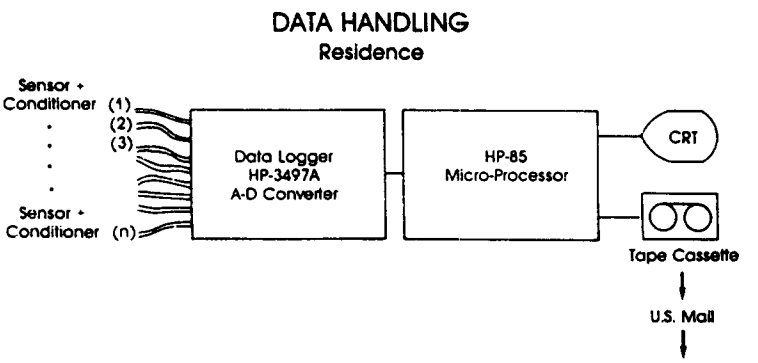


Figure 2-7

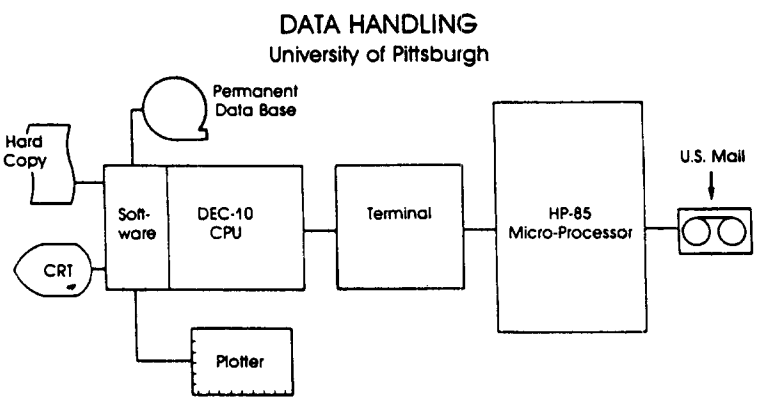


Figure 2-8

Section 3

TECHNICAL PERFORMANCE RESULTS

3.1 GENERAL RESULTS

This section of the report will describe the performance of the heat pumps over extended periods of time. The following two sections will then describe the operation on shorter time scales, i.e. typical daily operation and typical cycle operation. Data graphing of particular interest is included here. Additional data can be found in Appendix A.

As stated earlier, the data for the East Freedom site during the 1982-83 heating season is very complete. However, only data for the latter half of the same season is available for the Bedford site, i.e., February through May. Therefore, only data for this period will be used in the evaluation of performance there. Table 3-1 gives the general performance factors for the heating season. Approximations for a complete season at the Bedford site can be obtained by doubling the values given in Table 3-1.

First, the water supply temperatures were nearly constant with over 90% of the data falling in an interval of plus or minus 2 deg F about the value presented in the table. The amount of water used for the heating season is substantial.

The energy usage shown in the table is that obtained by adding up the available hourly data readings. The heat delivered is calculated by adding the energy of the fan and compressor to the energy extracted from the water. The energy extracted from the water was obtained by summing hourly energy extraction using hourly average flows, averaged temperature differences, and hourly run-times. Heat balances on the air side of the unit indicate this procedure is approximately correct. Transient and duct losses, such as heat leakage to the basement, are not distinguished from energy for heating the house proper. This is realistic, as real heat pumps will operate intermittently in most applications and the ducting in existing homes is believed to leak significantly.

The Coefficients of Performance are the heat delivered divided by the electrical energy used. The first values given in Table 3-1 do not include water pump energy. The latter values include the energy a theoretical pump would require to compress the actual gallonage recorded to 100 feet (30 m) of head at a wire-to-water efficiency of 29%. A common pumping head and efficiency were used so as to provide a common base for comparison of the efficiency of the two heat pumps while realistically accounting for water use. Capacity was determined by averaging many instantaneous values. These values should be compared to those claimed by the manufacturer in Table 2-4.

The Bedford system capacity was very close to the published value, while the East Freedom's capacity was significantly less than the published value.

As can be seen from the table, there is a substantial difference between the performance of the two heat pumps. This may be explained by the basic market that each heat pump was intended to supply. The unit at the East Freedom site is reversible. It appears designed for supplying air conditioning in the southern region of the United States, or possibly for commercial application in a "California" system. (In such a system, the heating cycle evaporator is supplied water at 60-90 deg F (16-32 deg C) from a closed loop. Supplemental heating or cooling is provided by central equipment. A common application is in commercial buildings.) It was probably designed to have maximum efficiency when operated as a cooling unit, with a resulting poorer efficiency as a heating unit. The heater installed at the Bedford site

Table 3-1

RESULTS
1982-1983 HEATING SEASON

	EAST FREEDOM	BEDFORD
Well water temperature, deg F	55	54
(deg C)	(12)	(13)
Heating Degree-days	7,284	2,900
Water usage, gallons	627,000	385,000
(m3)	(2,370)	(1,460)
Total house energy, kWh	12,982	9,607
Comp. & fan energy, kWh	5,211	4,364
Water pump energy, kWh(2)	996	1,410
Heat extracted from water, kWh	5,627	9,767
Heat to house, kWh(3)	10,839	14,131
Coefficient of Performance(4) (without water pump energy)	2.08	3.24
Water pump energy, calculated, kWh(5)	680	416
Coefficient of Performance(4) (With calculated water pump energy)	1.84	2.96

(1) Note values for Bedford site are for February through May.

(2) The Bedford pump also provided water used for domestic and some dairy hygiene purposes. Energy assignable to heat pump support is estimated at 612 kWh.

(3) Compressor + fan + water energy.

(4) Since negligible amounts of supplemental heat were used, coefficients of performance are also seasonal performance factors.

(5) Accounting for work performed by theoretical pump of 29% efficiency compressing the actual pump gallonage to 100' of head.

was designed to only be a heat extractor (a separate water coil in the air duct supplies direct water-to-air cooling). Thus it functions better in heating and requires a smaller water flow rate for normal operation. Another factor may be reduced air flow, which was especially pronounced in the East Freedom application.

3.2 OVERALL PERFORMANCE

3.2.1 East Freedom Site

A detailed discussion follows of the performance of the well-water-source heat pump system at the East Freedom site during the 1982-83 heating season. This is primarily on a daily basis. Monthly totals are shown in tables and plots in an appendix.

Figure 3-1 shows the total house electrical energy usage per day at the East Freedom site. It can be seen that the daily usage of the well-water-source heat pump system accounts for approximately one-half of the total electrical energy used in the house. The system energy is the energy used for fan, compressor, and water pump. Figure 3-2 shows that the system energy is predominately the energy needed for the compressor in the heat pump. The daily water usage of the heat pump at this site is shown in Figure 3-3.

The East Freedom house is well insulated, and in addition to the usual internal heat sources, some heating was apparently supplied by the wood cookstove in the basement on which the owners usually prepared their dinner. This is estimated at less than 18 kWh per day, but over the course of the heating season could have supplied 20-30% of the total heating requirements. Consequently, the heat pump demonstrated capacity of 32.6 MBTUH (9.6 kW) was more than adequate for all heating requirements encountered during the 1982-1983 heating season. This is shown in Figure 3-4 where the daily runtimes of the heat pump are plotted. This figure indicates that only rarely is the heat pump running more than eight hours in a single day, and, except for a single day, never more than twelve hours in a day.

Figure 3-5 shows that the daily number of cycles of the heat pump does not peak only in the colder months. Days with 60 to 70 cycles occur during every month from November through April. However, days with less than 10 cycles only occur during the warmer periods. The period of late December 1982 was an unusually warm period for this month and this fact is reflected in all the preceding figures. The water pump cycles are shown on Figure 3-6. Figure 3-6 shows that there was substantially more cycling of the water pump in the months of October through December. Then, the water pump cycles follow the heat pump cycles (i.e., water pump on continuously) during January through early April. The water tank at the East Freedom site had an air leak over the duration of the test. To compensate, the homeowner periodically would charge his tank with compressed air. This did not cause any substantial change in the heat pump performance. This was determined by examining the COP and capacity in a high-cycle frequency month such as December with a low-cycle frequency month like February. Water logging of the expansion tank has the same effect on cycling as installing a tank of inadequate capacity, as shown here: Excessive cycling of the well pump. While there was no evidence of extra energy cost, there may have been shortening of the life of the well pump.

The information contained in the previous three Figures is presented in a slightly different form in Figure 3-7. This figure considers all the hours for which valid data logger readings were obtained. It then breaks these down into runtime intervals. This shows that for the 1982-83 heating season, the heat pump had two separate peaks in runtime. The larger of these was the hours when the heat pump was running less than 10% of the time. This peak accounted for slightly over 32% of the recorded hours. The other peak was in the range where the heat pump was running between 20 and 30% of the time. This peak accounted for slightly under 25% of the

recorded hours. Only 2% of the time was the heat pump running over 50% of the time. This is the most dramatic demonstration of the fact that the heat pump has substantially greater capacity than is needed in this house despite the calculated heat loss being approximately equal to the nameplate capacity.

The water pump shows a steady decline in the number of recorded hours as the runtime fraction is increased. It again has less than 2% of the hours where it is running for over 30 minutes.

Figure 3-8 shows the daily variation of the energy supplied the house for January, 1983. The region below the first line is the energy extracted from the water. The region shown by the crosshatching is the energy supplied to the fan and compressor. Since the COP for the well-water-source heat pump at East Freedom is about 2, it can be seen that the magnitude of each component is about equal. Similar curves for other months of the heating season are found in Appendix A.

The final curve on the plots is the heating degree days at the site. It can be seen that the daily energy tracks the heating degree days very closely.

In order to establish the validity of the data, scatter diagrams of daily compressor energy, fan energy, water extraction energy, water consumption, and total energy input to the house were plotted versus daily heating degree day values. The plot of the total energy supplied the residence by the heat pump is shown in Figure 3-9. Plots for the other parameters are in Appendix A. There is a significant amount of scatter among the data, but a straight line gives a reasonable approximation.

Extrapolating the curve of Figure 3-9 to 65 degree-days, the equivalent of an average 24-hour outside air temperature of 0 deg F., suggests a required heating rate of 4.7 kW (114 kWh for 24 hours) or 16,200 BTUH. This is much less than the Manual J calculated value of 43,500 BTUH. These results are generally in agreement with the use of a correction factor, as defined in the ASHRAE Fundamentals handbook (1), of about 0.6 in this climate. The difference is suspected to be caused by one or more of the following:

1. The wood cookstove and other appliances contributed substantially to house internal heat gains and thus reduced the heating load from that determined in Manual J.

2. Second floor room air temperature was not maintained at the indoor design temperature of 70 deg F due to air system problems.

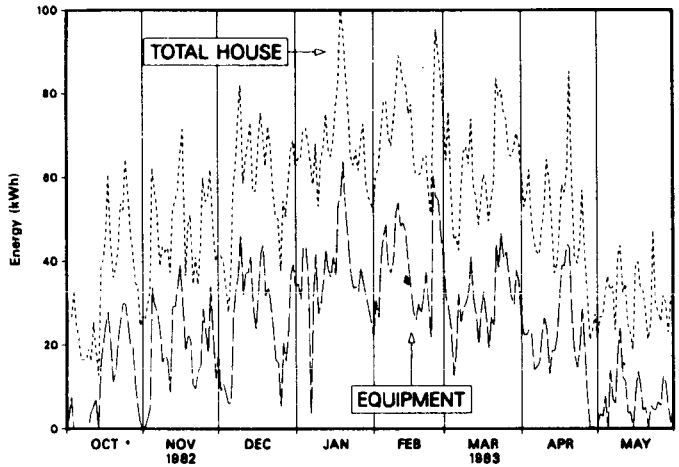
3. There was little wind during the test period (Manual J calculations are based on ASHRAE data (1) which assumes a 15 mph wind).

4. Solar gains were significant (and are not accounted for in manual J).

3.2.2 Bedford Site

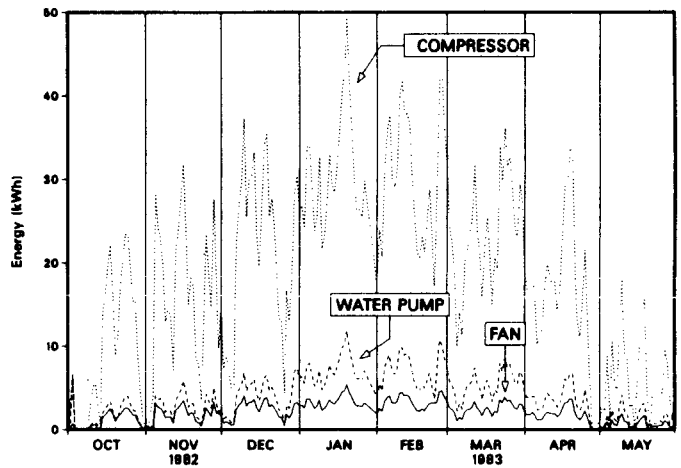
This section will use the same approach as the last section, for the Bedford site. Only data on the new heat pump is included, generated from February 1983 on. The data for the third week in March may appear unusual on some of the plots. The residents were away at this time and the thermostat was turned back to about 50 deg F (10 deg C). During this period, the heat pump did not supply heat; and at one point the weather was so warm the cooling coil was in operation.

Figure 3-10 shows the total house and heating system electrical energy consumption on a daily basis. Figure 3-11 breaks down the system energy into its component parts. The same basic ratios apply, i.e., the compressor uses the greatest energy



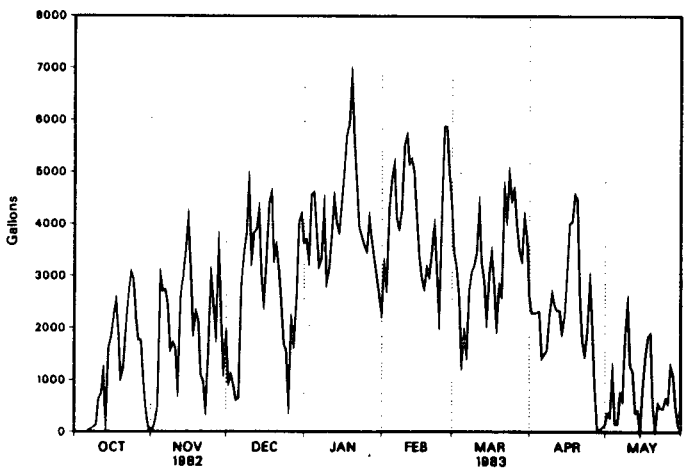
Daily electrical energy consumption heating season 82-83 East Freedom

Figure 3-1



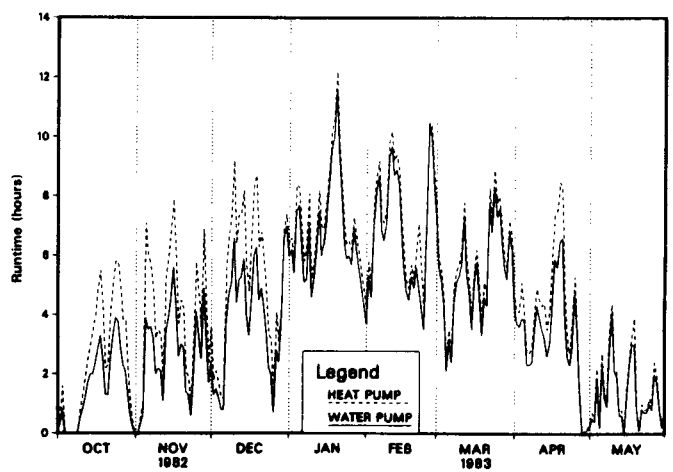
Daily system energy consumption heating season 82-83 East Freedom

Figure 3-2



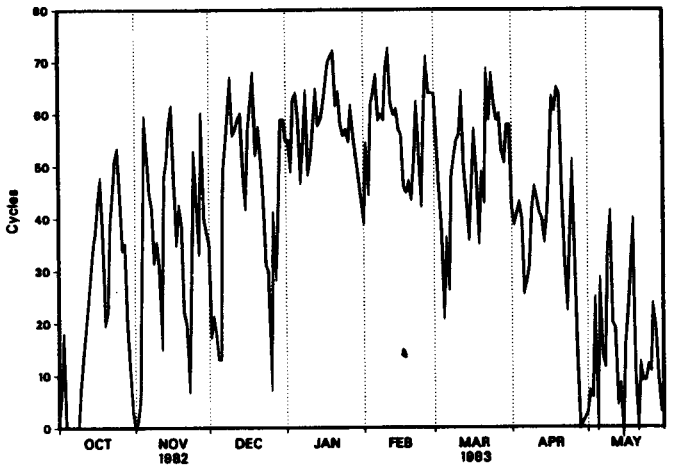
Daily water consumption of heat pump heating season 82-83 East Freedom

Figure 3-3



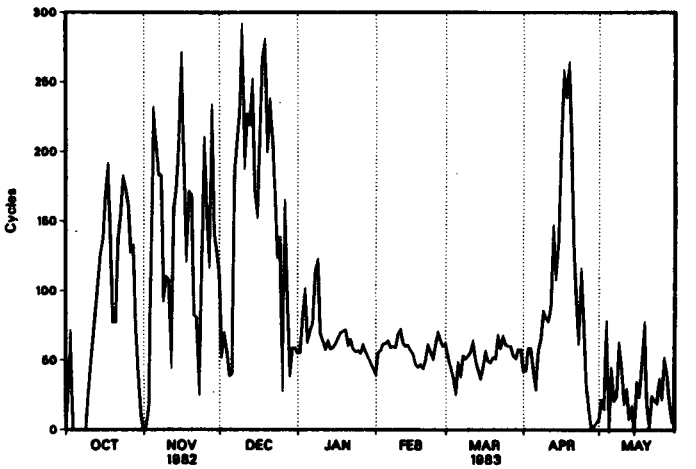
Daily runtime of pumps heating season 82-83 East Freedom

Figure 3-4



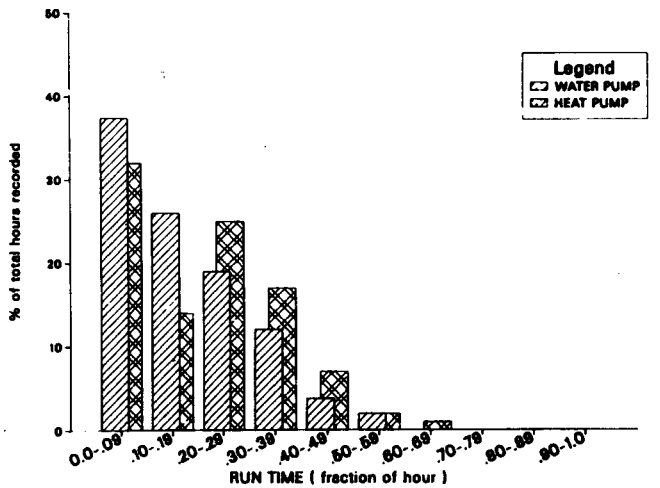
Daily heat pump cycles
heating season 82-83 East Freedom

Figure 3-5



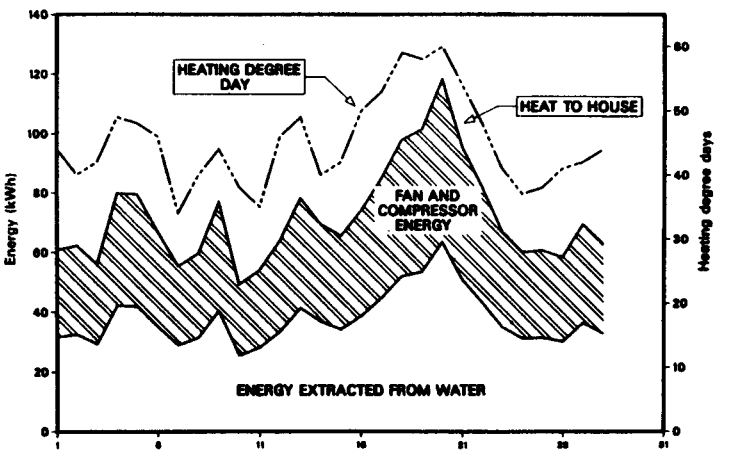
Daily water pump cycles
heating season 82-83 East Freedom

Figure 3-6



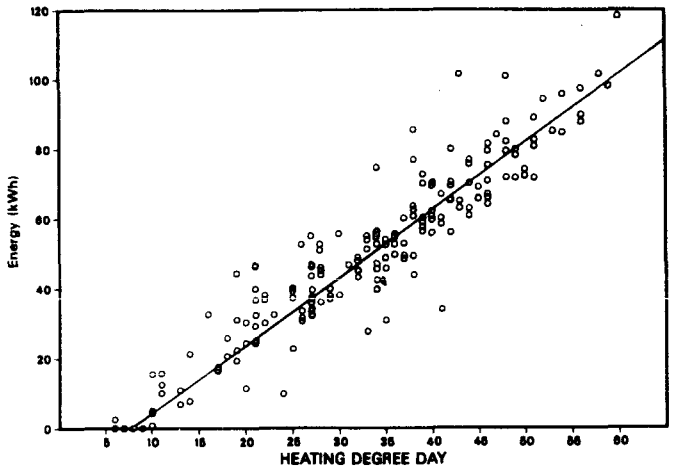
Fractional run time history of pumps
heating season 82-83 East Freedom

Figure 3-7



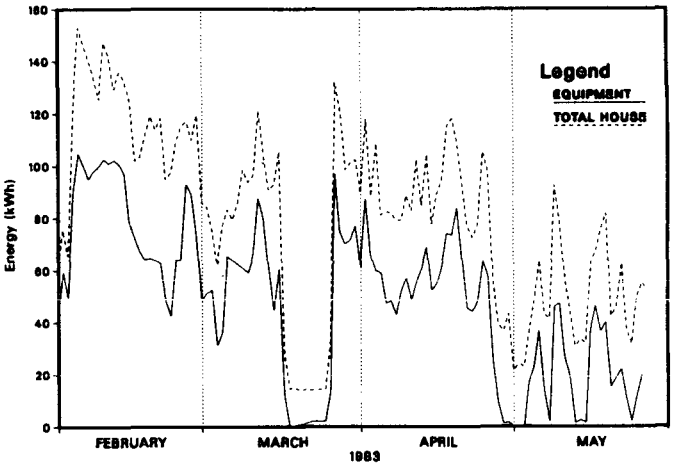
Components of heating energy & heating degree days Jan. 1983 East Freedom

Figure 3-8



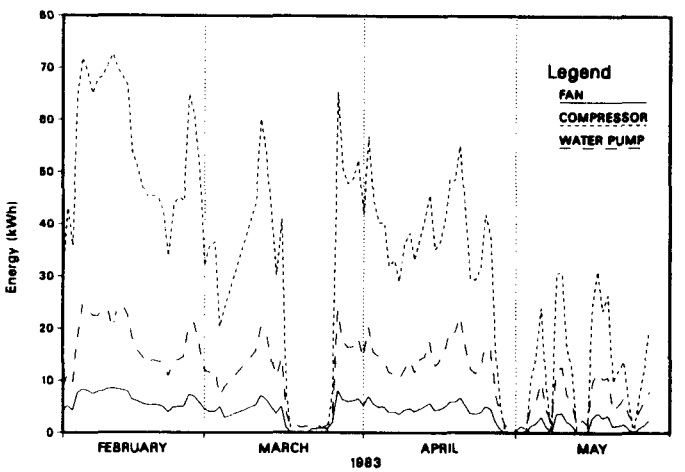
Total energy input (water + fan + compressor)
heating season 82-83 East Freedom

Figure 3-9



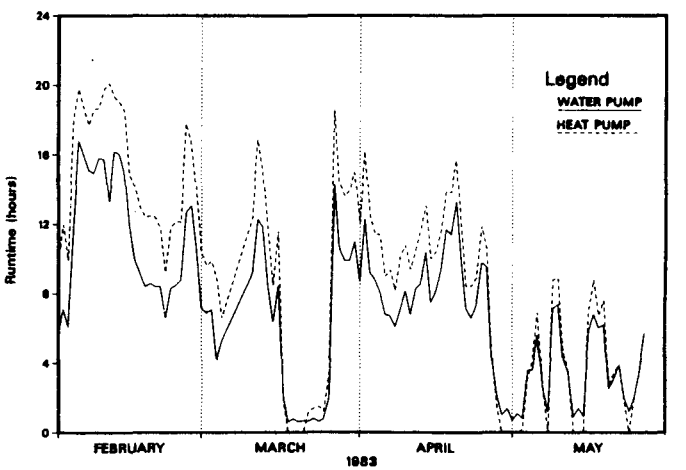
Daily electrical energy consumption
heating season 82-83 Bedford

Figure 3-10



Daily system energy consumption
heating season 82-83 Bedford

Figure 3-11



Daily runtime of pumps
heating season 82-83 Bedford

Figure 3-12

with the water pump and fan following in that order. A comparison of these Figures with those for East Freedom shows that the Bedford site is using slightly more energy per day. The water pump monitored supplied water to not only the heat pump, but for domestic and dairy parlor hygiene. It is estimated that over half the water pumped was used for these purposes. Since there was a water meter on the heat pump branch only, it is not possible to precisely determine the portion of well pump energy assignable to heat pump operation.

Figure 3-12 shows the runtimes of the heat pump and water pump. During the coldest period when data was available for Bedford, the heat pump is running nearly 20 hours a day. Figure 3-13 shows the number of daily cycles of the heat and water pump. The heat pump cycles are greater than those at East Freedom. The water cycles are usually less than those for the heat pump. Less correlation of cycles of the pump to those of the heat pump would be expected at Bedford. In addition to the water supplied being used for other applications, the diaphragm surge tank installed was about 5 times larger than ordinarily recommended for dedicated applications. (Recall that this water was also used in the dairy operation.)

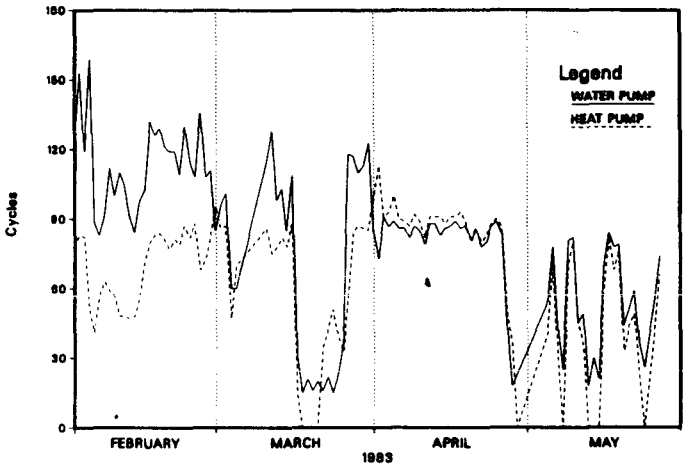
Figure 3-14 shows the run time history of the Bedford heat pump excluding the anomalous period in March. This plot gives a more detailed look at the operation since now there are a substantial number of hours with running times greater than 30 minutes during the recorded hours. The run times of both the heat pump and water pump now exhibit double peaks. Both have a peak at hourly runtimes less than 10% of the hour. The heat pump has a second peak for runtimes of 0.40 to 0.50 hours. The second peak for the water pump is for runtimes between 0.30 and 0.40 hours. Here there were periods when both the heat pump and water pump ran over 90% of the time in a given hour. There was no use of resistance backup heat at the site during the period when data were recorded. This is consistent with the homeowner's experience for the winter season before the instrumentation was installed. He stated that backup heat was used briefly for only two days during that heating season.

Figure 3-15 again shows the daily variation of the energy entering the system for February 1983. The better COP of this unit is now shown by the proportionately smaller cross-hatched area representing the electrical energy supplied to the fan and compressor as compared with the area represented by the energy extracted from the water. Again, it can be seen that the daily energy tracks the heating degree day curve. Similar curves for other months of the heating season are again found in Appendix A.

Figure 3-16 shows the scatter plot of energy supplied by the heat pump versus heating degree days. Again, additional data on daily values of compressor energy, fan energy, water extraction energy, water consumption, and total energy input to the house are plotted versus daily heating degree day values and are found in Appendix A. The scatter in the data from the Bedford site is now greater than that for the East Freedom site. An extrapolation of the curve of Figure 3-16 suggests a heating rate of 13.5 kW (324 kWh for 24 hours) or 46,100 BTUH at design temperature. This, again, is much less than the Manual J-calculated value of 83,100 BTUH and can probably be explained by the same reasons enumerated in the East Freedom discussion above, although there was no woodburning at this site.

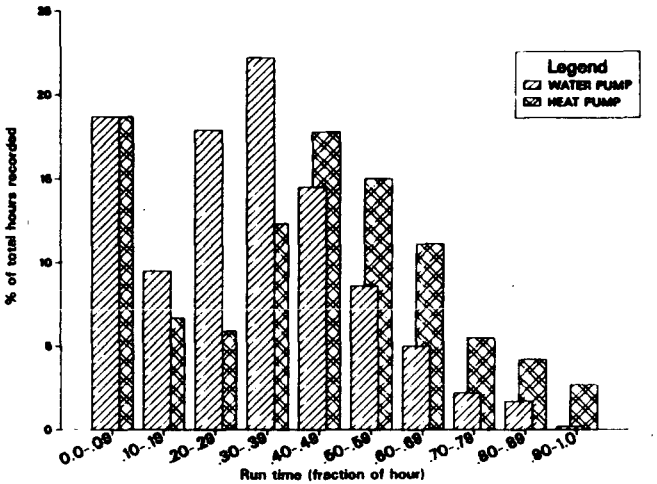
3.3 TYPICAL DAILY PERFORMANCE

This section describes the performance of the well-water-source heat pumps located at each field test site over a daily period of very cold conditions. Data is available for all types of daily conditions. A very cold day is of interest because it would show how near the heat pumps were to reaching the point where supplementary heating would be needed due to the higher heating loads, and how well the units operated during longer run times.



Daily heat and water pump cycles heating season 82-83 Bedford

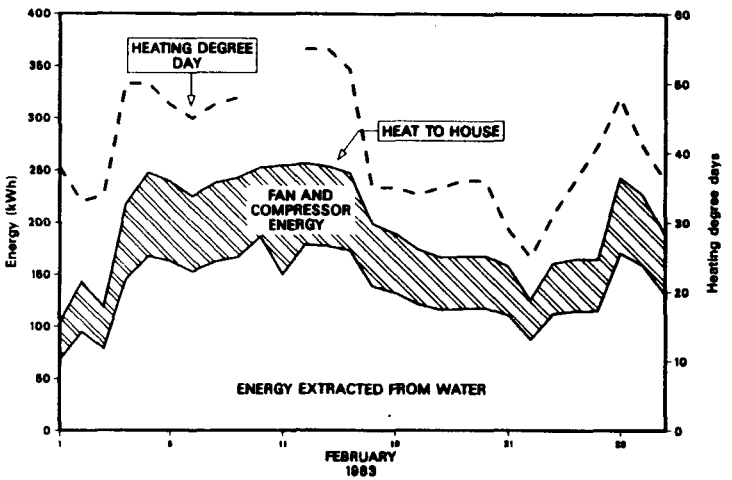
Figure 3-13



Fractional run time history of pumps Feb. 83 thru May 83 (3rd ht pump) Bedford

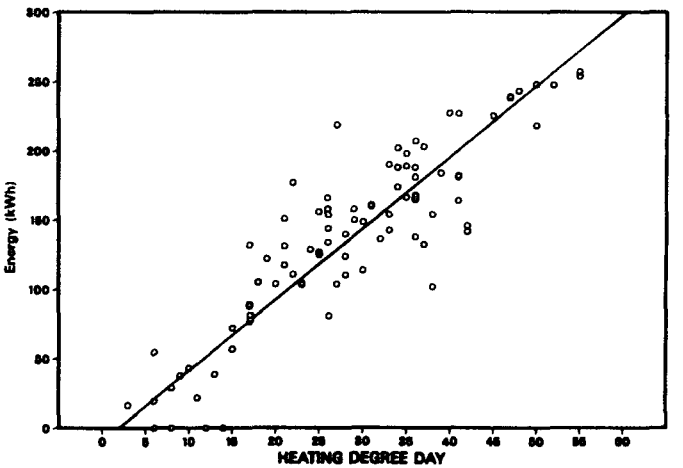
Note: Pump-supplied water also used in milking and for domestic purposes.

Figure 3-14



Component of heating energy & heating degree days Feb. 1983 Bedford

Figure 3-15



Total energy input (water + fan + compressor) heating season 82-83 Bedford

Figure 3-16

3.3.1 East Freedom Site

Data for Thursday, January 20, 1983 is selected for discussion as an example of a cold day. The hourly data file for this day is shown in Table 3-2. The corresponding fifteen-minute demand data is shown in Table 3-3.

Figure 3-17 shows the air temperature variation at the site for the day selected. It is based on averaging all temperature readings taken in a given hour to obtain an integrated mean value for that hour. This Figure shows temperature readings reaching -10 deg F(-23 deg C) around daybreak. The temperature then rose steadily to peak at slightly over 20 deg F (- 7 deg C) in the hours past noon. The temperature then steadily fell for the remainder of the day to about 0 deg F (-18 deg C) at midnight.

Figures 3-18 and 3-19 show the electrical energy use in the house during the day. The first of these Figures shows the total site electrical energy use and the sum of the energy used by the well-water-source heat pump system ("Total Equipment"). The heat pump components make up a substantial portion of the energy usage for any hour, i.e., approximately 75% of the total energy. However, the peak in the system energy does not coincide with the peak in total energy usage for this house. The heat pump system peaks slightly before the minimum of daily temperature is reached and just before dawn. The peak in total house energy occurs three hours later. Since this home has an electric kitchen, the peak in total house energy is connected with cooking. Figure 3-19 breaks down the energy used by the heat pump system into its components. This figure shows that the energy used by the compressor is the dominant component of equipment use.

Figure 3-20 shows the profile of water consumption during the day. This has essentially the same shape as the profile of compressor energy. Figure 3-21 shows how the number of cycles and runtime for the heat pump and water pump vary over the day. Both the heat pump and the water pump cycle about three times an hour over the day with minor variations. The hourly runtimes for both systems fluctuate around 50% on time. The shape of the runtime profiles again are similar to the compressor energy profile. The maximum runtime for this day is slightly less than 0.7 hours. This indicates that the heat pump system installed in this house has approximately another one-third capacity before it would require supplementary heating energy. This maximum runtime is among the longest obtained during these field tests which suggests that the system has capacity to heat the East Freedom site without supplementary heating for all but very improbable weather extremes. Thus, the unit is clearly oversized for its application. However, since the COP does not seem to fluctuate very much with load, it does not appear that this oversizing has much effect except for the initial cost of the unit.

As can be seen in Table 3-2, the temperature difference between the air entering the heat pump and that leaving is nearly constant with a mean value of 36.5 deg F(20 deg C). The standard deviation in the temperature difference is 0.44 deg F (0.24 deg C). Likewise the temperature difference of the water passing through the heat pump remains nearly constant with a mean value of 3.80 deg F(2.11 deg C) and a standard deviation of only 0.07 deg F(0.04 deg C).

Figure 3-22 graphs Table 3-3 and shows the fifteen-minute demand variation of the total house energy over the day. The demand follows the basic profile of energy use, but there is a band of fluctuation around the general shape that is about plus or minus one kilowatt. Figure 3-23 is the demand data for the heat pump system, i.e., usage of compressor, fan, and water pump. For demand values of the individual components, see Table 3-3.

Table 3-2

HOURLY DATA FILE
EAST FREEDOM
1/20/83

MONTH = 1 DAY = 30 YEAR = 83 STATE AT HALF HOUSEKIN, PA. I.D. = 61

HR	ROOM MEASURED (F) 1	2	3	4	5	6	OUTSIDE HUM	WS	TEMP	WATTMETER READINGS (KW) HUMIDE	FAN	COMP W	COMP	R. HT	TEMP. HATR	H2O	DELTA ATR	TEMP. H2O	HUM. HUM.	MODE H/C	A VEL. (FPS)	H2O OUT	CYCLES HP	HP	HUMIDITY(%) HPMP	WPMP
1	67	69	61	69	59	55	64	1	2 11	3.27	0.22	4.09	1.03	0.00	76.8	57.5	36.71	3.71	27.9	HT	7.40	9.3	3	3	0.437	0.410
2	67	68	61	67	59	52	64	0	1 9	3.89	0.22	4.02	1.03	0.00	70.5	52.4	36.78	3.79	28.1	HT	7.09	9.3	3	3	0.479	0.457
3	66	68	61	65	59	52	67	0	0 8	3.67	0.22	4.02	1.03	0.00	72.1	54.6	36.94	3.81	28.2	HT	7.13	9.4	3	3	0.516	0.493
4	66	68	60	63	59	52	68	0	-3 5	4.04	0.22	4.02	1.02	0.00	74.4	57.2	37.01	3.84	28.5	HT	7.35	9.4	3	3	0.564	0.543
5	66	68	60	62	59	52	74	0	-6 2	4.58	0.22	4.01	1.02	0.00	73.6	57.1	37.16	3.95	28.6	HT	7.45	9.4	3	3	0.613	0.594
6	66	68	60	61	59	51	77	0	-8 1	4.85	0.22	3.96	1.01	0.00	70.6	54.6	37.06	3.94	28.7	HT	7.23	9.4	3	3	0.696	0.668
7	66	68	60	65	60	51	77	0	-9 0	4.94	0.22	4.02	1.01	0.00	73.4	55.3	36.88	3.80	28.8	HT	7.27	9.3	3	3	0.648	0.622
8	66	69	60	69	60	51	78	0	-9 0	4.82	0.22	4.11	1.02	0.00	74.6	54.8	37.20	3.70	29.2	HT	7.39	9.4	3	2	0.610	0.594
9	66	68	60	69	60	51	77	0	-5 3	5.52	0.22	4.08	1.03	0.00	74.1	54.9	36.87	3.78	28.7	HT	7.16	9.3	3	4	0.571	0.538
10	68	68	60	68	60	53	62	0	8 12	3.84	0.22	4.07	1.03	0.00	74.3	54.7	36.17	3.75	27.8	HT	7.25	9.3	3	3	0.462	0.439
11	69	68	60	66	60	54	42	0	12 18	3.09	0.22	4.05	1.02	0.00	74.3	54.6	36.22	3.75	27.1	HT	7.23	9.4	3	2	0.408	0.391
12	70	68	61	64	60	55	33	0	17 22	3.31	0.22	4.02	1.04	0.00	72.5	53.6	35.70	3.77	26.9	HT	6.79	9.3	2	3	0.399	0.375
13	70	67	61	63	61	56	26	0	21 26	3.18	0.22	4.04	1.03	0.00	73.1	54.6	35.74	3.81	27.1	HT	7.03	9.3	3	3	0.419	0.394
14	69	67	61	62	62	57	22	0	22 28	3.03	0.22	4.04	1.03	0.00	72.8	54.6	35.70	3.79	27.1	HT	7.05	9.3	3	3	0.417	0.394
15	68	68	61	61	63	57	23	0	20 26	3.63	0.22	4.05	1.03	0.00	73.5	55.7	36.13	3.86	27.3	HT	7.22	9.3	3	3	0.436	0.411
16	67	68	61	61	62	57	25	0	16 23	3.48	0.22	4.05	1.03	0.00	72.2	54.7	36.40	3.90	27.9	HT	7.23	9.4	3	3	0.493	0.470
17	67	68	61	61	62	56	25	0	14 22	4.01	0.22	4.00	1.02	0.00	72.1	54.5	36.46	3.85	28.1	HT	7.26	9.4	3	3	0.536	0.513
18	67	69	61	65	62	56	36	0	9 17	4.56	0.22	4.06	1.02	0.00	74.1	54.6	36.45	3.75	28.3	HT	7.24	9.4	3	3	0.563	0.538
19	67	70	61	69	62	56	51	0	5 13	3.94	0.22	4.06	1.02	0.00	74.3	53.9	36.31	3.67	28.9	HT	7.10	9.4	3	3	0.509	0.487
20	67	70	61	68	62	55	57	0	3 12	4.21	0.22	4.09	1.02	0.00	74.6	54.7	36.38	3.72	28.4	HT	7.29	9.3	3	3	0.450	0.428
21	67	70	61	67	62	55	60	0	2 10	4.15	0.22	4.09	1.02	0.00	74.0	54.7	36.34	3.75	27.4	HT	7.19	9.4	3	3	0.444	0.424
22	67	69	61	66	62	55	63	0	0 9	3.99	0.22	4.04	1.03	0.00	73.1	54.6	36.61	3.79	26.9	HT	7.19	9.3	3	3	0.479	0.454
23	67	69	61	64	62	54	65	0	0 8	3.59	0.22	4.03	1.03	0.00	72.4	54.6	36.76	3.79	26.8	HT	7.29	9.4	3	3	0.504	0.483
24	66	69	60	64	62	54	67	0	-1 8	4.29	0.22	4.03	1.03	0.00	73.5	56.1	36.67	3.84	26.8	HT	7.34	9.3	4	4	0.554	0.521

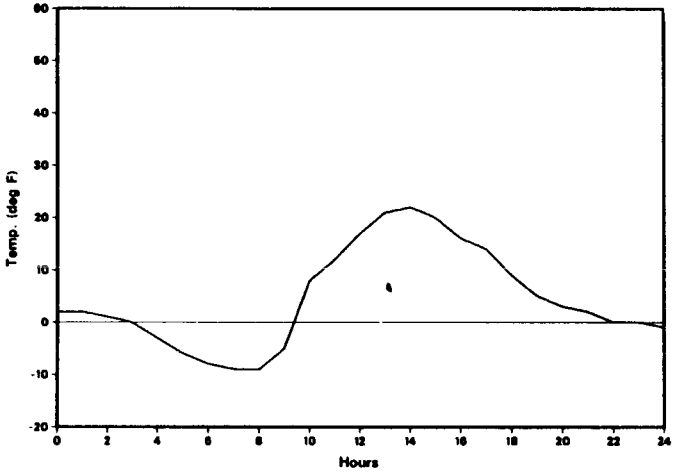
Table 3-3

15 MINUTE DEMAND FILE
EAST FREEDOM
1/20/83

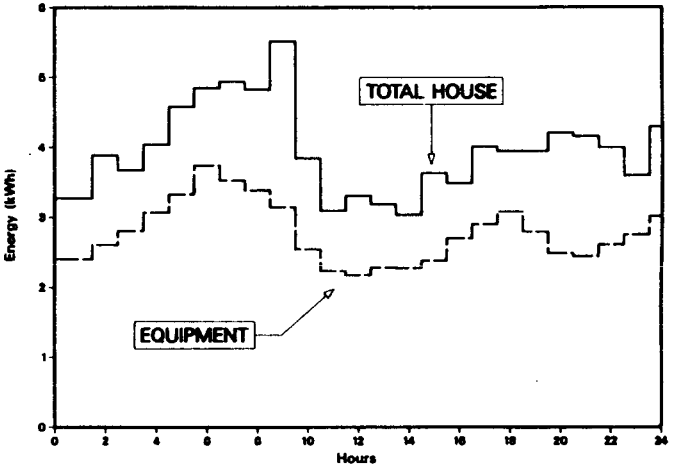
MONTH = 1 DAY = 20 YEAR = 83 RICHARD HOME, EAST FREEDOM, PA. I.D. = 61

ENERGY DEMANDS (WATTHOURS)

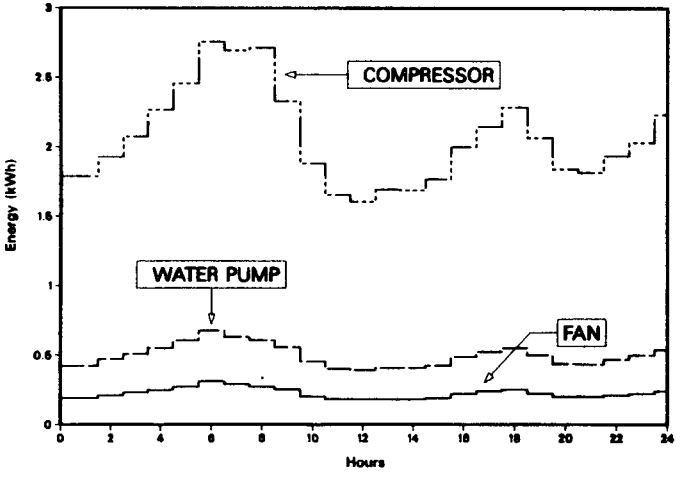
HOUR	0 MINUTES HOUSE WH	PAN WH	COMP WH	REHEAT WH	WPMP WH	15 MINUTES HOUSE WH	PAN WH	COMP WH	REHEAT WH	WPMP WH	30 MINUTES HOUSE WH	PAN WH	COMP WH	REHEAT WH	WPMP WH	45 MINUTES HOUSE WH	PAN WH	COMP WH	REHEAT WH	WPMP WH
0	786	22	411	0	91	692	19	353	0	81	828	24	451	0	113	964	31	567	0	134
1	1073	35	640	0	152	1064	20	365	0	87	788	22	403	0	94	962	28	516	0	133
2	1158	37	681	0	165	1006	32	581	0	138	763	22	407	0	96	750	22	405	0	104
3	1231	41	756	0	186	1155	36	659	0	159	860	24	434	0	101	792	22	416	0	107
4	1649	43	792	0	195	1087	35	637	0	154	841	24	451	0	106	995	31	575	0	148
5	1394	46	848	0	205	894	26	471	0	113	990	28	504	0	130	1557	51	929	0	228
6	989	27	510	0	121	1556	40	747	0	190	1392	44	821	0	197	1001	28	525	0	122
7	1429	45	833	0	210	1247	40	743	0	174	917	27	493	0	116	1221	23	438	0	104
8	1113	36	659	0	164	1351	45	837	0	200	1624	26	483	0	112	1426	19	350	0	78
9	1076	30	554	0	141	1305	32	594	0	142	795	23	440	0	101	594	15	287	0	65
10	813	25	460	0	117	973	31	582	0	137	812	22	414	0	95	493	10	195	0	48
11	931	29	536	0	133	943	30	550	0	131	279	4	87	0	12	1153	23	431	0	110
12	951	30	554	0	133	613	15	288	0	61	606	14	260	0	67	1005	32	589	0	142
13	801	26	485	0	114	404	9	170	0	35	902	26	485	0	125	922	29	542	0	130
14	543	14	269	0	57	668	18	334	0	86	1422	32	593	0	143	995	31	566	0	135
15	553	16	301	0	69	835	26	487	0	125	1169	33	703	0	170	926	27	502	0	117
16	703	19	344	0	78	1193	31	574	0	148	1115	35	651	0	159	987	31	575	0	136
17	1156	24	441	0	104	947	28	516	0	131	1350	39	735	0	175	1111	31	588	0	135
18	820	22	412	0	95	796	20	383	0	97	1146	33	616	0	147	1182	35	656	0	154
19	682	18	351	0	77	1108	16	305	0	67	1260	33	613	0	154	1150	30	568	0	135
20	832	21	393	0	89	748	17	329	0	75	1428	27	510	0	130	1143	31	593	0	137
21	940	28	515	0	121	1125	20	366	0	85	1047	23	430	0	107	1079	34	630	0	151
22	1068	36	657	0	161	895	26	474	0	111	923	24	447	0	106	880	26	453	0	116
23	1179	38	693	0	166	1101	36	655	0	157	893	26	474	0	111	1153	23	431	0	99



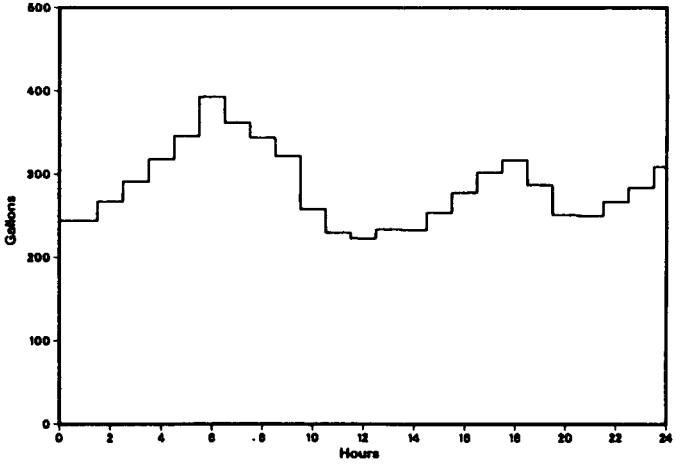
Hourly outdoor temperature
Jan. 20, 1983 East Freedom
Figure 3-17



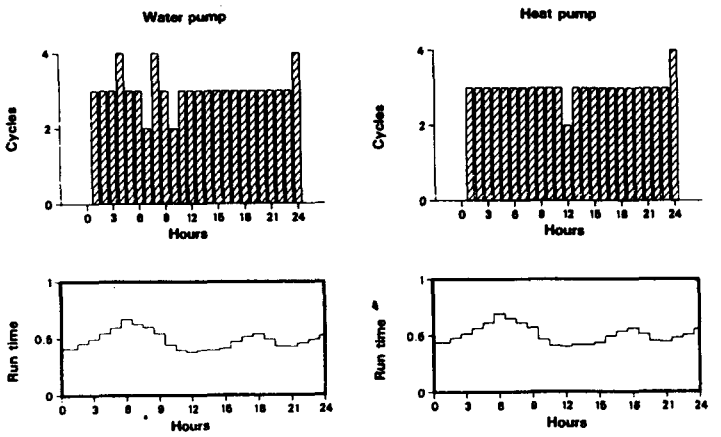
Hourly electrical energy consumption
Jan. 20, 1983 East Freedom
Figure 3-18



Hourly system energy consumption
Jan. 20, 1983 East Freedom
Figure 3-19

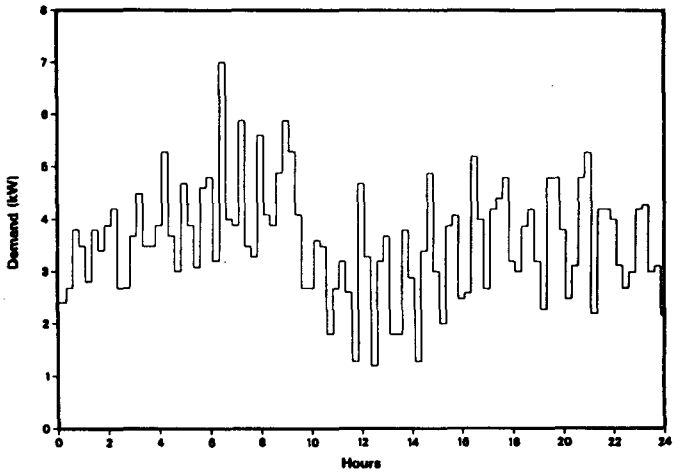


Hourly water consumption of heat pump
Jan. 20. 1983 East Freedom
Figure 3-20



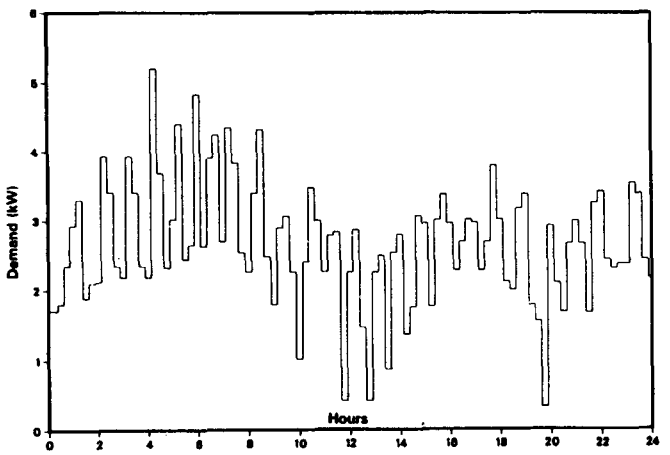
System operation on Jan. 20, 1983
East Freedom

Figure 3-21



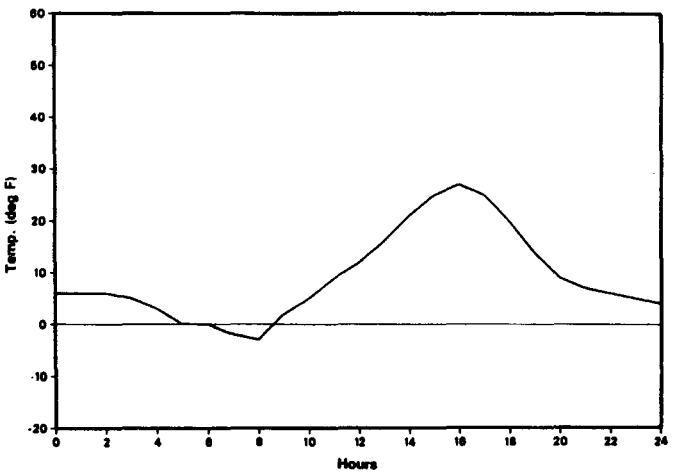
15 min. demand for house
Jan. 20, 1983 East Freedom

Figure 3-22



15 min. demand of system
(fan + compressor + water pump)
Jan. 20, 1983 East Freedom

Figure 3-23



Hourly outdoor temperature
Feb. 12, 1983 Bedford

Figure 3-24

3.3.2 Bedford Site

Data for Saturday, February 12, 1983 was selected to represent performance at this site during a very cold day. The hourly and fifteen-minute demand files for this day are shown in Tables 3-4 and 3-5.

Figure 3-24 shows the temperature variation for this day. This temperature profile is quite similar to the day selected for the East Freedom site. The temperature is very cold in the morning, reaching values of minus 3 deg F (-19 deg C) at 8:00 a.m. The temperature steadily rose during the day to a peak of around 30 deg F around 4:00 p.m. The temperature then steadily declined to about 5 deg F (-15 deg C) at midnight.

Figures 3-25 and 3-26 show the electrical energy use in the house during the day. The first of these figures shows the total site electrical energy use and the sum of the energy used by the well-water-source heat pump system ("Equipment"). Compared to East Freedom, the heat pump components make up an even more substantial portion of the energy usage for any hour, approaching 85% during the early morning hours. But again, the peaks in total house energy occur at times other than the peak use of energy by the heat pump system. There is a period of high energy use in the hours of 10:00 and 11:00 a.m. The highest peak occurs around 7:00 p.m. The evening peak is probably connected with the preparation of supper in the electric kitchen. The morning peak is probably connected with normal household tasks such as baking or clothes washing. The peak in heat pump energy occurs in the early morning hours before dawn when the outside temperature is the coldest. These result in a sustained high use of energy for nine hours which is only exceeded by three other hours during the day. There is a gradual decline in heat pump energy use as the air temperature increases during the day. This use of energy by the heat pump system reaches a plateau and remains nearly constant for the last half of the day. Figure 3-26 shows the breakdown of system energy use into its components. There is nothing unusual here. The compressor is the major user of energy. The water pump and fan follow the profile of the compressor.

Figure 3-27 shows the cycling and runtime information for this day. During the early morning hours, the heat pump is running almost continuously. In the time period from midnight until 8:00 a.m. the heat pump turns off only three times. During the middle of the day there is a gradual decline in runtime. Finally, during the last half of the day, the unit is running in the range of 65 to 76% of the time. The water pump supplying the heat pump continues to cycle throughout the day. Its minimum number of cycles in an hour is two. The maximum number of cycles in an hour is six.

Based on the information just presented, it can be concluded that the size of the heat pump model installed at the Bedford site is very close to optimum for the heating load. The homeowner reported that during the heating season, before the automated instrumentation was installed, (and presumably before that heat pump began to fail) supplementary heating by his oil furnace was required for only two days. From the data presented, it can be seen that when the outside temperature is approaching zero degrees F., the heat pump is operating nearly continuously.

The temperature difference between the air entering the heat pump and that leaving is nearly constant with a mean value of 24.1 deg F (13.3 deg C). The standard deviation in the temperature difference is only 0.60 deg F (0.33 deg C). Likewise, the temperature difference of the water passing through the heat pump remains nearly constant with a mean value of 10.8 deg F (6.0 deg C) and standard deviation of only 0.16 deg F (0.089 deg C).

Figure 3-28 shows the fifteen-minute demand variation of total house energy over the day. The demand follows the basic profile of energy use. There is a sustained period

Table 3-4

HOURLY DATA FILE
BEDFORD
2/12/83

MONTH = 2 DAY = 12 YEAR = 83 SITE AT BEDFORD, PA. I.D. = 62

HR	TEMPERATURES (F) 1 2 3 4 5 6 7 8 9 HUM	WS MPH	DA °F	WATTMETER READINGS (KW) HOUSE	FAN	COMP	PMP	HT1	HT2	TEMP. RAIN	H2O	DELTA TEMP. AIR	H2O	HUM. REL.	MODE H/C	A VEL (FPS)	H2O GPM	CYCLES HP	WP	RUNTIME(HR HPMP	WPM
1	42 42 43 41 41 37		0																		
	16 38 33 100	1	14	5.75	0.43	3.65	1.53	0.00	0.00	65.1	53.7	24.85	10.75	26.0	HT	9.67	5.85	1	5	0.929	0.75
2	42 42 43 41 41 37		0																		
	16 38 33 100	1	13	6.11	0.43	3.65	1.50	0.00	0.00	65.6	53.8	25.07	10.72	26.3	HT	9.70	5.87	0	4	0.999	0.81
3	42 42 43 41 41 37		5																		
	16 38 33 100	0	13	5.40	0.43	3.64	1.49	0.00	0.00	65.3	53.8	24.79	10.73	26.2	HT	9.61	5.87	1	4	0.927	0.75
4	42 42 43 41 41 37		3																		
	16 38 33 100	0	12	6.12	0.43	3.63	1.49	0.00	0.00	65.5	53.8	24.84	10.93	26.0	HT	9.66	5.74	0	3	0.999	0.86
5	42 42 43 41 41 37		0																		
	16 38 33 100	0	7	6.12	0.43	3.64	1.46	0.00	0.00	65.5	53.8	24.93	10.72	25.8	HT	9.66	5.90	0	3	1.001	0.86
6	42 42 43 41 41 37		2																		
	16 38 33 100	0	7	6.36	0.42	3.62	1.46	0.00	0.00	65.4	53.4	24.86	10.78	25.5	HT	9.67	5.86	0	3	0.999	0.857
7	42 42 43 41 41 37		-2																		
	16 38 33 100	0	5	6.17	0.42	3.61	1.44	0.00	0.00	65.3	53.8	24.95	10.75	25.4	HT	9.64	5.90	0	2	1.001	0.906
8	42 42 43 41 40 37		-3																		
	16 38 33 100	0	4	6.05	0.42	3.56	1.45	0.00	0.00	65.1	53.8	24.68	11.19	25.1	HT	9.65	5.56	0	2	1.001	0.907
9	42 43 43 41 41 38		2																		
	16 39 33 100	0	10	5.94	0.42	3.57	1.44	0.00	0.00	64.6	53.3	24.19	11.13	25.4	HT	9.57	5.61	1	2	0.837	0.814
10	42 43 43 41 41 38		5																		
	16 39 33 100	0	13	6.39	0.43	3.60	1.45	0.00	0.00	66.4	57.6	23.92	10.88	25.7	HT	9.98	5.88	3	3	0.805	0.696
11	43 43 43 41 41 39		9																		
	16 39 34 94	0	16	6.19	0.43	3.61	1.46	0.00	0.00	64.5	53.1	23.03	10.68	25.9	HT	9.48	5.94	2	2	0.724	0.639
12	42 43 43 41 41 40		22																		
	16 40 34 77	0	19	4.69	0.43	3.61	1.50	0.00	0.00	64.6	53.6	23.33	10.71	26.2	HT	9.63	5.93	3	3	0.684	0.578
13	42 43 43 41 40 40		16																		
	16 40 34 67	0	23	4.30	0.44	3.62	1.52	0.00	0.00	64.7	53.6	23.35	10.71	26.4	HT	9.67	5.90	3	3	0.658	0.509
14	43 43 43 41 41 40		21																		
	16 40 34 56	0	27	4.51	0.44	3.62	1.52	0.00	0.00	65.0	53.6	23.37	10.69	26.8	HT	9.77	5.93	3	4	0.669	0.552
15	42 43 43 41 41 40		25																		
	16 40 35 40	0	32	4.08	0.44	3.63	1.54	0.00	0.00	65.1	53.6	23.54	10.69	26.9	HT	9.77	5.89	3	4	0.653	0.488
16	42 43 43 41 41 40		27																		
	16 41 35 31	1	33	4.54	0.44	3.67	1.54	0.00	0.00	70.2	58.3	23.70	10.76	27.1	HT	10.23	5.91	4	6	0.678	0.581
17	42 43 43 41 41 40		25																		
	16 41 35 34	0	31	4.65	0.43	3.69	1.51	0.00	0.00	65.1	53.0	23.77	10.76	27.2	HT	9.62	5.82	2	5	0.727	0.581
18	42 43 43 41 41 40		20																		
	16 41 35 43	0	26	5.34	0.41	3.58	1.47	0.00	0.00	66.4	54.2	23.72	10.71	27.4	HT	9.70	5.86	3	5	0.761	0.589
19	43 43 43 41 41 39		14																		
	16 40 35 62	0	20	6.03	0.41	3.56	1.47	0.00	0.00	65.3	53.0	23.83	10.97	27.4	HT	9.68	5.68	2	4	0.707	0.691
20	42 43 43 42 41 39		9																		
	16 40 35 74	0	16	5.72	0.43	3.62	1.50	0.00	0.00	69.5	57.3	23.78	10.95	27.7	HT	10.19	5.82	3	3	0.751	0.611
21	42 43 43 42 40 39		7																		
	16 40 35 82	0	14	4.32	0.44	3.61	1.54	0.00	0.00	65.2	54.3	23.36	10.66	27.5	HT	9.83	5.96	4	4	0.632	0.501
22	42 42 43 41 40 39		0																		
	16 40 35 90	0	13	4.53	0.44	3.59	1.53	0.00	0.00	63.3	53.0	23.95	10.73	27.3	HT	9.66	5.94	3	5	0.681	0.507
23	42 42 42 41 40 39		5																		
	16 40 35 93	0	15	4.92	0.43	3.59	1.51	0.00	0.00	64.0	53.6	24.02	10.87	26.9	HT	9.72	5.84	3	6	0.738	0.552
24	42 42 42 41 40 39		4																		
	16 40 35 96	0	12	4.77	0.44	3.61	1.52	0.00	0.00	65.3	54.7	24.30	10.87	26.6	HT	9.79	5.86	3	6	0.767	0.555

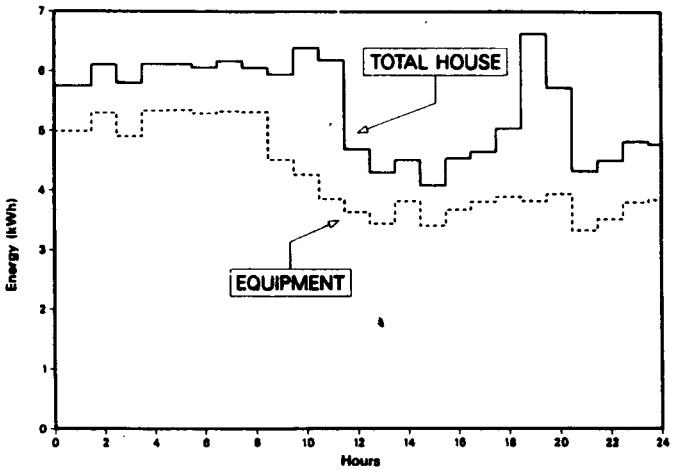
Table 3-5

15 MINUTE DEMAND FILE
BEDFORD
2/12/83

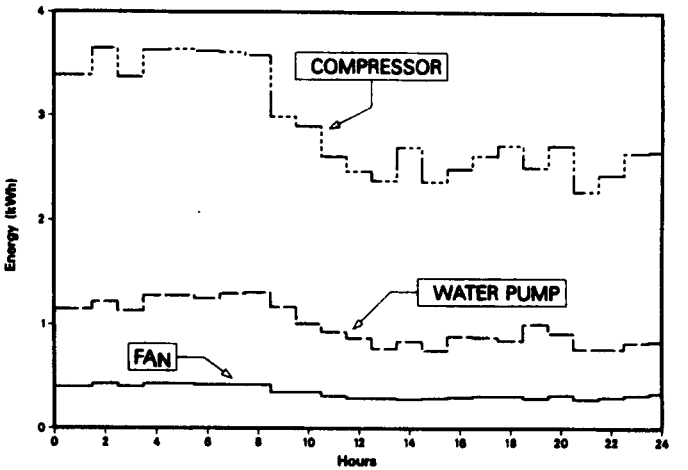
MONTH = 2 DAY = 12 YEAR = 83 KOONTZ HOME, BEDFORD, PA. I.D. = 62

ENERGY DEMANDS (WATTHOURS)

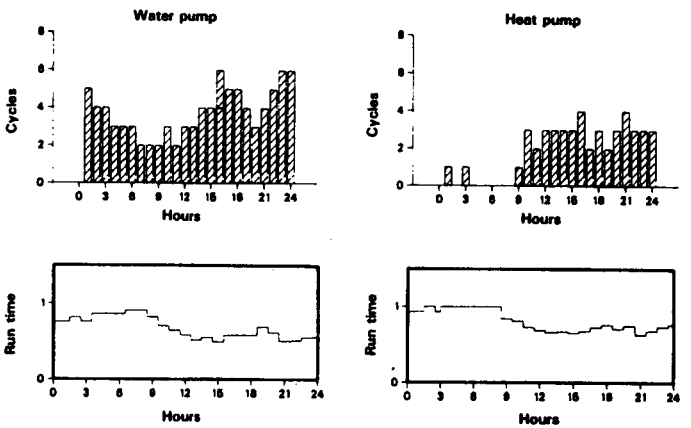
HOUR	3 MINUTES HOUSE WH	FAN WH	COMP WH	RESHT WH	WPMP WH	15 MINUTES HOUSE WH	FAN WH	COMP WH	RESHT WH	WPMP WH	30 MINUTES HOUSE WH	FAN WH	COMP WH	RESHT WH	WPMP WH	45 MINUTES HOUSE WH	FAN WH	COMP WH	RESHT WH	WPMP WH
0	1567	108	915	0	302	1158	76	642	0	235	1469	107	909	0	309	1560	109	919	0	312
1	1548	106	907	0	304	1551	107	916	0	309	1460	106	908	0	304	1543	106	913	0	303
2	1574	106	909	0	301	1453	104	895	0	305	1219	79	657	0	221	1562	106	906	0	300
3	1492	106	908	0	301	1539	106	909	0	304	1575	106	911	0	305	1507	106	894	0	373
4	1510	106	912	0	303	1503	106	913	0	300	1601	106	909	0	309	1429	106	907	0	303
5	1548	106	906	0	299	1518	104	907	0	293	[illegible]	104	903	0	363	1444	104	899	0	294
6	1661	104	910	0	346	1476	104	899	0	305	1426	105	900	0	294	1610	103	900	0	354
7	1470	103	697	0	292	1432	105	904	0	295	1595	104	889	0	365	1559	103	889	0	362
8	1617	102	885	0	355	1396	76	650	0	292	1490	99	834	0	280	1422	71	626	0	245
9	1779	102	869	0	292	1449	67	580	0	167	1853	105	891	0	363	1316	66	559	0	187
10	1678	82	707	0	233	1651	66	719	0	280	1246	62	534	0	150	1598	77	652	0	268
11	1521	92	767	0	254	867	59	489	0	162	[illegible]	62	524	0	164	1342	81	699	0	285
12	1164	87	725	0	249	881	60	496	0	154	[illegible]	63	523	0	156	1297	76	635	0	214
13	1527	94	786	0	281	913	60	503	0	186	913	61	512	0	128	1088	73	622	0	246
14	1315	95	795	0	232	962	63	527	0	209	858	63	525	0	133	940	63	531	0	176
15	1430	91	764	0	296	1162	78	656	0	291	917	64	530	0	151	1016	63	531	0	156
16	1371	93	785	0	289	1123	76	641	0	207	959	63	535	0	140	1193	76	656	0	239
17	1249	90	774	0	212	996	61	516	0	173	1204	73	641	0	241	1585	89	790	0	224
18	1427	62	544	0	173	230[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	143[illegible]	63	539	0	279	1469	63	542	0	249
19	1898	103	863	0	316	1375	67	556	0	187	108[illegible]	64	549	0	182	1373	69	747	0	229
20	1143	74	615	0	230	1065	73	605	0	214	1048	64	531	0	163	1036	64	531	0	161
21	909	65	540	0	162	1059	63	531	0	158	1238	73	607	0	235	1283	93	767	0	221
22	1230	76	632	0	206	1081	70	582	0	160	1023	71	598	0	193	1484	101	841	0	275
23	1158	77	638	0	255	972	72	591	0	173	1556	108	907	0	296	1086	76	627	0	167



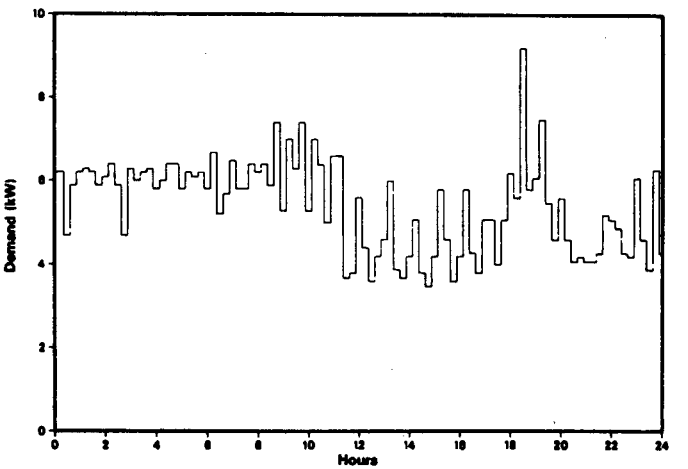
Hourly electrical energy consumption
Feb. 12, 1983 Bedford
Figure 3-25



Hourly system energy consumption
Feb. 12, 1983 Bedford
Figure 3-26



System operation on Feb. 12, 1983
Bedford
Figure 3-27



15 min. demand for house
Feb. 12, 1983 Bedford
Figure 3-28

of high demand during the first eleven hours of the day. For the remainder of the day, there is much more fluctuation. This fluctuation is particularly apparent during early evening when it is probably connected with the preparation of supper. Figure 3-29 shows the variation of demand for the heat pump system. Again, the demand is significant and sustained early in the day. Then there is a fluctuation that is a response to the greater cycling of the system.

3.4 TYPICAL CYCLE PERFORMANCE

This section describes the cycle performance of the well-water-source heat pump located at each field test site. This information was obtained by storing all the data collected during the heat pump on continuous scanning until that detailed data file was full, approximately 45 minutes of total heat pump running time. The start time was selected as either the first system startup after midnight or noon. After the detailed data file became full, no more of this type of data was gathered until a new tape was inserted in the microcomputer a week later.

3.4.1 East Freedom Site

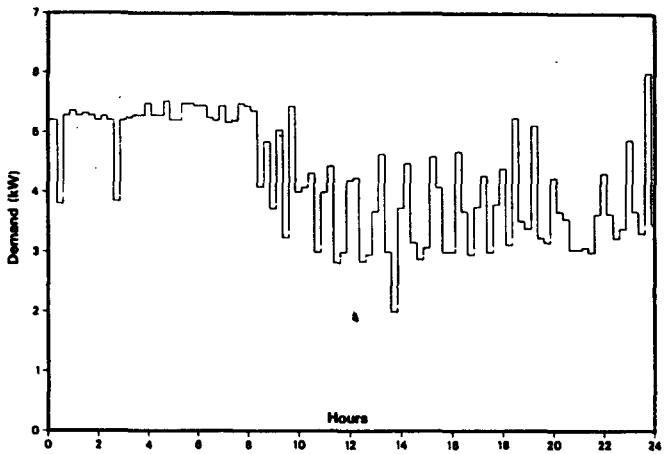
Reduced information for one cycle at the East Freedom site is shown in Table 3-6 and 3-7. Figure 3-30 shows a plot of the air and water flow rates. The airflow rises rather rapidly to its average value. However, the hot film anemometer is very sensitive in response to flow fluctuations and it shows that there is a large amount of turbulence in the airflow. The water flow does not respond as rapidly when the system is turned on. Initially, the system responds quickly, but then the accumulator tank pressure starts to fall. This causes the water pump to turn on. Once the water pump turns on, there is a gradual rise in flow rate for the rest of the cycle. The water flow does not closely approach its eventual average value until about 1.5 minutes after the system has been started.

The instantaneous capacity and COP based on average air flow and temperature differences is shown in Figures 3-31 and 3-32. These figures show that the initial amount of energy extracted from the water peaks early in the cycle, approximately at the first minute. Then, the capacity and COP gradually approach the average value. It takes approximately 20 seconds for the instantaneous capacity to practically reach the average value for the cycle. Figure 3-33 shows that the electrical energy use is rather flat. There is a slight increase in energy draw of the compressor at the start of the cycle.

Figure 3-34 shows that the air temperature difference responds rather quickly once the initial transient subsides and remains nearly constant. The water temperature difference is slower in response, but rather smooth. Return air temperature and water inlet temperature are shown in Figure 3-35. It appears to take about 40 seconds for the slug of warmer water initially stored in the lines and accumulator tank to pass the sensor. Then water fresh from the well at approximately constant temperature arrives. The return air temperature shows a gradual rise over most of the cycle.

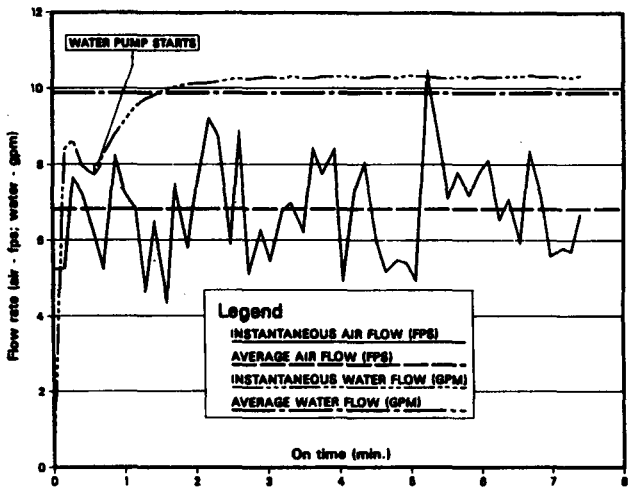
3.4.2 Bedford Site

Typical cycle data will now be presented for the Bedford site. Figure 3-36 shows the flow rate data again. The Bedford site is characterized by a larger heating load in comparison to the rated heat pump capacity. Therefore, the runtimes are generally longer. Also, the Bedford site had a larger accumulator tank which was in proper working form. (The bladder in the East Freedom tank was leaking.) The airflow again is very quick in response and again the sensor picks up a large amount of turbulence in the flow. The water flow follows a sawtooth pattern. It initially falls as the pressure in the accumulator falls. Then, there is a gradual rise as the water pump



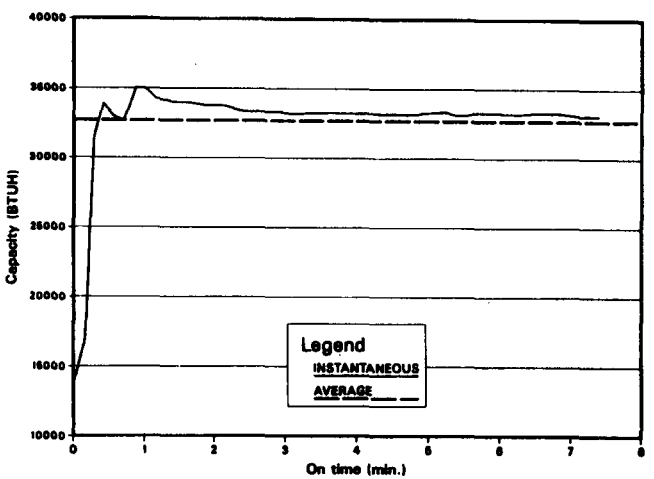
15 min. demand of system (fan + compressor + water pump) Feb. 12, 1983 Bedford

Figure 3-29



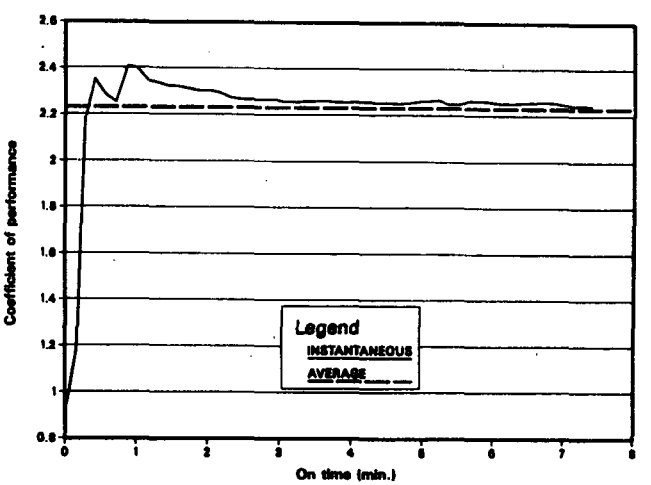
Air and water flow for a cycle at East Freedom

Figure 3-30



Capacity of unit for a cycle at East Freedom

Figure 3-31



COP of unit for a cycle at East Freedom

Figure 3-32

Table 3-6

CYCLE DATA

MONTH = 1 DAY = 18 YEAR = 85 SITE AT PALMT PRESSION, PA. I.D. = 61

STARTING TIME IS 10.2776 MODE IS HT

RTIME (MIN)	WATTMETER READINGS(KILOWATTS) PAN	COMP	W PMP	R. HT	TEMP. RAIR	DEWP H2O	TEMP. AIR	DEWP. H2O	HUM REL	AVEL FPS.	WATER GPM
0.00	0.218	4.329	0.000	0.000	76.9	65.3	17.69	0.31	28.1	7.42	0.00
0.12	0.214	4.184	0.000	0.000	76.5	65.3	21.28	-2.04	28.4	6.85	0.00
0.71	0.215	4.051	1.031	0.000	75.6	54.7	32.53	3.69	29.1	7.88	7.89
0.84	0.214	4.042	1.031	0.000	75.6	54.7	33.29	5.05	29.2	6.84	8.34
1.01	0.213	4.053	1.029	0.000	75.6	54.8	34.15	4.33	29.3	7.69	8.85
1.14	0.215	4.069	1.029	0.000	75.6	55.0	34.67	4.34	29.4	6.62	9.11
1.26	0.216	4.080	1.027	0.000	75.6	55.0	35.15	4.06	29.4	7.86	9.36
1.43	0.215	4.081	1.025	0.000	75.7	55.0	35.55	3.94	29.5	6.00	9.59
1.56	0.216	4.079	1.025	0.000	75.7	55.0	35.80	3.88	29.6	9.64	9.70
1.73	0.216	4.091	1.022	0.000	75.8	55.0	36.14	3.82	29.6	5.39	9.85
1.85	0.216	4.098	1.022	0.000	75.8	55.0	36.30	3.76	29.7	8.62	9.92
2.02	0.216	4.097	1.021	0.000	75.9	55.0	36.43	3.74	29.7	6.08	9.97
2.15	0.216	4.096	1.019	0.000	76.0	55.0	36.60	3.75	29.7	7.33	10.02
2.27	0.216	4.097	1.020	0.000	76.0	55.1	36.71	3.68	29.8	8.28	10.06
2.44	0.216	4.109	1.019	0.000	76.1	55.1	36.84	3.67	29.8	5.66	10.08
2.57	0.215	4.100	1.016	0.000	76.1	55.1	36.86	3.64	29.8	7.67	10.09
2.74	0.215	4.114	1.018	0.000	76.2	55.0	36.95	3.61	29.8	6.84	10.13
2.86	0.217	4.110	1.018	0.000	76.3	55.0	36.98	3.56	29.8	6.50	10.10
3.03	0.216	4.109	1.017	0.000	76.4	54.9	37.02	3.55	29.8	8.66	10.18
3.16	0.217	4.109	1.017	0.000	76.5	54.8	37.14	3.58	29.8	10.06	10.16
3.33	0.216	4.099	1.016	0.000	76.5	54.8	37.14	3.54	29.8	8.29	10.15
3.46	0.216	4.094	1.016	0.000	76.5	54.7	37.21	3.54	29.8	6.96	10.09
3.58	0.216	4.103	1.016	0.000	76.6	54.7	37.18	3.57	29.8	7.25	10.31
3.75	0.216	4.099	1.015	0.000	76.6	54.7	37.11	3.55	29.8	9.32	10.15
3.88	0.216	4.100	1.015	0.000	76.7	54.7	37.17	3.58	29.9	5.86	10.16
4.05	0.216	4.099	1.016	0.000	76.7	54.7	37.17	3.52	29.8	6.22	10.16
4.17	0.216	4.104	1.014	0.000	76.8	54.7	37.14	3.52	29.8	8.73	10.21
4.34	0.216	4.101	1.014	0.000	76.8	54.6	37.17	3.55	29.8	6.29	10.18
4.47	0.216	4.105	1.014	0.000	76.8	54.6	37.19	3.55	29.8	6.83	10.19
4.60	0.217	4.102	1.016	0.000	76.9	54.6	37.25	3.57	29.8	7.29	10.19
4.76	0.216	4.100	1.016	0.000	76.9	54.6	37.16	3.57	29.8	8.65	10.08
4.89	0.217	4.106	1.015	0.000	77.0	54.6	37.12	3.52	29.8	7.76	10.23
5.06	0.217	4.108	1.014	0.000	77.1	54.6	37.18	3.55	29.8	8.37	10.20
5.19	0.217	4.105	1.014	0.000	77.1	54.6	37.30	3.54	29.8	6.97	10.24
5.36	0.217	4.104	1.015	0.000	77.1	54.6	37.26	3.52	29.8	6.51	10.19
5.48	0.217	4.098	1.015	0.000	77.1	54.6	37.15	3.58	29.9	7.98	10.23
5.65	0.217	4.107	1.014	0.000	77.3	54.6	37.09	3.57	29.9	7.38	10.20
5.78	0.217	4.112	1.014	0.000	77.3	54.6	37.16	3.55	29.9	7.03	10.19
5.91	0.217	4.115	1.017	0.000	77.4	54.6	37.25	3.52	29.9	8.34	10.18
6.07	0.219	4.111	1.017	0.000	77.4	54.6	37.20	3.57	29.9	7.13	10.17
6.20	0.218	4.114	1.016	0.000	77.5	54.6	37.09	3.52	29.9	8.77	10.17
6.37	0.219	4.116	1.016	0.000	77.6	54.6	37.13	3.54	29.9	7.31	10.20
6.50	0.219	4.122	1.016	0.000	77.6	54.6	37.17	3.54	29.9	6.27	10.21
6.66	0.219	4.119	1.016	0.000	77.7	54.6	37.11	3.55	29.9	8.13	10.21
6.79	0.218	4.123	1.016	0.000	77.7	54.6	37.17	3.54	29.9	8.38	10.22
6.92	0.219	4.119	1.017	0.000	77.7	54.6	37.21	3.55	29.9	7.17	10.19
7.09	0.219	4.121	1.017	0.000	77.7	54.6	37.15	3.54	29.9	5.00	10.22
7.22	0.218	4.114	1.017	0.000	77.8	54.6	37.14	3.51	29.9	7.16	10.17
7.38	0.218	4.121	1.017	0.000	77.8	54.6	37.13	3.52	29.9	5.47	10.15
7.51	0.218	4.111	1.020	0.000	77.8	54.6	37.12	3.55	29.9	6.29	10.19

Table 3-7

CYCLE DATA SUMMARY

MONTH = 1 DAY = 18 YEAR = 83 SITE AT EAST FREEDOM, PA. I.D. = 61

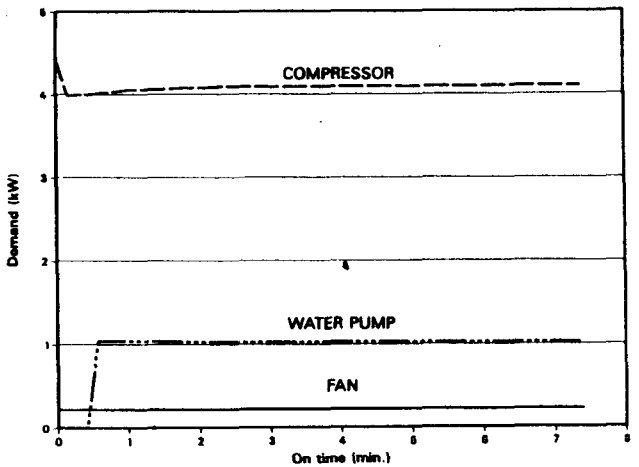
STARTING TIME IS 10.2776 MODE IS HT

RUNTIME IS 7.51 MINUTES

AVERAGE USAGE (WATTS) THIS CYCLE	PAN	216.	
	COMPRESSOR	4105.	
	RESIS. HEAT	0.	
	WATER PUMP	962.	(1018. WATTS WHILE RUNNING)
TOTAL CONSUMPTION (WH.) THIS CYCLE	PAN	27.	
	COMPRESSOR	514.	
	RESIS. HEAT	0.	
	SUM OF ABOVE	541.	
	WATER PUMP	120.	

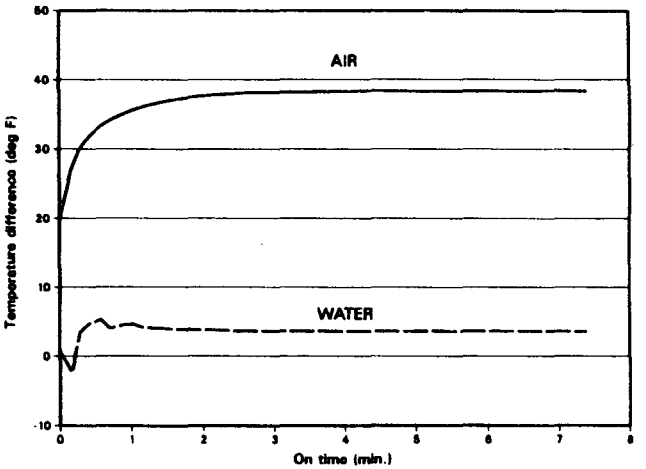
AVERAGE WATER FLOW	9.36 GPM.	
TOTAL WATER USAGE	70.3 GALLONS	
HEAT EXTRACTED FROM WATER	2095. BTU	611. WATTHOURS
AVERAGE AIR VELOCITY	7.35 FPS.	
AVERAGE RETURN AIR TEMP.	76.7 DEG.F.	
AVERAGE INLET WATER TEMP.	55.3 DEG.F.	
AVERAGE AIR TEMP. DIFF.	35.7 DEG.F.	
AVERAGE WATER TEMP. DIFF.	3.6 DEG.F.	
CAPACITY OF UNIT	31396.5 BTU/HR	9201.8 WATTS
TOTAL HEAT DELIVERED	3930.6 BTU.	1152.0 WATTHOURS
COEFFICENT OF PERFORMANCE	2.13	
PERFORMANCE FACTOR	2.13	

* - COEFFICENT OF PERFORMANCE = (PAN + COMPRESSOR + HEAT EXTRACTED FROM WATER) / (PAN + COMPRESSOR)
* - PERFORMANCE FACTOR = (PAN + COMPRESSOR + RES. HEAT + HEAT EXTRACTED FROM WATER) / (PAN + COMPRESSOR + RES. HEAT)



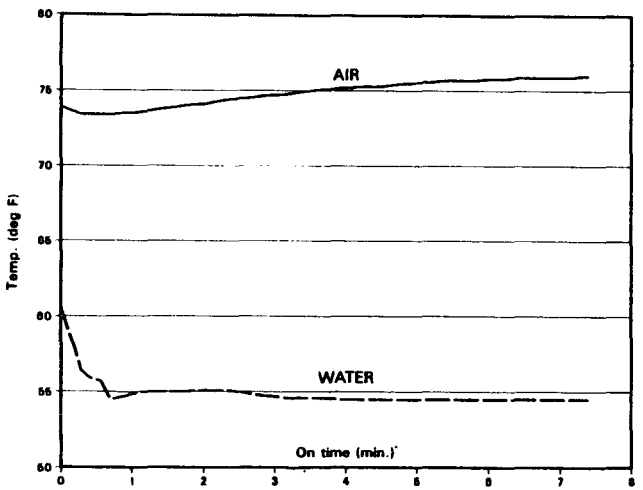
Typical demand for a cycle at East Freedom

Figure 3-33



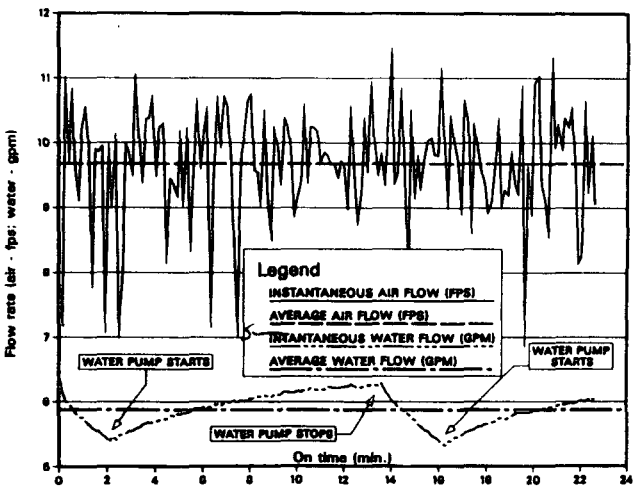
Differential temperatures of flows at East Freedom

Figure 3-34



Return air and water inlet temperatures for a cycle at East Freedom

Figure 3-35



Air and water flow for a cycle at Bedford

Figure 3-36

repressurizes the tank. This pattern is repeated a second time for the cycle shown in the Figure which is slightly over 22 minutes in duration.

The curves of instantaneous capacity and COP (Figures 3-37 and 3-38) are slightly influenced by the sawtooth pattern in water flow. Pressure drops in the storage tank until the pump turns on at about 2 minutes into the cycle, off at 13-1/2 minutes, and back on less than 3 minutes later. When the water pressure is above average, water flow is also. Probably due to a slightly improved water-side heat transfer coefficient, the capacity is above its average value, but when the water pressure is lower, the opposite occurs. The scale in Figures 3-37 and 3-38 should be noted. These changes due to water pressure cycling are less than 5% of the average values.

The curves of electrical energy usage are shown in Figure 3-39. Figures 3-40 and 3-41 show plots of temperature difference and inlet temperature of the air and water flows. These are very similar to the corresponding plots for East Freedom. However, the water inlet temperature does not have any significant indication of warmer water in the lines at the start of the cycle. This is probably due to the shorter stand-by periods (i.e. longer running times) which do not allow the water to remain stagnant in the lines long enough to be affected by ambient temperatures. Also, the heat pump at Bedford is in an unheated basement while the East Freedom is in a heated basement.

3.4.3 Cycling Losses

Due to the problem of accurately measuring air flow, as discussed above, it was not possible to distinguish cycling losses from the actual energy contributed to the air stream by the heat pump. That such losses can be significant is suggested by the work of Mei (2).

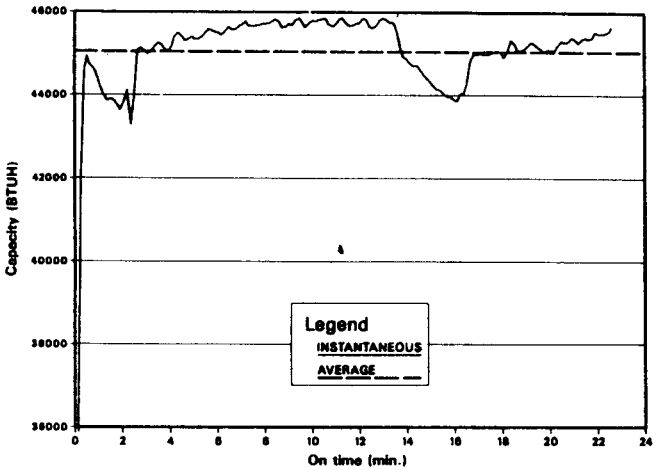
At East Freedom, cycling loss energy would probably still find its way into the heated space of the basement. At Bedford, the loss was to an unheated space. Since the approach of this report implicitly assumes all the energy extracted from the water and electricity into the heat pump heated the residences, the COP in heating at Bedford may be slightly lower than that calculated. But the economics of the unit in comparison with oil heating discussed below are still realistic.

3.5 ELECTRICAL LOAD CHARACTERISTICS

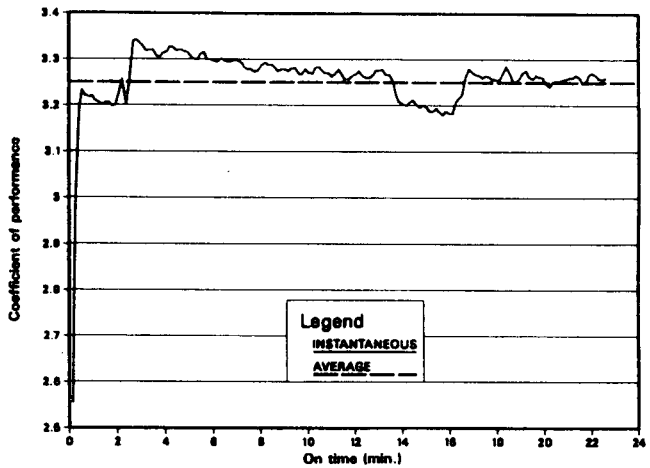
One question of interest to electrical utilities is how the installation of well-water-source heat pumps will influence the electrical load on their networks. Utilities do not want to encourage the addition of systems which will increase the electrical demand during their peak times. The well-water-source heat pump will help a winter peaking utility in this regard if it is reliable and is sized to carry the heating load under all conditions, or if the backup heat source for the system is not electrical resistance heat. The heat pumps at both sites were able to function without the requirement of backup energy during the 1982-83 heating season as long as the systems were working properly.

Table 3-8 shows data taken from the magnetic tape unit mounted on the watthour meter at each house. It can be seen that the maximum demand is fairly constant over the heating season. Review of the fifteen minute demand files show that the peak times do not necessarily correspond to the peak demand of the heat pump unit. Likewise, they do not always correspond to the coldest temperatures either.

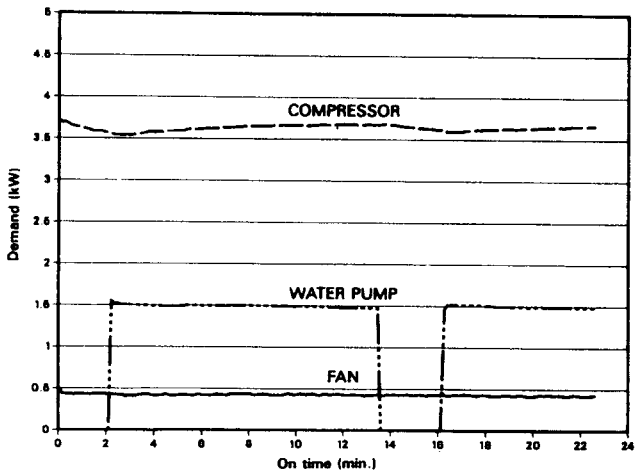
At Bedford, the complete month of February was surveyed and six days were found with the maximum demand between 10.0 and 11.5 kW. The hourly files were then studied for these days. On only one of these six days was the heat pump running above 80% of the time in the hour of peak demand. This was on February 6 with a peak demand of 10.8



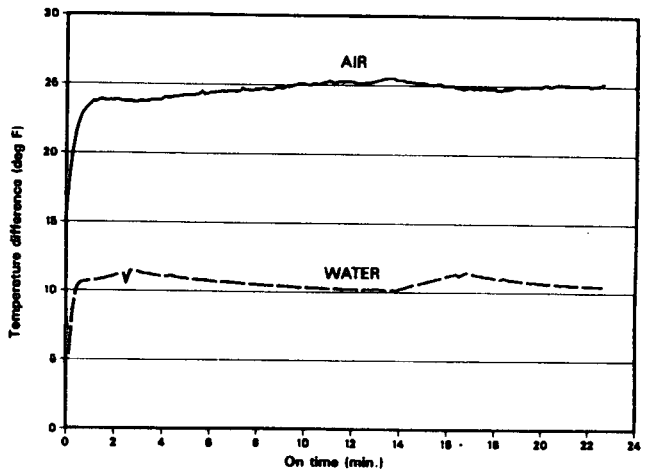
Capacity of unit for a cycle at Bedford
Figure 3-37



COP of unit for a cycle at Bedford
Figure 3-38



Typical demand for a cycle at Bedford
Figure 3-39



Differential temperatures of flows at Bedford
Figure 3-40

Table 3-8

ELECTRICAL DEMAND

East Freedom

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Day max. demand	18	17	22	19	28	3	4	23
Time max. demand	0745	1015	0800	1630	1445	0930	1545	1115
Max. demand, kW	11.5	11.9	9.1	10.6	9.3	10.1	10.7	11.2
Max. temp., peak day	57	48	33	16	46	53	38	71
Min. temp., peak day	25	14	21	1	12	23	31	46

Bedford

	FEB	MAR	APR	MAY
Day max. demand	5	28	18	18
Time max. demand	1215	1245	1115	1300
Max. demand, kW	13.6	12.0	11.6	10.0
Max. temp., peak day	24	38	33	63
Min. temp., peak day	10	26	20	28

Table 3-8m

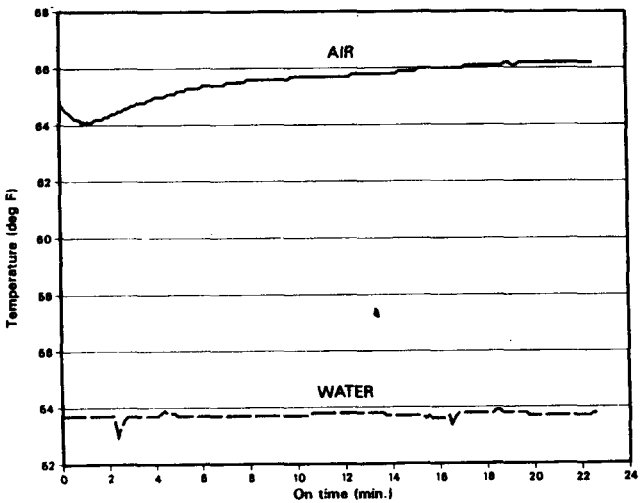
ELECTRICAL DEMAND
(METRIC)

East Freedom

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Day max. demand	18	17	22	19	28	3	4	23
Time max. demand	0745	1015	0800	1630	1445	0930	1545	1115
Max. demand, kW	11.5	11.9	9.1	10.6	9.3	10.1	10.7	11.2
Max. temp., peak day								
deg F	57	48	33	16	46	53	38	71
deg C	14	9	1	-9	8	12	3	22
Min. temp., peak day,								
deg F	25	14	21	1	12	23	31	46
deg C	-4	-10	-6	-17	-11	-5	-1	8

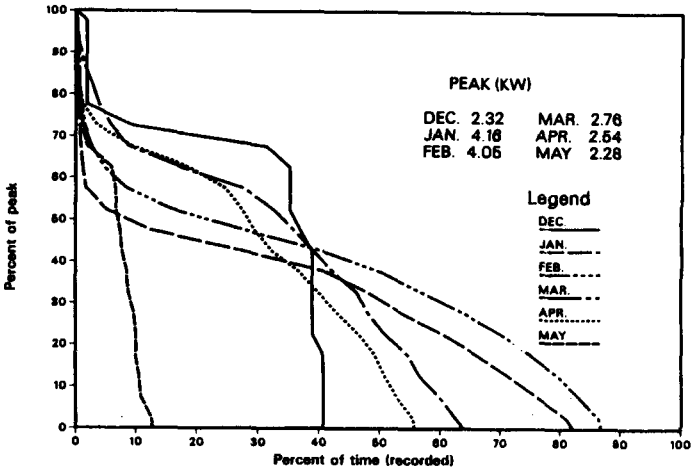
BEDFORD

	FEB	MAR	APR	MAY
Day max. demand	5	28	18	18
Time max. demand	1215	1245	1115	1300
Max. demand, kW	13.6	12.0	11.6	10.0
Max. temp., peak day,				
deg F	24	38	33	63
deg C	-4	3	1	17
Min. temp., peak day,				
deg F	10	26	20	28
deg C	-12	-3	-7	-2



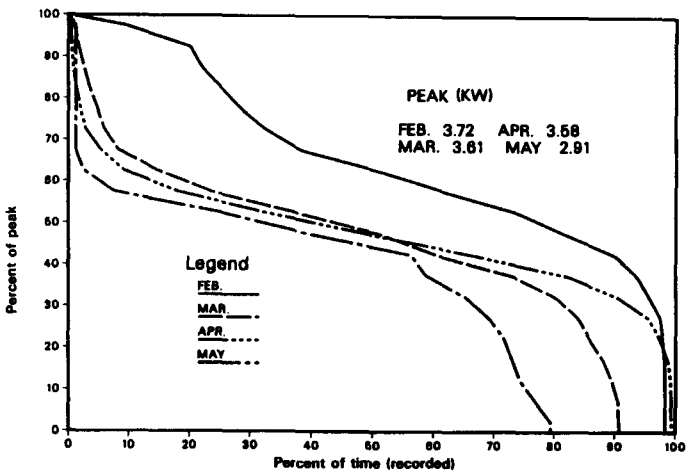
Return air and water inlet temperatures for a cycle at Bedford

Figure 3-41



15 min. compressor demand heating season 82-83 East Freedom

Figure 3-42



15 min. compressor demand heating season 82-83 Bedford

Figure 3-43

kW. Three other days of the six had demands between 10.7 and 11.5. The heat pump was running nearly 50% of the time in the hours of maximum demand for these days. The other two days of the sample had the heat pump running well below 50% during the time of peak demand. With a connected load of other appliances at the Bedford site of well over 30 KW, these uses determined the peak demand.

Figures 3-42 and 3-43 show the distribution of the compressor 15-minute demand at the two sites as a percentage of the recorded data. At East Freedom, high demand occurs for only a small fraction of the fifteen minute periods, less than 5% of the time.

Then, there is a flat distribution of moderate demand which finally falls to zero either abruptly or gradually depending on mild vs. extreme weather conditions, respectively. It can be seen that the maximum compressor demand is significantly higher in January and February. The data start in December for this site because this was the period when valid files of fifteen minute demand became available.

Figure 3-43 shows the same information at the Bedford site. The February profile shows a much longer operation near peak demand due to the higher heating loads compared to the capacity of that heat pump at this site.

3.6 SUMMARY PERFORMANCE RESULTS

Test data was collected and reduced, and the results presented addressing the questions of the feasibility and performance of residential groundwater heat pumps, their efficiency over short and long terms and their demand on electrical supply systems.

REFERENCES

1. ASHRAE Handbook 1981 Fundamentals. Atlanta: The American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1981, Chapter 28, "Energy Estimating Methods".

2. V.C. Mei. "Laboratory Test of a Residential Low-Temperature Water Source Heat Pump." ASHRAE Transactions 1983, V. 83, Pt. 2A & B.

Section 4

CONCLUSIONS

4.1 INTRODUCTION

The objectives of the program were to prove the technical feasibility of groundwater source heat pumps in the northeast, evaluate their performance over an extended period of time, consider the effects on utility loads, and compare the economics of these to other residential space heating concepts.

4.2 TECHNICAL FEASIBILITY & PERFORMANCE OVER TIME

In climates of about 6,000 degree-days, electric water-source heat pumps using deep (more than 50 feet (15 m) wells will operate reliably at efficiencies adequate to assure a payback, over oil heating, in a retrofit or new residence of less than five years. With well water of about 54 deg F(12 deg C), COP's of 3.0 can be expected.

Unlike air-source heat pumps, the capacity and efficiency of these units are unaffected by outside air temperature.

The heat pump selected should have capacity adequate to heat the house without supplementary heat. If backup heat is required, it should be nonelectric, such as fossil fuel.

Care must be taken in selecting a groundwater heat pump that is relatively insensitive to off-design air flow. In a retrofit, it may not be practical to increase air flow, due to duct sizing and the possibility of irritating drafts.

The non-reversing unit was easily cleaned on the water side. Aside from this, air and water filter replacement or cleaning of either unit are the only maintenance that can and should be performed by the homeowner.

When a failure occurs, it is critical that trained mechanics be readily available. Until there are many units installed, such expertise will be hard to come by. Owners may be faced with the prospect of waiting several days until the mechanic arrives, as was experienced during the test period when the non-reversing units failed.

There must be an adequate water source, and a means of disposal. A substantial volume of water is required in a heating season, 500,000 to 750,000 gallons (1,900 to 2,800 m^3) for the typical residence. Wells must be tested at the water volume flow rate recommended by the manufacturer, typically 4 to 9 gpm (0.3 to 0.6 l/s).

With the data available, it could not be determined whether efficiency is affected by the application of a water-source heat pump with capacity substantially greater than required. Such oversizing certainly avoids the significant threat of disproportionate demand increases during cold weather extremes that would be caused by the use of backup resistance heat, with its lower efficiency.

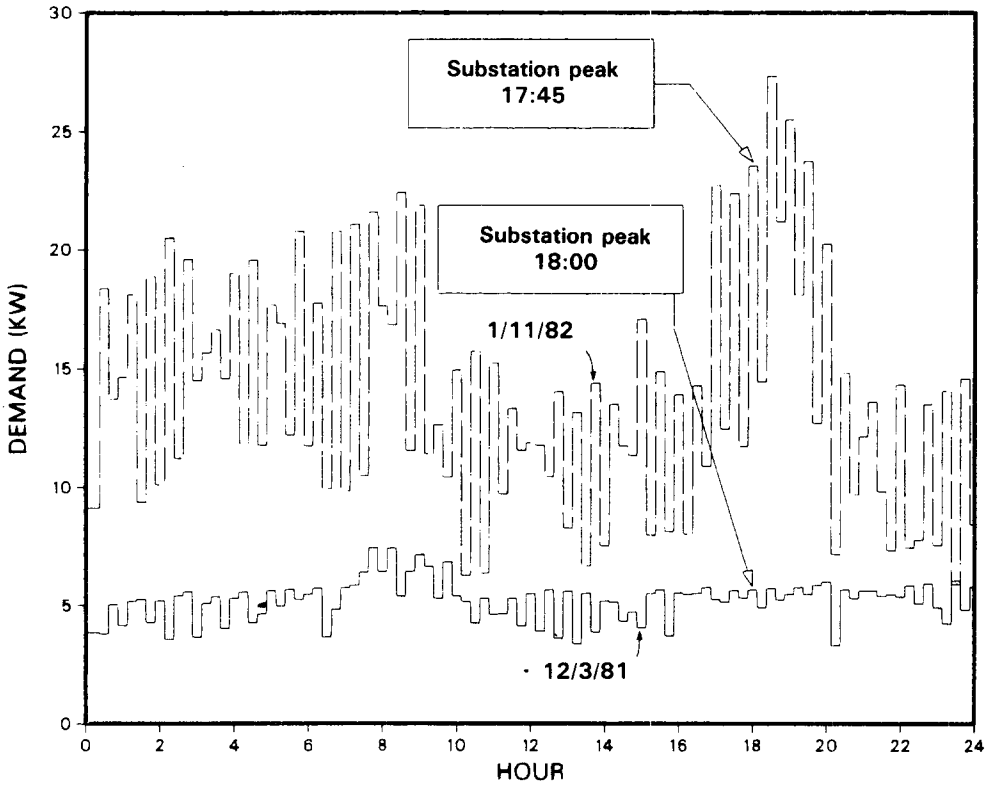
As reported, an industry-consensus standard is in place, but certification is not underway as of this writing. If and when this happens, the buyer will be able to make a more cost-effective decision.

Many sites may not have groundwater available at the rate recommended by manufacturers. And in retrofits, adequate air flow may not be possible. Manufacturers' literature should, therefore, reflect this with a statement of minimum tolerable flows and ARI-quality data on performance down to that point.

4.3 EFFECTS ON UTILITY LOADS

We now wish to explore the impact of a proliferation of groundwater heat pumps on capacity utilization and energy sales, and compare these systems to other space heating approaches.

Figure 4-1, entitled "Fifteen Minute Demand" compares the demand traces for the Bedford test house on two special days during 1981-82 heating season: the days of two months when the peak demand occurred at the Bedford substation, the substation supplying that home. During the December substation peak, the heat pump had adequate capacity to heat the home without supplemental heat. During the January substation peak, it was necessary to provide extra heating - here a resistance furnace. The choppiness of the January trace is caused by the cycling of the electric furnace (from off, to 28.8 kW, to off), and alternating coincidence and not with the regular 15-minute recording intervals.



15 Min. Demand for Total House
Bedford

Figure 4-1

If we smooth the choppiness of demand of this one house for the diversity of many residences, we can generalize by viewing these traces as suggestive of the demand signature of a large population of residences connected to such a substation. The backup system appears to have produced the high demand shown, typically three times as high as December even though the home heating load was about the same. While the need for supplemental capacity was caused by a malfunctioning heat pump, the curve shows the penalties paid for using electric resistance heat to supplement that provided by an under-sized heat pump.

In comparison to other residential space heating approaches, how desirable is a groundwater heat pump heating system, in terms of utility revenue and costs? The last graphs, Figures 4-2 and 4-3, perform such a comparison. Taking a house with thermal properties approximately those of the Bedford site, for each of the heating alternatives considered, each bar represents the kilowatt hours that would be consumed by the given system in a year. Compared are an oil furnace, a water-source heat pump of adequate capacity to heat the house down to the design point, an air-source heat pump that uses a resistance furnace (or baseboard, radiant, alcove, etc.) as backup, allowing for the decreasing capacity of an air-source heat pump with decreasing outside air temperature, and a simple "all-electric (resistance) home."

Figure 4-3 is a similar presentation of the system revenue factor based on the sum of the monthly 15 minute demand peaks of each heating approach. The bars could be treated as a reflection of kWh of sales or residential revenue potential per unit of capacity a winter-peaking utility must have available at those peak times. Revenue factor is defined as follows:

$$\text{Revenue factor} = \frac{\text{Annual electricity sales (kWh)}}{\sum_{n=1}^{12} 730 \times \text{MSP}},$$

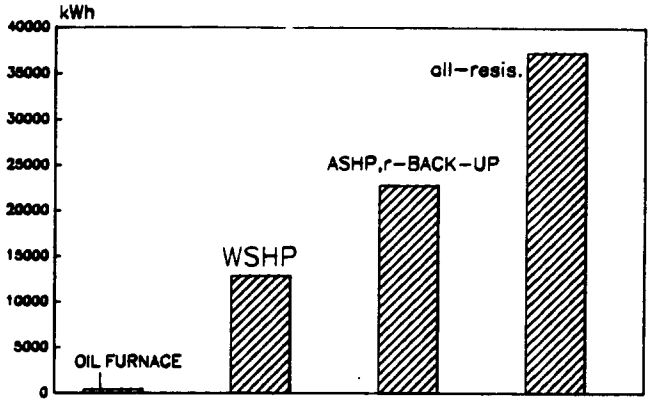
where MSP is the maximum monthly 15 minute demand of the heating system in kW (coincident with substation peak) and 730 is the average number of hours per month.

In the left-hand side of Figure 4-3, the first bar represents the results for a common installation of a home heated by an under-sized water-source heat pump ("WSHP") with supplemental resistance ("r BACK-UP") heat at low outside air temperature. The next is similar, but for an air-source heat pump ("ASHP"). Its productivity is better than the first as it was assumed a significant amount of energy would be used for summer vapor-compression air conditioning.

The next bar is the oil-fired forced air baseline system, and then the WSHP adequately sized to deliver heating under most conditions without supplementary heat. The next is the all-resistance system.

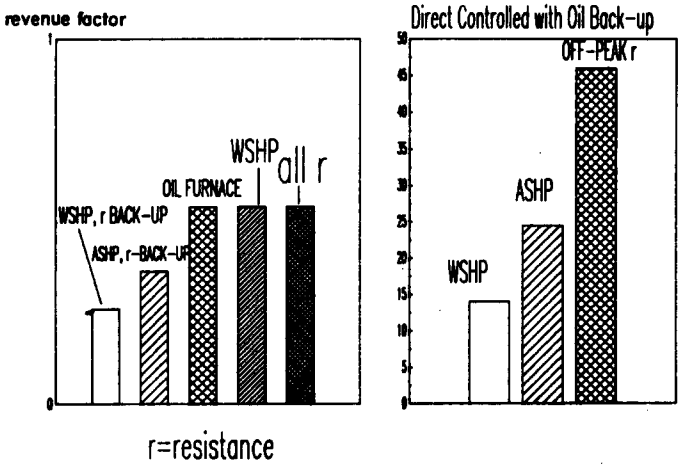
The heating load on the residence increases with decreasing outside air temperature. Thus the consumption of an electrically driven space heating scheme - heat pump or resistance - must increase. This represents a load management resource: an electricity-using primary heat source of resistance or add-on heat pump, in conjunction with a backup fossil fuel heater.

The three bars in the right-hand side of Figure 4-3 represent groundwater, air-source heat pumps, and resistance heat as primary heating systems, respectively, with oil backup. The backup oil heating system would be used for only a small portion of the total seasonal heating, on the order of less than 5%. It would be called upon by command from a central control point as in a direct control application or triggered by low outside air temperatures transmitted to a relay to suppress



Annual Sales

Figure 4-2



Revenue productivity potential

Figure 4-3

primary heating (i.e., restricted mode operation). In comparison to the primary system, the electric demand of the backup system is negligible, of the order of 250 diversified watts to operate the oil burner and fan. Note the scale difference of the two boxes: the first is 0 to 1, the second 0 to 50! It can be seen that, when controlled, these systems create a highly desirable combination of substantial energy use through the heating season and very little demand at critical times. Thus, the utility can maximize its energy sales while minimizing its investment in generation capacity or use of inefficient peakers for generation.

The value of the revenue factor index will vary from utility to utility. Current economic conditions, relative fuel costs and availability, power pool economics, and current and planned generation capacity and mix will shape each utility's unique strategy.

4.4 ECONOMIC PERFORMANCE

The owners of the Bedford home are saving about $683 a year in fuel costs in converting from oil heat to the groundwater heat pump. Based on an estimated currently installed cost of the heating system of $2,850 (excluding the separate cooling coil), the payback period for the groundwater heat pump system is less than four years. These figures were determined by assuming a cost of oil of $1.20 per gallon and an incremental electricity cost of 7.5¢/kWh. (The typical heating season was estimated at 6,000 degree-days to pro-rate actual heat pump consumption for the reported period containing 2,900 degree days. The seasonal efficiency of the oil furnace was assumed to be 60%.)

If the owners were faced with the choice of replacing a failed furnace and burner with a modern one, even with the higher seasonal efficiency that could be expected of modern burners versus installing a groundwater heat pump, payback would be about three years. This is based on an estimated installed cost for the new oil furnace of $1,650 and a 75% seasonal efficiency.

For a new residence, even allowing an improved seasonal efficiency of a new oil furnace of 75%, the payback would still be less than four years.

With the low COP at East Freedom, compared to oil the owners are only saving $62 annually. The forty-year-plus payback is not practical. This assumes an oil burner was already installed there.

In conclusion, two rural residences in the northeastern United States were retrofitted with groundwater heat pumps. The results of testing these devices indicate that with care in selection and installation, such heat pumps are not only feasible but highly competitive in comparison to oil space heat. Water supply must be ample and an appropriate means of disposition provided.

Appendix A

ADDITIONAL DATA

Components of Heating Energy and Heating Degree Days
October 1982 (East Freedom) A-2

Components of Heating Energy and Heating Degree Days
November 1982 (East Freedom) A-2

Components of Heating Energy and Heating Degree Days
December 1982 (East Freedom) A-2

Components of Heating Energy and Heating Degree Days
February 1983 (East Freedom) A-2

Components of Heating Energy and Heating Degree Days
March 1983 (East Freedom) A-3

Components of Heating Energy and Heating Degree Days
April 1983 (East Freedom) A-3

Components of Heating Energy and Heating Degree Days
May 1983 (East Freedom) A-3

Components of Heating Energy and Heating Degree Days
March 1983 (Bedford) A-3

Components of Heating Energy and Heating Degree Days
April 1983 (Bedford) A-4

Components of Heating Energy and Heating Degree Days
May 1983 (Bedford) A-4

Compressor Electrical Energy Consumption Heating Season
1982-1983 (East Freedom) A-4

Fan Electrical Energy Consumption Heating Season
1982-1983 (East Freedom) A-4

Energy Extracted from Water Heating Season
1982-1983 (East Freedom) A-5

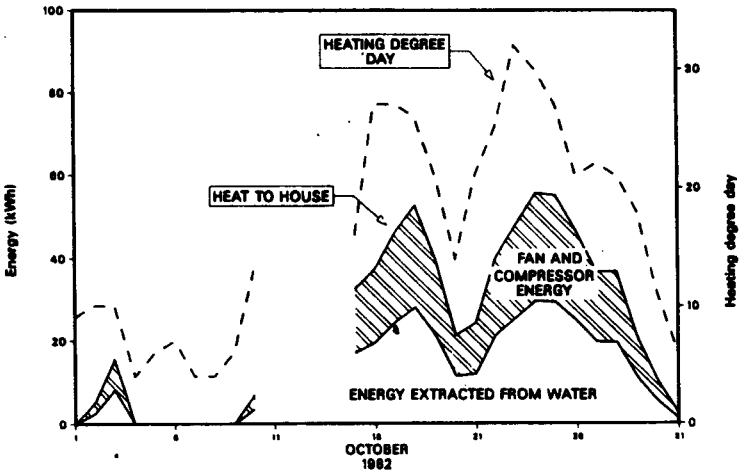
Heat Pump Water Consumption Heating Season
1982-1983 (East Freedom) A-5

Compressor Electrical Energy Consumption Heating Season
1982-1983 (Bedford) A-5

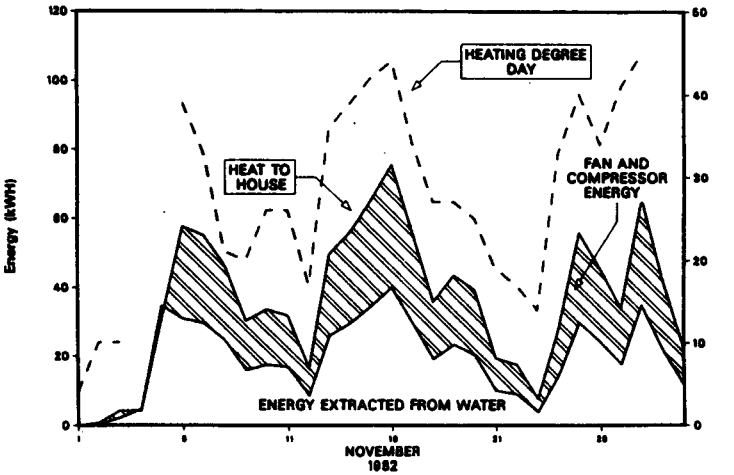
Fan Electrical Energy Consumption Heating Season
1982-1983 (Bedford) A-5

Energy Extracted from Water Heating Season 82-83
(Bedford) A-6

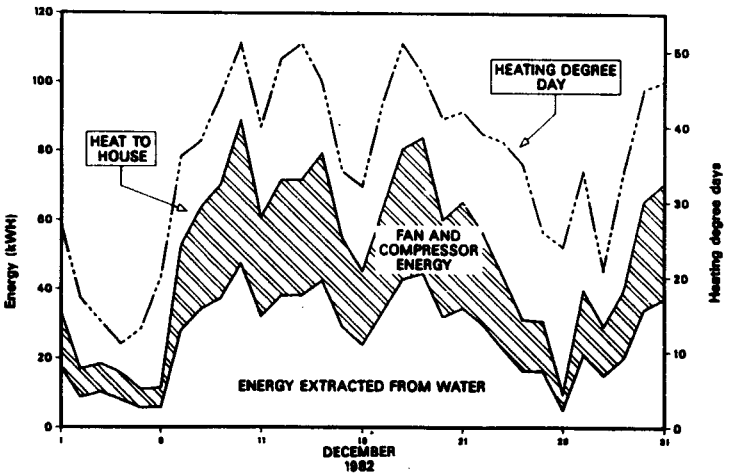
Heat Pump Water Consumption Heating Season 82-83
(Bedford) A-6



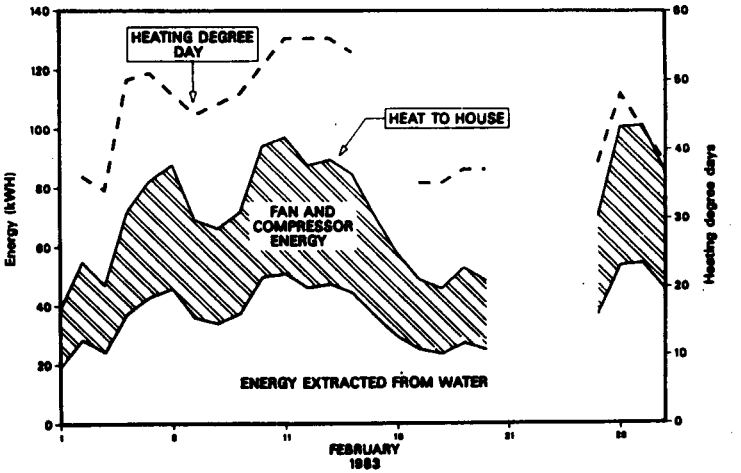
Components of heating energy & heating degree days Oct. 1982 East Freedom



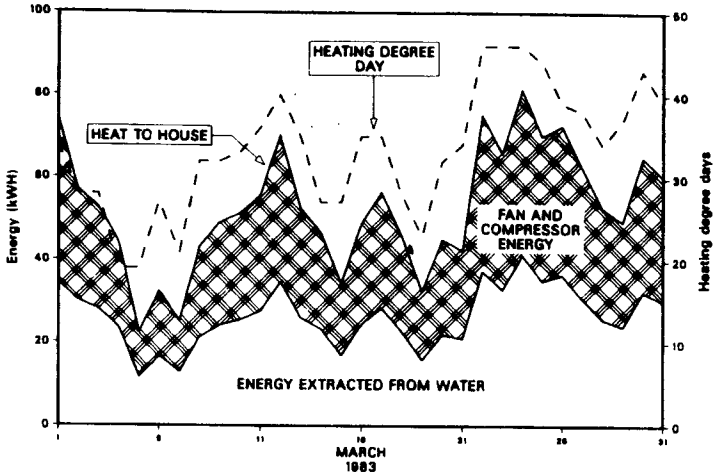
Components of heating energy & heating degree days Nov. 1982 East Freedom



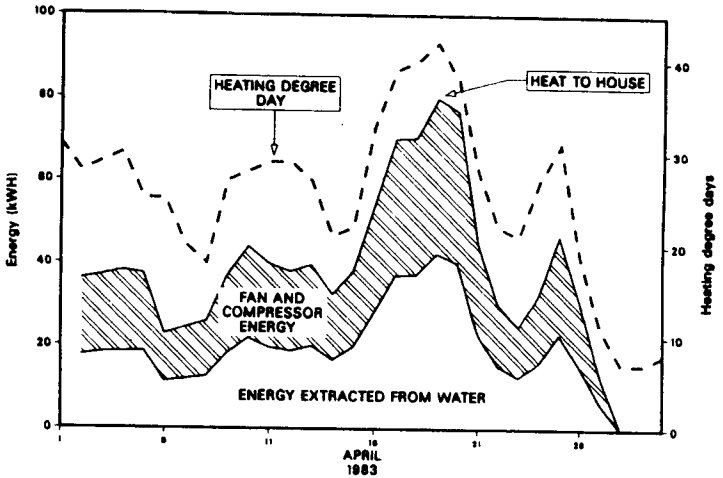
Components of heating energy & heating degree days Dec. 1982 East Freedom



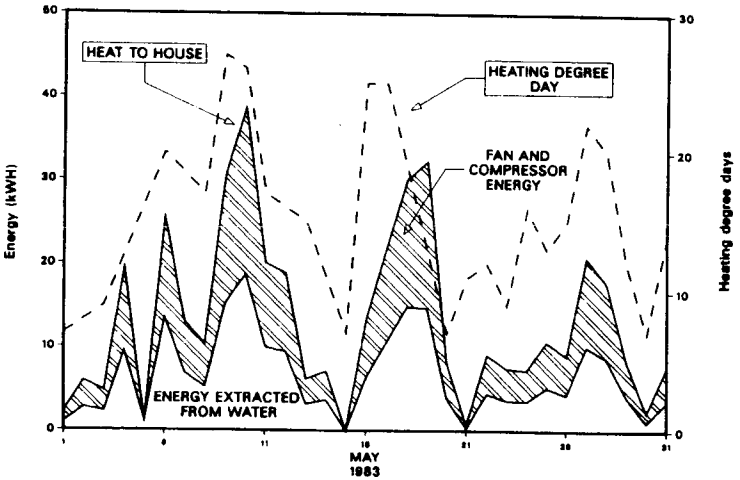
Components of heating energy & heating degree days Feb. 1983 East Freedom



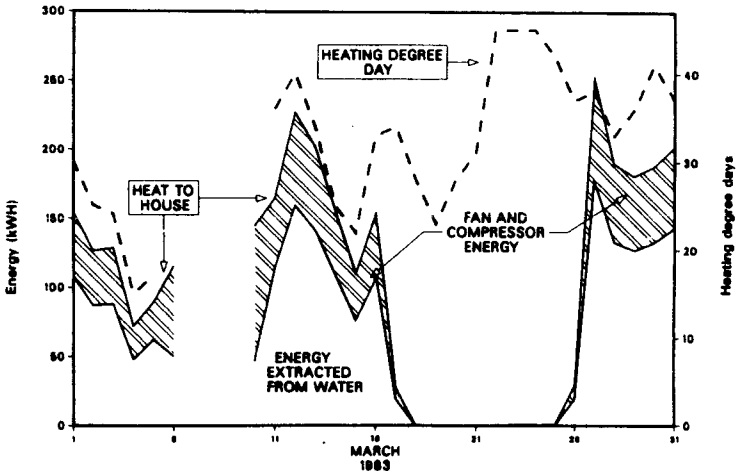
Components of heating energy & heating degree days Mar. 1983 East Freedom



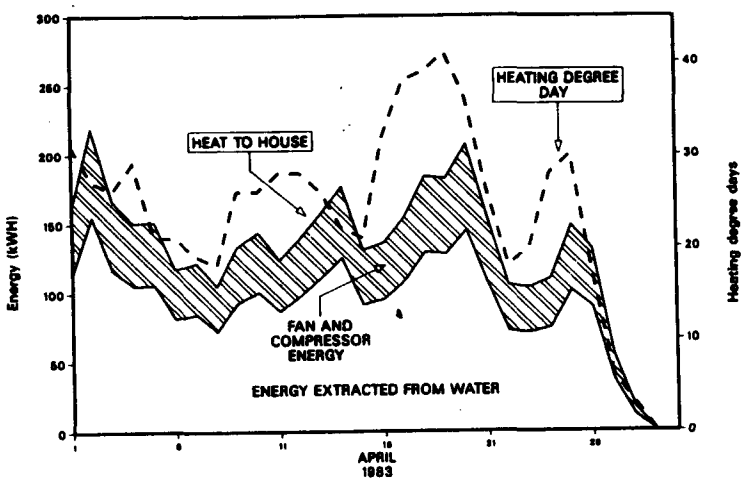
Components of heating energy & heating degree days Apr. 1983 East Freedom



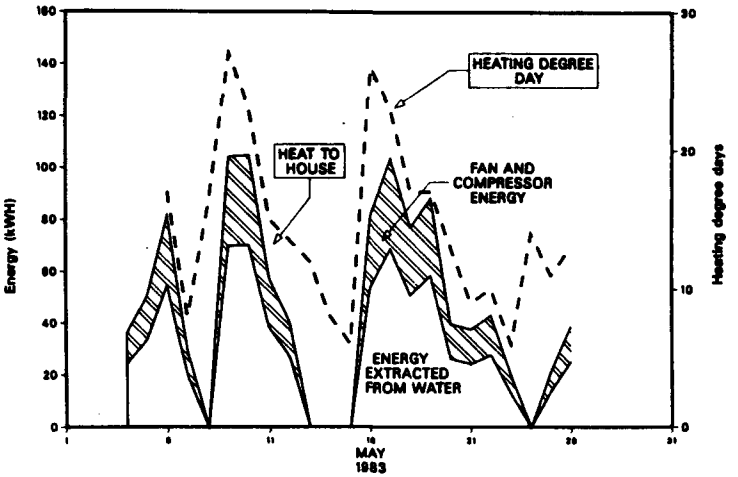
Components of heating energy & heating degree days May 1983 East Freedom



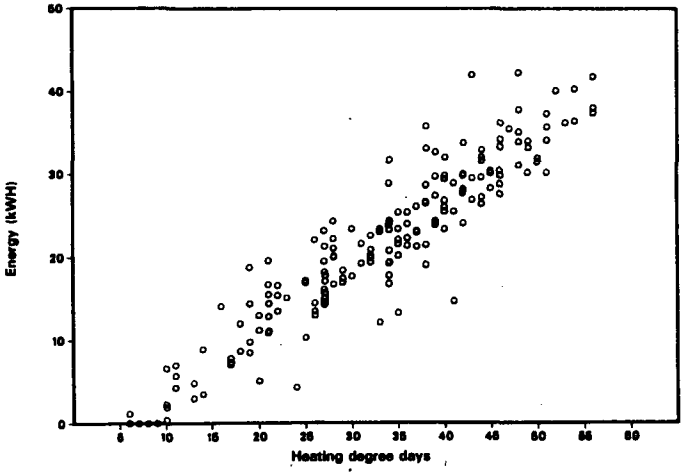
Components of heating energy & heating degree days Mar. 1983 Bedford



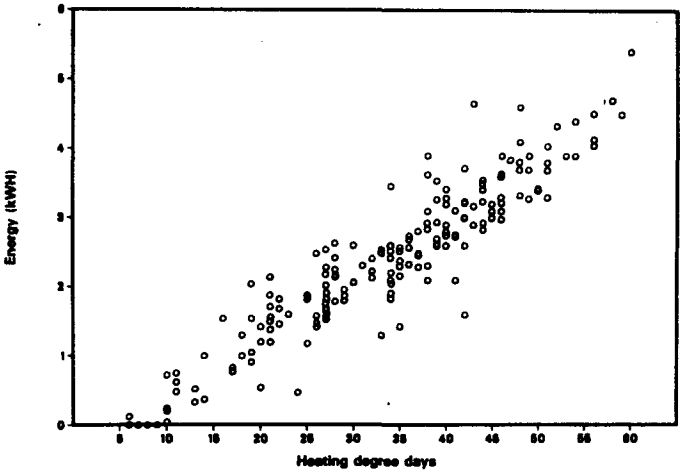
Components of heating energy & heating degree days Apr. 1983 Bedford



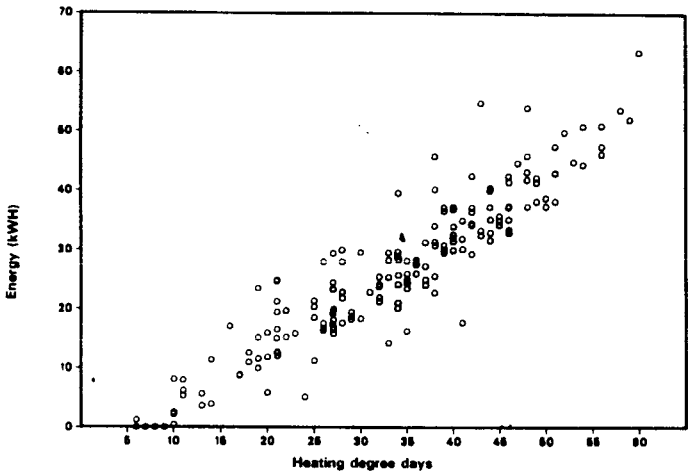
Components of heating energy & heating degree days May 1983 Bedford



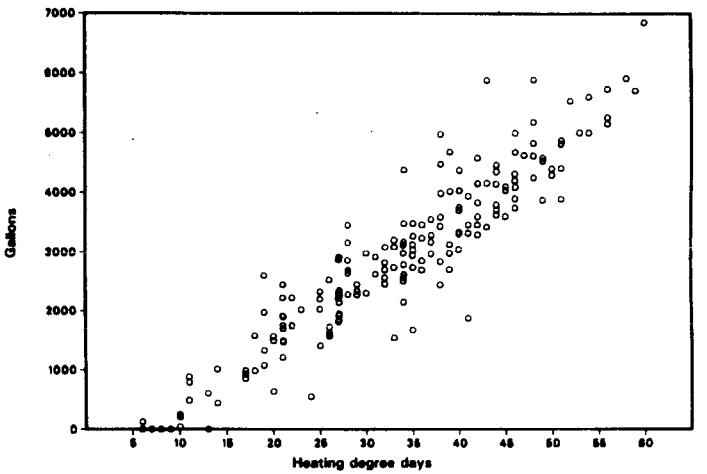
Compressor electrical energy consumption heating season 82-83 East Freedom



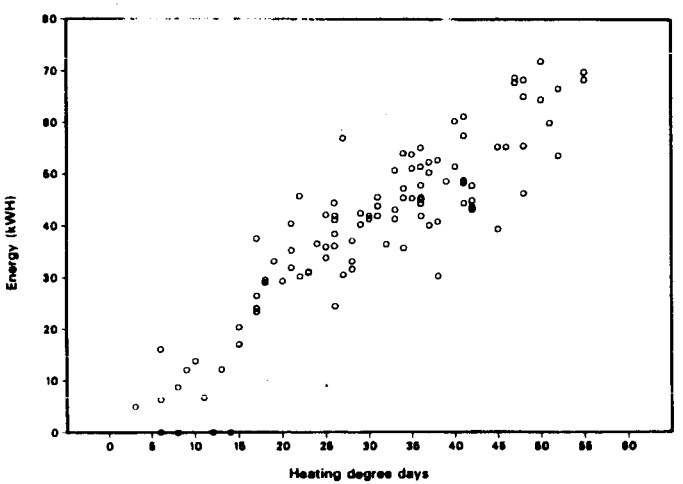
Fan electrical energy consumption heating season 82-83 East Freedom



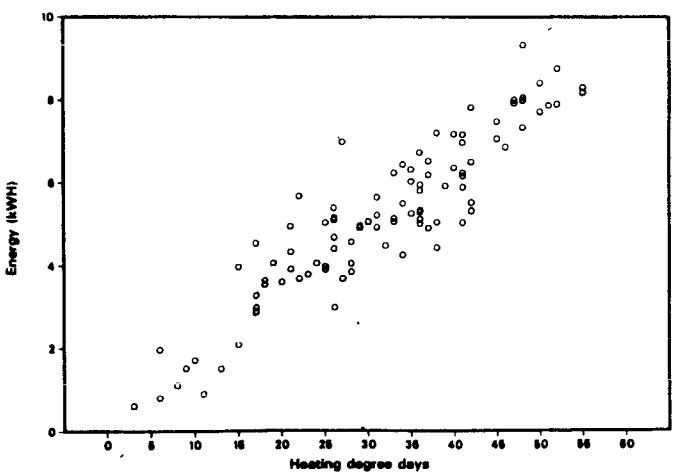
Energy extracted from water
heating season 82-83 East Freedom



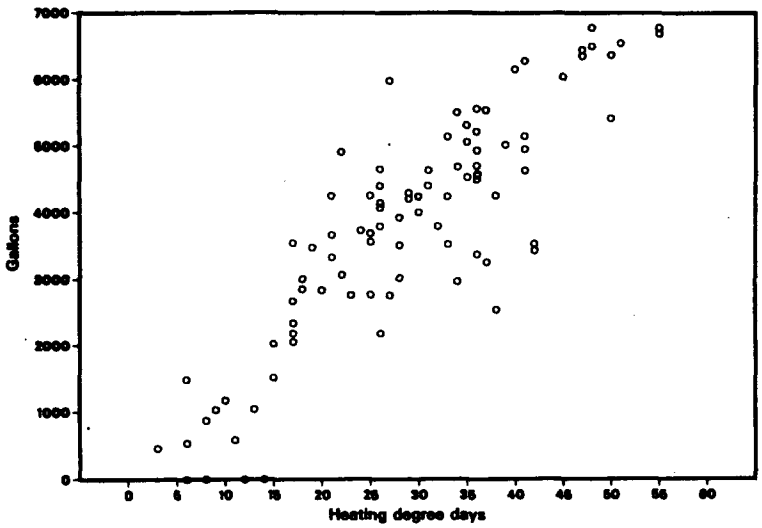
Heat pump water consumption
heating season 82-83 East Freedom



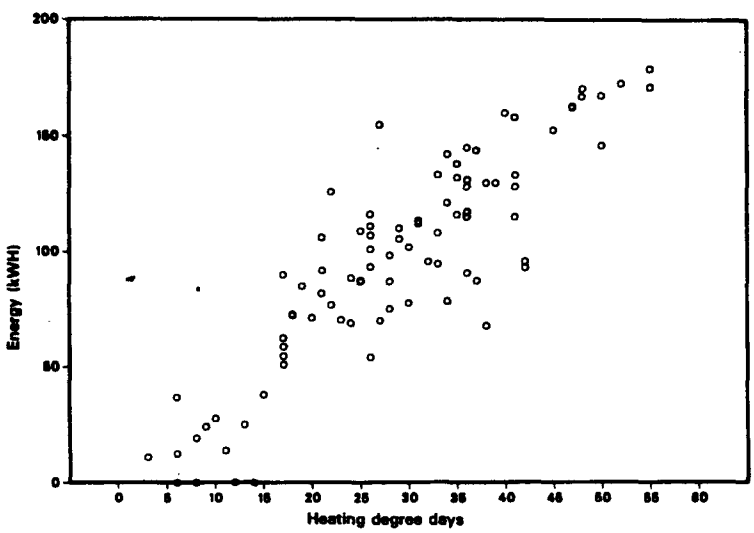
Compressor electrical energy consumption
heating season 82-83 Bedford



Fan electrical energy consumption
heating season 82-83 Bedford



Heat pump water consumption
heating season 82-83 Bedford



Energy extracted from water
heating season 82-83 Bedford

Appendix B

GLOSSARY

ASHP - Air Source Heat Pump. - Here an air-to-air electrically-driven vapor compression refrigeration system capable of providing heat to a structure by extracting heat from the outside air environment.

GWHP - Groundwater Source Heat Pump - Similar to ASHP but the heat is extracted from water supplied from a deep well.

Deep Well - a water well deeper than 50 feet. Water from such sources is usually the same temperature within a degree F, year round, at approximately the average annual temperature of that region.

ARI - Air Conditioning and Refrigeration Institute - The industry-sponsored nonprofit organization serving as the source of standardized test results of HVAC devices, including heat pumps.

American Association of Air Conditioning Contractors of America - publisher of "Manual J." "Manual J" provides widely-accepted, straightforward techniques for estimating the design load on residences, both in heating and cooling.

BTUH - a unit of power, BTU's per hour.

MBTUH - a thousand BTU's per hour.

COP - Coefficient of Performance. A measure of the efficiency of the heat pump, expressed as the dimensionless ratio of the heating (or cooling) energy delivered by the heat pump (Q) divided by the work (in this report the electric energy (W)) going into the process, including compressor and fan. In a water source heat pump, the work of pumping water is sometimes included.

$$COP = Q/W = (W+Qw)/w = 1 + Qw/w$$

where Qw is the heat extracted from the groundwater.

Design Load - The load determined by Manual J procedures. Based on an inventory of the physical properties of the residence, and regional climate.

Load at Design Temperature - for the purposes of this report, the load on the house observed at a design temperature, here 0 deg F.

Equivalent Static Head Conversion Factor - converts a given total gallons of water compressed a specified head in feet to electric energy in kWh; 0.000003142 kWh/gal-ft.

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