PERFORMANCE COMPARISON OF AIR-COUPLED AND GROUND-COUPLED HEAT PUMP SYSTEMS

By

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Bachelor of Engineering

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1980

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE

MAY, 1984

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Institution: Oklahoma State University

Location: Stillwater, Oklahoma

Title of Study: PERFORMANCE COMPARISON OF AIR-COUPLED AND GROUND-COUPLED HEAT PUMP SYSTEMS

Pages in Study: 93   Candidate for Degree of Master of Science

Major Field: Mechanical Engineering

Scope and Method of Study: The primary objective of this study was to compare the heating and cooling performance of air-coupled and ground-coupled heat pump installations. Air-coupled and ground-coupled heat pump systems were installed in two identical north facing houses on adjacent lots in Perkins,Oklahoma. Outdoor and indoor environmental conditions ,HVAC thermal and mechanical performances,and electric power consuption were measured every fifteen minutes for a period of one year(April,1982 to March,1983). Transient heating and cooling load demand of the occupied space in response to the external weather conditions were simulated by a computer model based on the ASHRAE algorithm.Energy consumption and performance of the environmental control system were simulated for both systems.

Findings and conclusions : The winter and summer simulations of the air-coupled and ground-coupled heat pump systems were performed for one year.The results of these simulation models yeilded the following information:

1. The building thermal load and system simulation models gave very good results in predicting the HVAC energy demand, closely following the path of the measured values.

2. The ground-coupled heat pump system showed a superiority to the air-coupled heat pump system by reducing the HVAC demand during the critical peak demand periods of both winter and summer. The energy savings were approximately 29 % of the yearly total HVAC consumption.

3. The Freidrich ground-coupled heat pump has a better manufacturer's rated performance characteristic than Commandaire ground-coupled heat pump and Carrier air-coupld heat pump systems and could apparently provide performance superior to that demonstrated by the units used in the project.

ADVISER'S APPROVAL Gerald D Parker

PERFORMANCE COMPARISON OF AIR-COUPLED
AND GROUND-COUPLED HEAT PUMP
SYSTEMS

Thesis Approved:

Thesis Adviser

Dean of Graduate College

ACKNOWLEDGMENTS

I wish to express my deepest appreciation and thanks to my adviser Dr.Jerald D.Parker for his execellent guidance, Patience, and understanding throughout this study. I would also like to extend my appreciation to Drs.Faye McQuistion, John Wiebelt, Ghajar and the Mechanical and Aerospace Engineering Department of Oklahoma State University for their help and co-operation.

A special sincere appreciation to my parents,and my brothers for their sacrifice, encouragement, and support throughout my studies.

Many thanks to all of my colleagues for their inspiration and suggestions: Jeffrey P. Harris, Shrikant Mukund Joshi, Richard Nelson, and Steve Kavanaugh.

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CHAPTER I

INTRODUCTION

In the early 1970's, people had to face the fact that the natural resources which were consumed at a prodigious rate and upon which our civilization had depended were no longer plentiful. The oil embargo of 1973 and subsequent escalation in fuel prices helped the recognition of the need to conserve enery resources. These events resulted in increased attention towards development and acceptance of energy conserving systems which use energy resources more efficiently. The fact that more than one-quarter of the total energy consumption in the United States is used for residential and commercial space heating,cooling and water heating diverted the researchers towards the study of more efficient heating and cooling equipment.

The heat pump has been attracting attention as an efficient, economical alternative to conventional heating and cooling systems. This is because, of all the conventional heating systems available today, it alone can deliver more energy in the form of heat than it takes to operate, and it can to perform the dual functions of heating and cooling with ths same equipment.

The first-cost differential for total electric heat pump systems compared to other types of heating and cooling systems has narrowed, because of improved designs and the desirability of air conditioning for comfort that is year-round.

Basically, a heat pump is a device that pumps heat from a relatively cool area to a warmer area. air-coupled heat pump in the cooling mode works like an ordinary air conditioner, by extracting heat from inside a building and pumping it outdoors. During cold weather, a heat pump can reverse itself to absorb heat from the air outdoors and transfer it inside to heat the air indoors.

Air-coupled heat pumps are the most commonly used hest pumps. The air-coupled heat pump has been in market for quite some time; air-coupled heat pump installers today make better applications and installations because of knowledge gained from earlier heat pump installations; manufacturers have developed heat pumps with better performance characteristics and reliability; and most importantly, air is universally available as a heat source/sink.

The air-coupled heat pump system efficiency is dependent on the ambient temperatures. The heat pump capacity and coefficient of performance decrease as the outdoor ambient temperature decreases in the heating mode. This is clearly shown in Figure 1 which is a plot of heat pump capacity and heating demand of a commercial heat pump unit as a function of ambient temperature. During periods of low ambient temperatures the air-coupled heat pumps were usually shut off. This requires the air-coupled heat pump to have backup heat-

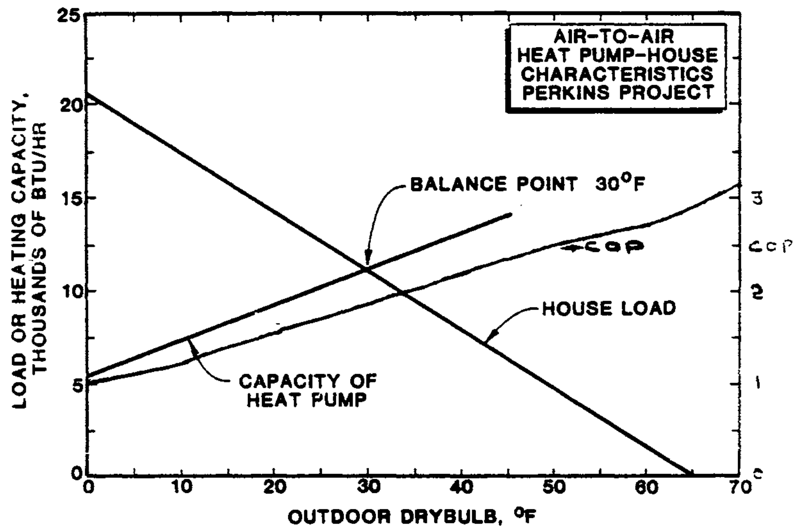


Figure 1. Air Coupled Heat Pump Characteristics

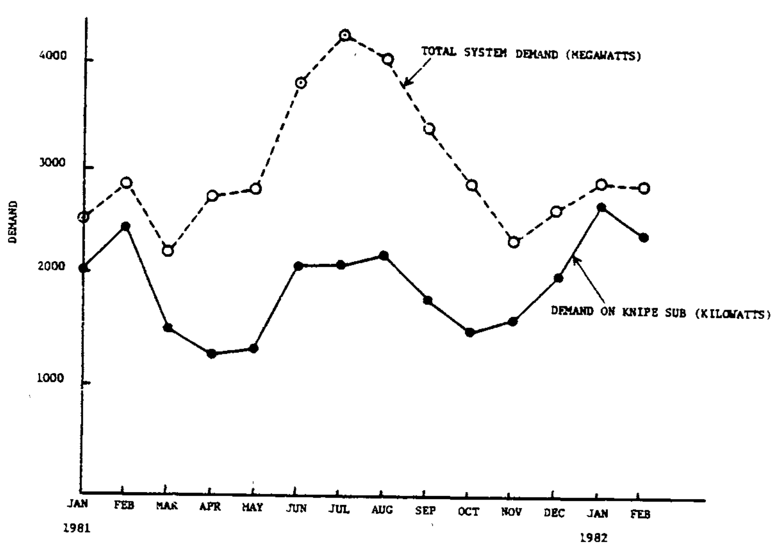


Figure 2. Peak Demands on OG&E System and on Knipe Substation

ing (usually electric resistance) to carry the heating load. The use of electric heat backup and inefficient heat pump operations present winter peaking problems to some utility companies. As these heavy peak loads occur for a relatively short duration, the incresed reserve power production capacity remains idle for most of the time in the year. This is clearly indicated in Figure 2 which shows the Knipe sub-station demand in comparison to the total OG&E system demfor the year 1981 and Figure 3 shows the system demand for the peak day July 23, 1981.

The large capital investments in power producing equipment to meet peak demands has forced the utility companies to find a solution to moderate the peak demand, encouraging research studies in more efficient heat pump systems and stable sources of low grade heat.

One heat source/sink that recently has received attention is the earth. The earth temperature varies with latitude, weather conditions, altitude, landscaping soil properties, rainfall and other properties. But at a sufficient depth, the ground retains a relatively uniform temperature throughout the year. Figure 4 shows the approximate temperature of water from a well at depths of 50 to 150 feet. A considerable area of the U.S. has a ground temperature in excess of 60 degrees Fahrenheit. Collins (1) states that at these depths the seasonal variations is not more than one degree Fahrenheit. This makes the ground an ideal heat source/sink for the heat pump and promises improved COP of

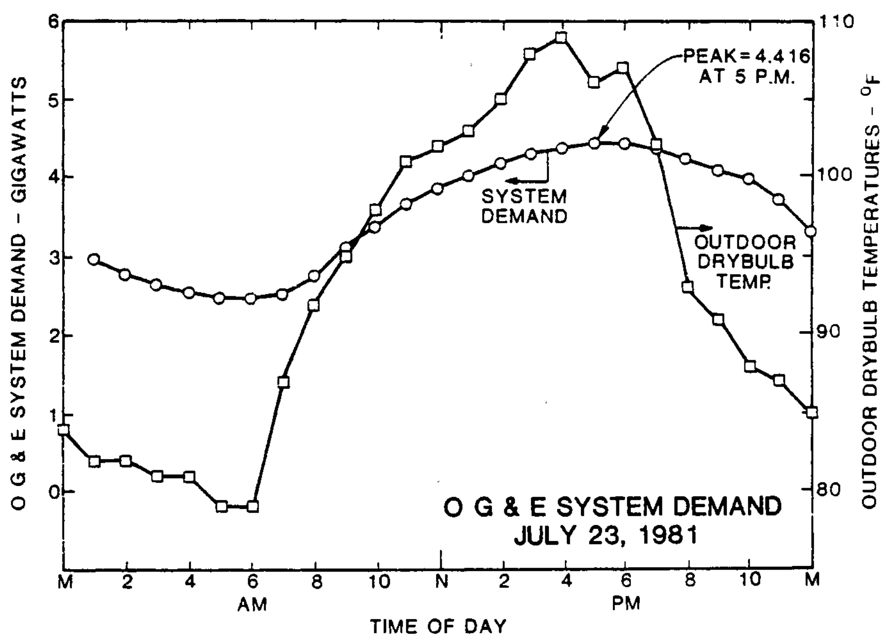


Figure 3. OG&E System Demand and Perkins Outdoor Temperature on July 23, 1981

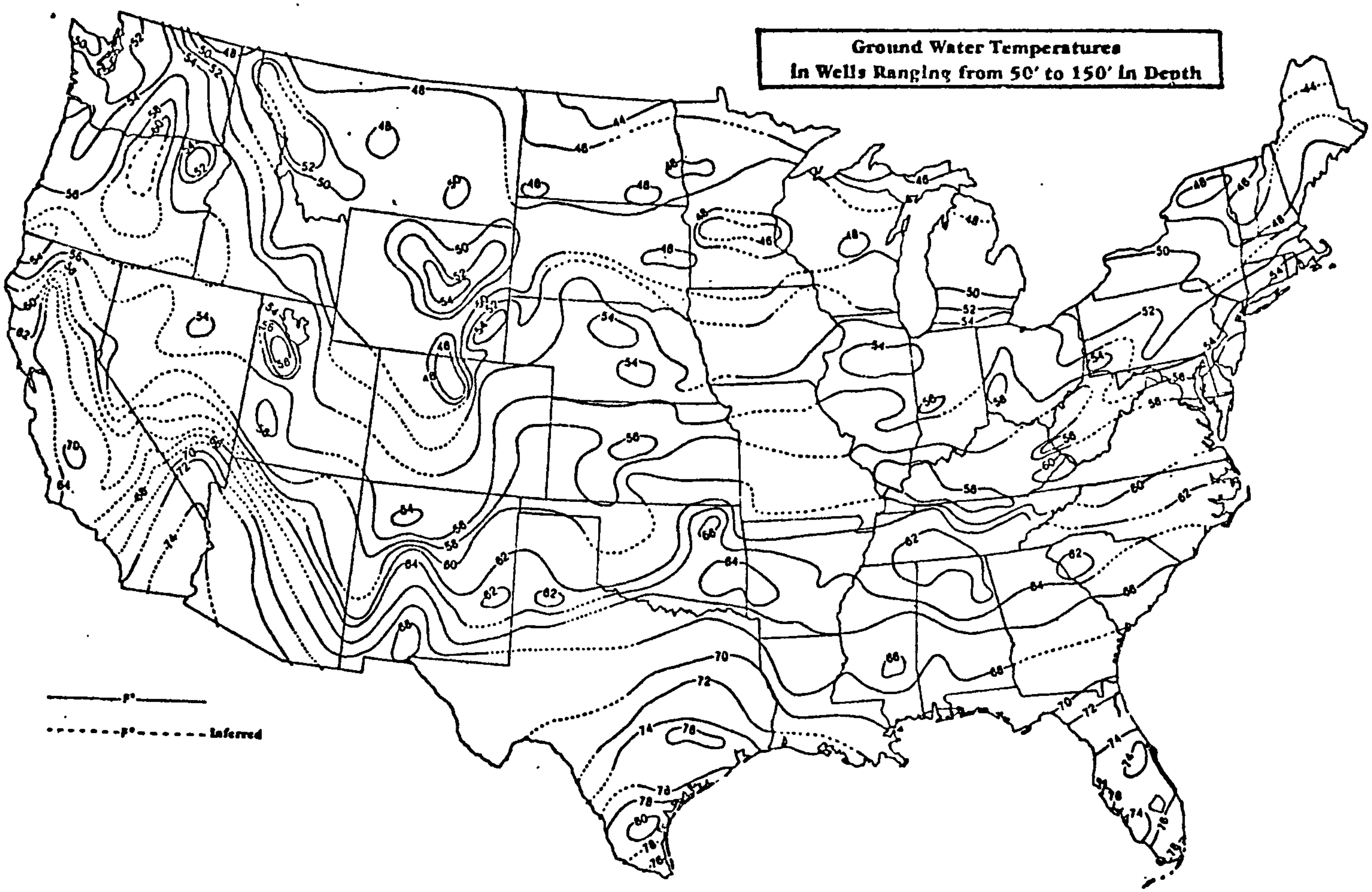


Figure 4. Ground Water Temperatures

heat pump systems. This can be seen from Figure 5 a plot of heat pump capacity and performance of a water source heat pump that might be used in a closed loop ground-coupled application.

The Electric Power Research Institute and the Oklahoma Gas and Electric Company funded a research project to conduct both experimental and theoretical work to determine whether Ground-Cooled Heat Pumps might signifacantly reduce electricity peak demand and residential energy consumption. air-coupled and ground-coupled heat pumps were installed in two identical houses in Perkins, Oklahoma, for this study.

The objectives of this Master's study were were:

1. To closely monitor and study the performance and reliability of the air-coupled and ground-coupled heat pump systems for a period of one year.

2. To develop a computer program to simulate the building thermal load and electric power consumption of the heat pump system and compare the measured and simulated HVAC demand.

3. To perform comparative analyses of the performance of air-coupled and ground-coupled systems in terms of electric power consumption and system efficiency.

4. To compare the performance of the installed air-coupled and ground-coupled heat pump systems to the ideal performance of a similar system using a recently developed, efficient ground-coupled pump.

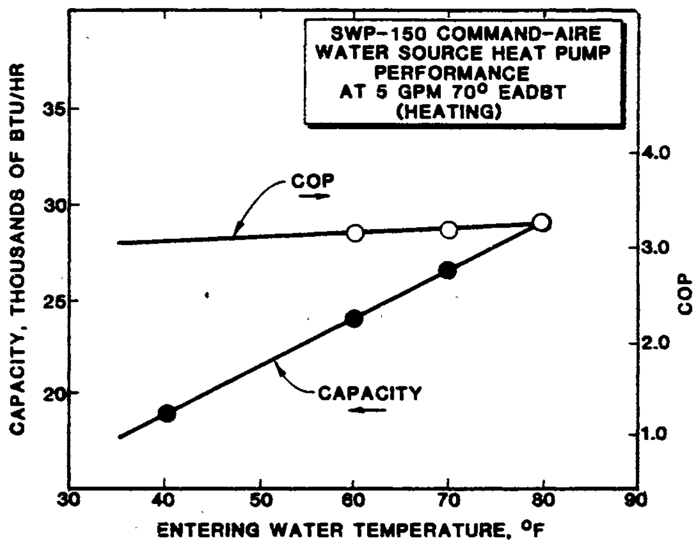


Figure 5. Heating Performance of Water Source Heat Pumps

CHAPTER II

DESCRIPTION OF THE HOUSES AND HEAT PUMP SYSTEMS

Environment

Oklahoma State University, a sub-contractor of the Oklahoma Gas and Electric Company and the Electric Power Research Institute, chose Perkins, a small town eleven miles south of Stillwater in north central Oklahoma for this study. Air-coupled and ground-coupled heat pump systems were installed in two identical north facing houses on adjacent lots in a new sub-division which includes approximatly 50 small two and three bedroom,single family houses. Typical wheather data of the area is shown in Table I. The Perkins community was chosen for this heat pump study mainly due to the reason that it was close to Oklahoma State University making it easy for data collection. Further the Knipe substation which serves the Perkins community has substantial summer and winter peak demands.

Design and Construction of the Houses

The houses were designed with energy conservation as a major consideration. Approximate floor area excluding the garage is 1100 Sq.ft. Basic floor plan of all the houses

TABLE I

WEATHER SUMMARY

Month	Avg. Min.		Avg. Max.		Rainfall Inches Normal
	C	F	C	F	
January	-4	25	9	48	1.16
February	-2	28	12	55	1.35
March	3	37	17	63	1.86
April	9	49	22	72	2.86
May	14	57	26	79	4.62
June	17	64	31	88	4.24
July	21	70	33	93	3.53
August	21	69	33	93	3.21
September	16	61	29	85	3.38
October	8	47	24	75	2.78
November	3	37	16	61	1.85
December	-2	28	9	48	1.34
Annual	8	47	22	72	32.18

Source: Climatological Data of Stillwater, Oklahoma 1893-1975. Agricultural Experiment Station, Oklahoma State University, Research Report P-739, August, 1976, pp. 6,9.

are shown in Figure 6. The houses are built on 10cm X 5cm(2 in) styrofoam insulation 30cm (12 in) deep around the perimeter. The walls are insulated with 9 cm (3.5 in) fiberglass batting and 1.27 cm (0.5 in) styrofoam (R-19), the roofs with 30 cm (12 in) (R-36) of rockwool and the floors padded and carpeted. As shown in Figure 7, the exterior of the houses are bricked, all plumbing is located on walls in order to reduce heat loss in the piping and the air ducts are located within the heated space of the house to minimize losses. The houses are equipped with steel insulated doors with magnetic seals and storm windows. The houses are furnished with almost identical lighting,cooking and laundry equipment. The furniture is similar but not identical. Table II shows the summary of residents consumption habits.

Air-Coupled Heat Pump System

The air-coupled heat pump installed in the east house is a Carrier model 38 CQ015/40AQa018 of split system type,with a rated cooling capacity of 15,500 Btu/hr and a heating capacity of 16,500 Btu/hr. The indoor section has a 10KW electric heater for emergency heat and a direct expansion fan coil unit. Compressor,fan coil and defrost mechanisms are present in the outdoor section. When the ambient temperature is below 45 F and the coil saturated suction temperature indicates freezing, the defrost cycle is actuated with a maximum defrost time of 10 minutes within each 90 minute period. Physical data, dimension, and performance

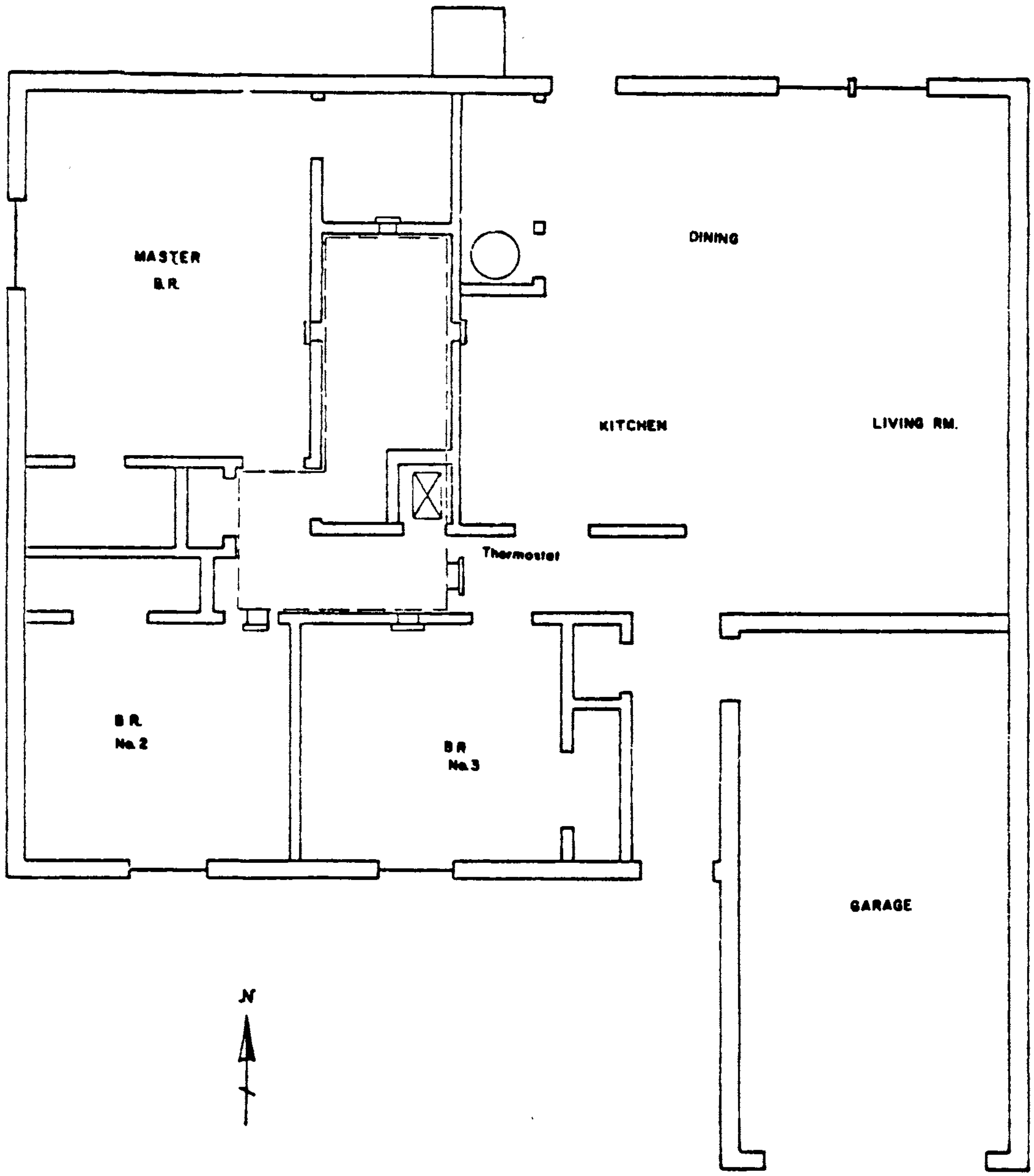


Figure 6. Basic Floor Plan of All Three Houses

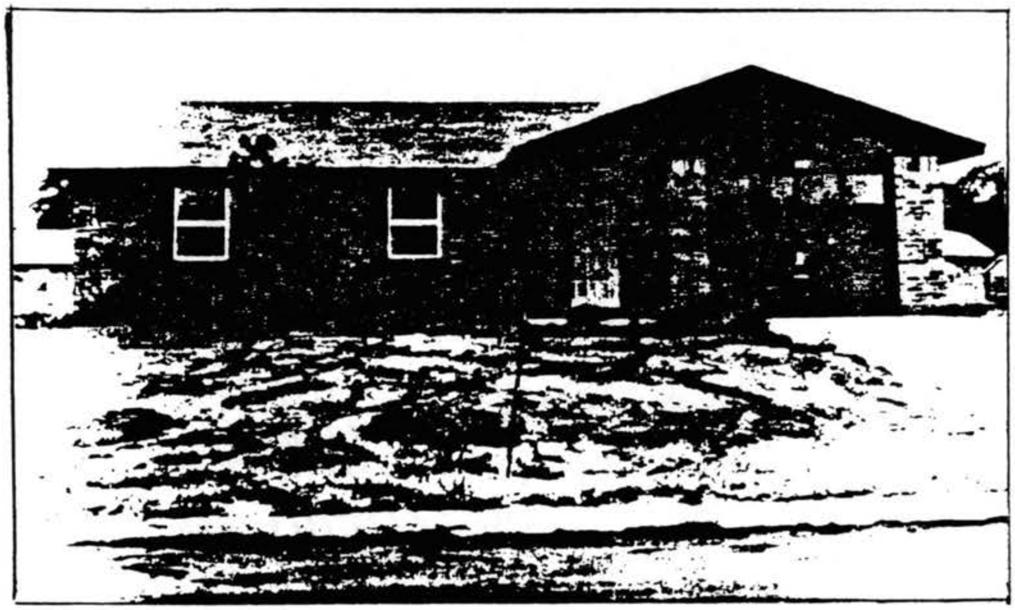


Figure 7. Exterior of the East House

TABLE II

SUMMARY OF RESIDENT'S CONSUMPTION HABITS

	EAST	WEST
Number of Occupants During the Day In the Evening On the Weekend	 1 4 4	 1 2 2
Thermostat Setting* Day Night	 72 68	 68 68
Appliances	washing machine dryer dishwasher refrigerator TV (2) oven range freezer stereo	washing machine dryer dishwasher refrigerator TV (2) oven range freezer stereo
Loads of Laundry/Week Water Temperature	15 warm	4 hot, warm
Windows	double paned curtains	double paned double curtains
Lights Commonly Used	(1) 250W (2) 200W (8) 60W (1) fluorescent	(3) 100W (1) fluorescent

*Heating season settings

data for the air-coupled system are presented in Appendix A.

The Ground Coupled Heat Pump System

The ground-coupled heat pump that is installed in the west house is Commandaire model SPW-150. It is a single-package unit with compressor,coils and blower all housed in a single cabinet. Figure 8 shows the schematic of the Ground-Coupled heat pump system. The heat pump has a rated cooling capacity of 19,500 Btu/hr and a rated heating capacity of 28,500 Btu/hr. The refrigerant-to- water heat exchanger is connected to a U-tube exchanger installed in the ground for heat rejection or extraction.

A schematic of the polyethylene U-tube ground coupling heat exchanger system is shown in Figure 9. In the backyard of the house the earth was drilled to contain the U-tube ground coupling system. The U-tube installation consists of two 250 ft long 1-1/2 inch IPS schedule 40-8600 driscopipe made of high density polyethylene fused to a U-bend at one end.The advantages of the system are that the scale deposit in the heat exchanger is almost eliminated,pumping power is greatly reduced to that necessary only to overcome friction in the system and no water must be disposed of. Both the air-coupled and the ground- coupled heat pump systems have a domestic water preheater that utilizes waste heat from the hot gases exiting the compressor.

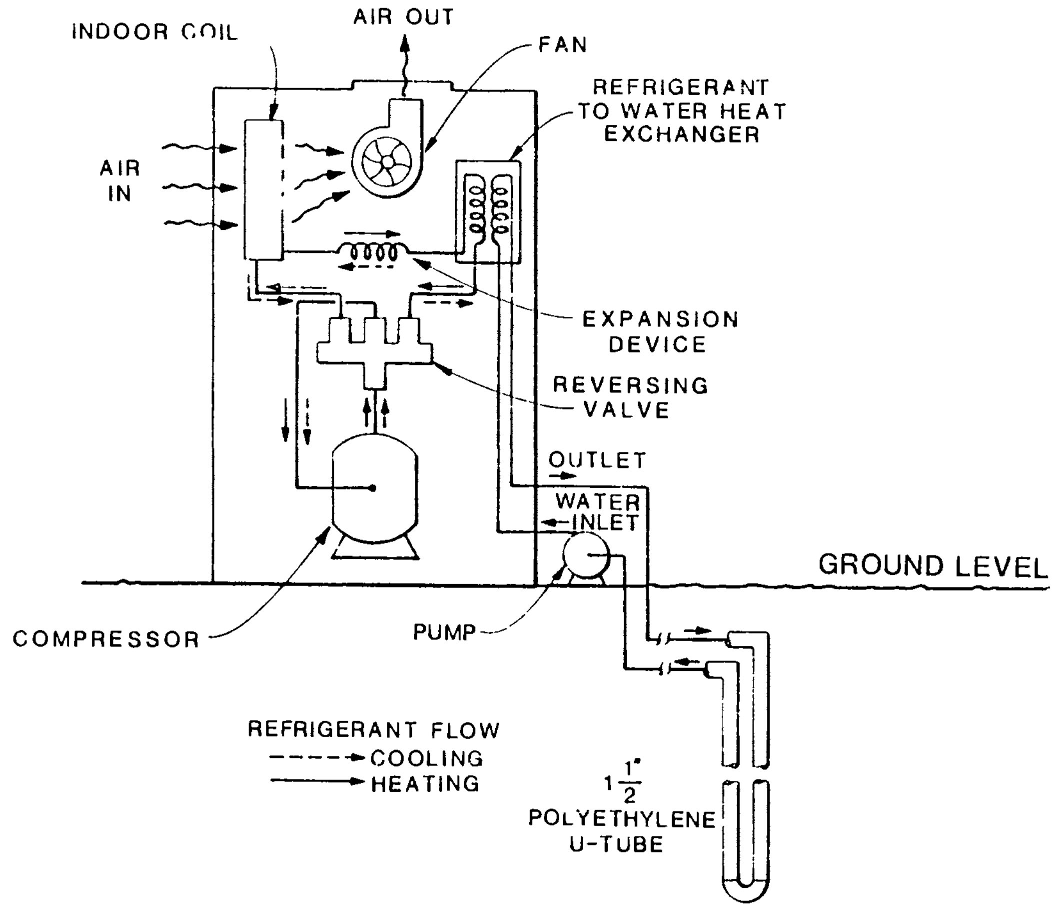


Figure 8. Schematic of Ground-Coupled Heat Pump

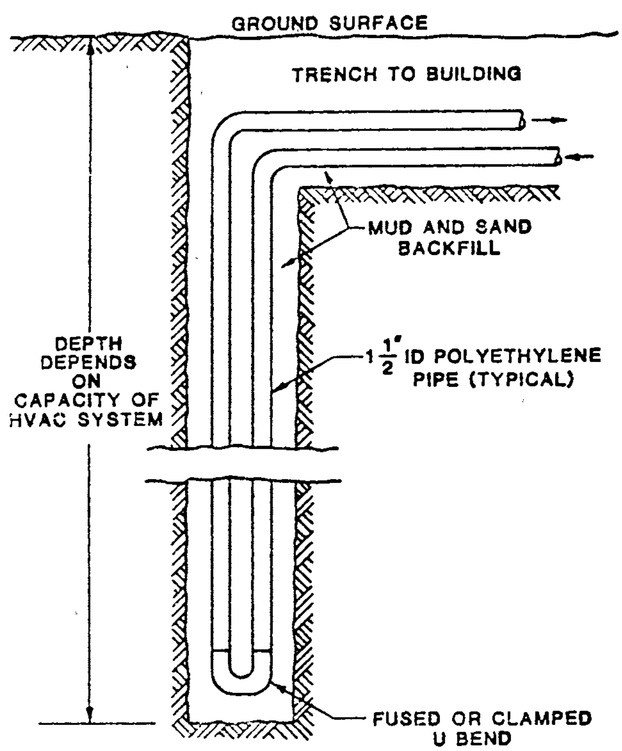


Figure 9. Schematic of the Vertical U-Tube Ground Heat Exchanger System

Thermostat

A Carrier model thermostat that uses mercury-in-glass for electrical switching was initially installed. The thermostat provided two stage heating and one stage cooling controls. The set point for energizing the second stage is set manually. The thermostat was provided with two levers and are parted to set the temperature differential. By setting a desired temperature differential,the heat pump mode of operation could be changed from heating to cooling or vice-versa. But continual adjusting of the thermostat had resulted in frequent indoor temperature changes and resistance usage.

In September 1982, Smartstat 1000 solid state thermostats were installed in the houses. With the cooperation of the occupants a better control of the indoor temperature was attained. The thermostat permited the scheduling of night time economy periods,whereby the building temperature was allowed to decrease during cold weather(setback) and increase during warm weather (set-up) at night while the occupants were asleep. It also allowed the scheduling day-time economy periods, whereby the temperature was decreased during winter and increased during the summer when the occupants were away from home.

CHAPTER III

DATA ACQUISITION AND MANAGEMENT

Considerable study, planning and attention was given to the amount and type of data to be collected for accurate comparison of the performance of the heat pump systems. Fifty one different parameters needed to compare the heat pump systems were determined from energy balances performed on various parts of the occupied space heat pump systems. A list of all the measured parameters is shown in Figure 10.

Instrumentation

The instruments used for environmental measurements were copper constantan thermocouples for temperatures, a variable capacitance device for humidity, pyranometers for insalation, a typical three cup anemometer with pulsed voltage outputs and a typical vane with an externally excited variable resistance output for wind velocity and direction.

Thermal performance of each system was monitored by temperature, flow and heat flux measurements. Temperatures were measured by thermocouple probes inserted into the system flow path. Fluid flow and heat flux measurements were made by a single unit that measures temperatures and flows and then digitally integrates to obtain a heat flux

Pole

Weather Data	Solar Insolation Dry Bulb Temperature Humidity Wind Speed and Direction

	East House	Middle House	West House
Environmental Measurements	Dry Bulb Temperature Humidity	Dry Bulb Temperature Humidity Water Temp from Well Water Temp to Well ECS Temp from Collector	Dry Bulb Temperature Humidity Water Temp from Well Water Temp to Well
Heat Transfer Measurements	Hot Water Usage Hot Water Btu	Hot Water Usage Hot Water Btu Rate Well Water Flow Rate Well Water Btu Rate Solar Loop Flow Rate Solar Loop Btu Rate	Hot Water Usage Hot Water Btu Well Water Flow Rate Well Water Btu Rate
Power Consumption Measurements	Total Resistance Heat Hot Water Hot Shot Compressor and Crankcase Heater Inside Blower Outside Blower	Total Resistance Heat Hot Water Hot Shot Compressor Inside Blower Well Pump Solar Loop Pump	Total Resistance Heat Hot Water Hot Shot Compressor Inside Blower Well Pump

Figure 10. Parameters to be Measured

measurement.

An array of kilowatt-hour meters were used to measure the electric power consumption. The meters were provided with special switch closures which were activated by the rotation of the meter. Each closure was measured as an electric pulse and represented a fraction of one-watt hour.

Data Collection

A shed arrangement shown in Figure 11 was used for housing the data collection and recording equipment. A Campbell Scientific CR5 data logging unit executed the conditioning, collecting and recording functions of the signals from the transducers. Figure 12 shows the basic data collection system.

The various measurements were transformed into appropriate digital values and were scanned by the CR-5 control module that contained the system clock and the software necessary to integrate each of the signal conditioning modules. The time period between scans was set for 15 minutes.

The CR-5 has several ouput options. Without the addition of special interface modules, the CR-5 can only output data to a small on-board printer. Two output modules were added; a R-235 audio tape interface was used to convert each scan to modulated analog signals that were recorded on audio tape. A TC-235 telecommunications module and an SC-232 serial communication interface were added to the data logger to provide a means of immediate access to recently collected

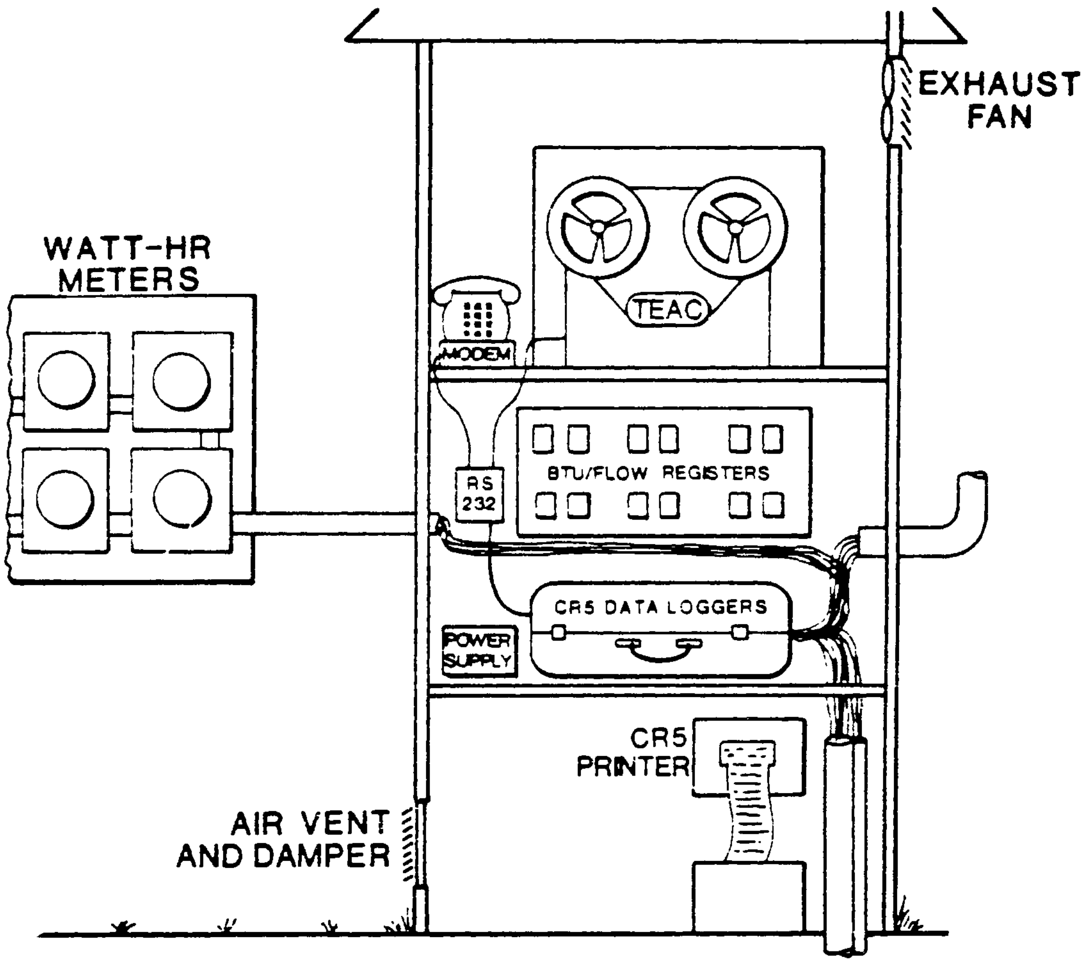


Figure 11. Instrumentation Shed Arrangement

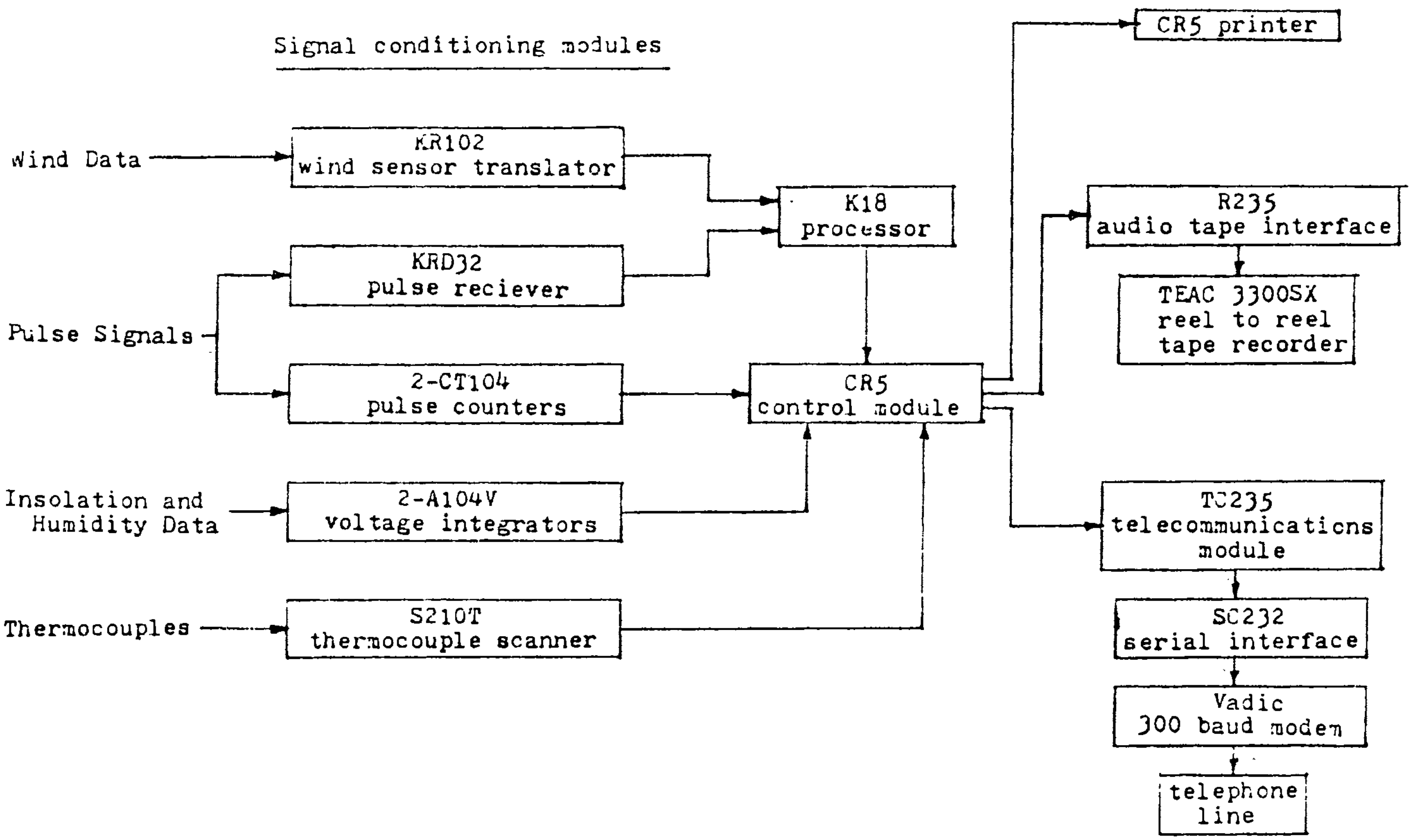


Figure 12. Basic Data Collection Systems

data. The TC-235 contained a random access memory that retained the last eight hours of data collected by the CR-5. A Vadic 300 Baud modem and a telephone line were connected in order to allow immediate access to the data.

Data Transfer

An IBM 370 main frame system at Oklahoma State University was used to store all the collected data. A data flow diagram in Figure 13 illustrates the path the data take through the various components of the data transfer system. A Campbell Scientific A-235 terminal/recorder interface connected to a TEAC 3300sx reel-to-reel tape recorder was used for the playback and decoding of audio tape data. The A-235 tape/terminal interface was equipped with a standard RS-232 port that can be operated at 300 or 1200 baud rate. A Biscomp 1022 intelligent modem was used to collect data directly by phone.

The Radio Shack TRS-80 model III Micro-Computer was used to link various data transfer devices. It offered a high level of control and interaction between various electronic and human interfaces necessary to achieve consistent, accurate data transfer. With two 5-1/4 inch soft magnetic disk drives and 32K of random-access memory, the TRS-80 micro-computer had adequate storage space to meet all the requirements of the data transfer operations. The data collected either on tape or in the memory of the TC-235 were first transferred to 5-1/4 inch soft magnetic floppy disks. Each disk has the capacity of holding 3-1/2 days of

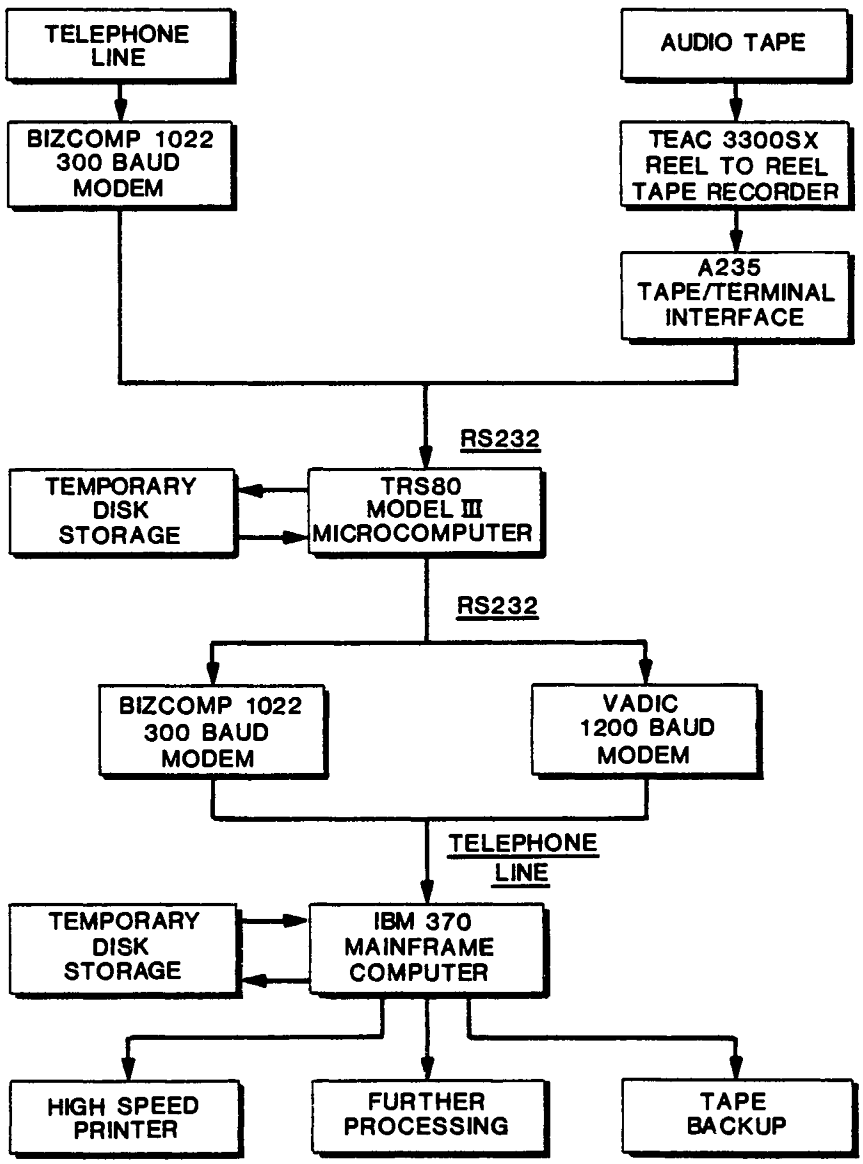


Figure 13. Data Transfer System

raw data. The TRS-80 software, transfer program 'TRS IBM/DISK IBM' was used to transfer data from floppy disk to the IBM 370 main frame temporary disk.

The software developed by Jeffrey P. Harris (2) to fill the requirements of an automatic data acquisition system helped to collect and transfer phone data to IBM 370 main-frame computer for immediate analysis. Most of the information on the above topics were obtained from Frienson (3) and Jeffrey (2).

Data Processing and Storage

TRS-80 micro-computer had the capability of transferring only data for 3-1/2 days from tape to IBM main frame at a time. So it was necessary to merge these IBM small data volumes to a single file containing all the data collected during one month and named according to the month and year (eg.Jan 82. tape. data). These files were copied to the IBM 6250 BPI data tapes before they were edited for long term usage and safety reasons. A sample of unedited tape data is given in Figure 14.

The ultimate goal of the data system was to provide continous and accurate data in a form that were acceptable to the user. In order to achieve this, the data were to be edited for problems like missing scans, missing channels, odd and over range characters. The data was also required to be expanded for easier use by Fortran Programs. The idea of editing and expanding the data by hand was given up mainly because it was expensive, time consuming and needed a

00+T83	01+T11	02+T15	03+050	04+222	05+117	06+207	07+217	08+207	09+194
10+158	11+163	12+155	13+395	14+273	15+276	16+171	17+390	18+148	19+001
20+000	21+000	22+017	23+011	24+044	25+302	26+032	27+033	28+000	29+000
30+120	31+000	32+021	33+000	34+412	35+279	36+156	37+000	38+000	39+000
40+000	41+000	42+000	43+000	44+000	45+000	46+000	47+000	48+000	49+000
50+000	51+018	52+001	53+000	54+000	55+010	56+148	57+058	58+032	59+007
60+000	61+000	62+001	63+005						

Unedited 15 Minutes Data

00+1566	01+1523	02+1545	03+0049	04+0203	05+0157	06+0231	07+0184	08+0185	09+0192
10+0172	11+0173	12+0151	13+0691	14+0378	15+0330	16+0305	17+0000	18+0000	19+0000
20+0000	21+0000	22+0003	23+0007	24+0011	25+0011	26+0004	27+0004	28+0000	29+0000
30+0000	31+0000	32+0000	33+0000	34+0014	35+0000	36+0000	37+0000	38+0000	39+0000
40+0000	41+0000	42+0000	43+0000	44+0000	45+0000	46+0000	47+0000	48+0000	49+0113
50+0406	51+0057	52+0007	53+0000	54+0000	55+0000	56+0009	57+0000	58+0102	59+0163
60+0000	61+0001	62+0001	63+0001						

Edited 15 Minutes Data

20 000	0 000	0 000	54.005	69 935	57 425	74 885	72 140	71 645	70 205
78 125	76 865	70 745	68 850	37 400	34.625	38 700	0 001	0 000	4 000
4.000	0 000	0.216	0.528	0 960	27 750	5 000	5 250	0	0 000
0 000	0 000	0 000	0.000	0 041	0 000	0 000	0.000	0	0 000
0	0 000	0	0 000	0 000	0 000	0 000	0	0 000	0 000
0	0 000	0	0.000	0 000	0 000	0.000	0 000	0 000	0 006
0 004	0.000	400.	4.000						

Hourly Values Data

Figure 14. Samples of Recorded Data from Data Set Files

large computer memory size for the monthly data files. A program written to do this automatically is "Raw.To.Disk". Further details about data editing are described by Richard (4). The monthly clean data files were also named according to the month and year (eq.Jan 82. Clean. Data) and were stored for later use in IBM 6250 BPI data tapes.

The clean data were quite voluminous and made little sense owing to the fact that each channel values have to be converted to proper units by a multiplication factor. A totaling program was written to convert these 15 minute values to proper units and to condense the data to hourly, daily and monthly values by summing or averaging. A sample of daily values are given in Figure 15. The hourly and daily values of the data were also stored in IBM 6250 BPI data tapes. A tabulation of the currently measured parameters, their corresponding "channel" numbers, conversion factors and units are given in the Appendix B.

In order to present the data graphically, statistical analysis system (SAS/Graph) programs were developed. SAS/Graph programs XPLOT, HRSAS, and DYSAS were used for the 15 minute, hourly and daily values. The data flow diagram in Figure 16 shows the data processing and storage system. The details of the monthly edited and unedited files that are stored in different IBM 6250 BPI data tapes are given in Appendix B.

THE DAILY VALUES FOR THE
DAY 30 OF THE 4 MONTH OF THE YEAR 1983

DESCRIPTION	EAST HOUSE	MIDDLE HOUSE	WEST HOUSE	UNITS
TEMPERATURE	72 056	73 938	69.867	FAHRENHEIT
HUMIDITY	39.458	37 406	35 071	
TOTAL	65 784	40 824	17 304	KW HR/DAY
HOT WATER BTU	1000 000	39000 000	3000 000	BTUS/DAY
HOT WATER USE	84 000	71 000	13 000	GALLONS/DAY
RESISTANCE	0.426	0 105	0 000	KW HR/DAY
HOT SHOT	0.014	0 008	0 019	KW HR/DAY
COMPRESSOR	1,939	0 438	0 638	KW HR/DAY
INDOOR FAN	0 190	0 066	0 080	KW HR/DAY
OUTDOOR FAN	0 137			KW HR/DAY
WELL FLOW		81 000	99.000	GALLONS/DAY
WELL PUMP		0 036	0.046	KW HR/DAY
HOT WATER	22 392	14 583	5 571	KW HR/DAY
WELL COOLING		300 000	400 000	BTUS/DAY
WELL HEATING			4900 000	BTUS/DAY
OTHERS	63 099	40 048	16 540	KW HR/DAY
HVAC	2 685	0.775	6 764	KW HR/DAY

SOLAR PUMP	0 131	KW HR/DAY
SOLAR FLOW	0 000	GALLONS/DAY
SOLAR HEATING	0 000	1000 BTUS/DAY
SOLAR OUTLET TEMP	71 504	FAHRENHEIT
OUTDOOR TEMP	57 024	FAHRENHEIT
SOLAR IN TEMP	62 720	FAHRENHEIT
OUTDOOR HUMIDITY	75 619	
HORZ INSOLATION	2 147	KW/SQ METER
VERT INSOLATION	0 937	KW/SQ METER
WIND DIRECTION	165 948	DEGREES
WIND SPEED	5 104	MILES/HR
WIND RUN	5 [illegible]06	
HIGH TEMP	61 220	FAHRENHEIT
LOW TEMP	51 665	FAHRENHEIT

Figure 15. Summary of Daily Values of the Data

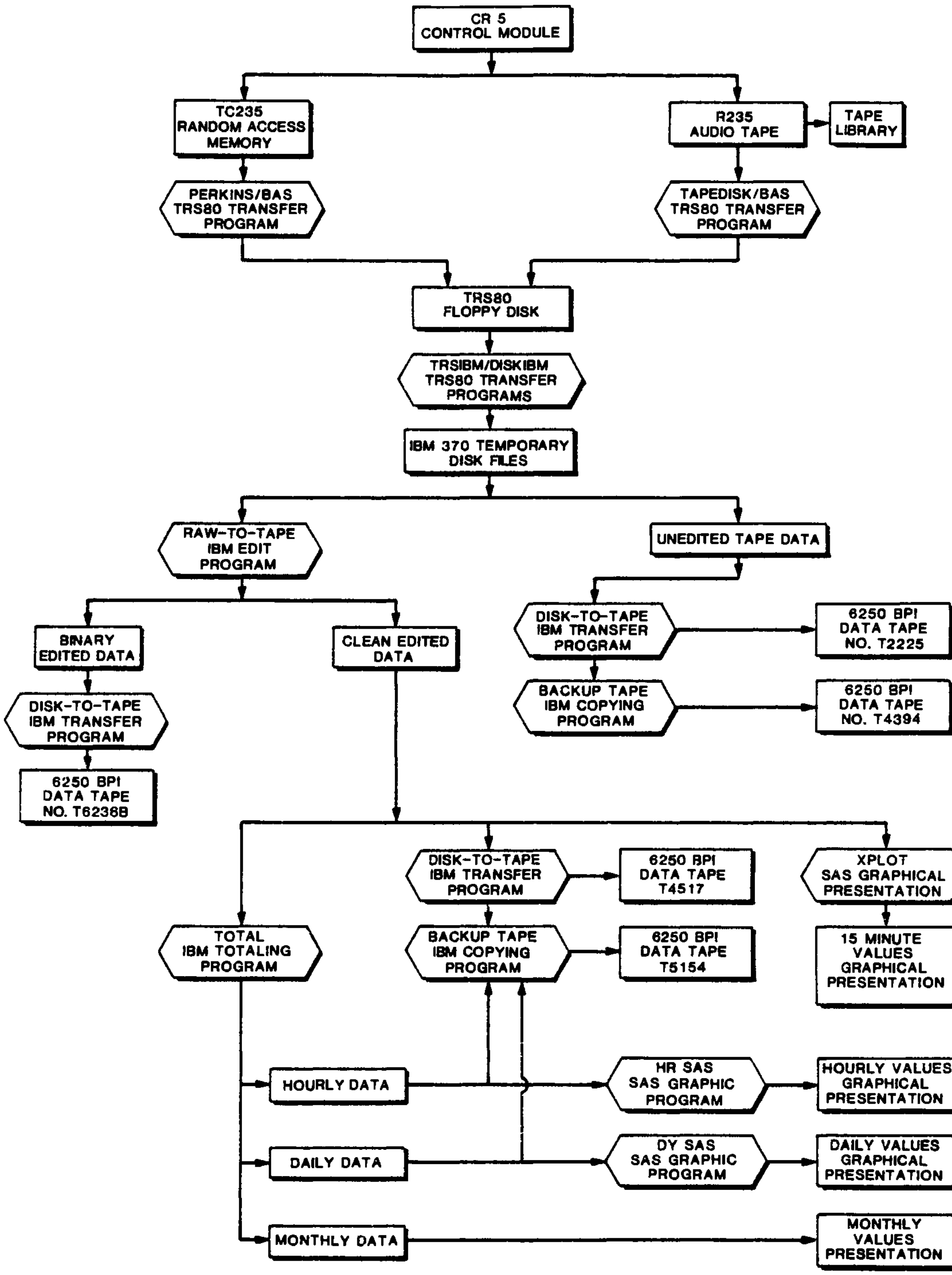


Figure 16. Data Storage and Processing System

CHAPTER IV

SIMULATION PROCEDURE

Simulation of the heating and cooling energy requirements of the occupied buildings was done by a two-step calculation procedure. First, the transient heating or cooling load demand of the occupied space in response to the external weather conditions were determined. Next the energy consumption and performance of an environmental control system (in this case air-coupled and ground-coupled heat pump system) to supply or dissipate the energy load were calculated.

Building Thermal Load Model

CHLSYM (5) is a computer simulation program developed in the School of Mechanical and Aero-Space Engineering Department at Oklahoma State University to determine the transient heating and cooling demands of residential and commercial buildings. The load simulation program simulates the hourly sensible and latent loads on the building taking into account the building's architectural characteristics, such as material properties,wall thickness,and shading patterns, along with outdoor weather data. The system simulation calculates the energy required by the system to satisfy the loads.

The CHLSYM program uses the transfer function method outlined in the 1972 ASHRAE Hand Book of Fundamentals(6). Solar input and internal heat generation due to people, lights, and appliances were accounted for in the calculations. The program also computes the indoor air temperatures and heat extraction or addition rates as a function of equipment capacity and schedule of operations. CHLYSM was efficient in determining the thermal requirements of the buildings, but some modifications and updated versions were necessary for accurate simulation of the Perkins house. The following modifications were applied to CHLSYM without conflicting with the calculation procedure.

Infiltration Model

Air infiltration has long been recognized as a significant portion of the total heating or cooling loads in a residence. The CHLYSM program uses the crack method to calculate the amount of infiltration air for the building. Irrespective of the season, it uses a constant amount of infiltrations for day and night. But, in reality, natural air leakage in residential structures is much smaller in a summer than winter. Winter air leakage a in specific structure is caused by two weather factors: (1) wind direction and velocity; and ,(2) inside-outside temperature difference, which causes the so called chimney effect. In summer, this effect is of course absent and wind velocities are lower in many localities. George (7) had developed a generalized computer simulation model to predict hourly air infiltration rates. The ASHRAE technique , which uses indoor outdoor temperature differences, wind velocity and statistical linear regression constants has been adopted in this model. The regression model has the form,

$$I=K1+K2*\Delta t+K*v.$$

Where I=air change rate per hour

Δt=indoor -outdoor temperature difference in centigrade

v=wind speed (mph)

K1,K2,K3=emprical constants

Typical values of the constants suitable for different classes or houses are given in Table III. Introduction of this model has greatly helped to simulate the infiltration load more accurately.

Internal Loads

An accurate estimate of thermal load due to people, lights, appliances and equipment was essential for load simulation. Both the air-coupled and ground-coupled houses were occupied by a two-member family. So the number of people to be accounted for internal load calculation was assumed constant. Owing to the inability of the data collection system to measure all the lighting and appliances energy consumption separately, it was decided to calculate the base load energy consumption by deducting the heat pump system energy consumption from total energy consumption.

TABLE III

COEFFICIENTS FOR MULTIPLE LINEAR REGRESSION INFILTRATION

Construction Type	K_1	K_2	K_3	Description
Tight	0.10	0.011	0.034	New building where special precautions have been taken to prevent infiltration.
Medium	0.10	0.017	0.049	Building constructed using conventional construction procedures.
Loose	0.10	0.023	0.067	Evidence of poor construction or older buildings where joints have separated.

Base load energy consists of all the energy consumed by the lights,cooking,washing,laundry,television, and other small household appliances. Most of the lights in the Perkins residences were of the incandescent type. The building load calculated by taking the whole base load as internal load resulted in poor results probably because that the sensible and latent heat gains by the appliances were reduced more than 50% by the positive exhaust systems. So it was necessary to find out by trial and error the percentage of base load that had to be taken for accurate simulation of the building load. Again, it was the behaviour of the occupants that determined the percentage to be calculated. Forty five percent of the base load was found to give good results for the themal load of the building.

Update of Transfer Functions

CHLSYM had been basically developed from the ASHRAE algorithm explained in the ASHRAE Book of Fundamentals 1972 volume(6). The transfer function method has been simplified and updated in the recent years. It was decided to update CHLSYM with the simplified transfer functions given in the ASHRAE fundamental volume of 1981.

The use of a transfer function is an accepted way of relating a heat gain component to a corresponding cooling load component. The transfer function depends on the nature of heat gain and heat storage characteristics of the space. The heat gain q and the corresponding cooling load Q at time

Carrier air-coupled and obtained good results. The capacity of the ground -coupled heat pump system is a funtion of three quantities : flow, entering water temperature and dry-bulb room temperature. Faisal fitted a second degree polynomial fit for the ground coupled heat pump system. According to this model the predicted capacity dropped with flow for the present simulation. In reality ,the heat pump capacity increases exponentially and approaches a constant value assymtotically. Hence a new funtion, which is a combination of two parabolic and one exponential curves were introduced in the curve fit.

The Polynomials for heating mode are:

Heating capacity (Btu/hr)

$$Q = CFHC\ (e0 + e1.EWT + e2.EWT^2 + e3.TDB + e4.TDB^2 + e5.EWT.TDB)\ (1 - Exp\ (e6.GPM))$$

Heat extraction rate (Btu/hr)

$$QHES = CFHE\ (f0 + f1.EWT + f2.EWT^2 + f3.TDB + F4.TDB^2 + f5.EWT.TDB).(1 - Exp\ (f6.GPM))$$

Power Input, heating (Kw)

$$PHS = CFKW\ (g0 + g1.EWT + g2.EWT^2 + g3.TDB + g4.TDB^2 + g5.EWT.TDB).(1 - Exp\ (g6.GPM))$$

Where

EWT = Entering Water Temperature(F)

GPM = Water Flow Rate (gal/min)

TDB = Air Dry Bulb Temperature(F)

CFHC,CFHE,CFKW = Correction factor for heating capacity heat extraction rate,and power Input respectively when the air volume is not equal to 600 cfm.

Similar polynomial curve-fits were introduced for cooling steady-state values.

Heat Pump Cyclic Effect

Under part load conditions most of the light residential heat pump systems are cycled ON and OFF. At the instant when the unit is turned ON, its heating or cooling capacity will be zero, though it is using electrical energy. It is followed by a transient period in which both capacity and power approach their steady-state levels. This is shown in Figure 17. Because of the lower thermal efficiency during the transient period, the unit has to run a for longer time and use more energy to match a given imposed thermal load. For an accurate simulation procedure, it was decided to include a good model to take into account the cyclic effect. Though equipment manufacturers provide detailed performance data for their units under continuous operation, cyclic performance data were not correctly available.

The procedure described by George (7) for cyclic performance was adopted in this modification. Figure 18 shows

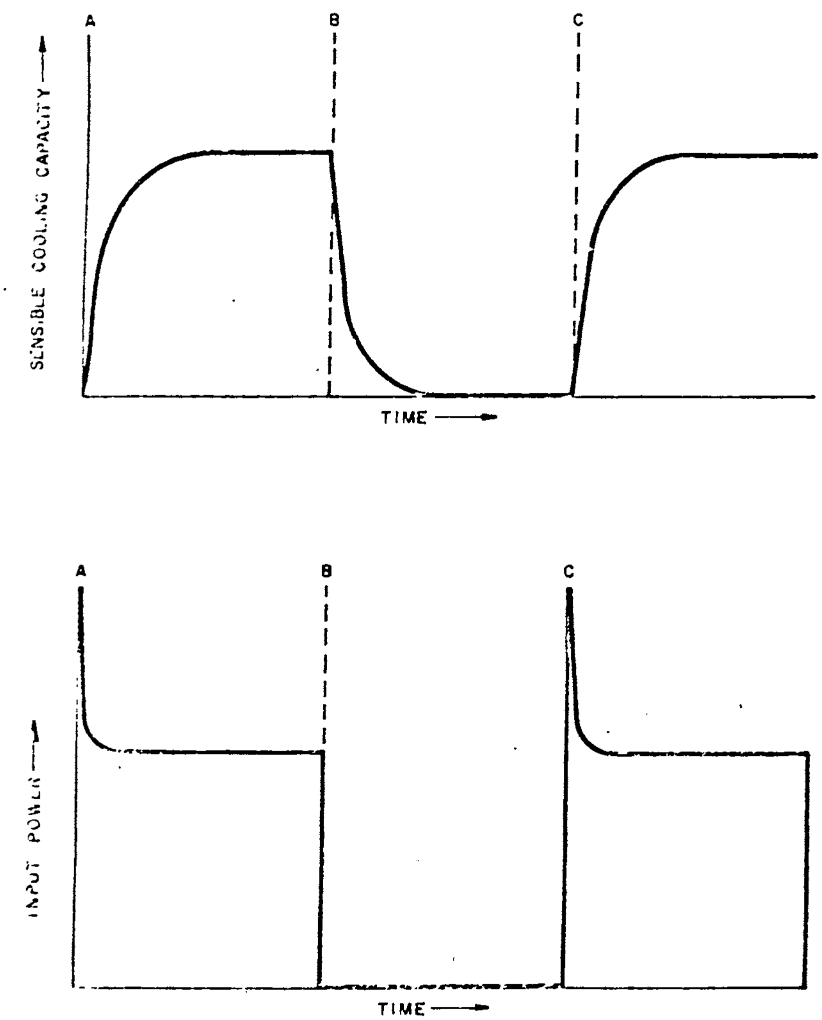


Figure 17. Typical Response Curves for Cooling Capacity and Input Power During Part-Load Operation

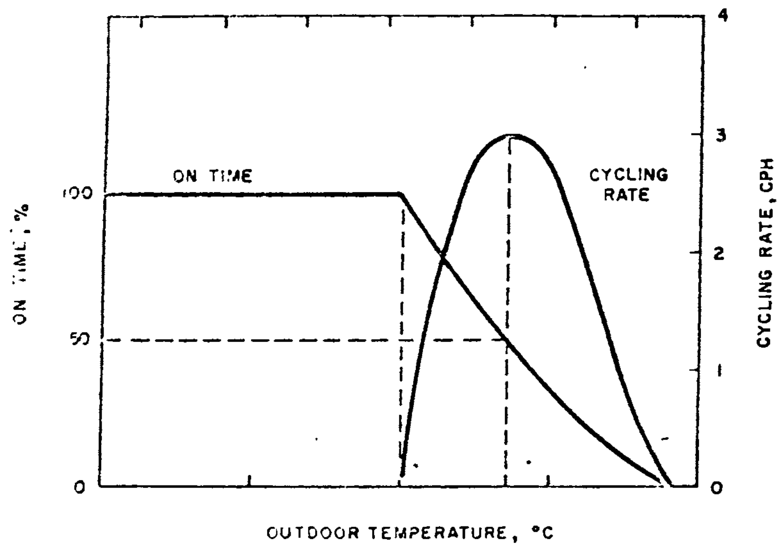


Figure 18. Heat Pump Ontime and Cycling Rate Heating Mode

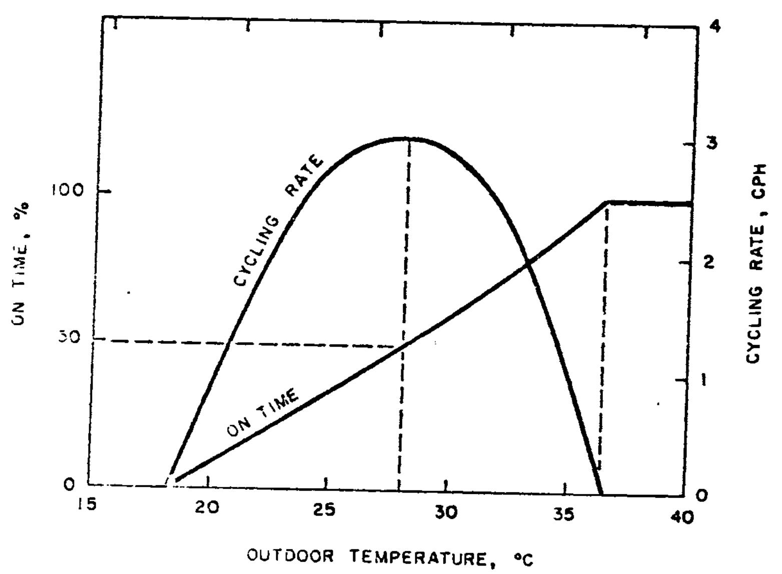


Figure 19. Heat Pump Ontime and Cycling Rate Cooling Mode

the heat pump on time and cycling rate for the heating mode. Figure 3 showed the balance point of a heat pump system. In the heating mode, at outdoor temperatures above the balance point the structure heating load will be less than the equipment heating capacity. The room thermostat will then cycle the equipment ON and OFF such that the delivered capacity matches the structural load. At lower outdoor temperatures the heat pump will run continuously. In the cooling mode, at lower outdoor temperatures the structure cooling load will be less than the equipment cooling capacity, leading to equipment cycling. At higher outdoor temperatures, the equipment will run continuously. Figure 19 shows ON time and Cycling rate characteristics for cooling.

The time taken to reach the 67% of the steady-state capacity varied from 15 to 45 seconds in most of the heat pump systems. An average of 30 seconds was taken as the heat pump time constant. Depending upon the thermal load, the cyclic rate was calculated. The product of cyclic rate and time constant was added to heat pump ON time to calculate the heat pump running time to supply or remove the thermal load.

Performance Correction

It was found during actual measurement of the heat pump system energy consumption that the system was not performing to the manufacturer's steady-state performance data. Both air coupled and ground-coupled units were consuming about 10 to 15 percent more than the stated steady-state values for that particular condition. This is clearly shown in Figures 20 and 21 for both the air-coupled and ground-coupled units. A correction factor was introduced for heat pump capacity and good results were obtained.

Flow of Information in the Simulation

The user first decides the period and the heat pump system for which he wishes to run this simulation program. The IBM data file which contains measured values of outdoor and indoor environmental conditions,HVAC thermal and mechanical performances and electrical power consumption for that particular period is linked to the main program. The building load program converts the 15 minute data to hourly values and uses them to calculate the building thermal load for every hour. The user inputs the thermostat throttling range,thermostat settings and their times, and the equipment's maximum and minimum capacities. The house parameters are stored in a separate file which is linked to this load program.

The program uses a subroutine SOLAR to convert the radiation falling on horizontal surface to that on an inclined plane, a subroutine XMOIST to determine the enthalpy,saturation moisture content and actual moisture content of the moist air, and a subroutine HEATX to compute the heat extraction rate and room temperature. The output of the program, which is the thermal load of the building is

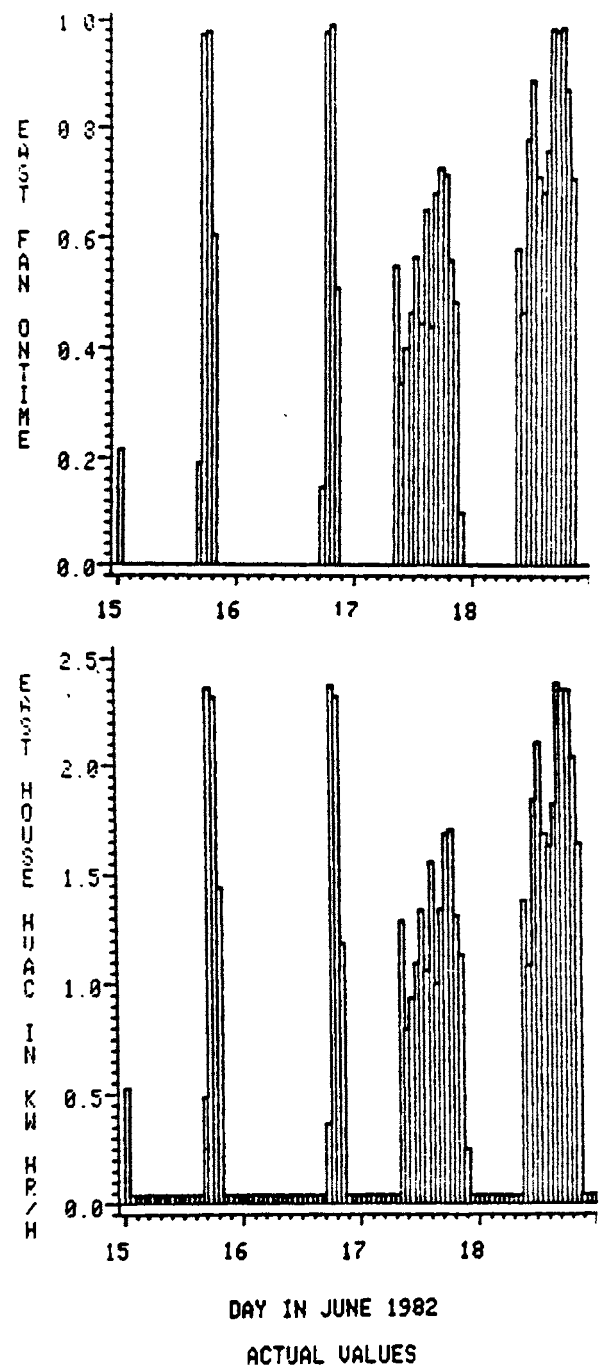


Figure 20. Air-Coupled Fan Ontime and HVAC Demand

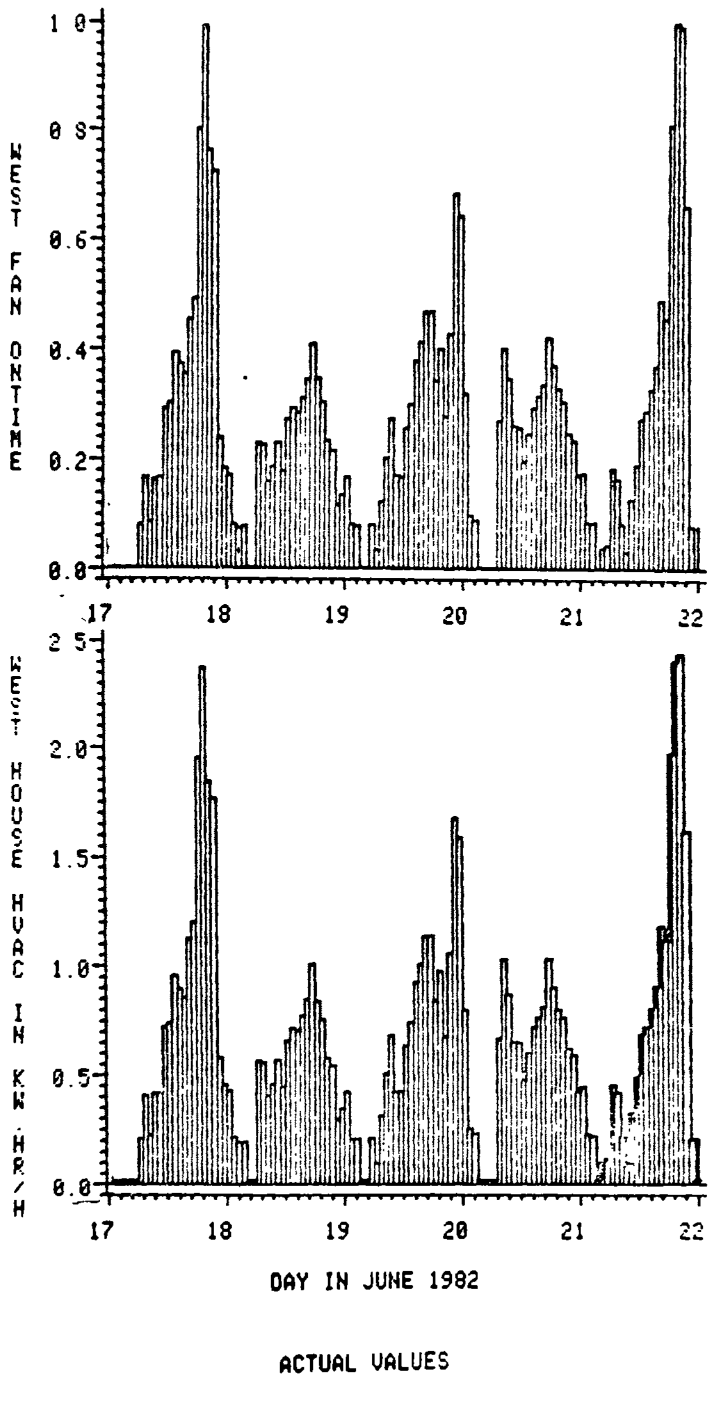


Figure 21. Ground-Coupled Fan Ontime and HVAC Demand

stored in a separate file for plotting and further use.

The system simulation program is then executed to simulate the performance of a particular heat pump system. The thermal load and indoor conditions were fed to this program. Depending upon the system,the house and the mode of operation, seperate subroutines computes the heat pump actual capacity, heat extraction or rejection rate to the ground,operation time, power usage and heat pump coefficient of performance are called. A subroutine VEWEX (Vertical Earth Water Heat Exchanger) is called by the ground-coupled heat pump simulation program to calculate the water temperature exiting the well. Further details of these programs can obtained from Faisal (8) and Joshi (9). The flow charts for this computer program are presented in APPENDIX C.

CHAPTER V

DISUSSION OF RESULTS

Comparison of the performance of the air-coupled and ground- coupled heat pump systems is done in three stages. First, the building load and system simulation model was validated by comparing the measured HVAC demand with simulated values for a period of one year from April,1982 to March 1983. Next, the air-coupled and ground-coupled heat pump systems HVAC demand and performances are compared. Third, the air-coupled and ground-coupled heat pump systems are compared with a similar system but using a recently developed Freidrich ground-coupled heat pump.

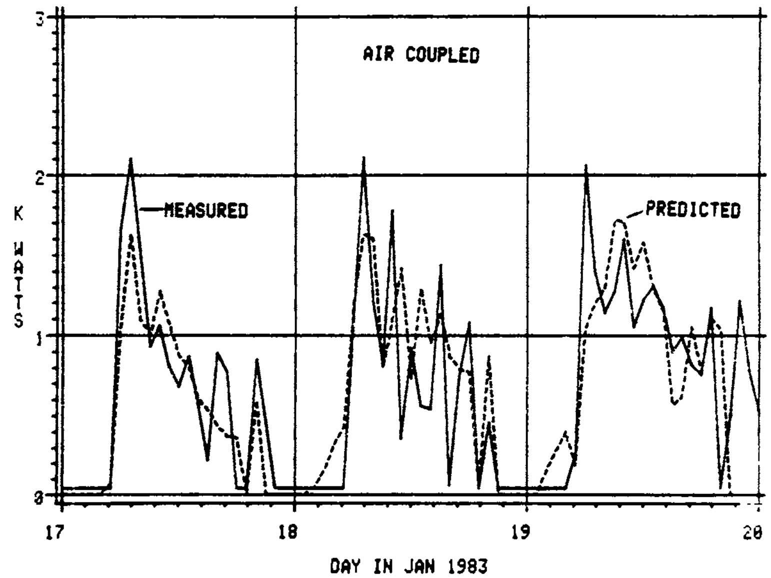
Measured versus Simulated HVAC Energy Demand

Comparison of measured versus simulated HVAC demand values are clearly shown in three types of graphical presentations. Hourly values for a few days in August,1982 and few days in January 1983, daily values for three summer months from July 1982 to September 1982 and three winter months from December 1982 to Feburary 1983 and monthly values for the whole year from April 1982 to March , 1983 are presented.

Both the air-coupled and ground-coupled heat pump systems were instrumented to measure energy consumed by the individual components of the system every 15 minutes. Figure 22 shows the comparison of measured and simulated hourly energy demand for a period of three consecutive days in January 1983. The air-coupled heat pump system shown in Figure 22 had a nighttime temperature set-back and can be seen clearly that the unit had been shut down by the smartsta t thermostat. The simulation model is also able to predict this set-back very accurately and follows the pattern of the measured values. The ground-coupled heat pump system shown in Figure 22 does not have a night time set back and so it can be seen that the HVAC energy demand at no time exceeds 1.0 kilo-watts/hour while in the air-coupled heat pump system has a peak of about 2.2 kilo-watts/hour.

Measured and simulated values of the HVAC demand in kilowatts are shown in Figure 23 for the cooling mode. It is clearly seen that during the period 18th to 22nd of August,1982, the simulated values closely followed the measured values and the air-coupled heat pump system consumed more energy than ground-coupled unit.

Figures 24 through 26 shows comparisons of simulated HVAC demand in Kwh/day of the air-coupled and ground-coupled heat pump systems for a period of three summer months from July 1982 to September 1982. The figures also show the measured outdoor daily average temperature along with measured indoor daily average temperatures of the air-coupled and ground-coupled houses. It can be seen that the simu-



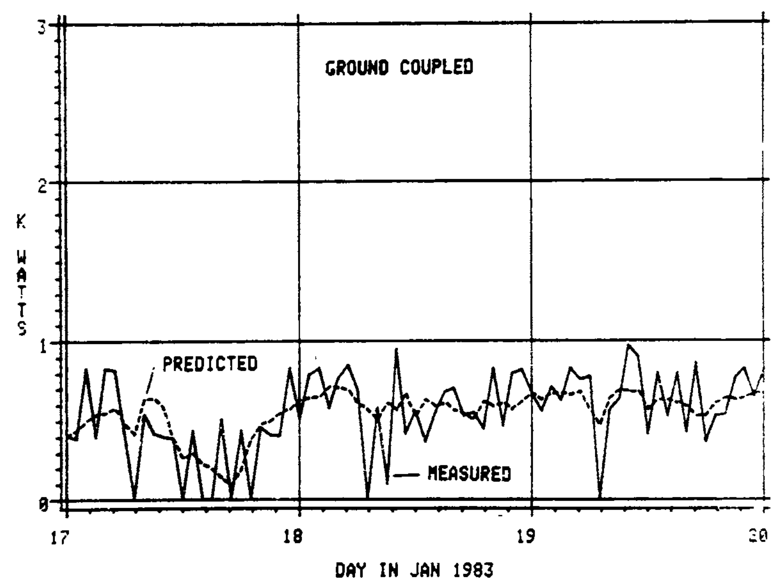


Figure 22. Comparison of Measured And Simulated Hourly HVAC Consumption for Heating

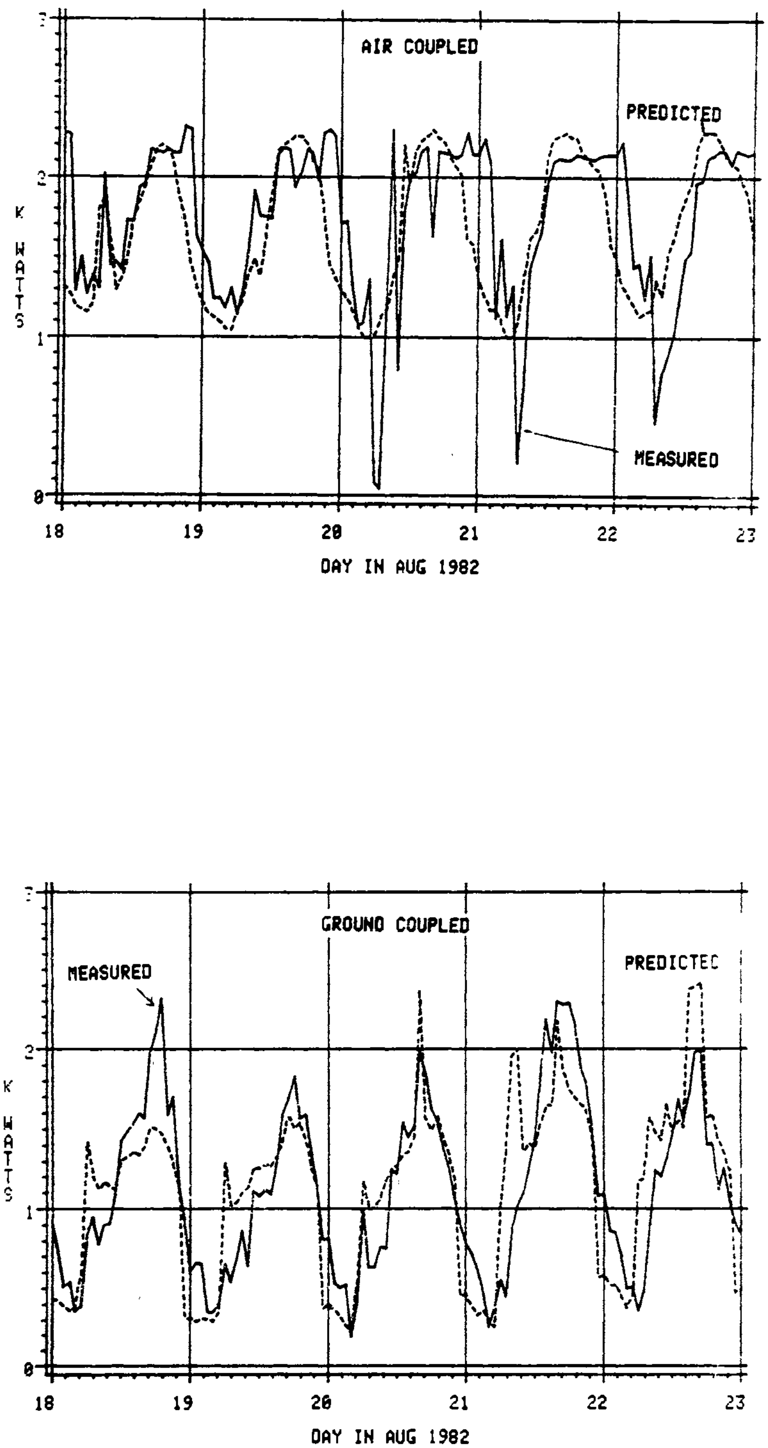


Figure 23. Comparison of Measured And Simulated Hourly HVAC Consumption for Cooling

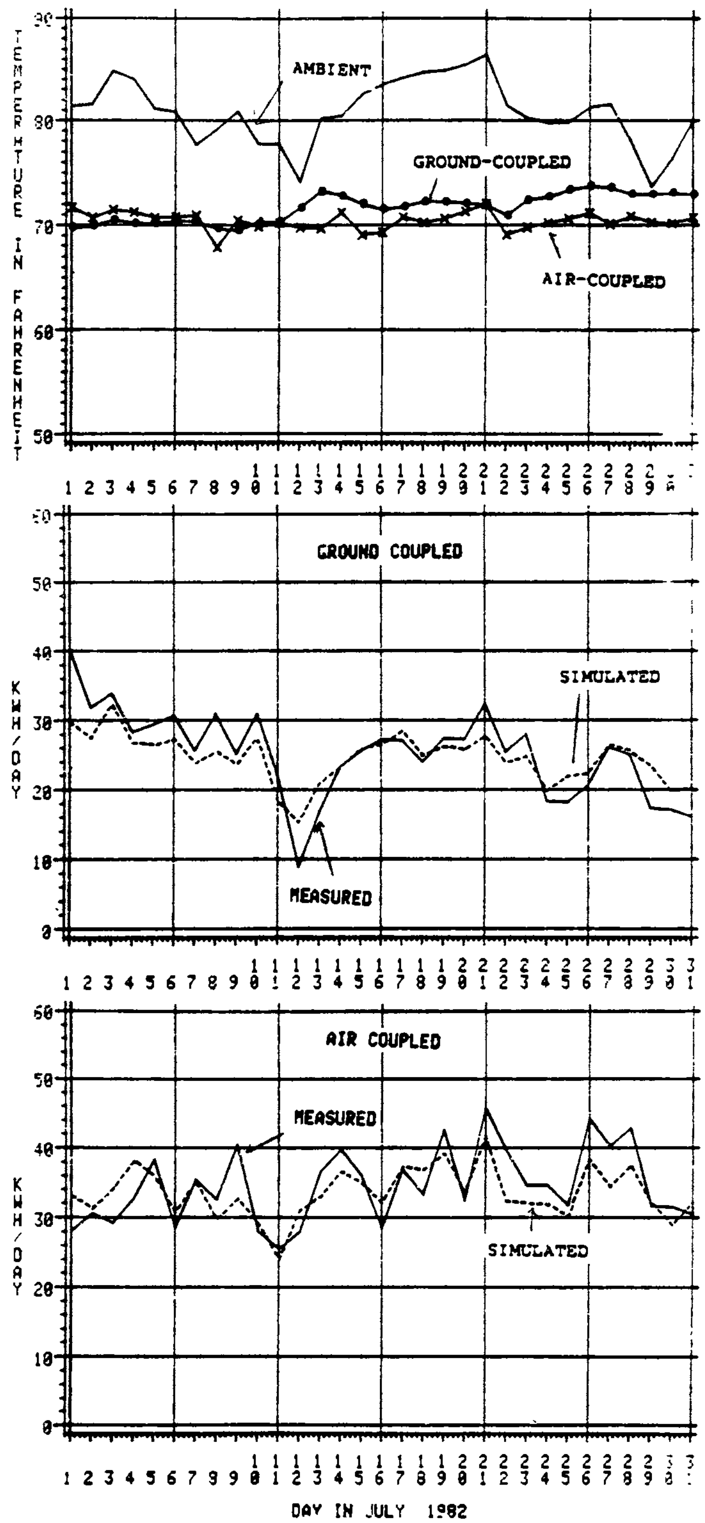


Figure 24. Comparison of Measured and Simulated Daily HVAC Consumption for July 1982 along with Measured Indoor and Outdoor Daily Average Temperature.

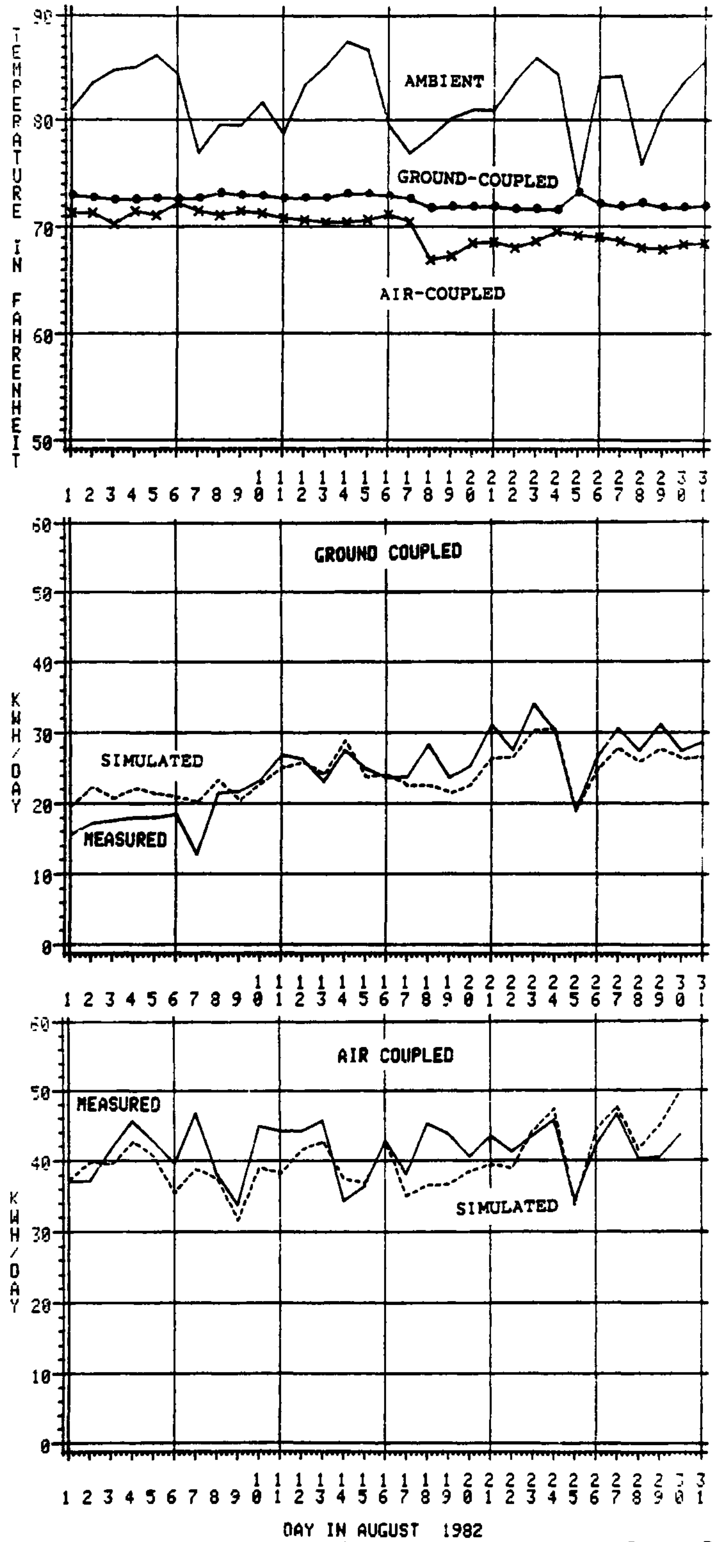


Figure 25. Comparison of Measured and Simulated Daily HVAC Consumption for August 1982 along with Measured Indoor and Outdoor Daily Average Temperature.

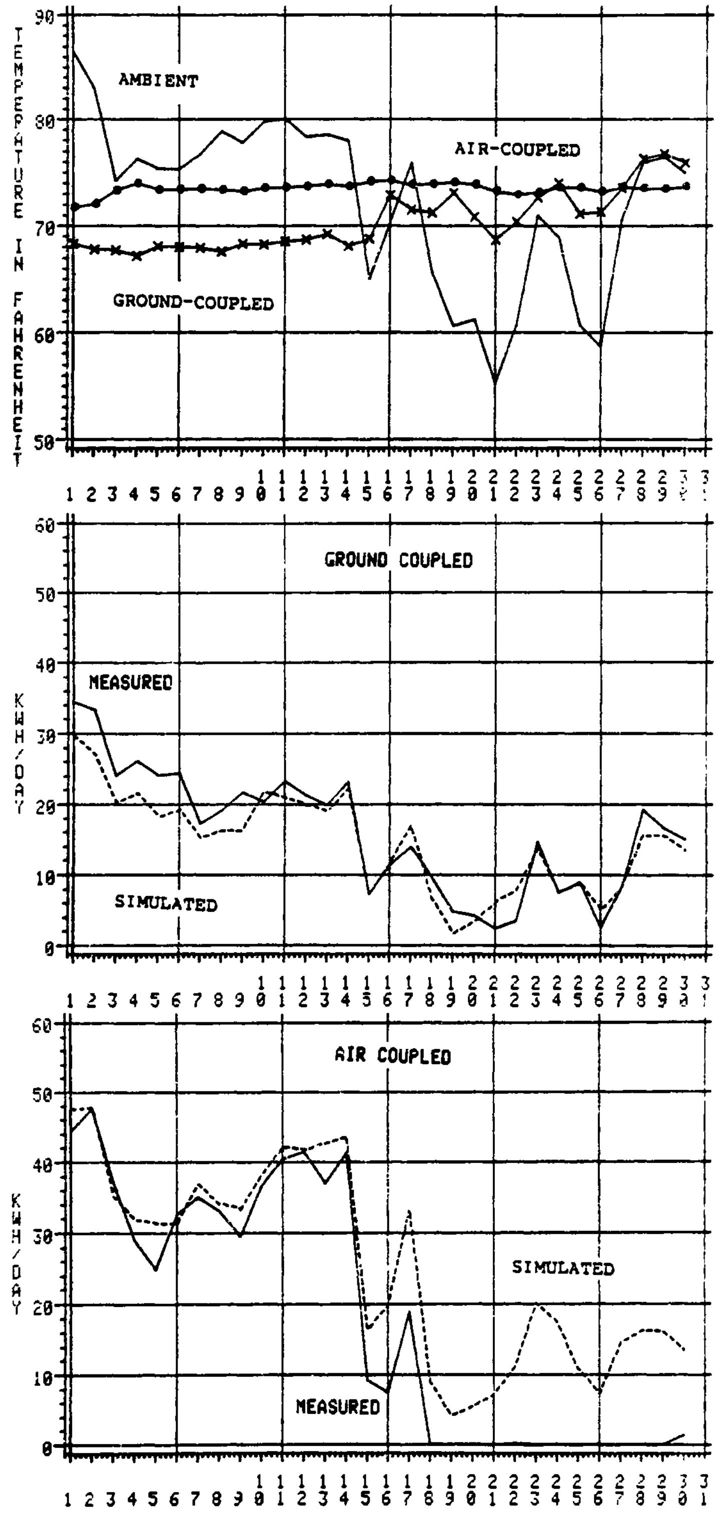


Figure 26. Comparison of Measured and Simulated Daily HVAC Consumption for September 1982 along with Measured Indoor and Outdoor Daily Average Temperature.

lated values follow the measured values and the simulated total HVAC demand of the whole month is very close to the measured actual values. However Figure 26 shows some discrepancy for the month of September 1982. The simulation results show that the heat pump system has to run to maintain a comfortable condition in the house. But measured values show the unit did not run during that period from September 18th-30th. On close examination of the indoor and outdoor temperature in Figure 26 it can be seen that the occupants had voluntarily switched off the unit and allowed the room temperature to rise.

Figures 27 through 29 show the comparison of measured and simulated HVAC energy demand for the air-coupled and ground-coupled heat pump systems for three winter months from December 1982 to February 1983. The simulated daily HVAC energy demand closely followed the pattern of measured values. The discrepancy between the measured values and simulation values can be mainly attributed to the habits of the occupants in the house. The occupants did not operate the positive ventilation system in the rest room and cooking range in the winter seasons and so a considerable amount of heat generated by hot water and appliances was added to the house and the inability to accurately measure the power consumption of the electrical equipment was also one of the reasons.

Monthly values of the simulated and measured HVAC energy demand for the whole year from April 1982 to March

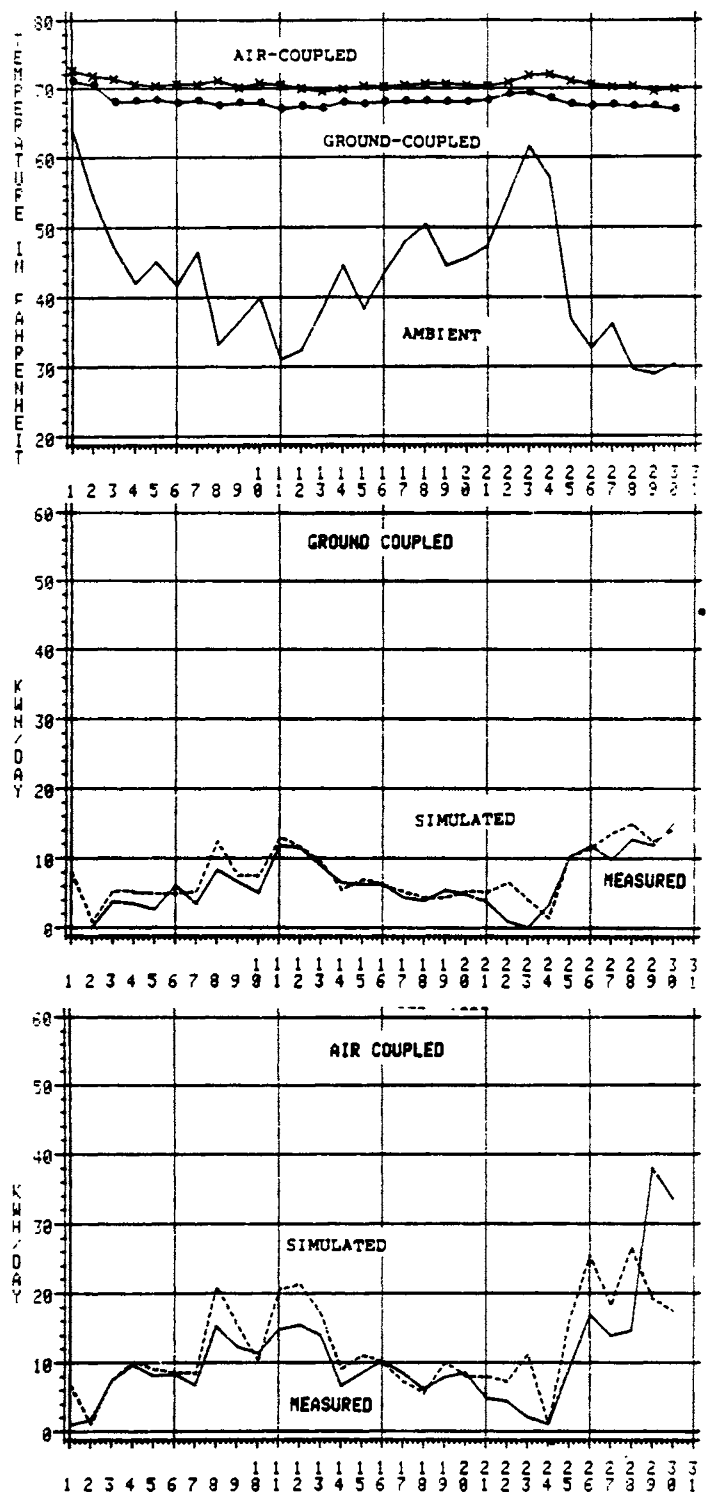


Figure 27. Comparison of Measured and Simulated Daily HVAC Consumption for December 1982 along with Measured Indoor and Outdoor Daily Average Temperature.

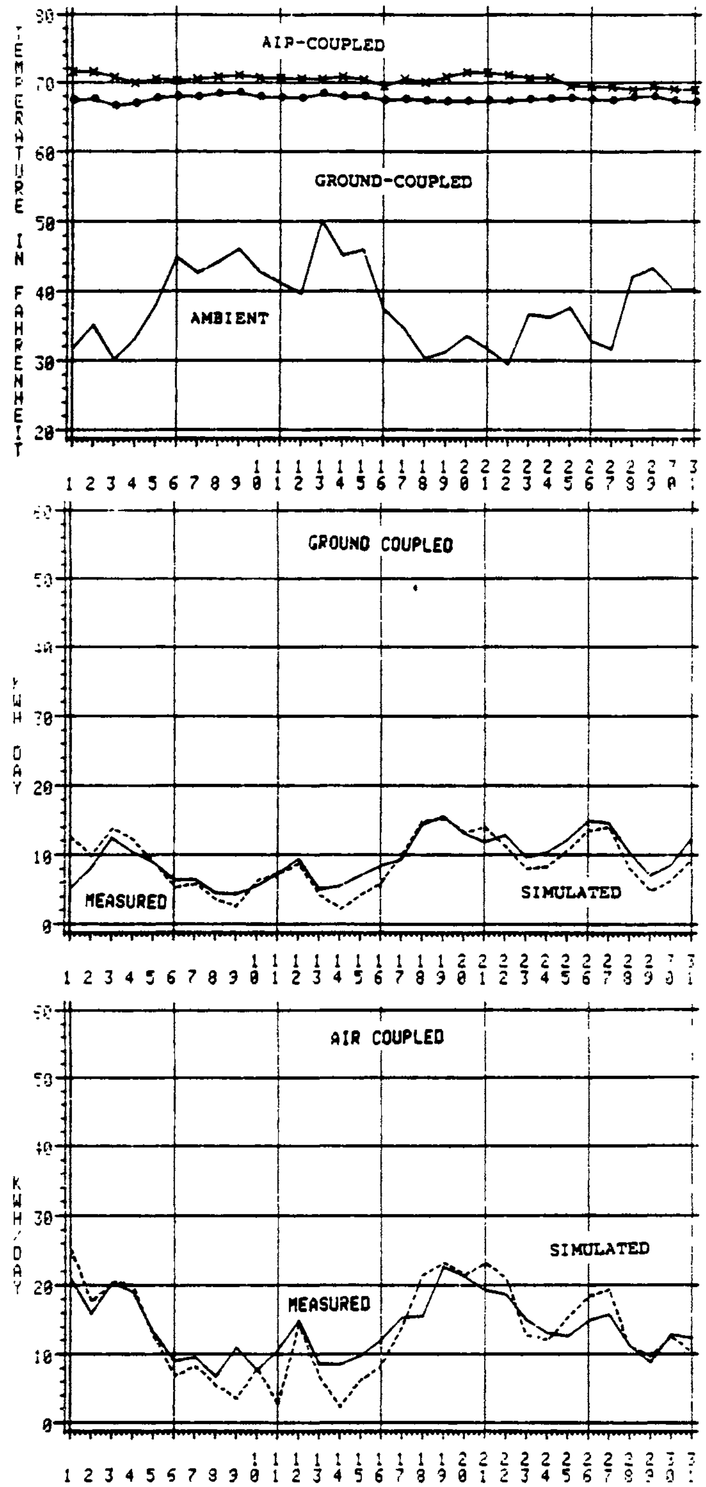


Figure 28. Comparison of Measured and Simulated Daily HVAC Consumption for January 1983 along with Measured Indoor and Outdoor Daily Average Temperature.

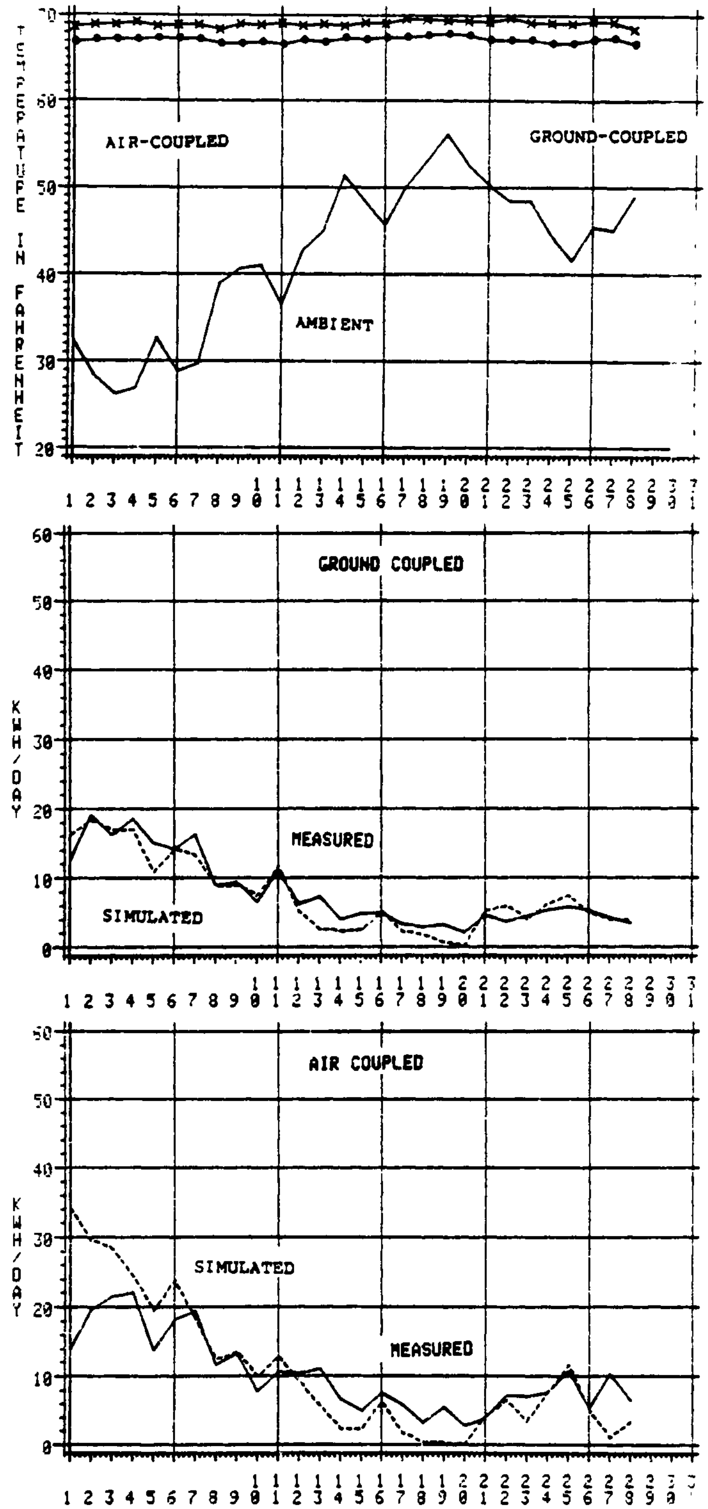
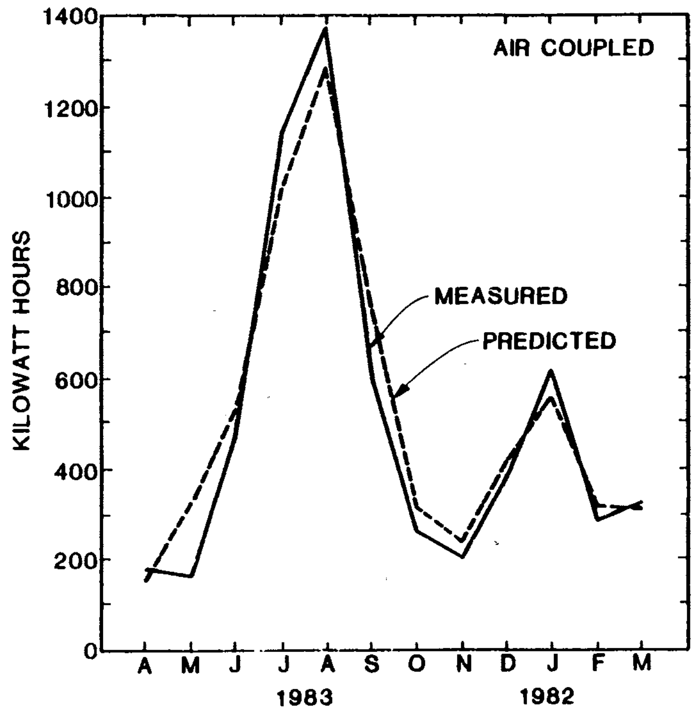


Figure 29. Comparison of Measured and Simulated Daily HVAC Consumption for February 1983 along with Measured Indoor and Outdoor Daily Average Temperature.

1983 are plotted in Figure 30 for the air-coupled heat pump system and in Figure 31 for the ground led -coupled system. Simulated values followed the path of measured values in a pretty good manner for winter and summer months. But in the month of May and November, the occupants had shut down the unit and allowed the room temperature to rise. The total annual values of the measured and simulated HVAC demand deviated only by less than 3% for both the houses.

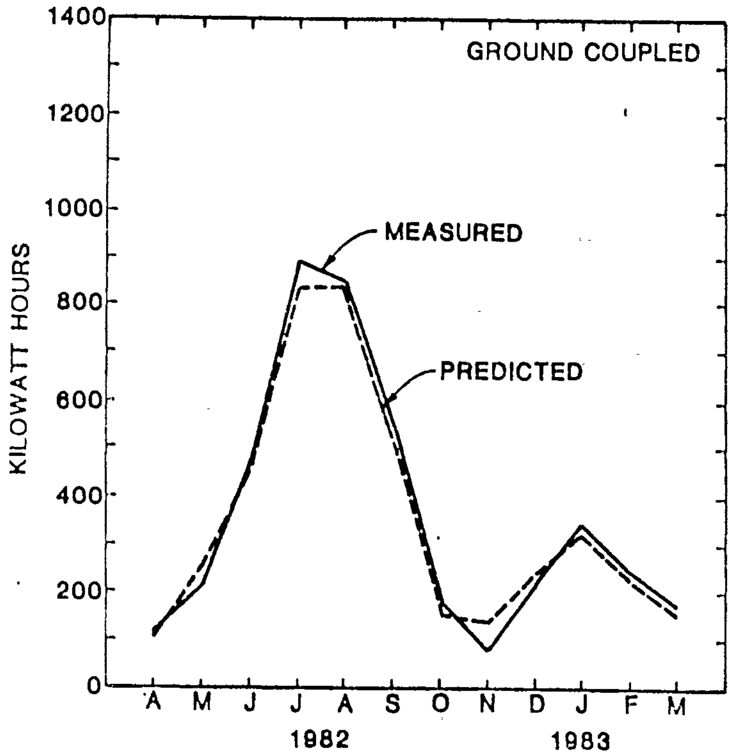
Comparison of Air-Coupled and Ground-coupled Heat Pump System Performances

Watthour meter readings were taken every week for both the air-coupled and ground-coupled houses for regular performance comparison. Figure 32 is a plot of the comparison of the monthly energy use of both the systems. Numerical values of the monthly energy use are given in the Table IV From the measured data, the number of hours the fan ran per day is determined and plotted in Figure 33, which is a comparison of hours of operation of the air-coupled and ground-coupled heat pump systems to the daily average outdoor temperature for a period of 15 months from January,1982 to March, 1983. Comparison of HVAC demand to outdoor temperature for air-coupled and ground-coupled houses for January,1982 is plotted in Figure 34. It can seen from the Figures 33 & 34 that the ground-coupled heat pump system is superior to air-coupled heat pump system in terms of demand



MONTH	MEASURED	PREDICTION	AVG PREDICTED COP
APR 82	186	169	1.75
MAY 82	176	329	1.82
JUN 82	474	521	1.79
JUL 82	1149	1038	1.72
AUG 82	1374	1288	1.71
SEP 82	601	759	1.77
OCT 82	279	321	1.81
NOV 82	208	240	1.60
DEC 82	391	411	1.64
JAN 83	613	561	1.57
FEB 83	288	318	1.63
MAR 83	322	311	1.70
TOTAL or Avg.	6061	6258	1.709

Figure 30. Comparison of Measured and Predicted Monthly HVAC Consumption for Air-Coupled House



MONTH	MEASURED	PREDICTED	AVG. PREDICTED COP
APR 82	113	100	2.47
MAY 82	206	249	2.61
JUN 82	482	468	2.08
JUL 82	895	834	1.91
AUG 82	851	845	1.98
SEP 82	541	521	2.18
OCT 82	181	165	2.59
NOV 82	84	136	2.60
DEC 82	212	226	2.55
JAN 83	353	329	2.60
FEB 83	252	222	2.59
MAR 83	177	163	2.00
TOTAL	4347	4256	2.396

Figure 31. Comparison of Measured and Predicted Monthly HVAC Consumption for Ground-Coupled House

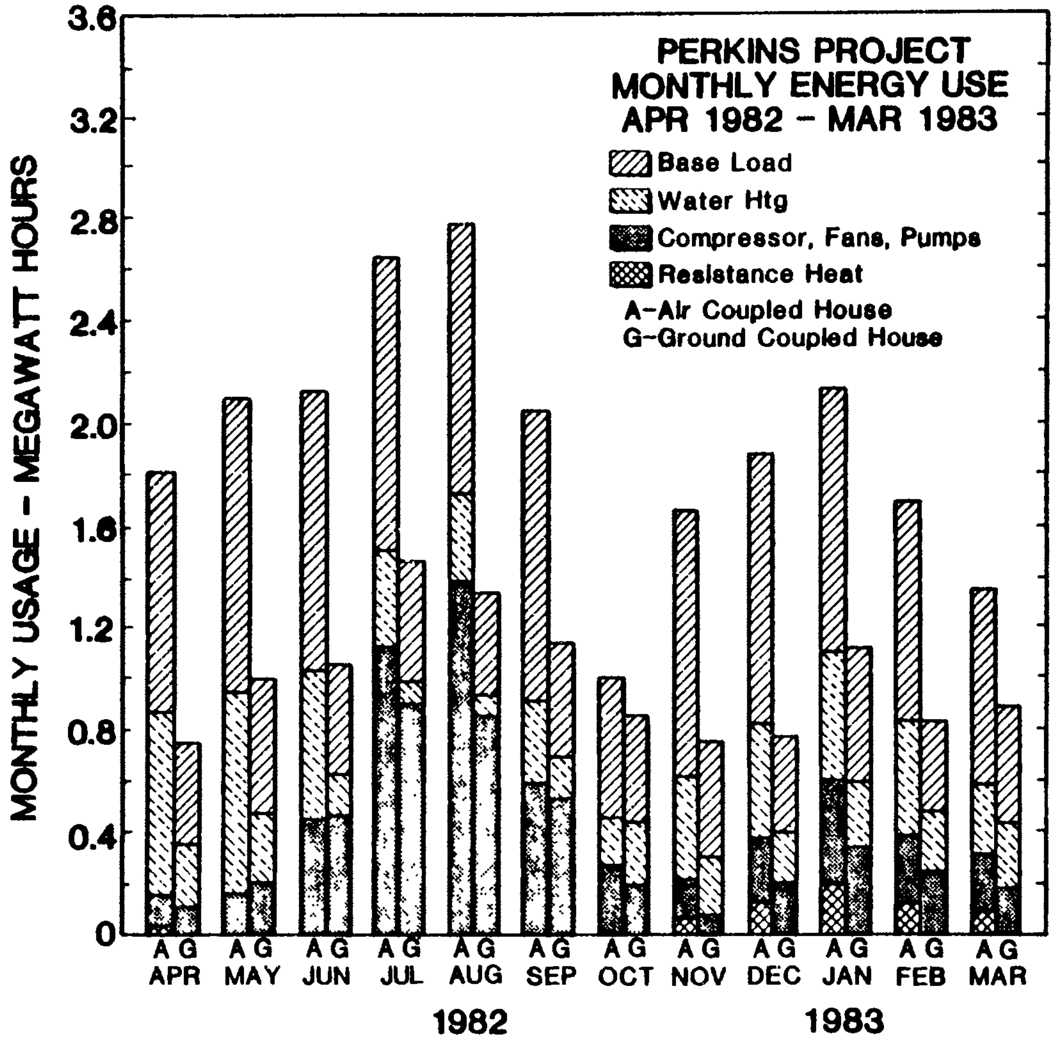


Figure 32. Comparison of Monthly Energy Use of Air-Coupled House and Ground-Coupled House

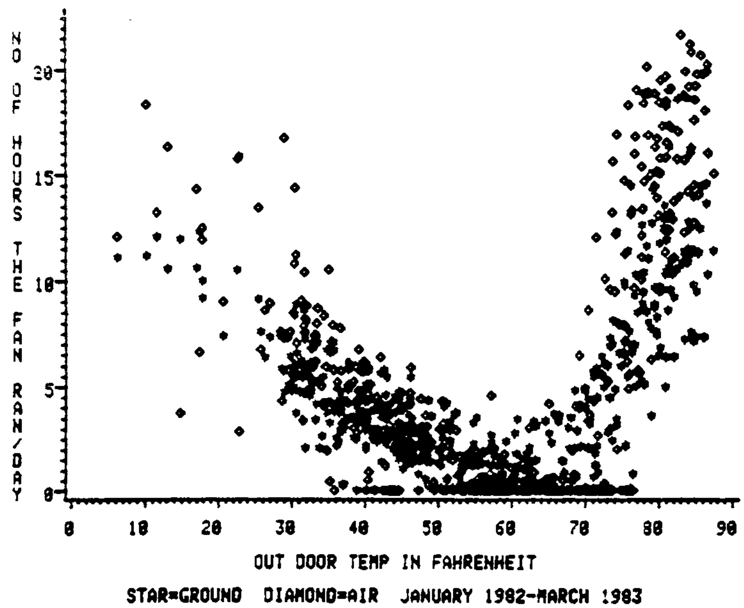


Figure 33. Comparison of Hours Of Operation of Air-Coupled and Ground-Coupled Heat Pumps to Average Outdoor Temperature

TABLE VII

MONTHLY ENERGY USE (KW) FOR THE AIR-COUPLED AND GROUND-COUPLED RESIDENCES, APRIL 1982- MARCH 1983

	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.
AIR COUPLED												
RESISTANCE	54	3	6	16	19	9	10	64	122	196	119	91
COMPRESSOR AND FANS	132	173	468	1133	1355	592	269	144	269	417	269	231
WATER HTG.	618	796	580	359	338	337	188	408	447	492	461	279
BASE LOAD	1010	1134	1073	1154	1070	1112	548	1032	1047	1028	859	765
TOTAL	1814	2106	2127	2662	2782	2050	1015	1648	1885	2133	1708	1366
GROUND COUPLED												
RESISTANCE	0	0	0	0	0	0	0	0	0	0	0	0
COMPRESSOR AND FANS	113	206	482	895	851	541	182	84	212	353	252	177
WATER HTG.	257	288	162	114	85	163	242	222	200	261	231	248
BASE LOAD	409	523	434	461	398	439	426	447	385	508	354	467
TOTAL	779	1017	1078	1470	1334	1143	850	753	797	1122	837	892

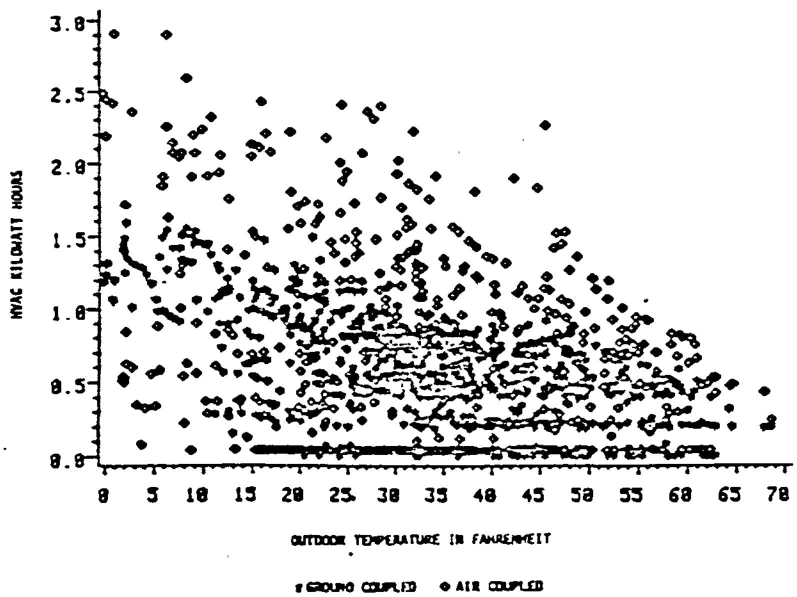
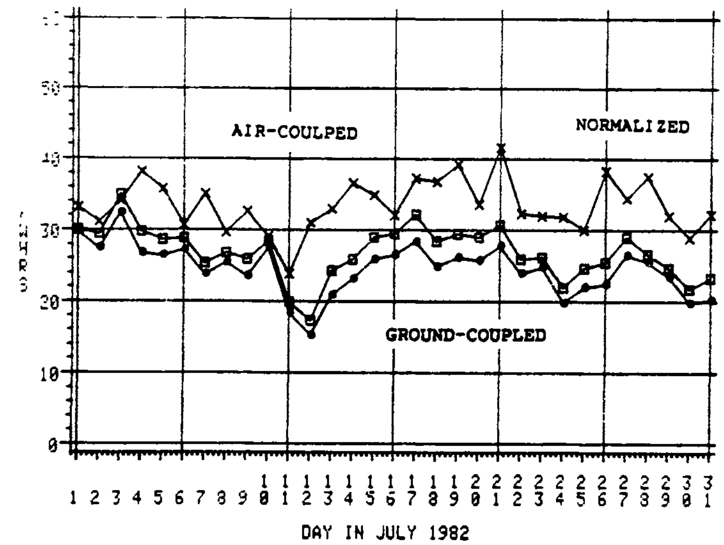


Figure 34. Comparison of Hourly Demand to Outdoor Temperature for Air-Coupled and Ground-Coupled Houses in January 1982

at temperature extremes.

The computer simulation program was run for air-coupled and ground-coupled heat heat pump systems to compare the HVAC energy demand and performance for a period of one year from April 1982 to March 1983. The simulation program utilizes the measured outdoor weather conditions and internal loads of the air-coupled and ground-coupled houses individually. The comparison of performance of heat pumps in the otherwise identically designed houses was complicated by the variation of life styles of the occupants, indoor temperature, number of people and internal appliances and equipment. So it was decided to compare the two systems under two main categories. First comparing HVAC demand and the performance of the heat pump systems by using individual house internal loads and conditions. Second,comparing with normalized load , that is both the systems are subjected to same internal and external load conditions. The ground-coupled heat pump system house thermal load was used for this purpose.

Figures 35 through 37 show the comparison of the air-coupled and ground-coupled heat pump system for the three summer months from July, 1982 to September 1982. It can be seen that EER of the ground-coupled system was always higher than air-coupled system. Even with normalized thermal loads the performance varied only by a very small percentage from the regular performance which clearly shows the superiority of the ground-coupled heat pump system.



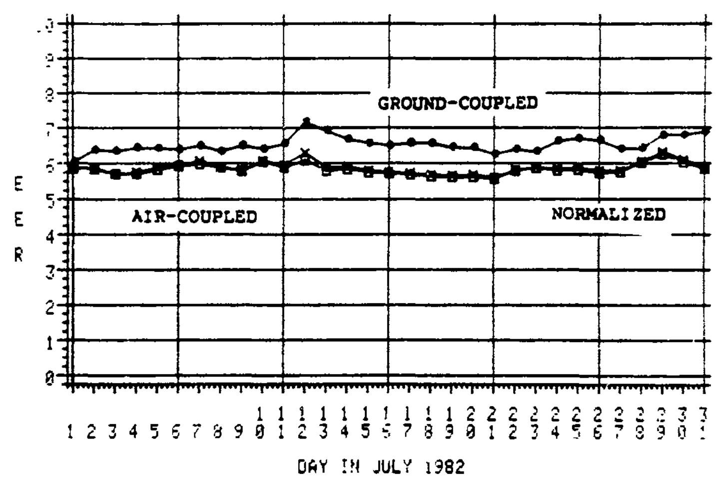
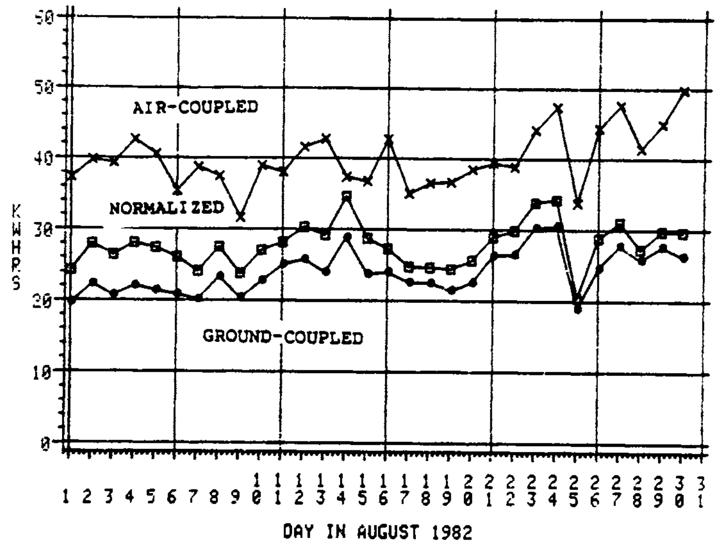


Figure 35. Comparison of Daily HVAC Consumption and Efficiencies of Air-Coupled ,Ground-Coupled and Normalised Ground-Coupled Heat Pumps for the Month of July 1982.



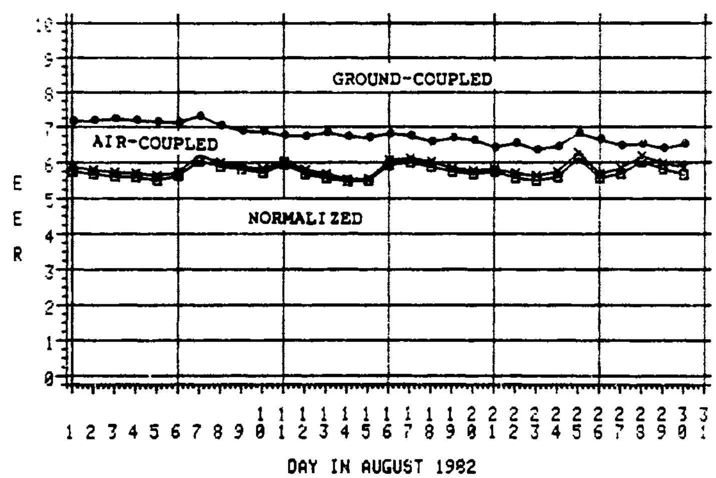
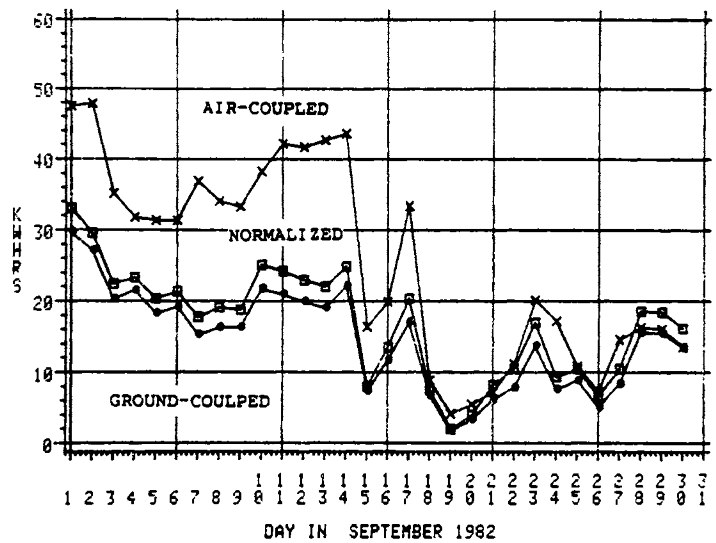


Figure 36. Comparison of Daily HVAC Consumption and Efficiencies of Air-Coupled ,Ground-Coupled and Normalised Ground-Coupled Heat Pumps for the Month of August 1982.



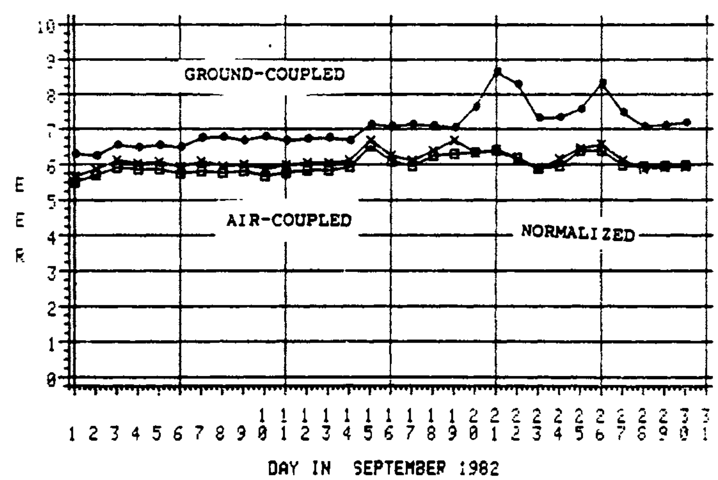


Figure 37. Comparison of Daily HVAC Consumption and Efficiencies of Air-Coupled ,Ground-Coupled and Normalised Ground-Coupled Heat Pumps for the Month of September 1982.

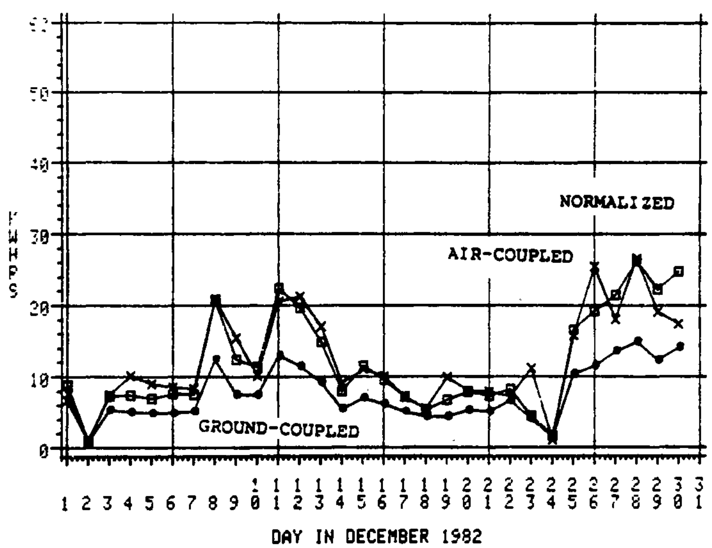
There is quite a difference in the HVAC energy usage during the summer months between normalized load and individual load curves. This is mainly due to the reason that the normalized load is that of the ground-coupled house which was maintained at a higher indoor temperature.

Figures 38 through 40 shows the comparison of the air-coupled and ground-coupled heat pump systems with normalized and individual loads for three winter months from December, 1982 to February, 1983. The high COP of the ground-coupled heat pump system can be very clearly seen in these plots . The performance of the air-coupled unit did not change even with the normalized load. On an average, the difference in COP of the system is one.

Comparison of the two systems with and without normalization loads is plotted for the whole year in Figure 41 and the numerical values are given in the same plot. The main objectives of this study were achieved and are shown in this plot, the Ground Coupled unit was consuming less energy for HVAC purposes throughout the year. It significantly reduced the peak demand both during the summer and winter months. The savings in the HVAC energy consumption is more than 29%.

Comparison with Freidrich Ground-Coupled Heat Pump System

During recent years, the design of ground-coupled heat pump system has undergone numerous changes for better efficiency. It was decided to compare the Carrier air-coupled



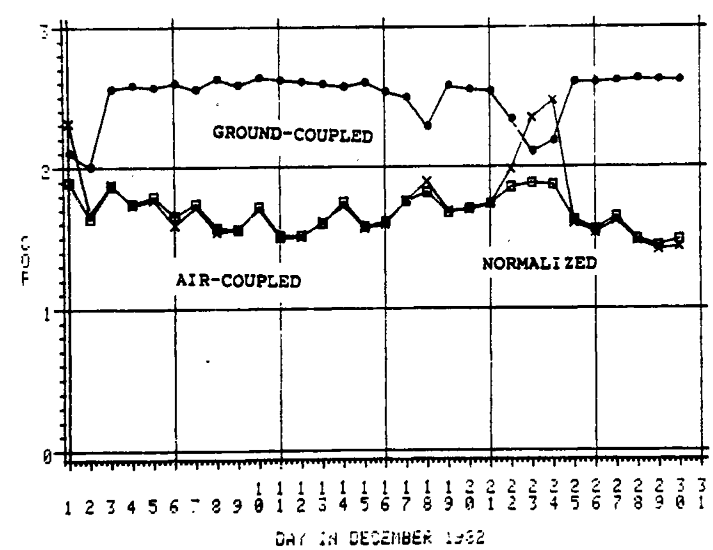
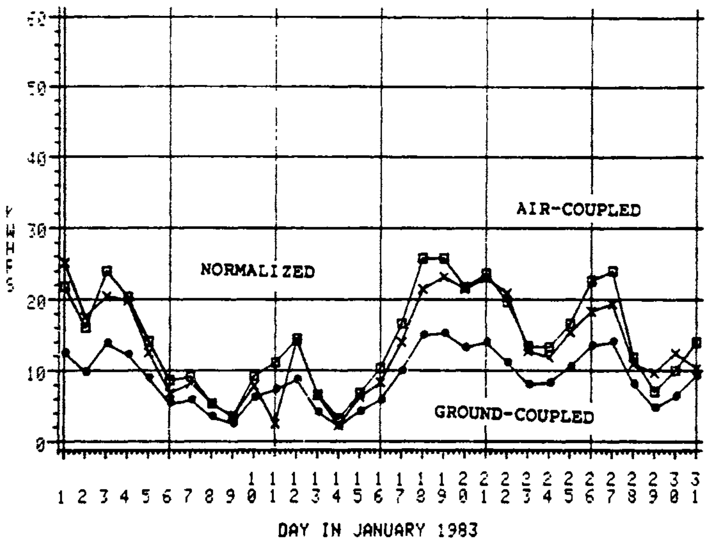


Figure 38. Comparison of Daily HVAC Consumption and Efficiencies of Air-Coupled ,Ground-Coupled and Normalised Ground-Coupled Heat Pumps for the Month of Decamber 1982.



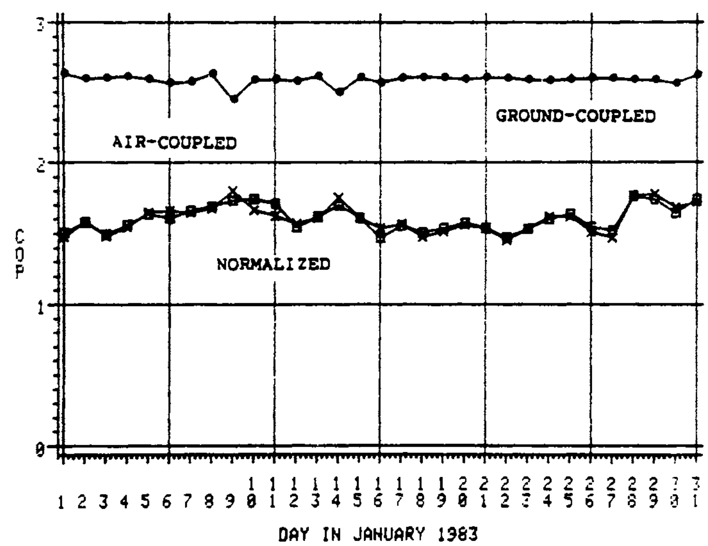
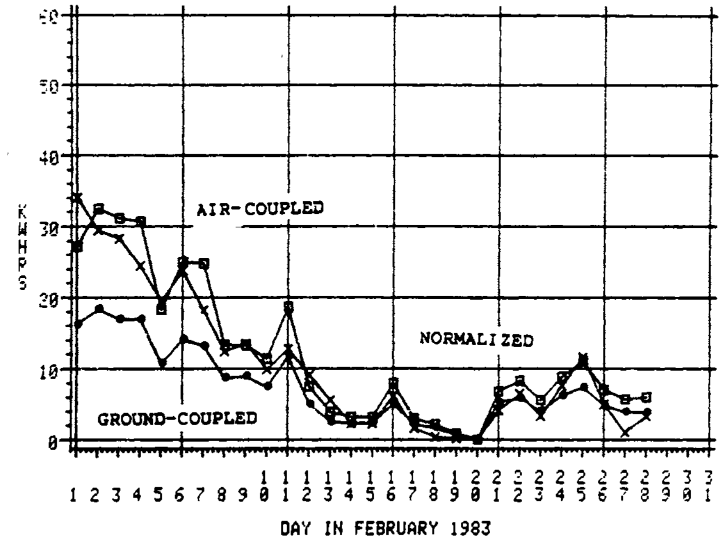


Figure 39. Comparison of Daily HVAC Consumption and Efficiencies of Air-Coupled ,Ground-Coupled and Normalised Ground-Coupled Heat Pumps for the Month of January 1983.



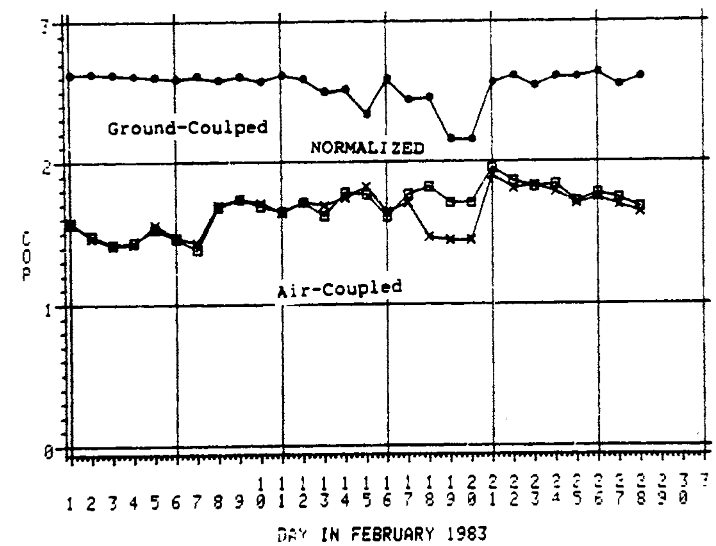
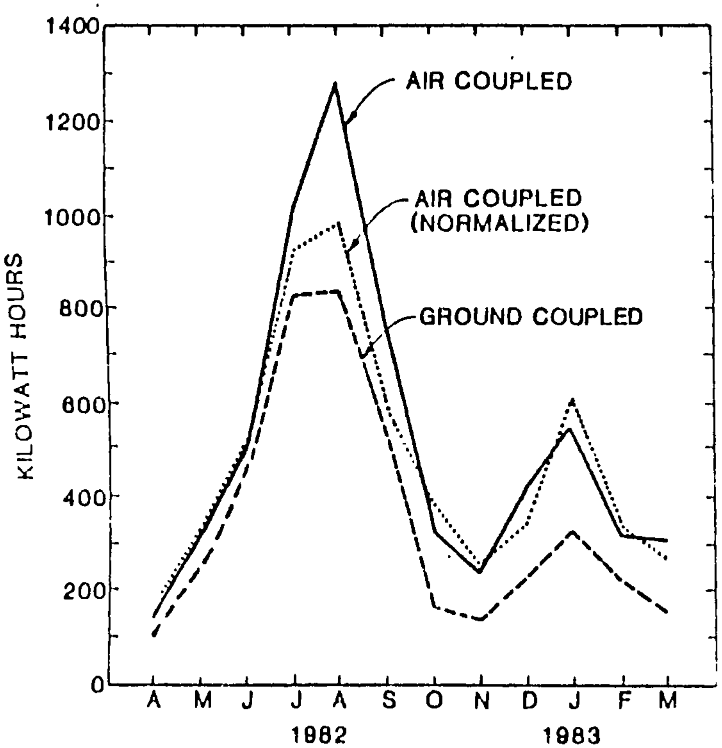


Figure 40. Comparison of Daily HVAC Consumption and Efficiencies of Air-Coupled ,Ground-Coupled and Normalised Ground-Coupled Heat Pumps for the Month of February 1983.

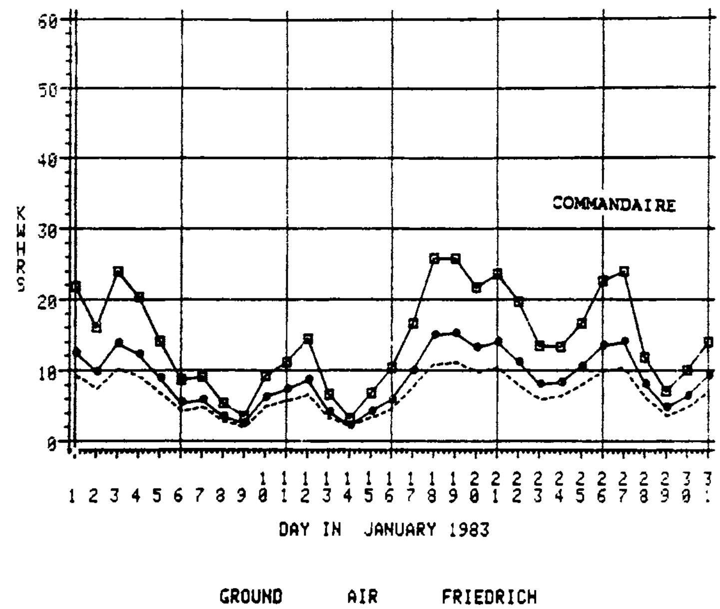


MONTH	AIR	GROUND	NORMALIZED AIR	NORMALIZED AIR COP
APR 82	161	100	163	1.75
MAY 82	329	249	334	1.81
JUN 82	521	468	508	1.80
JUL 82	1038	833	928	1.70
AUG 82	1288	844	989	1.72
SEP 82	759	521	589	1.73
OCT 82	321	165	380	1.81
NOV 82	240	136	244	1.62
DEC 82	411	226	352	1.64
JAN 83	561	329	614	1.58
FEB 83	318	222	337	1.58
MAR 83	311	163	272	1.68
TOTAL	6258	4256	5710	1.70

Figure 41. Normalized Comparison of Monthly HVAC Consumption for Air-coupled and Ground-Coupled Houses

and Commandaire ground-coupled heat pump system with a similar system using a recently developed Freidrich ground-coupled heat pump which has a higher manufacturers rated performance characteristics. The steady state performance data obtained from the manufacturers was incorporated in the system simulation computer program.

The thermal load of the ground-coupled (west house) was applied to the Carrier air-coupled, Commandaire ground-coupled and Freidrich ground-coupled systems and the results were plotted in Figure 42 for August 1982 (summer) and for January 1983 (winter) in Figure 43. The Freidrich ground-coupled heat pump with a higher manufacturers rated performance characteristics could apparantly both save more energy and further reduce the peak demand.



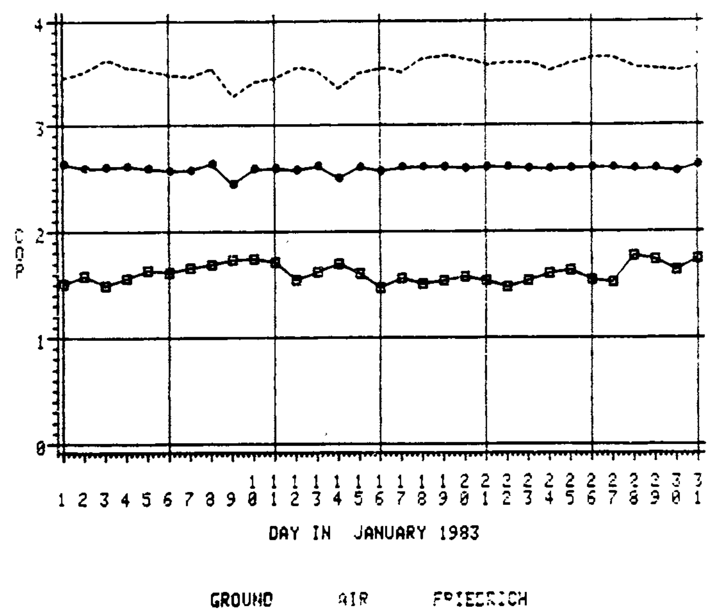
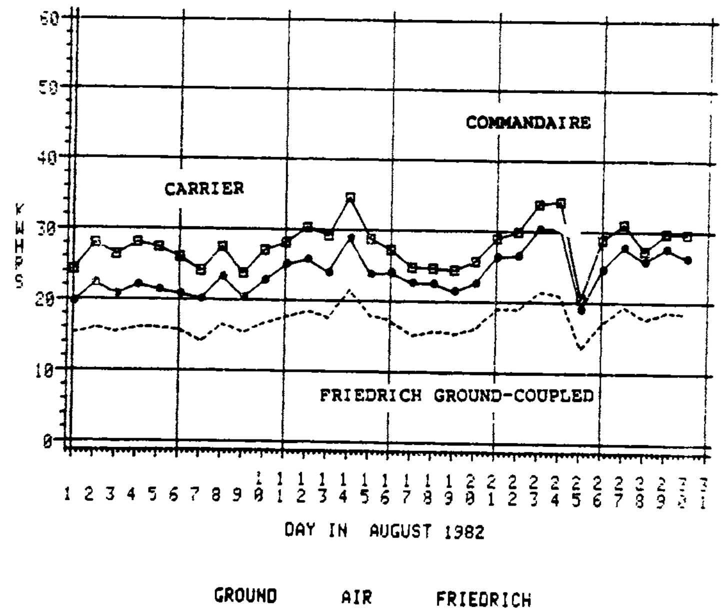


Figure 42. Normalised HVAC Consumption and Efficiencies for Three Heat Pumps for the Month of January 1983.



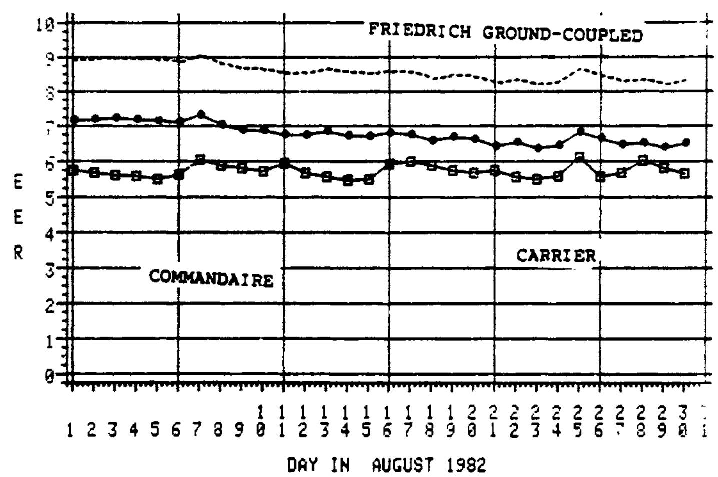


Figure 43. Normalised HVAC Consumption and Efficiencies for Three Heat Pumps for the Month of August 1982.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions were arrived at :

1. The building thermal load and system simulation programs gave good results in predicting the HVAC energy demand, closely following the path of the measured values.

2. The ground-coupled heat pump system was superior to the air-coupled heat pump system in reducing the HVAC demand.

3. The ground-coupled heat pump system operated throughout the study period (April 1982 to March 1983) without using any backup resistance heat.

4. The U-tube ground-coupled heat exchanger operated without any problem for the whole study period from April 1982 to March 1983.

5. The overall reliability of the heat pump systems was excellent.

6. The data acquisition system worked satisfactorily and good data have been collected and stored in IBM magnetic disk tapes for the period from January 1982 to March 1983.

7. The Freidrich ground-coupled heat pump system had better performance characteristics than the Commandaire

ground-coupled heat pump and the Carrier air-coupled heat pump systems when modeled in a simulation of the load.

A suggestion regarding further work on this project is:

1. A complete economic study should be performed in order to determine the economic feasibility of the ground-coupled systems.

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APPENDIX A.

PHYSICAL DATA,DIMENSIONS, AND PERFORMANCE DATA FOR THE HEAT PUMP UNITS

Carrier 38CQ015/40AQ018 Air-to-Air Heat Pump Heating and Cooling Performance

INTEGRATED HEATING CAPACITIES*

OUTDOOR UNIT	INDOOR UNIT	TEMPERATURE OF AIR ENTERING OUTDOOR UNIT (Edb)																				
		-10		0		10		17		20		30		40		47		50		60		70	
		Cap.	Kw	Cap.	Kw	Cap.	Kw	Cap.	Kw	Cap.	Kw	Cap.	Kw	Cap.	Kw	Cap.	Kw	Cap.	Kw	Cap.	Kw	Cap.	Kw
38CQ015	40AQ018	4.5	1.3	5.5	1.6	7.0	1.6	8.5	1.7	9.0	1.7	11.0	1.7	13.5	1.8	16.5	2.0	17.5	2.1	20.5	2.2	24.0	2.2

38CQ015/40AQ018

Temp (F) Air Ent Outdoor Unit		Air Ent Indoor Unit — Cfm/BF								
		515/.10			575/.11			645/.12		
		Indoor Unit Ent Air Temp — Ewb (F)								
		72	67	62	72	67	62	72	67	62
85	TC	16 5	15 6	14 7	16 4	15.6	14 9	16 5	15 7	15.2
	SHC	8 4	11 1	13 7	8 4	11 5	14.3	8 7	11 9	14 8
	KW	2 08	2 03	1 98	2.10	2.06	2.02	2 14	2 10	2.07
95	TC	16 4	15 3	14 1	16 4	15.5	14 4	16 6	15 6	14 7
	SHC	8 4	11 4	13 6	8 6	11 9	14 2	8 9	12 4	14 6
	KW	2 23	2 17	2 10	2.25	2 20	2.14	2.30	2 24	2.19
100	TC	16.2	15 0	13 8	16 3	15.1	14 1	16 4	15.3	14 4
	SHC	8 5	11 2	13 4	8 7	11 8	13 9	9 0	12 3	14 4
	KW	2 30	2 23	2 15	2.33	2.26	2 19	2.38	2 31	2.25
105	TC	16 1	14 7	13 4	16 2	14 8	13 7	16 3	15 0	14 1
	SHC	8 5	11 1	13 1	8 8	11 6	13 6	9 1	12 3	14 1
	KW	2 38	2 28	2 20	2 41	2 32	2.25	2 46	2 37	2 31
115	TC	15 8	14 0	12 8	15 9	14 1	13.1	16 1	14 3	13 4
	SHC	8 5	10 8	12 7	8 9	11.4	13 1	9 3	12 1	13 5
	KW	2 53	2 40	2 30	2 58	2 44	2.36	2 61	2 49	2 42

Cap. – Capacity (1000 Btuh), includes fan motor heat and deduction for thermal line losses of 15 ft of piping exposed to outdoor conditions

Kw – Power input includes compressor motor power input, indoor and outdoor fan motor input

*Integrated Heating Capacities – Values shown reflect a capacity reduction at those outdoor air temperatures at which frost forms on outdoor coil

HEATING CAPACITY CORRECTION FACTORS

CFM/TON* ENT INDOOR COIL	CORRECTION FACTORS		TEMP AIR ENT INDOOR COIL (F)	CORRECTION FACTORS	
	Cap.	Power		Cap.	Power
400	98	99	65	1 02	99
450	1 0	1 0	70	1 0	1 0
500	1 02	1 01	75	98	1 01

*Determine cfm/ton from Combination Rating tables

COMBINATION RATING NOTES

1. Direct interpolation is permissible Do not extrapolate
2. SHC is based on 80 F db temperature of air entering indoor unit. Below 80 F db, subtract (corr factor x cfm) from SHC.

   Above 80 F db, add (corr factor x cfm) to SHC.

BYPASS FACTOR	ENTERING AIR DRY-BULB TEMP (F)					
	79 / 81	78 / 82	77 / 83	76 / 84	75 / 85	under 75 / over 85
	Correction Factor					
.10	98	1 96	2 94	3 92	4 91	Use formula shown below
20	87	1 74	2 62	3 49	4 36	
30	76	1 53	2 29	3 05	3 82	

Interpolation is permissible

Correction Factor = 1 09 x (1 - BF) x (db - 80)

Command-Aire SWP-150 Water-to-Air Heat Pump Heating and Cooling Performance

Cooling Performance 150

EWT	600 CFM 80° ENT DB TEMP.	ENTERING AIR WET BULB TEMP 3 GPM 63°	3 GPM 67°	3 GPM 71°	4 GPM 63°	4 GPM 67°	4 GPM 71°	5 GPM 63°	5 GPM 67°	5 GPM 71°
80°	TOTAL / SENSIBLE MBH	17.0 / 14.9	18.0 / 12.7	19.2 / 10.4	18.2 / 15.4	19.5 / 13.2	20.8 / 10.8	19.0 / 15.6	20.4 / 13.6	21.8 / 11.3
	COMPRESSOR INPUT KW	2.31	2.44	2.56	2.13	2.23	2.33	2.04	2.11	2.19
	HEAT REJECTED MBH	25.6	27.0	28.8	26.1	27.8	29.4	26.6	28.3	30.0
90°	TOTAL / SENSIBLE MBH	15.9 / 14.4	17.0 / 12.3	17.9 / 9.9	17.1 / 14.9	18.4 / 12.8	19.7 / 10.6	18.0 / 15.2	19.4 / 13.2	20.7 / 10.9
	COMPRESSOR INPUT KW	2.46	2.58	2.70	2.27	2.38	2.48	2.18	2.27	2.35
	HEAT REJECTED MBH	25.0	26.5	27.8	25.5	27.2	28.8	26.1	27.8	29.4
100°	TOTAL / SENSIBLE MBH	14.9 / 14.0	15.8 / 11.8	16.6 / 9.3	16.1 / 14.5	17.2 / 12.3	18.4 / 10.1	16.9 / 14.8	18.2 / 12.7	19.5 / 10.5
	COMPRESSOR INPUT KW	2.62	2.74	2.86	2.43	2.55	2.65	2.32	2.42	2.52
	HEAT REJECTED MBH	24.5	25.8	27.0	25.1	26.6	28.1	25.5	27.1	28.8

Air Volume Factor - Cooling

CFM	400	500	600	700	800
TOT COOL & HT REJ MBH	0.92	0.97	1.00	1.03	1.05
SENSIBLE COOLING MBH	0.83	0.92	1.00	1.07	1.14
COMPRESSOR INPUT KW	0.97	0.99	1.00	1.01	1.02

Air Volume Factor - Heating

CFM	400	500	600	700	800
TOTAL HEATING MBH	0.97	0.98	1.00	1.01	1.02
HEAT EXTRACTED MBH	0.91	0.95	1.00	1.03	1.06
COMPRESSOR INPUT KW	1.21	1.09	1.00	0.93	0.90

Sensible Cooling Factor for Other Dry Bulb Temps.

ENT W.B.	ENTERING AIR DRY BULB TEMP 74°	76°	78°	80°	82°	84°	86°
63°	0.82	0.89	0.95	1.00	1.10		
67°		0.83	0.91	1.00	1.07	1.14	1.22
71°				1.00	1.07	1.16	1.25

150 SW - SWP
SWH - SWPH

Heating Performance 150

EWT	600 CFM	ENTERING AIR DRY BULB TEMP 3 GPM 60°	3 GPM 70°	3 GPM 80°	4 GPM 60°	4 GPM 70°	4 GPM 80°	5 GPM 60°	5 GPM 70°	5 GPM 80°
60°	TOTAL HEATING MBH	21.6	21.0	20.5	23.6	22.9	22.5	24.8	24.1	23.6
	HEAT EXTRACTED MBH	15.3	14.5	13.7	17.0	16.0	15.2	17.5	16.5	15.5
	COMPRESSOR INPUT KW	1.87	1.93	2.02	1.96	2.05	2.15	2.14	2.25	2.39
70°	TOTAL HEATING MBH	23.9	23.2	23.0	26.2	25.6	25.1	27.4	26.7	26.2
	HEAT EXTRACTED MBH	17.2	16.2	15.5	19.0	18.0	17.0	19.5	18.4	17.4
	COMPRESSOR INPUT KW	1.99	2.07	2.22	2.13	2.25	2.39	2.34	2.46	2.59
80°	TOTAL HEATING MBH	26.1	25.9	25.6	28.9	28.4	27.7	30.1	29.5	28.8
	HEAT EXTRACTED MBH	19.0	18.2	17.4	21.1	20.0	18.8	21.5	20.4	19.3
	COMPRESSOR INPUT KW	2.10	2.26	2.42	2.31	2.47	2.63	2.54	2.67	2.80

Channel No.	Description	Multiplier	Units
00	Day	---	Day
01	Hour	---	Hour
02	Minute	---	Minute
03	Outdoor temp	X 0.1	Celsius
04	East in temp	X 0.1	Celsius
05	Solar in temp	X 0.1	Celsius
06	Middle in temp	X 0.1	Celsius
07	West well out temp	X 0.1	Celsius
08	West well in temp	X 0.1	Celsius
09	West in temp	X 0.1	Celsius
10	Middle well in temp	X 0.1	Celsius
11	Middle well out temp	X 0.1	Celsius
12	Solarout temp	X 0.1	Celsius
13	Outside rel-humidity	X 0.1	% RH
14	East rel-humidity	X 0.1	% RH
15	West rel-humidity	X 0.1	% RH
16	Middle rel-humidity	X 0.1	% RH
17	Hori insolation	% 886	kw/sq.m
18	Ver insolation	% 688	kw/sq.m
19	Not used	---	---
20	Not used	---	---
21	Not used	---	---
22	West total power	X 24.0	W.hr/15.min
23	Mid total power	X 24.0	W.hr/15.min
24	East total power	X 24.0	W.hr/15.min
25	Wind direction	---	Degrees
26	Wind speed	---	M p h
27	Wind Run	---	---
28	East hot water	X 1000	Btus
29	East hot water	---	Gallons
30	East Resistance	X 0.72	W.hr/15.min
31	Not used	---	---
32	East hot shot	X 0.24	W.hr/15.min
33	Not used	---	---
34	East Comp	X 0.72	W.hr/15.min
35	East in fan	X 0.24	W.hr/15.min
36	East out fan	X 0.24	W.hr/15.min
37	West hot water	---	Gallons
38	West hot water	X 1000	Btus
39	West well flow	---	Gallons
40	West well cooing	X 100	Btus
41	West resistence	X 0.72	W.hr/15.min
42	West well heating	X 100	Btus
43	West hot shot	X 0.24	W.hr/15.min
44	West comp	X 0.72	W.hr/15.min

45	West indoor fan	X 0.24	W.hr/15.min
46	West well pump	X 0.24	W.hr/15.min
47	Mid hot water	X 1000	Btus
48	Mid hot water	---	Gallons
49	Mid solar flow	---	Gallons
50	Mid solar heat	X 1000	Btus
51	Mid well flow	---	Gallons
52	Mid well colling	X 100	Btus
53	Mid resistence	X 0.72	W.hr/15.min
54	Mid hot water	X 0.9	W.hr/15.min
55	Mid hot shot	X 0.24	W.hr/15.min
56	Mid comp	X 0.72	W.hr/15.min
57	Mid indoor fan	X 0.24	W.hr/15.min
58	Mid well pump	X 0.24	W.hr/15.min
59	Mid solar pump	X 0.24	W.hr/15.min
60	East hot water	X 0.9	W.hr/15.min
61	west hot water	X 0.9	W.hr/15.min
62	Mid well heating	X 100	Btus
63	Not used	---	---

APPENDIX B

DATA TAPES

SYSTEMS SECTION

TAPE MAP VERSION 1.2 25 MAY 1983 WEDNESDAY 1.35.03

CONTENTS OF MAGNETIC TAPE VOLUME - T2225 OWNER

FILE NO	DATASET NAME	BLOCK COUNT	CREATED	EXPIRES	PASSWORD	BLKSIZE	LRECL	RECFM	TRTCH	DEN	CREATED BY JOBNAME/STEPNAME	APP. LENGTH METERS
1	FEB81.TAPE DATA	130	82.140	00.000		6160	80	FB		4	U11833AA/	4.68
2	MAR81.TAPE.DATA	232	82.140	00.000		6160	80	FB		4	U11833AA/	8.06
3	APR81.TAPE.DATA	193	82.140	00.000		6160	80	FB		4	U11833AA/	6.79
4	JUN81.TAPE.DATA	47	82 144	00 000		6160	80	FB		4	U11833AA/	1.93
5	JUL81.TAPE DATA	36	82.144	00.000		6160	80	FB		4	U11833AA/	1.50
6	JUL81 CH28.DATA	68	82.144	00.000		6160	80	FB		4	U11833AA/	2.65
7	AUG81 CH28.DATA	59	82.144	00.000		6160	80	FB		4	U11833AA/	2.34
8	AUG81.TAPE DATA	44	82.144	00.000		6160	80	FB		4	U11833AA/	1.84
9	SEP81.TAPE.DATA	236	82.144	00 000		6160	80	FB		4	U11833AA/	8.20
10	OCT81.TAPE.DATA	201	82.144	00.000		6160	80	FB		4	U11833AA/	7.03
11	NOV81.TAPE DATA	248	82.144	00 000		6160	80	FB		4	U11833AA/	8.60
12	DEC81.TAPE.DATA	242	82.144	00.000		6160	80	FB		4	U11833AA/	8.38
13	JAN82 TAPE DATA	260	82.144	00.000		6160	80	FB		4	U11833AA/	8.98
14	FEB82.TAPE.DATA	239	82.144	00.000		6160	80	FB		4	U11833AA/	8.28
15	MAR82.TAPE.DATA	271	82.148	00.000		6160	80	FB		4	U11833AA/	9.36
16	APR82.TAPE DATA	262	82.247	00.000		6160	80	FB		4	U11833AA/	9.05
17	MAY82 TAPE DATA	271	82.247	00.000		6160	80	FB		4	U11833AA/	9.35
18	JUN82.TAPE.DATA	262	82.247	00.000		6160	80	FB		4	U11833AA/	9.05
19	JUL82.TAPE.DATA	271	82 247	00.000		6160	80	FB		4	U11833AA/	9 35
20	AUG82.TEL.DATA	265	82.260	00.000		6160	80	FB		4	U11833AA/	9 15
21	AUG82.TAPE.DATA	271	82.260	00.000		6160	80	FB		4	U11833AA/	9 32
22	SEP82 TAPE.DATA	262	82.301	00.000		6160	80	FB		4	U11833AN/	9 06
23	OCT82 TAPE DATA	271	82.323	00 000		6160	80	FB		4	U11833AC/	9.42
24	NOV82.TAPE.DATA	262	82.356	00.000		6160	80	FB		4	U11833AS/	9 06
25	DEC82.TAPE.DATA	254	83.022	00.000		6160	80	FB		4	U11833AK/	8.80
26	JAN83.TAPE DATA	271	83.055	00.000		6160	80	FB		4	U11833A4/	9 37
27	FEB83.TAPE DATA	245	83.071	00 000		6160	80	FB		4	U11833A4/	8.48
28	MAR83.TAPE DATA	271	83.093	00.000		6160	80	FB		4	U11833A1/	9 35
												207.43

SYSTEMS SECTION

TAPE MAP VERSION 1.2 25 MAY 1983 WEDNESDAY 1.36.09

CONTENTS OF MAGNETIC TAPE VOLUME - T4394 OWNER

FILE NO	DATASET NAME	BLOCK COUNT	CREATED	EXPIRES	PASSWORD	BLKSIZE	LRECL	RECFM	TRTCH	DEN	CREATED BY JOBNAME/STEPNAME	APP. LENGTH METERS
1	FEB81.TAPE DATA	130	82.140	00 000		6160	80	FB		4	U11833AA/	4.70
2	MAR81.TAPE.DATA	232	82.140	00.000		6160	80	FB		4	U11833AA/	8.09
3	APR81.TAPE.DATA	193	82.140	00.000		6160	80	FB		4	U11833AA/	6.79
4	JUN81.TAPE.DATA	47	82.144	00.000		6160	80	FB		4	U11833AA/	1.94
5	JUL81.TAPE.DATA	36	82.144	00.000		6160	80	FB		4	U11833AA/	1.58
6	JUL81.CH28.DATA	68	82.144	00 000		6160	80	FB		4	U11833AA/	2.65
7	AUG81.CH28 DATA	59	82.144	00 000		6160	80	FB		4	U11833AA/	2.34
8	AUG81.TAPE DATA	44	82.144	00.000		6160	80	FB		4	U11833AA/	1 85
9	SEP81.TAPE DATA	236	82.144	00.000		6160	80	FB		4	U11833AA/	8.22
10	OCT81.TAPE.DATA	201	82.144	00.000		6160	80	FB		4	U11833AA/	7.06
11	NOV81.TAPE DATA	248	82 144	00.000		6160	80	FB		4	U11833AA/	8.61
12	DEC81.TAPE:DATA	242	82.144	00.000		6160	80	FB		4	U11833AA/	8.41
13	JAN82.TAPE.DATA	260	82.144	00 000		6160	80	FB		4	U11833AA/	9.00
14	FEB82.TAPE.DATA	239	82.144	00.000		6160	80	FB		4	U11833AA/	8.30
15	MAR82.TAPE.DATA	271	82.148	00.000		6160	80	FB		4	U11833AA/	9.37
16	APR82.TAPE.DATA	262	82.247	00.000		6160	80	FB		4	U11833AA/	9.07
17	MAY82.TAPE.DATA	271	82 247	00.000		6160	80	FB		4	U11833AA/	9.37
18	JUN82.TAPE.DATA	262	82.247	00.000		6160	80	FB		4	U11833AA/	9.07
19	JUL82.TAPE.DATA	271	82.247	00.000		6160	80	FB		4	U11833AA/	9.37
20	AUG82.TEL.DATA	265	82.260	00.000		6160	80	FB		4	U11833AA/	9.18
21	AUG82.TAPE.DATA	271	82.260	00.000		6160	80	FB		4	U11833AA/	9.37
22	SEP82.TAPE.DATA	262	82.301	00.000		6160	80	FB		4	U11833AN/	9.08
23	OCT82.TAPE.DATA	271	82.323	00.000		6160	80	FB		4	U11833AC/	9 37
24	NOV82.TAPE.DATA	262	82.356	00 000		6160	80	FB		4	U11833AS/	9.08
25	DEC82.TAPE.DATA	254	83.022	00 000		6160	80	FB		4	U11833AK/	8.80
26	JAN83.TAPE.DATA	271	83.055	00.000		6160	80	FB		4	U11833A4/	9.37
27	FEB83.TAPE.DATA	245	83.071	00.000		6160	80	FB		4	U11833A4/	8.51
28	MAR83.TAPE.DATA	271	83.093	00.000		6160	80	FB		4	U11833A1/	9.37
												207 92

SYSTEMS SECTION

TAPE MAP VERSION 1.2 25 MAY 1983 WEDNESDAY 1 34.22

CONTENTS OF MAGNETIC TAPE VOLUME - T6236B OWNER

FILE NO.	DATASET NAME	BLOCK COUNT	CREATED	EXPIRES	PASSWORD	BLKSIZE	LRECL	RECFM	TRTCH	DEN	CREATED BY JOBNAME/STEPNAME	APP LENGTH METERS
1	NOV80.BIN.DATA	144	81.198	00.000		5284	264	VR		4	U11484A3/	4.66
2	NOV80.RAW.DATA	209	81.198	00.000		6160	80	FB		4	U11484A3/	7.35
3	DEC80.BIN.DATA	149	81.198	00.000		5284	264	VR		4	U11484AR/	4.81
4	DEC80.RAW.DATA	159	81.198	00.000		6160	80	FB		4	U11484AR/	5.68
5	JAN81.BIN.DATA	149	81.198	00.000		5284	264	VR		4	U11484AR/	4.81
6	JAN81.RAW.DATA	232	81.198	00.000		6160	80	FB		4	U11484AR/	8 11
7	FEB81.BIN.DATA	34	81.321	00.000		5284	264	VR		4	U11451AN/	1.39
8	FEB81.RAW DATA	53	81.321	00.000		6160	80	FB		4	U11451AN/	2.13
												38.94

SYSTEMS SECTION

TAPE MAP VERSION 1.2 25 MAY 1983 WEDNESDAY 1.38.35

CONTENTS OF MAGNETIC TAPE VOLUME - T4517 OWNER

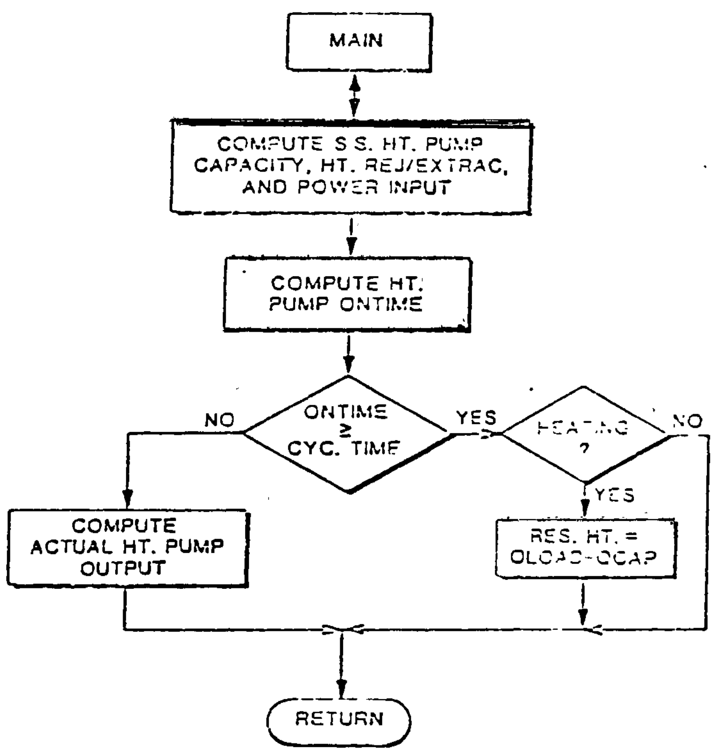
FILE NO	DATASET NAME	BLOCK COUNT	CREATED	EXPIRES	PASSWORD	BLKSIZE	LRECL	RECFM	TRTCH	DEN	CREATED BY JOBNAME/STEPNAME	APP. LENGTH METERS
1	JAN82.CLEAN.DATA	271	82.326	00.000		6160	80	FB		4	U11833AQ/	9.40
2	FEB82.CLEAN.DATA	245	82.326	00.000		6160	80	FB		4	U11833AW/	8 48
3	MAR82.CLEAN.DATA	271	82 326	00 000		6160	80	FB		4	U11833AE/	9.35
4	APR82.CLEAN.DATA	262	82.326	00.000		6160	80	FB		4	U11833AR/	9.05
5	MAY82.CLEAN.DATA	271	82.326	00.000		6160	80	FB		4	U11833AT/	9 41
6	JUN82 CLEAN.DATA	262	82.326	00.000		6160	80	FB		4	U11833AY/	9.13
7	JUL82.CLEAN.DATA	271	82.326	00.000		6160	80	FB		4	U11833AU/	9.35
8	AUG82.CLEAN.DATA	271	82.326	00.000		6160	80	FB		4	U11833AI/	9.35
9	SEP82.CLEAN.DATA	262	82.326	00.000		6160	80	FB		4	U11833AO/	9.12
10	OCT82.CLEAN.DATA	271	82.326	00.000		6160	80	FB		4	U11833AP/	9 42
11	NOV82.CLEAN.DATA	262	82.356	00.000		6160	80	FB		4	U11833AA/	9.01
12	DEC82.CLEAN.DATA	254	83.022	00.000		6160	80	FB		4	U11833AL/	8.79
13	JAN83.CLEAN.DATA	271	83.055	00.000		6160	80	FB		4	U11833A3/	9.32
14	FEB83.CLEAN.DATA	245	83.071	00.000		6160	80	FB		4	U11833A2/	8 51
15	MAR83.CLEAN.DATA	271	83.093	00.000		6160	80	FB		4	U11833AX/	9.31
16	JA82DY.TOTAL.DATA	5	83.103	00.000		6160	80	FB		4	U11833A0/	0.55
17	FB82DY TOTAL.DATA	4	83.103	00.000		6160	80	FB		4	U11833A1/	0.53
18	MR82DY.TOTAL.DATA	5	83.103	00.000		6160	80	FB		4	U11833A2/	0.55
19	AP82DY.TOTAL.DATA	5	83.103	00.000		6160	80	FB		4	U11833A3/	0.55
20	MY82DY.TOTAL.DATA	5	83.103	00.000		6160	80	FB		4	U11833A1/	0 55
21	JN82DY.TOTAL.DATA	5	83.103	00.000		6160	80	FB		4	U11833A2/	0.55
22	JY82DY.TOTAL.DATA	5	83.103	00.000		6160	80	FB		4	U11833A4/	0 55
23	AU82DY.TOTAL.DATA	5	83.103	00.000		6160	80	FB		4	U11833A9/	0.55
24	SP82DY TOTAL.DATA	5	83 103	00 000		6160	80	FB		4	U11833AM/	0.55
25	OC82DY TOTAL.DATA	5	83 103	00 000		6160	80	FB		4	U11833A9/	0.56
26	NV82DY TOTAL DATA	5	83 103	00.000		6160	80	FB		4	U11833AB/	0 55
27	DC82DY.TOTAL DATA	5	83.103	00 000		6160	80	FB		4	U11833A4/	0.55
28	JA83DY TOTAL DATA	5	83 103	00 000		6160	80	FB		4	U11833AS/	0 55
29	FB83DY.TOTAL DATA	4	83.103	00.000		6160	80	FB		4	U11833AV/	0 53
30	MR83DY.TOTAL.DATA	5	83.103	00.000		6160	80	FB		4	U11833A3/	0.55
												145 22

APPENDIX C

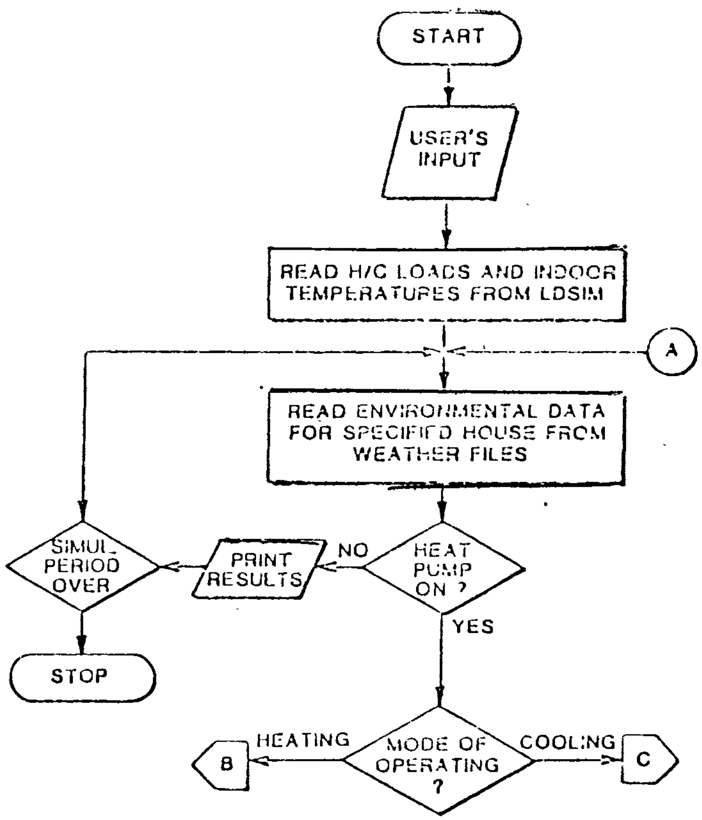
FLOW CHARTS

HEAT PUMP CAPACITY
SUBROUTINES

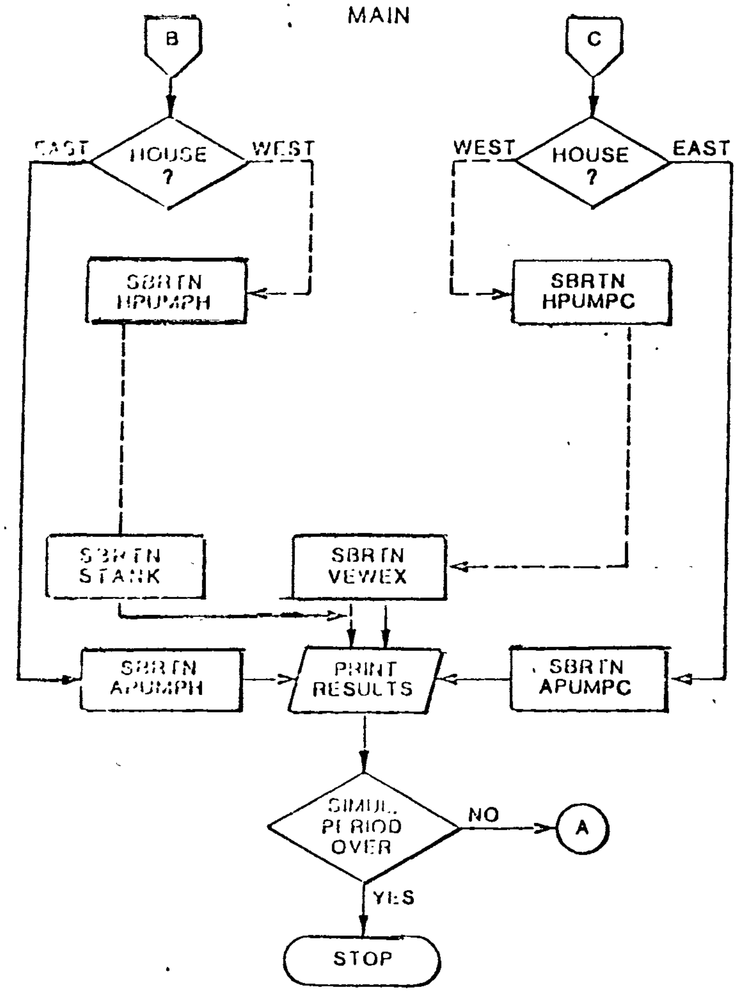
HPUMPC HPUMPH
APUMPC APUMPH



MAIN


START
USER'S INPUT
READ H/C LOADS AND INDOOR TEMPERATURES FROM LDSIM
A
READ ENVIRONMENTAL DATA FOR SPECIFIED HOUSE FROM WEATHER FILES
HEAT PUMP ON ?
NO
YES
PRINT RESULTS
SIMUL PERIOD OVER
STOP
MODE OF OPERATING ?
HEATING
COOLING
B
C

MAIN


B
C
HOUSE ?
EAST
WEST
HOUSE ?
WEST
EAST
SBRTN HPUMPH
SBRTN HPUMPC
SBRTN STANK
SBRTN VEWEX
SBRTN APUMPH
PRINT RESULTS
SBRTN APUMPC
SIMUL PERIOD OVER
NO
A
YES
STOP

VITA 2

Ramanathan Ravindran

Candidate for the Degree of

Master of Science

Thesis: PERFORMANCE COMPARISION OF AIR-COUPLED AND GROUND-COUPLED HEAT PUMP SYSTEMS

Major Field: Mechanical Engineering

Biographical:

Personal data: Born in Coimbatore, Madras, India, October 21,1954, the son of Mr.Vr.N.Ramanathan and Mrs Rm.Gnanambal.

Education: Graduated from Carmel Garden Matriculation School,Coimbatore, India, in May 1974; received Bachelor of Engineering from Unversity of Madras in May 1980; completed requirements for Master of Science degree at Oklahoma State University, in May , 1984.

Professional Experience: Trainee Engineer, Brilliant Engineering Company, Madras, India, June 1980, to December 1980; Site Engineer, Aban Constructions, Madras, India ,January ,1981 to August 1981; Graduate Teaching/Research Assistant, Oklahoma State University, August, 1981 to May , 1983.