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SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

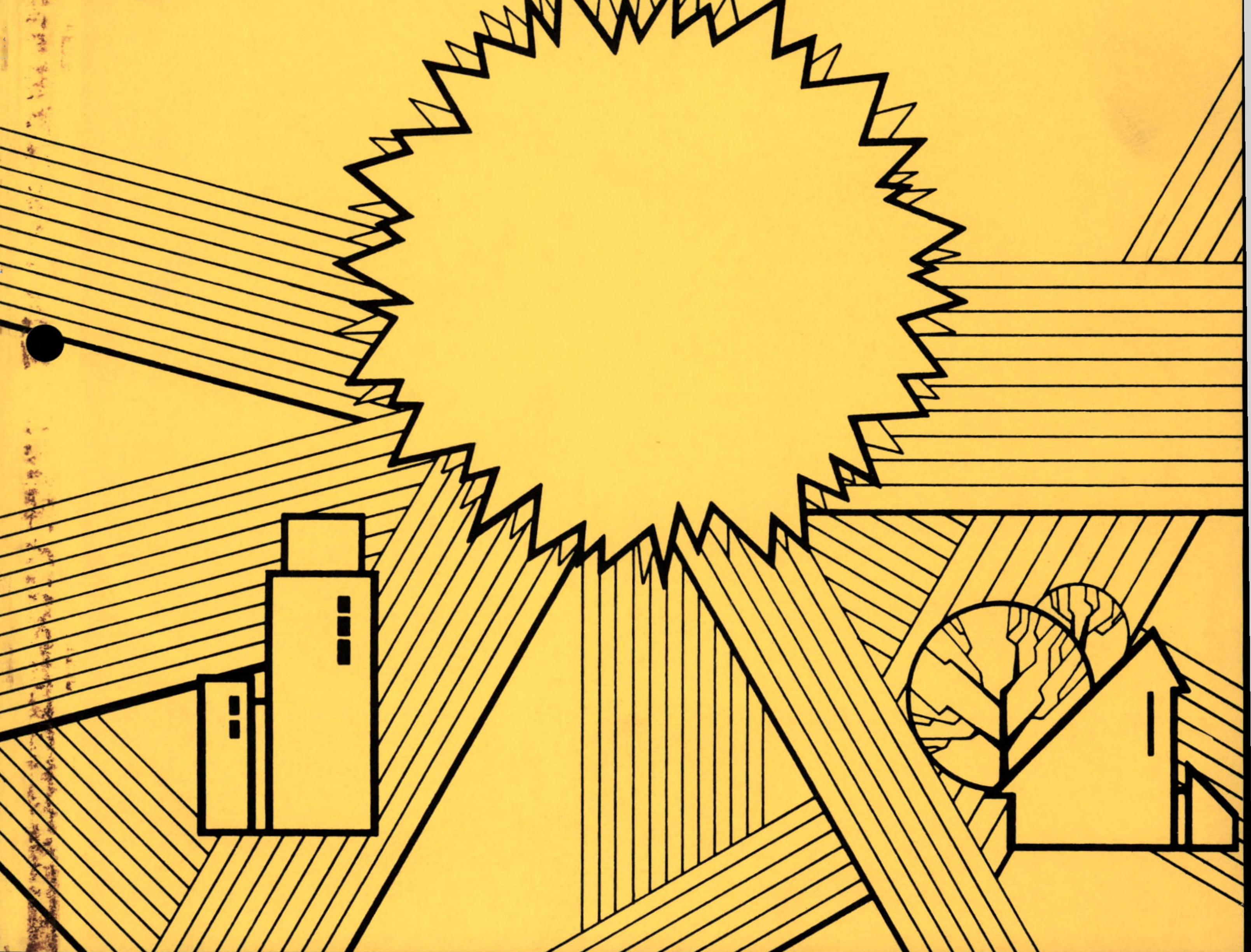
(In International Energy Agency Format)

SADDLE HILL TRUST LOT 36

Medway, Massachusetts

October 1979 through May 1980

DHW SH



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SADDLE HILL TRUST LOT 36

MEDWAY, MASSACHUSETTS

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

OCTOBER 1979 THROUGH MAY 1980

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SECTION 1

SOLAR ENERGY PERFORMANCE EVALUATION FOR SADDLE HILL TRUST LOT 36 OCTOBER 1979 THROUGH MAY 1980

1.1 ABSTRACT

Performance of the Saddle Hill Trust Lot 36 solar energy system from October 1979 through May 1980 is described. The solar system is in a single-family residence which has 178 square meters of conditioned space. The home is located in Medway, Massachusetts about 30 km southwest of Boston. The solar energy system is a liquid-based active type, with 29.26 m^2 of Daystar, flat-plate collector area and 2,840 liters of water thermal storage. The site experienced average, daily incident, irradiance of 13.93 MJ/m^2 and an average ambient temperature of 5°C during the period described. Under these conditions, the solar energy system supplied 47% of the energy required for space heating and domestic hot water, saving 1,237 liters of fuel oil and 3,839 kwh of electrical energy.

1.2 PREFACE

This report is one of a series which describes the performance of solar energy systems in the National Solar Data Network (NSDN) for the entire heating or cooling season. Domestic hot water is also included, if there is a solar contribution. Some NSDN installations are used solely for heating domestic hot water and annual performance reports are issued for such sites. In addition, Monthly Performance Reports are available for the solar systems in the network.

The National Solar Data Network consists of instrumented solar energy systems in buildings selected from among the 5,000 installations built (since early 1977) as part of the National Solar Heating and Cooling Demonstration Program. The overall purpose of this program is to reduce the use of nonrenewable fuels by encouraging the application of solar energy for heating, cooling, and domestic hot water. Vitro Laboratories Division operates the NSDN, under contract with the Department of Energy, to collect daily data from the sites, analyze the data, and disseminate information to interested users.

Buildings in the National Solar Data Network are comprised of residential, commercial and institutional structures which are geographically dispersed throughout the continental United States, Hawaii and Puerto Rico. The variety of solar systems installed employ "active" mechanical equipment systems or "passive" design features, or both, to supply solar energy to typical building thermal loads such as space heating, space cooling, and domestic hot water. Solar systems on some sites are used to supply commercial process heat.

The buildings in the NSDN program are instrumented to monitor thermal energy flows to the space conditioning, hot water, or process loads, from both the solar system and the auxiliary or backup system. Data collection from each site, and transmission to a central computer for processing and analysis is highly automated.

In addition to these "Seasonal" Reports, NSDN information is disseminated for each operational site via Monthly Performance Reports, and special reports.

1.3 TABLE OF CONTENTS

Section	Title	Page
1	Solar Energy Performance Evaluation for Saddle Hill Trust Lot 36, October 1979 through May 1980	1-1
	1.1 Abstract	1-1
	1.2 Preface	1-2
	1.3 Table of Contents (Illustrations, Tables)	1-3
	1.4 Summary	1-8
	1.5 Introduction	1-13
2	Description of the Surrounding Environment	2-1
	2.1 Description of Location and Site	2-1
	2.2 Description of Climate	2-1
3	Description of Overall System	3-1
	3.1 Description of the Load (Building)	3-2
	3.2 Description of the Solar and HVAC Systems	3-4
	3.2.1 Solar Collector Array	3-4
	3.2.2 Heat Storage	3-7
	3.2.3 Space Heating Subsystem	3-7
	3.2.4 Domestic Hot Water (DHW) Subsystem	3-8
	3.2.5 Heat Rejection	3-8
	3.3 Description of the Control System Hardware	3-8
4	System Operation	4-1
	4.1 Operating Modes	4-1
	4.2 Control Strategy	4-7
5	Thermal Performance Evaluation Program	5-1
	5.1 Definitions of the Thermal Performance Factors	5-4
	5.1.1 Performance Evaluation Guidelines	5-4
	5.1.1.1 Categories of Performance Factors	5-4
	5.1.1.2 Standard Designations for Sensors and Subsystems	5-5
	5.1.1.3 General Solar Description and Energy Balance	5-6
	5.1.1.4 Functions of Subsystems	5-6
	5.1.1.5 Thermal Energy Flow	5-7
	5.1.1.6 Subsystem Heat Loss	5-7
	5.1.2 Energy Quantities Evaluated	5-7
	5.1.3 Thermal Performance Indicators	5-9
	5.2 Description of the Monitoring System	5-16
	5.2.1 Instrumentation	5-17
	5.2.2 Data Acquisition	5-19
	5.3 Data Reduction Procedure	5-20

Section	Title	Page
6	Description of the Operating Period	6-1
7	Presentation of Results	7-1
	7.1 Solar System Performance	7-2
	7.2 Monthly Performance of the Solar Energy and HVAC Systems	7-5
	7.2.1 Monthly Performance of the Solar Collector Subsystem	7-11
	7.2.2 Monthly Performance of the Thermal Storage Subsystem	7-13
	7.2.3 Monthly Performance of the Space Heating Subsystem	7-14
	7.2.4 Monthly Performance of the DHW Subsystem	7-16
	7.3 Daily System Performance	7-17
	7.4 Hourly System Performance	7-39
	7.5 Performance Comparisons with Expected Results	7-40
8	Discussion	8-1
9	Conclusions and Recommendations	9-1
10	References	10-1

LIST OF ILLUSTRATIONS

Figure	Title	Page
1.1	Saddle Hill Trust Lot 36 Site Photo	1-9
1.2	Saddle Hill Trust Lot 36 Solar System Schematic	1-10
1.3	Overall System Thermal Performance, Saddle Hill Trust Lot 36, October 1979 through May 1980	1-11
1.4	Solar System Efficiency, Saddle Hill Trust Lot 36, October 1979 through May 1980	1-12
2.1	Meteorological Map of the United States Showing Saddle Hill Trust Lot 36 Location	2-2
3.1	Average Daily Hot Water Usage, Saddle Hill Trust Lot 36, 1979 to 1980 Heating Season	3-3
3.2	Solar Energy System Schematic for Saddle Hill Trust Lot 36	3-5
3.3	Control System Hardware, Saddle Hill Trust Lot 36	3-9
5.1	The National Solar Data Network	5-3

Figure	Title	Page
5.2	Energy Flow Diagram for Saddle Hill Trust Lot 36 with NBS Designations in Parentheses	5-8
5.3	Data Flow Path for the National Solar Data Network	5-16
5.4	Instrumentation at Saddle Hill Trust Lot 36	5-18
7.1	Overall System Thermal Performance, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-3
7.2	Energy Flow Diagram for Saddle Hill Trust Lot 36 for the period October 1979 through May 1980	7-4
7.3	Combined Thermal Energy Savings Compared to Total Energy Consumed by Subsystem, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-7
7.4	Solar Energy Use, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-8
7.5	Operating Energy, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-11
7.6	Space Heating Performance, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-15
7.7	DHW Subsystem Performance, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-17
7.8	Plot of Daily Ambient Temperatures and Daytime Ambient Temperatures, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-34
7.9	Plot of Daily Incident Solar Radiation and Collected Solar Energy, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-35
7.10	Plot of Daily Average Storage Temperatures and Storage Energy Losses, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-36
7.11	Plot of Daily Solar Energy and Auxiliary Energy Consumed by Space Heating Subsystem, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-37
7.12	Plot of Daily Solar Energy and Auxiliary Energy Consumed by DHW Subsystem, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-38
7.13	Typical Hourly Profiles of Selected Performance Factors, Saddle Hill Trust Lot 36	7-39

LIST OF TABLES

Table	Title	Page
2.1	Weather Conditions, Saddle Hill Trust Lot 36, October 1979 through May 1980	2-3
3.1	Designer's Performance Goals, Saddle Hill Trust Lot 36	3-1
3.2	$UAC_D\Delta T$ Load Calculations, Saddle Hill Trust Lot 36, October 1979 through May 1980	3-3
3.3a	Collector Parameters, Saddle Hill Trust Lot 36	3-6
3.3b	Collector Loop, Fluid Transfer Loop Parameters, Saddle Hill Trust Lot 36	3-6
3.4	Heat Storage Parameters, Saddle Hill Trust Lot 36	3-7
3.5	Space Heating Subsystem Parameters, Saddle Hill Trust Lot 36	3-7
3.6	Domestic Hot Water Parameters, Saddle Hill Trust Lot 36	3-8
3.7	Control System Hardware, Saddle Hill Trust Lot 36	3-9
4.1	Control Strategy, Saddle Hill Trust Lot 36	4-7
5.1	Instrumentation, Saddle Hill Trust Lot 36	5-17
7.1	Overall Solar System Thermal Performance, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-3
7.2	Solar Coefficient of Performance, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-5
7.3	Energy Savings, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-6
7.4	Solar Energy Losses, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-9
7.5	Operating Energy, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-10
7.6	Collector Subsystem Performance, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-12
7.7	Storage Performance, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-14
7.8	Space Heating Subsystem, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-15

Table	Title	Page
7.9	Domestic Hot Water Subsystem Performance, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-16
7.10a	Daily System Performance Factors, October 1979, Climate, Collector, and Storage, Saddle Hill Trust Lot 36	7-18
7.10b	Daily System Performance Factors, October 1979, Hot Water and Space Heating, Saddle Hill Trust Lot 36	7-19
7.11a	Daily System Performance Factors, November 1979, Climate, Collector, and Storage, Saddle Hill Trust Lot 36	7-20
7.11b	Daily System Performance Factors, November 1979, Hot Water and Space Heating, Saddle Hill Trust Lot 36	7-21
7.12a	Daily System Performance Factors, December 1979, Climate, Collector, and Storage, Saddle Hill Trust Lot 36	7-22
7.12b	Daily System Performance Factors, December 1979, Hot Water and Space Heating, Saddle Hill Trust Lot 36	7-23
7.13a	Daily System Performance Factors, January 1980, Climate, Collector, and Storage, Saddle Hill Trust Lot 36	7-24
7.13b	Daily System Performance Factors, January 1980, Hot Water and Space Heating, Saddle Hill Trust Lot 36	7-25
7.14a	Daily System Performance Factors, February 1980, Climate, Collector, and Storage, Saddle Hill Trust Lot 36	7-26
7.14b	Daily System Performance Factors, February 1980, Hot Water and Space Heating, Saddle Hill Trust Lot 36	7-27
7.15a	Daily System Performance Factors, March 1980, Climate, Collector, and Storage, Saddle Hill Trust Lot 36	7-28
7.15b	Daily System Performance Factors, March 1980, Hot Water and Space Heating, Saddle Hill Trust Lot 36	7-29
7.16a	Daily System Performance Factors, April 1980, Climate, Collector, and Storage, Saddle Hill Trust Lot 36	7-30
7.16b	Daily System Performance Factors, April 1980, Hot Water and Space Heating, Saddle Hill Trust Lot 36	7-31
7.17a	Daily System Performance Factors, May 1980, Climate, Collector, and Storage, Saddle Hill Trust Lot 36	7-32
7.17b	Daily System Performance Factors, May 1980, Hot Water and Space Heating, Saddle Hill Trust Lot 36	7-33
7.18	f-Chart Predictions, Saddle Hill Trust Lot 36, October 1979 through May 1980	7-40

1.4 SUMMARY

The Saddle Hill Trust Lot 36 site is a single-family residence in Medway, Massachusetts. The home, shown in Figure 1.1, is equipped with an active solar energy system that is designed to supply approximately 50% of the space heating and hot water requirements.

The solar system (see Figure 1.2) is equipped with a south-facing array of 14 Daystar, liquid, flat-plate collectors. The collectors are mounted on the roof at an angle of 58 degrees from horizontal and the gross area of the array is 29.26 square meters. Solar energy is transported from the collectors by a glycerol solution to a 2,840 liter steel storage tank in the basement. Solar energy is supplied from the storage tank to a conventional 303 liter hot water tank to preheat incoming city water. An electric heating element provides auxiliary heat if needed. Solar energy is also transported to a heating coil located in the return air duct of the furnace to provide space heating for the house. The oil fired furnace is used for auxiliary space heating.

Medway, Massachusetts is located about 30 kilometers southwest of Boston. The long-term average, daily, horizontal insolation for this area during the heating season (October through May) is 9.86 MJ/m^2. During the 1979 to 1980 heating season there was a seasonal average of 13.93 MJ/m^2 per day of solar energy incident to the collector array, compared to the long-term average of 12.03 MJ/m^2 per day. The average outside temperature during the period was 5°C compared to the long-term average of 6°C. The total number of heating degree-days (based on a 19°C reference) was 3,467 compared to the long-term average of 3,244.

The Saddle Hill Trust Lot 36 solar energy system supplied 41% of the space heating and 76% of the hot water requirements for the 1979 to 1980 heating season. The resulting overall solar fraction of 47% compared very well with the design goal of 50%. The solar system collected 39.61 gigajoules of energy and the collector array efficiency (based on total insolation) was 40%. The solar system provided a substantial energy savings of 62.08 gigajoules which is equivalent to the total of 1,237 liters of fuel oil and 3,839 kwh of electrical energy.

The overall system thermal performance for the reporting period is shown in Figures 1.3 and 1.4.

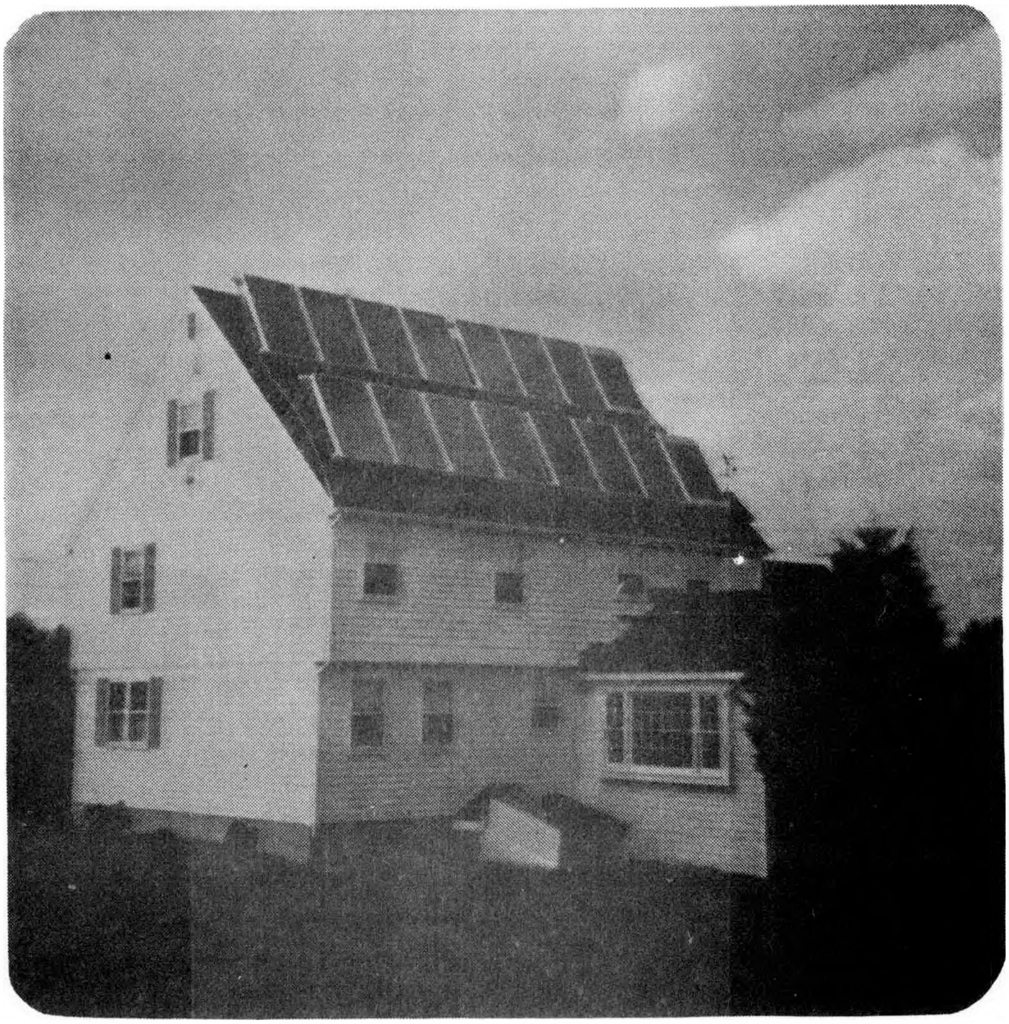


Figure 1-1. Saddle Hill Trust Lot 36 Site

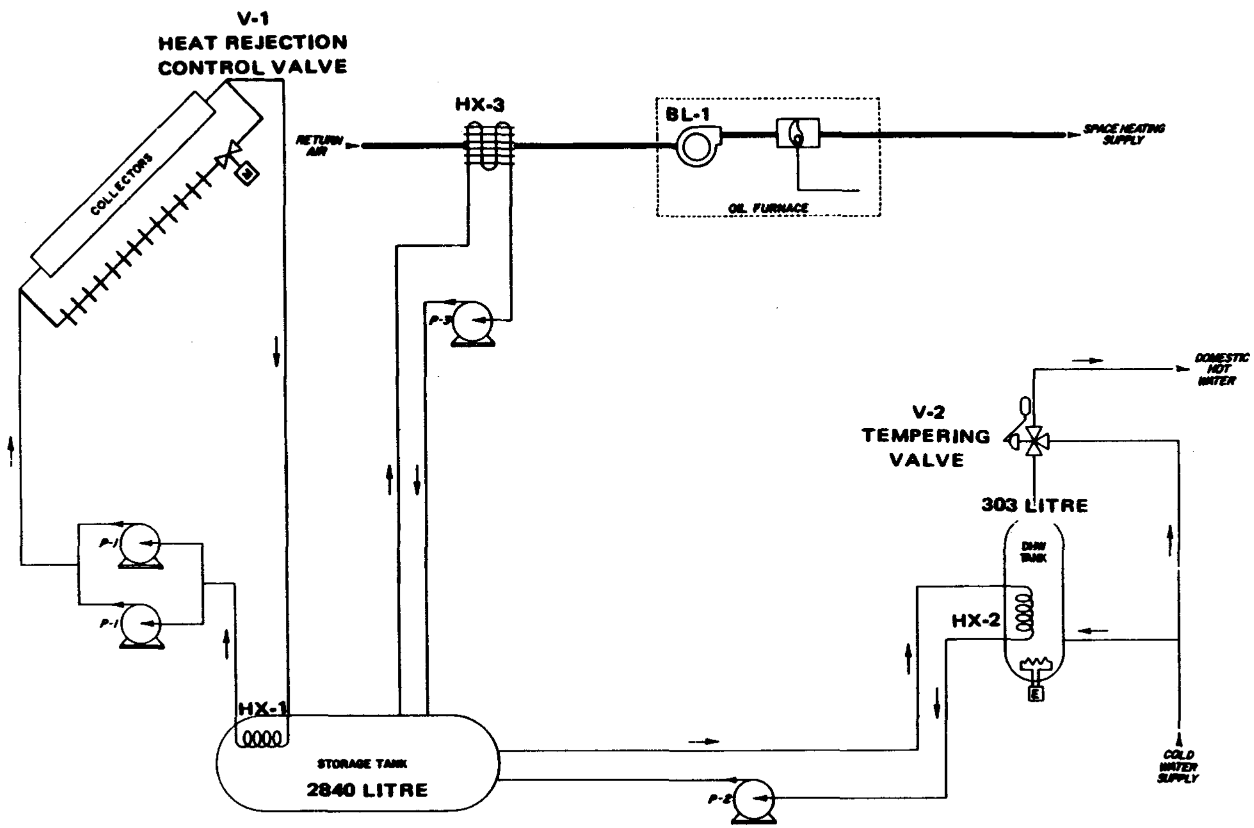
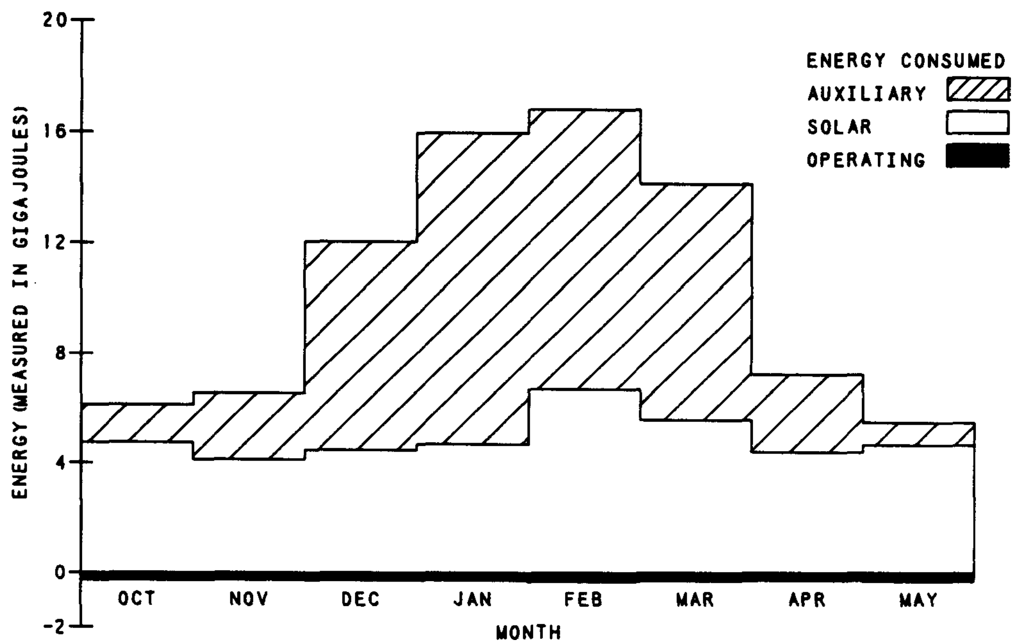


Figure 1.2. Saddle Hill Trust Lot 36 Solar System Schematic



Operating energy for the system is considered a system penalty and is plotted as a negative value below the origin.

Figure 1.3. Overall System Thermal Performance
Saddle Hill Trust Lot 36
October 1979 through May 1980

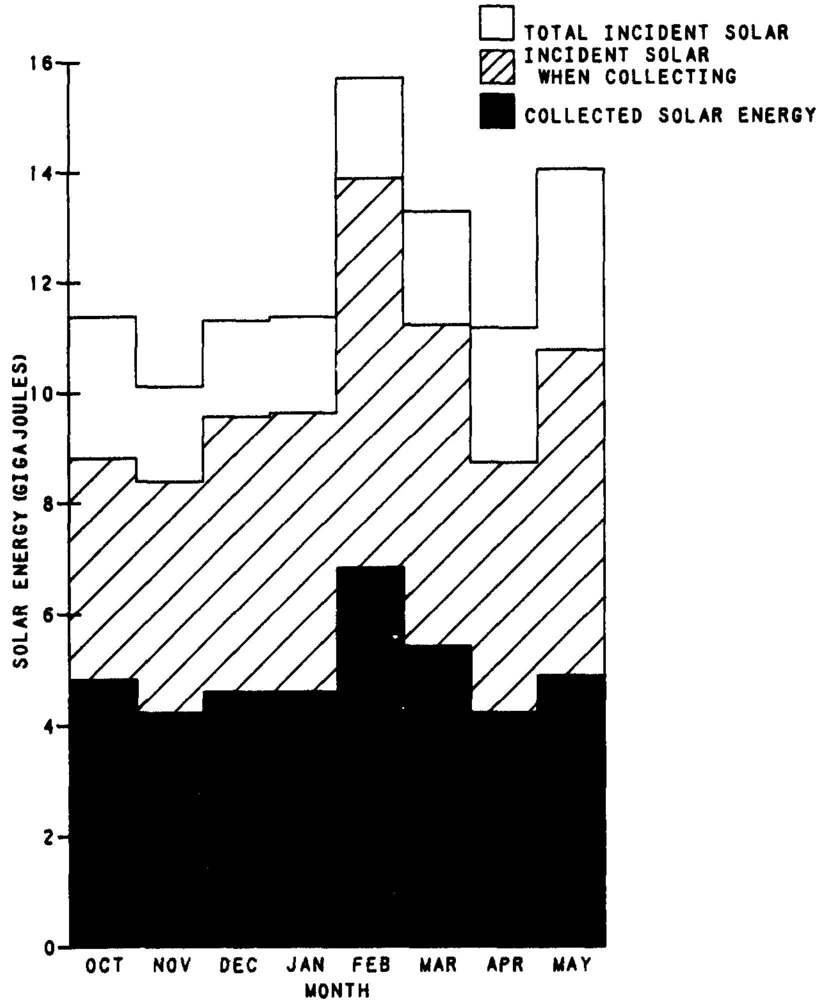


Figure 1.4. Solar System Efficiency
Saddle Hill Trust Lot 36
October 1979 through May 1980

1.5 INTRODUCTION

The Saddle Hill Trust Lot 36 site is one of over one hundred sites in the National Solar Data Network (NSDN). The solar energy system at each site is instrumented to provide sufficient measurements to support a thermal performance analysis of each solar system. The purpose of this report is to present the results of the thermal performance analysis for the Saddle Hill Trust Lot 36 site for the heating season of October 1979 through May 1980.

A project description is included to support understanding of the results of the thermal performance analysis. The project description is made up of the following sections:

Section 2, a description of the surrounding environment;

Section 3, a description of the overall system; and

Section 4, an explanation of the system operation.

Section 5 is an explanation of the thermal performance evaluation program and the results and a discussion of the thermal performance analysis are presented in Sections 7 and 8.

SECTION 2

DESCRIPTION OF THE SURROUNDING ENVIRONMENT

2.1 DESCRIPTION OF LOCATION AND SITE

The Saddle Hill Trust Lot 36 site is located in Medway, Massachusetts at 42 degrees N latitude and 71 degrees W longitude. Medway is about 30 kilometers southwest of Boston at an altitude of 61 meters. This single-family residence is located in a residential housing development of similar units. The development is mostly cleared of trees and there are no other obstructions that block sunlight from the collectors during the major part of the day. The horizon consists of a predominantly flat landscape with houses and trees in the distance. Therefore, the collectors are not obscured from the sun until near sundown.

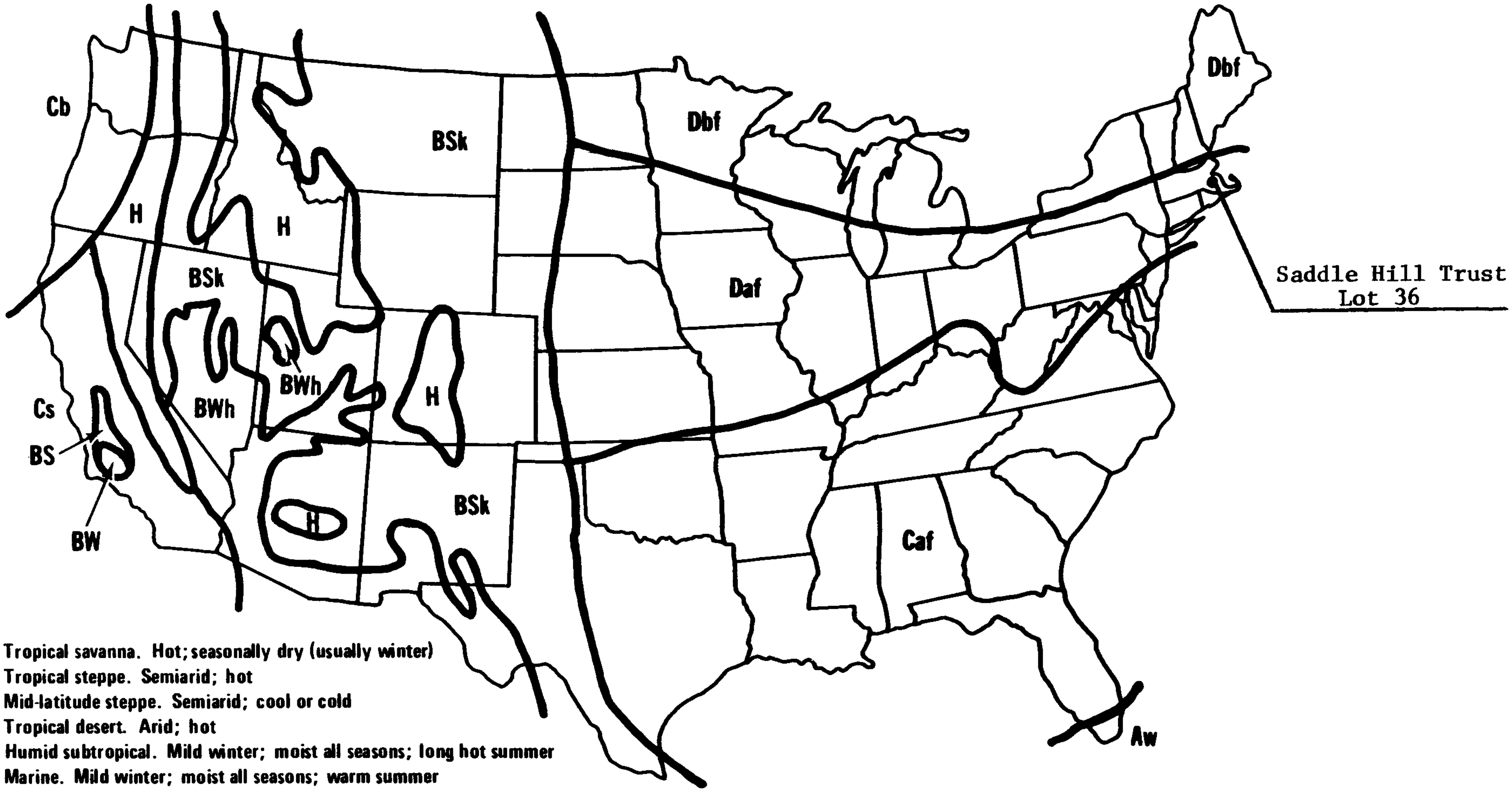
2.2 DESCRIPTION OF CLIMATE

The Medway, Massachusetts climate is generally considered a humid, continental, climate with long hot summers and cold winters. There are about 1,000 to 1,200 mm of precipitation evenly distributed throughout the year. The average daily temperatures extend into the 21° to 27°C range in the summer while the average winter temperatures drop into the -7° to -1°C range. The daytime high summer temperatures will extend into the 30° to 37°C range while nighttime winter temperatures will drop below -15°C on occasion.

Figure 2.1 is a meteorological map of the United States showing Saddle Hill Trust Lot 36 location.

Monthly values of the total solar energy incident in the plane of the collector array and the average outdoor temperature measured at the site during the reporting period are presented in Table 2.1. Also presented in the table are the corresponding long-term average monthly values of the measured weather parameters. These long-term average weather data were obtained from nearby representative National Weather Service and SOLMET meteorological stations. The long-term insolation values are total global horizontal radiation converted to collector angle and azimuth orientation.

During the period from October 1979 through May 1980, the average daily total incident solar radiation on the collector array was 13.93 million joules per square meter per day. This radiation was above the estimated average daily solar radiation for this geographical area during the reporting period of 12.03 million joules per square meter per day for a south-facing plane with a tilt of 58 degrees to the horizontal. During the period, the highest monthly average insolation was 18.73 million joules per day during February. The average ambient temperature during the reporting period was 5°C as compared with the long-term average of 6°C. The highest monthly average ambient temperature was 15°C during May, and the lowest monthly average ambient temperature was -4°C during February. The number of heating degree-days for the period (based on a 19°C reference) was 3,467 as compared with the long-term average of 3,244. The range of heating degree-days was from a high of 682 during January to a low of 124 during May.



KEY

Aw	Tropical savanna. Hot; seasonally dry (usually winter)
BS	Tropical steppe. Semiarid; hot
BSk	Mid-latitude steppe. Semiarid; cool or cold
BWh	Tropical desert. Arid; hot
Caf	Humid subtropical. Mild winter; moist all seasons; long hot summer
Cb	Marine. Mild winter; moist all seasons; warm summer
Cs	Coastal Mediterranean. Mild winter; dry summer; short warm summer
Daf	Humid continental. Severe winter; moist all seasons; long, hot summer
Dbf	Humid continental. Severe winter; moist all seasons; short warm summer
H	Undifferentiated highland climates

Trewartha, G.T. The Earth's Problem Climates. University Wisconsin Press, Madison, WI, 1961.

Figure 2.1. Meteorological Map of the United States Showing Saddle Hill Trust Lot 36 Location

Table 2.1. WEATHER CONDITIONS

SADDLE HILL TRUST LOT 36
OCTOBER 1979 THROUGH MAY 1980

	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA MJ/m²-day		AMBIENT TEMPERATURE (°C)		HEATING DEGREE-DAYS (19°C REF)		DAYTIME AMBIENT TEMP °C
MONTH	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED
OCT	12.53	14.35	10	13	279	195	14
NOV	11.51	9.56	8	7	330	354	11
DEC	12.44	8.61	1	1	558	572	4
JAN	12.74	9.78	-3	-2	682	641	0
FEB	18.73	12.05	-4	-1	667	583	0
MAR	14.84	13.60	2	3	527	487	5
APR	12.93	13.97	9	9	300	288	13
MAY	15.69	14.47	15	15	124	124	20
TOTAL	-	-	-	-	3,467	3,244	-
AVERAGE	13.93	12.03	5	6	433	405	8

The average daytime ambient temperature, computed for the time span of three hours before solar noon to three hours after solar noon, ranged from 0°C in January to 20°C in May for a seasonal average of 8°C.

Extraterrestrial radiation values are computed[1] and given below for each month during the period. The ratio of total insolation on a tilted surface to extraterrestrial radiation on a parallel surface is called the clearness index.

This parameter quantifies the effects of cloudiness and atmospheric transmission on the insolation received at the earth's surface. The clearness index ranged from a high of 55% during May to a low of 36% during January.

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Extra-terrestrial Insolation	*	*	34.58	35.52	37.32	36.87	32.89	28.60
TTL INS / EXT INS (%)	*	*	36	36	50	40	39	55

* DENOTES UNAVAILABLE DATA.

[1] Computation method given in "TRNSYS, a Transient Simulation Program," Engineering Experiment Station Report #38, Solar Energy Laboratory, University of Wisconsin, Madison.

SECTION 3

DESCRIPTION OF OVERALL SYSTEM

SUMMARY

The solar system in the Saddle Hill Trust Lot 36 solar demonstration project located in Medway, Massachusetts is designed to provide building space heating as well as domestic hot water (DHW) heating. This active solar system has an array of flat-plate collectors with a gross area of 29.26 m^2. The array faces south at an angle of 58 degrees to the horizontal. A 50% glycerol solution is the transfer medium that delivers solar energy from the collector array to storage; water is the transfer medium that delivers solar energy from storage to the space heating and hot water loads. Solar energy is stored in the basement in a steel storage tank which holds 2,840 liters of water.

City water is supplied, on demand, to a conventional 303-liter DHW tank. It is then preheated by solar energy by a heat exchanger which transfers heat from the storage tank to the DHW tank. If solar energy is not sufficient to maintain the DHW temperature at the desired level, a conventional electric heating element supplies auxiliary heat to the DHW tank.

Solar energy is tranferred to the space heating load via a heating coil located in the return air duct of the furnace. If solar energy is insufficient to satisfy the space heating requirement, the oil-fired furnace supplies auxiliary energy.

The solar system at Lot 36 was designed to supply approximately 50% of the total winter heating season load. Table 3.1 is a summary of the designer's performance goals expected for the site.

Table 3.1. DESIGNER'S PERFORMANCE GOALS

SADDLE HILL TRUST LOT 36

(All figures in gigajoules)

	DHW		SPACE HEATING		TOTAL	
MONTH	LOAD	SOLAR	LOAD	SOLAR	LOAD	SOLAR
OCT	2.61	2.61	5.14	5.14	7.75	7.75
NOV	2.52	1.58	8.81	3.80	11.33	5.38
DEC	2.61	1.58	13.82	3.59	16.43	5.17
JAN	2.61	1.58	15.40	3.90	18.01	5.48
FEB	2.35	1.58	13.61	4.64	15.96	6.22
MAR	2.61	2.11	11.82	5.17	14.43	7.28
APR	2.52	2.11	7.28	4.43	9.80	6.54
MAY	2.61	2.61	3.56	3.56	6.17	6.17
TOTAL	20.44	15.76	79.44	34.23	99.88	49.99

3.1 DESCRIPTION OF THE LOAD (BUILDING)

The Saddle Hill Trust Lot 36 home is a two-story, four-bedroom, single-family residence with a family/living/dining/kitchen/solar equipment room/two bathrooms and an attached garage. The total area of the house is approximately 181 square meters and the solar conditioned area is 178 square meters. The home is occupied by a family consisting of two adults and two children.

The roof of the house is about 10 meters above grade and sloped at a 42 degree pitch where the collectors are mounted. There is also a ventilation system to remove heat build-up in the attic.

The solar system and the auxiliary furnace are designed to maintain the indoor temperatures at 21°C during the heating season. This is achieved by heating the air as it recirculates through the central heating system. As air passes through the return air duct of the furnace (which is located in the basement) it is heated by solar energy via heating coils which are linked to the storage tank. If the solar energy is not sufficient to meet the 21°C heating requirement, the oil-fired furnace is activated to provide auxiliary energy to meet the space heating demand. Losses from the solar system also contribute to the space heating load. The system is well insulated, however there are significant losses from the storage and DHW tanks to the conditioned space which help satisfy the space heating requirements.

The overall space heating load on the house can be estimated by calculating building thermal losses due to transmission and ventilation per degree (Kelvin) temperature difference between the outdoor and indoor conditions. This calculation is made by multiplying the temperature difference by the heat loss factor (UA value) for the building. This number is then multiplied by an interim correction factor C_D which takes the heating effect versus degree-days for a given outdoor design temperature into account. The UA value calculated[1] for the Saddle Hill Trust Lot 36 site is 325 W/°K, and the C_D value for the Medway area is 0.75. This yields a UAC_D value of 244 W/°K for the site.

The resulting $UAC_D\Delta T$ calculation is used as a comparison for, or prediction of, the monthly space heating load. Calculated $UAC_D\Delta T$ load values based on the measured average indoor and outdoor temperatures are presented in Table 3.2. Three degrees were subtracted from the indoor temperature to account for internal gains from sources other than the solar and auxiliary system.

Solar energy is also used to heat domestic hot water as it is stored in a conventional 303-liter tank. If the solar energy is not sufficient to maintain the temperature in the tank at 49°C, the auxiliary electric heating element in the tank is activated to heat the water to the required temperature.

Hot water is consumed by the family for normal personal use (showers and clean-up) and by the dishwasher and washing machine. A profile of the average daily hot water use is shown in Figure 3.1. This profile was compiled from typical days during the 1979-80 heating season.

[1]Provided by Dubin-Bloome Associates.

Table 3.2. $UAC_D \Delta T$ LOAD CALCULATIONS

SADDLE HILL TRUST LOT 36
OCTOBER 1979 THROUGH MAY 1980

MONTH	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
INDOOR AVERAGE TEMP °C	20	20	19	19	20	20	20	21
OUTDOOR AVERAGE TEMP °C	10	8	1	-3	-4	2	9	15
$UAC_D \Delta T$ LOAD GIGAJOULES	4.57	5.68	9.79	12.39	12.82	9.79	5.05	1.96

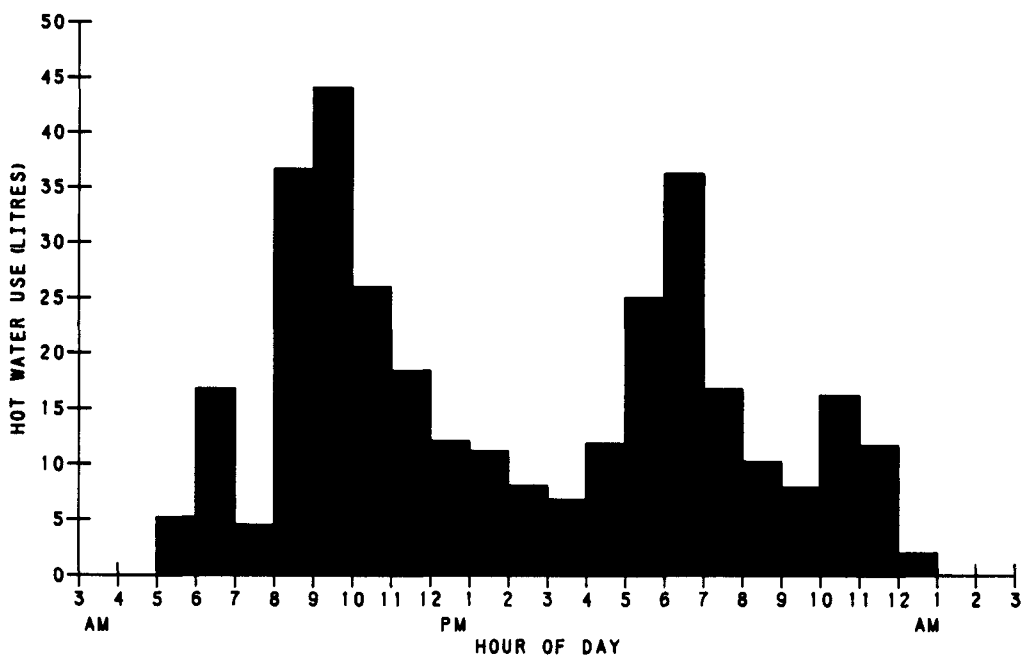


Figure 3.1. Average Daily Hot Water Usage
Saddle Hill Trust Lot 36
1979 to 1980 Heating Season

3.2 DESCRIPTION OF THE SOLAR AND HVAC SYSTEM

Subsystem Summary

The solar system at the Saddle Hill Trust Lot 36 site consists of a collector subsystem, solar energy storage subsystem, space heating subsystem, and a domestic hot water subsystem as shown in the schematic in Figure 3.2. There are three fluid transfer loops linking the subsystems to the storage subsystem.

The collector subsystem consists of a collector array which delivers heat to the storage tank via a glycerol solution fluid transfer loop. The glycerol is circulated by two pumps (designated P1) located in the line. The fluid passes through the collector array, absorbing heat from the collector panels, then through piping to a liquid-to-liquid heat exchanger (HX1) located in the storage tank. The fluid then passes through the pumps enroute back to the collector array.

The storage subsystem is made up of an insulated steel tank which holds 2,840 liters of water. The water is the solar energy storage medium and also the heat transfer fluid to the two load subsystems.

The DHW subsystem consists of a conventional 303-liter DHW tank which receives solar energy from the storage tank via a water-heat transfer loop. Water is circulated from the storage tank through a heat exchanger (HX2) in the DHW tank and is then pumped by a single pump (P2) back to the storage tank. City water is supplied to the DHW tank where it is heated by the solar and auxiliary elements and then delivered to the home through a tempering valve (V2). The tempering valve (V2) regulates the temperature of the water being delivered by mixing it with cold supply water. The auxiliary electric heating element in the DHW tank is used if the solar energy is not sufficient to heat the supply water to the desired temperature.

The space heating subsystem consists of a centralized air distribution system of ducts connecting the rooms to a furnace and air conditioner in the basement. A blower (BL1), located in the furnace, circulates air through the ducts into the rooms and back to the furnace. Solar energy is added to the air as it passes through the furnace by a heating coil located in the return air duct. Solar heated water from the storage tank passes through piping to the heating coil (HX3) and is then pumped (by P3) back to the storage tank. The auxiliary oil-fired burner in the furnace is activated if the solar energy is not sufficient to maintain the room temperature at the desired temperature.

Each subsystem is dealt with in detail in the following sections.

3.2.1 Solar Collector Array

The collector array consists of 14 Daystar model 2001 liquid, flat-plate collectors mounted on the roof. The collectors are single glazed and have a copper tube and plate absorber. Freeze protection is achieved by the use of a glycerol/water solution as the heat transfer fluid.

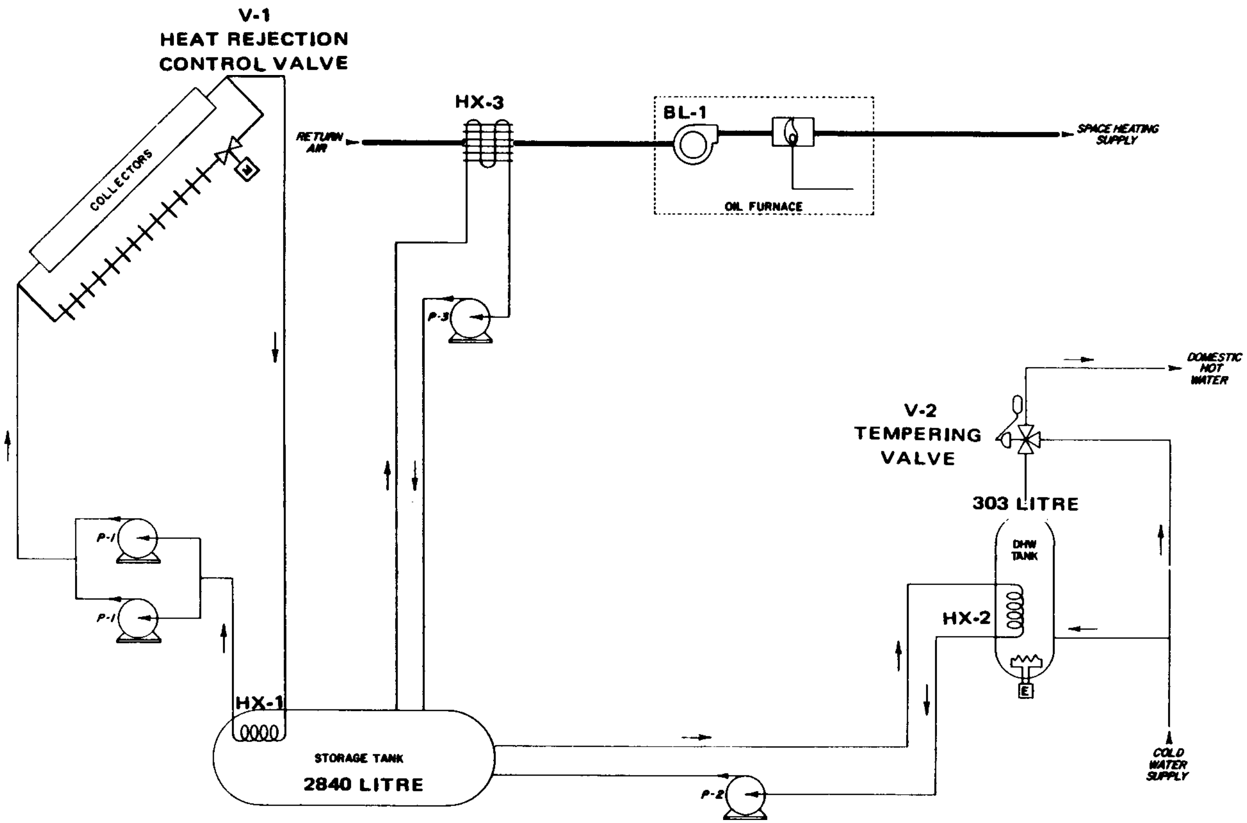


Figure 3.2. Solar Energy System Schematic for Saddle Hill Trust Lot 36

The Daystar-20 collector has a special "heat trap" which is a thin layer of a high-temperature polymer which is folded in an accordian shape between the the cover plate and absorber plate. It is designed for high transmission of solar energy to the absorber plate and to inhibit energy loss due to thermal radiation and convection, thereby increasing performance and efficiency.

Table 3.3a and 3.3b list collector array and collector fluid transfer loop parameters.

Table 3.3a. COLLECTOR PARAMETERS

SADDLE HILL TRUST LOT 36

Collector aperture area	27.22 m^2
Collector gross area	29.26 m^2
Orientation (azimuth)	South-facing
Tilt	58° from horizontal
Array Configuration	2 rows of 7 panels
Heat Rejection	1 panel in each row
Cover plate	Glass, low iron, tempered, 4.76 mm thick
Heat trap	Polycarbonate sheet, accordian folded, 0.20 mm thick.
Absorber	Copper, "black nextel" epoxy coating, copper tubes soldered beneath absorber in serpentine pattern.
Collector Performance	Collector efficiency curve: Intercept $F_R(\tau\alpha) = 0.82$ Slope $F_R U_L \cong 0.76$

Table 3.3b. COLLECTOR LOOP

FLUID TRANSFER LOOP PARAMETERS
SADDLE HILL TRUST LOT 36

Medium	Water/glycerol 50%/50%
Piping	Copper, basement to roof
Insulation	Polyurethane foam
Two pumps (P1)	Grundfos, centrifugal, 37.29 W
Heat exchanger (HX1)	Daystar, finned copper tube
Design flow	0.44 kg/sec

3.2.2 Heat Storage

Solar energy is stored in a 2,840-liter steel tank located in the basement. The interior is galvanized and the exterior is covered with polyurethane insulation (R = 1.9 m^2-°K/W). The tank is 1.22 m in diameter and 2.74 m in length. Water is used as the storage medium.

Table 3.4 HEAT STORAGE PARAMETERS

SADDLE HILL TRUST LOT 36

Mass of storage medium	2,840 kg
Heat capacity	4,187 J/kg°K
Maximum temperature	93 °C
Minimum temperature	0 °C
Heat loss factor	7 W/°K

3.2.3 Space Heating Subsystem

The space heating subsystem as described in Section 3.2 consists of the components listed in Table 3.5.

Table 3.5. SPACE HEATING SUBSYSTEM PARAMETERS

SADDLE HILL TRUST LOT 36

Storage-to-Space Heat Fluid transfer loop	
Medium	Water
Piping	Copper, type L
Insulation	Polyurethane foam (R = 1.9 m^2-°K/W)
Heat exchanger (HX3)	Singer, cross flow, finned coil
Pump (P3)	Liquid-to-air forced convection, Grundfos, centrifugal, 37.29 W
Design flow	0.32 kg/sec
Air circulation loop	
Blower (BL1)	Squirrel cage fan
Ducting	Steel, galvanized
Deign air flow	0.66 m^3/sec
Auxiliary Space Heat	
Furnace	Friedrich oil-fired, #2 heating oil energy input - 41,030 W energy output - 35,758 W

3.2.4 Domestic Hot Water (DHW) Subsystem

The DHW subsystem as described in Section 3.2 consists of the components in Table 3.6.

Table 3.6. DOMESTIC HOT WATER PARAMETERS

SADDLE HILL TRUST LOT 36

Fluid Transfer Loop	
Medium	Water
Piping	Copper, type L
Insulation	Polyurethane foam (R = 1.9 m^2-°K/W)
Pump (P2)	Taco, contrifugal, 29.83 W
Heat exchanger (HX2)	Vaughn, liquid-to-liquid convection, finned copper tube
Design flow rate	0.44 kg/sec
DHW tank	Vaughn, 303 liter capacity (R = 1.23 m^2-°K/W)
Auxiliary	Electric element energy input - 4,302 W energy output - 4,302 W
Tempering Valve (V2)	Watts model 70A, 3-way, automatic

3.2.5 Heat Rejection

The Daystar heat dump panels are located on the roof as a protection from overheating. When the heat rejection condition exists (See System Operation section) valve (V1) diverts some of the collector flow through the heat dump panels. The distribution valve (V1) is an automatic, motorized, temperature-controlled, flow adjusting valve manufactured by Treice. If the collector-to-storage mode is not on, then one of the two collector loop pumps (P1) is activated in conjunction with the heat rejection mode.

3.3 DESCRIPTION OF THE CONTROL SYSTEM HARDWARE

The control system consists of control temperature sensors (CTS) and control mode selectors (CMS) which activate or deactivate the various pumps, auxiliary heating elements, or the blower. The CMS receives input signals from the control temperature sensors located within the system. The CMS then compares the signals to either a preset internal value or to other input signals to determine if the output mode will be activated or deactivated. The devices controlled by the different control mode selectors are included in Table 3.7. The locations of the control temperature sensors are shown in Figure 3.3 and are also listed in Table 3.7. The description of the modes and input conditions are in Section 4.

Table 3.7. CONTROL SYSTEM HARDWARE

SADDLE HILL TRUST LOT 36

MODE SELECTOR		INPUT TEMPERATURE SENSOR		OUTPUT CONTROLLED	MODE
CMS-1	Rho Sigma	CTS-1	Collector	Pumps (P1) (2)	Collector-to-
	Differential thermostat	CTS-2	Storage bottom		storage
CMS-2	Rho Sigma	CTS-3	Storage top	Pump (P2)	Storage-to-
	Differential thermostat	CTS-4	DHW tank top		DHW tank
CMS-3	Dual thermostat	CTS-6	House temperature sensors (2)	Pump (P3)	Storage-to- space heating
		CTS-3	Storage top	Blower (BL1) oil burner	Auxiliary-to- space heating
CMS-4	"Aquastat"	CTS-5	DHW tank middle	Electric heating element	Auxiliary-to-DHW
CMS-5		CTS-1	Collector	Pump (P1) (1)	Heat rejection
		CTS-3	Storage top	Valve (V1)	

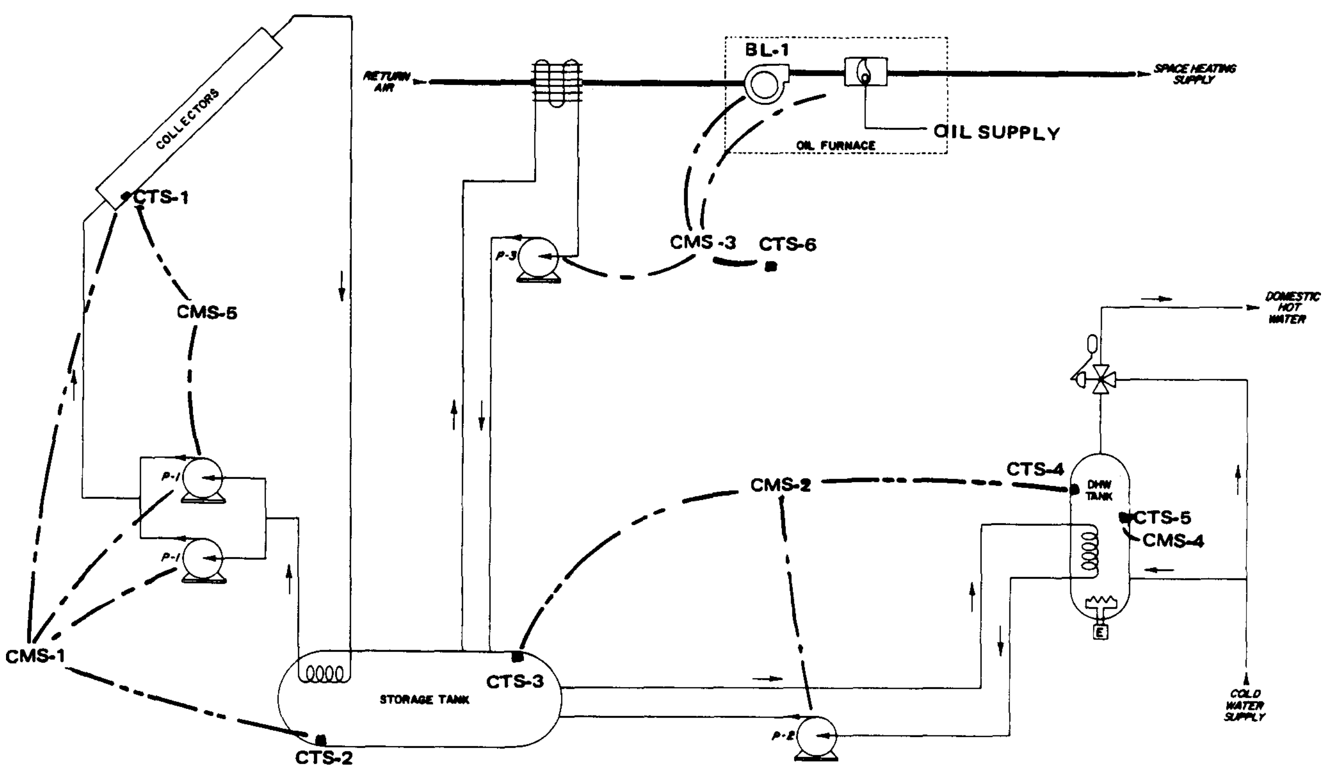


Figure 3.3. Control System Hardware
Saddle Hill Trust Lot 36

SECTION 4

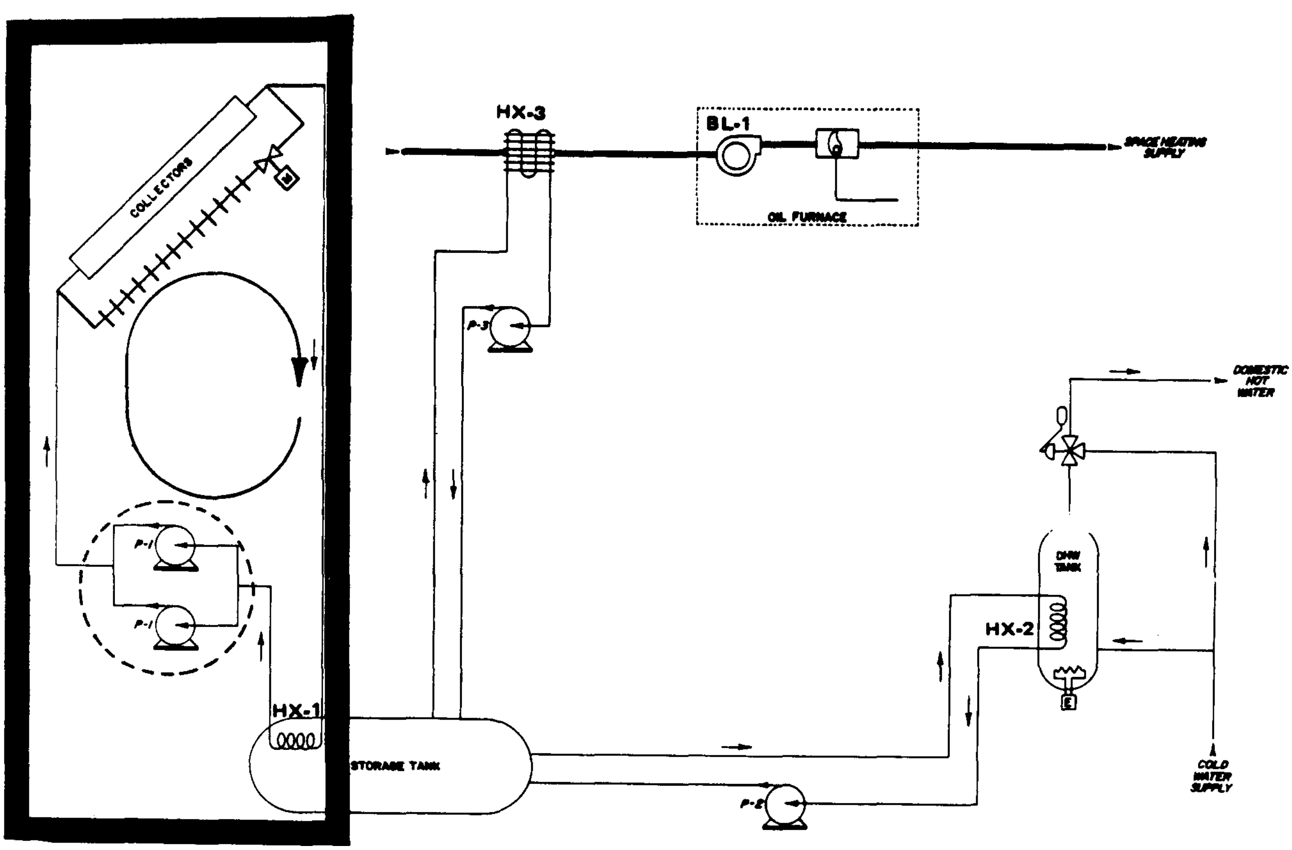
SYSTEM OPERATION

4.1 OPERATING MODES

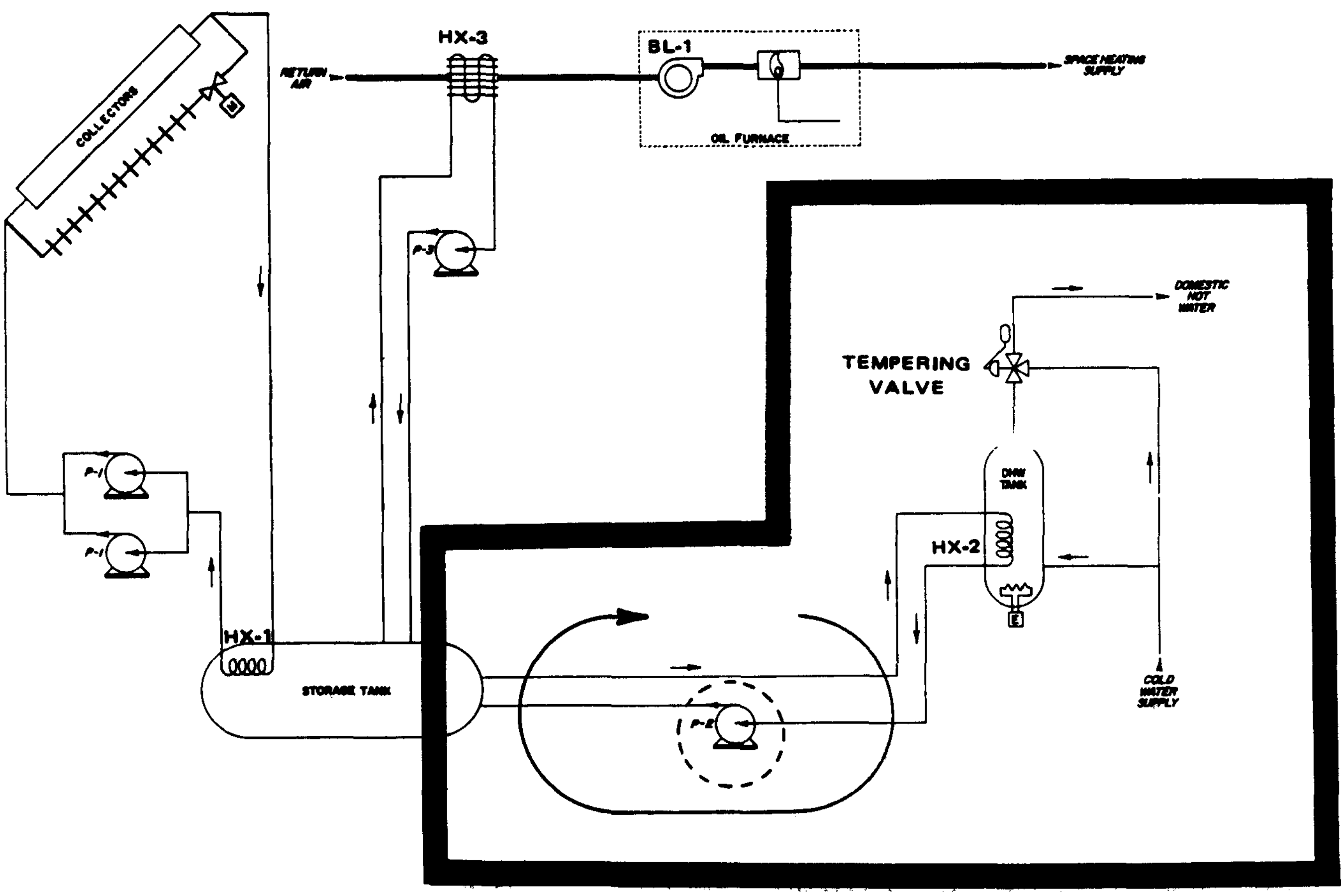
The solar system may operate in one or more of the modes described in this section. Details of the control conditions are included in Section 4.2

Modes: Collector-to-Storage
Domestic Hot Water Heating-from-Storage
Auxiliary DHW Heating
Space Heating-from-Storage
Auxiliary Space Heating
Heat Rejection

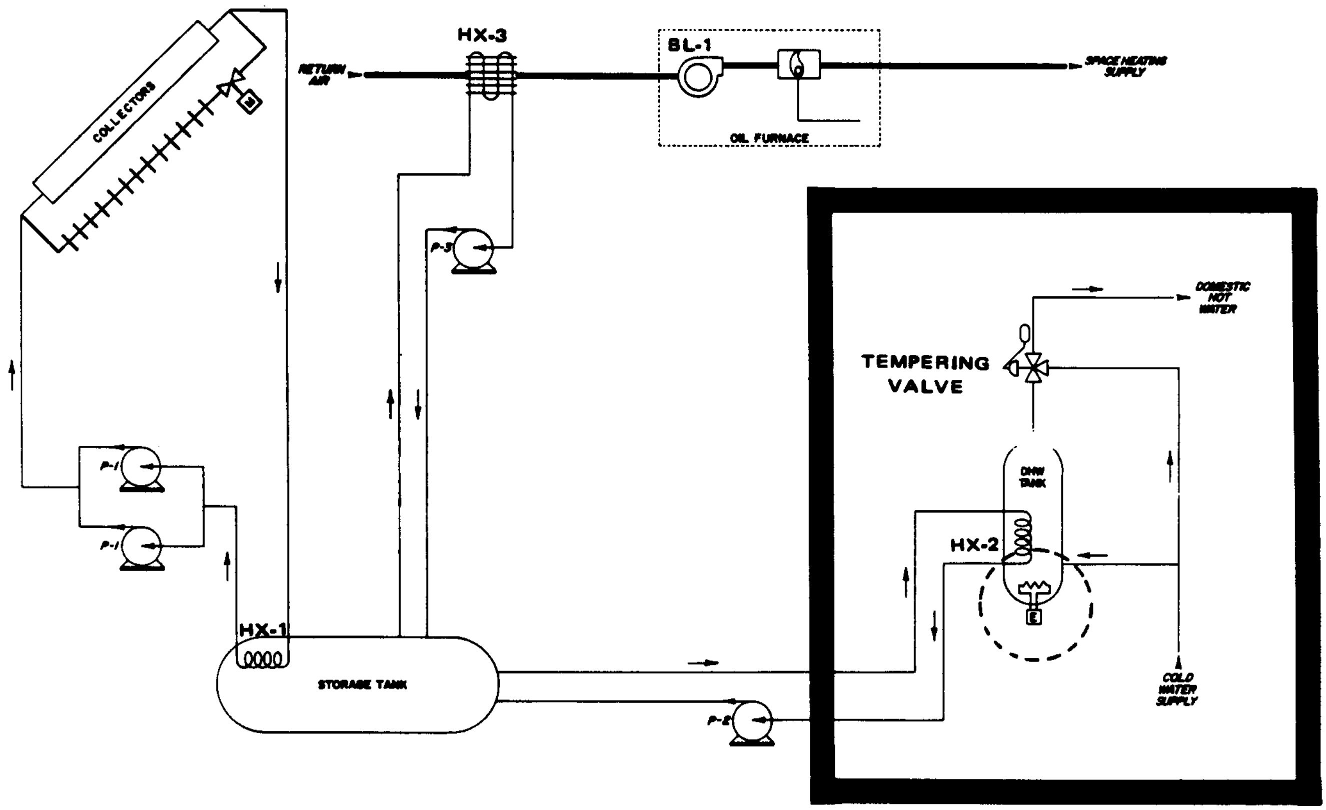
Collector-to-Storage Mode - When the collector temperature control sensor, located in the collector outlet manifold, indicates a temperature 22°C greater than the storage temperature control sensor, located at the bottom of the storage tank, collector pumps (P1) are activated and will circulate water through the storage tank and the collectors. The collector pumps (P1) continue to run until the collector temperature becomes less than 1°C greater than the storage temperature.



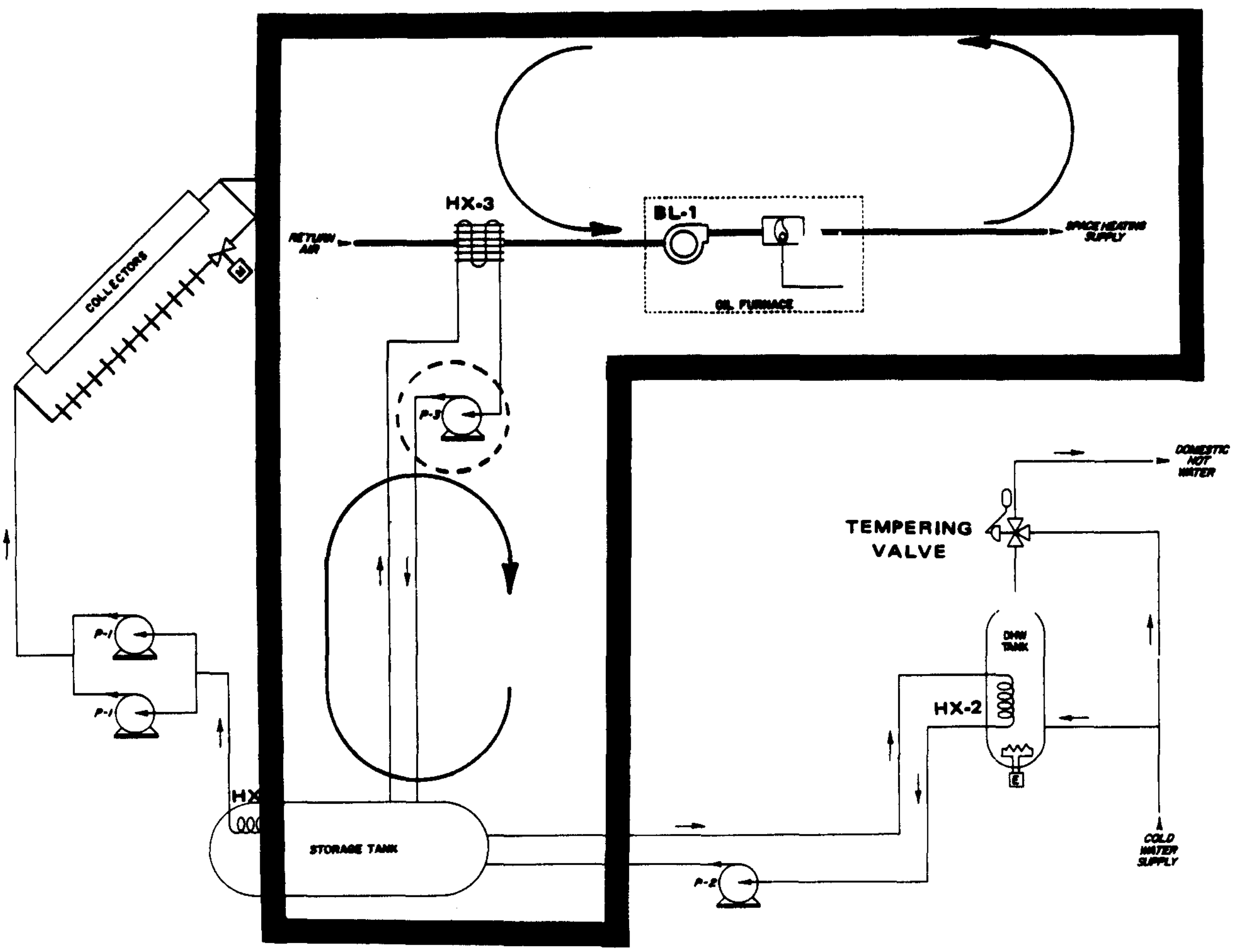
<u>Domestic Hot Water Heating from Storage Mode</u> - Energy from solar storage is used to heat domestic hot water when the temperature differential between the storage tank and DHW tank top is greater than 3°C. When this condition is met, pump P2 is activated, circulating water from the DHW heater through a heat exchanger located in the DHW tank.



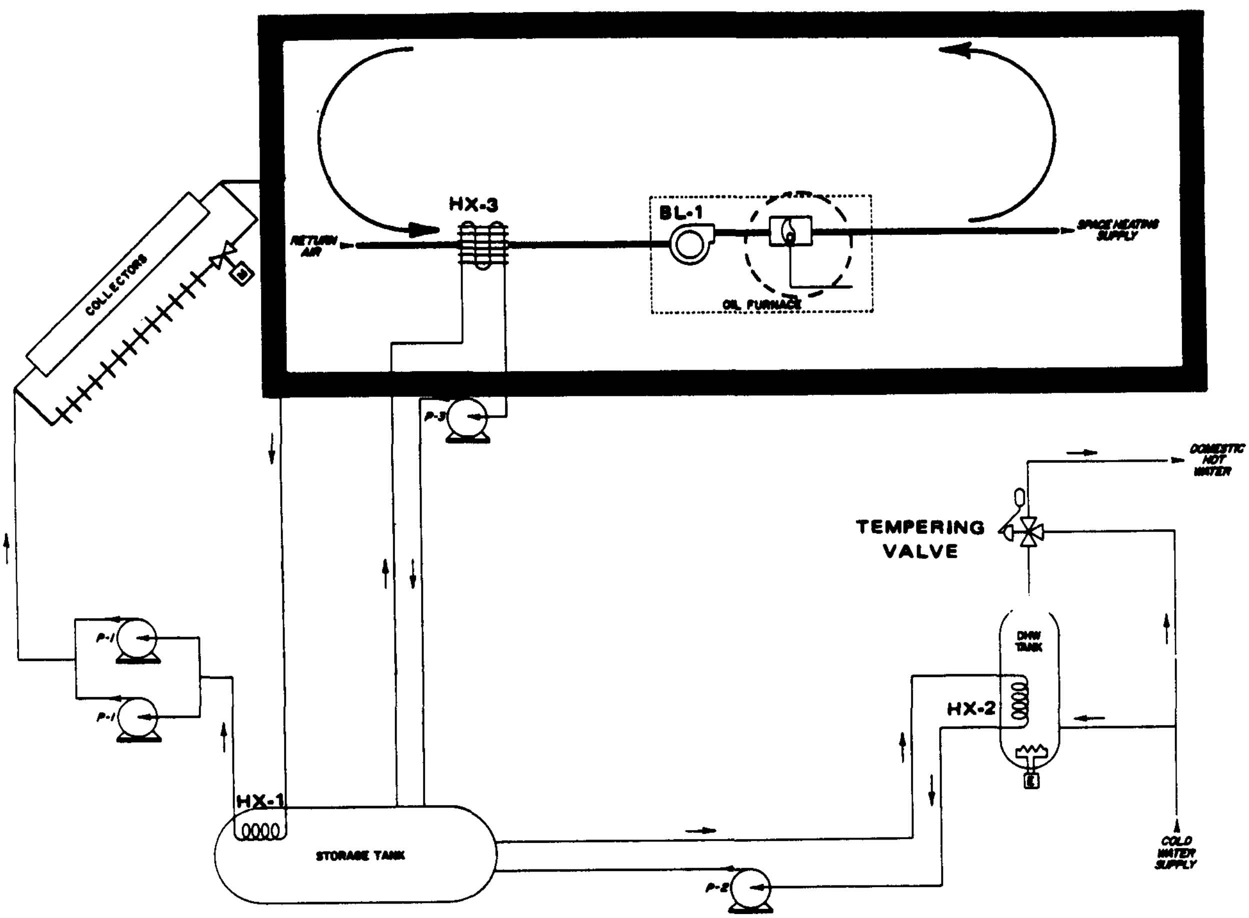
Auxiliary DHW Heating Mode - The auxiliary electric heating element in the DHW tank is activated when the temperature in the tank drops below 49°C.



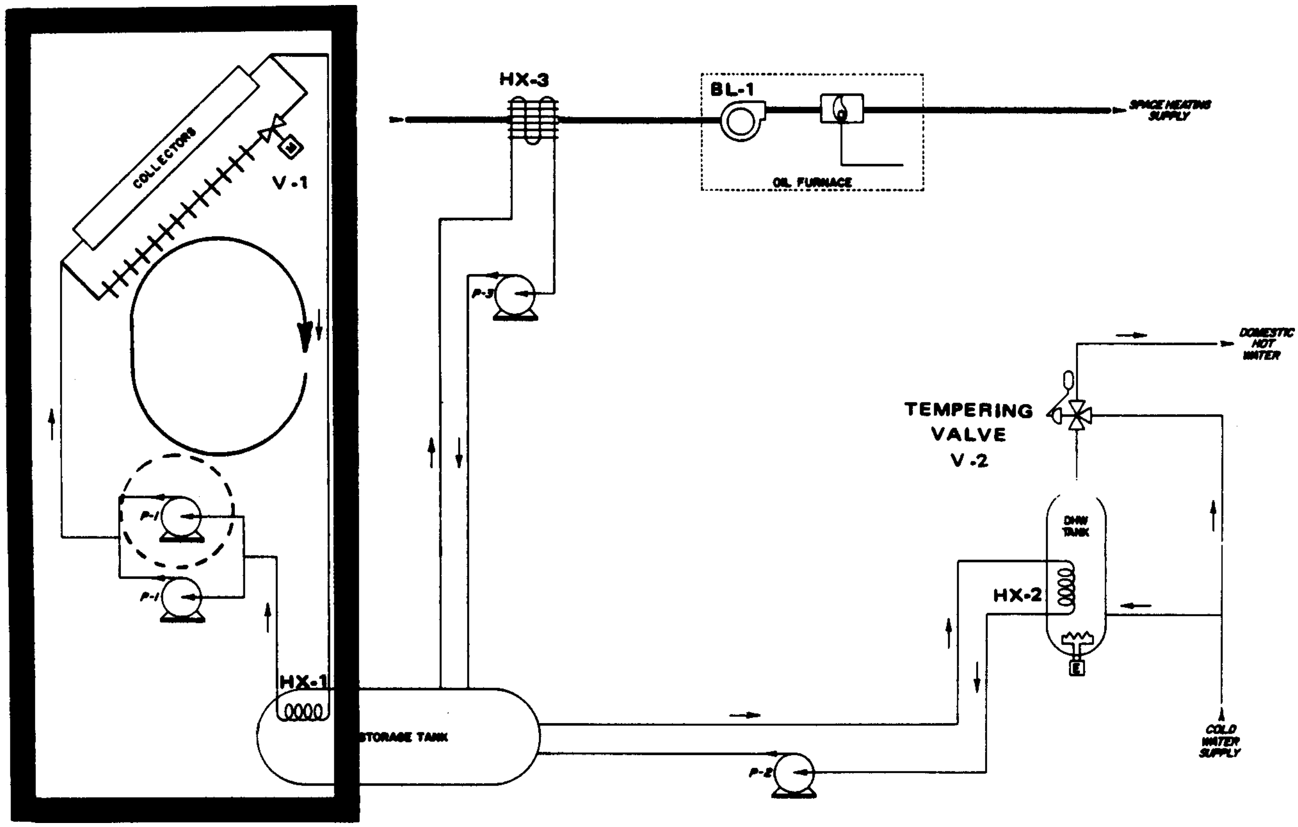
Space Heating-from-Storage Mode - Solar energy from storage is used for space heating when there is a demand from the space heating thermostat and there is sufficient thermal energy in storage, as indicated by the storage tank top temperature not being less than 29°C. In this mode, space heating circulating pump and the blower in the air distribution system are activated. A valve is positioned to allow flow from the storage tank through the heating coils of the heat exchanger and back to the storage tank. The oil-fired furnace does not operate in this mode.



Auxiliary Space Heating Mode - The auxiliary heating mode is used when there is a demand for space heating as indicated by the space thermostat and there is not sufficient thermal energy in storage to meet the demand. In this mode the oil-fired furnace is activated.



Heat Rejection Mode: Whenever the collector liquid heat transfer media exceeds 66°C, the energy dumping mode will be initiated. In this mode, valve V1 is positioned to allow flow through the heat rejection heat exchanger and one collector pump P1 is activated to remove the heat.



4.2 CONTROL STRATEGY

The conditions which control the various operating modes are shown in Table 4.1. Each mode is governed by one or more on and off conditions which are determined by the settings of various control temperature sensors as shown in the table. As a result of the various input conditions being met, the controlled elements (pumps, blower, heaters, etc.) in the subsystems are activated or deactivated according to the truth table also in Table 4.1.

There are two pumps in the collector-to-storage loop that are activated when the difference between the collector and storage tank control sensors reaches 22°C. Also, one of these pumps (if not already running) is activated when the collector temperature sensor registers 66°C or higher. Distribution valve V1 is used along with this pump to divert the collector fluid through the heat dump panels to reject excess heat from the system.

The storage-to-DHW mode operates when there is a temperature difference of 3°C between the storage tank and DHW tank sensors. However, if the DHW temperature drops below 49°C, the auxiliary electric element will be turned on to bring the temperature back up to 49°C. Therefore, both the storage-to-DHW and the auxiliary-to-DHW modes may operate simultaneously.

The storage-to-space heat mode is initiated when the room temperature drops below 21°C and if the storage temperaure is above 29°C. However, if the room temperature continues to drop below 20°C, the auxiliary oil furnace is then activated to bring the room temperature back up to 20°C. Both of the space heating modes may be operating at the same time.

Table 4.1. CONTROL STRATEGY

SADDLE HILL TRUST LOT 36

CONTROL SENSORS

CTS-1	COLLECTOR TEMP. SENSOR	CTS-4	DHW TANK TOP TEMP. SENSOR
CTS-2	STORAGE BOTTOM TEMP. SENSOR	CTS-5	DHW TANK MIDDLE TEMP. SENSOR
CTS-3	STORAGE TOP TEMP. SENSOR	CTS-6	HOUSE TEMP. SENSORS

MODE		INPUT CONDITIONS	OUTPUT TO CONTROLLED ELEMENTS: (2) COLLECTOR PUMPS P1	STORAGE TO DHW PUMP P2	STORAGE TO SPACE HEATING PUMP P3	BLOWER BL1	FURNACE OIL BURNER	DHW ELECTRIC HEATER
COLLECTOR-TO-STORAGE	ON	CTS-1 - CTS-2 > 22°C	1					
	OFF	CTS-1 - CTS-2 < 1°C	0					
STORAGE-TO-DOMESTIC HOT WATER	ON	CTS-3 - CTS-4 > 3°C		1				
	OFF	CTS-3 - CTS-4 < 3°C		0				
AUXILIARY-TO-DOMESTIC HOT WATER	ON	CTS-5 < 49°C						1
	OFF	CTS-5 > 49°C						0
STORAGE-TO-SPACE HEATING	ON	CTS-6 < 21°C and CTS-3 > 29°C			1	1		
	OFF	CTS-6 > 21°C or CTS-3 < 29°C			0	0		
AUXILIARY-TO-SPACE HEATING	ON	CTS-6 < 20°C				1	1	
	OFF	CTS-6 > 20°C				0	0	
HEAT REJECTION	ON	CTS-1 > 66°C	1*					
	OFF	CTS-1 < 66°C	0					

1 - ON 0 - OFF * ONE PUMP ONLY

SECTION 5

THERMAL PERFORMANCE EVALUATION PROGRAM

This seasonal performance evaluation on the Saddle Hill Trust Lot 36 site is a report on one of over one hundred sites in the National Solar Data Network.

The National Solar Data Network (NSDN) is part of the National Solar Data Program of the Department of Energy. The NSDN supports the Data Program by evaluating the performance of a large variety of solar systems which are installed in residential, commercial and institutional buildings. These buildings are dispersed throughout the continental United States, Hawaii, and Puerto Rico. The systems employ "active" mechanical equipment or "passive" design features, or both, to supply solar energy to typical building thermal loads such as space heating, space cooling, and domestic hot water. Solar systems on some sites are used to supply industrial process heat.

The buildings in the NSDN are instrumented to monitor thermal energy flows to space conditioning, hot water, or process loads from both solar and auxiliary or backup systems. Collection, storage, and distribution of solar energy are monitored daily and evaluated monthly on the basis of the processed data obtained. To disseminate the results of the performance analysis, Monthly Performance and Solar System Evaluation Reports are prepared for each site.

The data produced by the National Solar Data Program are used to:

1. Determine the savings in fossil fuel and electrical energy resulting from the use of solar energy for space heating, space cooling, and/or hot water.

2. Determine the total heating, cooling and/or hot water thermal energy loads and the fraction of each load supplied by solar energy.

3. Measure the solar energy system efficiency for converting solar radiation into useful thermal energy.

4. Measure the thermal performance of major subsystems or components and the thermal interactions between collector array, storage, and energy conversion equipment.

5. Measure the occupants' use of the system by means of parameters such as the temperature level maintained and hot water demand.

6. Determine the major system operational characteristics and degradation over the life of the demonstration.

7. Obtain records of the incident solar radiation and other pertinent site environmental parameters that could affect the performance of the system over the life of the demonstration.

8. Determine the performance of systems other than heating and cooling systems, e.g., wind energy and photovoltaic systems.

The categories of information included in the NSDN in order to meet these goals are:

- o Detailed solar energy system descriptions,
- o Design and construction problems and solutions,
- o Solar system costs,
- o Reliability and maintenance information,
- o Solar system operating history, and
- o Solar system thermal performance.

Site analysis is concerned mainly with this last category.

Technical performance evaluation of each solar energy system/building/climatic region demonstration is based upon the following factors: (from NBSIR-76/1137)

1. Determining the savings in fossil fuel and electrical energy resulting from the use of solar energy for space heating, space cooling and/or hot water.
2. Measuring the total heating, cooling and/or hot water thermal energy loads and the fraction of each load supplied by solar energy for monthly, seasonal, or annual periods.
3. Measuring the solar energy system efficiency for converting solar radiation into useful thermal energy for monthly and seasonal or annual periods.
4. Measuring the thermal performance of major subsystems or components and the thermal interactions between collector array, storage and energy conversion equipment.
5. Measuring the occupants' use of the system by means of parameters such as the temperature level maintained and hot water demand.
6. Determining the major system operational characteristics and degradation over the life of the demonstration (one to five years).
7. Obtaining records of the incident solar radiation and other pertinent site environmental parameters that could affect the performance of the system over the life of the demonstration.

The information flow for performance evaluation employed in the NSDN is illustrated in Figure 5.1

The performance evaluation instrumentation at each selected demonstration site is part of a comprehensive data collection system that allows for valid analyses of the solar system performance. Collected data are both applicable

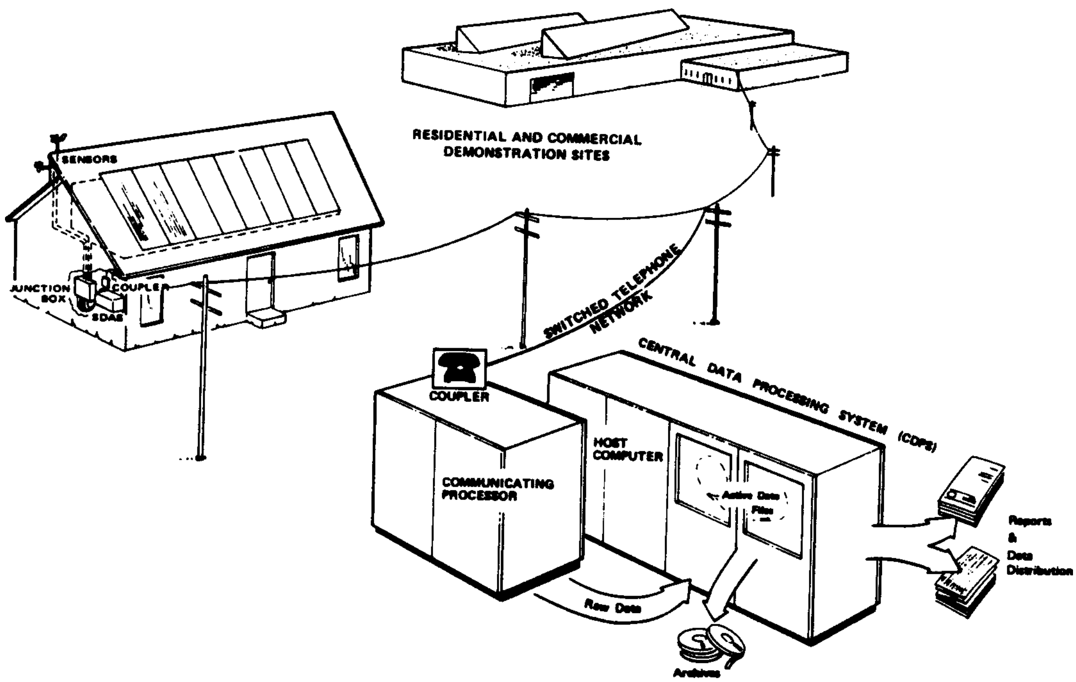


Figure 5.1. The National Solar Data Network

and practical in calculating thermal performance factors that describe the behavior of the solar system (see References 3 and 3a). Additional instrumentation may also be included as a result of site-specific requirements. Typically, the instrumentation includes sensors that monitor the following:

- Total insolation in the plane of the collector array
- Ambient temperature
- Collector subsystem flow rate and temperatures
- Storage inlet flow rate and temperatures
- Storage outlet flow rate and temperatures
- Storage temperature
- Storage-to-load subsystem flow rate and temperatures
- Auxiliary fuel flow rates

Site data are recorded automatically at prescribed intervals by the Site Data Acquisition Subsystem (SDAS). The recorded data are transmitted daily to the communications processor in the Central Data Processing System (CDPS). The communications link between every SDAS and the CDPS consists of voice-grade telephone lines and telephone data couplers. A reading is transmitted from the SDAS internal timer with every data sample to ensure that the data are time-tagged correctly.

The communications processor scans the receiving data to identify any apparent transmission errors and verifies correct site contact by checking the address code transmitted by the SDAS. Data is stored temporarily in the communications processor. It is then transmitted to and processed by the host computer. The processing includes measurement checking to ensure that the data are reasonable; that is, that they are not beyond the known instrument limits and that they are not erratic. Data which appear questionable are discarded and are not used in the solar system performance analyses.

Appropriate equations are formulated and programmed to define desired performance factors for the solar energy systems at each selected demonstration site. A performance factor is a number that describes either the efficiency or the quantity of energy lost, gained, or converted by a solar energy system or by a component. All void data are processed using the performance factor equations to generate hourly performance factors. These hourly, daily, and monthly performance factors are stored in data files in the CDPS.[1] These data files also include measurement data, expressed in engineering units; numerical and textual site identification; and specific site data used in generating the performance factors.

Specific equations for Saddle Hill Trust Lot 36 site are listed beginning on Page 5-23.

5.1 DEFINITIONS OF THE THERMAL PERFORMANCE FACTORS

The performance of the solar energy system is evaluated by calculating a set of primary performance factors which are based on those in the intergovernmental agency report Thermal Data Requirements and Performance Evaluation Procedures of the National Solar Heating and Cooling Demonstration Program NBSIR-76/1137. The following discussion is taken from this document.

5.1.1 Performance Evaluation Guidelines

5.1.1.1 Categories of Performance Factors - Performance factors and associated data requirements have been classified into three categories. Category one (primary) items are required for a data summary that is considered essential to adequately measure the solar energy system or subsystem thermal effectiveness and determine the energy saved by the solar energy system in comparison with the energy that would have been used by conventional hot

[1]Data tapes are available in any standard computer format.

water, space heating, or space cooling systems. Without this data, comparative evaluations of different solar energy subsystems and systems would be incomplete or impossible.

Category two (secondary) requirements are for data deemed important and useful in evaluating different subsystems or components. Such data make it easier to understand the component interactions that occur in system operation and serve as an aid in comparative analysis or simulation but are not essential. In general, category two data can be determined by appropriate calculations or approximations using category one measurements. However, in some cases the data can only be obtained by measurements.

An example of a secondary performance factor is the storage efficiency. The average storage medium temperature is the significant parameter in determining the amount of stored energy available. The change of storage medium temperature during a time period with no addition or withdrawal of energy can provide a measure of the storage efficiency. The storage medium temperature is thus very useful but is not unique to the system thermal evaluation.

Category three data are obtained from special measurements which are not particularly essential for current analysis needs, but which serve to define system operational conditions. System operating pressure or component pressure differential are examples of such measurement.

5.1.1.2 Standard Designations for Sensors and Subsystems - In order to standardize the performance calculations and identify sensors according to type and location, an alphanumeric name is provided for each performance factor and sensor. A five-character name is used consisting of one or two letters which designate either the sensor type or the measured or calculated quantity and a three-digit number which identifies the subsystems or data group as follows:

Letter Designations

C = Specific Heat

D = Direction or Position

EE = Electric Energy

EP = Electric Power

F = Fuel Flow Rate

I = Incident Solar Flux (Insolation)

N = Performance Parameter

P = Pressure

PD = Differential Pressure

Q = Thermal Energy

T = Temperature

TD = Differential Temperature

V = Velocity

W = Heat Transport Medium Volume Flow Rate

TI = Time

Subsystem Designations

Number Sequence	Subsystem/Data Group
001 to 099	Climatological
100 to 199	Collector and Heat Transport
200 to 299	Thermal Storage
300 to 399	Hot Water
400 to 499	Space Heating
500 to 599	Space Cooling
600 to 699	Building/Load

Thus, sensor designation T101 defines a temperature measurement in the collector subsystem and the variable name Q600 defines a heat flow measurement or calculation for a building load grouping.

5.1.1.3 General Solar Description and Energy Balance - Prior to discussing the performance evaluation and measurement requirements of solar energy systems, it is useful to describe in general terms the equipment and subsystems that comprise a solar energy system and to describe the flow of thermal energy from the solar equipment, through the energy conversion and distribution equipment to the building. The basic elements of a solar hot water, space heating and space cooling system include a solar energy collection and storage subsystem (ECSS), and energy conversion and distribution subsystem (ECDS) and the building.

5.1.1.4 Functions of Subsystems - The function of the collector subsystem, collector energy transport subsystem, and storage subsystem (ECSS) is to convert the relatively variable incident solar radiation to a relatively steady source of thermal energy in the form of elevated temperature heat transport fluid or storage medium. This solar source acts as a significant thermal energy source for the building's energy conversion equipment. The major purpose of the ECSS is to reduce the consumption of nonrenewable energy sources such as natural gas, oil, and electricity normally used to provide the hot water, heating, and cooling for the building.

The energy conversion and distribution subsystem is comprised of three subsystems to provide the distinct functions of hot water heating, space heating and space cooling; and utilizes conventional HVAC equipment such as electric or fuel-fired heating furnaces, hot water heaters, heat pumps, absorption chillers and their associated pumps, fans, heat exchangers, controls, piping and ductwork. The function of this equipment is to combine the energy available from the solar subsystem with the auxiliary energy available from the conventional energy sources when the supply of solar energy is inadequate, and to convert the solar energy to a useful energy form for the building. To accomplish this conversion and distribution function, additional electrical energy is required to power the pumps, fans, and controls.

The building consists of the various structural elements in which the transfer of thermal energy between the outdoor and indoor environments occurs primarily by the process of conduction, convection, radiation, and infiltration. When the solar heat gain and the structural heat losses and gains are combined with the internal heat gains from the lights, appliances, and other equipment and the metabolic heat from the occupants, and these loads are absorbed by the air in the temperature-controlled spaces of the building, they comprise the building thermal load. If the HVAC equipment's rate of heat removal or addition to the building is exactly equal to the building thermal load, the air temperature is stabilized and the building is in balance. Hot water is also treated as a building thermal load for some NSDN sites and the hot water subsystem capability to provide the thermal energy required at the desired temperature is balanced against the actual rate of hot water consumption.

5.1.1.5 Thermal Energy Flow - The primary tool which is used in the location and choice of measurements is the concept of energy balances. For a given component, the amount of energy input must equal the energy output plus the change in storage energy within the component.

This tool is particularly useful as a check on the installed instrumentation. By obtaining the heat balance periodically on a component or subsystem, evaluation of the losses and accuracy of the installed data instrumentation can be made. When the heat balance "error" is not within acceptable limits, investigation on a particular subsystem may be required to determine the need for sensor recalibration or subsystem maintenance.

5.1.1.6 Subsystem Heat Loss - The quantity "energy loss" represents the difference between the total energy entering the subsystem (plus, in the case of thermal storage, the energy given up by the storage medium in the time period) and the thermal energy delivered by the subsystem. In most cases, the subsystem energy loss represents thermal energy transferred to the subsystem environment by heat loss through component insulation.

Depending on the physical location of a component, the subsystem environment can be outside the building either above or below ground or inside the building either in a temperature-controlled or a noncontrolled space. No further use is made of the heat lost by components located outside the building and above ground. However, the heat lost by components in the other locations can affect the performance of the solar energy system.

Examination of each subsystem element reveals the energy quantities that must be either measured or estimated to determine the subsystem heat balance. Subsystem heat loss is probably the most difficult quantity to measure. Therefore, it must be determined from the heat balance by measuring or calculating all the other quantities.

5.1.2 Energy Quantities Evaluated

The energy flow and the major measured energy quantities flowing into and out of the subsystems of the Saddle Hill Trust Lot 36 solar energy system are shown in Figure 5.2. A detailed list of the definitions of each of the performance factors and energy quantities is included in the next section.

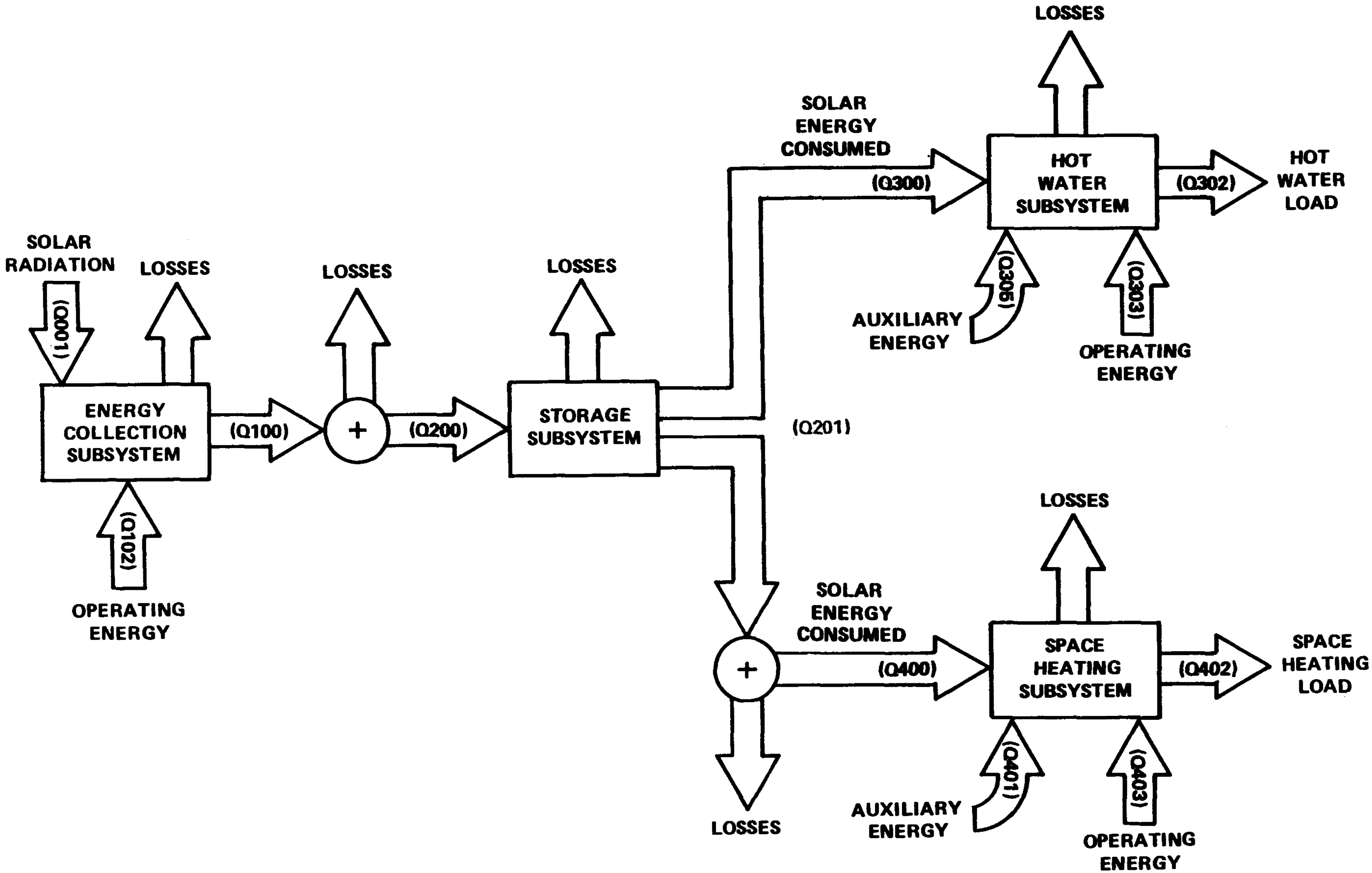


Figure 5.2. Energy Flow Diagram for Saddle Hill Trust Lot 36 with NBS Designations in Parentheses

5.1.3 Thermal Performance Indicators

The factors used to describe the performance of sites in the NSDN program are defined below. Those performance factors that are not applicable to the Saddle Hill Trust Lot 36 site are indicated by an N next to the symbol.

PERFORMANCE FACTOR DEFINITIONS

NBS ID	SYMBOL	NAME	DEFINITION
-	AXE	Auxiliary Electric Fuel Energy to Load Subsystem	Amount of electrical energy required as a fuel source for all load systems. (J)
-	AXF	Auxiliary Fossil Fuel Energy to Load Subsystem	Amount of fossil energy required as a fuel source for all load subsystems. (J)
Q600	* AXT	Auxiliary Thermal Energy to Load Subsystems	Thermal energy delivered to all load subsystems to support a portion of the subsystem loads, from all auxiliary sources. (J)
Q511	(N)CAE	SCS Auxiliary Electrical Fuel Energy	Amount of electrical energy provided to the SCS to be converted and applied to the SCS load. (J)
Q508	(N)CAF	SCS Auxiliary Fossil Fuel Energy	Amount of fossil energy provided to the SCS to be converted and applied to the SCS load. (J)
N100	CAREF	Collector Array Efficiency	Ratio of the collected solar energy to the incident solar energy.
Q501	(N)CAT	SCS Auxiliary Thermal Energy	Amount of energy provided to the SCS by a heat transfer fluid from an auxiliary source. (J)
Q502	*(N)CL	Space Cooling Subsystem Load	Energy required to satisfy the temperature control demands of the space cooling subsystem. (J)
Q503	(N)COPE	SCS Operating Energy	Amount of energy required to support the SCS operation which is not intended to be applied directly to the SCS load. (J)

* Primary Performance Factors
(N) Not applicable to the Saddle Hill site

BS ID	SYMBOL	NAME	DEFINITION
-	(N)CSAUX	Auxiliary Energy to ECSS	Amount of auxiliary energy supplied to the ECSS. (J)
N111	* CSCEF	ECSS Solar Conversion Efficiency	Ratio of the solar energy supplied from the ECSS to the load subsystems to the incident solar energy on the collector array. (J)
Q500	(N)CSE	Solar Energy to SCS	Amount of solar energy delivered to the SCS. (J)
-	CSEO	Energy Delivered from ECSS to Load Subsystems	Amount of energy supplied from the ECSS to the load subsystems including any auxiliary energy supplied to the ECSS). (J)
N500	*(N)CSFR	SCS Solar Fraction	Portion of the SCS load which is supported by solar energy. (J)
Q102	CSOPE	ECSS Operating Energy	Amount of energy used to support the ECSS operation (which is not intended to be supplied to the ECSS thermal state). (J)
-	(N)CSRJE	ECSS Rejected Energy	Amount of energy intentionally rejected or dumped from the ECSS subsystem. (J)
Q512	*(N)CSVE	SCS Electrical Energy Savings	Difference in the electrical energy required to support an assumed similar conventional SCS and the actual electrical energy required to support the demonstration SCS, for identical SCS loads. (J)
Q514	* CSVF (N)	SCS Fossil Energy Savings	Difference in the fossil energy required to support an assumed similar conventional SCS and the actual fossil energy required to support the demonstration SCS, for identical loads. (J)
Q409	(N)HAE	SHS Auxiliary Electrical Fuel Energy	Amount of electrical energy provided to the SHS to be converted and applied to the SHS load. (J)

* Primary Performance Factors
(N) Not applicable to the Saddle Hill site

NBS ID	SYMBOL	NAME	DEFINITION
Q410	HAF	SHS Auxiliary Fossil Fuel Energy	Amount of fossil energy provided to the SHS to be converted and applied to the SHS load. (J)
Q401	HAT	SHS Auxiliary Thermal Energy	Amount of energy provided to the SHS by a heat transfer fluid from an auxiliary source. (J)
Q402	* HL	Space Heating Subsystem Load	Energy required to satisfy the temperature control demands of the space heating subsystem. (J)
Q403	HOPE	SHS Operating Energy	Amount of energy required to support the SHS operation (which is not intended to be applied directly to the SHS load). (J)
N400	* HSFR	SHS Solar Fraction	Portion of the SHS load which is supported by solar energy.
Q400	HSE	Solar Energy to SHS	Amount of solar energy delivered to the SHS. (J)
N415	* HSVE	SHS Electrical Energy Savings	Difference in the electrical energy required to support an assumed similar conventional SHS and the actual electrical energy required to support the demonstration SHS, for identical SHS loads. (J)
Q417	* HSVF	SHS Fossil Energy Savings	Difference in the fossil energy required to support an assumed similar conventional SHS and the actual fossil energy required to support the demonstration SHS, for identical SHS loads. (J)
Q305	HWAE	HWS Auxiliary Electrical Fuel Energy	Amount of electrical energy provided to the HWS to be converted and applied to the HWS load. (J)
Q306	(N)HWAF	HWS Auxiliary Fossil Fuel Energy	Amount of fossil energy provided to the HWS to be converted and applied to the HWS load. (J)

* Primary Performance Factors
(N) Not applicable to the Saddle Hill site

NBS ID	SYMBOL	NAME	DEFINITION
Q301	HWAT	HWS Auxiliary Thermal Energy	Amount of energy provided to the HWS by a heat transfer fluid from an auxiliary source. (J)
N308	HWCSM	Service Hot Water Consumption	Amount of heated water delivered to the load from the hot water subsystem. (liter)
Q302	* HWL	Hot Water Subsystem Load	Energy required to satisfy the temperature control demands of the building service hot water system. (J)
Q303	HWOPE	HWS Operating Energy	Amount of energy required to support the HWS operation which is not intended to be applied directly to the HWS load. (J)
Q300	HWSE	Solar Energy to HWS	Amount of solar energy delivered to the HWS. (J)
N300	* HWSFR	HWS Solar Fraction	Portion of the HWS load which is supported by solar energy.
Q311	* HWSVE	HWS Electrical Energy Savings	Difference in the electrical energy required to support an assumed similar conventional HWS and the actual electrical energy required to support the demonstration HWS, for identical HWS loads. (J)
Q313	*(N)HWSVF	HWS Fossil Energy Savings	Difference in the fossil energy required to support an assumed similar conventional HWS and the actual fossil energy require[d] to support the demonstration HWS for identical loads. (J)
-	(N)RELH	Relative Humidity	Average outdoor relative humidit[y] at the site.
Q001	* SE	Incident Solar Energy	Amount of solar energy incident per unit area of the collector plane. (J/m^2)
Q001	SEA	Incident Solar Energy on Array	Amount of solar energy incident upon the collector array. (J)

* Primary Performance Factors
(N) Not applicable to the Saddle Hill site

NBS ID	SYMBOL	NAME	DEFINITION
Q100	* SEC	Collector Solar Energy	Amount of thermal energy added to the heat transfer fluid per unit area of the collector area. (J/m^2)
Q100	SECA	Collected Solar Energy by Array	Amount of thermal energy added to the heat transfer fluid by the collector array. (J)
-	(N)SEDF	Diffuse Insolation	Amount of diffuse solar energy incident per unit area of a collector plane. (J/m^2)
Q003	SEOP	Operational Incident Solar Energy	Amount of incident solar energy upon the collector array wheneve the collector loop is active. (
Q203	* SEL	Solar Energy to Load Subsystems	Amount of solar energy supplied by the ECSS to all load subsystems. (J)
N601	* SFR	Solar Fraction of System Load	Portion of the system load which was supported by solar energy.
Q202	STECH	Change in ECSS Stored Energy	Change in ECSS stored energy during reference time period. (
N108	STEFF	ECSS Storage Efficiency	Ratio of the sum of energy supplied by ECSS storage and the change in ECSS stored energy to the energy delivered to the ECSS storage.
Q200	STEI	Energy Delivered to ECSS Storage	Amount of energy delivered to ECSS storage by the collector array and from auxiliary sources (J)
Q201	STEO	Energy Supplied by ECSS Storage	Amount of energy supplied by ECSS storage to the load subsystems. (J)
Q602	* SYSL	System Load	Energy required to satisfy all desired temperature control demands at the output of all subsystems. (J)

* Primary Performance Factors
(N) Not applicable to the Saddle Hill site

NBS ID	SYMBOL	NAME	DEFINITION
Q601	* SYSOPE	System Operating Energy	Amount of energy required to support the system operation, including all subsystems, which is not intended to be applied directly to the system load. (J)
N602	* SYSPF	System Performance Factor	Ratio of the system load to the total equivalent fossil energy expended or required to support the system load.
N113	* TA	Ambient Temperature	Average temperature of the ambient air. (°C)
N406	* TB	Building Temperature	Average temperature of the controlled space of the building. (°C)
N403	(N)TCECOP	TCE Coefficient of Performance	Coefficient of performance of the thermodynamic conversion equipment.
-	(N)TCEI	TCE Thermal Input Energy	Equivalent thermal energy which is supplied as a fuel source to thermodynamic conversion equipment. (J)
Q407	(N)TCEL	Thermodynamic Conversion Equipment Load	Controlled energy output of thermodynamic conversion equipment. (J)
Q404	(N)TCEOPE	TCE Operating Energy	Amount of energy required to support the operation of thermodynamic conversion equipment which is not intended to appear directly in the load. (J)
-	(N)TCERJE	TCE Reject Energy	Amount of energy intentionally rejected or dumped from thermodynamic conversion equipment as a by-product or consequence of its principal operation. (J)
-	TDA	Daytime Average Ambient Temperature	Average temperature of the ambient air during the daytime (during normal collector operation period). (°C)

* Primary Performance Factors
(N) Not applicable to the Saddle Hill site

NBS ID	SYMBOL	NAME	DEFINITION
Q603	* TECSM	Total Energy Consumed by System	Amount of energy demand of the system from external sources; sum of all fuels, operating energies, and collected solar energy. (J)
N307	THW	Service Hot Water Temperature	Average temperature of the service hot water supplied by the system. (°C)
(T200)	TST	ECSS Storage Temperature	Average temperature of the ECSS storage medium. (°C)
Q604	* TSVE	Total Electrical Energy Savings	Difference in the estimated electrical energy required to support an assumed similar conventional system and the actual electrical energy required to support the system, for identical loads; sum of electrical energy savings for all subsystems. (J)
Q605	* TSVF	Total Fossil Energy Savings	Difference in the estimated fossil energy required to support an assumed similar conventional system and the actual fossil energy required to support the system, for identical loads; sum of fossil energy savings for all subsystems. (J)
N305	TSW	Supply Water Temperature	Average temperature of the supply water to the hot water subsystem. (°C)
N114	(N)WDIR	Wind Direction	Average wind direction at the site.
N115	(N)WIND	Wind Velocity	Average wind velocity at the site. (m/sec)

* Primary Performance Factors
(N) Not applicable to the Saddle Hill site

5.2 DESCRIPTION OF THE MONITORING SYSTEM

Data collection and transmission from residential and commercial sites in the National Solar Data Network are illustrated in Figure 5.3. As shown, the major elements are:

1. On-site instrumentation, including temperature and flow sensors, power sensors, valve and damper position indicators, an electrical junction box, and a Site Data Acquisition Subsystem (SDAS) (electronic scanner and signal conditioning device).

2. A telephone link between the instrumented site and a communication processor at Vitro Laboratories.

3. Data processing systems at Vitro Laboratories that convert the data from the site into engineering units, in suitable format for daily printout of performance information and monthly compilation of energy performance factors suitable for analysis and preparation of Monthly Performance and Solar System Evaluation Reports.

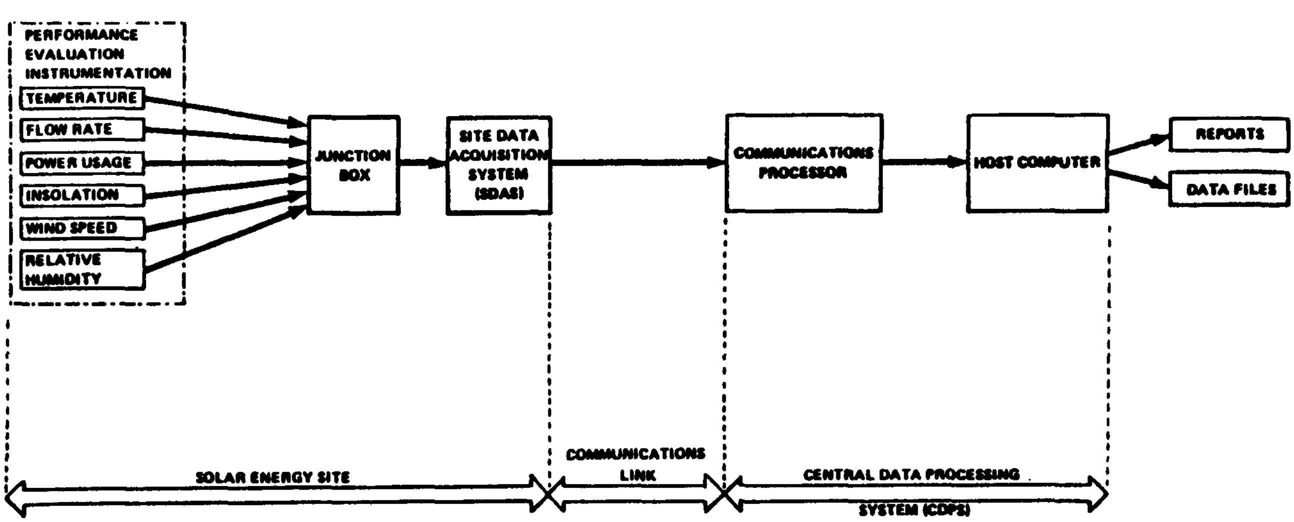


Figure 5.3. Data Flow Path for the National Solar Data Network

5.2.1 Instrumentation

Each site contains standard industrial instrumentation modified for the particular site. Sensors measure temperatures, flows, insolation, electric power, fossil fuel usage, and other parameters.

Sensors are placed within the solar system to measure the state of variables needed to determine the various performance factors defined in Section 5.1. The list of these sensors for Saddle Hill Trust Lot 36 is given in Table 5.1 and their locations are shown on Figure 5.4. The designations for the sensors (alphanumberic symbol) are those described in Section 5.1. More detailed sensor information is given in Appendices B and C.

Table 5.1. INSTRUMENTATION

SADDLE HILL TRUST LOT 36

SUBSYSTEM	SENSOR	DESCRIPTION
Climatic	I001	Outdoor ambient temperature
	T001	Total insolation
ECSS	T100	Collector inlet temperature
	T150	Collector outlet temperature
	T101	Storage HX (HX1) outlet temperature
	T151	Storage HX (HX1) inlet temperature
	W100	Collector flow rate
	EP100	Collector pump power (P1)
Storage	T200	Storage tank top temperature
	T201	Storage tank middle temperature
	T202	Storage tank bottom temperature
DHW	T300	Storage tank from HW preheat coil HX (HX2) temperature
	T350	Storage tank to HW preheat coil (HX2) temperature
	T301	HW preheat coil (HX2) exit temperature
	T351	HW preheat coil (HX2) inlet temperature
	W300	Preheat coil (HX2) flow rate
	EP300	DHW pump (P2) power
	EP301	Hot water heater auxiliary power
	T302	Cold water supply temperature
	T352	DHW tank outlet temperature
	W301	Cold water supply total flow
Space Heating	T400	Storage from coil (HX3) inlet temperature
	T450	Storage outlet to coil (HX3) temperature
	T401	Heating coil (HX3) outlet temperature
	T451	Heating coil (HX3) inlet temperature
	W400	Heating coil (HX3) to storage flow rate
	EP400	Space heating fluid loop pump (P3) power
	T402	Return air temperature

Table 5.1. INSTRUMENTATION (Cont'd)

SADDLE HILL TRUST LOT 36

SUBSYSTEM	SENSOR	DESCRIPTION
Space Heating (Cont'd)	T452	Heating coil (HX3) outlet to furnace temperature
	W401	Return air flow rate
	EP401	Furnace blower
	F400	Switch - fuel flow to oil furnace
	T453	Space heating outlet air temperature
Building	T600	Building interior ambient temperature

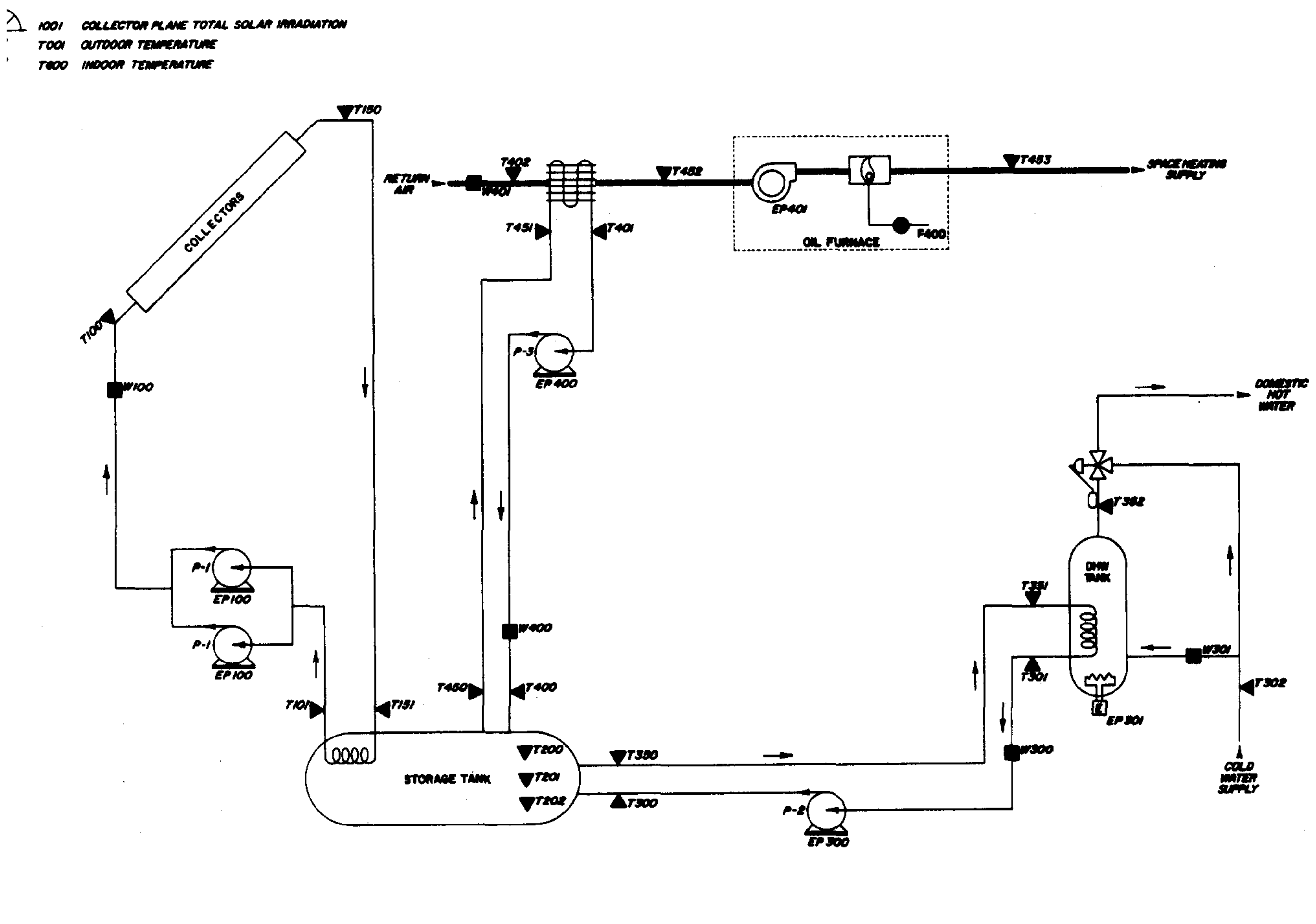


Figure 5.4. Instrumentation at Saddle Hill Trust Lot 36

5.2.2 Data Acquisition

Sensors at the site are all wired into a junction box (J-box) which is in turn connected to a microprocessor data logger called the Site Data Acquisition Subsystem (SDAS). The SDAS can read up to 96 different channels, one channel for each sensor. The SDAS takes the analog voltage input to each channel and converts it to a 10-bit word. At intervals of five minutes (actually every 320 seconds) the SDAS samples each channel and records the values on a cassette tape. Some of the channels can be sampled 10 times in each five-minute period, and the average value is recorded in the tape.

Each SDAS is connected through a modem to voice-grade telephone lines which are used to transmit the data to a central computer facility. This facility is the Central Data Processing System (CDPS), located at Vitro Laboratories in Silver Spring, Maryland. The CDPS hardware consists of an IBM System 7, an IBM 370/145, and an IBM 3033. The System 7 periodically calls up each SDAS in the system and has the SDAS transmit the data on the cassette tape back to the System 7. Typically, the System 7 collects data from each SDAS six times a week, although the tape can hold three to five days of data, depending on the number of channels.

The data received by the System 7 are in the form of digital counts in the range of 0-1,023. These counts are then processed by software in the CDPS, where they are converted from counts to engineering units (EU) by applying the appropriate calibration constants. The engineering unit data called "detailed measurements" in the software are then tabulated on a daily basis for the site analyst, and these tabulations are also called "tab data." The CDPS is also capable of transforming this data into plots or graphs.

An important factor in the above process is the assurance of valid data. Data integrity is maintained by checking data received from various sites to insure that the transmission quality is acceptable. Incoming data are examined, and data with apparent errors are tagged by the data processing software and recognized thereafter as invalid.

Similarly, there are data which may be transmitted properly but may appear questionable because of the values obtained after conversion to engineering units. These apparent anomalies may be caused by a sensor failure at the site, incorrect sensor installation, a transmission problem (otherwise undetected), a software problem not previously detected, or a malfunction of the solar energy system. Data of this character are also tagged as invalid.

No data which have been identified as invalid are used by the Central Data Processing System for the computation of performance factors. The existence of such invalid data, however, implies that suitable procedures must be incorporated into the software to assure usable performance factors in the Monthly Performance Reports, and to identify the existence of any unacceptable data. Such procedures are implemented in the software by enforcing a requirement for a minimum amount of data necessary to provide reasonable validity. These minimum limits are selected (from the results of data analysis studies) to insure that the performance factors computed from the data fall within 10% of the true value even in the case of missing data.

There may be a maximum of 12 measurement scans recorded within any particular clock hour. When there is a missing measurement, the next good measurement is assumed to replace the missing measurement for the purpose of computing the hourly performance factors. (The missing measurement is assumed only for the purpose of computing the appropriate performance factors; it is not actually replaced in the data.) Therefore, all performance factors which are computed are supported by a reasonable amount of good data. All other performance factors are tagged as invalid.

Similarly, there must be a representative number of good, hourly samples within any one calendar day to initiate the calculation of daily performance factors. When there are sufficient data, any invalid data are replaced (for computational purposes) by the average of the good samples.

The monthly performance factors are computed only if there is a minimum number of good daily samples. Invalid data are replaced (for computation) by the average of all the good daily samples. These techniques provide performance factors which are supported by sufficient data, thereby producing a high confidence level in the information.

5.3 DATA REDUCTION PROCEDURE

The analyst develops a unique set of "site equations" for each site in the NSDN, following the guidelines presented herein.

The equations calculate the flow of energy through the system, including solar energy, auxiliary energy, and losses. These equations are programmed in PL/1 and become part of the Central Data Processing System. The PL/1 program for each site is termed the site software. The site software processes the detailed data, using as input a "measurement record" containing the data for each five-minute period. The site software produces as output a set of performance factors; on an hourly, daily, and monthly basis.

These performance factors quantify the thermal performance of the system by measuring energy flows throughout the various subsystems. The system performance may then be evaluated based on the efficiency of the system in transferring these energies.

Solar energy system performance is evaluated by performing energy balance calculations on the system and its major subsystems. These calculations are based on physical measurement data taken from each sensor every 320 seconds (scan time). This data is then mathematically combined to determine the hourly, daily, and monthly performance of the system. This section describes the general computational methods and the specific energy balance equations used for this site.

Data samples from the system measurements are integrated to provide discrete approximations of the continuous functions which characterize the system's dynamic behavior. This integration is performed by summation of the product of the measured rate of the appropriate performance parameters and the sampling interval over the total time period of interest.

There are several general forms of integration equations which are applied to each site. These general forms are exemplified as follows: the total solar energy available to the collector array is given by

$$\text{SOLAR ENERGY AVAILABLE} = (1/60)\ \Sigma\ [\text{I001} \times \text{CLAREA}] \times \Delta\tau$$

where I001 is the solar radiation measurement provided by the pyranometer in Joules per square meter per hour, CLAREA is the area of the collector array in square meters, $\Delta\tau$ is the sampling interval in minutes, and the factor (1/60) is included to correct the solar radiation "rate" to the proper units of time.

Similarly, the energy flow within a system is given typically by

$$\text{COLLECTED SOLAR ENERGY} = \Sigma\ [\text{M100} \times \Delta H] \times \Delta\tau$$

where M100 is the mass flow rate of the heat transfer fluid in kg/min and ΔH is the enthalpy change, in J/kg, of the fluid as it passes through the heat exchanging component.

For a liquid system ΔH is generally given by

$$\Delta H = \bar{C}_p\ \Delta T$$

where $\bar{C}_p$ is the average specific heat (in joules/kg°C) of the heat transfer fluid and ΔT, in °C, is the temperature differential across the heat exchanging component.

For an air system ΔH is generally given by

$$\Delta H = H_a(T_{out}) - H_a(T_{in})$$

where $H_a(T)$ is the enthalpy, in J/kg, of the transport air evaluated at the inlet and outlet temperatures of the heat exchanging component.

$H_a(T)$ can have various forms, depending on whether or not the humidity ratio of the transport air remains constant as it passes through the heat exchanging component.

For electrical power, a general example is

$$\text{ECSS OPERATING ENERGY} = \Sigma\ [\text{EP100}] \times \Delta\tau$$

where EP100 is the power required by electrical equipment.

Letter Designations

CP	=	Specific Heat
D	=	Direction or Position
EE	=	Electric Energy
EP	=	Electric Power
F	=	Fuel Flow Rate
I	=	Incident Solar Flux (Insolation)
N	=	Performance Parameter
P	=	Pressure
PD	=	Differential Pressure
Q	=	Thermal Energy
RHO	=	Density
T	=	Temperature
TD	=	Differential Temperature
V	=	Velocity
W	=	Heat Transport Medium Volume Flow Rate
TI	=	Time

Subsystem Designations

Number Sequence	Subsystem/Data Group
001 to 099	Climatological
100 to 199	Collector and Heat Transport
200 to 299	Thermal Storage
300 to 399	Hot Water
400 to 499	Space Heating
500 to 599	Space Cooling
600 to 699	Building/Load

Initial Equations and Conditions

STOCAP = Storage volume = 2,840 liters

CLAREA = Collector area = 29.26 m^2

GEFF = Furnace efficiency = 0.6

HVF = Heating value of fuel = 2.46 MJ/min

F400 = Fuel switch, 1 = on, 0 = off

WCONST = 1 kg/liter

CP_g = Specific heat glycerol solution
CP_w = Specific heat water
RHO_g = Density glycerol solution
RHO_w = Density water
(Temperature dependent)

Mass Flow Rates

M100 = W100 x SQRT (WCONST x RHO_g) evaluated at T100

M300 = W300 x SQRT (WCONST x RHO_w) evaluated at T301

M400 = W400 x SQRT (WCONST X RHO_w) evaluated at T400

M301 = WD301 x RHO evaluated at T302

PERFORMANCE EQUATIONS

s = Scan level equation (320 seconds)
h = Hourly level equation

s AVERAGE AMBIENT TEMPERATURE (N113, °C)

$$TA = (1/60) \times \Sigma\ T001 \times \Delta\tau$$

s AVERAGE BUILDING TEMPERATURE (N406, °C)

$$TB = (1/60) \times \Sigma\ T600 \times \Delta\tau$$

s DAYTIME AVERAGE AMBIENT TEMPERATURE (°C)

$$TDA = (1/360) \times \Sigma\ T001 \times \Delta\tau$$

for ± three hours from solar noon

s INCIDENT SOLAR ENERGY PER SQUARE METER (Q001, J/m^2)

$SE = (1/60) \times \Sigma\ I001 \times \Delta\tau$

h INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (J)

$SEA = CLAREA \times SE$

s OPERATIONAL INCIDENT SOLAR ENERGY (Q003, J)

$SEOP = (1/60) \times [I001 \times CLAREA] \times \Delta\tau$

when the collector loop is active

s SOLAR ENERGY COLLECTED BY THE ARRAY (Q100, J)

$SECA = \Sigma\ [M100 \times CP_g \times (T150 - T100) \times \Delta\tau$

h COLLECTOR SOLAR ENERGY (J/m^2)

$SEC = SECA/CLAREA$

h COLLECTOR ARRAY EFFICIENCY (N100)

$CAREF = SECA/SEA$

s SOLAR ENERGY TO STORAGE (Q200, J)

$STEI = \Sigma\ [M100 \times CP_g \times (T151 - T101) \times \Delta\tau$

s AVERAGE TEMPERATURE OF STORAGE TANK (°C)

$TST = (1/60) \times \Sigma\ [(T200 + T201 + T202)/3] \times \Delta\tau$

s ENERGY OUT OF STORAGE TO DHW SUBSYSTEM (J)

$STEOW = \Sigma\ [M300 \times CP_w \times (T350 - T300)] \times \Delta\tau$

s ENERGY OUT OF STORAGE TO SPACE HEATING SUBSYSTEM (J)

$STEOH = \Sigma\ [M400 \times CP_w \times (T450, T400)] \times \Delta\tau$

h TOTAL ENERGY OUT OF STORAGE (Q201, J)

$STEO = STEOH + STEOW$

h CHANGE IN STORED ENERGY (Q202, J)

$STECH = STOCAP \times (TST1 \times RHO \times CP_w - TST1P \times RHO \times CP)$

where TST1 is the sum of the average temperatures in the storage ta
for the present hour

s $TST1 = \Sigma\ [(T200 + T201 + T203)/3] \times \Delta\tau$

and

TST1P is the sum of the average temperatures in the storage tank for the previous hour

h STORAGE EFFICIENCY (N108)

$STEFF = (STECH + STEO)/STEI$

s ECSS OPERATING ENERGY (Q102, J)

$CSOPE = \Sigma\ EP100 \times \Delta\tau$

s ENERGY DELIVERED TO DHW TANK (Q300), J)

$HWSE = \Sigma\ [M300 \times CP \times (T351 - T301)] \times \Delta\tau$

s DHW OPERATING ENERGY (Q303, J)

$HWOPE = \Sigma\ EP300 \times \Delta\tau$

s HOT WATER AUXILIARY ELECTRIC ENERGY (Q305, J)

$HWAE = \Sigma\ EP301 \times \Delta\tau$

h HOT WATER AUXILIARY THERMAL (Q301, J)

$HWAT = HWAE$

h ENERGY SAVINGS FOR DHW SUBSYSTEM (Q311, J)

$HWSVE = HWSE - HWOPE$

h WEIGHTED TEMPERATURE OF SUPPLY WATER (N305, °C)

$TSW = TSW1/TSW2$

s where $TSW1 = \Sigma\ [M301 \times T302] \times \Delta\tau$
and $TSW2 = \Sigma\ M301 \times \Delta\tau$

h WEIGHTED TEMPERATURE OF HOT WATER DELIVERED (N307, °C)

$THW = THW1/THW2$

where $THW1 = \Sigma\ [M301 \times T352] \times \Delta\tau$

h DHW TANK RELATIVE ENERGY

$TANKV = HWCAP \times (RHO_H \times CP_H \times THW - RHO_C \times CP_C \times TSW)$

where CP_H is the specific heat of the heated water

CP_C is the specific heat of the supply water

RHO_H is the density of the heated water, and

RHO_C is the density of the supply water

h SOLAR ENERGY IN HOT WATER TANK

$HWTKSE = (TANKV - HWSE - HWAT) \times (HWSFRP/100) + HWSE$

where HWSFRP is the previous hour's DHW tank solar fraction

h AUXILIARY ENERGY IN DHW TANK

$HWTKAUX = (TANKV - HWSE - HWAT) \times (1 - HWSFRP/100) + HWAT$

h DHW TANK SOLAR FRACTION (N300)

$HWSFR = 100 \times HWTKSE/(HWTKSE + HWTKAUX)$

s HOT WATER CONSUMPTION (N308, liters)

$HWSCM = \Sigma\ WD301 \times \Delta\tau$

where WD301 is derived from WD301 and a complex set of totalizer equations

s HOT WATER LOAD (Q302, J)

$HWL = \Sigma\ [M301 \times CP_w \times (T352 - T302) \times \Delta\tau$

s SOLAR ENERGY TO SPACE HEATING SUBSYSTEM (Q400, J)

$HSE = \Sigma\ [M400 \times CP_w \times (T451 - T401)] \times \Delta\tau$

s SPACE HEATING OPERATING ENERGY (Q403, J)

$HOPE = \Sigma\ [EP400 + EP401] \times \Delta\tau$

s SPACE HEATING SUBSYSTEM OPERATING ENERGY (Pump P3 only)

$HOPE1 = \Sigma\ EP400 \times \Delta\tau$

h AUXILIARY THERMAL TO SPACE HEATING (Q401, J)

HAT = GEFF x HAF

where GEFF is the furnace efficiency

and

HAF = Σ (HVF x F400) x $\Delta\tau$ (Q410, J)

where HVF is the heating value of the fuel

h SPACE HEATING LOAD (Q402, J)

HL = HSE + HAT

h HEATING SOLAR FRACTION (N400, J)

HSFR = 100 x HSE/HL

h ELECTRICAL SPACE HEATING SUBSYSTEM SAVINGS (EXPENSE) (Q415, J)

HSVE = HOPE1

h FOSSIL FUEL SPACE HEATING SAVINGS (Q417, J)

HSVF = HSE/GEFF

h SOLAR ENERGY TO SUBSYSTEMS

CSEO = STEO

h ECSS SOLAR CONVERSION EFFICIENCY (N111)

CSCEF = CSEO/SEA

h SOLAR ENERGY UTILIZED BY LOAD SUBSYSTEMS (Q203, J)

SEL = HSE + HWSE

h SYSTEM LOAD (Q602, J)

SYSL = HWL + HL

h SYSTEM SOLAR FRACTION (N601)

SFR = (HWSFR x HWL + HSFR x HL)/SYSL

h SYSTEM OPERATING ENERGY (Q601, J)

SYSOPE = HWOPE + HOPE + CSOPE

h SYSTEM AUXILIARY THERMAL ENERGY (Q600, J)

AXT = HWAT + HAT

h SYSTEM AUXILIARY ELECTRIC ENERGY

AXE = HWAE

h SYSTEM AUXILIARY FOSSIL ENERGY

AXF = HAF

h TOTAL ELECTRICAL SAVINGS (Q604, J)

TSVE = HWSVE + HSVE - CSOPE

h TOTAL FOSSIL SAVINGS (Q605, J)

TSVE = HSVF

h TOTAL ENERGY CONSUMED (Q603, J)

TECSM = AXF + SYSOPE + SECA + AXE

h SYSTEM PERFORMANCE FACTOR

SYSPF = SYSL/[(AXE + SYSOPE) x 3.33]

SECTION 6

DESCRIPTION OF THE OPERATING PERIOD

The solar and instrumentation systems functioned consistently during the reporting period. There were no major data gaps and each of the solar subsystems operated normally throughout the period.

There were no instrumentation changes, however, there was a problem with the measurement of the flow in the storage-to-DHW fluid transport loop involving flow meter W300. This flow meter was oversized for the magnitude of flow in the line, so the actual flow reading was near the noise level of the flow meter. To correct for this, a fixed value for the flow (based on the flow measured by W300) was used in the equations for calculations involving W300.

SECTION 7

PRESENTATION OF RESULTS

The performance of the Saddle Hill Trust Lot 36 site was evaluated for the heating season of October 1979 through May 1980. A summary of the overall performance of the system along with the design goals and long term averages is given below.

Overall Solar Fraction[1]	47%[4], measured 39%, design 50%
Solar Savings Ratio[2]	44%
Fuel Savings Fossil	48.25 gigajoules[4], measured 28.01 gigajoules
Fuel Savings Electrical	13.83 gigajoules
Solar System COP[3]	14

Seasonal Energy Requirements
October 1979 through May 1980
(Figures in gigajoules, unless otherwise indicated)

	Total Load	Solar Consumed	% Solar
Space Heating			
Equipment Heating[4]	70.64	28.85	41
Measured	56.73	16.80	30
Design	79.44	34.23	43
$UAC_D \times \Delta\tau$	62.05	-	-
Hot Water Demand Load			
Measured	16.13	13.57	76[5]
Design	20.44	15.76	77

Environmental Data

	Measured Average	Long-Term Average
Outdoor temperature	5°C	6°C
Heating degree-days (seasonal total)	3,467	3,244
Daily incident solar energy	13.93 MJ/m^2	12,03 MJ/m^2

1. $$\text{Solar Fraction} = \frac{\text{Solar Energy Supplied to Loads}}{\text{Total Load}} \times 100$$

2. $$\text{Solar Savings Ratio} = \frac{\text{Solar Energy Supplied to Load-Solar System Operating Energy}}{\text{Total Load}} \times 100$$

3. $$\text{Solar System COP} = \frac{\text{Solar Energy Used}}{\text{Operating Energy Required For Collection}}$$

4. Based on equipment heating load which includes losses from system to conditioned space

5. $$\text{DHW Solar Fraction} = \frac{\text{Solar Energy in DHW Tank}}{\text{Total Energy in DHW Tank}} \times 100$$

The measured values for the system's performance were derived from the data gathered by the instrumentation located in each subsystem. The data is then processed into performance factors according to the definitions and equations specified in Section 5. The equipment heating load refers to the total amount of energy given up by the system to the subsystem (including losses which reach the conditioned space to satisfy the space heating load). Therefore the equipment space heating load is defined as the measured load plus the losses from the storage and DHW tanks. The overall equipment heating load includes the equipment space heating load plus the measured DHW demand load. Since the losses from the system reduce the amount of auxiliary energy needed, it is likely that the equipment heating contribution more accurately reflects the actual contribution of the system.

The design and $UAC_D\Delta T$ values are those that were introduced and explained in Section 3 and the environmental data summary was taken from Section 2. Section 7 will present the results quantatively and serve as the basis for the qualitative discussion of results in Section 8.

7.1 SOLAR SYSTEM PERFORMANCE

The Saddle Hill Trust Lot 36 solar energy system supplied 41% of the space heating and 76% of the domestic hot water requirement during the heating season. The overall solar system performance is presented in Table 7.1 and shown graphically in Figure 7.1.

The solar system collected 39.61 GJ of solar energy and used 39.26 GJ of this energy to help satisfy the load. The use of this solar energy provided a fossil savings of 48.25 GJ and an electrical savings of 13.84 GJ. The fossil savings, solar fraction, and solar energy consumed were calculated based on the equipment heating load. The solar fraction was 47%. There were 66.53 GJ of auxiliary fossil fuel consumed by the space heating subsystem and 5.06 GJ of auxiliary electrical energy consumed by the DHW subsystem. In addition, there were 2.32 GJ of electrical energy used by the subsystem to operate the pumps in the fluid transfer lines.

The flow of energy through the system during the eight-month period is shown in Figure 7.2. The overall energy flows into, out of, lost or transported from subsystems are shown on this diagram. Operating energies are included in the losses on this diagram. The figure listed in the storage subsystem box (0.09 GJ) is the positive change in stored energy. This diagram is discussed in more detail in Section 8.

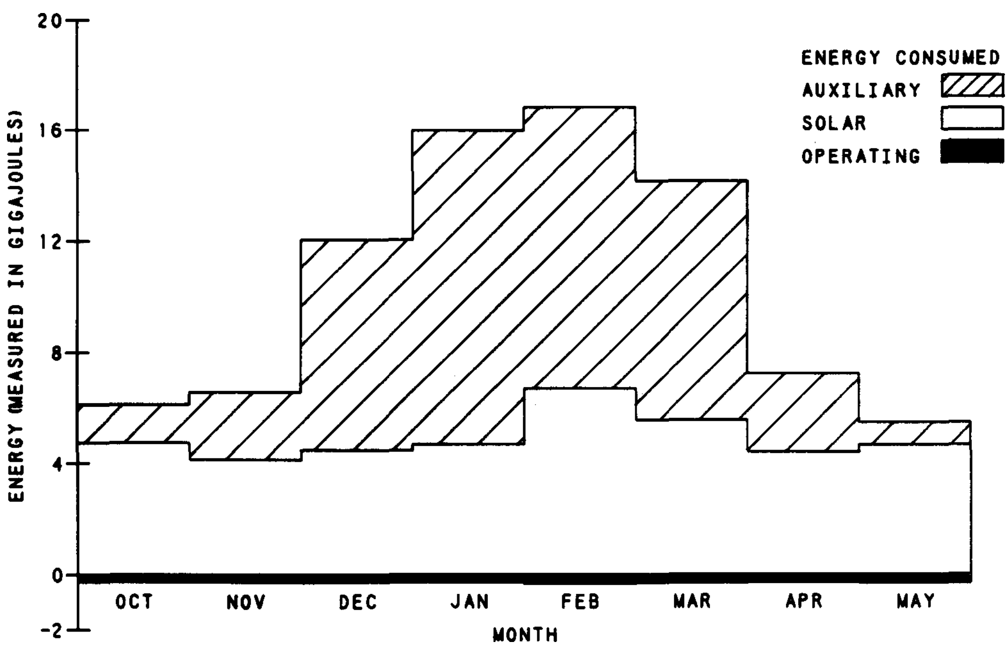
Table 7.1. OVERALL SOLAR SYSTEM THERMAL PERFORMANCE

SADDLE HILLS TRUST LOT 36
OCTOBER 1979 THROUGH MAY 1980

(All values in gigajoules, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED	SYSTEM LOAD		SOLAR ENERGY CONSUMED		AUXILIARY THERMAL CONSUMED	AUXILIARY ENERGY		OPERATING ENERGY		ENERGY SAVINGS			SOLAR FRACTION (%)	
											FOSSIL				
		EQUIPMENT HEATING[1]	MEASURED	EQUIPMENT HEATING[1]	MEASURED		FOSSIL	ELECTRICAL	SOLAR SPECIFIC	TOTAL	EQUIPMENT HEATING[1]	MEASURED	ELECTRICAL	EQUIPMENT HEATING[1]	MEASURED
OCT	4.82	6.09	3.86	4.74	3.32	1.34	1.88	0.21	0.27	0.40	5.78	2.21	1.72	78	67
NOV	4.22	6.52	5.41	4.12	3.74	2.39	3.21	0.46	0.26	0.45	5.02	3.43	1.43	63	59
DEC	4.60	12.03	10.92	4.47	4.29	7.53	11.12	0.86	0.28	0.64	5.65	4.32	1.42	37	34
JAN	4.60	15.96	14.53	4.68	4.30	11.27	17.05	1.04	0.28	0.71	5.77	4.00	1.63	29	25
FEB	6.84	16.81	15.53	6.67	6.29	10.17	15.88	0.64	0.33	0.87	8.88	7.10	1.70	40	36
MAR	5.42	14.13	12.19	5.54	4.49	8.61	12.97	0.83	0.30	0.68	6.85	4.03	1.77	39	32
APR	4.22	7.21	5.34	4.39	3.35	2.88	3.81	0.59	0.28	0.44	5.00	2.19	1.77	61	51
MAY	4.89	5.46	2.52	4.65	3.15	0.80	0.61	0.43	0.32	0.35	5.30	0.73	2.40	85	76
TOTAL	39.61	84.21	70.30	39.26	32.93	44.99	66.53	5.06	2.32	4.54	48.25	28.01	13.84	-	-
AVERAGE	4.95	10.53	8.79	4.91	4.08	5.62	8.32	0.63	0.29	0.57	6.03	3.50	1.73	47	39

[1]Based on equipment heating load as defined at the beginning of Section 7.



Operating energy for the system is considered a system penalty and is plotted as a negative value below the origin.

Figure 7.1. Overall System Thermal Performance
Saddle Hill Trust Lot 36
October 1979 through May 1980

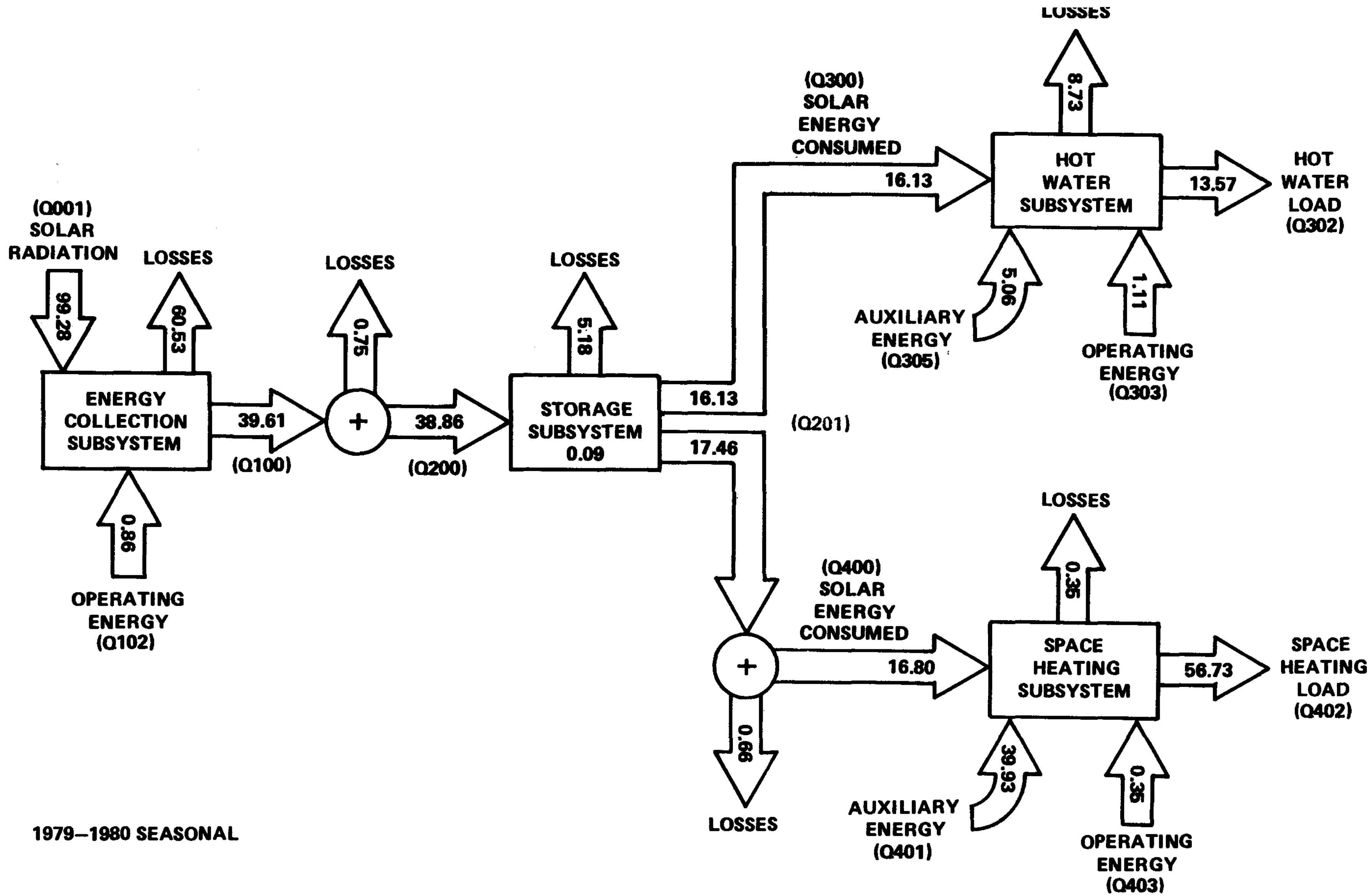


Figure 7.2. Energy Flow Diagram for Saddle Hill Trust Lot 36 for the Period October 1979 through May 1980

7.2 MONTHLY PERFORMANCE OF THE SOLAR ENERGY AND HVAC SYSTEMS

GENERAL SYSTEM PERFORMANCE FACTORS

Coefficient of Performance - The solar energy coefficient of performance (COP), shown in Table 7.2, simply provides a numerical value for the relationship of solar energy used or collected and the energy required to collect or deliver it. The greater the COP value, the more efficient the subsystem. The solar energy system at Saddle Hill Trust Lot 36 functioned at a reporting weighted average COP value of 14 for the heating season.

Table 7.2. SOLAR COEFFICIENT OF PERFORMANCE

SADDLE HILL TRUST LOT 36
OCTOBER 1979 THROUGH MAY 1980

MONTH	SOLAR ENERGY SYSTEM*	COLLECTION SUBSYSTEM	DOMESTIC HOT WATER SOLAR	SPACE HEATING SOLAR*
OCT	12	54	13	66
NOV	14	47	13	52
DEC	15	46	14	43
JAN	15	46	15	48
FEB	19	53	18	47
MAR	15	45	16	48
APR	12	42	14	44
MAY	10	38	15	44
AVERAGE	14	46	15	48

*Based on measured solar energy.

Energy Savings

Energy savings for this site for the reporting period are presented in Table 7.3. For this eight-month period, the total savings were 62.08 GJ, for a monthly average of 7.76 GJ. This is equivalent to the energy in 1,237 liters of oil (48.25 GJ) and 13.83 GJ of electricity. An electrical energy expense of 2.32 GJ was incurred during the reporting period for the operation of solar energy components.

Table 7.3. ENERGY SAVINGS

SADDLE HILL TRUST LOT 36
OCTOBER 1979 THROUGH MAY 1980

(All values in gigajoules)

	SOLAR ENERGY CONSUMED		SOLAR ENERGY SAVINGS ATTRIBUTED TO						NET ENERGY SAVINGS		
			SPACE HEATING			DOMESTIC HOT WATER				FOSSIL FUEL	
				FOSSIL FUEL			ECSS				
MONTH	EQUIPMENT HEATING	MEASURED	ELECTRICAL	EQUIPMENT HEATING	MEASURED	ELECTRICAL	OPERATING ENERGY		ELECTRICAL	EQUIPMENT HEATING	MEASURED
OCT	4.74	3.32	-0.02	5.78	2.21	1.83	0.09		1.72	5.78	2.21
NOV	4.12	3.74	-0.04	5.02	3.43	1.56	0.09		1.43	5.02	3.43
DEC	4.47	4.29	-0.06	5.65	4.32	1.58	0.10		1.42	5.65	4.32
JAN	4.68	4.30	-0.05	5.77	4.00	1.77	0.10		1.62	5.77	4.00
FEB	6.67	6.29	-0.09	8.88	7.10	1.92	0.13		1.70	8.88	7.10
MAR	5.54	4.49	-0.05	6.85	4.03	1.94	0.12		1.77	6.85	4.03
APR	4.39	3.35	-0.03	5.00	2.19	1.90	0.10		1.77	5.00	2.19
MAY	4.65	3.15	-0.01	5.30	0.73	2.54	0.13		2.40	5.30	0.73
TOTAL	39.26	32.93	-0.35	48.25	28.01	15.04	0.86		13.83	48.25	28.01
AVERAGE	4.91	4.08	-0.04	6.03	3.50	1.73	0.11		1.73	6.03	3.50

Solar energy system savings are realized whenever energy provided by the solar energy system is used to meet system demands which would otherwise be met by auxiliary energy sources. The operating energy required to transport solar energy from the collector to storage is subtracted from the solar energy contribution to the loads to determine net savings.

The auxiliary oil-fired furnace at Saddle Hill Trust Lot 36 is considered to be 67% efficient for computational purposes.

The equipment heating savings for space heating were the amount of solar energy that went to satisfy the equipment heating load. Any solar losses from the system to the conditioned space that reduced the amount of energy required by the auxiliaries were equipment heating savings. The measured savings were the measured amount of solar energy consumed by the subsystem (but not counting losses). The DHW savings represented the amount of solar energy contributed to the DHW subsystem that would have otherwise been provided by the auxiliaries. The solar system operating energy is subtracted from the savings of both subsystems to give the net electrical savings for the system. Figure 7.3 graphically shows the energy savings compared to the energy consumed for the space heating and DHW subsystems.

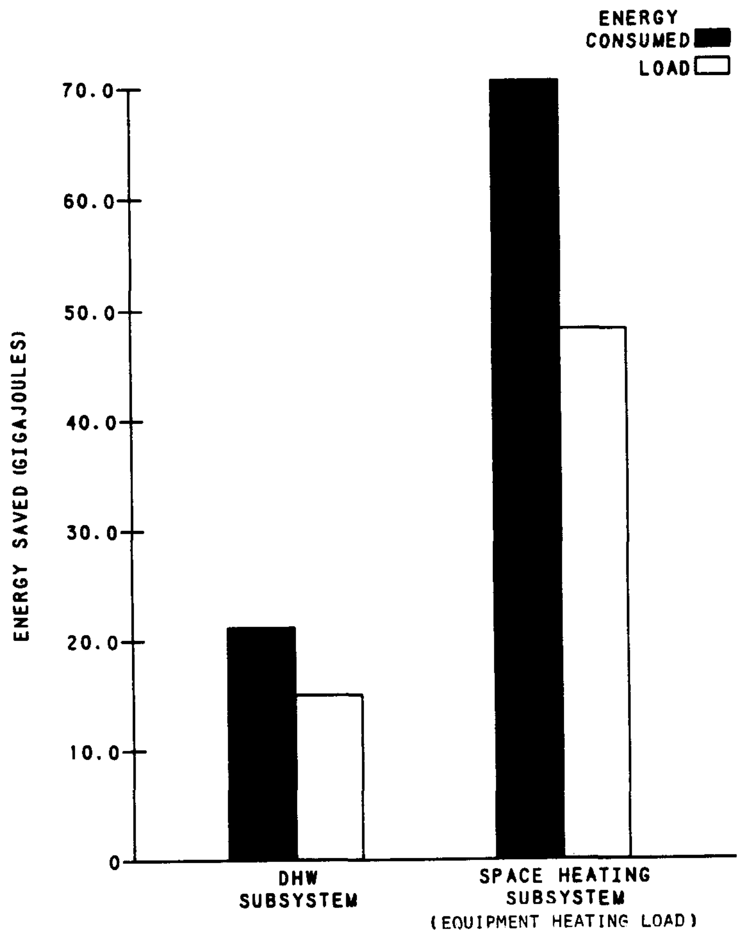


Figure 7.3. Combined Thermal Energy Savings Compared to Total Energy Consumed by Subsystem
Saddle Hill Trust Lot 36
October 1979 through May 1980

Solar Energy Utilization

Figure 7.4 shows the overall solar energy used and the percentage of losses for the heating season.

Of the 80.97 GJ of incident energy available while the collectors were operating, 51%, or 41.36 GJ, were lost. Of the 39.61 GJ collected, two percent, or 0.75 GJ were lost in transit to the storage tank. Fifteen percent of the energy delivered to the storage tank was then lost from storage and in transit to the subsystems. The remaining 32.93 GJ went toward satisfying the subsystem loads. This represented 33% of the total incident radiation for the period.

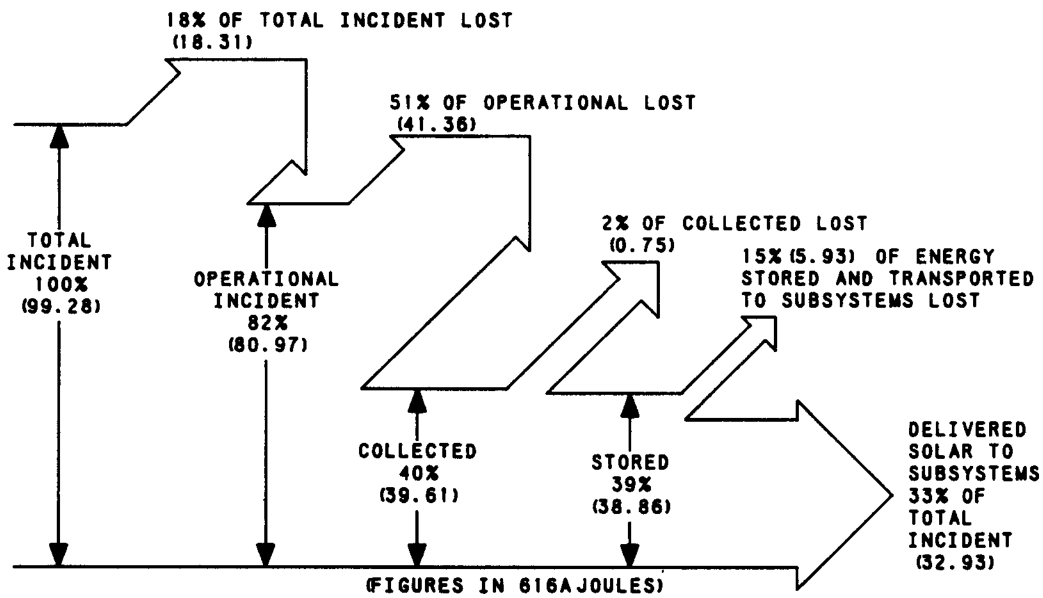


Figure 7.4. Solar Energy Use
Saddle Hill Trust Lot 36
October 1979 through May 1980

The losses of solar energy at the different stages through the system, from incident radiation to the loads are also presented by monthly breakdown in Table 7.4

Table 7.4. SOLAR ENERGY LOSSES

SADDLE HILL TRUST LOT 36
OCTOBER 1979 THROUGH MAY 1980

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
1. SOLAR ENERGY COLLECTED (gigajoules)	4.82	4.22	4.60	4.60	6.84	5.42	4.22	4.89
2. SE TO STORAGE (gigajoules)	4.58	4.00	4.48	4.51	6.74	5.41	4.25	4.89
3. LOSS - COLLECTOR TO STORAGE (%)	5	5	6	2	1	0	-1	0
4. CHANGE IN STORED ENERGY (gigajoules)	-0.05	-0.07	-0.01	-0.16	0.07	-0.08	0.00	0.39
5. SOLAR ENERGY - STORAGE TO DHW SUBSYSTEM (gigajoules)	2.00	1.68	1.70	1.90	2.03	2.07	2.04	2.71
6. SOLAR ENERGY - STORAGE TO SPACE HEATING SUBSYSTEM (gigajoules)	1.36	2.13	2.70	2.51	4.40	2.52	1.38	0.46
7. SOLAR ENERGY - STORAGE TO SUBSYSTEMS (gigajoules)	3.36	3.81	4.40	4.41	6.43	4.59	3.42	3.17
8. LOSS FROM STORAGE (%)	28	7	2	6	4	17	20	27
9. SOLAR IN HOT WATER DEMAND LOAD (gigajoules)	1.27	1.11	1.08	1.22	1.34	1.43	1.39	1.47
10. LOSS SOLAR ENERGY FROM DHW Tank (%)	37	34	36	36	34	31	32	46
11. HEATING SOLAR ENERGY FROM STORAGE (gigajoules)	1.32	2.06	2.59	2.40	4.26	2.42	1.31	0.44
12. LOSS - STORAGE TO HSE (%)	3	3	4	4	3	4	5	4

Operating Energy

Measured monthly values of the Saddle Hill Trust Lot 36 solar energy system and subsystem operating energy for the report period are presented in Table 7.5. A total 4.57 GJ of operating energy was consumed by the entire system during the reporting period. A distribution of this operating energy among the subsystems is illustrated in Figure 7.5.

Total system operating energy is the electrical energy required to support the subsystems without affecting their thermal states. The total solar unique operating energy was 2.32 GJ.

Table 7.5. OPERATING ENERGY

SADDLE HILL TRUST LOT 36
OCTOBER 1979 THROUGH MAY 1980

(All values in gigajoules)

MONTH	ECSS OPERATING ENERGY (SOLAR UNIQUE)	DHW OPERATING ENERGY (SOLAR UNIQUE)	SHS OPERATING ENERGY		TOTAL SOLAR UNIQUE OPERATING ENERGY	TOTAL SYSTEM OPERATIN ENERGY
			TOTAL*	SOLAR UNIQUE		
OCT	0.09	0.16	0.14	0.02	0.27	0.40
NOV	0.09	0.13	0.23	0.04	0.26	0.45
DEC	0.10	0.12	0.42	0.06	0.28	0.64
JAN	0.10	0.13	0.49	0.05	0.28	0.71
FEB	0.13	0.11	0.63	0.09	0.33	0.87
MAR	0.12	0.13	0.43	0.05	0.30	0.68
APR	0.10	0.15	0.19	0.03	0.28	0.44
MAY	0.13	0.18	0.05	0.01	0.32	0.35
TOTAL	0.86	1.11	2.58	0.35	2.32	4.54
AVERAGE	0.11	0.14	0.32	0.04	0.29	0.57

*INCLUDES ELECTRICAL ENERGY TO RUN THE BLOWER IN THE FURNACE.

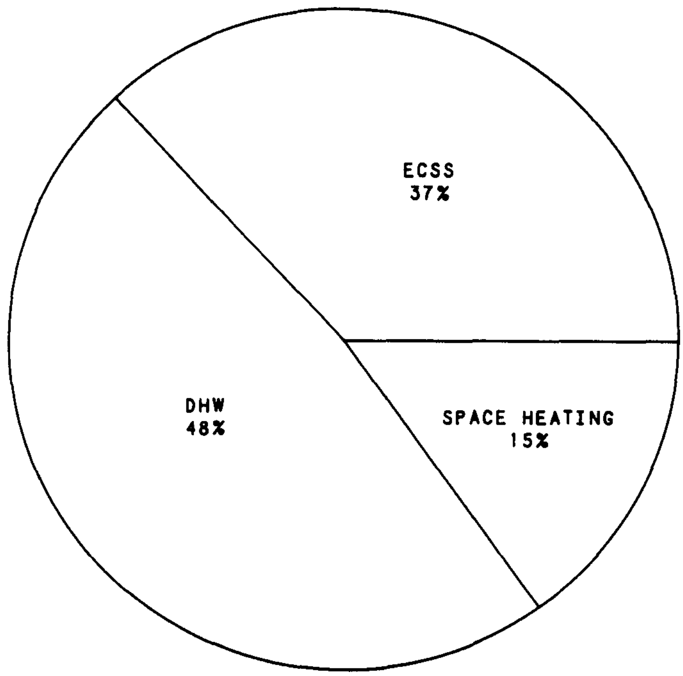


Figure 7.5. Operating Energy
Saddle Hill Trust Lot 36
October 1979 through May 1980

7.2.1 Monthly Performance of the Solar Collector Subsystem

The Saddle Hill Trust Lot 36 collector array is composed of 14 Daystar, liquid, flat-plate collectors which use a glycerol solution as the heat transfer fluid. The gross area of the array is 29.27 m.

Collector subsystem performance for the Saddle Hill Trust Lot 36 site is presented in Table 7.6

During the period from October 1979 through May 1980, there was a total of 99.28 GJ of solar energy that fell on the collector array. Of this total, 80.97 GJ of energy were incident while the collectors were operating. The amount of solar energy collected was 39.61 GJ which represented a collector array efficiency of 40% based on a total insolation and 49% based on the operational incident solar energy. Of the collected solar energy, 38.86 GJ were delivered to the storage tank. Therefore, 0.75 GJ, or two percent of the collected energy, were lost in transport to storage from the collector lines. The operating energy required to run the pump in the collector loop was 0.86 GJ for the eight-month period.

Table 7.6. COLLECTOR SUBSYSTEM PERFORMANCE

SADDLE HILL TRUST LOT 36
OCTOBER 1979 THROUGH MAY 1980

(All values in gigajoules, unless otherwise indicated)

MONTH NBS ID	INCIDENT SOLAR RADIATION (Q001)	COLLECTED SOLAR ENERGY (Q100)	COLLECTOR SUBSYSTEM EFFICIENCY % (N100)	OPERATIONAL INCIDENT ENERGY (Q003)	OPERATIONAL COLLECTOR EFFICIENCY %	ECSS OPERATING ENERGY (Q102)	SOLAR ENERGY TO STORAGE (Q200)	AMBIENT TEMPERATURE °C (N113)
OCT	11.37	4.82	42	8.81	55	0.09	4.58	10
NOV	10.10	4.22	42	8.38	50	0.09	4.00	8
DEC	11.29	4.60	41	9.56	48	0.10	4.48	1
JAN	11.56	4.60	40	9.63	48	0.10	4.51	-3
FEB	15.90	6.84	43	13.89	49	0.13	6.74	-4
MAR	13.47	5.42	40	11.22	48	0.12	5.41	2
APR	11.35	4.22	37	8.72	48	0.10	4.25	9
MAY	14.24	4.89	34	10.76	45	0.13	4.89	15
TOTAL	99.28	39.61	-	80.97	-	0.86	38.86	-
AVERAGE	12.41	4.95	40	10.12	49	0.11	4.86	5

Collector subsystem efficiency has been computed from two bases. The first assumes that the efficiency is based upon all available solar energy. This approach makes the operation of the control system part of array efficiency. For example, energy may be available at the collector, but the collector fluid temperature is below the control minimum; thus, the energy is not collected. In this approach, collector array performance is described by comparing the net amount of collected solar energy to the incident solar energy. Energy that is deliberately or inadvertently rejected or lost from the collector subsystem is subtracted from the collected energy in computing the net value. The ratio of these two energies represents the collector array efficiency which may be expressed as

$$n_c = Q_s/Q_i$$

where: n_c = collector array efficiency

Q_s = collected solar energy

Q_i = incident solar energy

The monthly efficiency computed by this method is listed in the column entitled "Collector Efficiency" in Table 7.6.

The second approach assumes the efficiency is based upon the incident solar energy only during the periods of collection.

Evaluation of collector efficiency using operational incident energy yields operational collector efficiency. Operational collector efficiency, n_{co}, is computed as follows:

$$n_{co} = Q_s/Q_{oi}$$

where: Q_s = collected solar energy

Q_{oi} = incident solar energy while the collector pumps operated

The monthly efficiency computed by this method is listed in the column entitled "Operational Collector Efficiency" in Table 7.6. This latter efficiency term is not the same collector efficiency as represented by the ASHRAE Standard 93-77. Both operational collector efficiency and the ASHRAE collector efficiency are defined as the ratio of actual useful energy collected to solar energy incident upon the collector, and both use the same definition of collector area. However, the ASHRAE efficiency is determined from instantaneous evaluation under tightly controlled, steady-state test conditions, while the operational collector efficiency is determined from the actual conditions of daily solar energy system operation. Measured monthly values of operational incident energy and computed values of operational collector efficiency are presented in Table 7.6.

7.2.2 Monthly Performance of the Thermal Storage Subsystem

Storage performance data for the site for the reporting period is shown in Table 7.7.

During the reporting period, total solar energy delivered to storage was 38.86 GJ. There were 16.13 GJ delivered from storage to the DHW subsystem and 17.46 GJ delivered from storage to the space heating subsystem. Energy loss from storage was 5.18 GJ. This loss represented 13% of the energy delivered to storage. The storage efficiency was 87%.

Storage subsystem performance is evaluated by comparison of energy to storage, energy from storage, and the change in stored energy. The ratio of the sum of energy from storage and the change in stored energy to the energy to storage is defined as storage efficiency. This relationship is expressed in the following equation:

$$STEFF = (STECH + STEO)/STEI$$

Where:
STEFF = Storage efficiency
STECH = Change in stored energy
STEO = Energy removed from storage
STEI = Energy added to storage

Effective storage heat loss coefficient (c) for the storage subsystem can be defined as follows:

$$c = (STEI-STEO-STECH)/[(T_s - T_a) \times t]$$

Where: c = Effective storage heat loss coefficient

T_s = Average storage temperature

T_a = Average ambient temperature in the vicinity of storage

t = Number of seconds in the month

Table 7.7. STORAGE PERFORMANCE

SADDLE HILL TRUST LOT 36
OCTOBER 1979 THROUGH MAY 1980

(All values in gigajoules, unless otherwise indicated)

MONTH (NBS ID)	ENERGY TO STORAGE (Q200)	ENERGY FROM STORAGE (Q201)	CHANGE IN STORED ENERGY (Q202)	STORAGE EFFICIENCY (N108)	AVERAGE STORAGE TEMP (°C)	EFFECTIVE HEAT LOSS COEFFICIENT (W/°K)	STORA LOSS
OCT	4.58	3.36	-0.05	72	56	13.17	1.27
NOV	4.00	3.81	-0.07	94	47	3.72	0.26
DEC	4.48	4.40	-0.01	98	41	1.53	0.09
JAN	4.51	4.41	-0.16	94	39	4.85	0.26
FEB	6.74	6.43	0.07	97	44	3.99	0.24
MAR	5.41	4.59	-0.08	84	43	14.61	0.90
APR	4.25	3.42	0.00	81	46	12.32	0.83
MAY	4.89	3.17	0.39	73	57	13.79	1.33
TOTAL	38.86	33.59	0.09	-	-	-	5.18
AVERAGE	4.86	4.20	0.01	87	47	9.10	0.65

This effective storage heat loss coefficient has been calculated for each month in this reporting period and included, along with storage average temperature, in Table 7.7. Effective storage heat coefficient is comparable to the heat loss rate defined in ASHRAE Standard 94.77. (See Reference 6.)

7.2.3 Monthly Performance of the Space Heating Subsystem

The space heating performance for the Saddle Hill Trust Lot 36 site is shown in Table 7.8 and presented graphically in Figure 7.6.

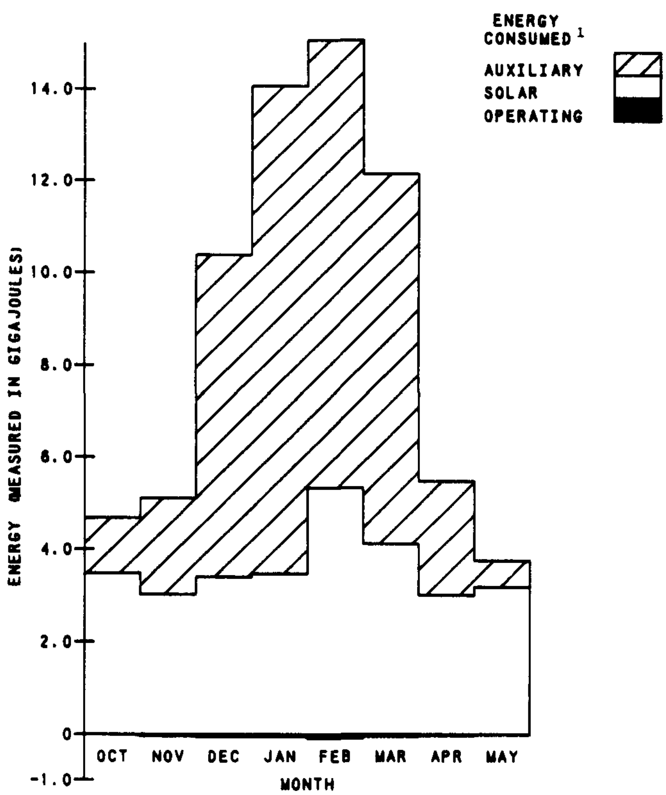
The equipment heating load of 70.64 GJ was satisfied by 28.95 GJ of solar energy and 39.93 GJ of auxiliary energy. The solar fraction of this load was 41%.

Table 7.8. SPACE HEATING SUBSYSTEM

SADDLE HILL TRUST LOT 36
OCTOBER 1979 THROUGH MAY 1980

(All values in gigajoules, unless otherwise indicated)

	SPACE HEATING LOAD (Q402)		ENERGY CONSUMED: SOLAR (Q400)		ENERGY CONSUMED		ENERGY CONSUMED: OPERATING ENERGY (Q403)		SOLAR FRACTON % (N400)		
MONTH (NBS ID)	EQUIPMENT HEATING	MEASURED	EQUIPMENT HEATING	MEASURED	AUXILIARY THERMAL (Q401)	AUXILIARY FOSSIL (Q410)	SOLAR SPECIFIC	TOTAL	EQUIPMENT HEATING	MEASURED	BUILDING TEMPERATURE °C (N406)
OCT	4.68	2.45	3.47	1.32	1.13	1.88	0.02	0.14	74	54	20
NOV	5.10	3.99	3.01	2.06	1.93	3.21	0.04	0.23	59	52	20
DEC	10.37	9.26	3.39	2.59	6.67	11.12	0.06	0.42	33	28	19
JAN	14.06	12.63	3.46	2.40	10.23	17.05	0.05	0.49	25	19	19
FEB	15.07	13.79	5.33	4.26	9.53	15.88	0.09	0.63	35	31	20
MAR	12.14	10.20	4.11	2.42	7.78	12.97	0.05	0.43	34	24	20
APR	5.47	3.60	3.00	1.31	2.29	3.81	0.03	0.19	55	37	20
MAY	3.75	0.81	3.18	0.44	0.37	0.61	0.01	0.05	85	55	21
TOTAL	70.64	56.73	28.95	16.80	39.93	66.53	0.35	2.58	-	-	-
AVERAGE	8.85	7.09	3.74	2.10	4.99	8.32	0.04	0.32	41	30	20



[1] BASED ON EQUIPMENT HEATING LOAD

Operating energy for the system is considered a system penalty and is plotted as a negative value below the origin.

Figure 7.6. Space Heating Performance
Saddle Hill Trust Lot 36
October 1979 through May 1980

The measured space heating load was 56.73 GJ. This load was calculated as the measured amount of solar energy transported to the space heating subsystem plus the auxiliary thermal energy added by the furnace. The solar energy in the measured load was 16.80 GJ for a solar fraction of 30%. There were also considerable losses from the solar system to the conditioned space which also supplied heat to the overall space heating requirement. The equipment heating load was therefore assumed to include the measured load plus all losses from the storage and DHW tanks. (See Discussion section for further explanation.) The solar system consumed 0.35 GJ of operating energy to run the pump in the storage to space heating loop. The total operating energy, 2.58 GJ, included the energy consumed to operate the blower in the furnace during the winter heating season. The average building temperature for the period was 20°C.

7.2.4 Monthly Performance of the DHW Subsystem

The DHW subsystem performance for the Saddle Hill Trust Lot 36 site for the reporting period is shown in Table 7.9 and illustrated in Figure 7.7.

Table 7.9. DOMESTIC HOT WATER SUBSYTEM PERFORMANCE

SADDLE HILL TRUST LOT 36
OCTOBER 1979 THROUGH MAY 1980

(All values in gigajoules, unless otherwise indicated)

		ENERGY CONSUMED						
MONTH (NBS ID)	MEASURED[1] DHW DEMAND (LOAD) (Q302)	SOLAR (Q300)	AUXILIARY (ELECTRICAL/ THERMAL) (Q305)	OPERATING EXPENSE (Q303)	SOLAR FRACTION % (N300)	HOT WATER CONSUMPTION LITER/DAY (N308)	DELIVERY WATER TEMPERATURE °C	SUPPLY WATER TEMPERATURE
OCT	1.41	2.00	0.21	0.16	90	284	56	17
NOV	1.42	1.68	0.46	0.13	78	299	51	14
DEC	1.66	1.70	0.86	0.12	65	341	48	11
JAN	1.90	1.90	1.04	0.13	64	367	48	9
FEB	1.74	2.03	0.64	0.11	77	341	48	8
MAR	1.99	2.07	0.83	0.13	72	363	48	7
APR	1.74	2.04	0.59	0.15	80	337	49	9
MAY	1.71	2.71	0.43	0.18	86	284	59	12
TOTAL	13.57	16.13	5.06	1.11	-	2,616	-	-
AVERAGE	1.70	2.12	0.63	0.14	76	326	51	11

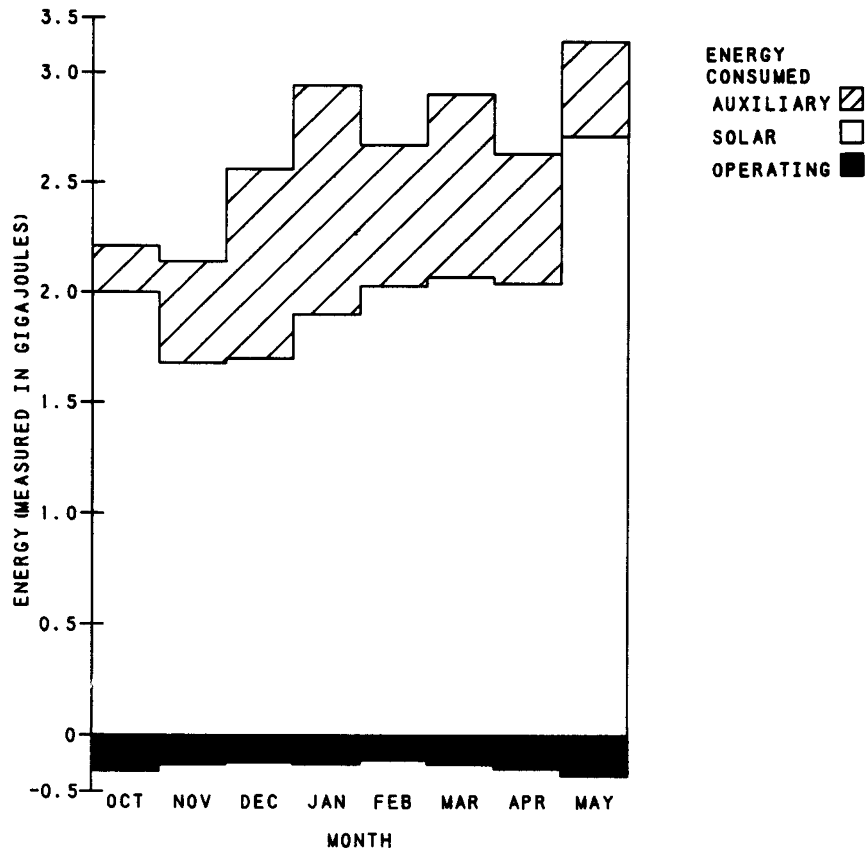
[1]The measured load does not include standby losses from the DHW tank.

The DHW subsystem required 16.13 GJ of solar energy and 5.06 GJ of auxiliary electric energy to satisfy a measured hot water load of 13.57 GJ. The solar fraction of this load was 76%. Losses from the DHW subsystem were 8.73 GJ.

A daily average of 326 liters of DHW was consumed at an average temperature of 51°C. This water was heated from an average supply water temperature of 11°C. There were 1.11 GJ of electrical operating energy consumed to run the pump in the storage to the DHW heat transport loop.

The measured hot water load is a measure of the hot water demand on the system. This number does not include all of the energy consumed by the subsystem to maintain the water in the tank at the desired temperature. The difference between the measured load and the total solar and auxiliary energies consumed is the standby loss. The solar energy in the measured load was 10.31 GJ. This was calculated by multiplying the solar fraction (which was calculated on a hourly basis as explained below) times the measured demand load.

The hot water solar fraction is calculated on a hourly basis by considering the relative amounts of solar and auxiliary energy in the hot water tank (see equations in Section 5). This solar fraction may vary somewhat from the solar fraction of the energy consumed for a given day (due to the residual energy stored in the tank), but over the period of a month the difference should balance out and the two should be very close to the same.



Operating energy for the system is considered a system penalty and is plotted as a negative value below the origin.

Figure 7.7. DHW Subsystem Performance
Saddle Hill Trust Lot 36
October 1979 through May 1980

7.3 DAILY SYSTEM PERFORMANCE

This section shows daily performance factors listed in Tables 7.10a through 7.17b and plotted in Figures 7.8 through 7.12.

Table 7.10a. DAILY SYSTEM PERFORMANCE FACTORS
OCTOBER 1979, CLIMATE, COLLECTOR, AND STORAGE

SADDLE HILL TRUST LOT 36

	CLIMATE				COLLECTOR			STORAGE				
DAY OF MONTH (NBS ID)	AVERAGE AMBIENT TEMP DEG C (N113)	DAYTIME AMBIENT TEMP DEG C	TOTAL SOLAR INCIDENT GJOULES (Q001)	INCIDENT SOLAR WHILE COLLECTING GJOULES (Q003)	SOLAR ENERGY COLLECTED GJOULES (Q100)	DAILY COLLECTOR EFFICIENCY (N100)	COLLECTOR ON EFFICIENCY	ENERGY DELIVERED TO STORAGE GJOULES (Q200)	ENERGY DELIVERED FROM STORAGE GJOULES (Q201)	ENERGY LOSS FROM STORAGE GJOULES (Q204)	CHANGE IN STORED ENERGY GJOULES (Q202)	STORAGE MEDIUM AVG TEMP DEG C (T200)
1	13	14	0.058	0.000	0.000	0.001	0.000	0.000	0.075	0.015	-0.090	60
2	17	19	0.309	0.224	0.128	0.415	0.572	0.134	0.053	0.064	0.018	55
3	15	16	0.045	0.000	0.000	0.005	0.000	0.000	0.065	0.010	-0.075	54
4	17	22	0.515	0.434	0.264	0.514	0.609	0.258	0.070	0.076	0.112	56
5	19	22	0.122	0.017	0.006	0.051	0.372	0.007	0.062	0.015	-0.069	57
6	14	17	0.732	0.660	0.407	0.556	0.616	0.409	0.103	0.160	0.146	62
7	12	15	0.128	0.000	0.000	0.002	0.000	0.000	0.081	0.015	-0.096	63
8	8	11	0.600	0.479	0.270	0.450	0.564	0.267	0.115	0.104	0.048	62
9	6	10	0.032	0.000	0.000	0.004	0.000	0.000	0.178	-0.028	-0.150	55
10	1	1	0.030	0.001	-0.005	-0.177	-4.060	-0.008	0.145	0.008	-0.161	41
11	3	8	0.484	0.438	0.234	0.484	0.535	0.222	0.073	0.043	0.106	40
12	6	8	0.058	0.000	0.000	0.000	0.000	0.000	0.074	0.022	-0.096	39
13	9	11	0.104	0.043	0.021	0.196	0.472	0.020	0.022	0.028	-0.030	34
14	6	*	0.372	0.308	0.158	0.426	0.514	0.161	0.027	0.028	0.106	39
15	5	*	0.195	0.089	0.042	0.215	0.472	0.037	0.055	0.008	-0.026	41
16	8	13	0.758	0.710	0.387	0.511	0.545	0.379	0.092	0.069	0.219	51
17	10	14	0.261	0.140	0.065	0.248	0.463	0.064	0.130	0.010	-0.075	54
18	13	18	0.191	0.136	0.071	0.371	0.521	0.071	0.056	0.026	-0.011	52
19	11	*	0.453	0.384	0.202	0.446	0.525	0.178	0.095	0.028	0.056	53
20	16	19	0.382	0.307	0.159	0.415	0.516	0.148	0.079	0.046	0.023	57
21	19	23	0.558	0.491	0.259	0.464	0.529	0.251	0.097	0.063	0.091	63
22	21	28	0.557	0.477	0.248	0.445	0.520	0.240	0.087	0.070	0.083	71
23	19	23	0.534	0.456	0.258	0.484	0.567	0.244	0.095	0.109	0.040	77
24	15	16	0.237	0.057	0.031	0.130	0.539	0.029	0.066	0.043	-0.080	74
25	8	10	0.854	0.727	0.391	0.458	0.538	0.355	0.095	0.130	0.130	74
26	4	7	0.571	0.392	0.231	0.405	0.590	0.178	0.202	0.082	-0.105	76
27	2	6	0.361	0.203	0.095	0.264	0.470	0.073	0.246	-0.008	-0.165	64
28	2	3	0.029	0.000	0.000	0.013	0.000	0.000	0.255	-0.043	-0.211	46
29	7	11	0.553	0.498	0.271	0.491	0.545	0.266	0.114	0.032	0.119	46
30	8	12	0.582	0.500	0.276	0.475	0.552	0.265	0.192	0.023	0.049	53
31	6	13	0.705	0.641	0.345	0.490	0.538	0.332	0.268	0.013	0.051	56
SUM	-	-	11.371	8.813	4.816	-	-	4.582	3.365	1.263	-0.045	-
AVG	10	14	0.367	0.284	0.155	0.424	0.547	0.148	0.109	0.041	-0.001	56

* DENOTES UNAVAILABLE DATA.

Table 7.10b. DAILY SYSTEM PERFORMANCE FACTORS
OCTOBER 1979, HOT WATER AND SPACE HEATING

SADDLE HILL TRUST LOT 36

	HOT WATER				SPACE HEATING			
DAY OF MONTH (NBS ID)	HOT WATER DEMAND LOAD GJOULES (Q302)	TOTAL ENERGY CONSUMED FOR HOT WATER GJOULES (Q300 + Q305)	SOLAR ENERGY CONSUMED FOR HOT WATER GJOULES (Q300)	SOLAR FRACTION OF ENERGY CONSUMED FOR HOT WATER (N301)	SPACE HEATING LOAD GJOULES (Q402)	TOTAL ENERGY CONSUMED FOR SPACE HEATING GJOULES (Q400 + Q401)	SOLAR ENERGY CONSUMED FOR SPACE HEATING GJOULES (Q400)	SOLAR FRACTION OF ENERGY CONSUMED FOR SPACE HEATING (N401)
1	0.062	0.075	0.075	1.000	0.000	0.000	0.000	0.000
2	0.025	0.053	0.053	1.000	0.000	0.000	0.000	0.000
3	0.053	0.065	0.065	1.000	0.000	0.000	0.000	0.000
4	0.033	0.070	0.070	1.000	0.000	0.000	0.000	0.000
5	0.040	0.062	0.062	1.000	0.000	0.000	0.000	0.000
6	0.060	0.103	0.103	1.000	0.000	0.000	0.000	0.000
7	0.065	0.081	0.081	1.000	0.000	0.000	0.000	0.000
8	0.038	0.077	0.077	1.000	0.047	0.047	0.037	0.781
9	0.050	0.055	0.055	1.000	0.112	0.112	0.112	1.000
10	0.043	0.045	0.034	0.739	0.264	0.264	0.110	0.416
11	0.044	0.070	0.048	0.688	0.152	0.152	0.024	0.161
12	0.048	0.056	0.028	0.492	0.171	0.171	0.047	0.273
13	0.035	0.056	0.022	0.396	0.093	0.093	0.000	0.000
14	0.040	0.055	0.027	0.485	0.156	0.156	0.000	0.000
15	0.051	0.080	0.055	0.683	0.241	0.241	0.000	0.000
16	0.057	0.108	0.082	0.758	0.009	0.009	0.009	1.000
17	0.034	0.046	0.046	1.000	0.077	0.077	0.077	1.000
18	0.043	0.056	0.056	1.000	0.000	0.000	0.000	0.000
19	0.050	0.066	0.066	1.000	0.024	0.024	0.024	1.000
20	0.035	0.079	0.079	1.000	0.000	0.000	0.000	0.000
21	0.040	0.097	0.097	1.000	0.000	0.000	0.000	0.000
22	0.032	0.087	0.087	1.000	0.000	0.000	0.000	0.000
23	0.053	0.095	0.095	1.000	0.000	0.000	0.000	0.000
24	0.041	0.066	0.066	1.000	0.000	0.000	0.000	0.000
25	0.044	0.095	0.095	1.000	0.000	0.000	0.000	0.000
26	0.071	0.099	0.099	1.000	0.120	0.120	0.102	0.845
27	0.036	0.038	0.038	1.000	0.200	0.200	0.200	1.000
28	0.039	0.035	0.028	0.793	0.335	0.335	0.219	0.655
29	0.053	0.096	0.082	0.861	0.118	0.118	0.031	0.261
30	0.046	0.071	0.063	0.882	0.126	0.126	0.126	1.000
31	0.049	0.067	0.061	0.910	0.205	0.205	0.205	1.000
SUM	1.411	2.206	1.995	-	2.451	2.451	1.324	-
AVG	0.046	0.071	0.064	0.904	0.079	0.079	0.043	0.540

Table 7.11a. DAILY SYSTEM PERFORMANCE FACTORS
NOVEMBER 1979, CLIMATE, COLLECTOR, AND STORAGE

SADDLE HILL TRUST LOT 36

	CLIMATE				COLLECTOR			STORAGE				
DAY OF MONTH (NBS ID)	AVERAGE AMBIENT TEMP DEG C (N113)	DAYTIME AMBIENT TEMP DEG C	TOTAL SOLAR INCIDENT GJOULES (Q001)	INCIDENT SOLAR WHILE COLLECTING GJOULES (Q003)	SOLAR ENERGY COLLECTED GJOULES (Q100)	DAILY COLLECTOR EFFICIENCY (N100)	COLLECTOR ON EFFICIENCY	ENERGY DELIVERED TO STORAGE GJOULES (Q200)	ENERGY DELIVERED FROM STORAGE GJOULES (Q201)	ENERGY LOSS FROM STORAGE GJOULES (Q204)	CHANGE IN STORED ENERGY GJOULES (Q202)	STORAGE MEDIUM AVG TEMP DEG C (T200)
1	7	14	0.679	0.622	0.339	0.500	0.545	0.312	0.254	0.020	0.039	58
2	13	19	0.460	0.390	0.196	0.426	0.502	0.192	0.163	0.027	0.001	60
3	11	11	0.023	0.000	0.000	0.000	0.000	0.000	0.100	0.002	-0.102	58
4	7	12	0.649	0.558	0.315	0.486	0.565	0.285	0.191	0.028	0.067	58
5	5	11	0.703	0.632	0.329	0.469	0.521	0.317	0.275	0.011	0.031	60
6	5	10	0.308	0.232	0.117	0.381	0.505	0.103	0.250	-0.015	-0.132	54
7	8	12	0.127	0.046	0.025	0.198	0.548	0.017	0.149	-0.020	-0.112	43
8	6	8	0.212	0.105	0.051	0.242	0.489	0.051	0.047	0.012	-0.008	40
9	9	12	0.157	0.092	0.046	0.290	0.495	0.043	0.032	0.010	0.001	39
10	16	18	0.073	0.000	0.000	0.000	0.000	0.000	0.017	0.007	-0.024	39
11	7	9	0.032	0.000	0.000	0.000	0.000	0.000	0.005	0.007	-0.012	37
12	5	5	0.023	0.000	0.000	0.000	0.000	0.000	0.026	0.003	-0.029	35
13	4	*	0.009	0.000	0.000	0.000	0.000	0.000	0.026	0.005	-0.031	33
14	4	6	0.054	0.000	0.000	0.000	0.000	0.000	0.017	0.016	-0.033	30
15	3	5	0.682	0.650	0.333	0.489	0.513	0.328	0.132	0.028	0.169	38
16	1	3	0.631	0.576	0.280	0.444	0.486	0.272	0.218	0.002	0.052	48
17	4	7	0.223	0.137	0.062	0.280	0.455	0.050	0.129	-0.003	-0.075	42
18	7	*	0.372	0.335	0.157	0.423	0.469	0.152	0.108	-0.022	0.066	45
19	6	12	0.558	0.506	0.258	0.462	0.509	0.253	0.172	0.015	0.066	50
20	8	12	0.166	0.075	0.032	0.195	0.434	0.034	0.200	-0.028	-0.139	45
21	8	13	0.444	0.393	0.196	0.442	0.500	0.196	0.116	0.025	0.055	44
22	7	9	0.060	0.000	0.000	0.000	0.000	0.000	0.081	0.020	-0.101	40
23	13	17	0.380	0.340	0.176	0.463	0.516	0.177	0.051	0.035	0.091	40
24	15	18	0.257	0.221	0.106	0.412	0.479	0.106	0.103	0.007	-0.005	45
25	17	20	0.310	0.248	0.135	0.435	0.543	0.131	0.042	0.024	0.064	48
26	14	16	0.058	0.000	0.000	0.001	0.000	0.000	0.062	0.001	-0.063	46
27	10	13	0.630	0.588	0.286	0.455	0.487	0.280	0.096	0.036	0.148	52
28	9	16	0.557	0.503	0.236	0.424	0.470	0.225	0.104	0.041	0.079	62
29	2	5	0.632	0.556	0.260	0.412	0.468	0.224	0.271	-0.007	-0.041	63
30	0	3	0.636	0.576	0.280	0.441	0.486	0.255	0.377	-0.031	-0.092	56
SUM	-	-	10.104	8.382	4.218	-	-	4.001	3.814	0.256	-0.069	-
AVG	8	11	0.337	0.279	0.141	0.417	0.503	0.133	0.127	0.009	-0.002	47

* DENOTES UNAVAILABLE DATA.

Table 7.11b. DAILY SYSTEM PERFORMANCE FACTORS
NOVEMBER 1979, HOT WATER AND SPACE HEATING

SADDLE HILL TRUST LOT 36

	HOT WATER				SPACE HEATING			
DAY OF MONTH (NBS ID)	HOT WATER DEMAND LOAD GJOULES (Q302)	TOTAL ENERGY CONSUMED FOR HOT WATER GJOULES (Q300 + Q305)	SOLAR ENERGY CONSUMED FOR HOT WATER GJOULES (Q300)	SOLAR FRACTION OF ENERGY CONSUMED FOR HOT WATER (N301)	SPACE HEATING LOAD GJOULES (Q402)	TOTAL ENERGY CONSUMED FOR SPACE HEATING GJOULES (Q400 + Q401)	SOLAR ENERGY CONSUMED FOR SPACE HEATING GJOULES (Q400)	SOLAR FRACTION OF ENERGY CONSUMED FOR SPACE HEATING (N401)
1	0.040	0.085	0.085	1.000	0.167	0.167	0.167	1.000
2	0.046	0.072	0.072	1.000	0.088	0.088	0.088	1.000
3	0.042	0.039	0.039	1.000	0.059	0.059	0.059	1.000
4	0.068	0.119	0.111	0.937	0.076	0.076	0.076	1.000
5	0.060	0.094	0.094	1.000	0.170	0.170	0.170	1.000
6	0.065	0.079	0.079	1.000	0.160	0.160	0.160	1.000
7	0.036	0.043	0.030	0.707	0.137	0.137	0.112	0.816
8	0.040	0.073	0.047	0.645	0.187	0.187	0.000	0.000
9	0.043	0.062	0.032	0.524	0.126	0.126	0.000	0.000
10	0.021	0.032	0.017	0.528	0.011	0.011	0.000	0.000
11	0.023	0.021	0.005	0.242	0.125	0.125	0.000	0.000
12	0.035	0.051	0.026	0.498	0.206	0.206	0.000	0.000
13	0.071	0.085	0.026	0.310	0.202	0.202	0.000	0.000
14	0.049	0.064	0.017	0.262	0.264	0.264	0.000	0.000
15	0.050	0.080	0.041	0.513	0.210	0.210	0.090	0.428
16	0.055	0.092	0.069	0.747	0.198	0.198	0.146	0.734
17	0.047	0.064	0.047	0.731	0.230	0.230	0.081	0.355
18	0.050	0.097	0.088	0.908	0.143	0.143	0.019	0.136
19	0.033	0.068	0.057	0.841	0.140	0.140	0.114	0.815
20	0.055	0.056	0.042	0.763	0.165	0.165	0.149	0.902
21	0.065	0.107	0.088	0.822	0.106	0.106	0.028	0.266
22	0.043	0.045	0.025	0.551	0.209	0.209	0.056	0.266
23	0.039	0.070	0.051	0.723	0.063	0.063	0.000	0.000
24	0.066	0.096	0.076	0.798	0.025	0.025	0.025	1.000
25	0.018	0.049	0.042	0.864	0.000	0.000	0.000	0.000
26	0.058	0.073	0.062	0.856	0.000	0.000	0.000	0.000
27	0.064	0.109	0.096	0.874	0.000	0.000	0.000	0.000
28	0.035	0.070	0.070	1.000	0.033	0.033	0.033	1.000
29	0.049	0.077	0.077	1.000	0.188	0.188	0.188	1.000
30	0.049	0.069	0.069	1.000	0.299	0.299	0.299	1.000
SUM	1.416	2.139	1.680	-	3.987	3.987	2.061	-
AVG	0.047	0.071	0.056	0.785	0.133	0.133	0.069	0.517

Table 7.12a. DAILY SYSTEM PERFORMANCE FACTORS
DECEMBER 1979, CLIMATE, COLLECTOR, AND STORAGE

SADDLE HILL TRUST LOT 36

	CLIMATE				COLLECTOR			STORAGE				
DAY OF MONTH (NBS ID)	AVERAGE AMBIENT TEMP DEG C (N113)	DAYTIME AMBIENT TEMP DEG C	TOTAL SOLAR INCIDENT GJOULES (Q001)	INCIDENT SOLAR WHILE COLLECTING GJOULES (Q003)	SOLAR ENERGY COLLECTED GJOULES (Q100)	DAILY COLLECTOR EFFICIENCY (N100)	COLLECTOR ON EFFICIENCY	ENERGY DELIVERED TO STORAGE GJOULES (Q200)	ENERGY DELIVERED FROM STORAGE GJOULES (Q201)	ENERGY LOSS FROM STORAGE GJOULES (Q204)	CHANGE IN STORED ENERGY GJOULES (Q202)	STORAGE MEDIUM AVG TEMP DEG C (T200)
1	-1	2	0.387	0.319	0.144	0.374	0.453	0.141	0.306	-0.033	-0.132	45
2	-2	2	0.353	0.269	0.130	0.369	0.484	0.126	0.154	0.020	-0.049	40
3	-2	2	0.678	0.646	0.317	0.467	0.490	0.303	0.093	0.039	0.171	45
4	1	3	0.256	0.193	0.092	0.360	0.477	0.085	0.222	-0.019	-0.119	44
5	2	3	0.174	0.037	0.009	0.049	0.229	0.009	0.029	0.010	-0.030	39
6	9	11	0.351	0.304	0.160	0.455	0.524	0.158	0.121	0.006	0.031	41
7	6	8	0.573	0.535	0.264	0.460	0.492	0.247	0.106	0.015	0.126	48
8	3	*	0.497	0.428	0.207	0.416	0.483	0.200	0.306	-0.020	-0.087	49
9	-3	-1	0.319	0.235	0.102	0.321	0.434	0.101	0.155	-0.005	-0.049	42
10	1	5	0.528	0.464	0.223	0.423	0.482	0.219	0.144	0.012	0.062	45
11	7	14	0.485	0.445	0.223	0.461	0.503	0.223	0.157	0.018	0.048	47
12	12	16	0.515	0.473	0.235	0.457	0.498	0.233	0.122	0.025	0.086	53
13	1	0	0.022	0.000	0.000	0.000	0.000	0.000	0.237	-0.035	-0.202	49
14	-4	-1	0.589	0.483	0.240	0.408	0.497	0.221	0.169	0.007	0.045	44
15	-4	2	0.615	0.553	0.278	0.452	0.504	0.272	0.255	-0.005	0.022	47
16	7	10	0.248	0.207	0.100	0.401	0.482	0.097	0.153	-0.002	-0.054	43
17	-4	-5	0.630	0.590	0.278	0.441	0.471	0.269	0.241	-0.014	0.042	45
18	-9	-5	0.477	0.408	0.177	0.372	0.435	0.173	0.235	-0.016	-0.046	43
19	-12	-11	0.048	0.000	0.000	0.000	0.000	0.000	0.053	0.000	-0.054	38
20	-7	-3	0.473	0.428	0.196	0.415	0.458	0.183	0.106	0.019	0.058	39
21	-3	-1	0.054	0.000	0.000	0.000	0.000	0.000	0.044	0.028	-0.072	38
22	1	4	0.087	0.030	0.008	0.091	0.267	0.007	0.017	0.024	-0.034	32
23	5	7	0.066	0.000	0.000	0.000	0.000	0.000	0.033	0.001	-0.035	30
24	8	10	0.105	0.076	0.031	0.300	0.417	0.036	0.032	0.006	-0.001	28
25	9	12	0.015	0.000	0.000	0.000	0.000	0.000	0.016	0.003	-0.019	28
26	5	7	0.074	0.025	0.012	0.158	0.463	0.015	0.020	-0.002	-0.004	27
27	2	3	0.234	0.178	0.077	0.330	0.432	0.081	0.038	0.010	0.033	28
28	1	3	0.644	0.613	0.306	0.475	0.499	0.302	0.159	0.006	0.137	38
29	4	7	0.604	0.539	0.266	0.440	0.493	0.261	0.166	0.009	0.087	48
30	3	6	0.528	0.460	0.224	0.425	0.488	0.222	0.281	-0.018	-0.041	48
31	-1	3	0.661	0.616	0.301	0.456	0.489	0.294	0.226	0.001	0.067	50
SUM	-	-	11.289	9.555	4.602	-	-	4.477	4.397	0.091	-0.011	-
AVG	1	4	0.364	0.308	0.148	0.408	0.482	0.144	0.142	0.003	-0.000	41

* DENOTES UNAVAILABLE DATA.

Table 7.12b. DAILY SYSTEM PERFORMANCE FACTORS
DECEMBER 1979, HOT WATER AND SPACE HEATING

SADDLE HILL TRUST LOT 36

	HOT WATER				SPACE HEATING			
DAY OF MONTH (NBS ID)	HOT WATER DEMAND LOAD GJOULES (Q302)	TOTAL ENERGY CONSUMED FOR HOT WATER GJOULES (Q300 + Q305)	SOLAR ENERGY CONSUMED FOR HOT WATER GJOULES (Q300)	SOLAR FRACTION OF ENERGY CONSUMED FOR HOT WATER (N301)	SPACE HEATING LOAD GJOULES (Q402)	TOTAL ENERGY CONSUMED FOR SPACE HEATING GJOULES (Q400 + Q401)	SOLAR ENERGY CONSUMED FOR SPACE HEATING GJOULES (Q400)	SOLAR FRACTION OF ENERGY CONSUMED FOR SPACE HEATING (N401)
1	0.036	0.027	0.025	0.913	0.381	0.381	0.273	0.719
2	0.085	0.128	0.078	0.612	0.447	0.447	0.073	0.164
3	0.037	0.076	0.059	0.773	0.233	0.233	0.029	0.124
4	0.063	0.099	0.075	0.756	0.242	0.242	0.143	0.591
5	0.029	0.050	0.029	0.575	0.289	0.289	0.000	0.000
6	0.076	0.119	0.089	0.749	0.086	0.086	0.024	0.279
7	0.048	0.078	0.063	0.813	0.099	0.099	0.040	0.401
8	0.050	0.057	0.048	0.844	0.246	0.246	0.246	1.000
9	0.038	0.069	0.046	0.668	0.473	0.473	0.106	0.223
10	0.045	0.084	0.072	0.860	0.178	0.178	0.071	0.398
11	0.074	0.106	0.095	0.897	0.137	0.137	0.061	0.445
12	0.038	0.072	0.068	0.948	0.053	0.053	0.053	1.000
13	0.077	0.084	0.075	0.899	0.220	0.220	0.158	0.717
14	0.025	0.066	0.046	0.697	0.392	0.392	0.122	0.310
15	0.046	0.065	0.053	0.805	0.415	0.415	0.199	0.479
16	0.061	0.099	0.077	0.779	0.167	0.167	0.073	0.436
17	0.046	0.072	0.061	0.846	0.418	0.418	0.169	0.405
18	0.045	0.067	0.052	0.779	0.585	0.585	0.174	0.298
19	0.051	0.086	0.053	0.620	0.790	0.790	0.000	0.000
20	0.064	0.096	0.050	0.515	0.585	0.585	0.050	0.086
21	0.043	0.070	0.044	0.638	0.566	0.566	0.000	0.000
22	0.051	0.056	0.017	0.308	0.358	0.358	0.000	0.000
23	0.079	0.109	0.033	0.305	0.233	0.233	0.000	0.000
24	0.090	0.107	0.032	0.294	0.109	0.109	0.000	0.000
25	0.068	0.096	0.016	0.166	0.000	0.000	0.000	0.000
26	0.047	0.081	0.020	0.249	0.120	0.120	0.000	0.000
27	0.070	0.107	0.038	0.350	0.336	0.336	0.000	0.000
28	0.044	0.073	0.047	0.638	0.393	0.393	0.109	0.278
29	0.038	0.088	0.079	0.904	0.257	0.257	0.085	0.328
30	0.058	0.083	0.081	0.967	0.226	0.226	0.194	0.856
31	0.033	0.086	0.078	0.899	0.231	0.231	0.140	0.607
SUM	1.657	2.558	1.700	-	9.264	9.264	2.591	-
AVG	0.053	0.083	0.055	0.665	0.299	0.299	0.084	0.280

Table 7.13a. DAILY SYSTEM PERFORMANCE FACTORS
JANUARY 1980, CLIMATE, COLLECTOR, AND STORAGE

SADDLE HILL TRUST LOT 36

	CLIMATE				COLLECTOR			STORAGE				
DAY OF MONTH (NBS ID)	AVERAGE AMBIENT TEMP DEG C (N113)	DAYTIME AMBIENT TEMP DEG C	TOTAL SOLAR INCIDENT GJOULES (Q001)	INCIDENT SOLAR WHILE COLLECTING GJOULES (Q003)	SOLAR ENERGY COLLECTED GJOULES (Q100)	DAILY COLLECTOR EFFICIENCY (N100)	COLLECTOR ON EFFICIENCY	ENERGY DELIVERED TO STORAGE GJOULES (Q200)	ENERGY DELIVERED FROM STORAGE GJOULES (Q201)	ENERGY LOSS FROM STORAGE GJOULES (Q204)	CHANGE IN STORED ENERGY GJOULES (Q202)	STORAGE MEDIUM AVG TEMP DEG C (T200)
1	0	6	0.624	0.573	0.283	0.453	0.493	0.277	0.315	-0.019	-0.019	50
2	-1	1	0.305	0.216	0.094	0.308	0.434	0.091	0.189	-0.015	-0.083	45
3	-4	-1	0.638	0.586	0.283	0.444	0.483	0.279	0.240	-0.009	0.048	46
4	-5	-2	0.523	0.469	0.221	0.422	0.470	0.217	0.304	-0.026	-0.062	44
5	-4	-3	0.056	0.000	0.000	0.000	0.000	0.000	0.041	0.033	-0.074	39
6	-7	-2	0.686	0.656	0.320	0.466	0.488	0.317	0.220	0.018	0.079	41
7	0	5	0.068	0.000	0.000	0.000	0.000	0.000	0.046	0.030	-0.076	38
8	-1	1	0.594	0.565	0.270	0.455	0.478	0.270	0.177	0.025	0.068	40
9	-5	-3	0.092	0.000	0.000	0.000	0.000	0.000	0.055	0.029	-0.084	38
10	-5	-2	0.638	0.603	0.294	0.461	0.488	0.290	0.190	0.024	0.077	39
11	4	7	0.076	0.000	0.000	0.000	0.000	0.000	0.045	0.004	-0.049	38
12	1	0	0.558	0.490	0.225	0.404	0.460	0.222	0.171	0.001	0.050	40
13	-4	1	0.469	0.414	0.187	0.397	0.451	0.185	0.189	-0.002	-0.001	42
14	1	4	0.101	0.000	0.000	0.000	0.000	0.000	0.041	0.007	-0.048	38
15	6	7	0.018	0.000	0.000	0.000	0.000	0.000	0.053	-0.001	-0.052	34
16	2	5	0.464	0.422	0.222	0.477	0.525	0.215	0.087	0.016	0.113	37
17	-2	-1	0.079	0.000	0.000	0.000	0.000	0.000	0.084	0.020	-0.105	38
18	1	3	0.093	0.011	0.005	0.054	0.471	0.005	0.019	0.023	-0.036	30
19	3	5	0.088	0.026	0.011	0.124	0.427	0.013	0.033	0.004	-0.024	28
20	0	3	0.334	0.264	0.121	0.363	0.460	0.116	0.036	0.007	0.074	30
21	-3	-1	0.546	0.507	0.230	0.421	0.454	0.227	0.129	0.016	0.082	38
22	-2	-1	0.095	0.000	0.000	0.000	0.000	0.000	0.034	0.009	-0.043	38
23	-1	0	0.050	0.000	0.000	0.000	0.000	0.000	0.049	0.023	-0.072	35
24	-9	-8	0.520	0.485	0.205	0.395	0.424	0.203	0.076	0.044	0.082	34
25	-7	-4	0.640	0.578	0.291	0.455	0.504	0.287	0.233	0.004	0.050	43
26	-4	-1	0.710	0.659	0.321	0.452	0.487	0.308	0.278	-0.002	0.032	47
27	-4	1	0.709	0.653	0.326	0.459	0.499	0.318	0.278	0.006	0.034	48
28	-4	0	0.458	0.357	0.181	0.396	0.508	0.171	0.272	-0.012	-0.089	44
29	-5	-1	0.433	0.361	0.168	0.387	0.465	0.167	0.165	0.005	-0.003	41
30	-9	-7	0.731	0.676	0.325	0.444	0.481	0.318	0.249	0.010	0.058	45
31	-11	-9	0.162	0.060	0.023	0.143	0.388	0.017	0.110	-0.004	-0.089	40
SUM	-	-	11.557	9.629	4.605	-	-	4.511	4.407	0.266	-0.163	-
AVG	-3	0	0.373	0.311	0.149	0.398	0.478	0.146	0.142	0.009	-0.005	40

Table 7.13b. DAILY SYSTEM PERFORMANCE FACTORS
JANUARY 1980, HOT WATER AND SPACE HEATING

SADDLE HILL TRUST LOT 36

	HOT WATER				SPACE HEATING			
DAY OF MONTH (NBS ID)	HOT WATER DEMAND LOAD GJOULES (Q302)	TOTAL ENERGY CONSUMED FOR HOT WATER GJOULES (Q300 + Q305)	SOLAR ENERGY CONSUMED FOR HOT WATER GJOULES (Q300)	SOLAR FRACTION OF ENERGY CONSUMED FOR HOT WATER (N301)	SPACE HEATING LOAD GJOULES (Q402)	TOTAL ENERGY CONSUMED FOR SPACE HEATING GJOULES (Q400 + Q401)	SOLAR ENERGY CONSUMED FOR SPACE HEATING GJOULES (Q400)	SOLAR FRACTION OF ENERGY CONSUMED FOR SPACE HEATING (N401)
1	0.058	0.091	0.077	0.845	0.273	0.273	0.227	0.831
2	0.051	0.069	0.058	0.839	0.258	0.258	0.125	0.484
3	0.063	0.101	0.088	0.872	0.352	0.352	0.136	0.386
4	0.077	0.106	0.077	0.729	0.462	0.462	0.215	0.464
5	0.053	0.068	0.041	0.599	0.585	0.585	0.000	0.000
6	0.061	0.113	0.085	0.752	0.565	0.565	0.128	0.226
7	0.036	0.063	0.043	0.687	0.510	0.510	0.003	0.006
8	0.053	0.098	0.065	0.668	0.318	0.318	0.109	0.343
9	0.057	0.084	0.055	0.649	0.428	0.428	0.000	0.000
10	0.090	0.127	0.083	0.654	0.431	0.431	0.102	0.237
11	0.057	0.074	0.045	0.608	0.293	0.293	0.000	0.000
12	0.062	0.083	0.053	0.635	0.250	0.250	0.113	0.450
13	0.080	0.113	0.086	0.758	0.414	0.414	0.100	0.243
14	0.040	0.066	0.041	0.625	0.339	0.339	0.000	0.000
15	0.062	0.108	0.053	0.491	0.169	0.169	0.000	0.000
16	0.030	0.055	0.030	0.549	0.296	0.296	0.055	0.185
17	0.114	0.153	0.084	0.550	0.434	0.434	0.000	0.000
18	0.033	0.056	0.019	0.344	0.379	0.379	0.000	0.000
19	0.072	0.095	0.033	0.345	0.291	0.291	0.000	0.000
20	0.068	0.106	0.036	0.336	0.370	0.370	0.000	0.000
21	0.067	0.122	0.079	0.649	0.396	0.396	0.048	0.122
22	0.038	0.059	0.034	0.573	0.410	0.410	0.000	0.000
23	0.061	0.099	0.049	0.494	0.430	0.430	0.000	0.000
24	0.095	0.148	0.076	0.516	0.535	0.535	0.000	0.000
25	0.049	0.082	0.057	0.694	0.472	0.472	0.171	0.362
26	0.043	0.069	0.058	0.844	0.420	0.420	0.213	0.508
27	0.095	0.135	0.119	0.883	0.385	0.385	0.146	0.380
28	0.061	0.104	0.071	0.683	0.372	0.372	0.191	0.514
29	0.056	0.094	0.067	0.712	0.415	0.415	0.096	0.230
30	0.049	0.076	0.063	0.827	0.642	0.642	0.183	0.285
31	0.070	0.113	0.071	0.627	0.734	0.734	0.039	0.053
SUM	1.900	2.933	1.898	-	12.627	12.627	2.399	-
AVG	0.061	0.095	0.061	0.647	0.407	0.407	0.077	0.190

Table 7.14a. DAILY SYSTEM PERFORMANCE FACTORS
FEBRUARY 1980, CLIMATE, COLLECTOR, AND STORAGE

SADDLE HILL TRUST LOT 36

	CLIMATE				COLLECTOR			STORAGE				
DAY OF MONTH (NBS ID)	AVERAGE AMBIENT TEMP DEG C (N113)	DAYTIME AMBIENT TEMP DEG C	TOTAL SOLAR INCIDENT GJOULES (Q001)	INCIDENT SOLAR WHILE COLLECTING GJOULES (Q003)	SOLAR ENERGY COLLECTED GJOULES (Q100)	DAILY COLLECTOR EFFICIENCY (N100)	COLLECTOR ON EFFICIENCY	ENERGY DELIVERED TO STORAGE GJOULES (Q200)	ENERGY DELIVERED FROM STORAGE GJOULES (Q201)	ENERGY LOSS FROM STORAGE GJOULES (Q204)	CHANGE IN STORED ENERGY GJOULES (Q202)	STORAGE MEDIUM AVG TEMP DEG C (T200)
1	-10	-5	0.700	0.646	0.324	0.463	0.501	0.319	0.246	0.006	0.067	42
2	-9	-5	0.706	0.634	0.309	0.438	0.488	0.302	0.256	0.006	0.040	46
3	-8	-5	0.731	0.670	0.323	0.442	0.482	0.317	0.345	-0.008	-0.021	47
4	-7	-3	0.779	0.723	0.370	0.475	0.512	0.352	0.281	0.057	0.014	47
5	-7	-3	0.719	0.665	0.331	0.461	0.499	0.325	0.281	0.008	0.035	48
6	-5	2	0.541	0.457	0.232	0.428	0.507	0.230	0.343	-0.019	-0.095	45
7	-3	-3	0.033	0.000	0.000	0.000	0.000	0.000	0.081	-0.003	-0.078	38
8	-2	2	0.726	0.676	0.354	0.487	0.524	0.353	0.182	0.028	0.143	43
9	-4	0	0.582	0.514	0.261	0.449	0.508	0.247	0.291	-0.008	-0.035	46
10	-3	2	0.724	0.666	0.330	0.455	0.495	0.325	0.299	0.000	0.026	48
11	-4	0	0.508	0.432	0.196	0.386	0.455	0.196	0.276	-0.014	-0.065	43
12	-3	1	0.575	0.479	0.245	0.426	0.511	0.245	0.205	0.012	0.028	44
13	-3	1	0.736	0.674	0.333	0.452	0.493	0.328	0.254	0.020	0.054	47
14	-1	3	0.313	0.221	0.100	0.318	0.451	0.100	0.207	-0.006	-0.101	42
15	-2	1	0.648	0.595	0.309	0.476	0.519	0.297	0.200	0.024	0.073	44
16	-4	-2	0.038	0.000	0.000	0.000	0.000	0.000	0.094	-0.010	-0.084	40
17	-9	-5	0.825	0.701	0.324	0.392	0.462	0.317	0.200	0.017	0.101	44
18	-6	-1	0.797	0.731	0.348	0.437	0.477	0.343	0.286	0.016	0.041	49
19	0	7	0.719	0.657	0.316	0.439	0.481	0.314	0.343	-0.002	-0.027	49
20	2	11	0.686	0.629	0.325	0.473	0.516	0.319	0.235	0.023	0.061	50
21	3	8	0.353	0.305	0.159	0.450	0.520	0.160	0.291	-0.011	-0.120	45
22	-2	-1	0.050	0.000	0.000	0.000	0.000	0.000	0.060	0.001	-0.061	39
23	1	4	0.405	0.330	0.170	0.419	0.515	0.168	0.099	0.026	0.042	39
24	1	3	0.136	0.029	0.008	0.060	0.285	0.010	0.029	0.011	-0.029	39
25	1	6	0.518	0.447	0.237	0.459	0.532	0.239	0.130	0.028	0.081	43
26	-5	-2	0.643	0.580	0.289	0.449	0.498	0.287	0.311	0.000	-0.023	45
27	-8	-4	0.302	0.179	0.062	0.206	0.347	0.063	0.080	0.014	-0.031	42
28	-6	-4	0.611	0.537	0.252	0.412	0.469	0.249	0.237	0.010	0.002	43
29	-12	-10	0.793	0.717	0.336	0.424	0.469	0.330	0.293	0.004	0.034	45
SUM	-	-	15.899	13.894	6.842	-	-	6.735	6.434	0.230	0.071	-
AVG	-4	-0	0.548	0.479	0.236	0.430	0.492	0.232	0.222	0.008	0.002	44

Table 7.14b. DAILY SYSTEM PERFORMANCE FACTORS
FEBRUARY 1980, HOT WATER AND SPACE HEATING

SADDLE HILL TRUST LOT 36

DAY OF MONTH (NBS ID)	HOT WATER: HOT WATER DEMAND LOAD GJOULES (Q302)	HOT WATER: TOTAL ENERGY CONSUMED FOR HOT WATER GJOULES (Q300 + Q305)	HOT WATER: SOLAR ENERGY CONSUMED FOR HOT WATER GJOULES (Q300)	HOT WATER: SOLAR FRACTION OF ENERGY CONSUMED FOR HOT WATER (N301)	SPACE HEATING: SPACE HEATING LOAD GJOULES (Q402)	SPACE HEATING: TOTAL ENERGY CONSUMED FOR SPACE HEATING GJOULES (Q400 + Q401)	SPACE HEATING: SOLAR ENERGY CONSUMED FOR SPACE HEATING GJOULES (Q400)	SPACE HEATING: SOLAR FRACTION OF ENERGY CONSUMED FOR SPACE HEATING (N401)
1	0.065	0.106	0.073	0.687	0.655	0.655	0.167	0.256
2	0.040	0.058	0.049	0.842	0.648	0.648	0.203	0.313
3	0.050	0.084	0.075	0.894	0.584	0.584	0.261	0.447
4	0.058	0.088	0.075	0.848	0.486	0.486	0.191	0.392
5	0.031	0.066	0.053	0.799	0.565	0.565	0.221	0.392
6	0.110	0.133	0.108	0.807	0.549	0.549	0.230	0.419
7	0.085	0.136	0.081	0.596	0.624	0.624	0.000	0.000
8	0.033	0.076	0.053	0.694	0.467	0.467	0.126	0.269
9	0.045	0.053	0.043	0.803	0.413	0.413	0.239	0.580
10	0.060	0.099	0.091	0.918	0.476	0.476	0.198	0.416
11	0.077	0.107	0.073	0.685	0.479	0.479	0.189	0.394
12	0.043	0.074	0.053	0.719	0.403	0.403	0.150	0.373
13	0.063	0.101	0.095	0.937	0.402	0.402	0.157	0.390
14	0.088	0.123	0.084	0.679	0.398	0.398	0.120	0.302
15	0.061	0.084	0.061	0.725	0.366	0.366	0.138	0.376
16	0.053	0.078	0.046	0.584	0.577	0.577	0.045	0.078
17	0.019	0.053	0.041	0.759	0.552	0.552	0.151	0.273
18	0.079	0.104	0.097	0.929	0.400	0.400	0.186	0.464
19	0.084	0.117	0.102	0.873	0.354	0.354	0.229	0.647
20	0.066	0.103	0.086	0.832	0.279	0.279	0.145	0.520
21	0.064	0.093	0.072	0.771	0.286	0.286	0.217	0.758
22	0.066	0.091	0.049	0.536	0.495	0.495	0.011	0.023
23	0.036	0.068	0.045	0.654	0.335	0.335	0.054	0.161
24	0.035	0.051	0.029	0.557	0.373	0.373	0.000	0.000
25	0.054	0.101	0.082	0.805	0.286	0.286	0.046	0.161
26	0.065	0.103	0.079	0.773	0.535	0.535	0.227	0.425
27	0.058	0.075	0.056	0.753	0.589	0.589	0.021	0.035
28	0.087	0.129	0.088	0.683	0.497	0.497	0.145	0.291
29	0.065	0.110	0.093	0.849	0.713	0.713	0.192	0.269
SUM	1.742	2.666	2.028	-	13.788	13.788	4.260	
AVG	0.060	0.092	0.070	0.761	0.475	0.475	0.147	0.309

Table 7.15a. DAILY SYSTEM PERFORMANCE FACTORS
MARCH 1980, CLIMATE, COLLECTOR, AND STORAGE

SADDLE HILL TRUST LOT 36

	CLIMATE				COLLECTOR			STORAGE				
DAY OF MONTH (NBS ID)	AVERAGE AMBIENT TEMP DEG C (N113)	DAYTIME AMBIENT TEMP DEG C	TOTAL SOLAR INCIDENT GJOULES (Q001)	INCIDENT SOLAR WHILE COLLECTING GJOULES (Q003)	SOLAR ENERGY COLLECTED GJOULES (Q100)	DAILY COLLECTOR EFFICIENCY (N100)	COLLECTOR ON EFFICIENCY	ENERGY DELIVERED TO STORAGE GJOULES (Q200)	ENERGY DELIVERED FROM STORAGE GJOULES (Q201)	ENERGY LOSS FROM STORAGE GJOULES (Q204)	CHANGE IN STORED ENERGY GJOULES (Q202)	STORAGE MEDIUM AVG TEMP DEG C (T200)
1	-11	-8	0.531	0.450	0.195	0.368	0.434	0.195	0.212	0.009	-0.027	43
2	-7	-4	0.494	0.426	0.181	0.367	0.426	0.181	0.158	0.017	0.007	42
3	-4	0	0.716	0.648	0.314	0.438	0.484	0.310	0.194	0.031	0.085	48
4	0	6	0.774	0.685	0.347	0.448	0.506	0.334	0.322	0.014	-0.003	49
5	3	5	0.067	0.000	0.000	0.000	0.000	0.000	0.159	0.010	-0.169	40
6	2	3	1.033	0.997	0.515	0.498	0.516	0.517	0.164	0.197	0.156	40
7	4	8	0.342	0.271	0.136	0.396	0.501	0.133	0.144	0.020	-0.031	42
8	3	3	0.028	0.000	0.000	0.000	0.000	0.000	0.030	0.008	-0.038	40
9	3	5	0.468	0.391	0.180	0.384	0.460	0.183	0.127	0.027	0.029	40
10	3	8	0.663	0.595	0.292	0.440	0.490	0.292	0.155	0.045	0.092	47
11	1	0	0.231	0.077	0.040	0.172	0.512	0.035	0.159	-0.008	-0.116	42
12	-5	-3	0.835	0.763	0.359	0.430	0.470	0.357	0.282	0.034	0.041	44
13	-2	3	0.610	0.506	0.252	0.412	0.498	0.250	0.257	0.030	-0.037	44
14	1	3	0.075	0.000	0.000	0.000	0.000	0.000	0.031	0.049	-0.080	35
15	-1	1	0.586	0.536	0.242	0.413	0.452	0.243	0.104	0.051	0.088	37
16	-1	2	0.801	0.732	0.352	0.439	0.480	0.349	0.227	0.025	0.098	47
17	7	13	0.354	0.302	0.139	0.391	0.458	0.137	0.159	0.019	-0.041	45
18	6	7	0.271	0.187	0.081	0.298	0.433	0.083	0.129	0.005	-0.051	43
19	3	6	0.781	0.710	0.350	0.448	0.493	0.349	0.125	0.055	0.170	49
20	7	13	0.681	0.610	0.295	0.433	0.483	0.295	0.252	0.030	0.013	54
21	6	7	0.018	0.000	0.000	0.000	0.000	0.000	0.229	-0.027	-0.202	45
22	3	2	0.129	0.045	0.014	0.106	0.305	0.015	0.059	0.009	-0.052	37
23	8	13	0.749	0.698	0.374	0.500	0.536	0.374	0.122	0.055	0.197	45
24	7	14	0.673	0.599	0.310	0.460	0.517	0.309	0.254	0.025	0.031	52
25	3	4	0.104	0.000	0.000	0.000	0.000	0.000	0.177	-0.001	-0.176	46
26	4	7	0.235	0.137	0.065	0.277	0.476	0.062	0.065	0.036	-0.039	37
27	6	8	0.213	0.136	0.068	0.317	0.496	0.066	0.057	0.017	-0.008	34
28	5	11	0.541	0.491	0.236	0.436	0.481	0.242	0.120	0.033	0.089	41
29	7	11	0.243	0.170	0.066	0.270	0.387	0.072	0.060	0.026	-0.014	42
30	5	6	0.074	0.000	0.000	0.000	0.000	0.000	0.038	0.026	-0.065	38
31	3	6	0.148	0.056	0.021	0.145	0.383	0.023	0.025	0.025	-0.027	33
SUM	-	-	13.468	11.219	5.421	-	-	5.406	4.595	0.891	-0.080	-
AVG	2	5	0.434	0.362	0.175	0.402	0.483	0.174	0.148	0.029	-0.003	43

Table 7.15b. DAILY SYSTEM PERFORMANCE FACTORS
MARCH 1980, HOT WATER AND SPACE HEATING

SADDLE HILL TRUST LOT 36

	HOT WATER				SPACE HEATING			
DAY OF MONTH (NBS ID)	HOT WATER DEMAND LOAD GJOULES (Q302)	TOTAL ENERGY CONSUMED FOR HOT WATER GJOULES (Q300 + Q305)	SOLAR ENERGY CONSUMED FOR HOT WATER GJOULES (Q300)	SOLAR FRACTION OF ENERGY CONSUMED FOR HOT WATER (N301)	SPACE HEATING LOAD GJOULES (Q402)	TOTAL ENERGY CONSUMED FOR SPACE HEATING GJOULES (Q400 + Q401)	SOLAR ENERGY CONSUMED FOR SPACE HEATING GJOULES (Q400)	SOLAR FRACTION OF ENERGY CONSUMED FOR SPACE HEATING (N401)
1	0.073	0.101	0.075	0.743	0.672	0.672	0.136	0.202
2	0.053	0.063	0.037	0.592	0.646	0.646	0.117	0.181
3	0.062	0.103	0.086	0.834	0.500	0.500	0.097	0.194
4	0.042	0.091	0.074	0.815	0.374	0.374	0.232	0.621
5	0.082	0.101	0.068	0.676	0.362	0.362	0.087	0.240
6	0.094	0.146	0.104	0.712	0.287	0.287	0.060	0.209
7	0.044	0.079	0.054	0.685	0.307	0.307	0.085	0.278
8	0.026	0.049	0.030	0.612	0.313	0.313	0.000	0.000
9	0.078	0.117	0.081	0.690	0.278	0.278	0.047	0.168
10	0.059	0.101	0.087	0.857	0.277	0.277	0.067	0.241
11	0.072	0.085	0.063	0.743	0.406	0.406	0.095	0.233
12	0.075	0.108	0.086	0.794	0.586	0.586	0.192	0.328
13	0.081	0.114	0.091	0.797	0.530	0.530	0.154	0.290
14	0.036	0.068	0.031	0.459	0.409	0.409	0.000	0.000
15	0.078	0.094	0.062	0.654	0.505	0.505	0.041	0.081
16	0.042	0.082	0.060	0.738	0.431	0.431	0.160	0.371
17	0.076	0.096	0.076	0.786	0.192	0.192	0.079	0.410
18	0.085	0.093	0.065	0.703	0.124	0.124	0.055	0.447
19	0.048	0.112	0.093	0.824	0.196	0.196	0.032	0.162
20	0.096	0.122	0.108	0.884	0.137	0.137	0.137	1.000
21	0.075	0.087	0.066	0.752	0.263	0.263	0.151	0.575
22	0.074	0.109	0.059	0.541	0.369	0.369	0.000	0.000
23	0.069	0.096	0.073	0.759	0.148	0.148	0.048	0.322
24	0.065	0.096	0.087	0.907	0.164	0.164	0.164	1.000
25	0.073	0.075	0.061	0.811	0.208	0.208	0.112	0.538
26	0.073	0.111	0.065	0.586	0.255	0.255	0.000	0.000
27	0.063	0.111	0.057	0.512	0.270	0.270	0.000	0.000
28	0.051	0.089	0.053	0.601	0.220	0.220	0.065	0.294
29	0.063	0.074	0.054	0.722	0.205	0.205	0.006	0.027
30	0.038	0.067	0.038	0.572	0.263	0.263	0.000	0.000
31	0.044	0.058	0.025	0.436	0.301	0.301	0.000	0.000
SUM	1.989	2.899	2.068	-	10.199	10.199	2.417	-
AVG	0.064	0.094	0.067	0.714	0.329	0.329	0.078	0.237

Table 7.16a. DAILY SYSTEM PERFORMANCE FACTORS
APRIL 1980, CLIMATE, COLLECTOR, AND STORAGE

SADDLE HILL TRUST LOT 36

	CLIMATE				COLLECTOR			STORAGE				
DAY OF MONTH (NBS ID)	AVERAGE AMBIENT TEMP DEG C (N113)	DAYTIME AMBIENT TEMP DEG C	TOTAL SOLAR INCIDENT GJOULES (Q001)	INCIDENT SOLAR WHILE COLLECTING GJOULES (Q003)	SOLAR ENERGY COLLECTED GJOULES (Q100)	DAILY COLLECTOR EFFICIENCY (N100)	COLLECTOR ON EFFICIENCY	ENERGY DELIVERED TO STORAGE GJOULES (Q200)	ENERGY DELIVERED FROM STORAGE GJOULES (Q201)	ENERGY LOSS FROM STORAGE GJOULES (Q204)	CHANGE IN STORED ENERGY GJOULES (Q202)	STORAGE MEDIUM AVG TEMP DEG C (T200)
1	8	13	0.781	0.718	0.372	0.477	0.519	0.377	0.112	0.067	0.198	44
2	4	8	0.106	0.000	0.000	0.000	0.000	0.000	0.175	0.004	-0.180	41
3	9	13	0.760	0.711	0.369	0.486	0.519	0.371	0.083	0.068	0.220	45
4	5	7	0.028	0.000	0.000	0.000	0.000	0.000	0.187	-0.016	-0.171	44
5	6	8	0.388	0.275	0.126	0.323	0.456	0.132	0.089	0.027	0.015	41
6	10	14	0.619	0.564	0.268	0.433	0.475	0.274	0.098	0.053	0.122	47
7	8	15	0.719	0.640	0.308	0.428	0.481	0.310	0.222	0.034	0.054	52
8	9	12	0.134	0.000	0.000	0.000	0.000	0.000	0.191	-0.020	-0.172	46
9	10	13	0.134	0.015	0.005	0.040	0.342	0.007	0.050	0.007	-0.050	38
10	10	11	0.052	0.000	0.000	0.000	0.000	0.000	0.037	0.017	-0.054	34
11	12	16	0.631	0.587	0.301	0.477	0.512	0.308	0.058	0.065	0.185	40
12	12	*	0.385	0.331	0.146	0.380	0.440	0.150	0.093	0.046	0.011	49
13	12	15	0.575	0.497	0.247	0.429	0.496	0.248	0.098	0.048	0.102	53
14	7	8	0.096	0.000	0.000	0.000	0.000	0.000	0.222	-0.037	-0.186	49
15	14	18	0.449	0.398	0.196	0.436	0.491	0.201	0.096	0.038	0.067	44
16	6	9	0.247	0.103	0.047	0.188	0.454	0.050	0.103	0.009	-0.061	43
17	5	8	0.741	0.666	0.324	0.438	0.487	0.326	0.219	0.030	0.077	48
18	7	12	0.543	0.433	0.215	0.395	0.496	0.219	0.164	0.035	0.021	48
19	11	16	0.707	0.637	0.310	0.439	0.487	0.298	0.184	0.038	0.075	54
20	14	21	0.571	0.484	0.216	0.379	0.447	0.216	0.096	0.065	0.056	60
21	14	18	0.719	0.614	0.285	0.396	0.464	0.270	0.104	0.077	0.088	67
22	5	9	0.366	0.114	0.053	0.144	0.460	0.047	0.141	0.014	-0.108	66
23	8	10	0.160	0.000	0.000	0.000	0.000	0.000	0.256	-0.023	-0.233	48
24	12	15	0.383	0.311	0.149	0.389	0.478	0.155	0.090	0.032	0.034	42
25	12	17	0.379	0.311	0.153	0.405	0.493	0.153	0.083	0.046	0.024	43
26	11	14	0.139	0.019	0.007	0.049	0.347	0.008	0.042	0.013	-0.047	42
27	12	19	0.239	0.151	0.064	0.268	0.425	0.067	0.039	0.028	-0.000	41
28	6	6	0.039	0.000	0.000	0.000	0.000	0.000	0.038	0.007	-0.045	39
29	6	7	0.078	0.000	0.000	0.000	0.000	0.000	0.020	0.022	-0.043	35
30	11	15	0.186	0.135	0.058	0.312	0.429	0.065	0.028	0.031	0.005	32
SUM	-	-	11.352	8.717	4.217	-	-	4.252	3.421	0.826	0.005	-
AVG	9	13	0.378	0.291	0.141	0.371	0.484	0.142	0.114	0.028	0.000	46

* DENOTES UNAVAILABLE DATA.

Table 7.16b. DAILY SYSTEM PERFORMANCE FACTORS
APRIL 1980, HOT WATER AND SPACE HEATING

SADDLE HILL TRUST LOT 36

	HOT WATER				SPACE HEATING			
DAY OF MONTH (NBS ID)	HOT WATER DEMAND LOAD GJOULES (Q302)	TOTAL ENERGY CONSUMED FOR HOT WATER GJOULES (Q300 + Q305)	SOLAR ENERGY CONSUMED FOR HOT WATER GJOULES (Q300)	SOLAR FRACTION OF ENERGY CONSUMED FOR HOT WATER (N301)	SPACE HEATING LOAD GJOULES (Q402)	TOTAL ENERGY CONSUMED FOR SPACE HEATING GJOULES (Q400 + Q401)	SOLAR ENERGY CONSUMED FOR SPACE HEATING GJOULES (Q400)	SOLAR FRACTION OF ENERGY CONSUMED FOR SPACE HEATING (N401)
1	0.072	0.143	0.109	0.762	0.157	0.157	0.003	0.018
2	0.069	0.113	0.069	0.611	0.248	0.248	0.103	0.416
3	0.061	0.113	0.074	0.654	0.130	0.130	0.009	0.066
4	0.046	0.067	0.048	0.720	0.218	0.218	0.136	0.626
5	0.071	0.099	0.066	0.665	0.201	0.201	0.022	0.111
6	0.082	0.116	0.092	0.789	0.113	0.113	0.006	0.054
7	0.056	0.095	0.081	0.858	0.139	0.139	0.139	1.000
8	0.062	0.062	0.047	0.761	0.152	0.152	0.139	0.917
9	0.067	0.085	0.050	0.590	0.119	0.119	0.000	0.000
10	0.067	0.082	0.037	0.452	0.101	0.101	0.000	0.000
11	0.043	0.091	0.058	0.637	0.051	0.051	0.000	0.000
12	0.072	0.086	0.083	0.967	0.009	0.009	0.009	1.000
13	0.030	0.083	0.080	0.959	0.015	0.015	0.015	1.000
14	0.047	0.057	0.048	0.843	0.179	0.179	0.158	0.885
15	0.059	0.117	0.096	0.817	0.027	0.027	0.000	0.009
16	0.027	0.054	0.039	0.713	0.208	0.208	0.062	0.297
17	0.078	0.126	0.108	0.858	0.303	0.303	0.108	0.355
18	0.042	0.078	0.068	0.879	0.114	0.114	0.095	0.833
19	0.087	0.124	0.118	0.952	0.064	0.064	0.064	1.000
20	0.046	0.086	0.086	1.000	0.009	0.009	0.009	1.000
21	0.063	0.104	0.104	1.000	0.000	0.000	0.000	0.000
22	0.074	0.069	0.069	1.000	0.078	0.078	0.058	0.741
23	0.083	0.082	0.082	1.000	0.207	0.207	0.166	0.801
24	0.076	0.090	0.090	1.000	0.045	0.045	0.000	0.000
25	0.043	0.070	0.070	1.000	0.082	0.082	0.012	0.151
26	0.032	0.042	0.042	1.000	0.053	0.053	0.000	0.006
27	0.026	0.039	0.039	1.000	0.088	0.088	0.000	0.000
28	0.054	0.078	0.038	0.492	0.217	0.217	0.000	0.000
29	0.062	0.090	0.020	0.223	0.191	0.191	0.000	0.000
30	0.048	0.086	0.028	0.327	0.083	0.083	0.000	0.000
SUM	1.743	2.629	2.042	-	3.600	3.600	1.314	-
AVG	0.058	0.088	0.068	0.776	0.120	0.120	0.044	0.365

Table 7.17a. DAILY SYSTEM PERFORMANCE FACTORS
MAY 1980, CLIMATE, COLLECTOR, AND STORAGE

SADDLE HILL TRUST LOT 36

	CLIMATE				COLLECTOR			STORAGE				
DAY OF MONTH (NBS ID)	AVERAGE AMBIENT TEMP DEG C (N113)	DAYTIME AMBIENT TEMP DEG C	TOTAL SOLAR INCIDENT GJOULES (Q001)	INCIDENT SOLAR WHILE COLLECTING GJOULES (Q003)	SOLAR ENERGY COLLECTED GJOULES (Q100)	DAILY COLLECTOR EFFICIENCY (N100)	COLLECTOR ON EFFICIENCY	ENERGY DELIVERED TO STORAGE GJOULES (Q200)	ENERGY DELIVERED FROM STORAGE GJOULES (Q201)	ENERGY LOSS FROM STORAGE GJOULES (Q204)	CHANGE IN STORED ENERGY GJOULES (Q202)	STORAGE MEDIUM AVG TEMP DEG C (T200)
1	10	11	0.069	0.000	0.000	0.000	0.000	0.000	0.034	0.013	-0.048	32
2	12	17	0.635	0.583	0.283	0.446	0.485	0.294	0.062	0.061	0.171	35
3	16	23	0.627	0.561	0.295	0.471	0.527	0.297	0.077	0.057	0.164	50
4	16	18	0.698	0.590	0.270	0.387	0.458	0.272	0.108	0.064	0.100	62
5	15	21	0.575	0.468	0.211	0.367	0.451	0.211	0.109	0.064	0.038	67
6	14	21	0.575	0.463	0.188	0.327	0.406	0.188	0.119	0.060	0.010	69
7	9	10	0.112	0.000	0.000	0.000	0.000	0.000	0.117	0.017	-0.134	64
8	7	8	0.069	0.000	0.000	0.000	0.000	0.000	0.163	-0.002	-0.161	51
9	10	14	0.571	0.494	0.227	0.397	0.459	0.220	0.098	0.044	0.078	47
10	11	15	0.553	0.459	0.200	0.362	0.436	0.204	0.176	0.025	0.003	50
11	13	17	0.246	0.097	0.046	0.185	0.469	0.039	0.125	0.001	-0.087	46
12	18	21	0.318	0.246	0.118	0.370	0.479	0.120	0.091	0.027	0.003	43
13	18	19	0.176	0.080	0.039	0.220	0.483	0.034	0.056	0.012	-0.035	42
14	16	20	0.365	0.288	0.128	0.351	0.445	0.137	0.054	0.037	0.047	43
15	13	18	0.456	0.355	0.164	0.360	0.463	0.159	0.099	0.024	0.036	47
16	15	*	0.560	0.450	0.230	0.410	0.510	0.229	0.114	0.013	0.101	52
17	18	26	0.665	0.556	0.261	0.392	0.470	0.266	0.122	0.063	0.081	61
18	14	16	0.158	0.000	0.000	0.000	0.000	0.000	0.076	0.020	-0.097	59
19	19	23	0.404	0.305	0.138	0.342	0.454	0.144	0.083	0.041	0.020	56
20	19	26	0.627	0.527	0.243	0.388	0.462	0.247	0.117	0.064	0.066	60
21	11	11	0.073	0.000	0.000	0.000	0.000	0.000	0.116	0.004	-0.120	58
22	21	26	0.574	0.487	0.239	0.416	0.490	0.248	0.155	0.041	0.052	53
23	23	30	0.577	0.487	0.227	0.393	0.466	0.234	0.103	0.066	0.066	59
24	19	27	0.488	0.373	0.158	0.325	0.424	0.165	0.089	0.060	0.015	63
25	19	24	0.637	0.506	0.224	0.352	0.443	0.225	0.089	0.072	0.065	67
26	14	18	0.600	0.461	0.191	0.318	0.414	0.176	0.122	0.051	0.002	70
27	15	19	0.613	0.472	0.199	0.325	0.422	0.184	0.103	0.060	0.020	71
28	16	21	0.617	0.473	0.195	0.316	0.412	0.195	0.098	0.073	0.024	73
29	17	24	0.707	0.503	0.217	0.307	0.432	0.217	0.138	0.088	-0.009	74
30	17	25	0.600	0.447	0.188	0.313	0.420	0.178	0.083	0.083	0.012	73
31	19	24	0.292	0.032	0.009	0.030	0.269	0.008	0.069	0.032	-0.093	70
SUM	-	-	14.236	10.764	4.888	-	-	4.891	3.166	1.335	0.390	-
AVG	15	20	0.459	0.347	0.158	0.343	0.454	0.158	0.102	0.043	0.013	57

* DENOTES UNAVAILABLE DATA.

Table 7.17b. DAILY SYSTEM PERFORMANCE FACTORS
MAY 1980, HOT WATER AND SPACE HEATING

SADDLE HILL TRUST LOT 36

	HOT WATER				SPACE HEATING			
DAY OF MONTH (NBS ID)	HOT WATER DEMAND LOAD GJOULES (Q302)	TOTAL ENERGY CONSUMED FOR HOT WATER GJOULES (Q300 + Q305)	SOLAR ENERGY CONSUMED FOR HOT WATER GJOULES (Q300)	SOLAR FRACTION OF ENERGY CONSUMED FOR HOT WATER (N301)	SPACE HEATING LOAD GJOULES (Q402)	TOTAL ENERGY CONSUMED FOR SPACE HEATING GJOULES (Q400 + Q401)	SOLAR ENERGY CONSUMED FOR SPACE HEATING GJOULES (Q400)	SOLAR FRACTION OF ENERGY CONSUMED FOR SPACE HEATING (N401)
1	0.073	0.101	0.075	0.743	0.672	0.672	0.136	0.202
1	0.100	0.135	0.034	0.253	0.153	0.153	0.000	0.000
2	0.080	0.141	0.044	0.310	0.107	0.107	0.018	0.172
3	0.060	0.106	0.072	0.678	0.054	0.054	0.004	0.072
4	0.058	0.117	0.108	0.923	0.000	0.000	0.000	0.000
5	0.057	0.109	0.109	1.000	0.000	0.000	0.000	0.000
6	0.045	0.119	0.119	1.000	0.000	0.000	0.000	0.000
7	0.040	0.097	0.097	1.000	0.036	0.036	0.020	0.562
8	0.086	0.087	0.087	1.000	0.111	0.111	0.073	0.659
9	0.043	0.075	0.075	1.000	0.023	0.023	0.023	1.000
10	0.039	0.069	0.069	1.000	0.105	0.105	0.105	1.000
11	0.049	0.061	0.061	1.000	0.062	0.062	0.062	1.000
12	0.048	0.070	0.063	0.904	0.026	0.026	0.026	1.000
13	0.060	0.088	0.056	0.641	0.000	0.000	0.000	0.000
14	0.029	0.102	0.054	0.533	0.000	0.000	0.000	0.000
15	0.043	0.116	0.080	0.689	0.016	0.016	0.016	1.000
16	0.051	0.111	0.099	0.893	0.015	0.015	0.015	1.000
17	0.081	0.141	0.122	0.868	0.000	0.000	0.000	0.000
18	0.035	0.076	0.076	1.000	0.000	0.000	0.000	0.000
19	0.034	0.086	0.083	0.971	0.000	0.000	0.000	0.000
20	0.047	0.119	0.117	0.981	0.000	0.000	0.000	0.000
21	0.056	0.100	0.089	0.889	0.045	0.045	0.026	0.583
22	0.077	0.127	0.103	0.810	0.050	0.050	0.050	1.000
23	0.041	0.103	0.103	1.000	0.000	0.000	0.000	0.000
24	0.052	0.089	0.089	1.000	0.000	0.000	0.000	0.000
25	0.019	0.089	0.089	1.000	0.000	0.000	0.000	0.000
26	0.078	0.122	0.122	1.000	0.000	0.000	0.000	0.000
27	0.069	0.103	0.103	1.000	0.000	0.000	0.000	0.000
28	0.064	0.098	0.098	1.000	0.000	0.000	0.000	0.000
29	0.086	0.138	0.138	1.000	0.000	0.000	0.000	0.000
30	0.036	0.083	0.083	1.000	0.000	0.000	0.000	0.000
31	0.050	0.069	0.069	1.000	0.000	0.000	0.000	0.000
SUM	1.715	3.145	2.711	-	0.805	0.805	0.440	-
AVG	0.055	0.101	0.087	0.862	0.026	0.026	0.014	0.546

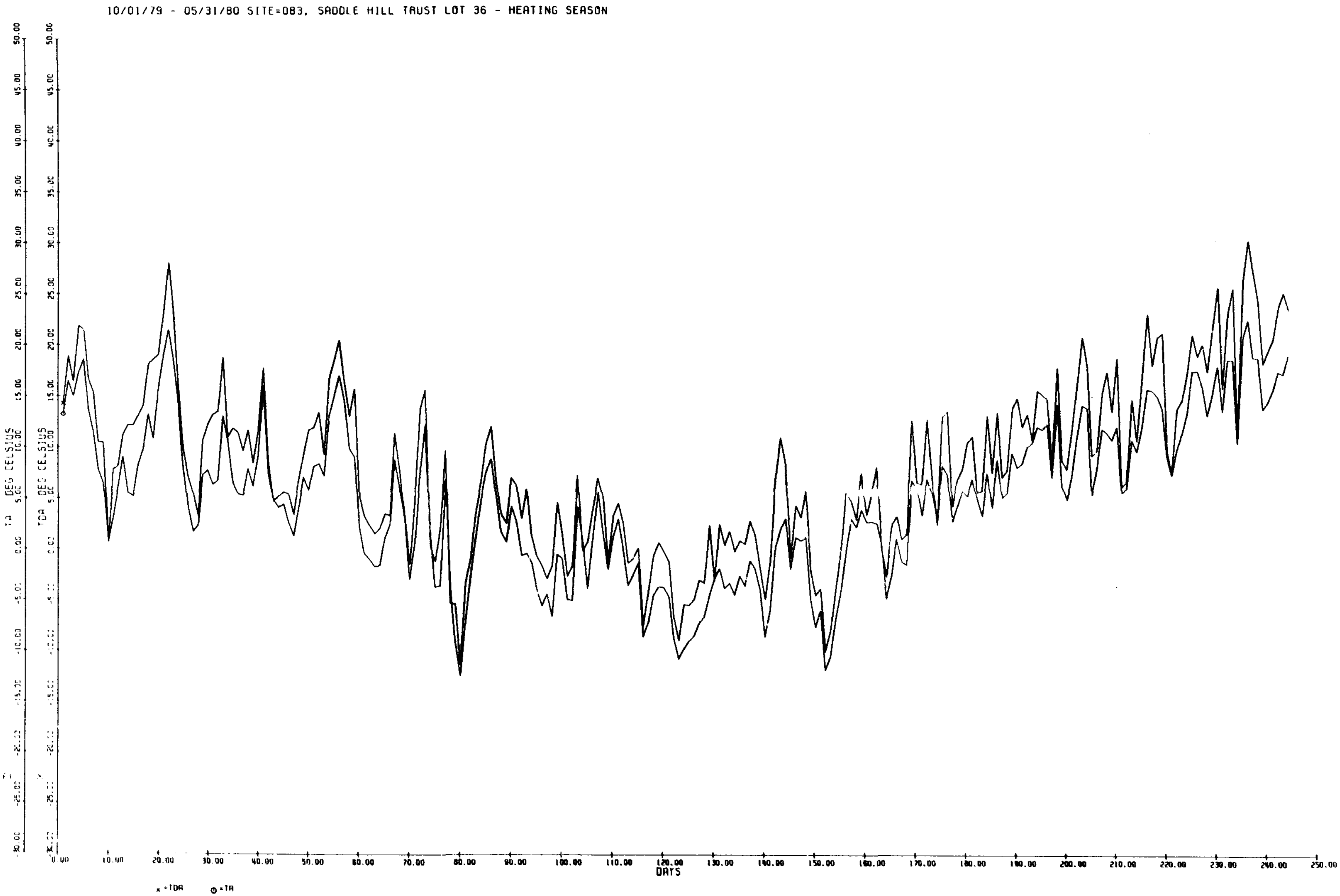


Figure 7.8. Plot of Daily Ambient Temperatures and Daytime Ambient Temperatures
Saddle Hill Trust Lot 36
October 1979 through May 1980

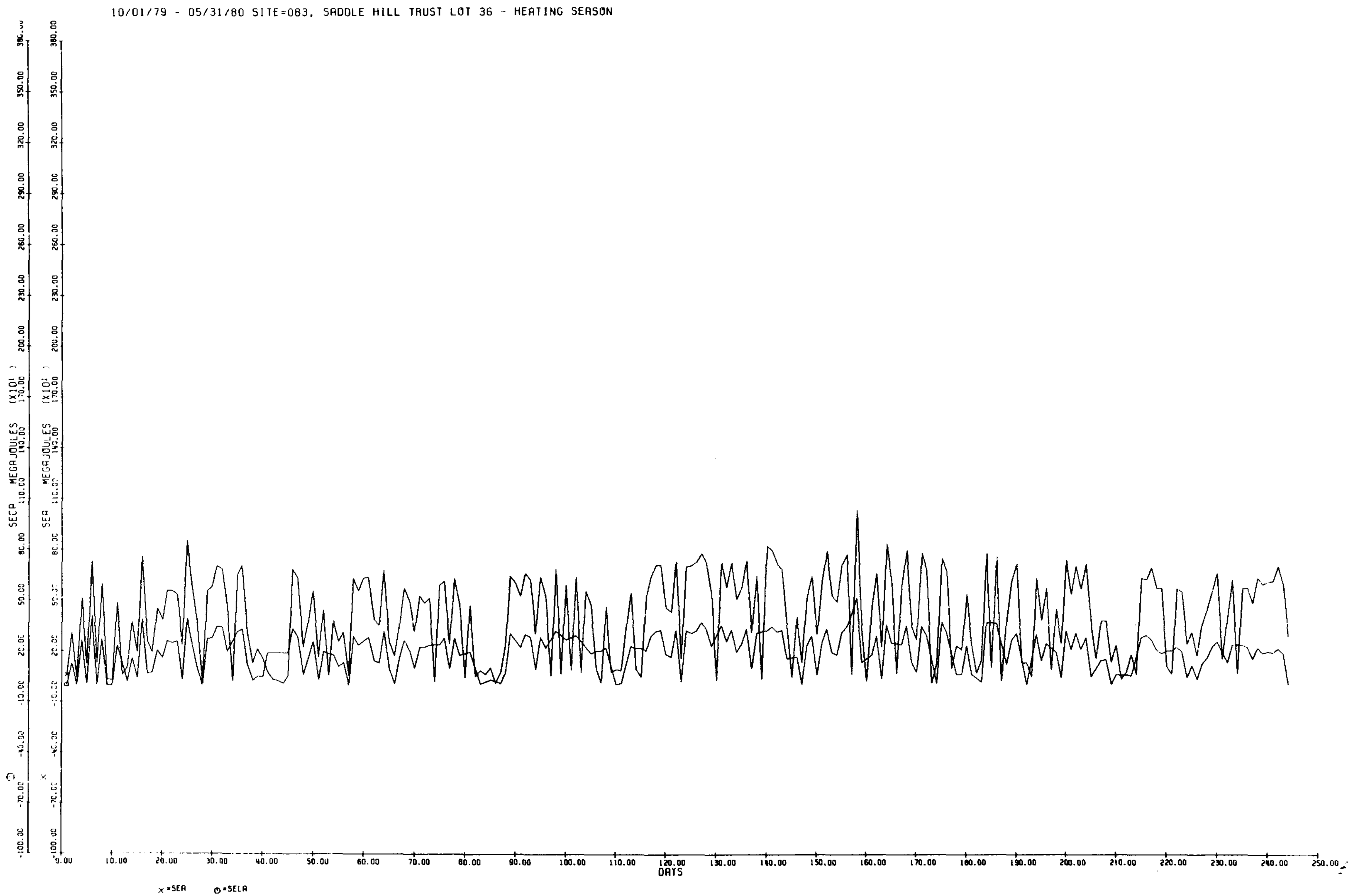


Figure 7.9. Plot of Daily Incident Solar Radiation and Collected Solar Energy
Saddle Hill Trust Lot 36
October 1979 through May 1980

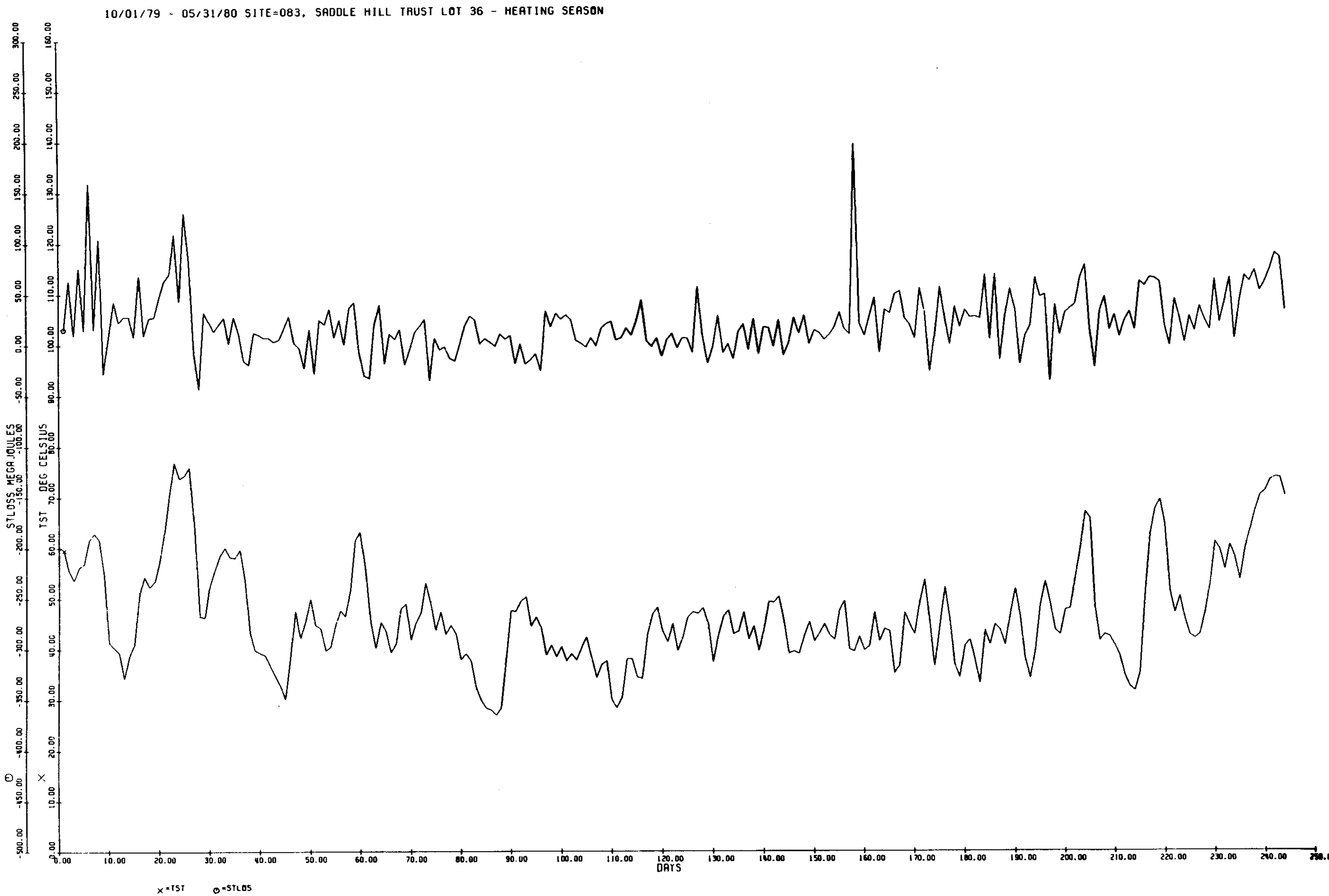


Figure 7.10. Plot of Daily Average Storage Temperatures and Storage Energy Losses
Saddle Hill Trust Lot 36
October 1979 through May 1980

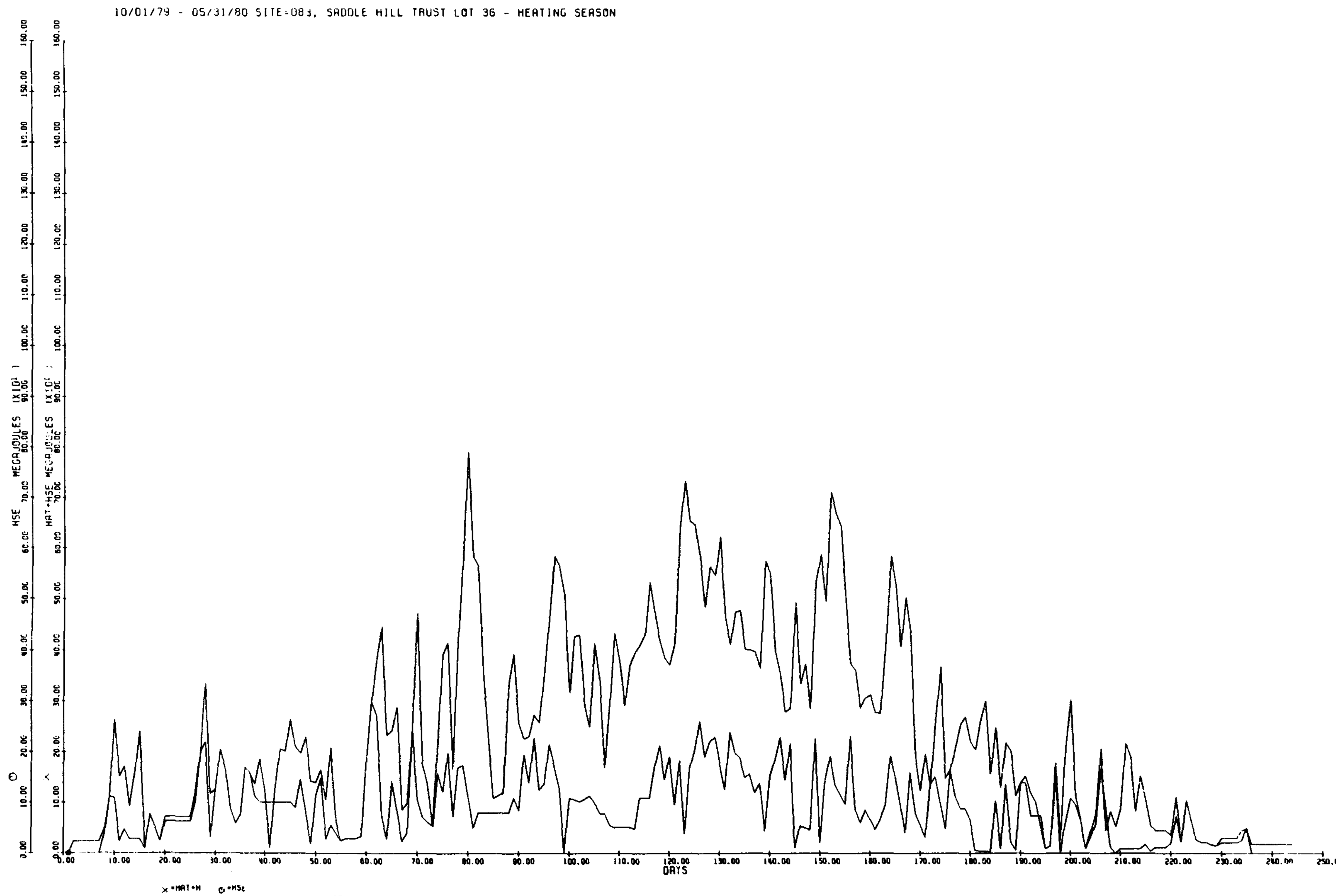


Figure 7.11. Plot of Daily Solar Energy and Auxiliary Energy Consumed for Space Heating Subsystem Saddle Hill Trust Lot 36 October 1979 through May 1980

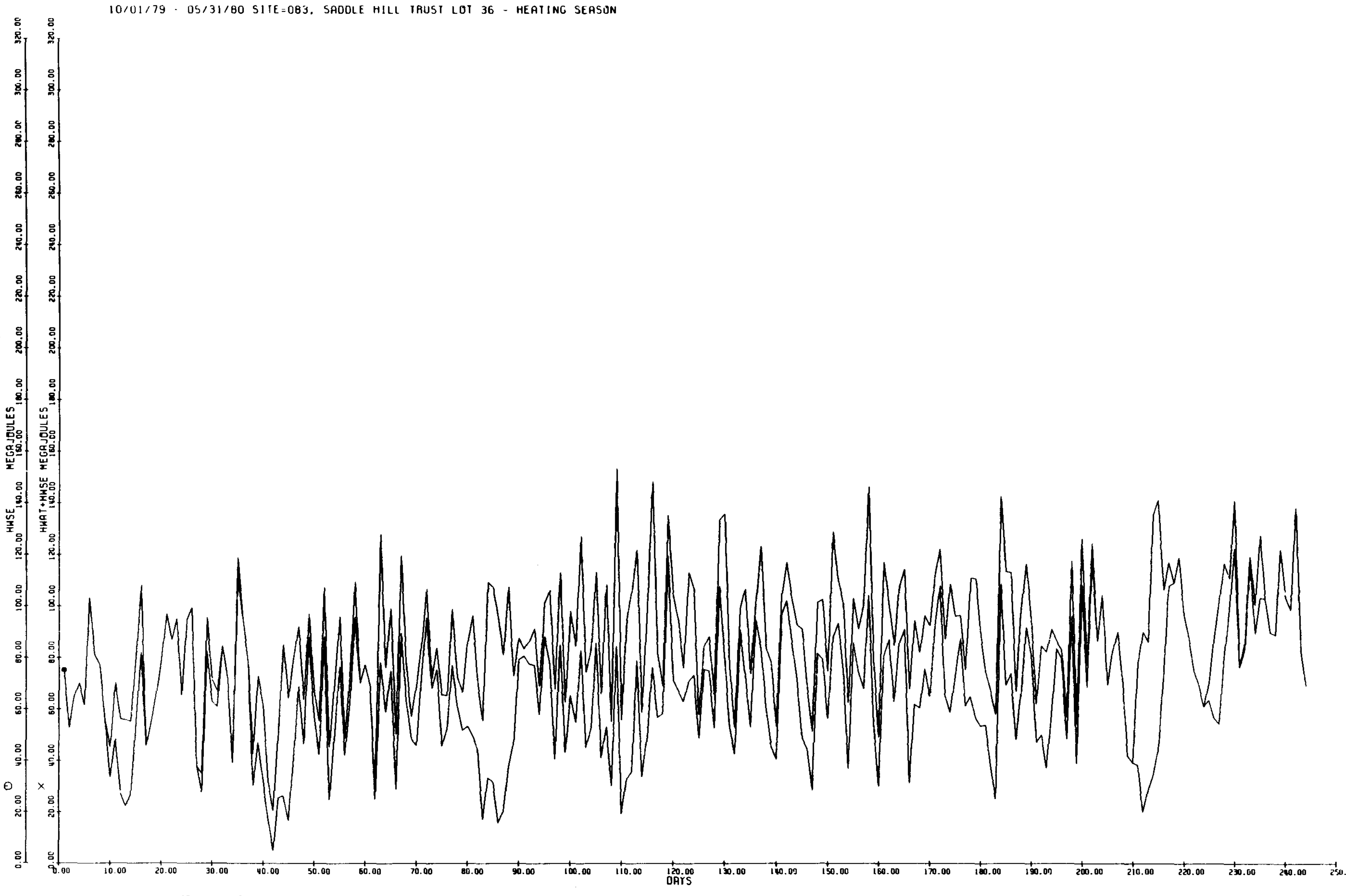


Figure 7.12. Plot of Daily Solar and Auxiliary Energy
Consumed by DHW Subsystem
Saddle Hill Trust Lot 36
October 1979 through May 1980

7.4 HOURLY SYSTEM PERFORMANCE

Hourly system performance, including DHW usage, space heating demand, storage tank temperature, solar energy collected, and incident solar energy, is plotted in Figure 7.13.

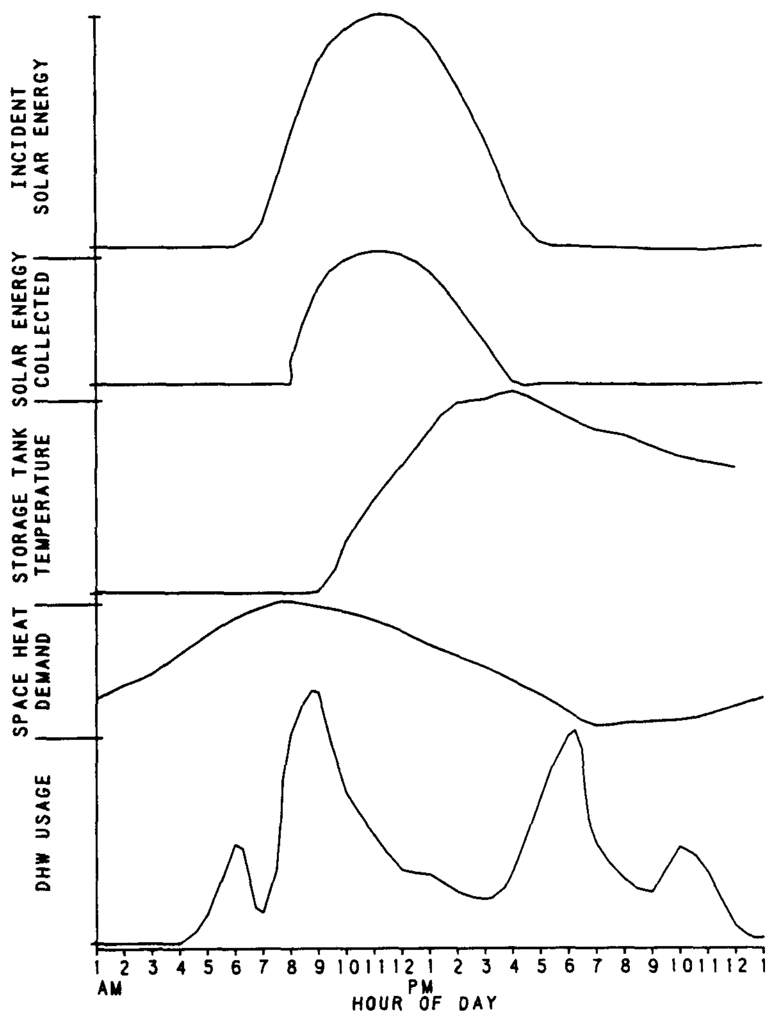


Figure 7.13. Typical Hourly Profiles of Selected Performance Factors

7.5 PERFORMANCE COMPARISONS WITH EXPECTED RESULTS

The f-Chart (FCHART 3.0) program was used to estimate performance of the solar system. The f-Chart program was developed by the Solar Energy Laboratory, University of Wisconsin-Madison, and was originally intended to be used as a design tool. Measured weather data and measured subsystem loads have been used in place of average long-term weather data and ASHRAE building heat loss (UA) estimated loads. The results help to determine if the system is performing well.

FCHART 3.0 does not account for solar energy utilizability or losses. This partly explains the disparity between predicted and measured solar fractions.

Ref:

(1) Solar Heating Design by the F-Chart Method. William A. Beckman, Sanford A. Klein, John A. Duffie, Wiley Interscience, N.Y. (1977)

(2) F-Chart User's Manual. EES Report 49-3, SERI, Department of Energy, (June 1978)

Table 7.18. f-CHART PREDICTIONS

SADDLE HILL TRUST LOT 36
OCTOBER 1979 THROUGH MAY 1980

MONTH	SOLAR FRACTION % PREDICTED	SOLAR FRACTION % MEASURED
OCT	75	67
NOV	66	59
DEC	40	34
JAN	39	25
FEB	52	36
MAR	49	32
APR	66	51
MAY	93	76
WEIGHTED AVERAGE	49	39

SECTION 8

DISCUSSION

The solar system at the Saddle Hill Trust Lot 36 site provided 47% of the overall energy requirement for the 1979 to 1980 heating season. This figure was based on the equipment heating solar energy. The equipment heating solar energy consumed (as explained in Section 7) includes the losses from the system to the conditioned space which help satisfy the space heating requirement.

The 47% solar fraction calculated for the reporting period compares very well to the designer's goal of 50%. The calculated solar fractions for the individual load subsystems also compare very closely to the design values. The space heating subsystem solar fraction was 41% versus the design value of 43% and the DHW subsystem had an actual solar fraction of 76% compared to the design goal of 77%.

The measured and long-term weather conditions for the winter heating season were presented in Section 2 in Table 2.1. The measured insolation was approximately 14% higher than the long-term average for the period. There was particularly more than average insolation during the winter months of December, January and February. The measured ambient temperature was lower than normal for the eight-month period, expecially during the months of January and February. So the positive solar heating effect of the extra insolation for the period was offset by the increased heating load caused by the colder than normal winter. In general the 1979-80 winter was clearer but colder than normal.

Whenever the measured value is given along with the equipment heating value for a load, energy consumed, energy savings, etc., the measured value does not take into account the contribution of the losses from the system to the load. The measured values were based on the instrumentation in the space heating subsystem which calculated the load as the sum of the solar plus auxiliary thermal energies consumed by the subsystem. So the space heating loads and solar fractions given in the daily tables and plots in Section 7.3 are the measured values. Solar losses from the system clearly contribute positively towards satisfying the space heating load (resulting in savings of fossil fuel). Therefore, the equipment heating values are considered the more accurate contribution of the system and are used in the performance charts in Section 7. The measured values are also given in the monthly tables since they are the basis for computing the equipment heating values.

The solar savings ratio for the heating season was 44%. This figure represents the (equipment heating) solar energy consumed, minus the operating energy required to run the pumps in the solar system, divided by the equipment heating load. This ratio indicates that there was a three percent penalty imposed on the solar fraction if the solar system operating energy is considered.

The energy flow through the Saddle Hill Trust Lot 36 solar system was shown in Figure 7.2. The important features to notice on this diagram are the relative amounts of solar energy distributed to each subsystem and the magnitude of losses at different points in the system.

It is interesting to note that relatively equal amounts of solar energy were drawn from the storage tank, even though the space heating load was almost four times as great. The reason for this most likely lies in the consumption patterns of the DHW and space heating subsystems. Figure 7.13 shows that one of the peak demands for DHW is in the late afternoon and evening hours when solar energy is available in the storage tank. This energy had been collected in the afternoon and the storage temperature is at its peak during one of the DHW demand peaks. Also, the space heating load is spread out throughout the night hours after the DHW demand has lowered the storage temperature.. (The space heating load is an estimated profile based on the outside ambient temperature pattern.) Therefore, the space heating demand tended to rely more on the auxiliary during the nighttime. The higher solar fraction of the DHW subsystem reflects this trend.

The other important feature to notice from the energy flow diagram is the magnitude of losses at various points in the system. In general, the system is well insulated. The storage tank and fluid transport lines have all been carefully covered with insulation of R = 1.93 m^2-°K/W and the DHW tank has R = 1.23 m^2-°K/W insulation.

The result is very low line losses throughout the system. The collector transport lines lost only 0.75 GJ or two percent of the collected energy. The space heating subsystem transport lines lost only 0.66 GJ of energy and the DHW subsystem lost less than a detectable amount of energy. (This is because the DHW line is a very short, well insulated run of piping. The temperature drop in the lines between the storage and DHW tanks was less than the accuracy of the instrumentation.)

The losses from the DHW tank were of the same magnitude as those from the storage tank even though it has a larger surface area. This was due to the DHW tank not being as well insulated and also due to the presence of a larger temperature differential between the water in the DHW tank and the room air. There also seems to have been a controls adjustment problem in the DHW loop indicated by the DHW pump running until a Delta T between the DHW and storage tank was less than 1°C. This is evidenced by the smaller COP for the DHW subsystem compared to the other subsystems' COP. (See Table 7.2) The COP is the measure of energy transferred by the subsystem per unit operating energy. While the seasonal averages for the collector and space heating subsystems were in the upper 40's, the COP for the DHW subsystem was only 15. This probably indicates that the DHW pump operated longer to transfer an equal amount of energy to that of the other subsystem, making the possibility of a control problem likely.

There were significant fossil and electrical savings made possible by the solar system. The equipment heating fossil fuel savings (which more accurately reflect the actual contribution of the solar system than the measured savings) were 48.25 GJ. This is equivalent to 1,237 liters of fuel oil. (At 0.25 U.S. dollars/liter this would be a savings of $309.00.) The electrical savings (after subtracting operating energy) were 13.83 GJ which is equivalent to 3,839 kwh of electrical energy. (At 0.05 U.S. dollars per kwh, the savings would be $192.00.)

The collector subsystem performed well, as a seasonal average of 40% of the total incident energy on the collector plane was collected. During the period that the collector was operating, the system collected 49% of the available insolation. The solar system collected 39.61 GJ of energy which was an average of 4.95 GJ per month. As seen from the collector performance Table 7.6, this energy was very evenly distributed throughout the month. The only significant variation from the average was in February when there was a much higher than normal amount of insolation available. The system collected about 40% more energy than the monthly average during February.

The "rule of thumb" for determining optimum collector tilt for a site with both space heating and DHW heating is to mount the collectors at an angle equal to the latitude plus 15°. This is to maximize collection during the winter months for space heating. This orientation has effectively distributed the collected solar energy evenly throughout the heating season, making possible maximum winter collection.

The seasonal average storage subsystem efficiency was 87%. As expected, the storage efficiency increased and the losses decreased when there was a lower temperature differential between the storage fluid and the room air temperature. This means that there will be a greater storage loss during the summer months when the average storage temperature is high and the space heat demand on storage is low.

The measured storage loss was used to calculate the UA (effective heat loss coefficient) for the storage tank. The average UA value for the heating season was 9.10 W/°K. This compares favorably to the estimated UA value of 7 W/°K which was based on the insulation and surface area of the storage tank.

The total (equipment heating) space heating load for the heating season was 70.64 GJ. Solar energy delivered from the storage tank to the subsystem, as well as solar losses from the subsystem, satisfied 41% of this load. Including losses in the calculation of the space heating load was valid as long as the average indoor temperature did not exceed the thermostat-set temperature for space heating. The control temperature for activating and deactiviting the auxiliary furnace was 20°C. From Table 7.6 it is clear that the thermostat was indeed operating near 20°C. Any building temperature rise in excess of 20°C would not have otherwise been made up by the auxiliary. This temperature rise would have been caused by excess solar energy losses to the conditioned space. This condition only occurred in May when the average indoor temperature rose to 21°C. This does not significantly affect the validity of the equipment heating load as the more accurate value for the heating requirement.

The DHW demand load for the reporting period was 13.57 GJ. Solar energy was used to supply 76% of this energy. The hot water consumption and demand load were spread out fairly evenly throughout the heating season. None of the months deviated more than 20% from the monthly averages of 1.70 GJ for the load and 326 liter/day consumption. From the data in Figure 7.7 for the delivery water temperature, it appears that the thermostat-set temperature was near 48°C. During the months December through March, the storage water temperature was not sufficient to bring the DHW water above the set temperature, so it was clear that the auxiliary was set to supply the DHW at about 48°C.

The hot water load profile was shown in Figure 3.1 and in Figure 7.7.

The morning peak represents typical before work or school usage and the early evening peak occurs during dinner time indicating heavy dishwasher usage. The third significant peak, in the late evening, is due to usage by members of the family returning from a late work shift.

SECTION 9

CONCLUSIONS AND RECOMMENDATIONS

(1) The solar system at the Saddle Hill Trust Lot 36 site performed very well, as 47% of the overall heating and hot water load was satisfied by solar energy. This compared well to the design goal of 50%.

(2) The solar system made possible a substantial energy savings of 62.08 GJ. Part of these savings was due to the solar energy losses from the system to the conditioned space. The energy contained in the losses to the conditioned space would have otherwise been made up by the auxiliary energy sources. The equipment heating load, which includes these losses plus the measured load, is considered the accurate representation of the energy requirement on the system for the heating season.

(3) The system is well insulated as evidenced by the low losses from the fluid transport lines.

(4) The 1979 to 1980 heating season was clearer but colder than the long-term average conditions.

(5) The collectors were oriented to maximize collection during the winter months when the insolation was lowest. The effect of this orientation was to distribute the collected solar energy evenly throughout the heating season.

(6) There were two peak hot water usage periods during a typical day; one in the morning around 9 a.m. and one in the evening around 6 p.m. The evening peak usage occurred when solar availability was highest, after the afternoon collection. This favorable usage pattern helped to boost the hot water solar fraction.

(7) The DHW subsystem coefficient of performance was significantly lower than that of the other subsystems. An adjustment in the DHW subsystem controls would probably increase the subsystem COP.

SECTION 10

REFERENCES

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2. J. T. Smok, V. S. Sohoni, J. M. Nash, "Processing of Instrumented Data for the National Solar Heating and Cooling Demonstration Program," Conference on Performance Monitoring Techniques for Evaluation of Solar Heating and Cooling Systems, Washington, D.C., April 1978.

3. E. Streed, et al, Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program, NBSIR-76-1137, National Bureau of Standards, Washington, D.C., 1976.

3A. Streed, E.R. (ed), 1979, Data Requirements and Thermal Performance Evaluation Procedures for Solar Heating and Cooling Systems. International Energy Agency, Solar Heating and Cooling Program, Task 1, NTIS, Springfield, Virginia 22151.

4. Mears, J. C., Reference Monthly Environmental Data for Systems in the National Solar Data Network. Department of Energy report SOLAR/0019-79/36. Washington, D.C., 1979.

5. ASHRAE Standard 93-77, Methods of Testing to Determine the Thermal Performance of Solar Collectors, The American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., New York, N.Y., 1977.

*6. ASHRAE Standard 94-77, Methods of Testing Thermal Storage Devices Based on Thermal Performance, The American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., New York, N.Y., 1977.

*6A. User's Guide to Monthly Performance Reports, June 1980, SOLAR/0004-80/18, Vitro Laboratories, Silver Spring, Maryland.

*6B. Instrumentation Installation Guidelines, July 1980, Parts 1, 2, and 3, SOLAR/0001-80/15, Vitro Laboratories, Silver Spring, Maryland.

*7. Monthly Performance Report, Saddle Hill Trust (36), October 1979, SOLAR/1038-79/10, IBM, Huntsville, Alabama.

* Copies of these reports may be obtained from Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830.

**Note. Reference [6] only used if the heat transfer coefficient discussion in Section 5.3.1.2 applies.

*8. Monthly Performance Report, Saddle Hill Trust (36), November 1979, SOLAR/1038-79/11, Vitro Laboratories, Silver Spring, Maryland.

*9. Monthly Performance Report, Saddle Hill Trust (36), December 1979, SOLAR/1038-79/12, Vitro Laboratories, Silver Spring, Maryland.

*10. Monthly Performance Report, Saddle Hill Trust (36), January 1980, SOLAR/1038-80/01, Vitro Laboratories, Silver Spring, Maryland.

*11. Monthly Performance Report, Saddle Hill Trust (36), February 1980, SOLAR/1038-80/02, Vitro Laboratories, Silver Spring, Maryland.

*12. Monthly Performance Report, Saddle Hill Trust (36), March, 1980, SOLAR/1038-80/03, Vitro Laboratories, Silver Spring, Maryland.

*13. Monthly Performance Report, Saddle Hill Trust (36), April 1980, SOLAR/1038-80/04, Vitro Laboratories, Silver Spring, Maryland.

*14. Monthly Performance Report, Saddle Hill Trust (36), May 1980, SOLAR/1038-80/05, Vitro Laboratories, Silver Spring, Maryland.

*15. HUD Residential Solar Demonstration Program, Project ID 26910AC010000, Site Data Package (Design Integration Monitor) by AIA/RC.

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17. P. Isakson, W. Kennish, E. Ofuerholm, Reporting Format for Thermal Performance of Solar Heating and Cooling Systems in Buildings, International Energy Agency, Solar Heating and Cooling Program, Task 1, Subtask C: Reporting Format, February 1980.

* Copies of these reports may be obtained from Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830.

APPENDIX A

NOMENCLATURE, DEFINITIONS AND UNITS

APPENDIX A

NOMENCLATURE, DEFINITIONS AND UNITS

Section 1 - Solar terminology
Section 2 - Abbreviations
Section 3 - Conversion factors

The data given in these appendices is given in British units.

SECTION 1. SOLAR TERMINOLOGY

Absorptivity	The ratio of absorbed radiation by a surface to the total incident radiated energy on that surface.
Active Solar System	A system in which a transfer fluid (liquid or air) is circulated through a solar collector where the collected energy is converted, or transferred, to energy in the medium.
Air Conditioning	Popularly defined as space cooling, more precisely, the process of treating indoor air by controlling the temperature, humidity and distribution to maintain specified comfort conditions.
Ambient Temperature	The surrounding air temperature.
Auxiliary Energy	In solar energy technology, the energy supplied to the heat or cooling load from other than the solar source, usually from a conventional heating or cooling system. Excluded are operating energy, and energy which may be supplemented in nature but does not have the auxiliary system as an origin, i.e., energy supplied to the space heating load from the external ambient environment by a heat pump. The electric energy input to a heat pump is defined as operating energy.
Auxiliary Energy Subsystem	In solar energy technology the Auxiliary Energy System is the conventional heating and/or cooling equipment used as supplemental or backup to the solar system.
Array	An assembly of a number of collector elements, or panels, into the solar collector for a solar energy system.
Backflow	Reverse flow.
Backflow Preventer	A valve or damper installed to prevent reverse flow.
Beam Radiation	Radiated energy received directly, not from scattering or reflecting sources.
Collected Solar Energy	The thermal energy added to the heat transfer fluid by the solar collector.

Collector Array Efficiency	Same as Collector Conversion Efficiency. Ratio of the collected solar energy to the incident solar energy. (See also Operational Collector Efficiency.)
Collector Subsystem	The assembly of components that absorbs incident solar energy and transfers the absorbed thermal energy to a heat transfer fluid.
Concentrating Solar Collector	A solar collector that concentrates the energy from a larger area onto an absorbing element of smaller area.
Conversion Efficiency	Ratio of thermal energy output to solar energy incident on the collector array.
Conditioned Space	The space in a building in which the air is heated or cooled to maintain a desired temperature range.
Control System or Subsystem	The assembly of electric, pneumatic, or hydraulic, sensing, and actuating devices used to control the operating equipment in a system.
Cooling Degree Days	The sum over a specified period of time of the number of degrees the average daily temperature is above 65°F.
Cooling Tower	A heat exchanger that transfers waste heat to outside ambient air.
Diffuse Radiation	Solar Radiation which is scattered by air molecules, dust, or water droplets and incapable of being focused.
Drain Down	An arrangement of sensors, valves and actuators to automatically drain the solar collectors and collector piping to prevent freezing in the event of cold weather.
Duct Heating Coil	A liquid-to-air heat exchanger in the duct distribution system.
Effective Heat Transfer Coefficient	The heat transfer coefficient, per unit plate area of a collector, which is a measure of the total heat losses per unit area from all sides, top, back, and edges.
Energy Gain	The thermal energy gained by the collector transfer fluid. The thermal energy output of the collector.

Energy Savings	The estimated difference between the fossil and/or electrical energy requirements of an assumed conventional system (carrying the full measured load) and the actual electrical and/or fossil energy requirements of the installed solar-assisted system.
Expansion Tank	A tank with a confined volume of air (or gas) whose inlet port is open to the system heat transfer fluid. The pressure and volume of the confined air varies as to the system heat transfer fluid expands and contracts to prevent excessive pressure from developing and causing damage.
F-Curve	The collector instantaneous efficiency curve. Used in the "F-curve" procedure for collector analysis (see Instantaneous Efficiency).
Figure of Merit, FMS	A calculated number showing the relative net fraction of the system load supplied from solar energy.

$$\text{FMS} = \frac{\text{Solar Energy}}{\text{Supplied to Load}} - \frac{\text{Solar System}}{\text{Operating Energy}}$$

Fixed Collector	A solar collector that is fixed in position and cannot be rotated to follow the sun daily or seasonably.
Flat Plate Collector	A solar energy collecting device consisting of a relatively thin panel of absorbing material. A container with insulated bottom and sides and covered with one or more covers transparent to visible solar energy and relatively opaque to infrared energy. Visible energy from the sun enters through the transparent cover and raises the temperature of the absorbing panel. The infrared energy re-radiated from the panel is trapped within the collector because it cannot pass through the cover. Glass is an effective cover material (see Selective Surface).
Focusing Collector	A concentrating type collector using parabolic mirrors or optical lenses to focus the energy from a large area onto a small absorbing area.
Fossil Fuel	Petroleum, coal, and natural gas derived fuels.

Glazing	In solar/energy technology, the transparent covers used to reduce energy losses from a collector panel.
Heat Exchanger	A device used to transfer energy from one heat transfer fluid to another while maintaining physical segregation of the fluids. Normally used in systems to provide an interface between two different heat transfer fluids.
Heat Transfer Fluid	The fluid circulated through a heat source (solar collector) or heat exchanger that transports the thermal energy by virtue of its temperature.
Heating Degree Days	The sum over a specified period of time of the number of degrees the average daily temperature is below 65°F.
Instantaneous Efficiency	The efficiency of a solar collector at one operating point, $\frac{Ti-Ta}{I}$, under steady state conditions (see Operating Point).
Instantaneous Efficiency Curve	A plot of solar collector efficiency against operating point, $\frac{Ti-Ta}{I}$ (see Operating Point).
Incidence Angle	The angle between the line to a radiating source (the sun) and a line normal to the plane of the surface being irradiated.
Incident Solar Energy	The amount of solar energy irradiating a surface taking into account the angle of incidence. The effective area receiving energy is the product of the area of the surface times the cosine of the angle of incidence.
Insolation	The solar energy received by a surface.
Load	That to which energy is supplied, such as space heating load or cooling load. The system load is the total solar and auxiliary energy required to satisfy the required heating or cooling.
Manifold	The piping that distributes the transport fluid to and from the individual panels of a collector array.

Nocturnal Radiation	The loss of thermal energy by the solar collector to the night sky.
Operating Energy	The amount of energy (usually electrical energy) required to operate the solar and auxiliary equipments and to transport the thermal energy to the point of use, and which is not intended to directly affect the thermal state of the system.
Operating Point	A solar energy system has a dynamic operating range due to changes in level of insolation (I), fluid input temperature (T), and outside ambient temperature (Ta). The operating point is defined as: $\frac{Ti-Ta}{I}$ $\frac{°F \times hr. \times sq. ft.}{BTU}$
Operational Collector Efficiency	Ratio of collected solar energy to incident solar energy only during the time the collector fluid is being circulated with the intention of delivering solar-source energy to the system.
Outgassing	The emission of gas by materials and components, usually during exposure to elevated temperature, or reduced pressure.
Passive Solar System	A system that converts energy to useful thermal energy for heating without the use of collector circulating fluid.
Pebble Bed (Rock Bed)	A space filled with uniform-sized pebbles to store solar-source energy by raising the temperature of the pebbles.
Reflected Radiation	Insolation reflected from a surface, such as the ground or a reflecting element onto the solar collector.
Rejected Energy	Energy intentionally rejected, dissipated, or dumped from the solar system.
Retrofit	The addition of a solar energy system to an existing structure.
Selective Surface	A surface that has the ability to readily absorb solar radiation, but re-radiates little of it as thermal radiation.

Sensor	A device used to monitor a physical param eter in a system, such as temperature or flow rate, for the purpose of measurement or control.
Solar Conditioned Space	The area in a building that depends on solar energy to provide a fraction of the heating and cooling needs.
Solar Fraction	The fraction of the total load supplied by solar energy. The ratio of solar energy supplied to loads divided by total load. Often expressed as a percentage.
Solar Savings Ratio	The ratio of the solar energy supplied to the load minus the solar system operating energy, divided by the system load.
Storage Efficiency, N_s	Measure of effectiveness of transfer of energy through the storage subsystem taking into account system losses.
Storage Subsystem	The assembly of components used to store solar-source energy for use during periods of low insolation.
Stratification	A phenomenon that causes a distinct thermal gradient in a heat transfer fluid, in contrast to a thermally homogeneous fluid. Results in the layering of the heat transfer fluid, with each layer at a different temperature. In solar energy systems, stratification can occur in liquid storage tanks or rock beds, and may even occur in pipes and ducts. The temperature gradient or layering may occur in a horizontal, vertical or radial direction.
System Performance Factor	Ratio of system load to the total equivalent fossil energy expended or required to support the system load.
Ton of Refrigeration	The heat equivalent to the melting of one ton (2,000 pounds) of ice at 32°F in 24 hours. A ton of refrigeration will absorb 12,000 BTU/hr, or 288,000 BTU/day.
Tracking Collector	A solar collector that moves to point in the direction of the sun.
Zone	A portion of a conditioned space that is controlled to meet heating or cooling requirements separately from the other space or other zones.

SECTION 2. ABBREVIATIONS

ASHRAE — American Society of Heating, Refrigeration, and Air Conditioning Engineering.

BTU — British Thermal Unit, a measure of heat energy. The quantity of heat required to raise the temperature of one pound of pure water one Fahrenheit degree. One BTU is equivalent to 2.932 x 10^{-4} kwh of electrical energy.

COP — Coefficient of Performance. The ratio of total load to solar-source energy.

DHW — Domestic Hot Water.

ECSS — Energy Collection and Storage System.

HWS — Domestic or Service Hot Water Subsystem.

KWH — Kilowatt Hours, a measure of electrical energy. The product of kilowatts of electrical power applied to a load times the hours it is applied. One kwh is equivalent to 3410.6412 BTU of heat energy.

NSDN — National Solar Data Network.

SCS — Space Cooling Subsystem.

SHS — Space Heating Subsystem.

SOLMET — Solar Radiation/Meteorology Data.

SECTION 3

CONVERSION FACTORS

Energy Conversion Factors[1]

Fuel Type	Energy Content	Fuel Source Conversion Factor
Distillate fuel oil[2]	38.66×10^{6} joules/liter	25.87×10^{-9} liter/joule
Residual fuel oil[3]	41.72×10^{6} joules/liter	23.97×10^{-9} liter/joule
Kerosene	37.63×10^{6} joules/liter	26.58×10^{-9} liter/joule
Propane		
Natural gas	38.03×10^{6} joules/m^3	26.29×10^{-9} m^3/joule
Electricity	3.600×10^{6} joules/kwh	0.2778×10^{-6} kwh/joule

[1] Source information is from the Dept. of Energy "Monthly Energy Review" FEB 1980

[2] No. 1 and No. 2 heating oils, diesel fuel, No. 4 fuel oils

[3] No. 5 and No. 6 fuel oils

English to Metric System Conversion Factors

To Convert From	To	Multiply By
BTU	joules	1.055×10^{3}
BTU/ft^2	joule/m^2	1.135×10^{4}
BTU/hr	watts	2.931×10^{-1}
BTU/hr °F	watts/°K	5.276×10^{-1}
BTU/hr-ft^2	watts/m^2	3.154
BTU/hr-ft^2°F	watts/m^2°K	5.677
BTU/lbm	joules/kg	2.326×10^{3}
cubic feet	cubic meters	2.832×10^{-2}
°F	°C	°C = (°F - 32) x 5/9
°F-day ("degree day")	°C-day	5/9
feet	meters	3.048×10^{-1}
gallons	cubic meters	3.785×10^{-3}
gallons	liters	3.785
inches	centimeters	2.540
miles	kilometers	1.609
mph	m/sec	4.470×10^{-1}
MMBTU	GJ	1.055
MMBTU (°F-day)$^{-1}$	GJ (°C-day)$^{-1}$	1.899
MMBTU/ft^2-day	megajoules/m^2-day	1.135×10^{4}
lbm	kg	4.536×10^{-1}
square feet	square meters	9.29×10^{-2}

APPENDIX B

SENSOR TECHNOLOGY

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SENSOR TECHNOLOGY

Temperature Sensors

Temperatures are measured by a Minco Products S53P platinum Resistance Temperature Detector (RTD). Because the resistance of platinum wire varies as a function of temperature, measurement of the resistance of a calibrated length of platinum wire can be used to accurately determine the temperature of the wire. This is the principle of the platinum RTD which utilizes a tiny coil of platinum wire encased in a copper-tipped probe to measure temperature. The probes are designed to have a normal resistance of 100 Ohms at 32°F.

Ambient temperature sensors are housed in a WeatherMeasure Radiation Shield in order to protect the probe from solar radiation. Care is taken to locate the sensor away from extraneous heat sources which could produce erroneous temperature readings. Temperature probes mounted in ducts or pipes are installed in stainless steel thermowells for physical protection of the sensor and to allow easy removal and replacement of the sensors. A thermally conductive grease is used between the probe and the thermowell to assure faster temperature response.

The RTDs are connected in a Wheatstone bridge arrangement to yield an output signal of 0-100 millivolts, which is measured by the SDAS. Different resistance values are used in the bridge, depending on the temperature range the sensor must measure. A third wire is brought out from the sensor and connected into the bridge to compensate for the resistance of the lead wires between the sensor and the SDAS.

The RTDs are individually calibrated by the manufacturer to National Bureau of Standards traceable standards. In addition, a five-point transmission system calibration check is done at the site to compensate for any deviation of the measurement system from nominal values.

The data-processing software takes these checks and calibrations into account, using a third-order polynomial curve fit to relate SDAS output to temperature.

Wind Sensor

Wind speed and direction are measured by a Model W101-P-DC/540 (or W102-P-DC/540) sensor made by the WeatherMeasure Corporation. This sensor is rugged, reliable and accurate and will withstand severe environments such as icing and hurricane winds.

Wind speed is measured by a four-bladed propeller vehicle coupled to a DC generator. The balanced propeller is fabricated from a special low-density, fiberglass-reinforced plastic to yield maximum sensitivity and strength. The DC generator has excellent linearity but somewhat higher threshold due to brush friction.

Dual-wiper, precious-metal slip rings are used to connect the wind speed generator signal (15 Volts DC at 100 miles per hour) to the data transmission lines. These generally provide trouble-free use for several years.

Wind direction is measured by means of a dual-wiper 1000-Ohm long-life conductive plastic potentiometer housed in the base of the sensor (0-540°). It is attached to the stainless steel shaft which supports and rotates with the upper body assembly.

The potentiometer is of high commercial grade and has sealed bearings. The conductive plastic resistance element has infinite resolution and a lifetime about 10 times that of wire-wound potentiometers. The base is of aluminum, and corrosion-resistant materials are used in the construction.

Humidity Sensors

Relative humidity is measured by a WeatherMeasure Corporation Model HM111-P/HM14-P sensor. This measurement is of particular importance in solar cooling systems.

This solid-state sensor measures relative humidity over the full range of 0-100%. Response of the sensing element is linear within approximately 1%, from 0-80% relative humidity, with small hysteresis and negligible temperature dependence.

The sensor is based upon the capacitance change of a polymer thin-film capacitor. A one-micron thick dielectric polymer layer absorbs water molecules through a thin metal electrode and causes capacitance change proportional to relative humidity. The thin polymer layer reacts very quickly and, therefore, the response time is very short (one second to 90% humidity change at 68°F).

The polymer material is resistant to most chemicals. Because the sensor response is based on "bulk" effect, under normal conditions dust and dirt do not easily influence its operation. For use outdoors, a sintered filter is used because sulphur dioxide absorbed on small particles can corrode the thin film electrodes of the sensor. The smaller the pore size of the filter, the greater the protection. The response time, however, is increased.

The sensor is mounted in a small probe which contains all the electronics necessary to provide a millivolt output. The output of the probe electronics is linear from 0-100% relative humidity. Because the capacitance change of the sensor is sensitive only to ambient water vapor, temperature compensation is not required in most situations.

Insolation Sensors

Eppley pyranometers and shadowband pyranometers are used to measure the amount of radiant energy incident on a surface. A standard pyranometer measures the total amount of solar energy available, including both the direct beam component and the diffuse component, while the shadow-band instrument is designed to measure the diffuse component only. The instruments are calibrated in the horizontal position, with an Eppley thermopile used as the signal generator of the sensor. The heating of the thermopile by the radiation of the sun generates the signal, with the response being linear over the operating range. Measurements are in BTU/ft^2-hr.

The addition of a shadow band to a pyranometer enables the instrument to record only the diffuse portion of the sunlight by shielding the sensor from the direct rays of the sun (the beam component). The amount of beam radiation available is readily calculated by subtracting the diffuse radiation measurement from the total radiation measured by the unshaded standard pyranometer. This beam radiation measurement is useful when working with focusing solar collectors. When using the shadowband pyranometer, the accuracy of its measurement depends on the correct adjustment of the shadow band to be certain that the sensor is shielded from the direct rays of the sun.

The pyranometer includes a circular multi-junction thermopile of the wire-wound type. The thermopile has the advantage of withstanding some mechanical vibration and shock. The receiver is circular, and coated with Parsons black lacquer. The instrument has a pair of removable precision ground and polished hemispheres of Schott optical glass. It also has a spirit level and a desiccator that can be readily inspected. The clear glass is transparent from a wave/length of about 285 to 2,800 nanometers. The temperature dependence is ±1% over the range of -4°F to 104°F. It has a response time of one second and a linearity of ±5% over the range of the instrument.

Flow Sensors

The Ramapo flowmeter is an accurate and sensitive liquid flow rate measuring device. The dynamic force of fluid flow, or velocity head of the approaching stream, is sensed as a drag force on a target (disc) suspended in the flow stream. This force is transmitted via a lever rod and flexure tube to an externally bonded, four active arm strain gage bridge. This strain gage bridge circuit translates the mechanical stress due to the sensor (target) drag into a directly proportional electrical output. Translation is linear, with infinite resolution, and is hysteresis free. The drag force itself is usually proportional to the flow rate squared. The electrical output is unaffected by variations in fluid temperature or static pressure head, within the stated limitations of the unit.

Power Sensors

A major component of the watt meter is a concentrating magnetic core (usually a toroid). The conductor carrying current to the load is passed through the window (eye) of the magnetic core one or more times. The magnetic field surrounding the conductor (load-carrying wire) is instantaneously proportional to the current flowing in the conductor. This field is intercepted by the magnetic core, producing a magnetic flux which is also instantaneously proportional to the current flowing in the conductor. A Hall effect transducer is cemented into a thin slot milled through the concentrating magnetic core.

In this position it intercepts nearly all of the magnetic flux present in the core. Two of the transducer's terminals provide a full scale output of 50MVDC. The remaining two terminals are referred to as a control input. The output of the Hall transducer is not only proportional to the magnetic flux passing through it but also to any EMF which appears across its control terminals. The load voltage is applied to the transducer's control terminals.

The resultant measurements of the watt meter are summarized below:

1. Output is directly proportional to the flux in the magnetic core which in turn is directly proportional to the load current (I).

2. Output is directly proportional to the load voltage (E).

3. Final output is directly proportional to the vector product of E, I, and cos ϕ (power factor angle). This output is read into the SDAS as an electrical power in watts.

APPENDIX C

INSTRUMENTATION PROGRAM AND COMPONENTS LIST

APPENDIX C

INSTRUMENTATION PROGRAM AND COMPONENTS LIST

The Instrumentation Program and Components List (IPCL) for a site in the National Solar Data Network documents the calibration software in the Central Data Processing System which processes the raw digital count data received from the site data aquisition system (SDAS) converting the data into engineering units and checking for data validity. The IPCL lists the sensors at the site in order of their SDAS channel assignment. For each sensor the IPCL lists the parameter monitored by the sensor. It also lists the type, manufacturer, serial number, operating range, microboard type and counts-to-engineering-units conversion coefficients for each sensor. The coefficients are for either straight-line, cubic or square-root functions. The IPCL is thus a detailed inventory of the instrumentation at the site.

The IPCL for the Saddle Hill Trust Lot 36 site during the October 1979 through May 1980 reporting period is listed on the following pages.

REPORT BY CHANNEL ASSIGNMENT

LINE	MEAS NUMBER / OSM CODE	MEASUREMENT NAME	CHAN #	ASYN	# WIRE	OPERATING RANGE / SENSOR OUTPUT RANGE / SDAS GAIN / ACTUAL OPER RANGE		MICROBRD TYPE / MICROBRD P/N / SENSOR EXCIT	TEMP SERIAL # / SCALE FACTOR UNITS / CPDS SCALE FACTORS (A0,A1,A2,A3)	SENSOR TYPE / SENSOR MANUFACT / SENSOR P/N / WELL P/N	NOTES / SERIAL #
1	EP100-0083	COLL PUMP(P-1)	02	A	3	0/.5	KW	STRAIGHT		WATT XDCR	
2		POWER				0-50	MV	7932985	KW/BIT	OHIO SEMITRONICS	
3	0240					50			0.	PC5-1	
4									+0009765E-07		
5	EP300-0083	PUMP(P-2)POWER	03	A	3	0/.5	KW	STRAIGHT		WATT XDCR	
6						0-50	MV	7932985	KW/BIT	OHIO SEMITRONICS	
7	0340					50			0.	PC5-1	
8									+0009765E-07		
9	EP301-0083	HOT WATER HTR	04	A	3	0/5	KW	STRAIGHT		WATT XDCR	NOTE 5
10		POWER				0-50	MV	7932985	KW/BIT	OHIO SEMITRONICS	
11	0445					50			0.	PC5-28	
12									+0097656E-07		
13	T150 -0083	COLLECTOR	05	-	3	30/230	DEGF	BRIDGE		PRT	S/N 3-448
14		OUTLET TEMP				0-100	MV	7932988	DEGF/BIT	MINCO	
15	0502					50			+3116344E-05	S53-P60	
16						+31.163 /+234.09			+1936808E-07	F203U34	
17									+0004580E-09		
18									+0000000E-07		
19	T100 -0083	COLLECTOR INLET	06	-	3	30/230	DEGF	BRIDGE		PRT	S/N 7-408
20		TEMP				0-100	MV	7932988	DEGF/BIT	MINCO	
21	0602					50			+3220067E-05	S57-P60	
22						+32.200 /+235.33			+1923868E-07	F203U34	
23									+0006039E-09		
24									+0000000E-07		
25	T101 -0083	STORAGE HX	07	-	3	30/230	DEGF	BRIDGE		PRT	S/N 7-454
26		OUTLET TEMP				0-100	MV	7932988	DEGF/BIT	MINCO	
27	0702					50			+3215462E-05	S57-P60	
28						+32.154 /+235.11			+1922279E-07	F203U34	
29									+0006026E-09		
30									+0000000E-07		
31	T151 -0083	STORAGE HX	08	-	3	30/230	DEGF	BRIDGE		PRT	S/N 3-445
32		INLET TEMP				0-100	MV	7932988	DEGF/BIT	MINCO	
33	0802					50			+3149995E-05	S53-P60	
34						+31.499 /+235.66			+1940816E-07	F203U34	
35									+0005374E-09		
36									+0000000E-07		
37	SP001-0083	SPARE	09	-	3	N/A		SHORT		N/A	
38						N/A		7932938	N/A	N/A	
39						50					
40									N/A		
41											
42											

REPORT BY CHANNEL ASSIGNMENT

MEAS NUMBER / OSM CODE	MEASUREMENT NAME	CHAN #	ASYN	# WIRE	OPERATING RANGE / SENSOR OUTPUT RANGE / SDAS GAIN / ACTUAL OPER RANGE		MICROBRD TYPE / MICROBRD P/N / SENSOR EXCIT	TEMP SERIAL # / SCALE FACTOR UNITS / CPDS SCALE FACTORS (A0,A1,A2,A3)	SENSOR TYPE / SENSOR MANUFACT / SENSOR P/N / WELL P/N	NOTES / SERIAL #
T001 -0083	OUTDOOR AMBIENT	10	-	3	-20/120	DEGF	BRIDGE		PRT	S/N 3-254
	TEMP				0-100	MV	7932986	DEGF/BIT	MINCO	
1000					50			-1884033E-05	S53-P60	
					-18.840 /+119.67			+1319984E-07		
								+0003324E-09		
								+0000000E-07		
T200 -0083	STOR TANK TOP	11	-	3	30/230	DEGF	BRIDGE		PRT	
	TEMP				0-100	MV	7932988	DEGF/BIT	MINCO	
1102					50			+3209116E-05	S53-P122	
					+32.091 /+235.32			+1932247E-07	F203U96	
								+0005318E-09		
								+0000000E-07		
T201 -0083	STOR TANK MIDD	12	-	3	30/230	DEGF	BRIDGE		PRT	
	TEMP				0-100	MV	7932988	DEGF/BIT	MINCO	
1202					50			+3199521E-05	S53-P266	
					+31.995 /+235.55			+1938248E-07	F203U240	
								+0005040E-09		
								+0000000E-07		
T202 -0083	STOR TANK BOT	13	-	3	30/230	DEGF	BRIDGE		PRT	
	TEMP				0-100	MV	7932988	DEGF/BIT	MINCO	
1302					50			+3206897E-05	S53-P426	
					+32.068 /+235.62			+1932325E-07	F203U400	
								+0005620E-09		
								+0000000E-07		
T300 -0083	STOR TANK FROM	14	-	3	30/230	DEGF	BRIDGE		PRT	S/N 3-352
	HW HX TEMP				0-100	MV	7932988	DEGF/BIT	MINCO	
1402					50			+3180835E-05	S57-P60	
					+31.808 /+235.05			+1939768E-07	F203U34	
								+0004595E-09		
								+0000000E-07		
T350 -0083	STOR TANK TO	15	-	3	30/230	DEGF	BRIDGE		PRT	S/N 3-446
	HW HX TEMP				0-100	MV	7932988	DEGF/BIT	MINCO	
1502					50			+3235240E-05	S53-P60	
					+32.352 /+235.73			+1932111E-07	F203U34	
								+0005469E-09		
								+0000000E-07		
W401 -0083	RETURN AIR	16	-	3	0/1000	FPM	STRAIGHT		ANEMOMETER	
	FLOW RATE				0-5	V	7932985	FPM/BIT	SIERRA	S/N160
NOTE 2					1		+12 VDC	0.	430-DC	
								+1442508E-07		
								+0003687E-07		
								+0006568E-10		

REPORT BY CHANNEL ASSIGNMENT

MEAS NUMBER OSM CODE	MEASUREMENT NAME	CHAN #	A SYN	# WIRE	OPERATING RANGE SENSOR OUTPUT RANGE SDAS GAIN ACTUAL OPER RANGE	MICROBRD TYPE MICROBRD P/N SENSOR EXCIT	TEMP SERIAL # SCALE FACTOR UNITS CPDS SCALE FACTORS (A0,A1,A2,A3)	SENSOR TYPE SENSOR MANUFACT SENSOR P/N WELL P/N	NOTES SERIAL #
W100 -0083 1754	COLL FLOW RATE	17	-	3	0/9.61 GPM 0-10 MV 50	STRAIGHT 7932985 +5 VDC	 GPM/BIT 0. +9496985E-07 SQCT	FLOW METER RAMAPO MKV-1-J02	 S/N4702
W300 -0083 1853	HW PREHEAT COIL FLOW RATE	18	-	3	0/7.07 GPM 0-10 MV 50	STRAIGHT 7932985 +5 VDC	 GPM/BIT 0. +6986855E-07 SQCT	FLOW METER RAMAPO MKV-3/4-J02	 S/N5792
EP400-0083 1940	PUMP(P-3) POWER	19	A	3	0/.5 KW 0-50 MV 50	STRAIGHT 7932985	 KW/BIT 0. +0009765E-07	WATT XDCR OHIO SEMITRONICS PC5-1	
I001 -0083 2025	TOT INSOLATION	20	\	3	0/385.21 BTU/FT2-HR 0-12 MV 50	CAPACITOR 7934363	 B/F2-H/BIT 0 3.1348662	PYRONOM EPPLEY PSP	 15914F3
T301 -0083 2102	HW/HX EXIT TEMP	21	-	3	30/230 DEGF 0-100 MV 50 +31.634 /+234.36	BRIDGE 7932988	 DEGF/BIT +3163476E-05 +1930614E-07 +0004997E-09 +0000000E-07	PRT MINCO S57-P60 F203U34	S/N 7-460
T351 -0083 2202	HW/HX INLET TEMP	22	-	3	30/230 DEGF 0-100 MV 50 +32.181 /+235.19	BRIDGE 7932988	 DEGF/BIT +3218150E-05 +1930214E-07 +0005304E-09 +0000000E-07	PRT MINCO S53-P60 F203U34	S/N 3-442
T302 -0083 2300	COLD WATER SUPP TEMP	23	-	3	-20/120 DEGF 0-100 MV 50 -19.113 /+118.99	BRIDGE 7932986	 DEGF/BIT -1911380E-05 +1321283E-07 +0002812E-09 +0000000E-07	PRT MINCO S57-P60 F203U34	S/N 7-413
T352 -0083 2402	DHW TANK OUTLET TEMP	24	-	3	30/230 DEGF 0-100 MV 50 +31.588 /+234.67	BRIDGE 7932988	 DEGF/BIT +3158897E-05 +1933857E-07 +0005017E-09 +0000000E-07	PRT MINCO S53-P60 F203U34	S/N 3-444

REPORT BY CHANNEL ASSIGNMENT

MEAS NUMBER / OSM CODE	MEASUREMENT NAME	CH #	ASYN	# WIRE	OPERATING RANGE / SENSOR OUTPUT RANGE / SDAS GAIN / ACTUAL OPER RANGE	MICROBRD TYPE / MICROBRD P/N / SENSOR EXCIT	TEMP SERIAL # / SCALE FACTOR UNITS / CPDS SCALE FACTORS (A0,A1,A2,A3)	SENSOR TYPE / SENSOR MANUFACT / SENSOR P/N / WELL P/N	NOTES / SERIAL #
D400 -0083	SWITCH-FUEL FLW	25	A	3	0/1 ON/OFF	STRAIGHT		SWITCH	1=125K
	TO OIL FURN.				0-5 V	7932985		MAGNECRAFT	BTU/HR
2530					1	+5 VDC	0.	W88ACPX-4	
							+0009775E-07		
SP002-0083	SPARE	26	-	3	N/A	SHORT		N/A	
					N/A	7932938	N/A	N/A	
					50				
							N/A		
W301 -0083	COLD WTR SUPPLY	27	-	3	0/100 GALS	STRAIGHT		TOTALIZER	
	TOTAL FLOW				0-5 V	7932985	GALS/BIT	HERSEY-AMERICAN	
NOTE 2					1		0	7945124-3	
							.0977517		
T400 -0083	STOR FROM COIL	28	-	3	30/230 DEGF	BRIDGE		PRT	S/N 7-420
	INLET TEMP				0-100 MV	7932988	DEGF/BIT	MINCO	
2802					50		+3176990E-05	S57-P60	
					+31.769 /+234.73		+1932805E-07	F203U34	
							+0005010E-09		
							+0000000E-07		
T450 -0083	STORAGE OUTLET	29	-	3	30/230 DEGF	BRIDGE		PRT	S/N 3-466
	TO HX TEMP				0-100 MV	7932988	DEGF/BIT	MINCO	
2902					50		+3172836E-05	S53-P60	
					+31.728 /+234.55		+1928487E-07	F203U34	
							+0005291E-09		
							+0000000E-07		
T401 -0083	HEATING COIL	30	-	3	30/230 DEGF	BRIDGE		PRT	S/N 7-428
	OUTLET TEMP				0-100 MV	7932988	DEGF/BIT	MINCO	
3002					50		+3272540E-05	S57-P60	
					+32.725 /+236.43		+1932224E-07	F203U34	
							+0005771E-09		
							+0000000E-07		
T451 -0083	HEATING COIL	31	-	3	30/230 DEGF	BRIDGE		PRT	S/N 3-450
	INLET TEMP				0-100 MV	7932988	DEGF/BIT	MINCO	
3102					50		+3153769E-05	S53-P100	
					+31.537 /+234.48		+1936956E-07	F203U34	
							+0004581E-09		
							+0000000E-07		

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MEAS NUMBER / OSM CODE	MEASUREMENT NAME	CH#	ASYN	# WIRE	OPERATING RANGE / SENSOR OUTPUT RANGE / SDAS GAIN / ACTUAL OPER RANGE	MICROBRD TYPE / MICROBRD P/N / SENSOR EXCIT	TEMP SERIAL # / SCALE FACTOR UNITS / CPDS SCALE FACTORS (A0,A1,A2,A3)	SENSOR TYPE / SENSOR MANUFACT / SENSOR P/N / WELL P/N	NOTES / SERIAL #
T900 -0083 3200	JUNCTION BOX AMBIENT TEMP	32	-	3	-20/120 DEGF 0-100 MV 50 -18.945 /+119.40	BRIDGE 7932986	DEGF/BIT -1894548E-05 +1329541E-07 +0002232E-09 +0000000E-07	PRT MINCO S53P-	
EP401-0083 3341	FURNACE BLOWER	33	A	3	0/1 KW 0-100 MV 50	STRAIGHT 7932985	KW/BIT 0. +0019531E-07	WATT XDCR OHIO SEMITRONICS PC5-10	
SP003-0083	SPARE	34	-	3	N/A N/A 50	SHORT 7932938	N/A N/A	N/A N/A	
W400 -0083 3554	HX TO STORAGE FLOW RATE	35	-	3	0/9.87 GPM 0-10 MV 50	STRAIGHT 7932985 +5 VDC	GPM/BIT 0. +9753927E-07 SQCT	FLOW METER RAMAPO MKV-3/4-J02	S/N5021
T402 -0083 3600	RETURN AIR TEMP	36	-	3	-20/120 DEGF 0-100 MV 50 -18.673 /+119.64	BRIDGE 7932986	DEGF/BIT -1867352E-05 +1321223E-07 +0003015E-09 +0000000E-07	PRT MINCO S57-P100	S/N 70-126
T452 -0083 3701	HX OUTLET TO FURNACE TEMP	37	-	3	30/160 DEGF 0-100 MV 50 +31.714 /+159.61	BRIDGE 7932990	DEGF/BIT +3171483E-05 +1232326E-07 +0001753E-09 +0000000E-07	PRT MINCO S57-P100	S/N 70-159
T453 -0083 3801	SPACE HTG OUTLT AIR TEMP	38	-	3	30/160 DEGF 0-100 MV 50 +31.479 /+158.44	BRIDGE 7932990	DEGF/BIT +3147899E-05 +1220664E-07 +0001997E-09	PRT MINCO S53-P100	S/N 30-142

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T600 -0083	BLDG INTERIOR	39	-	3	-20/120 DEGF	BRIDGE		PRT	
	AMB TEMP				0-100 MV	7932986	DEGF/BIT	MINCO	
3900					50		-1879393E-05	S53-P60	
					-18.793 /+119.39		+1327040E-07		
							+0002324E-09		
							+0000000E-07		
SP004-0083	SPARE	40	-	3	N/A	SHORT		N/A	
					N/A	7932938	N/A	N/A	
					50				
							N/A		
SP005-0083	SPARE	41	-	3	N/A	SHORT		N/A	
					N/A	7932938	N/A	N/A	
					50				
							N/A		
SP006-0083	SPARE	42	-	3	N/A	SHORT		N/A	
					N/A	7932938	N/A	N/A	
					50				
							N/A		
SP007-0083	SPARE	43	-	3	N/A	SHORT		N/A	
					N/A	7932938	N/A	N/A	
					50				
							N/A		
SP008-0083	SPARE	44	-	3	N/A	SHORT		N/A	
					N/A	7932938	N/A	N/A	
					50				
							N/A		
SP009-0083	SPARE	45	-	3	N/A	SHORT		N/A	
					N/A	7932938	N/A	N/A	
					50				
							N/A		

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LINE	MEAS NUMBER / OSM CODE	MEASUREMENT NAME	CHAN #	ASYN	# WIRE	OPERATING RANGE / SENSOR OUTPUT RANGE / SDAS GAIN / ACTUAL OPER RANGE	MICROBRD TYPE / MICROBRD P/N / SENSOR EXCIT	TEMP SERIAL # / SCALE FACTOR UNITS / CPDS SCALE FACTORS / (A0,A1,A2,A3)	SENSOR TYPE / SENSOR MANUFACT / SENSOR P/N / WELL P/N	NOTES / SERIAL #
1	SP010-0083	SPARE	46	-	3	N/A	SHORT		N/A	
2						N/A	7932938	N/A	N/A	
3						50				
4								N/A		
5										
6										
7	SP011-0083	SPARE	47	-	3	N/A	SHORT		N/A	
8						0-5 V	7932938	N/A	N/A	
9						1				
10								N/A		
11										
12										
13	SP012-0083	SPARE	48	-	3	N/A	SHORT		N/A	
14						N/A	7932938	N/A	N/A	
15						50				
16								N/A		
17										
18										

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