SOLAR/1039-81/14

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

SADDLE HILL TRUST LOT 73
Medway, Massachusetts
January 1980 through December 1980
DHW

U.S. DEPARTMENT OF ENERGY
NATIONAL SOLAR DATA PROGRAM

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MEDWAY, MASSACHUSETTS

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JANUARY 1980 THROUGH DECEMBER 1980

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FOREWORD

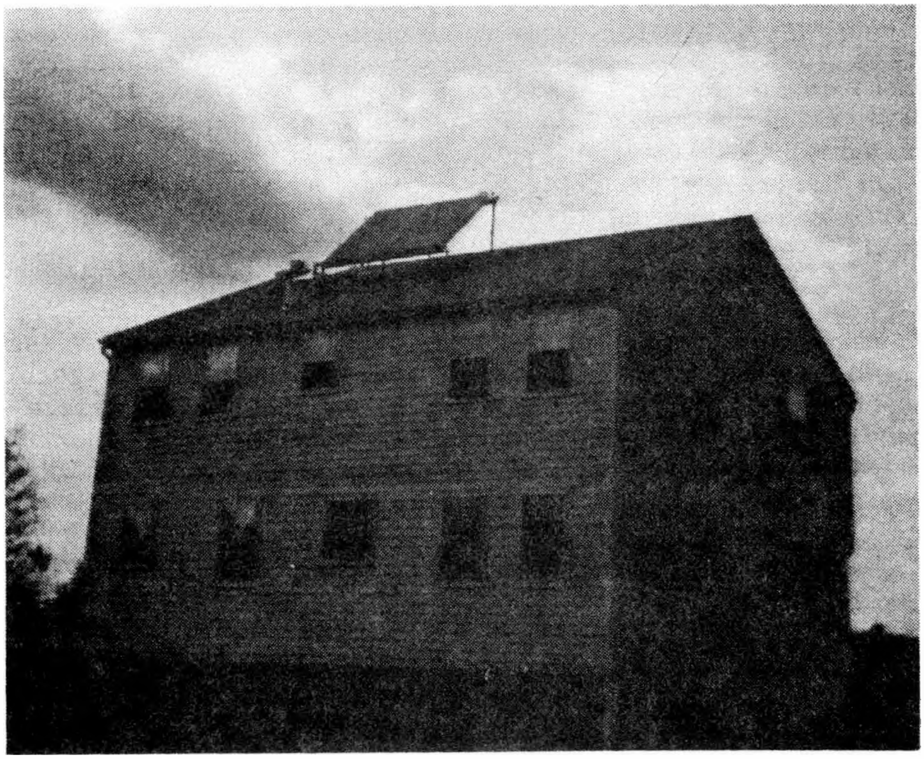
This report is one of a series which describes the performance of solar energy systems in the National Solar Data Network (NSDN) for the entire heating or cooling season. Domestic hot water is also included, if there is a solar contribution. Some NSDN installations are used solely for heating domestic 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.



SADDLE HILL TRUST LOT 73

SADDLE HILL TRUST LOT 73

The Saddle Hill Trust Lot 73 site is a single family residence in Medway, Massachusetts. The solar energy system is designed to supply the following:

Annual Design Factors from F-Chart
(Million BTU)

	Total Load	Solar Contribution	% Solar
Hot Water	18.70	10.16	54

It is equipped with:

Collector	45 square feet of Daystar model 2001
Storage	80-gallon preheat tank, model SWH/TC80 by Ford Products
Auxiliary	State model SV-40-NRT7 gas-fired, 40-gallon DHW tank

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION 1

SOLAR SYSTEM PERFORMANCE

SADDLE HILL TRUST LOT 73
JANUARY 1980 THROUGH DECEMBER 1980

Solar Fraction[1]	56%
Solar Savings Ratio[2]	49%
Conventional Fuel Savings[3]	12,419 cubic feet of gas
Solar System COP[4]	4.91

Seasonal Energy Requirements
January 1980 through December 1980
(Million BTU)

	Load	Solar Consumed	% Solar[1]
Hot Water*	12.47	7.61	56

*11 month totals.

Environmental Data

	Measured	Long-Term
Outdoor temperature (average)	49°F	51°F
Heating degree-days (total)	6,521	5,621
Cooling degree-days (total)	804	661
Daily incident solar energy (average)	1,332 BTU/ft^2	1,212 BTU/ft^2

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

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

3. Conventional Fuel Savings (Natural Gas) = Number of BTU's Saved x 979.43 x 10^{-6} Cubic Feet/BTU

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

1.1 SUMMARY AND CONCLUSIONS

The Saddle Hill Trust Lot 73 site is a single family residence in Medway, Massachusetts that uses solar energy to preheat domestic hot water (DHW). The solar energy system consists of an array of two, Daystar model 2001, flat-plate collectors having a total area of 45 square feet. The array faces south at a tilt of 45 degrees to the horizontal. A glycerol solution transfers heat from the collector array to a heat exchanger in an 80-gallon storage tank. Solar energy stored in this tank is used to preheat incoming city water which is then supplied to a conventional gas-fired (auxiliary energy) 40-gallon DHW tank.

The Saddle Hill Trust Lot 73 solar energy system supplied 56% of the DHW heating needs during the period from January 1980 through December 1980. There were 10.43 million BTU of energy collected by the system and 7.61 million BTU, or 73% of this energy, was used to help satisfy the DHW load. The collector array efficiency (based on the total solar radiation incident on the collector array) was 52%. The use of solar energy saved 12,419 cubic feet of natural gas.

The solar energy system functioned consistently throughout the reporting period, providing significant amounts of solar energy to the DHW subsystem. The measured system solar fraction of 56% was close to the 54% design solar fraction for the system. However, the net dollar savings for the year were low, as the cost of natural gas saved was low and the cost of the electrical energy used to operate the system was high, almost 25% of the cost of the fossil fuel saved.

The fossil energy savings were 12.68 million BTU which (at an estimated fuel cost of $0.30 per 100 cubic feet of natural gas) represented a savings of $37.25. The electrical energy required to run the collector pump was 0.60 million BTU. This is equivalent to an electrical expense of $8.78 (based on an electrical energy rate of $0.05 per kwh).

The system is well insulated, so most of the solar energy collected was delivered to the DHW load. As a result, the overall system performance was somewhat better than the f-Chart prediction. The collector array performed very well as 52% of the total insolation, and 57% of the insolation available while the collectors were operational was collected.

Though the system performed well, the monetary savings at the site were low. Solar energy is used to replace the natural gas auxiliary source, which, presently is very difficult to compete with on a cost basis, especially when relatively small loads (such as at residential single family DHW installations) are experienced. However, if the auxiliary source at the site were oil or electricity, the savings would be significantly better. Based on a nominal cost of $1.00 per gallon of oil, the savings would be $91.42 minus the $8.78 operating expense; and, if electricity were the auxiliary source, the savings would be $102.63 including the operating expense (based on $0.05 per kwh). Also, as the cost of natural gas rises, the cost effectiveness of DHW applications, such as at Saddle Hill Trust Lot 73, will improve.

During April, there was a data communications problem that prevented the collection of data for the month. In July, the pyranometer, which measures insolation, was not operational so the insolation values were estimated for that month.

The insolation for the year was higher than the long-term average, while the ambient temperature was lower than normal. During the months of January and February, the sky was clearer than normal; therefore, the solar system provided higher than expected solar fractions for those months.

1.2 OVERALL SYSTEM PERFORMANCE

The flow of solar energy through the Saddle Hill Trust Lot 73 site for the 12-month period from January 1980 through December 1980 is presented in Figure 1. This Energy Flow Diagram shows the amount of energy collected, transported, stored, consumed or lost at each major subsystem.

There were 20.13 million BTU of solar energy incident on the collector array, of which 10.43 million BTU were collected. Eighty-eight percent or 9.18 million BTU of the collected energy was delivered to the storage tank and 7.61 million BTU or 84% of the stored solar energy were delivered to the hot water tank. In addition, 6.73 million BTU of auxiliary thermal energy were added to the hot water tank to satisfy the hot water demand load of 12.47 million BTU.

The overall thermal performance of the solar energy system is presented in Table 1 and shown graphically in Figure 2. The system load is actually a measure of the hot water demand on the system and does not include standby losses from the DHW tank. The total energy consumed to satisfy the DHW load was 14.34 million BTU and includes the solar plus the auxiliary thermal energy used. A monthly breakdown of solar and auxiliary thermal energy consumption is shown in Figure 2.

The operating energy consumed by the system was that used for the collector pump. This operating energy is considered a system penalty and is plotted as a negative value in Figure 2 and listed as negative electrical savings in Table 1.

The solar fraction was calculated by considering the amount of solar energy present in the DHW tank on an hourly basis. The measured value, listed in Table 1, differs slightly from the solar percentage of the energy consumed, which would be 53%. The f-Chart prediction of the solar fraction, 44%, varies considerably from the measured value of 56% since the values for the months of July and August, which should have been high, were not available.

The solar energy coefficient of performance (COP) is indicated in Table 2. The COP simply provides a numerical value for the relationship of solar energy used or collected and the energy required for collection or delivery. The greater the COP value, the more efficient the subsystem. The solar energy system at Saddle Hill Trust Lot 73 functioned at a weighted average COP value of 12.60 for the period January through December.

The operating energy in the system is used for the collector pump, which delivers solar energy from the collectors to the preheat tank. City water pressure is used to move the supply water through the preheat tank to the DHW tank; so no pump is needed in the DHW loop. Therefore a DHW COP is not calculated.

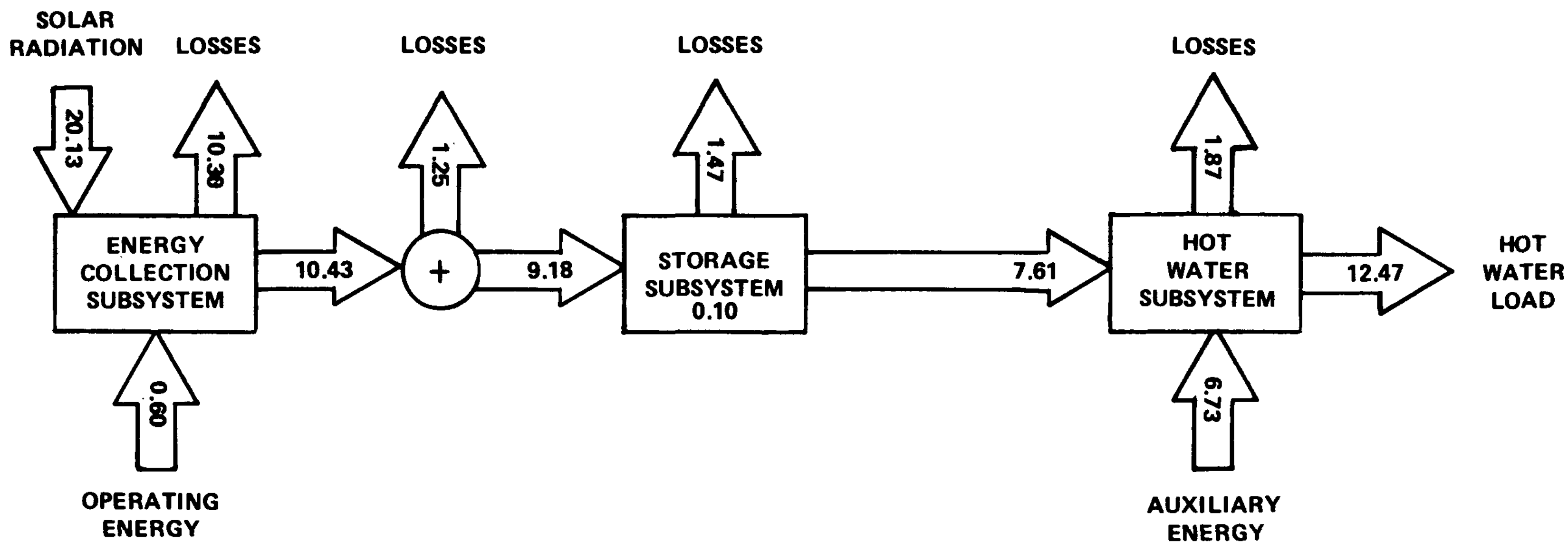


Figure 1. Energy Flow Diagram for Saddle Hill Trust Lot 73
January 1980 through December 1980
(Figures in million BTU)

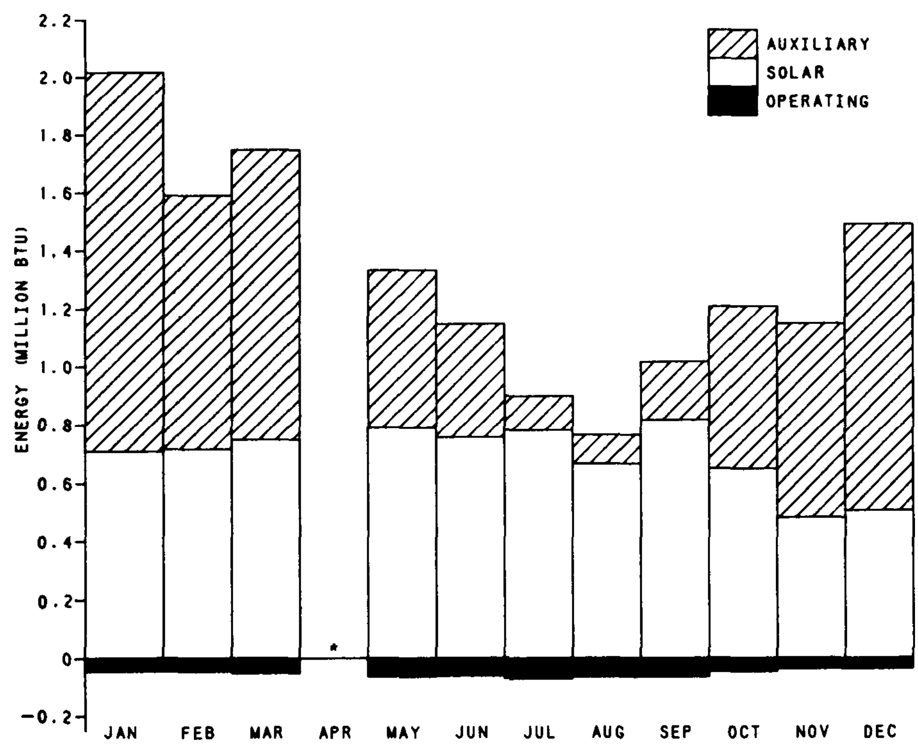
Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

SADDLE HILL TRUST LOT 73
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED	SYSTEM LOAD	SOLAR ENERGY USED		AUXILIARY ENERGY		OPERATING ENERGY	ENERGY SAVINGS		SOLAR FRACTION (%)	
			PREDICTED	MEASURED	FOSSIL	THERMAL		FOSSIL	ELECTRICAL	PREDICTED	MEASURED
JAN	0.92	1.75	*	0.71	2.18	1.31	0.047	1.18	-0.047	*	45
FEB	0.90	1.32	0.76	0.72	1.44	0.87	0.047	1.20	-0.047	47	52
MAR	0.95	1.50	0.80	0.75	1.66	1.00	0.055	1.25	-0.055	46	47
APR	*	*	*	*	*	*	*	*	*	*	*
MAY	1.03	1.20	0.70	0.79	0.90	0.54	0.066	1.32	-0.066	52	62
JUN	0.98	1.03	0.65	0.76	0.65	0.39	0.062	1.26	-0.062	57	65
JUL	1.10	0.75	*	0.78	0.21	0.12	0.070	1.30	-0.070	*	86
AUG	1.08	0.62	*	0.66	0.18	0.11	0.066	1.10	-0.066	*	88
SEP	1.16	0.99	*	0.82	0.34	0.20	0.066	1.36	-0.066	88	80
OCT	0.99	1.10	*	0.64	0.96	0.57	0.047	1.07	-0.047	42	50
NOV	0.68	0.92	*	0.47	1.06	0.64	0.039	0.79	-0.039	39	46
DEC	0.64	1.29	*	0.51	1.63	0.98	0.039	0.85	-0.039	33	38
TOTAL	10.43	12.47	*	7.61	11.21	6.73	0.604	12.68	-0.604	-	-
AVERAGE	0.95	1.13	*	0.69	1.02	0.61	0.055	1.15	-0.055	44	56

*Denotes unavailable data.



* DENOTES UNAVAILABLE DATA

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

Figure 2. System Thermal Performance
Saddle Hill Trust Lot 73
January 1980 through December 1980

Table 2. SOLAR COEFFICIENT OF PERFORMANCE

SADDLE HILL TRUST LOT 73
JANUARY 1980 THROUGH DECEMBER 1980

MONTH	SOLAR ENERGY SYSTEM	COLLECTOR ARRAY	DOMESTIC HOT WATER SOLAR
JAN	15.11	19.57	N.A.
FEB	15.32	19.15	N.A.
MAR	13.64	17.27	N.A.
APR	*	*	N.A.
MAY	11.97	15.61	N.A.
JUN	12.26	15.81	N.A.
JUL	11.14	15.71	N.A.
AUG	10.00	16.36	N.A.
SEP	12.42	17.58	N.A.
OCT	13.62	21.06	N.A.
NOV	12.05	17.44	N.A.
DEC	13.08	16.41	N.A.
WEIGHTED AVERAGE	12.60	17.27	N.A.

* Denotes unavailable data.
N.A. Denotes not applicable.

1.3 ENERGY SAVINGS

Energy savings for this site for the reporting period, January 1980 through December 1980, are presented in Table 3 and shown graphically in Figure 3. For this 12-month period, the total savings were 12.68 million BTU, for a monthly average of 1.15 million BTU. This is approximately 91 gallons of oil, or 12,419 cubic feet of natural gas, or 2,228 kwh of electricity. An electrical energy expense of 0.60 million BTU was incurred during the reporting period for the operation of solar energy components.

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.

Table 3. ENERGY SAVINGS

SADDLE HILL TRUST LOT 73
JANUARY 1980 THROUGH DECEMBER 1980

MONTH	SOLAR ENERGY USED	SOLAR ENERGY SAVINGS ATTRIBUTED TO DOMESTIC HOT WATER FOSSIL FUEL	ECSS OPERATING ENERGY	NET ENERGY SAVINGS ELECTRICAL	NET ENERGY SAVINGS FOSSIL
JAN	0.71	1.18	0.047	-0.047	1.18
FEB	0.72	1.20	0.047	-0.047	1.20
MAR	0.75	1.25	0.055	-0.055	1.25
APR	*	*	*	*	*
MAY	0.79	1.32	0.066	-0.066	1.32
JUN	0.76	1.26	0.062	-0.062	1.26
JUL	0.78	1.30	0.070	-0.070	1.30
AUG	0.66	1.10	0.066	-0.066	1.10
SEP	0.82	1.36	0.066	-0.066	1.36
OCT	0.64	1.07	0.047	-0.047	1.07
NOV	0.47	0.79	0.039	-0.039	0.79
DEC	0.51	0.85	0.039	-0.039	0.85
TOTAL	7.61	12.68	0.604	-0.604	12.68
AVERAGE	0.69	1.15	0.055	-0.055	1.15

*Denotes unavailable data.

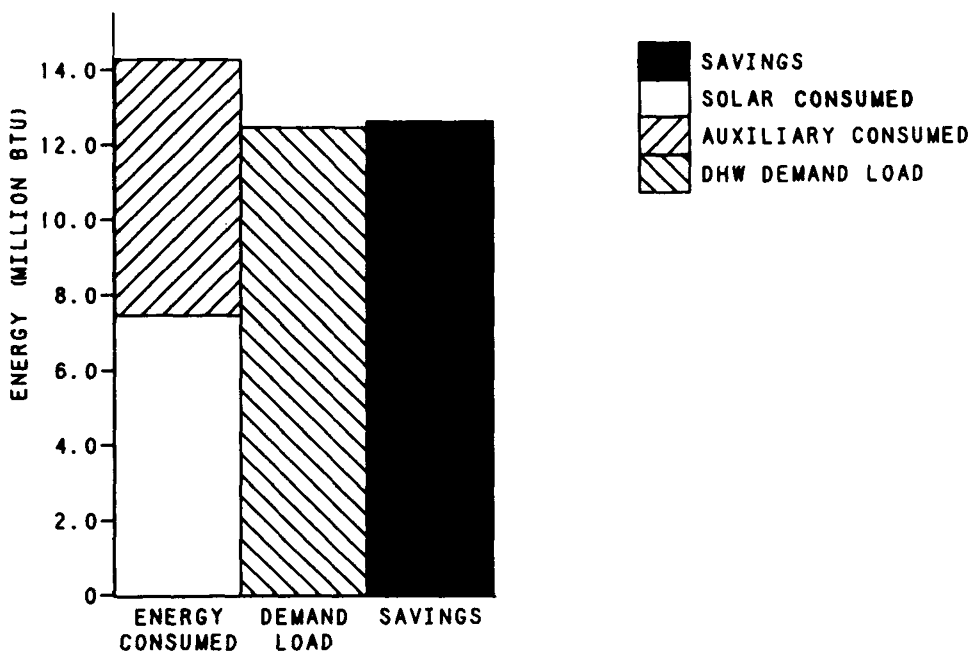


Figure 3. Combined Thermal Energy Savings Compared to Load
Saddle Hill Trust Lot 73
January 1980 through December 1980

The auxiliary source at Saddle Hill Trust Lot 73 consists of a conventional gas-fired DHW tank. This unit is considered to be 67% efficient for computational purposes. The equivalent electrical savings are computed by converting the solar energy used (7.61 million BTU) directly to kwh (i.e. 100% efficiency).

The fossil fuel savings represented a monetary savings of $37.25, which is based on an estimated fuel cost of $0.30 per therm (100 cubic feet) of natural gas. The cost of the electrical energy required to operate the collector pump was $8.78 (based on an electrical energy rate at the site of $0.05 per kwh). Therefore, the net dollar savings for the year were $28.47.

Presently, the relatively low cost of natural gas makes it difficult to compete with on a cost basis. However, if the auxiliary fuel source at the site were oil or electricity, the savings would have been much better. Based on nominal costs of $1.00 per gallon of oil or $0.05 per kwh, the savings would have been $82.64 for oil or $102.63 for an electrical auxiliary after the $8.78 operating expense.

1.4 SOLAR ENERGY UTILIZATION

Figure 4 shows the use of solar energy and the percentage of losses.

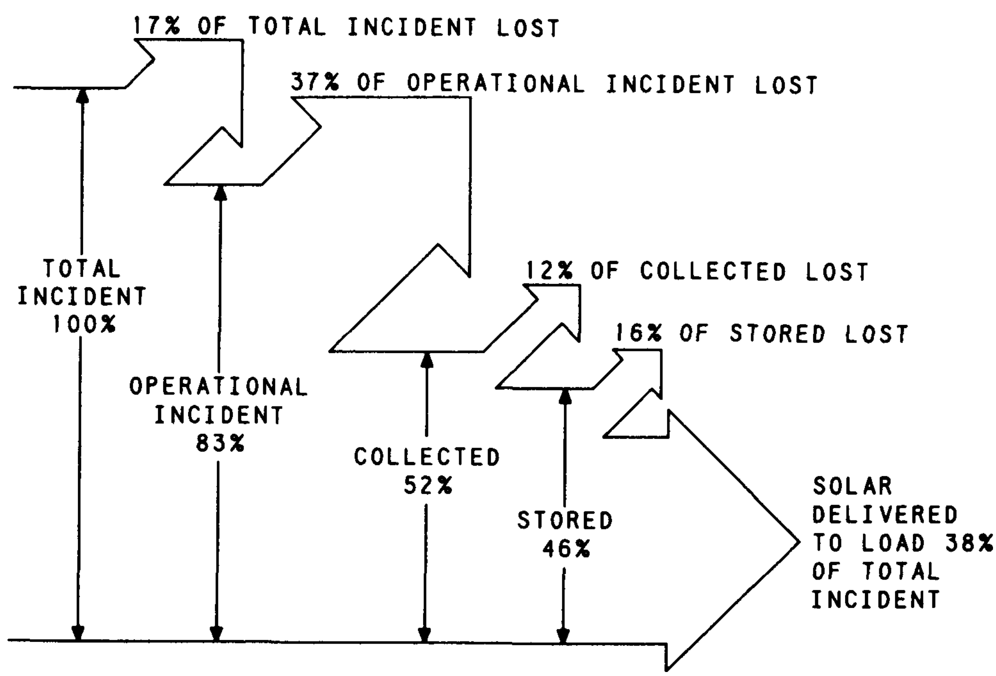


Figure 4. Solar Energy Use
Saddle Hill Trust Lot 73
January 1980 through December 1980

The total incident solar radiation for the year of January 1980 through December 1980 was 20.13 million BTU, of which 16.62 million BTU were incident while the collector loop was operating. Total solar energy collected was 10.43 million BTU for an overall collector array efficiency of 52%. Of the collected energy, the transport losses were 1.25 million BTU, while 9.18 million BTU were delivered to the storage tank. The solar energy delivered to the load was 7.61 million BTU or 38% of the total incident solar energy. The standby losses from the storage tank were 1.47 million BTU. (See Figure 4.)

The losses of solar energy at the different stages through the system, from collected energy to the load, are also presented in Table 4.

Table 4. SOLAR ENERGY LOSSES

SADDLE HILL TRUST LOT 73
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED	SOLAR TO STORAGE	LOSS COLLECTOR TO STORAGE (%)	CHANGE IN STORED ENERGY	SOLAR ENERGY FROM STORAGE TO DHW LOAD	STORAGE LOSS (%)
JAN	0.92	0.82	11	0.02	0.71	11
FEB	0.90	0.79	12	0.02	0.72	6
MAR	0.95	0.84	12	0.06	0.75	4
APR	*	*	*	*	*	*
MAY	1.03	0.90	13	0.03	0.79	9
JUN	0.98	0.85	13	0.01	0.76	9
JUL	1.10	0.96	13	0.02	0.78	17
AUG	1.08	0.96	11	-0.01	0.66	32
SEP	1.16	1.03	11	-0.02	0.82	22
OCT	0.99	0.88	11	0.00	0.64	27
NOV	0.68	0.59	13	-0.01	0.47	22
DEC	0.64	0.56	12	-0.02	0.51	13
TOTAL	10.43	9.18	-	0.10	7.61	-
AVERAGE	0.95	0.83	12	0.01	0.69	16

*Denotes unavailable data.

From month to month, the collector to storage loss did not deviate more than one percent from 12% average for the year. The loss from storage generally increased as the average storage temperature increased. (See Storage Performance Section.)

SECTION 2

SUBSYSTEM PERFORMANCE

2.1 COLLECTOR

The Saddle Hill Trust Lot 73 collector array is composed of two, Daystar model 2001, flat-plate collectors which use a glycerol solution as the heat transfer fluid.

The collector subsystem performance for the site is presented in Table 5.

Table 5. COLLECTOR SUBSYSTEM PERFORMANCE

SADDLE HILL TRUST LOT 73
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU, unless otherwise indicated)

MONTH	INCIDENT SOLAR RADIATION	COLLECTED SOLAR ENERGY	COLLECTOR EFFICIENCY (%)	OPERATIONAL INCIDENT ENERGY	OPERATIONAL COLLECTOR EFFICIENCY (%)	ECSS OPERATING ENERGY	SOLAR ENERGY TO STORAGE	DAYTIME AMBIENT TEMPERATURE (°F)
JAN	1.68	0.92	55	1.51	61	0.047	0.82	*
FEB	1.91	0.90	47	1.74	52	0.047	0.79	39
MAR	2.02	0.95	47	1.86	51	0.055	0.84	40
APR	*	*	*	*	*	*	*	*
MAY	1.96	1.03	53	1.81	57	0.066	0.90	70
JUN	1.86	0.98	53	1.71	57	0.062	0.85	79
JUL	2.07E	1.10	53	*	*	0.070	0.96	88
AUG	1.71	1.08	55	1.61	67	0.066	0.96	87
SEP	2.25	1.16	52	2.14	54	0.066	1.03	78
OCT	1.76	0.99	56	1.64	60	0.047	0.88	60
NOV	1.46	0.68	46	1.31	52	0.039	0.59	49
DEC	1.45	0.64	45	1.29	50	0.039	0.56	*
TOTAL	20.13	10.43	-	16.62	-	0.604	9.18	-
AVERAGE	1.83	0.95	52	1.66	57	0.055	0.83	65

E Denotes estimated value.
* Denotes unavailable data.

During the period from January 1980 through December 1980, there was a total of 20.13 million BTU of solar energy on the collector array. Of this total, 16.62 million BTU of energy were incident while the collectors were operating. The amount of solar energy collected was 10.43 million BTU which represented a collector array efficiency of 52% based on a total insolation and 57% based on the operational incident solar energy. Of the collected solar energy, 9.18 million BTU were delivered to the storage tank. Therefore, 1.25 million BTU, or 12% of the collected energy, were lost in transport to storage from the collector lines. There were 0.60 million BTU of electrical energy expended to operate the collector pump.

The measured collector performance compares very well with the manufacturer's data. The 52% collector efficiency (based on total insolation) is considered very good compared to other liquid flat-plate collectors evaluated in the NSDN. The special "heat trap" feature of the Daystar-20 collector appears to effectively boost the performance of the collector. The "heat trap" is a thin layer of a high-temperature polymer, which is folded in an accordian shape and placed between the cover plate and the absorber plate. This configuration seems to successfully reduce thermal losses from the collector and increase efficiency.

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 Subsystem Efficiency" in Table 5.

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 5. 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 5.

2.2 STORAGE

The storage/preheat tank contains 80 gallons of water and is covered with insulation of R-value 6 hr-°F-ft^2/BTU. The surface area of the tank is approximately 42 square feet. City water, supplied to this tank is preheated by solar energy and then delivered to the DHW heater.

Storage performance data for the site for the reporting period are shown in Table 6.

Table 6. STORAGE PERFORMANCE

SADDLE HILL TRUST LOT 73
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU, unless otherwise indicated)

MONTH	ENERGY TO STORAGE	ENERGY FROM STORAGE	CHANGE IN STORED ENERGY	STORAGE EFFICIENCY (%)	AVERAGE STORAGE TEMP. (°F)	LOSS FROM STORAGE
JAN	0.82	0.71	0.02	89	68	0.09
FEB	0.79	0.72	0.02	94	79	0.05
MAR	0.84	0.75	0.06	96	76	0.03
APR	*	*	*	*	*	*
MAY	0.90	0.79	0.03	91	92	0.08
JUN	0.85	0.76	0.01	91	102	0.08
JUL	0.96	0.78	0.02	83	111	0.16
AUG	0.96	0.66	-0.01	68	111	0.31
SEP	1.03	0.82	-0.02	78	108	0.23
OCT	0.88	0.64	0.00	73	93	0.24
NOV	0.59	0.47	-0.01	78	85	0.13
DEC	0.56	0.51	-0.02	87	77	0.07
TOTAL	9.18	7.61	0.10	-	-	1.47
AVERAGE	0.83	0.69	0.01	84	91	0.13

*Denotes unavailable data.

During the reporting period, total solar energy delivered to storage was 9.18 million. There were 7.61 million BTU delivered from storage to the DHW subsystem. Energy loss from storage was 1.47 million BTU. This loss represented 16% of the energy delivered to storage, resulting in a storage efficiency of 84%. (See Footnote 1.)

2.3 DOMESTIC HOT WATER (DHW)

The DHW subsystem performance for the Saddle Hill Trust Lot 73 site for the reporting period is shown in Table 7 and is illustrated graphically in Figure 5.

The DHW subsystem required 7.61 million BTU of solar energy and 6.73 million BTU of auxiliary thermal energy to satisfy a hot water load of 12.47 million BTU. The solar fraction of this load was 56%. Losses from the DHW subsystem were 1.87 million BTU. A daily average of 62 gallons of DHW was consumed at an average temperature of 129°F.

The auxiliary thermal energy was provided by a natural gas burner in the DHW tank. This burner was assumed to be 67% efficient. The energy content of the natural gas used was therefore 11.21 million BTU.

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1. 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:

$$c = (STEI-STEO-STECH)/ \quad (T_s - T_a) \times t \quad \frac{BTU}{Hr\ {}^\circ F}$$

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 hours in the month

Table 7. DOMESTIC HOT WATER SUBSYSTEM PERFORMANCE

SADDLE HILL TRUST LOT 73
JANUARY 1980 THROUGH DECEMBER 1980

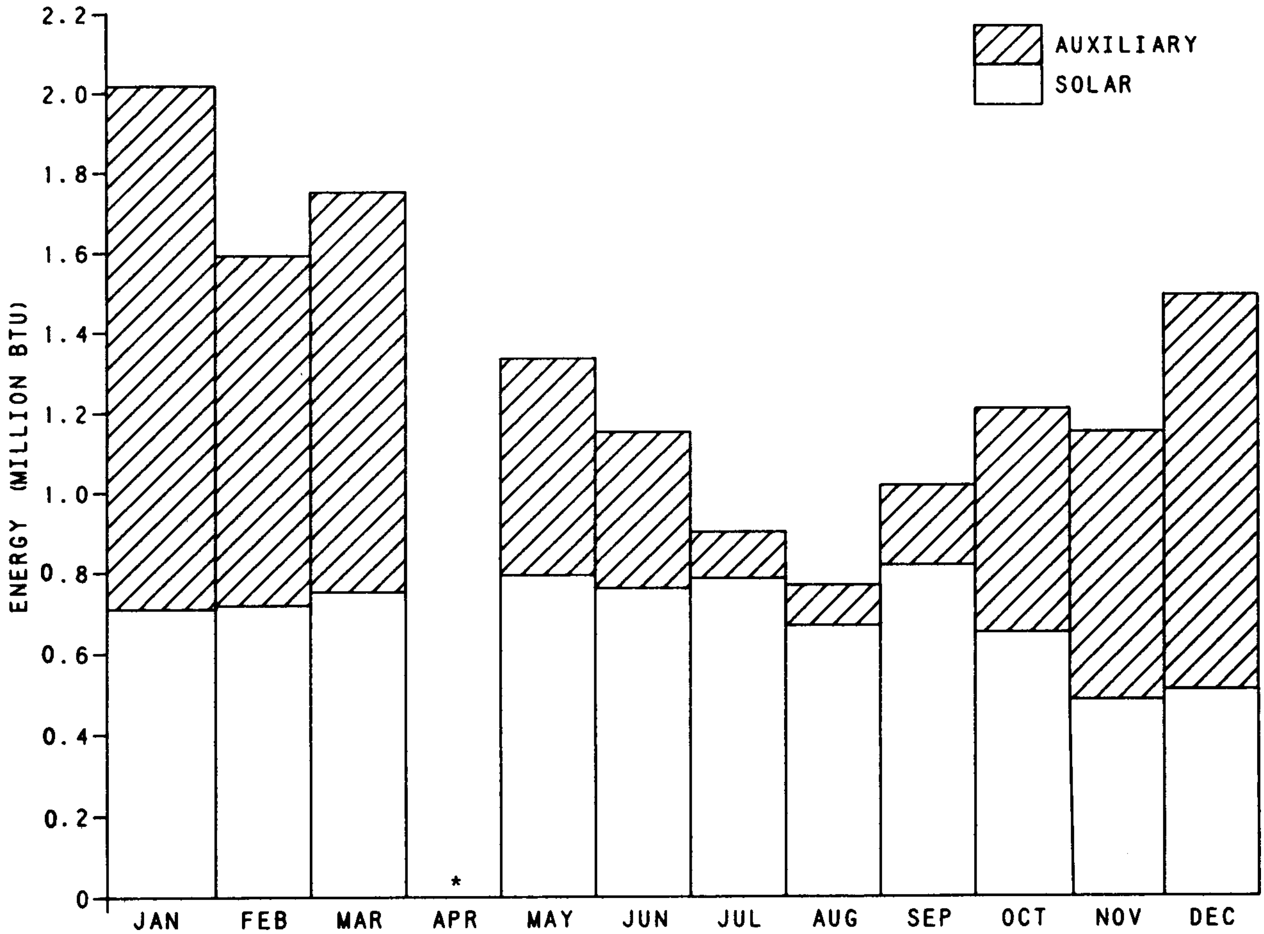
(All values in million BTU, unless otherwise indicated)

MONTH	DHW LOAD	ENERGY CONSUMED SOLAR	ENERGY CONSUMED AUXILIARY THERMAL	SOLAR FRACTION (%)	HOT WATER CONSUMPTION (GAL/DAY)	HOT WATER DELIVERY TEMPERATURE (°F)
JAN	1.75	0.71	1.31	45	79	134
FEB	1.32	0.72	0.87	52	63	130
MAR	1.50	0.75	1.00	47	63	135
APR	*	*	*	*	*	*
MAY	1.20	0.79	0.54	62	64	129
JUN	1.03	0.76	0.39	65	66	124
JUL	0.75	0.78	0.12	86	56	119
AUG	0.62	0.66	0.11	88	49	122
SEP	0.99	0.82	0.20	80	64	129
OCT	1.10	0.64	0.57	50	66	129
NOV	0.92	0.47	0.64	55	49	131
DEC	1.29	0.51	0.98	38	60	132
TOTAL	12.47	7.61	6.73	-	679	-
AVERAGE	1.13	0.69	0.61	56W	62	129

W Denotes weighted average.
* Denotes unavailable data.

The DHW "load" is a measure of the hot water demand on the system. This value represents the energy added, by the solar and auxiliary energy sources, to the water drawn from the DHW tank. This value does not include standby losses from the DHW tank. The total energy required to maintain the water in the tank at the desired delivery temperature is the solar energy consumed plus the auxiliary thermal energy added to the tank and is somewhat larger than the load.

The hot water solar fraction was calculated on an hourly basis by considering the relative amounts of solar and auxiliary energy in the hot water tank. (See equations in Appendix D.) Calculating the solar fraction in this manner may yield slightly different results than taking the solar fraction of the inputs to the DHW tank.



* DENOTES UNAVAILABLE DATA

Figure 5. DHW Subsystem Performance
Saddle Hill Trust Lot 73
January 1980 through December 1980

SECTION 3

OPERATING ENERGY

Measured monthly values of the Saddle Hill Trust Lot 73 solar energy system operating energy for the report period are presented in Table 8. A total 0.66 million BTU of operating energy was consumed by the energy collection and storage subsystem (ECSS) during the reporting period. There is no operating energy required by the DHW subsystem since city water pressure is used to pump the supply water through the storage tank to the DHW tank.

Table 8. OPERATING ENERGY

SADDLE HILL TRUST LOT 73
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU)

MONTH	ECSS OPERATING ENERGY (SOLAR UNIQUE)
JAN	0.047
FEB	0.047
MAR	0.055
APR	*
MAY	0.066
JUN	0.062
JUL	0.070
AUG	0.066
SEP	0.066
OCT	0.047
NOV	0.039
DEC	0.039
TOTAL	0.604
AVERAGE	0.055

*Denotes unavailable data.

For solar systems where there is a relatively small load (such as with the residential, DHW-only system at this site), the operating energy can impose a substantial penalty on energy savings. At Saddle Hill Trust Lot 73, the only use of operating energy is for the collector pump and is equivalent to about eight percent of the solar energy used. The solar savings ratio of 49% indicates that the operating energy has imposed a penalty of about seven percent on the system solar fraction. When considering monetary savings, the penalty is somewhat higher since the relative cost of electrical energy is much higher than that of the natural gas fuel source that solar is being used to replace. The cost of the electrical operating energy is almost 25% of the cost of the natural gas saved, based on rates of $0.30 per therm of natural gas and $0.05 per kwh of electricity. If the auxiliary source at the site were oil or electricity, the monetary penalty of the operating energy would be much less significant. (See Energy Savings.)

SECTION 4

WEATHER CONDITIONS

Saddle Hill Trust Lot 73 is located in Medway, Massachusetts at 42 degrees N latitude and 71 degrees W longitude.

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 9. 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.

Table 9. WEATHER CONDITIONS

SADDLE HILL TRUST LOT 73
JANUARY 1980 THROUGH DECEMBER 1980

	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT^2-DAY)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS		COOLING DEGREE-DAYS	
MONTH	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE
JAN	1,201	828	26	29	1,209	1,110	0	0
FEB	1,465	1,051	26	30	1,131	969	0	0
MAR	1,449	1,237	36	38	899	834	0	0
APR	*	1,334	49	49	492	492	0	0
MAY	1,402	1,433	59	59	191	218	14	20
JUN	1,377	1,513	67	68	67	27	112	117
JUL	1,482E	1,497	75	73	2	0	310	260
AUG	1,223	1,414	75	71	14	8	251	203
SEP	1,666	1,441	64	65	124	76	117	61
OCT	1,264	1,264	49	55	496	301	0	0
NOV	1,080	818	39	45	780	594	0	0
DEC	1,038	724	29	33	1,116	992	0	0
TOTAL	-	-	-	-	6,521	5,621	804	661
AVERAGE	1,332	1,212	49	51	543	468	67	55

E Denotes estimated value.
* Denotes unavailable data.

During the period from January 1980 through December 1980, the average daily total incident solar radiation on the collector array was 1,332 BTU per square foot per day. This radiation was above the estimated average daily solar radiation for this geographical area during the reporting period of 1,212 BTU per square foot per day for a south-facing plane with a tilt of 45 degrees to the horizontal. During the period, the highest monthly average insolation was 1,666 BTU per square foot per day during September. The average ambient temperature during the reporting period was 49°F as compared with the long-term average of 52°F. The highest monthly average ambient temperature was 75°F during July, and the lowest monthly average ambient temperature was 26°F during January and February. The number of heating degree-days for the period (based on a 65°F reference) was 6,521 as compared with the long-term average of 5,621. The range of heating degree-days was from a high of 1,209 during January to a low of two during July.

Extraterrestrial radiation values are computed (see Footnote 1) and given in the table below for each month. 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 46% during February to a low of 38% during November.

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EXTRA-TERRESTRIAL INSOLATION	2,936	3,188	3,330	3,207	3,191	3,103	*	3,098	3,277	3,227	2,832	2,830
TTL INS / EXT INS (%)	41	46	44	*	44	44	*	39	51	39	38	37

* Denotes unavailable data.

For a more complete set of meteorological data see Appendix F, which contains daily average values for the months of the reporting period.

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

SECTION 5

REFERENCES

*1. National Solar Data Network, Department of Energy, prepared under Contract Number DE-AC01-79CS30027, Vitro Laboratories, Silver Spring, Maryland, January 1980.

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.

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 Lot 73, February 1980, SOLAR/1039-80/02, Vitro Laboratories, Silver Spring, Maryland.

*8. Monthly Performance Report, Saddle Hill Trust Lot 73, March 1980, SOLAR/1039-80/03, Vitro Laboratories, Silver Spring, Maryland.

*9. Monthly Performance Report, Saddle Hill Trust Lot 73, May 1980, SOLAR/1039-80/05, Vitro Laboratories, Silver Spring, Maryland.

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* 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.

*10. Monthly Performance Report, Saddle Hill Trust Lot 73, June 1980, SOLAR/1039-80/06, Vitro Laboratories, Silver Spring, Maryland.

*11. Monthly Performance Report, Saddle Hill Trust Lot 73, July 1980, SOLAR/1039-80/07, Vitro Laboratories, Silver Spring, Maryland.

*12. Monthly Performance Report, Saddle Hill Trust Lot 73, August 1980, SOLAR/1039-80/08, Vitro Laboratories, Silver Spring, Maryland.

*13. Monthly Performance Report, Saddle Hill Trust Lot 73, September 1980, SOLAR/1039-80/09, Vitro Laboratories, Silver Spring, Maryland.

*14. Monthly Performance Report, Saddle Hill Trust Lot 73, October 1980, SOLAR/1039-80/10, Vitro Laboratories, Silver Spring, Maryland.

*15. Monthly Performance Report, Saddle Hill Trust Lot 73, November 1980, SOLAR/1039-80/11, Vitro Laboratories, Silver Spring, Maryland.

*16. Monthly Performance Report, Saddle Hill Trust Lot 73, December 1980, SOLAR/1039-80/12, Vitro Laboratories, Silver Spring, Maryland.

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

APPENDIX A

SYSTEM DESCRIPTION

Saddle Hill Trust Lot 73 is a single family residence in Medway, Massachusetts. Solar energy is used for preheating incoming city water. The system has an array of two liquid flat-plate, Daystar model 2001 collectors, with a gross area of 45 square feet which faces south at an angle of 45 degrees to the horizontal. A 60% glycerol solution is used as the medium for delivering solar energy from the collector array to storage. Water is the transport medium that delivers solar energy to storage and to the domestic hot water (DHW) heater. Solar energy is stored in the basement in an 80-gallon preheated tank, model SWH/TC80 manufactured by Ford products. This preheated city water is supplied, on demand, to a conventional 40-gallon natural gas, DHW tank, model SV-40-NRT7 manufactured by State. When solar energy is insufficient to satisfy the hot water requirements, the gas-driven DHW heater provides auxiliary energy for water heating. The system, shown schematically, has two modes of solar operation.

Mode 1 - Collector-to-Storage - This mode activates the solar pump when a 40°F temperature difference exists between the collector and the preheated tank. This mode continues operating until the temperature difference drops to 20°F.

Mode 2 - Storage-to-DHW Tank - This mode activates when there is a demand for hot water. Hot water from the top of the preheated tank is transferred to the DHW tank to replace the amount removed. Simultaneously, city water is automatically supplied to the preheated tank.

SUBSYSTEMS

Collector - The gross collector array area (2 feet x 22.5 feet) is 45 square feet. The collectors face south and are tilted to an angle of 45 degrees from the horizontal. Orientation of the collectors is close to the optimum orientation for a system of this type, located at 42 degrees North latitude. Optimum collector orientation at this site is estimated to be south-facing at a tilt of 42 degrees.

The collector panels have one glass cover and a nonselective absorber surface. The absorber surface has a solar absorptivity of 0.97 and an infrared emissivity of 0.97. Between the glass cover and the absorber plate, there is a special "heat trap" which is a thin layer of a high-temperature polymer which is folded in an accordian shape. Total solar transmissivity of the glazing is 0.83. The absorber surface is composed of a black painted copper plate. The fluid circulated through the collectors is a glycerol solution.

Storage - Solar energy is stored in an 80-gallon water storage tank, model SHW/TC80, manufactured by Ford Products. The metal tank located in the basement of the house has been covered with R-6 insulation. Incoming city water is preheated in this tank and then supplied, on demand, to the DHW tank.

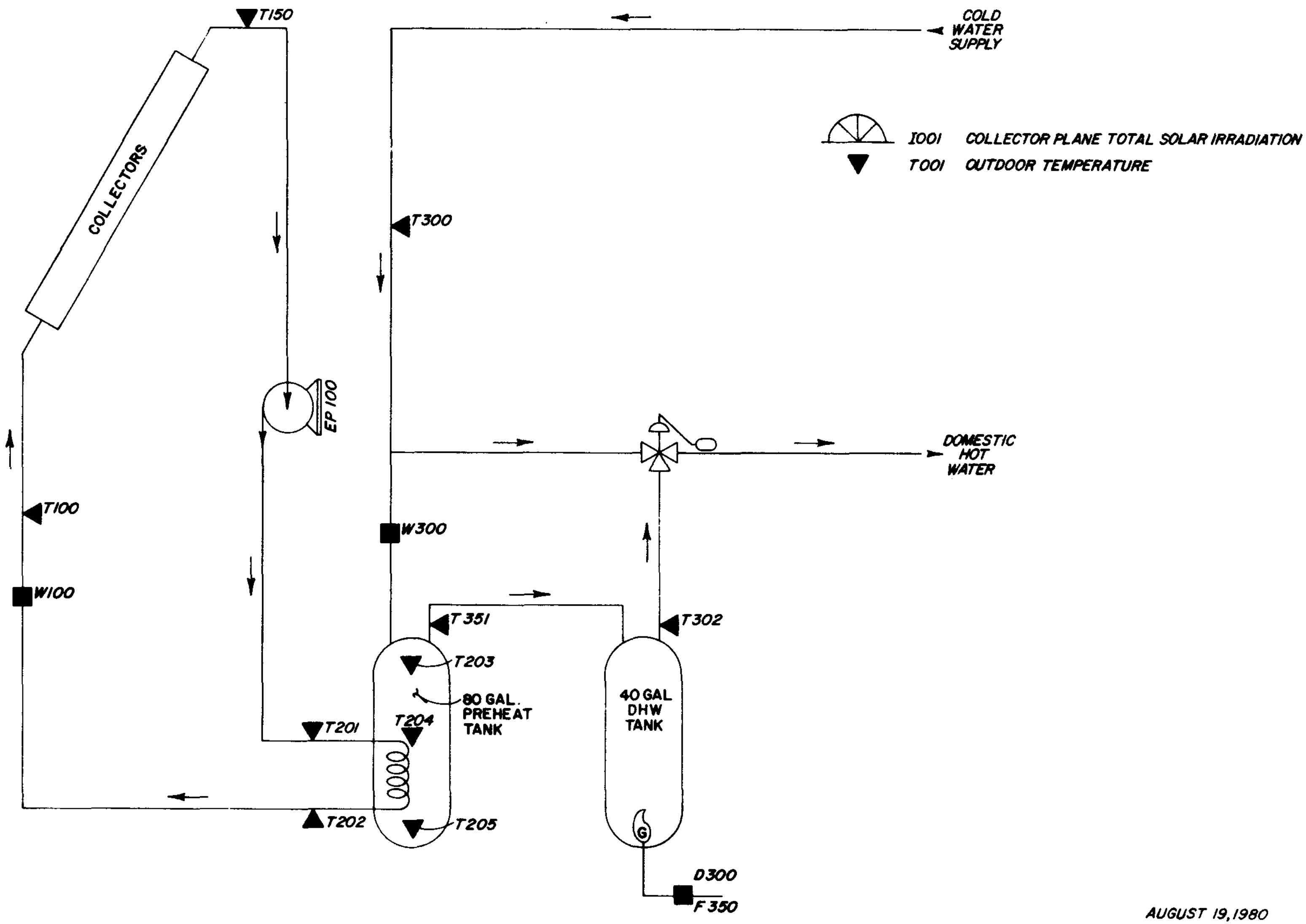

Figure A-1. Saddle Hill Trust Lot 73 Solar Energy System Schematic

Hot Water - The hot water tank is a conventional 40-gallon DHW tank, model SV-40-NRT7, manufactured by State. When solar energy is not sufficient to satisfy the hot water requirements, the automatic natural gas burner in the tank supplies auxiliary heat.

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

The performance of the Saddle Hill Trust Lot 73 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 for the National Solar Heating and Cooling Demonstration Program" (NBSIR-76/1137).

An overview of the NSDN data collection and dissemination process is shown in Figure B-1.

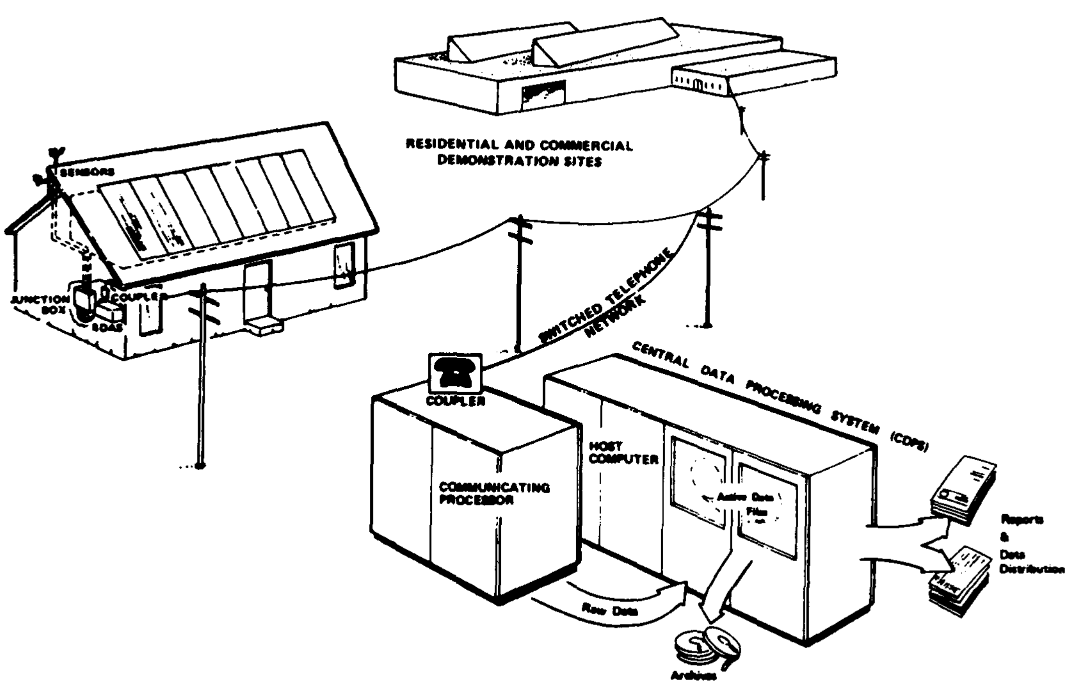

Figure B-1. The National Solar Data Network

DATA COLLECTION AND PROCESSING

Each site contains standard industrial instrumentation modified for the particular site. Sensors measure temperatures, flows, insolation, electric power, fossil fuel usage, and other parameters. These sensors are all wired into a junction box (J-box), which is in turn connected to a micro-processor 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 0-1023. These counts are then processed by software in the CDPS, where they are converted from counts to engineering units (EU) by applying 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.

Solar system performance reports present system parameters as monthly values. If some of the data during the month is not collected due to solar system, instrumentation system, or data acquisition problems, or if some of the collected data is invalid, then the collected valid data is extrapolated to provide the monthly performance estimates. Researchers and other users who require unextrapolated, "raw" data may obtain such by contacting Vitro Laboratories.

DATA ANALYSIS

The analyst develops a unique set of "site equations" (given in Appendix D) 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 (Appendix C) 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.

Performance factors which are considered to be of primary importance are those which are essential for system evaluation. Without these primary performance factors (which are denoted by an asterisk in Appendix C), comparative evaluation of the wide variety of solar energy systems would be impossible. An example of a primary performance factor is SECA - Solar Energy Collected by the Array. This is quite obviously a key parameter in system analysis.

Secondary performance factors are data deemed important and useful in comparison and evaluation of solar systems, particularly with respect to component interactions and simulation. In most cases these secondary performance factors are computed as functions of primary performance factors.

There are irregularly occurring cases of missing data as is normal for any real time data collection from mechanical equipment. When data for individual scans or whole hours are missing, values of performance factors are assigned which are interpolated from measured data. If no valid measured data are available for interpolation, a zero value is assigned. If data are missing for a whole day, each hour is interpolated separately. Data are interpolated in order to provide solar system performance factors on a whole hour, whole day and whole month basis for use by architects and designers.

REPORTING

The performance of the Saddle Hill Trust Lot 73 solar energy system from January 1980 through December 1980 was analyzed during the year, and Monthly Performance Reports were published for the months when sufficient valid data were available. See the following page for a list of these reports.

In addition, data are included in this report which are not in Monthly Performance Reports.

OTHER DATA REPORTS ON THIS SITE*

Monthly Performance Reports:

January 1979, SOLAR/1039-79/01
February 1979, SOLAR/1039-79/02
March 1979, SOLAR/1039-79/03
April 1979, SOLAR/1039-79/04
May 1979, SOLAR/1039-79/05
June 1979, SOLAR/1039-79/06
July 1979, SOLAR/1039-79/07
February 1980, SOLAR/1039-80/02
March 1980, SOLAR/1039-80/03
May 1980, SOLAR/1039-80/05
June 1980, SOLAR/1039-80/06
July 1980, SOLAR/1039-80/07
August 1980, SOLAR/1039-80/08
September 1980, SOLAR/1039-80/09
October 1980, SOLAR/1039-80/10
November 1980, SOLAR/1039-80/11
December 1980, SOLAR/1039-80/12

* These reports can be obtained (free) by contacting: U.S. Department Energy, Technical Information Center, P.O. Box 62, Oak Ridge, TN 37830.

APPENDIX C

PERFORMANCE FACTORS AND SOLAR TERMS

The performance factors identified in the site equations (Appendix D) by the use of acronyms or symbols are defined in this Appendix in Section 1. Appendix C includes the symbol, the actual name of the performance factor, and a short definition.

Section 2 contains a glossary of solar terminology, in alphabetical order. These terms are included for quick reference by the reader.

Section 3 describes abbreviations used in this report.

SECTION 1. PERFORMANCE FACTOR DEFINITIONS

SYMBOL	NAME	DEFINITION
AXE	Auxiliary Electric Fuel Energy to Load Subsystem	Amount of electrical energy required as a fuel source for all load subsystems.
AXF	Auxiliary Fossil Fuel Energy to Load Subsystem	Amount of fossil energy required as a fuel source for all load subsystems.
* 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.
CAE	SCS Auxiliary Electrical Fuel Energy	Amount of electrical energy provided to the SCS to be converted and applied to the SCS load.
CAF	SCS Auxiliary Fossil Fuel Energy	Amount of fossil energy provided to the SCS to be converted and applied to the SCS load.
CAREF	Collector Array Efficiency	Ratio of the collected solar energy to the incident solar energy.
CAT	SCS Auxiliary Thermal Energy	Amount of energy provided to the SCS by a BTU heat transfer fluid from an auxiliary source.
* CL	Space Cooling Subsystem Load	Energy required to satisfy the temperature control demands of the space cooling subsystem.
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.
CSAUX	Auxiliary Energy to ECSS	Amount of auxiliary energy supplied to the ECSS.
* 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.
CSE	Solar Energy to SCS	Amount of solar energy delivered to the SCS.

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* Primary Performance Factors

SYMBOL	NAME	DEFINITION
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).
* CSFR	SCS Solar Fraction	Portion of the SCS load which is supported by solar energy.
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).
CSRJE	ECSS Rejected Energy	Amount of energy intentionally rejected or dumped from the ECSS subsystem.
* 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.
* CSVF	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.
HAE	SHS Auxiliary Electrical Fuel Energy	Amount of electrical energy provided to the SHS to be converted and applied to the SHS load.
HAF	SHS Auxiliary Fossil Fuel Energy	Amount of fossil energy provided to the SHS to be converted and applied to the SHS load.
HAT	SHS Auxiliary Thermal Energy	Amount of energy provided to the SHS by a heat transfer fluid from an auxiliary source.
* HL	Space Heating Subsystem Load	Energy required to satisfy the temperature control demands of the space heating subsystem.

* Primary Performance Factors

SYMBOL	NAME	DEFINITION
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).
HOURCT	Record Time	Count of hours elapsed from the start of 1977.
* HSFR	SHS Solar Fraction	Portion of the SHS load which is supported by solar energy.
HSE	Solar Energy to SHS	Amount of solar energy delivered to the SHS.
* 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.
* 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.
HWAE	HWS Auxiliary Electrical Fuel Energy	Amount of electrical energy provided to the HWS to be converted and applied to the HWS load.
HWAF	HWS Auxiliary Fossil Fuel Energy	Amount of fossil energy provided to the HWS to be converted and applied to the HWS load.
HWAT	HWS Auxiliary Thermal Energy	Amount of energy provided to the HWS by a heat transfer fluid from an auxiliary source.
HWCSM	Service Hot Water Consumption	Amount of heated water delivered to the load from the hot water subsystem.
* HWL	Hot Water Subsystem Load	Energy required to satisfy the temperature control demands of the building service hot water system.

* Primary Performance Factors

SYMBOL	NAME	DEFINITION
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.
HWSE	Solar Energy to HWS	Amount of solar energy delivered to the HWS.
* HWSFR	HWS Solar Fraction	Portion of the HWS load which is supported by solar energy.
* 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.
* HWSVF	HWS Fossil Energy Savings	Difference in the fossil energy required to support an assumed similar conventional HWS and the actual fossil energy required to support the demonstration HWS, for identical loads.
RELH	Relative Humidity	Average outdoor relative humidity at the site.
* SE	Incident Solar Energy	Amount of solar energy incident upon one square foot of the collector plane.
SEA	Incident Solar Energy on Array	Amount of solar energy incident upon the collector array.
* SEC	Collector Solar Energy	Amount of thermal energy added to the heat transfer fluid for each square foot of the collector area.
SECA	Collected Solar Energy by Array	Amount of thermal energy added to the heat transfer fluid by the collector array.
SEDF	Diffuse Insolation	Amount of diffuse solar energy incident upon one square foot of a collector plane.
SEOP	Operational Incident Solar Energy	Amount of incident solar energy upon the collector array whenever the collector loop is active.

* Primary Performance Factors

SYMBOL	NAME	DEFINITION
* SEL	Solar Energy to Load Subsystems	Amount of solar energy supplied by the ECSS to all load subsystems.
* SFR	Solar Fraction of System Load	Portion of the system load which was supported by solar energy.
STECH	Change in ECSS Stored Energy	Change in ECSS stored energy during reference time period.
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.
STEI	Energy Delivered to ECSS Storage	Amount of energy delivered to ECSS storage by the collector array and from auxiliary sources.
STEO	Energy Supplied by ECSS Storage	Amount of energy supplied by ECSS storage to the load subsystems.
* SYSL	System Load	Energy required to satisfy all desired temperature control demands at the output of all subsystems.
* 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.
* SYSPF	System Performance Factor	Ratio of the system load to the total equivalent fossil energy expended or required to support the system load.
* TA	Ambient Temperature	Average temperature of the ambient air.
* TB	Building Temperature	Average temperature of the controlled space of the building.
TCECOP	TCE Coefficient of Performance	Coefficient of performance of the thermodynamic conversion equipment.
TCEI	TCE Thermal Input Energy	Equivalent thermal energy which is supplied as a fuel source to thermodynamic conversion equipment.

* Primary Performance Factors

SYMBOL	NAME	DEFINITION
TCEL	Thermodynamic Conversion Equipment Load	Controlled energy output of thermodynamic conversion equipment.
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.
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.
TDA	Daytime Average Ambient Temperature	Average temperature of the ambient air during the daytime (during normal collector operation period).
* 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.
THW	Service Hot Water Temperature	Average temperature of the service hot water supplied by the system.
TST	ECSS Storage Temperature	Average temperature of the ECSS storage medium.
* 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.
* 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 of all subsystems.
TSW	Supply Water Temperature	Average temperature of the supply water to the hot water subsystem.

* Primary Performance Factors

SYMBOL	NAME	DEFINITION
WDIR	Wind Direction	Average wind direction at the site.
WIND	Wind Velocity	Average wind velocity at the site.

* Primary Performance Factors

SECTION 2. 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.

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

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:

$$\frac{Ti-Ta}{I} \quad \frac{°F \times hr. \times sq.\ ft.}{BTU}$$

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 3. 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 2.932×10^{-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 3,413 BTU of heat energy.
NSDN	National Solar Data Network.
SCS	Space Cooling Subsystem.
SHS	Space Heating Subsystem.
SOLMET	Solar Radiation/Meteorology Data.

APPENDIX D

PERFORMANCE EQUATIONS

SADDLE HILL TRUST LOT 73

INTRODUCTION

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.* This data is then mathematically combined to determine the hourly, daily, and monthly performance of the system. This appendix 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

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

where I001 is the solar radiation measurement provided by the pyranometer in BTU per square foot per hour, AREA is the area of the collector array in square feet, $\Delta\tau$ 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 lb_m/min and ΔH is the enthalpy change, in BTU/lb_m, 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 C_p is the average specific heat, in BTU/lb_m-°F), of the heat transfer fluid and ΔT, in °F, is the temperature differential across the heat exchanging component.

* See Appendix B.

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 BTU/lb_m, 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

$$\text{ECSS OPERATING ENERGY} = (3413/60)\ \Sigma\ [\text{EP100}] \times \Delta\tau$$

where EP100 is the power required by electrical equipment in kilowatts and the two factors (1/60) and 3413 correct the data to BTU/min.

<u>Letter Designations</u>

CP	=	Specific Heat
D	=	Direction or Position
EE	=	Electric Energy
EP	=	Electric Power
F	=	Fuel Flow Rate
I	=	Incident Solar Flux (Insolation)
M	=	Mass Flow Rate
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

Initialization

CP_W = Specific heat of water evaluated at fluid temperature

CP_G = Specific heat of glycerol solution evaluated at fluid temperature

RHO_W = Density of water evaluated at fluid temperature

RHO_G = Density of glycerol solution evaluated at fluid temperature

FCONST = Energy content of natural gas used per minute = 666.67 BTU/min

HWFEFF = Assumed DHW tank burner efficiency = 0.6

STOCAP = Storage capacity = 80 gallons

HWCAP = Hot water tank capacity = 40 gallons

WCONST = 8.338 lbs/gallon

M100 = W100 x SQRT (WCONST x RHO_G)

M300 = WD300 x RHO_W
Where WD300 is calculated from W300 and a complex set of totalizer equations.

EQUATIONS USED TO GENERATE MONTHLY PERFORMANCE VALUES

SCAN LEVEL EQUATIONS

AVERAGE AMBIENT TEMPERATURE (°F)

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

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

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

for ± three hours from solar noon

INCIDENT SOLAR ENERGY PER SQUARE FOOT (BTU/FT^2)

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

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

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

when the collector loop is active

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

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

SOLAR ENERGY TO STORAGE (BTU)

$STEI = \Sigma\ [M100 \times CP_G \times (T201 - T202)] \times \Delta\tau$

SOLAR ENERGY FROM STORAGE (BTU)

$STEO = \Sigma\ [M300 \times CP_W \times (T351 - T300)] \times \Delta\tau$

AVERAGE TEMPERATURE OF STORAGE (°F)

$TST = (1/60) \times \Sigma\ [T203 + T204 + T205)/3] \times \Delta\tau$

ECSS OPERATING ENERGY (BTU)

$CSOPE = 56.8833 \times \Sigma\ EP100 \times \Delta\tau$

when system is in the collector-to-storage mode

SOLAR ENERGY TO HOT WATER SUBSYSTEM (BTU)

$HWSE = STEO$

HOT WATER CONSUMPTION (GALLONS)

$HWCSM = \Sigma\ [WD300] \times \Delta\tau$

where WD300 is calculated for W300 and a complex set of totalizer equations

HOT WATER LOAD

$HWL = \Sigma\ [M300 \times CP_W \times (T302 - T300)] \times \Delta\tau$

HOT WATER AUXILIARY FUEL

$HWAF = \Sigma\ [FCONST \times F300] \times \Delta\tau$

FLOW WEIGHTING FOR SUPPLY WATER TEMPERATURE

$TSW1 = \Sigma\ [M300 \times T300] \times \Delta\tau$

$TWS2 = \Sigma\ [M300] \times \Delta\tau$

FLOW WEIGHTING FOR DELIVERY WATER TEMPERATURE

$THW1 = \Sigma\ [M300 \times T302] \times \Delta\tau$

HOURLY LEVEL EQUATIONS

SUPPLY WATER TEMPERATURE (°F)

$TSW = TSW1/TSW2$

DELIVERY WATER TEMPERATURE (°F)

$DHW = THW1/TSW2$

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

$SEA = CLAREA \times SE$

COLLECTED SOLAR ENERGY PER UNIT AREA (BTU/ft^2)

$SEC = SECA/CLAREA$

COLLECTOR ARRAY EFFICIENCY

$CAREF = SECA/SEA$

CHANGE IN STORED ENERGY (BTU)

$$STECH = STOCAP \times [(RHO_W \times CP_W \times TST)_{present\ hour} - (RHO_W \times CP_W \times TST)_{previous\ hour}]$$

STORAGE TANK LOSS (BTU)

$STLOSS = STEI - STEO - STECH$

STORAGE TANK EFFICIENCY

STEFF = (STECH + STEO)/STEI

ECSS SOLAR CONVERSION EFFICIENCY

CSCEF = CSEO/SEA

AUXILIARY THERMAL ENERGY TO HOT WATER TANK

HWAT = HWFEFF x HWAF

HOT WATER FOSSIL FUEL SAVINGS (BTU)

HWSVF = HWSF/HWFEFF

CHANGE IN DHW TANK ENERGY (BTU)

$$TANKV = HWCAP \times [(RHO_W \times CP_W \times THW) - (RHO_W \times CP_W \times TSW)]$$

HOT WATER TANK SOLAR FRACTION (PERCENT)

HWSFR = HWTKSE/(HWTKSE + HWTKAUX)

where HWTKSE is the solar energy in the hot water tank

$$HWTKSE = (HWSFR)_{previous\ hour} \times (TANKV - HWSE - HWAT) + HWSE$$ and HWTKAUX is the auxiliary energy in the hot water tank

$$HWTKAUX = (1 - HWSFR)_{previous\ hour} \times (TANKV - HWSE - HWAT) + HWAT$$

SYSTEM LOAD (BTU)

SYSL = HWL

SYSTEM SOLAR FRACTION (PERCENT

SFR = HWSFR

AUXILIARY THERMAL TO LOAD (BTU)

AXT = HWAT

SYSTEM OPERATING ENERGY (BTU)

SYSOPE = CSOPE

SOLAR ENERGY TO LOAD

SEL = HWSE

SYSTEM FOSSIL ENERGY USED

AXF = HWAF

SYSTEM ELECTRICAL SAVINGS

TSVE = CSOPE

SYSTEM FOSSIL SAVINGS

TSVF = HWSVF

TOTAL ENERGY CONSUMED

TESCM = SECA + AXF + SYSOPE

APPENDIX E

CALCULATION OF PREDICTED VALUES

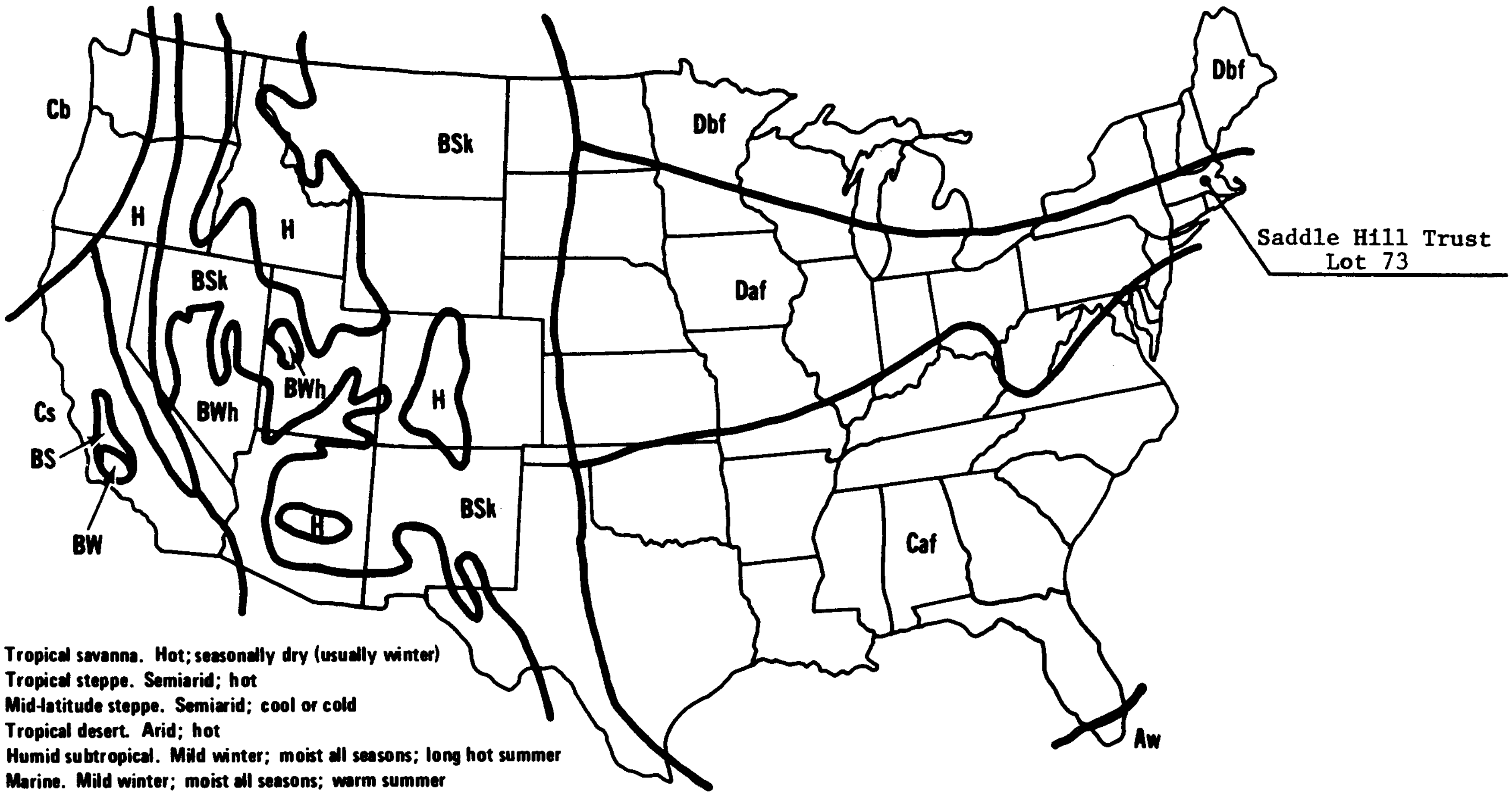
The modified f-Chart program is used by the NSDN to estimate performance of the solar system. The f-Chart program was developed by the Solar Energy laboratory, University of Wisconsin-Madison, and was originally intended to be used as a design tool. This program has been modified to use measured weather data and measured subsystem loads and losses 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.

In addition to the assumptions made for a normal f-Chart analysis, the modified f-Chart assumes that all subsystem loads and losses are reasonable and are the result of good design and insulation practice.

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)



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 F-1. Meteorological Map of the United States Showing Saddle Hill Trust Lot 73 Location

SADDLE HILL TRUST LOT 73 LONG-TERM WEATHER DATA

COLLECTOR TILT: 45 DEGREES
LATITUDE: 42 DEGREES

LOCATION: MEDWAY, MASSACHUSETTS
COLLECTOR AZIMUTH: 0 DEGREES

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
JAN	1,219	476	0.39016	1.741	828	1,110	0	29
FEB	1,691	712	0.42091	1.476	1,051	969	0	30
MAR	2,311	1,018	0.44025	1.216	1,237	834	0	38
APR	2,971	1,327	0.44678	1.005	1,334	492	0	49
MAY	3,446	1,622	0.47077	0.883	1,433	218	20	59
JUN	3,643	1,818	0.49893	0.832	1,513	27	117	68
JUL	3,540	1,751	0.49469	0.855	1,497	0	260	73
AUG	3,151	1,486	0.47155	0.952	1,414	8	203	71
SEP	2,547	1,261	0.49515	1.143	1,441	76	61	65
OCT	1,870	889	0.47507	1.422	1,264	301	0	55
NOV	1,328	501	0.37755	1.631	818	594	0	45
DEC	1,092	402	0.36801	1.802	724	992	0	33

LEGEND:

HOBAR - Monthly average daily extraterrestrial radiation (ideal) in BTU/day-Ft^2.

HBAR - Monthly average daily radiation (actual) in BTU/day-Ft^2.

KBAR - Ratio of HBAR to HOBAR.

RBAR - Ratio of monthly average daily radiation on tilted surface to that on a horizontal surface for each month (i.e., multiplier obtained by tilting).

SBAR - Monthly average daily radiation on a tilted surface (i.e., RBAR x HBAR) in BTU/day-Ft^2.

HDD - Number of heating degrees days per month.

CDD - Number of cooling degrees days per month.

TBAR - Average ambient temperature in degrees Fahrenheit.

MONTHLY REPORT: SADDLE HILL TRUST LOT 73
JANUARY 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1759	29	45
2	*	*	*
3	*	*	*
4	1577	24	*
5	120	24	*
6	1722	17	*
7	204	28	*
8	*	*	*
9	*	*	*
10	1461	22	*
11	281	38	*
12	*	*	*
13	1472	27	*
14	478	32	41
15	*	*	*
16	*	*	*
17	*	*	*
18	*	*	*
19	*	*	*
20	724	32	*
21	1605	27	*
22	331	28	*
23	*	*	*
24	1130	18	*
25	1809	22	*
26	1860	26	*
27	2190	28	42
28	1497	28	39
29	*	*	*
30	2062	20	28
31	530	16	22
SUM	37220	-	-
AVG	1201	26	*

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: SADDLE HILL TRUST LOT 73
FEBRUARY 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1751	19	*
2	2016	20	32
3	2074	21	33
4	2035	22	35
5	1989	23	*
6	1587	23	37
7	89	28	*
8	2217	30	41
9	296	21	*
10	2024	25	36
11	1391	24	39
12	1618	30	43
13	2087	27	45
14	880	32	45
15	1807	31	45
16	44	25	27
17	2253	20	31
18	2184	24	38
19	1993	34	49
20	1970	34	54
21	1058	38	48
22	95	28	28
23	1100	37	47
24	381	34	41
25	1473	34	48
26	1625	24	*
27	888	20	*
28	1301	25	*
29	2267	16	25
SUM	42492	-	-
AVG	1465	26	39

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: SADDLE HILL TRUST LOT 73
MARCH 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1545	18	28
2	1485	18	25
3	2096	23	32
4	2155	33	52
5	156	37	41
6	1848	37	*
7	984	38	*
8	*	*	*
9	*	*	*
10	*	*	*
11	*	*	*
12	2379	27	36
13	1670	26	32
14	157	35	39
15	1712	33	42
16	2322	33	47
17	1014	44	57
18	691	43	*
19	2800	42	54
20	2342	45	*
21	*	*	*
22	413	36	*
23	1418	45	*
24	2351	45	*
25	*	*	*
26	660	42	*
27	815	40	*
28	*	*	*
29	866	45	*
30	*	*	*
31	*	*	*
SUM	44917	-	-
AVG	1449	36	40

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: SADDLE HILL TRUST LOT 73
APRIL 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	*	46	56
2	*	39	46
3	*	48	56
4	*	41	45
5	*	42	46
6	*	49	57
7	*	47	59
8	*	47	54
9	*	50	56
10	*	51	51
11	*	54	60
12	*	53	*
13	*	54	59
14	*	45	47
15	*	58	64
16	*	43	48
17	*	41	46
18	*	45	54
19	*	52	61
20	*	58	70
21	*	57	64
22	*	42	49
23	*	46	50
24	*	53	60
25	*	53	63
26	*	51	57
27	*	54	66
28	*	42	43
29	*	43	44
30	*	51	59
SUM	*	-	-
AVG	*	49	55

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: SADDLE HILL TRUST LOT 73
MAY 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	127	49	51
2	1794	50	55
3	1943	61	78
4	2171	62	70
5	1751	59	75
6	1744	53	64
7	283	47	49
8	129	46	47
9	1727	54	69
10	1716	55	66
11	719	57	63
12	955	65	74
13	511	64	67
14	1109	64	77
15	1394	59	73
16	1863	60	75
17	2225	62	75
18	435	56	61
19	1205	68	81
20	1891	60	69
21	[illegible]	50	50
22	1754	72	89
23	1774	68	80
24	1446	63	73
25	1962	64	78
26	1876	59	76
27	2073	60	77
28	2081	59	78
29	1932	62	80
30	1850	64	80
31	879	66	73
SUM	43453	-	-
AVG	1402	59	70

MONTHLY REPORT: SADDLE HILL TRUST LOT 73
JUNE 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1910	75	88
2	611	65	79
3	263	58	63
4	993	65	75
5	1226	60	71
6	1929	66	84
7	88	57	58
8	448	58	62
9	1294	56	67
10	1103	58	67
11	1490	59	74
12	1744	59	74
13	1927	64	81
14	1565	63	77
15	1653	75	89
16	1840	66	76
17	1819	66	82
18	1669	67	83
19	1898	65	82
20	489	56	63
21	1577	67	81
22	1863	74	91
23	1844	76	93
24	1796	80	98
25	*	82	*
26	*	77	*
27	*	81	100
28	*	70	86
29	*	*	*
30	*	*	*
SUM	41299	-	-
AVG	1377	67	79

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: SADDLE HILL TRUST LOT 73
JULY 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	*	65	70
2	*	68	75
3	*	74	81
4	*	80	93
5	*	77	94
6	*	69	79
7	*	71	86
8	*	63	73
9	*	74	90
10	*	72	83
11	*	78	91
12	*	72	84
13	*	73	89
14	*	78	96
15	*	78	92
16	*	83	102
17	*	81	89
18	*	78	89
19	*	78	93
20	*	84	102
21	*	86	100
22	*	83	96
23	*	74	80
24	*	72	*
25	*	77	95
26	*	80	97
27	*	74	*
28	*	73	84
29	*	68	71
30	*	77	93
31	*	78	93
SUM	45954 E	-	-
AVG	1482 E	75	88

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: SADDLE HILL TRUST LOT 73
AUGUST 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	I	76	89
2	I	82	98
3	I	79	90
4	I	83	98
5	I	82	96
6	1252	82	98
7	1945	81	98
8	1605	83	99
9	1763	81	93
10	1878	75	87
11	377	68	70
12	1348	74	91
13	1034	72	*
14	713	70	80
15	*	*	*
16	*	*	*
17	*	*	*
18	*	*	*
19	*	*	*
20	*	*	*
21	*	*	*
22	700	62	64
23	1932	66	80
24	1952	74	92
25	1574	72	88
26	1891	78	98
27	807	77	*
28	329	66	69
29	571	68	76
30	344	68	76
31	1227	77	88
SUM	37921	-	-
AVG	1223	75	87

* DENOTES UNAVAILABLE DATA.
I DENOTES INVALID DATA.

MONTHLY REPORT: SADDLE HILL TRUST LOT 73
SEPTEMBER 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1661	81	93
2	1989	84	97
3	2144	75	89
4	1820	68	84
5	713	69	79
6	2129	75	91
7	1966	66	83
8	2381	62	82
9	2199	63	81
10	2290	67	79
11	2340	65	80
12	1860	67	84
13	628	64	69
14	547	69	78
15	239	58	60
16	1574	54	66
17	1412	65	76
18	1239	67	73
19	2195	59	75
20	1036	61	71
21	1506	75	89
22	1978	79	93
23	1531	74	86
24	1728	50	59
25	814	49	*
26	1652	59	72
27	2339	51	66
28	2125	54	75
29	2209	47	57
30	1730	55	77
SUM	49975	-	-
AVG	1666	64	78

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: SADDLE HILL TRUST LOT 73
OCTOBER 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1762	59	69
2	1473	64	73
3	56	56	57
4	1218	55	*
5	1184	55	69
6	428	48	53
7	513	43	*
8	1404	52	66
9	2174	55	69
10	2062	45	*
11	82	54	57
12	1904	53	66
13	638	44	52
14	1822	40	*
15	1776	45	*
16	1071	55	62
17	1424	59	71
18	58	64	68
19	1357	57	66
20	1753	49	63
21	515	43	51
22	2040	45	60
23	2162	40	53
24	1817	36	*
25	75	44	50
26	1626	49	56
27	1885	45	57
28	18	40	40
29	2073	38	52
30	1310	36	51
31	1497	41	*
SUM	39178	-	-
AVG	1264	49	60

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: SADDLE HILL TRUST LOT 73
NOVEMBER 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1252	43	53
2	1658	35	*
3	1826	35	50
4	583	52	60
5	1363	48	60
6	2047	38	52
7	1194	50	55
8	876	49	56
9	584	35	43
10	906	40	*
11	1477	36	43
12	1691	39	48
13	452	42	47
14	158	46	*
15	877	35	*
16	2199	33	43
17	1425	34	46
18	75	31	*
19	1932	32	*
20	1497	30	46
21	1150	36	51
22	1492	37	*
23	847	37	50
24	86	44	43
25	419	47	51
26	1932	38	48
27	490	33	41
28	6	42	41
29	993	39	*
30	904	35	*
SUM	32390	-	-
AVG	1080	39	49

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: SADDLE HILL TRUST LOT 73
DECEMBER 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1291	44	56
2	394	44	49
3	547	34	*
4	1928	26	33
5	2033	29	39
6	1627	28	*
7	1372	32	49
8	520	47	52
9	634	44	*
10	839	34	*
11	1320	24	*
12	1222	27	*
13	1042	41	*
14	829	24	*
15	796	19	*
16	58	25	25
17	1393	21	*
18	435	17	*
19	*	*	*
20	2224	11	*
21	1238	13	*
22	*	*	*
23	62	29	*
24	*	*	*
25	*	*	*
26	*	*	*
27	*	*	*
28	*	*	*
29	*	*	*
30	*	*	*
31	*	*	*
SUM	32185	-	-
AVG	1038	29	*

* DENOTES UNAVAILABLE DATA.

APPENDIX G

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

Saddle Hill Trust Lot 73 was occupied for all of the reporting period. During this time, the solar system operated normally. This system has been in operation since the summer of 1977. Since being put into operation, there have not been any major operational problems. There were, however, some data collection and instrumentation problems during the period as listed below.

Date	Event
1/80	Data collection problem preventing monthly report but not preventing calculation of performance factors.
4/80	Data collection problem preventing calculating of performance factors and monthly report.
7/80	Pyranometer failed, preventing calculation of insolation for the month.

APPENDIX H

CONVERSION FACTORS

Energy Conversion Factors[1]

Fuel Type	Energy Content	Fuel Source Conversion Factor
Distillate fuel oil[2]	138,690 BTU/gallon	7.21×10^{-6} gallon/BTU
Residual fuel oil[3]	149,,690 BTU/gallon	6.68×10^{-6} gallon/BTU
Kerosene	135,000 BTU/gallon	7.41×10^{-6} gallon/BTU
Propane	91,500 BTU/gallon	10.93×10^{-6} gallon/BTU
Natural gas	1,021 BTU/cubic feet	979.4×10^{-6} cubic feet/ BTU
Electricity	3,413 BTU/kilowatt-hour	292.8×10^{-6} kwh/BTU

[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

APPENDIX I

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 shadowband 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/ft2-hr.

The addition of a shadowband 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 multijunction 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 wavelength 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 wattmeter 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 wattmeter 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.

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