SOLAR/2028-81/14

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

HOGATE'S RESTAURANT

Washington, District of Columbia
January 1980 through December 1980
DHW

MASTER

U.S. DEPARTMENT OF ENERGY

NATIONAL SOLAR DATA PROGRAM

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WASHINGTON, D.C.

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

JANUARY 1980 THROUGH DECEMBER 1980

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FOREWORD

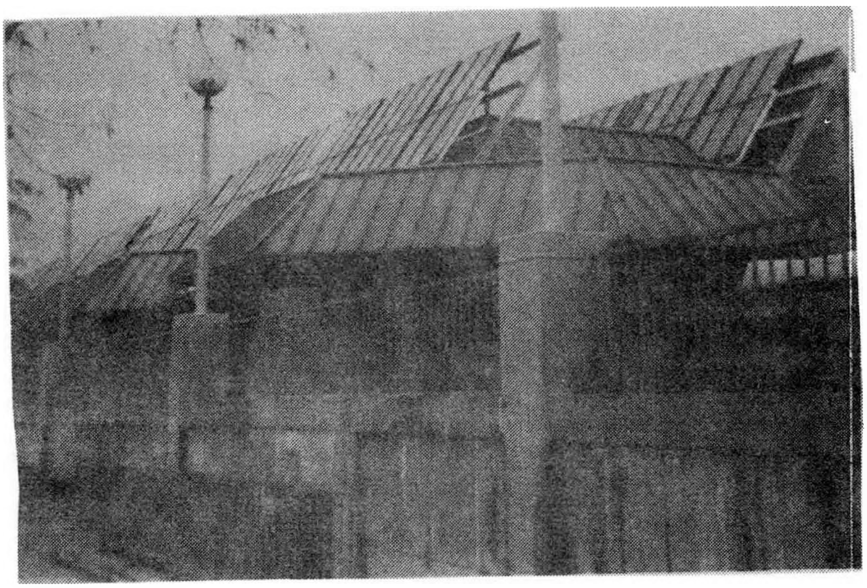
This report is one of a series which describes the performance of solar energy systems in the National Solar Data Network (NSDN) for the entire heating or cooling season. Domestic hot water is also included, if there is a solar contribution. Some NSDN installations are used solely for heating domestic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



HOGATE'S RESTAURANT

HOGATE'S RESTAURANT

The Hogate's Restaurant site is a business establishment which serves as a restaurant on the waterfront in Washington, D.C. The active solar energy system is designed to supply the following:

Seasonal Design Factors

	% Solar
Hot Water	64

It is equipped with:

Collector	6,254 square feet of liquid flat-plate collectors manufactured by Sunworks, Incorporated, Model SOLECTOR
Storage	Two 5,000-gallon tanks located in the parking garage
Auxiliary	Gas boiler

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SOLAR SYSTEM PERFORMANCE

HOGATE'S RESTAURANT
JANUARY 1980 THROUGH DECEMBER 1980

Solar Fraction[1]	40%
Solar Savings Ratio[2]	39%
Conventional Fuel Savings[3]	1,302,838 cubic feet of gas
System Performance Factor[4]	1.06
Solar System COP[5]	35.48

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

	Load	Solar Consumed	% Solar
Hot Water*	2,109.72	838.44	40

*12-month totals.

Environmental Data

	Measured	Long-Term
Outdoor temperature (average)	58°F	54°F
Heating degree-days (total)	4,319	5,015
Cooling degree-days (total)	1,747	940
Daily incident solar energy (average)	1,125 BTU/ft^2	1,223 BTU/ft^2

1. Solar Fraction $= \dfrac{\text{Solar Energy Supplied to Loads}}{\text{Total Energy}}$

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

3. Conventional Fuel Savings (Natural Gas) = Product of the fossil fuel savings in BTU times the conventional fuel conversion factor for natural (979.4 million cubic feet/BTU)

4. Ratio of system load to the total equivalent fossil energy expended or required to support the system load.

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

1.1 SUMMARY AND CONCLUSIONS

The Hogate's Restaurant, which is located in Washington, D.C., has a simple design solar system. The collected energy is delivered directly to storage via the collector/storage heat exchanger. City-supplied water flows through the two 5,000-gallon preheat tanks and continues to the boiler. Hot water then flows from the boiler into the recirculation loop to deliver hot water instantaneously upon demand. Thus losses in the recirculation loop are supplied by the boiler. It is possible that improved solar usage could be realized if the system were designed so that the recirculated water also passed through the solar storage tanks.

In comparison with more complicated system designs, this system design is more effective at maximizing the use of collected solar energy. Over half of the collected solar energy aided in preheating domestic hot water.

The system performed well during the year. This is primarily due to well-designed collector arrays and adequate insulation of the system.

The system was shut down for repairs to the collector array expansion joints in November 1979. These repairs were made in January and the system reactivated January 21, 1980. On January 27 the coupler on pump P1 failed. The system is designed so that pump P2 will be activated when pump P1 fails but since pump P1 motor continued to run, the controller did not activate pump P2. Pump P1 was repaired February 8 and the system placed back in operation.

Table 1 summarizes the thermal performance of Hogates' Restaurant.

The system performance was as expected. The computed solar fraction was slightly less than the predicted solar fraction. The solar system supplied 40% of the domestic hot water load compared to an f-Chart prediction of 43%. The f-Chart computer simulation uses measured weather, measured subsystem loads, and computed losses as inputs.

Fossil fuel savings calculations provide a reasonable method of determing the overall impact the solar system had on the energy consumption. The actual nonsolar energy requirements for Hogate's Restaurant are compared to those which would be required if the building used a conventional hot water system. For the year, the computed fossil fuel savings were 1,330.20 million BTU, or 1,302,838 cubic feet of natural gas. The system saved $5,341.64 worth of natural gas [based on a rate of $0.41 per therm (100 cubic feet) of natural gas]. There were 23.63 million BTU or 6,919 kwh of electrical operating energy used to operate the solar system components. This energy expense was equivalent to $345.94 based on a rate of $0.05 per kwh. Thus, the net dollar savings were $4,995.70 for the year. If the auxiliary fuel source were oil or electricity, the net monetary savings would have been $9,245.00 and $11,929.00 respectively (based on $1.00 per gallon for oil and $0.05 per kwh for electricity). The yearly total of monetary savings was extrapolated from an average of the seven data months available.

Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

HOGATE'S RESTAURANT
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 (PERCENT)	
			PREDICTED	MEASURED	FOSSIL		FOSSIL	ELECTRICAL	PREDICTED	MEASURED
JAN	16.29	224.84	*	16.41	297.91	0.88	24.91	-0.45	*	7
FEB	65.15	211.03 E	54.34	59.16 E	222.13	2.01	91.52 E	-1.61	34	28
MAR	84.94	247.05 E	64.83	91.63 E	226.40	2.61	140.43 E	-2.18	26	37
APR	102.95	*	*	*	172.50	2.61	*	-2.22	*	*
MAY	95.98	*	*	*	143.89	2.99	*	-2.59	*	*
JUN	86.61	*	*	*	76.70	2.74	*	-2.35	*	*
JUL	98.12	121.78	60.92	89.47	42.22	2.82	145.31	-2.42	50	73
AUG	82.39	97.45	49.74	74.17	30.15	2.56	132.63	-2.15	51	76
SEP	88.41	131.37	*	80.43	70.41	2.38	127.00	-1.99	61	61
OCT	88.37	197.18	*	77.79	163.39	2.53	114.17	-2.11	43	39
NOV	73.44	*	*	*	212.08	2.24	*	-1.82	*	*
DEC	62.02	*	*	*	235.83	2.18	*	-1.74	*	*
TOTAL	944.67	1,230.70	229.83	489.06	1,893.61	28.55	775.97	-23.63	-	-
AVERAGE	78.72	175.81	57.46	69.87	157.80	2.38	110.85	-1.97	43	40

* Denotes unavailable data. E Denotes estimated value.

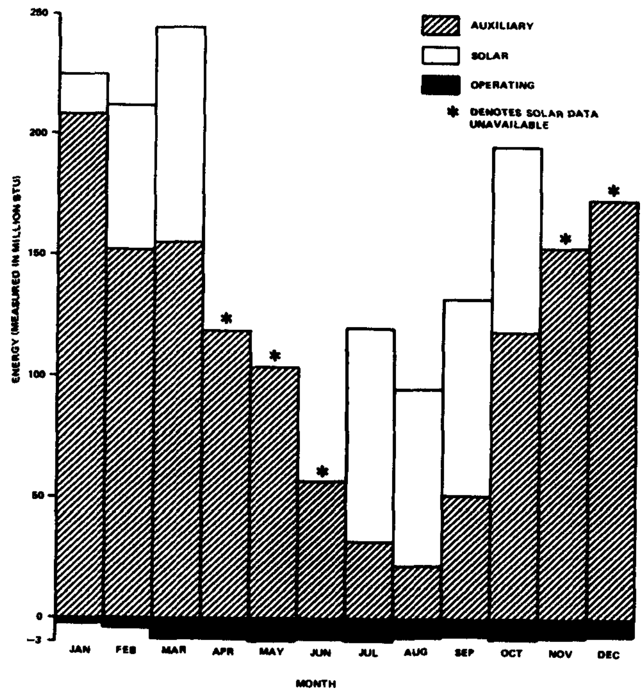
The collector subsystem performed well. The collector efficiency was 37% for the year. The collectors were manufactured by Sunworks, Incorporated. The incident solar energy was 2,571.21 million BTU. There were 944.67 million BTU of solar energy collected. During the season, 97% of the collected energy was delivered to storage. The low losses, 25.70 million BTU, occurred in the piping and heat exchanger. The collector subsystem operated continuously except during 23 days in January and seven days in February. Leaky collector expansion couplings prevented solar system operation. Collector subsystem repairs were made in late January and early February.

Storage system performance was excellent, having an overall storage efficiency of 91%. Solar energy delivered to storage was 918.97 million BTU. Of this total, nine percent was lost to the environment. This loss was small due to good storage tank and piping insulation and also high hot water consumption which nearly eliminated standby thermal energy losses by keeping the storage temperatures moderate.

The performance of the hot water subsystem was acceptable. The hot water solar fraction was 40%. The design solar fraction was 64%. Hot water consumption totaled 1,943,685 gallons during the year. This consumption is an average of 242,961 gallons a month and an average of 7,966 gallons daily. Natural gas is the auxiliary energy source. The supply water was heated to an average temperature of 149°F. The annual DHW loss was estimated to be 248.65 million BTU. This constituted 30% of the DHW solar energy used and 12% of the DHW load. These are low percentages for a system with a recirculation loop.

1.2 OVERALL SYSTEM PERFORMANCE

The overall thermal performance of the solar energy system is shown graphically in Figure 1.



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

Figure 1. System Thermal Performance
Hogate's Restaurant
January 1980 through December 1980

The flow of solar energy through the Hogate's Restaurant site for the 12-month period from January 1980 through December 1980 is presented in Figure 2. This Energy Flow Diagram shows the amount of energy collected, transported, stored, consumed, or lost at each point in the system.

The measured hot water solar energy used was 838.44 million BTU. This represents 40% of the hot water load.

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 to collect or deliver it. The greater the COP value, the more efficient the subsystem. The solar energy system at Hogate's Restaurant weighted average COP value was 29.36 for 1980. For this specific system, there is no DHW solar specific operating energy because of the recirculation loop.

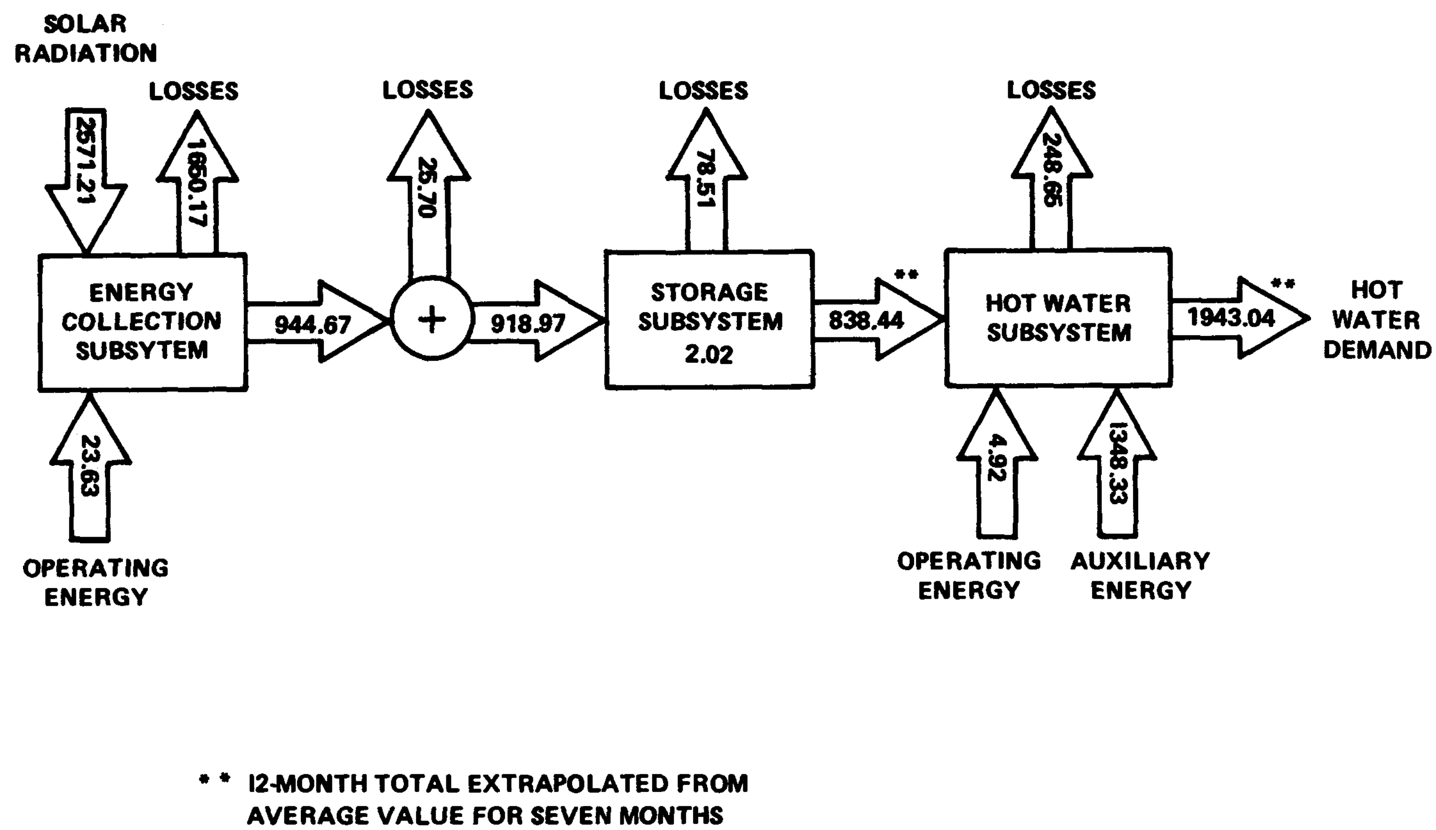


Figure 2. Energy Flow Diagram for Hogate's Restaurant
January 1980 through December 1980
(Figures in million BTU)

Table 2. SOLAR COEFFICIENT OF PERFORMANCE

HOGATE'S RESTAURANT
JANUARY 1980 THROUGH DECEMBER 1980

MONTH	SOLAR ENERGY SYSTEM	COLLECTOR SUBSYSTEM
JAN	18.65	36.20
FEB	29.43 E	40.47
MAR	35.10 E	38.96
APR	*	46.37
MAY	*	37.06
JUN	*	36.86
JUL	31.73	40.55
AUG	28.97	38.32
SEP	33.79	44.43
OCT	30.73	41.88
NOV	*	40.35
DEC	*	35.64
WEIGHTED AVERAGE	29.36	39.88

E Denotes estimated data.
* Denotes unavailable data.

1.3 ENERGY SAVINGS

Energy savings for this site are presented in Table 3 and shown graphically in Figure 3. For the 12-month period, the total fossil savings were 1,330.20 million BTU for a monthly average of 110.85 million BTU. This total was extrapolated from the average of the seven data months. An electrical energy expense of 23.63 million BTU was incurred during the reporting period for the operation of the collector pump. The DHW recirculating pump was not considered a solar system operating expense because the pump would also be required for a nonsolar system.

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

Table 3. ENERGY SAVINGS

HOGATE'S RESTAURANT
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU)

MONTH	SOLAR ENERGY USED	DOMESTIC HOT WATER	ECSS OPERATING ENERGY	ENERGY SAVINGS	
		FOSSIL FUEL		ELECTRICAL	FOSSIL FUEL
JAN	16.41	24.91	0.45	-0.45	24.91
FEB	59.16 E	91.52 E	1.61	-1.61	91.52
MAR	91.63 E	140.43 E	2.18	-2.18	140.43
APR	*	*	2.22	-2.22	*
MAY	*	*	2.59	-2.59	*
JUN	*	*	2.35	-2.35	*
JUL	89.47	145.31	2.42	-2.42	145.31 E
AUG	74.17	132.63	2.15	-2.15	132.63 E
SEP	80.43	127.00	1.99	-1.99	127.00 E
OCT	77.79	114.17	2.11	-2.11	114.17 E
NOV	*	*	1.82	-1.82	*
DEC	*	*	1.74	-1.74	*
TOTAL	489.06	775.97	23.63	-23.63	775.97
AVERAGE	69.87	110.85	1.97	-1.97	110.85

E Denotes estimated value.
* Denotes unavailable data.

auxiliary energy sources. The operating energy required to transport solar energy from the collector to storage is subtracted from the solar energy contribution to the loads to determine net savings.

The total yearly savings of 1,330.20 million BTU are equivalent to 1,302,838 cubic feet of natural gas. Based on a rate of $0.41 per therm (100 cubic feet) of natural gas, the monetary savings would be $5,341.64. The 23.63 million BTU operating energy is equivalent to 6,919 kwh which at $0.05 per kwh

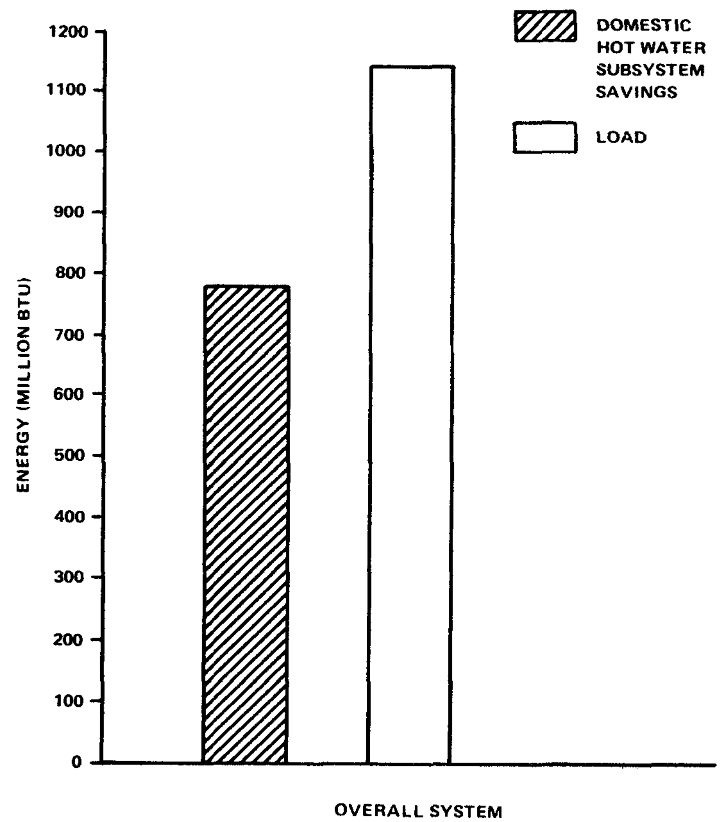


Figure 3. Combined Thermal Energy Savings Compared to Load
Hogate's Restaurant
January through March 1980 and July through October 1980

would be a monetary expense of $345.94. Therefore, the net yearly dollar savings were $4,995.70. The equivalent net dollar savings if oil were the auxiliary energy source at the site would have been $9,245.00 based on $1.00 per gallon of oil. If the auxiliary energy source were electricity, the net dollar savings would have been $11,929.00 based on $0.05 per kwh.

The auxiliary source at Hogate's Restaurant site consists of a gas boiler. This unit is considered to be 63% efficient for computational purposes.

1.4 SOLAR ENERGY UTILIZATION

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

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

Eighty-one percent of the incident solar energy was available when the collector pump was operating. Thirty-seven percent of the incident solar energy was collected and 36% was stored. Solar energy delivered to the loads was 33% of the total incident energy or 89% of the collected energy. These percentages are based on the 12-month extrapolated value for solar energy used (838.44 million BTU).

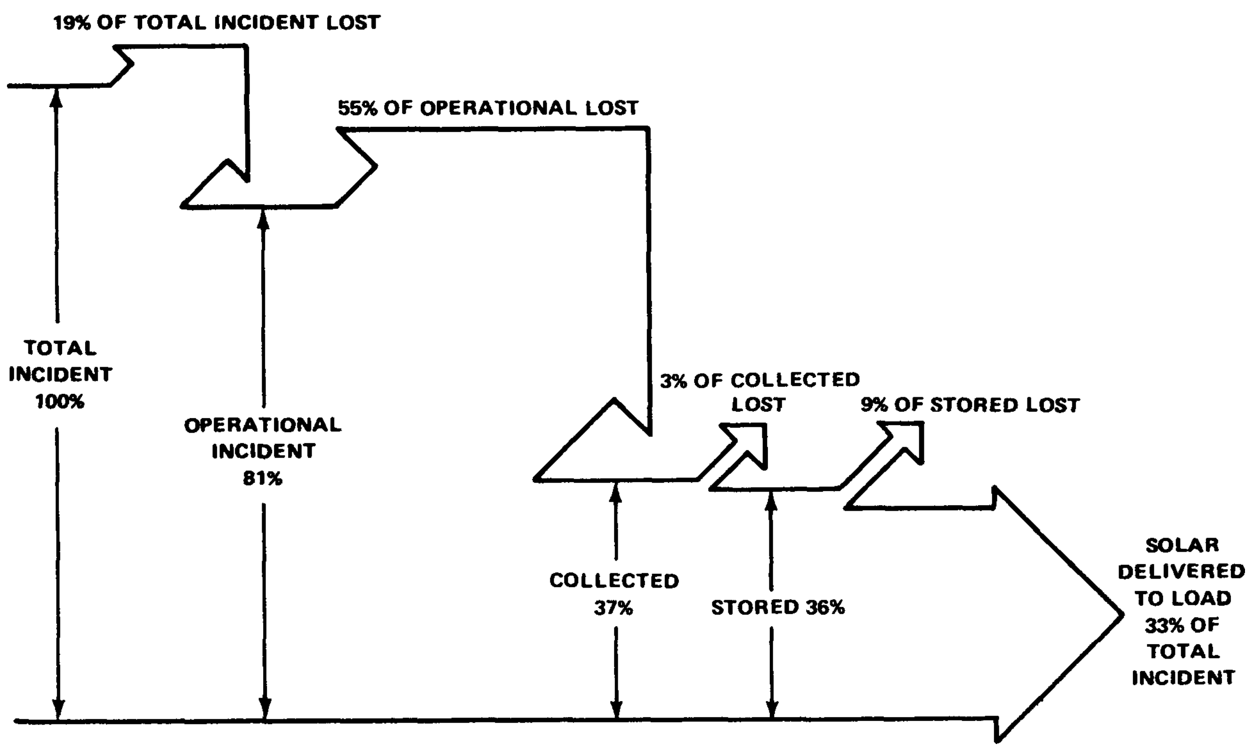


Figure 4. Solar Energy Use
Hogate's Restaurant
January 1980 through December 1980

Table 4. SOLAR ENERGY LOSSES

HOGATE'S RESTAURANT
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
JAN	16.29	13.10	20	-0.15	16.41
FEB	65.15	57.96	11	0.80	59.16
MAR	84.94	81.12	4	2.02	91.63
APR	102.95	95.94	7	1.28	*
MAY	95.98	97.71	*	1.60	*
JUN	86.61	94.42	*	1.73	*
JUL	98.12	94.63	4	0.30	89.47
AUG	82.39	79.29	4	-0.37	74.17
SEP	88.41	86.33	2	-1.61	80.43
OCT	88.37	86.02	3	0.61	77.79
NOV	73.44	71.74	2	-2.21	*
DEC	62.02	60.71	2	-1.98	*

*Denotes unavailable data.

1.5 SOLAR SYSTEM AVAILABILITY

The solar system was continuously operational during the periods January 21 through January 28 and February 8 through December 31, 1980. Leaky collector expansion couplings prevented system operation during the periods January 1 through January 20 and January 29 through February 7, 1980.

SECTION 2

SUBSYSTEM PERFORMANCE

2.1 COLLECTOR

During the year, the collector subsystem performed extremely well. During parts of January and February the solar system was shut down for replacement of the expansion couplings between collector plates and due to failure of pump P1. The Hogate's Restaurant collector array is composed of 300 liquid, flat-plate collector panels, which are manufactured by Sunworks, Incorporated. The collector model is the SOLECTOR. The panel exterior dimensions are three feet by seven feet, with a gross collector array area of 6,254 square feet. These panels are mounted in two banks on the roof and face southwesterly at a tilt 55 degrees to the horizon. Fifty percent propylene glycol with water is the transfer medium. Collector subsystem performance for Hogate's Restaurant is presented in Table 5.

Table 5. COLLECTOR SUBSYSTEM PERFORMANCE

HOGATE'S RESTAURANT
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU, unless otherwise indicated)

MONTH	INCIDENT SOLAR RADIATION	COLLECTED SOLAR ENERGY	COLLECTOR SUBSYSTEM EFFICIENCY (%)	OPERATIONAL INCIDENT ENERGY	CORRECTOR ARRAY OPERATONAL EFFICIENCY (%)	ECSS OPERATING ENERGY	SOLAR ENERGY TO STORAGE	DAYTIME AMBIENT TEMPERATURE (°F)
JAN	123.82	16.29	13	27.95	58	0.45	13.10	39
FEB	221.80	65.15	29	139.25	47	1.61	57.96	37
MAR	200.95	84.94	42	179.55	47	2.18	81.12	48
APR	235.65	102.95	44	211.55	49	2.22	95.94	64
MAY	239.18	95.98	40	208.01	46	2.59	97.71	75
JUN	254.42	86.61	34	208.28	42	2.35	94.42	80
JUL	257.63	98.12	38	216.98	45	2.42	94.63	81
AUG	227.22	82.39	36	183.41	45	2.15	79.29	88
SEP	248.71	88.41	36	203.55	43	1.99	86.33	82
OCT	223.36	88.37	40	199.88	44	2.11	86.02	63
NOV	183.24	73.44	40	166.28	44	1.82	71.74	51
DEC	155.23	62.02	40	139.51	45	1.74	60.71	41
TOTAL	2,571.21	944.67	-	2,084.20	-	23.63	918.97	-
AVERAGE	214.27	78.72	37	173.68	45	1.97	76.58	62

The total solar radiation incident on the collector array was 2,571.21 million BTU.. This represents an average of 1,125 BTU per square foot per day for the year. Of the total incident solar radiation, 2,084.20 million BTU were incident while the collector loop was operating. The system collected 944.67

million BTU, representing 37% of the total available insolation and 45% of the insolation available during collector loop operation. Solar energy collection required 23.63 million BTU of operating energy for the pumps P1, P2, P3, and P4. The energy delivered to storage was 918.97 million BTU. The average daytime ambient temperature was 62°F.

During January, the solar system at Hogate's Restaurant was not operational for 23 days due primarily to repair of the collector array. The system had been shut down for a few months prior to January 21, pending collector repairs. On January 21, the leaky straight couplings were replaced with fortified globe shaped couplings and the system was refilled with 50% propylene glycol/water solution. After this, the collectors operated until January 27 when the coupler broke, on pump P1. The collector loop was not functional until the coupler was replaced on February 7, 1980. The collector loop functioned properly for the remainder of the year.

2.2 STORAGE

Storage consists of two insulated, 5,000-gallon steel tanks, manufactured by RECO, Incorporated. These tanks are piped in series to enhance the temperature differential/stratification effects between the two. They are located in the parking garage, which is one floor beneath the kitchen level, and two floors below the mechanical room. Preheated water from storage is transferred to the DHW boiler.

Storage performance data are shown in Table 6. During the year, total solar energy delivered to storage was 918.97 million BTU. There was a total of 838.44 million BTU delivered from storage to the domestic hot water system. The total change in stored energy was an increase of 2.02 million BTU. Energy lost from storage for the year was 78.51 million BTU. This loss resulted in a storage efficiency of 91% based on the monthly averages. (See Footnote 1.) The 12-month totals for the energy from storage and storage loss were also extrapolated from the monthly averages.

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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

Table 6. STORAGE SUBSYSTEM PERFORMANCE

HOGATE'S RESTAURANT
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	13.10	16.41	-0.15	105	45	-3.16
FEB	57.96	59.16 E	0.80	102 E	61	-2.00 E
MAR	81.12	91.63 E	2.02	102 E	69	-12.53 E
APR	95.94	*	1.28	*	89	*
MAY	97.71	*	1.60	*	98	*
JUN	94.42	*	1.73	*	112	*
JUL	94.63	89.47	0.30	95	119	4.86
AUG	79.29	74.17	-0.37	93	120	5.49
SEP	86.33	80.43	-1.61	91	122	7.51
OCT	86.02	77.79	0.61	91	92	7.62
NOV	71.74	*	-2.21	*	74	*
DEC	60.71	*	-1.98	*	64	*
TOTAL	918.97	489.06	2.02	-	-	78.51**
AVERAGE	76.58	69.87	0.17	91**	89	6.54**

E Denotes estimated value.
* Denotes unavailable data.
** Based on monthly averages.

Failure of the storage-to-load totalizing flow sensor (W303) during the period February through December resulted in lack of energy from storage data during five months and estimated storage performance factors for February and March. Estimations were based on the flow rate of W302 (recirculation flow rate sensor). The new flow meter for W303 was installed at Hogate's Restaurant in mid-October. Although the sensor was replaced, W303 scaling in the site data acquisition subsystem (SDAS) was incompatible with the instrument in November and December.

During the period February through April, storage heat exchanger output flow sensor W300 read low. On April 17, Marshall Space Flight Center performed a demonstration at Hogate's Restaurant, using an ultrasonic flow meter to compare flow with sensor W300. During three hours of monitoring, sensor W300 read consistently lower than the ultrasonic flow meter by 6.8%. The average difference in the flow rates was 5.3 gallons per minute. This sensor discrepancy resulted in lower calculation of energy delivered to storage in the February through April performance reports. To correct the problem for the February through December reports, the Marshall Space Flight Center results for sensor W300 were used in the site software.

2.3 DOMESTIC HOT WATER (DHW)

The DHW system at Hogate's Restaurant consists of a gas-fired boiler which maintains a minimum water temperature of 139°F in a recirculating hot water line for the restaurant's fixtures and dishwashers.

The DHW system performance was satisfactory. The solar fraction was 40%. If the misleading January hot water data (when the solar system was shut down) were ignored, the hot water solar fraction would be 47%. This compares more favorably with the designed solar fraction of 64% for this reporting period.

The DHW system performance data for Hogate's Restaurant are shown in Table 7 and by graphic illustration in Figure 5. The DHW system required 838.44 million BTU of solar energy and 1,348.33 million BTU of auxiliary thermal

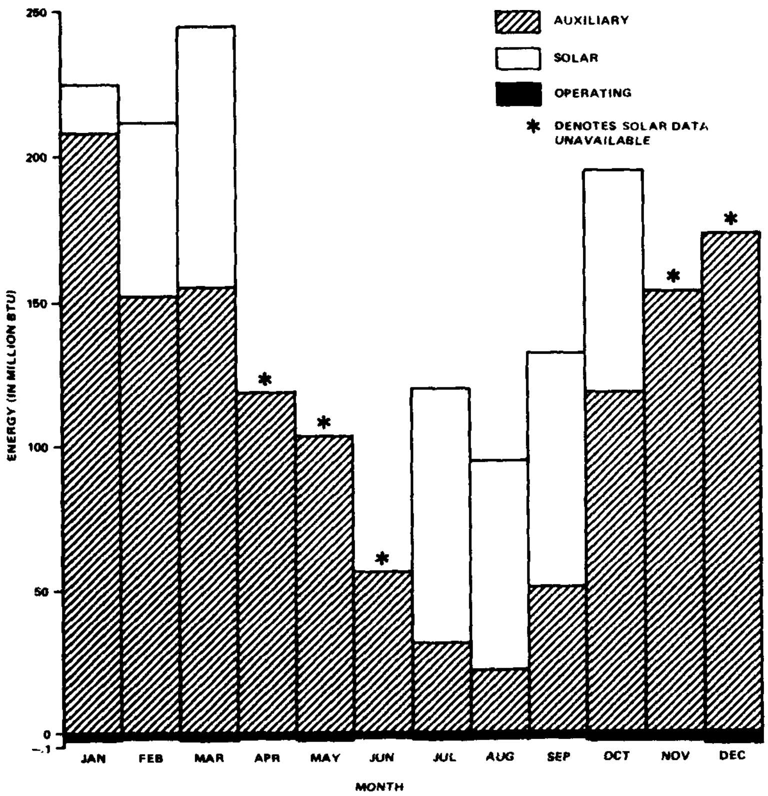
Table 7. DOMESTIC HOT WATER SUBSYSTEM PERFORMANCE

HOGATE'S RESTAURANT
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU, unless otherwise indicated)

MONTH	HOT WATER LOAD	SOLAR FRACTION OF LOAD (%)	HOT WATER DEMAND	SOLAR ENERGY USED	OPERATING ENERGY	AUX THERMAL USED	AUX FOSSIL FUEL	SUPPLY WATER TEMP (°F)	HOT WATER TEMP (°F)	HOT WATER CONSUMPTION (GALLONS)
JAN	224.84	7	232.71	16.41	0.43	208.43	297.91	42	148	280,195
FEB	211.03 E	28	195.99 E	59.16	0.40	151.87	222.13	40 E	151 E	249,848 E
MAR	247.05 E	37	197.88 E	91.63	0.43	155.42	226.40	44 E	153 E	254,448
APR	*	*	*	*	0.39	119.06	172.50	*	*	*
MAY	*	*	*	*	0.40	103.47	143.89	*	*	*
JUN	*	*	*	*	0.39	56.48	76.70	*	*	*
JUL	121.78	73	105.31	89.47	0.40	32.31	42.22	83	143	221,636
AUG	97.45	76	82.50	74.17	0.41	23.28	30.15	83	139	187,645
SEP	131.37	61	110.69	80.43	0.39	50.94	70.41	80	154	181,452
OCT	197.18	39	208.37	77.79	0.42	119.43	163.39	64	154	280,781
NOV	*	*	*	*	0.42	154.51	212.08	*	*	*
DEC	*	*	*	*	0.44	173.13	235.83	44	147	287,680
TOTAL	1,230.70	-	1,133.45	489.06	4.92	1,348.33	1,893.61	-	-	1,943,685
AVERAGE	175.81	40	161.92	69.87	0.41	112.36	157.80	60	149	242,961

E Denotes estimated 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 5. DHW Subsystem Performance
Hogate's Restaurant
January 1980 through December 1980

energy to satisfy a hot water load of 2,109.72 million BTU. There were 4.92 million BTU of operating energy used to recirculate hot water. The yearly total for the load and solar energy used were extrapolated from the monthly averages of the seven months of available data.

A monthly average of 242,961 gallons of DHW (7,966 gallons daily) was consumed at an average temperature of 149°F. During December, the largest amount of DHW, 287,680 gallons, was consumed. Hot water consumption for the year totaled 2,915,532 gallons, an average of 7,966 gallons daily.

Cold water supply totalizing flow sensor W301 was not functional from February to December. This resulted in lack of DHW data during April through June and November. Data estimates were made for February and March. These estimations were based on hot water recirculation flow rates for W302. As a result, DHW totals in Table 7 are based on eight months of data for Supply Water Temperature, Hot Water Temperature and Hot Water Consumption.

Failure of storage-to-load totalizing flow sensor W303 resulted in lack of DHW data for Solar Energy Used, Hot Water Load, and Solar Fraction of Load during five months. Estimated values for these performance factors were made for February and March. Therefore, several DHW performance factor totals are based on seven months of data.

In mid-October, flow meters W303 and W301 were replaced. Accurate data was obtained for totalizer W301 during December. However, totalizer W303 data were not available due to improper SDAS digital ramp converter scaling.

SECTION 3

OPERATING ENERGY

Measured monthly values of Hogate's Restaurant solar energy system and subsystem operating energies for the report period are presented in Table 8. A total 28.55 million BTU of operating energy was consumed by the solar system during the reporting period. A distribution of this operating energy among the subsystems is illustrated in Figure 6.

Table 8. OPERATING ENERGY

HOGATE'S RESTAURANT
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU)

MONTH	ECSS OPERATING ENERGY (SOLAR UNIQUE)	DHW OPERATING ENERGY TOTAL	TOTAL SOLAR UNIQUE OPERATING ENERGY	TOTAL SYSTEM OPERATING ENERGY
JAN	0.45	0.43	0.45	0.88
FEB	1.61	0.40	1.61	2.01
MAR	2.18	0.43	2.18	2.61
APR	2.22	0.39	2.22	2.61
MAY	2.59	0.40	2.59	2.99
JUN	2.35	0.39	2.35	2.74
JUL	2.42	0.40	2.42	2.82
AUG	2.15	0.41	2.15	2.56
SEP	1.99	0.39	1.99	2.38
OCT	2.11	0.42	2.11	2.53
NOV	1.82	0.42	1.82	2.24
DEC	1.74	0.44	1.74	2.18
TOTAL	23.63	4.92	23.63	28.55
AVERAGE	1.97	0.41	1.97	2.38

Total system operating energy for Hogate's Restaurant is the electrical energy required to support the collector and DHW subsystems without affecting their thermal states. During the year, the total system operating energy of 28.55

million BTU was reasonably low. There was low system operating energy during January when the system was turned off due to leaky collector expansion couplings. The couplings were repaired during January. The failure of pump P1 coupler at the end of January had little impact since the pump continued to run during part of this time.

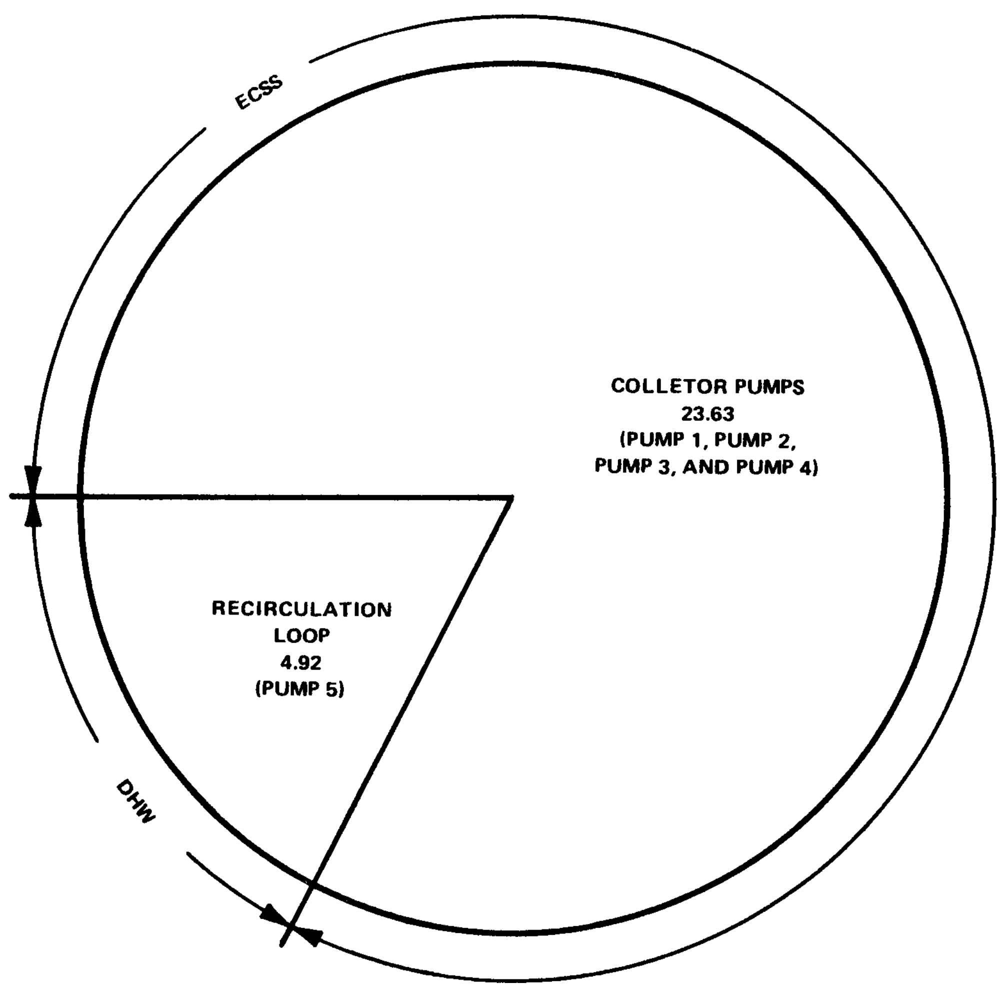


Figure 6. Total Operating Energy
Hogate's Restaurant
January 1980 through December 1980

SECTION 4

WEATHER CONDITIONS

Hogate's Restaurant is located in Washington, D.C. at 39 degrees N latitude and 77 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

HOGATE'S RESTAURANT
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	639	825	36	32	897	1,020	0	0
FEB	1,223	1,030	33	34	921	874	0	0
MAR	1,036	1,223	44	42	652	719	0	0
APR	1,256	1,374	58	53	211	367	4	0
MAY	1,234	1,447	68	63	14	131	137	57
JUN	1,356	1,521	73	71	0	0	240	188
JUL	1,329	1,592	81	77	0	0	494	319
AUG	1,172	1,456	81	77	0	0	502	267
SEP	1,326	1,342	76	67	5	43	344	100
OCT	1,152	1,232	59	56	226	291	26	9
NOV	977	920	47	45	555	609	0	0
DEC	801	713	38	34	838	961	0	0
TOTAL	13,501	14,675	-	-	4,319	5,015	1,747	940
AVERAGE	1,125	1,223	58	54	360	418	145	78

During the period from January 1980 through December 1980, the average daily total incident solar radiation on the collector array was 1,125 BTU per square foot per day. This radiation was below the estimated average daily solar radiation for this geographical area during the reporting period of 1,223 BTU per square foot per day for a southwest-facing plane with a tilt of 55 degrees to the horizontal. During the period, the highest monthly average insolation was 1,356 BTU per square foot per day during June. The average ambient temperature during the reporting period was 58°F as compared with the long-term average for the 12-month period of 54°F. The highest monthly average ambient temperature was 81°F during July and August, and the lowest monthly average ambient temperature was 33°F during February. The number of heating degree-days for the period (based on a 65°F reference) was 4,319 as compared with the long-term average of 5,015. The range of heating degree-days was from a high of 921 during February to a low of zero during June, July, and August.

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 50% during June to a low of 26% during January.

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EXTRA-TERRESTRIAL INSOLATION	2,503	2,709	2,877	2,894	2,785	2,695	2,728	2,835	2,871	2,750	2,542	2,819
TTL INS / EXT INS (%)	26	45	36	43	44	50	49	41	46	42	38	28

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, Hogate's Restaurant, February 1980, SOLAR/2028-80/02, Vitro Laboratories, Silver Spring, Maryland.

*8. Monthly Performance Report, Hogate's Restaurant, March 1980, SOLAR/2028-80/03, Vitro Laboratories, Silver Spring, Maryland.

*9. Monthly Performance Report, Hogate's Restaurant, July 1980, SOLAR/2028-80/07, 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, Hogate's Restaurant, August 1980, SOLAR/2028-80/08, Vitro Laboratories, Silver Spring, Maryland.

*11. Monthly Performance Report, Hogate's Restaurant, September 1980, SOLAR/2028-80/09, Vitro Laboratories, Silver Spring, Maryland.

*12. Monthly Performance Report, Hogate's Restaurant, October 1980, SOLAR/2028-80/10, Vitro Laboratories, Silver Spring, Maryland.

*13. Monthly Performance Report, Hogate's Restaurant, November 1980, SOLAR/2028-80/11, Vitro Laboratories, Silver Spring, Maryland.

*14. Monthly Performance Report, Hogate's Restaurant, December 1980, SOLAR/2028-80/12, 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

The solar energy system of Hogate's Restaurant in Washington, D.C. supplies part of the energy necessary to heat approximately 10,000 gallons of domestic hot water (DHW) each day. The DHW is used by the restaurant's kitchen and must be maintained at a temperature of 150°F.

The solar energy system was added to the existing water heating system and has an array of Sunworks flat-plate collectors model SOLECTOR with a gross area of 6,254 square feet. The array faces southwest at an angle of 55 degrees to the horizontal. Propylene glycol and water is the transfer medium that delivers solar energy from the collector array to storage and to the hot water load. Potable water is isolated from the heat transfer fluid by a liquid-to-liquid heat exchanger. Solar-heated water is stored in two insulated 5,000-gallon tanks which are located in the garage. When solar energy is insufficient to satisfy the hot water load, a gas-fired boiler provides auxiliary energy for water heating. The system, shown schematically, has two modes of operation.

Mode 1 - Collector-to-Storage - This mode activates when the temperature difference between the collector absorber plate and the water in the bottom of tank T2 exceeds the temperature setting in the controller. Pumps P1 and P3 turn on to circulate the solar-heating water; pumps P2 and P4 are backup pumps. Water in the DHW preheat loop circulates from tank T2, through the heat exchanger to tank T1, and returns to tank T2. This mode terminates when the temperature difference between the collector plate and the cooler tank T2 is less than the control setting, or the temperature of tank T1 is higher than 180°F.

Mode 2 - Storage-to-Load - This mode activates when there is a hot water demand. In this mode, makeup water from the cold water supply flows through valves V7 and V6, replacing the preheated water in tank T2. Before entering the DHW recirculation loop, preheated water from tank T1 may be mixed with cold water by tempering valve V1 to maintain the design temperature of 150°F. If there is insufficient solar energy in storage to maintain this design temperature, the water is heated to 150°F by the existing boiler.

SUBSYSTEMS

Collector - The collector array consist of 300 liquid, flat-plate collector panels which were manufactured by Sunworks, Incorporated. The model is the SOLECTOR.

The gross collector array area is 6,254 square feet. The collectors face in a southwesterly direction at a tilt of 55 degrees from the horizontal. The orientation of the collectors is close to the optimum orientation for a system of this type. The site latitude is 39 degrees North. (Optimum collector orientation is due South at a tilt of 45 degrees.)

The collector panels have double glass covers and a selective absorber surface. The absorber surface has a solar absorptivity of 0.87 and an infrared emissivity of 0.07. Total solar transmissivity of the glazing is 0.07. The absorber surface is composed of black, nonelectrolytic thin-film oxide coated copper. The fluid circulated through the collectors is 50% propylene glycol/water. Insulation is 2.5 inches thick, with an R-value of 10.

Storage - Storage consists of two insulated galvanized steel 5,000-gallon capacity preheat tanks located in the parking garage. Each tank has six inches of glass fiber sheathed with 0.02 inches of aluminum sheet, with a lining of epoxy plastic. The tanks were made by RECO, Incorporated. The overall R-value is approximately 26. Water is used as the medium to transfer solar energy to the DHW system.

Hot Water - City water is preheated and stored in the two 5,000-gallon preheat tanks. When solar energy is insufficient to satisfy the DHW load, a gas furnace provides auxiliary energy for heating the water from the preheat tanks. Solar energy is transferred from the preheat tanks to the furnace.

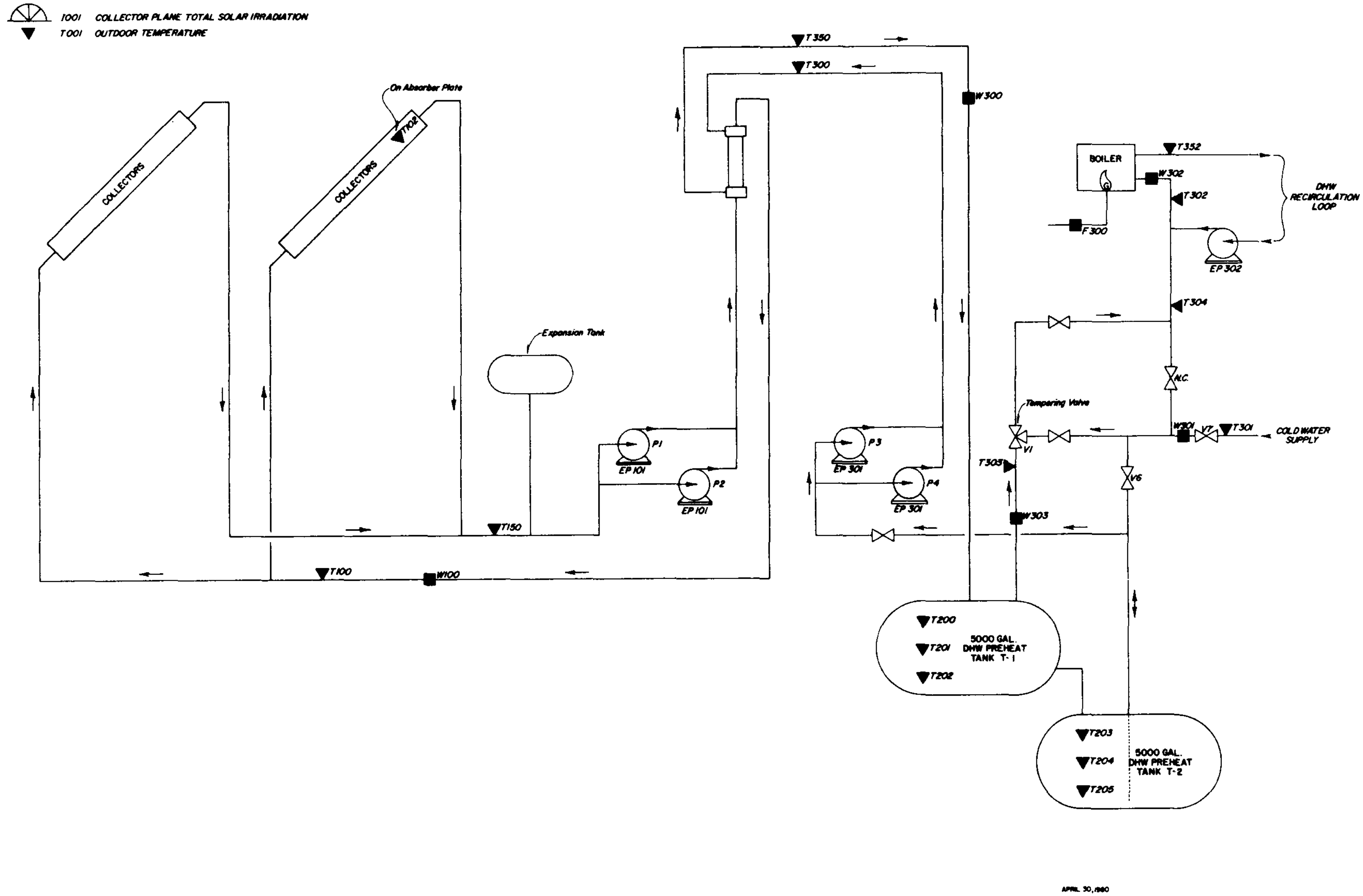


Figure A-1. Hogate's Restaurant Solar Energy System Schematic

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

The performance of the Hogate's Restaurant 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.

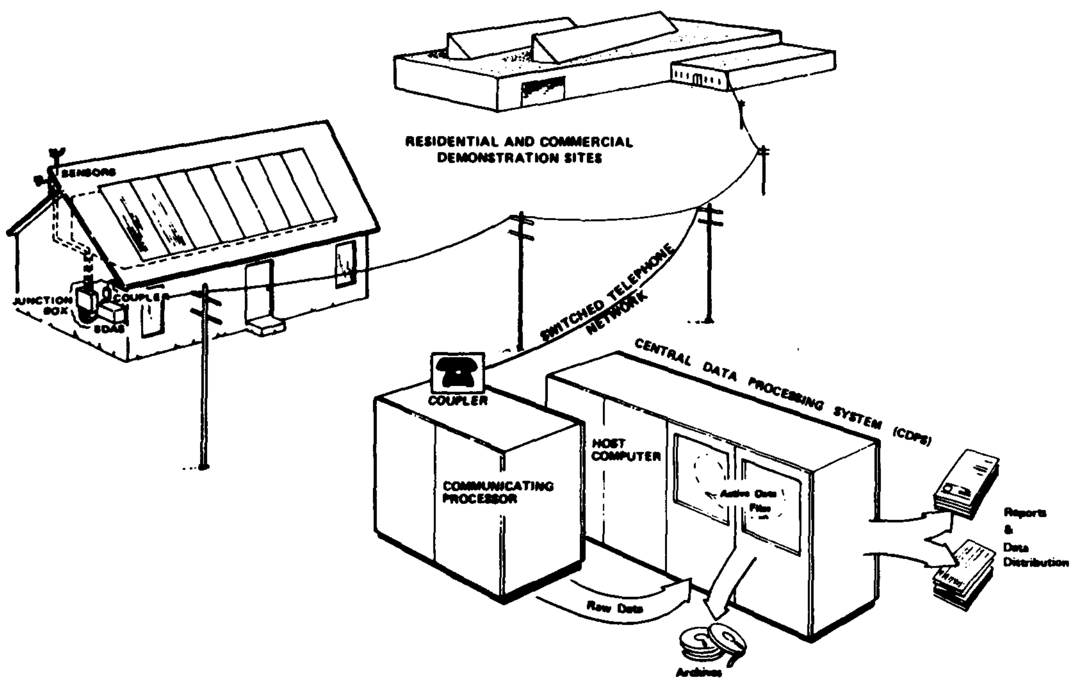


Figure B-1. The National Solar Data Network

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 Hogate's Restaurant 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:

June 1978, SOLAR/2028-78/06
July 1978, SOLAR/2028-78/07
August 1978, SOLAR/2028-78/08
October 1978, SOLAR/2028-78/10
March 1979, SOLAR/2028-79/03
April 1979, SOLAR/2028-79/04
May 1979, SOLAR/2028-79/05
June 1979, SOLAR/2028-79/06
July 1979, SOLAR/2028-79/07
August 1979, SOLAR/2028-79/08
September 1979, SOLAR/2028-79/09
October 1979, SOLAR/2028-79/10
January 1980, SOLAR/2028-80/01
February 1980, SOLAR/2028-80/02
March 1980, SOLAR/2028-80/03
July 1980, SOLAR/2028-80/07
August 1980, SOLAR/2028-80/08
September 1980, SOLAR/2028-80/09
October 1980, SOLAR/2028-80/10
November 1980, SOLAR/2028-80/11
December 1980, SOLAR/2028-80/12

Solar Energy System Performance Evaluation:

SOLAR/2028-78/14

Solar Project Description:

SOLAR/2028-78/50

Solar Project Cost Report:

SOLAR/2028-78/60

Thermal Performance Evaluation of Hogate's Restaurant Solar Energy Hot Water System:

SOLAR/2028-78/35

* 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.

* 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.

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

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: $\frac{Ti-Ta}{I}$ $\frac{°F \times hr. \times sq.\ ft.}{BTU}$
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 which uses architectural components of the building to collect, distribute and store solar energy.
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 lbsses.
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

HOGATE'S RESTAURANT

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

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

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.

Letter Designations

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

EQUATIONS USED TO GENERATE MONTHLY PERFORMANCE VALUES

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)

$$SECA = \Sigma\ [M100 \times (T150 - T100) \times CPP50W\ [(T100 + T150)/2]] \times \Delta\tau$$

SOLAR ENERGY TO STORAGE (BTU)

$$STEI = \Sigma\ [M300 \times HWD \times (T350 - T300)] \times \Delta\tau$$

SOLAR ENERGY FROM STORAGE (BTU)

$$STEO = \Sigma\ [M303 \times HWD \times (T200, T301)] \times \Delta\tau$$

AVERAGE TEMPERATURE OF STORAGE (°F)

$$TSTM = \Sigma\ [(T201 + T202 + T203 + T204 + T205 + T200)/6] \times \Delta\tau$$
$$TST = (1/60) \times \Sigma\ (TSTM) \times \Delta\tau$$

ENERGY DELIVERED FROM ECSS TO SPACE HEATING SUBSYSTEM (BTU)

$$CSEO = STEO$$

ECSS OPERATING ENERGY (BTU)

$$CSOPE = EPCONST \times \Sigma\ (EP101 + EP301) \times \Delta\tau$$

when system is in the collector-to-storage mode

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

$$SEA = CLAREA \times SE$$

COLLECTED SOLAR ENERGY (BTU)

$$SEC = SECA/CLAREA$$

COLLECTOR ARRAY EFFICIENCY

$$CLEF = SECA/SEA$$

COLLECTOR ARRAY OPERATIONAL EFFICIENCY

$$CLEFOP = SECA/SEOP$$

CHANGE IN STORED ENERGY (BTU)

$$STECH = IEL - IEF \text{ (HOURLY)}$$
$$STECH = IELM - IEFM \text{ (MONTHLY)}$$

STORAGE EFFICIENCY

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

SOLAR ENERGY TO LOAD SUBSYSTEMS (BTU)

$$SEL = HWSE$$

EFFECTIVE HEAT TRANSFER COEFFICIENT

$$STPER = SURF\_AREA \times (TST - TA) \qquad \text{(SURF\_AREA = 1,356.5 SQUARE FEET)}$$

STORAGE MASS SPECIFIC HEAT PRODUCT

$$STM\_CP = TST \times CP(TST) \times RHO(TST) \times STOCAP \qquad \text{(STOCAP = 10,000 GALLONS)}$$

STORAGE LOSS

$$STLOSS = STEI - STEO - STECH$$

ESCC SOLAR CONVERSION EFFICIENCY

$$CSCEF = SEL/SEA$$

HOT WATER SOLAR ENERGY USED (BTU)

$$HWSE = STEO$$

HOT WATER LOAD (BTU)

$$HWL = HWSE + HWAT$$

HOT WATER DEMAND (BTU)

$$HWDM = \Sigma\ [M301 \times HWD\ (T352,\ T301)] \times \Delta\tau$$

HOT WATER OPERATING ENERGY (BTU)

$$HWOPE = \Sigma\ (EP302 \times EPCONST) \times \Delta\tau$$

HOT WATER AUXILIARY FOSSIL ENERGY (BTU)

$$HWAF = \Sigma\ (FCON \times FD300) \times \Delta\tau$$

HOT WATER CONSUMPTION (GALLONS)

$$HWCSM = \Sigma\ [WD301] \times \Delta\tau$$

HOT WATER AUXILIARY THERMAL ENERGY (BTU)

$$HWAT = \Sigma\ [M302 \times HWD\ (T352,\ T302)] \times \Delta\tau$$

HOT WATER FOSSIL ENERGY SAVINGS (BTU)

$$HWSVF = HWSE/0.6$$

SUPPLY WATER TEMPERATURE (°F)

$$TSW = \Sigma\ [(M301 \times T301)/M301] \times \Delta\tau$$

HOT WATER TEMPERATURE (°F)

$$THW = \Sigma\ [M301 \times T352)/M301] \times \Delta\tau$$

HOT WATER TANK TOTAL ENERGY (BTU PER HR)

$$TANKV = STOCAP \times [[RHO\ (THW) \times CP\ (THW) \times THW] - [RHO\ (TSW) \times CP\ (TSW) \times TSW]]$$

HOT WATER SOLAR FACTION (PERCENT)

HWSFR = [HWSE/(HWSE + HWAT)] x 100

HOT WATER PREVIOUS SOLAR FRACTION (PERCENT)

HWSFR_P = HWSFR

HOT WATER DEMAND SOLAR FRACTION (PERCENT)

HWDSFR = [(HWSE/(HWAT + HWSE)) x (1-TEMP) + (HWSFR_P/100) x TEMP] x 100

where TEMP = EXP[-(HWAT + HWSE)/TANKV]

HOT WATER PREVIOUS SOLAR FRACTION (PERCENT)

HWDSFR_P = HWDSFR

ELECTRIC CONVERSION CONSTANT

EPCONST = 56.8833

FOSSIL CONVERSION CONSTANT

FCON = 1,000

SYSTEM LOAD

SYSL = HWL

SYSTEM OPERATING ENERGY (BTU)

SYSOPE = CSOPE + HWOPE

AUXILIARY THERMAL ENERGY (BTU)

AXT = HWAT

AUXILIARY FOSSIL ENERGY (BTU)

AXF = HWAF

SYSTEM SOLAR FRACTION

SFR = HWSFR

TOTAL ELECTRICAL ENERGY SAVINGS

TSVE = -CSOPE

TOTAL FOSSIL ENERGY SAVINGS

TSVF = HWSVF

TOTAL ENERGY CONSUMED

TECSM = SYSOPE + SECA + AXF

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.

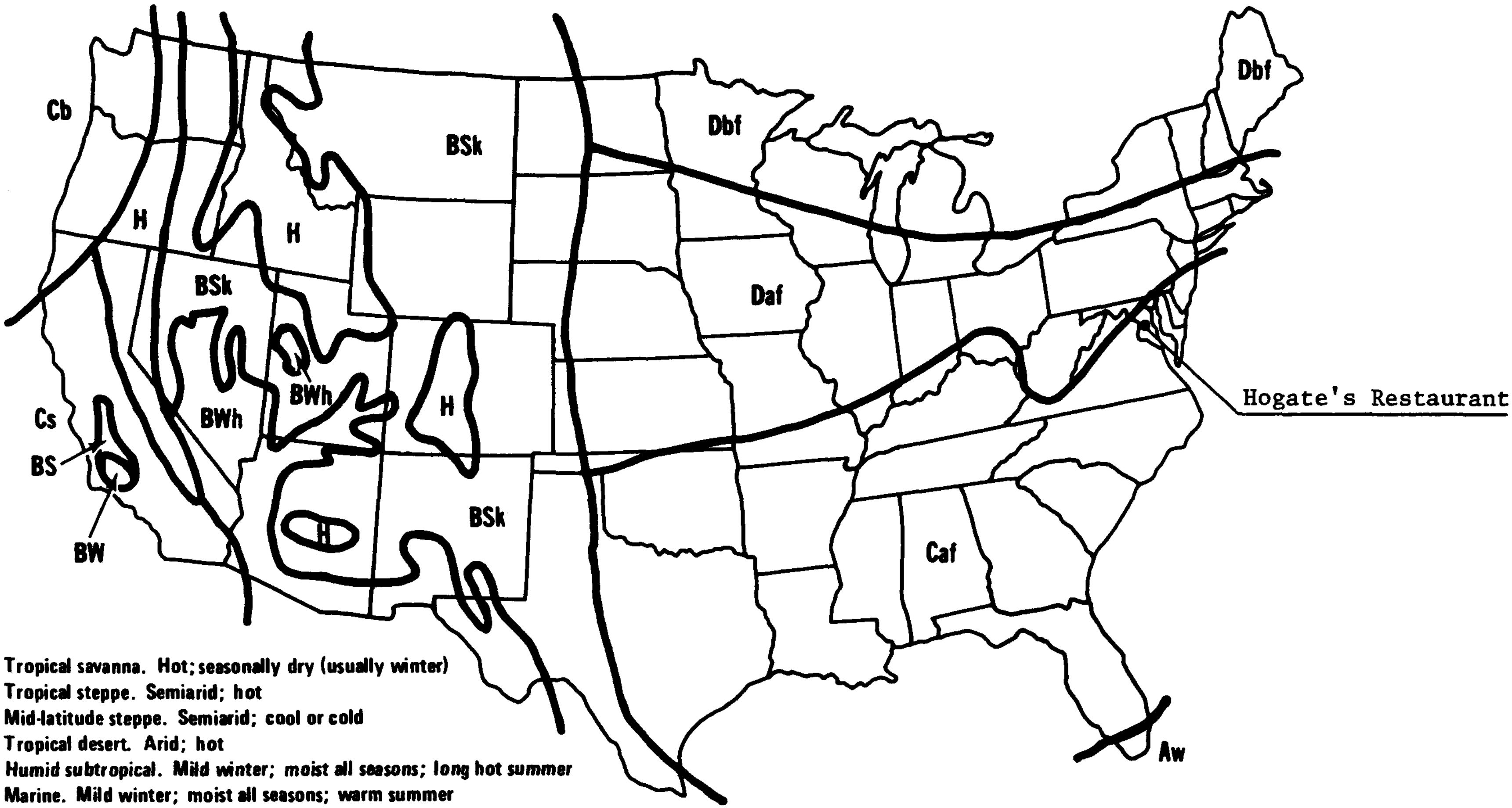
Ref:

(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)

APPENDIX F

METEOROLOGICAL CONDITIONS



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 Hogate's Restaurant Location

HOGATE'S RESTAURANT LONG-TERM WEATHER DATA

COLLECTOR TILT: 55 DEGREES
LATITUDE: 39 DEGREES

LOCATION: WASHINGTON, D.C.
COLLECTOR AZIMUTH: 45 DEGREES

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
JAN	1,380	571	0.41409	1.443	825	1,020	0	32
FEB	1,841	815	0.44269	1.264	1,030	874	0	34
MAR	2,432	1,125	0.46234	1.088	1,223	719	0	42
APR	3,043	1,460	0.47987	0.941	1,374	367	0	53
MAY	3,468	1,718	0.49542	0.843	1,449	131	57	63
JUN	3,639	1,902	0.52276	0.800	1,523	5	188	71
JUL	3,548	1,818	0.51230	0.820	1,490	0	319	75
AUG	3,202	1,619	0.50550	0.899	1,456	0	267	74
SEP	2,649	1,342	0.50665	1.036	1,391	43	100	67
OCT	2,011	1,003	0.49861	1.228	1,232	291	9	56
NOV	1,486	653	0.43906	1.409	920	609	0	45
DEC	1,254	483	0.38526	1.476	713	961	0	34

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: HOGATE'S RESTAURANT
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	551	38	44
2	1157	36	40
3	1256	38	45
4	52	31	30
5	97	29	29
6	1519	31	38
7	45	35	36
8	857	38	42
9	363	36	38
10	775	33	37
11	32	42	42
12	170	38	37
13	277	32	33
14	33	40	39
15	781	45	50
16	1219	46	56
17	113	42	42
18	23	42	43
19	1446	41	46
20	1392	40	46
21	1629	38	45
22	35	41	42
23	850	37	40
24	599	26	29
25	214	35	36
26	1386	37	40
27	639	33	36
28	229	36	39
29	531	33	36
30	747	25	27
31	780	24	25
SUM	19798	-	-
AVG	639	36	39

MONTHLY REPORT: HOGATE'S RESTAURANT
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	1703	21	25
2	1730	22	27
3	1724	24	28
4	1667	27	32
5	1518	30	35
6	120	28	28
7	1661	31	35
8	1538	33	38
9	255	32	35
10	1195	30	31
11	1392	32	37
12	1803	31	33
13	1754	32	40
14	1352	40	49
15	434	40	41
16	741	36	40
17	1866	26	29
18	1577	30	37
19	1312	38	46
20	1550	45	56
21	1517	51	58
22	*	*	*
23	361	47	*
24	982	51	57
25	241	39	39
26	1701	32	34
27	688	34	39
28	108	28	28
29	1754	22	25
SUM	35466	-	-
AVG	1223	33	37

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: HOGATE'S RESTAURANT
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	340	16	17
2	982	19	19
3	2047	27	31
4	1078	37	42
5	850	45	46
6	1696	43	46
7	715	49	55
8	594	60	65
9	1717	50	52
10	1068	49	57
11	2030	41	38
12	1138	35	37
13	7	33	31
14	1205	38	42
15	1972	44	50
16	1694	48	56
17	165	55	54
18	1978	49	49
19	1245	48	56
20	688	55	62
21	274	53	60
22	852	40	40
23	1943	46	54
24	133	47	50
25	1007	48	53
26	1560	44	50
27	1899	49	58
28	277	46	51
29	381	52	54
30	418	54	59
31	178	43	43
SUM	32131	-	-
AVG	1036	44	48

MONTHLY REPORT: HOGATE'S RESTAURANT
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	1051	47	*
2	1594	55	61
3	1397	59	66
4	1123	58	66
5	2001	52	55
6	1808	58	67
7	656	58	66
8	698	62	69
9	*	*	*
10	*	*	*
11	*	*	*
12	*	*	*
13	*	*	*
14	*	*	*
15	*	*	*
16	*	*	*
17	1956	48	54
18	1928	57	66
19	1697	63	74
20	1723	67	*
21	1996	66	72
22	1568	65	70
23	1633	63	68
24	1367	66	77
25	1243	63	71
26	53	51	49
27	117	52	53
28	70	54	55
29	1495	60	67
30	458	55	58
SUM	37680	-	-
AVG	1256	58	64

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: HOGATE'S RESTAURANT
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	901	60	67
2	994	66	73
3	1626	68	77
4	1795	71	79
5	1712	75	87
6	1169	74	87
7	1292	70	*
8	604	54	53
9	1205	54	59
10	1788	61	70
11	827	66	65
12	1313	75	86
13	1334	76	83
14	1589	69	*
15	1851	63	68
16	1758	66	73
17	960	65	73
18	875	66	67
19	568	69	80
20	317	66	68
21	292	62	65
22	1681	72	80
23	1291	74	83
24	861	72	81
25	989	73	77
26	1883	68	73
27	1576	66	72
28	1563	72	80
29	1488	74	84
30	1295	74	81
31	845	75	80
SUM	38245	-	-
AVG	1234	68	75

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: HOGATE'S RESTAURANT
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	1423	79	90
2	963	80	86
3	833	77	85
4	1594	70	73
5	1640	70	76
6	727	67	72
7	1130	79	91
8	1605	74	82
9	1509	66	82
10	1386	64	65
11	1557	66	73
12	1368	67	74
13	1676	70	81
14	1737	74	85
15	1039	75	92
16	475	67	67
17	1819	67	73
18	1482	69	76
19	1409	71	*
20	1723	69	71
21	1439	73	80
22	1594	77	87
23	1655	80	88
24	1161	79	84
25	1528	78	86
26	677	75	80
27	1335	83	92
28	1483	84	90
29	*	*	*
30	*	*	*
SUM	40680	-	-
AVG	1356	73	80

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: HOGATE'S RESTAURANT
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	RELATIVE HUMIDITY PERCENT
1	1739	76	85	I
2	1540	82	90	I
3	373	76	77	I
4	1583	81	86	I
5	1193	81	90	I
6	1860	79	84	I
7	1774	77	85	I
8	38	69	68	I
9	1332	80	88	I
10	1454	80	87	I
11	1622	83	91	I
12	1054	81	90	I
13	1844	79	84	I
14	1752	81	89	I
15	1558	83	89	I
16	1459	88	98	I
17	960	83	96	I
18	1765	83	92	I
19	1289	86	93	I
20	1411	90	96	I
21	1388	87	98	I
22	691	78	86	I
23	518	74	76	I
24	1173	78	86	I
25	1484	81	90	I
26	1453	83	92	I
27	1533	81	88	I
28	1092	81	87	I
29	1580	81	86	I
30	1285	82	91	I
31	1398	85	93	I
SUM	41195	-	-	-
AVG	1329	81	88	I

I DENOTES INVALID DATA.

MONTHLY REPORT: HOGATE'S RESTAURANT
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	RELATIVE HUMIDITY PERCENT
1	811	83	91	125
2	1274	87	96	120
3	1460	85	96	129
4	1203	83	92	135
5	908	83	96	135
6	1418	84	92	131
7	1535	86	95	138
8	1689	88	97	146
9	1294	87	93	148
10	1318	85	92	140
11	1433	85	95	141
12	1267	83	89	143
13	1358	80	85	141
14	1531	85	93	142
15	344	78	79	139
16	1666	73	77	124
17	1060	74	83	135
18	361	70	71	122
19	825	76	78	107
20	555	77	83	113
21	442	72	75	109
22	577	71	75	103
23	1136	75	81	110
24	1149	79	90	125
25	1593	81	91	135
26	1351	82	92	142
27	1605	84	95	144
28	1426	85	95	144
29	1116	83	93	138
30	1553	83	91	141
31	1073	84	89	137
SUM	36332	-	-	-
AVG	1172	81	88	132

MONTHLY REPORT: HOGATE'S RESTAURANT
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	1576	87	96
2	1426	87	96
3	1702	82	90
4	1121	80	89
5	1392	81	89
6	1577	82	93
7	1890	76	81
8	1788	78	85
9	1314	78	86
10	1905	72	76
11	1906	71	78
12	1751	76	88
13	1690	77	89
14	1067	78	87
15	1388	73	78
16	665	69	76
17	1181	78	85
18	793	74	78
19	1538	74	81
20	802	75	80
21	1152	79	88
22	1284	83	94
23	676	79	84
24	496	69	71
25	108	67	69
26	1931	68	72
27	1854	60	65
28	1792	64	72
29	1594	66	74
30	408	66	70
SUM	39768	-	-
AVG	1326	75	82

MONTHLY REPORT: HOGATE'S RESTAURANT
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	954	69	74
2	1164	68	76
3	68	56	56
4	1118	57	62
5	992	58	64
6	1839	57	64
7	1648	57	64
8	1674	62	71
9	1112	68	81
10	127	58	59
11	833	62	69
12	943	54	59
13	1308	51	56
14	1687	51	57
15	1582	60	70
16	1535	64	74
17	1372	67	63
18	552	67	75
19	1458	62	67
20	976	55	60
21	1683	60	70
22	1592	60	68
23	863	50	55
24	847	52	57
25	193	52	55
26	1449	45	49
27	1352	47	51
28	412	55	58
29	1180	47	50
30	1553	48	54
31	1648	50	60
SUM	35715	-	-
AVG	1152	57	63

MONTHLY REPORT: HOGATE'S RESTAURANT
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	1459	55	64
2	1627	45	52
3	1580	48	56
4	60	52	52
5	1112	50	55
6	1420	47	54
7	1114	57	64
8	947	62	70
9	918	55	61
10	1502	50	58
11	1688	41	44
12	1674	43	47
13	1062	51	58
14	577	54	58
15	133	51	53
16	1533	42	46
17	103	34	36
18	258	37	40
19	1918	38	43
20	1510	40	48
21	1453	43	49
22	1475	42	48
23	201	43	48
24	1	45	44
25	903	44	49
26	1181	40	46
27	252	40	41
28	42	40	39
29	134	39	40
30	1464	46	54
SUM	29300	-	-
AVG	977	46	51

MONTHLY REPORT: HOGATE'S RESTAURANT
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	1136	52	61
2	1324	53	61
3	1561	38	39
4	1409	36	41
5	1176	39	44
6	856	46	54
7	511	52	57
8	963	58	66
9	19	57	56
10	139	45	46
11	323	37	38
12	1058	41	44
13	195	45	48
14	1345	38	47
15	136	32	34
16	182	38	40
17	1438	32	34
18	769	37	41
19	514	38	43
20	1425	20	22
21	1463	21	26
22	769	26	30
23	884	32	36
24	13	30	30
25	1519	16	17
26	1106	20	24
27	293	27	28
28	57	35	36
29	534	42	45
30	1241	41	46
31	462	29	32
SUM	24821	-	-
AVG	801	37	41

APPENDIX G

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

Hogate's Restaurant used domestic hot water throughout the 1980 reporting period. During this time the solar system operated normally except for the periods in January and February when the leaky collector couplings and the collector pump were repaired. These problems and other instrumentation system and data collection problems that occurred during the year are listed below.

Date	Event
1/80	Expansion couplings replaced, system down until January 21. Pump P1 inoperative between January 28 and February 8.
3/80	Flow meters W301 and W303 inoperative.
4/80	Data communications problem 9-16 March.
10/80	Flow meters W301 and W303 replaced but not calibrated until end of year.

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 1,000-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/ft^2-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 shadowband 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 gauge bridge. This strain gauge 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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