SOLAR/1041-81/14
(DE81028174)
Distribution Category UC-59

FOREST CITY DILLON

WASHINGTON, D.C.

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

JANUARY 1980 THROUGH DECEMBER 1980

Prepared by David W. Missal

Approved: D. Roha

D. M. Roha
Program Manager

Vitro Laboratories Division
Automation Industries, Inc.
14000 Georgia Avenue
Silver Spring, Maryland 20910

The National Solar Data Network
Department of Energy Contract Number DE-AC01-79CS30027
Contract Management by:
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

A. A. Longnecker, Project Manager

Blank Page

FOREWORD

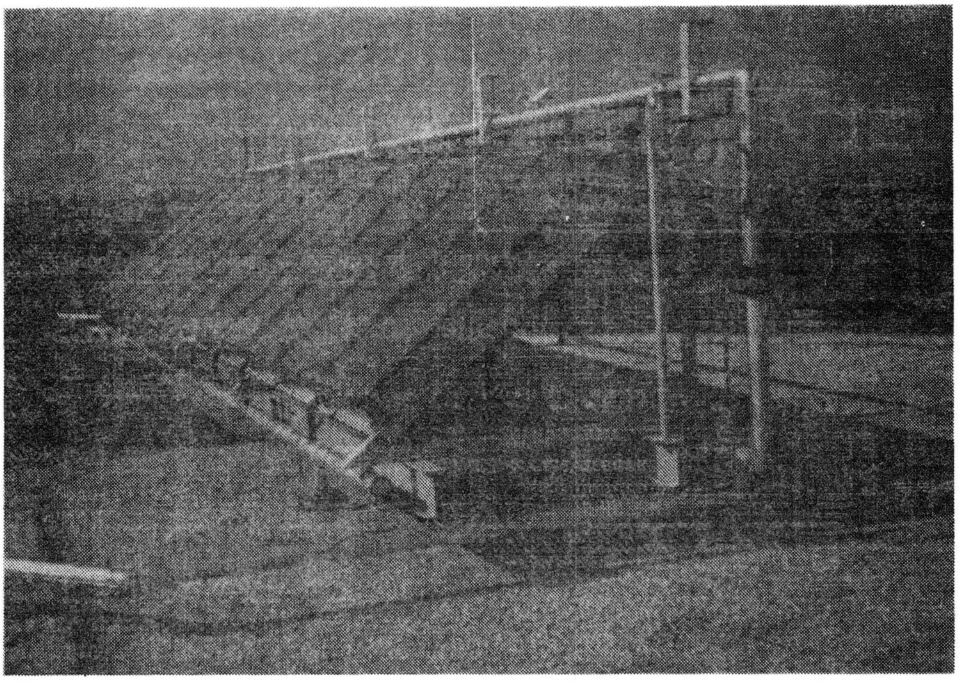
This report is one of a series which describes the performance of solar energy systems in the National Solar Data Network (NSDN) for the entire heating or cooling season. Domestic hot water is also included, if there is a solar contribution. Some NSDN installations are used solely for heating domestic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



FOREST CITY DILLON

FOREST CITY DILLON

The Forest City Dillon site is the Fort Lincoln Senior Village 1 in Washington, D.C. The active solar energy system is designed to supply the following:

Annual Design Factors
(Million BTU)

	Total Load	Solar Contribution	% Solar
Hot Water	1,145.00	672.00	59

It is equipped with:

Collector 2,592 square feet of single-glazed flat-plate collectors manufactured by Lennox (Model #LCS-181S).

Storage 3,200-gallon liquid storage tank manufactured by National Tank and Manufacturing Company (#SW32553). The tank is located in the boiler room of the apartment building.

Auxiliary Oil-fired boiler, manufactured by Ace Tank and Heater Company (#V542G).

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION 1

SOLAR SYSTEM PERFORMANCE

FOREST CITY DILLON
JANUARY 1980 THROUGH DECEMBER 1980

Solar Fraction[1]	32%
Solar Savings Ratio[2]	0.30
Conventional Fuel Savings[3]	3,825 gallons of fuel oil
System Performance Factor[4]	0.89
Solar System COP[5]	17.52

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

	Total Load	Solar Contribution	% Solar
Hot Water	1,003.59	318.28	32

Environmental Data

	Measured	Long-Term
Outdoor temperature (average)	56°F	53°F
Heating degree-days	4,339	4,887
Cooling degree-days	1,406	850
Daily incident solar energy (average)	1,366 BTU/ft^2	1,298 BTU/ft^2

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

2. Solar Savings Ratio $= \dfrac{\text{Solar Energy Used by the Load Subsystem} - \text{Solar System Operating Energy}}{\text{Total Load}}$

3. Conventional Fuel Savings $\dfrac{\text{Solar Energy Used}}{138{,}690 \text{ (BTU per gallon) x } .60 \text{ (operational efficiency coefficient)}}$

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

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

1.1 SUMMARY AND CONCLUSIONS

The solar energy system at the Forest City Dillon site performed very well throughout the reporting period from January 1980 through December 1980 (excluding June). During the year, the solar system actually used 14% less solar energy than was predicted by the f-Chart version 4.0 computer simulation. This is considered to be a very good comparison. The f-Chart version 4.0 computer simulation for Forest City Dillon used measured weather, measured subsystem loads, computed hot water and storage tank losses, computed recirculation loop losses, and known physical parameters for the solar equipment at the site. The predicted amount of solar energy delivered to storage was 374.72 million BTU compared to an actual 328.52 million BTU. The amount of solar energy used was 318.28 million BTU compared to a predicted 371.98 million BTU. The predicted annual solar fraction was 37%, compared to the actual solar fraction of 32%.

The thermal performance of the solar system during 1980 is summarized in Table 1.

Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

FOREST CITY DILLON
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[1]	FOSSIL		FOSSIL	ELECTRICAL	PREDICTED	MEASURED
JAN	14.80	119.33	18.79	14.70	170.66	3.33	24.50	-0.90	17	12
FEB	27.40	106.09	26.50	25.68	132.17	3.94	42.80	-1.46	26	25
MAR	33.56	111.81	31.86	28.85	136.47	3.59	48.08	-1.82	29	26
APR	21.42	92.42	35.29	20.00	120.34	3.90	33.33	-1.07	39	22
MAY	21.39	80.11	39.08	20.24	99.59	4.17	33.73	-1.23	48	25
JUN	*	*	*	*	*	*	*	*	*	*
JUL	48.58	65.69	46.47	45.02	34.44	3.02	75.03	-2.67	69	69
AUG	52.03	61.42	47.88	42.74	31.08	3.29	71.23	-2.79	79	70
SEP	39.14	61.24	38.57	37.88	37.77	2.45	63.13	-2.17	63	62
OCT	36.88	89.42	37.12	34.09	91.88	2.88	56.82	-1.65	42	38
NOV	31.22	103.52	28.60	30.06	120.17	2.31	50.10	-1.35	28	29
DEC	19.38	112.54	21.82	19.02	150.26	2.19	31.70	-1.06	21	17
TOTAL	345.80	1,003.59	371.98	318.28	1,124.83	35.07	530.45	-18.17	-	-
AVERAGE	31.44	91.24	33.82	28.93	102.26	3.19	48.22	-1.65	37	32

*DENOTES UNAVAILABLE DATA.
[1]NOT INCLUDING NONSOLAR ENERGY GAINED BY THE STORAGE SUBSYSTEM. ALSO SEE STORAGE SUBSYSTEM, 2.2.

Solar system performance improved in general after changes were made at the site in June.

Operational collector efficiency, which averaged 41%, was very good throughout the year. The control system could use some adjustment to allow more collection time. Less than optimum operation of the controller resulted in a collector efficiency of 29%.

Losses from the domestic hot water subsystem were quite high, amounting to 47% of the hot water load of 1,003.59 million BTU. These losses were almost all due to the recirculation loop.

Storage performance of 97% was excellent during the reporting period. During many months, the storage tank gained energy from the boiler room since storage temperatures frequently were lower than the ambient boiler room temperature. This gain totaled 7.98 million BTU during the year.

Insolation during the reporting period averaged 1,366 BTU/ft^{2}day. This is five percent higher than the long term average of 1,298 BTU/ft^2-day. The average ambient temperature was also higher, 56°F compared to a long-term average of 53°F. Warmer outdoor temperatures resulted in only 4,339 heating degree-days compared to a long-term average of 4,887.

Data collection problems prevented analysis of the system performance during June.

1.2 OVERALL SYSTEM PERFORMANCE

During the year, the system performed approximately the same as the f-Chart version 4.0 prediction. System changes in June improved the system performance during the last six months of the year. The changes allowed the solar system to help maintain the recirculation loop water temperature. Additionally, the high temperature limit on storage was raised from 140°F to 160°F. This allowed more collection in the summer months when higher daytime storage temperatures are possible.

The flow of solar energy through the Forest City Dillon site for the 11-month reporting period from January 1980 through December 1980 (excluding June) is presented in Figure 1. This Energy Flow Diagram shows the amount of energy collected, transported, stored, consumed, or lost at each point in the system. Figure 2 shows the amount of solar and auxiliary energy consumed by the system each month. Operating energy, shown in solid black, is very small compared to solar energy used.

All of the solar system components had high average performance for the year. The collector array average operational efficiency was 41%. This is very good for liquid-medium flat-plate collectors. Overall storage efficiency was 97%. This was mainly due to low storage temperatures in relation to the ambient air temperature where the storage is located. The solar energy system supplied 92% of the collected solar energy to the hot water subsystem. All of the subsystems combined resulted in excellent overall performance for the year.

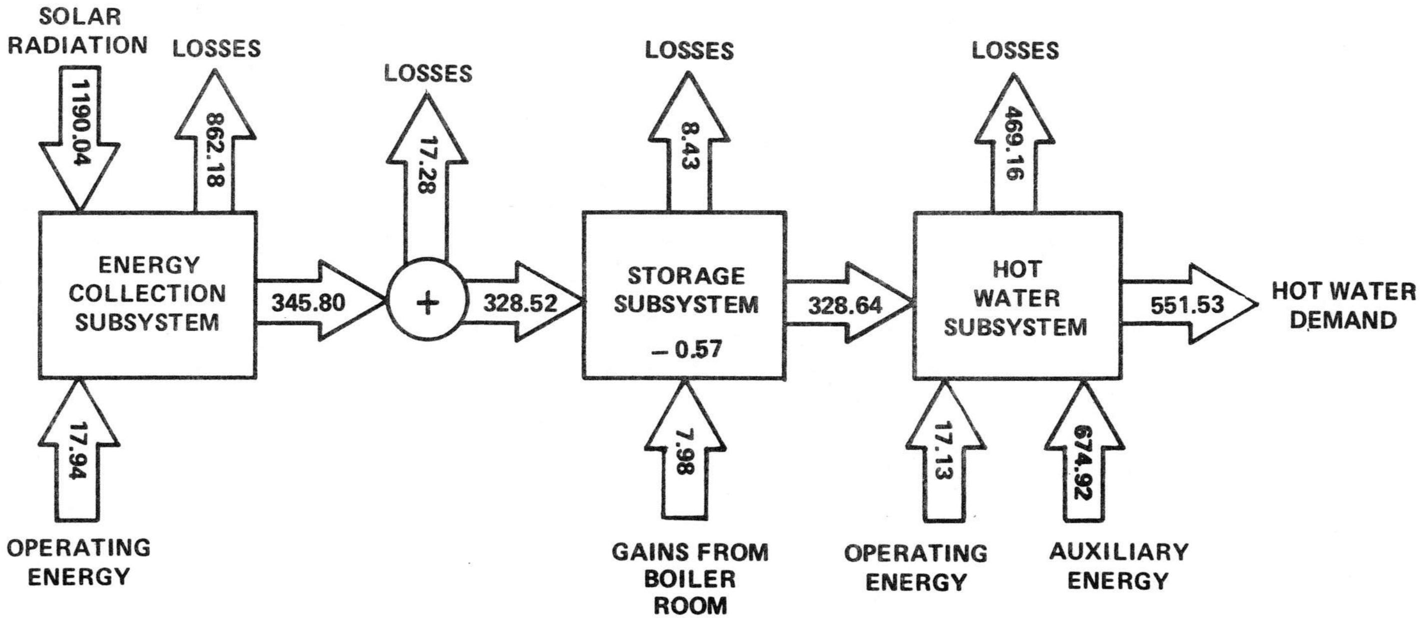


Figure 1. Energy Flow Diagram for Forest City Dillon
January 1980 through December 1980
(Figures in million BTU)

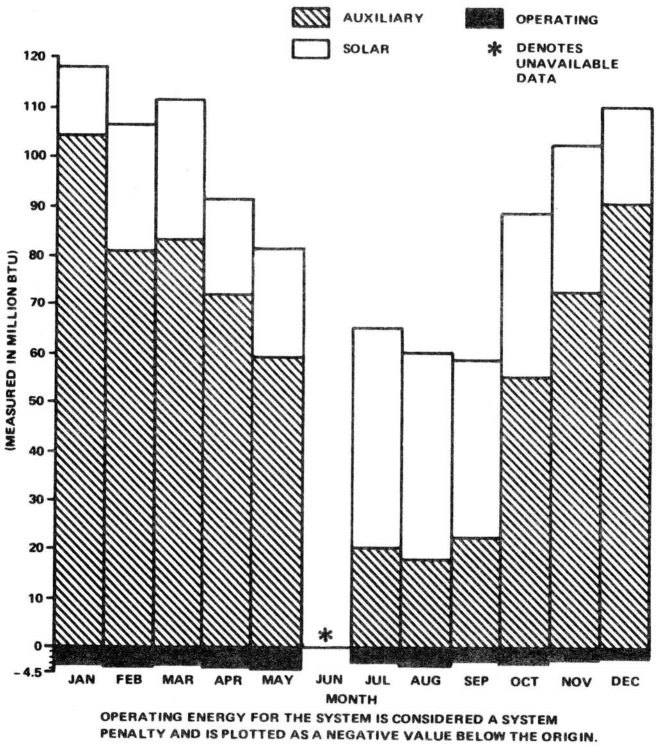


Figure 2. System Thermal Performance
Forest City Dillon
January 1980 through December 1980

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 Forest City Dillon functioned at a reporting period weighted average COP value of 17.52 for the period January 1980 through December 1980. The collector subsystem has a weighted average COP of 19.28 for the season.

The domestic hot water coefficient of performance was only calculated for the last four months of data. (No solar unique hot water subsystem operating energy was used prior to September.) November and December used almost no solar unique operating energy due to the low storage tank temperatures. The average COP for the four-month period was 539.17.

Table 2. SOLAR COEFFICIENT OF PERFORMANCE

FOREST CITY DILLON
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU)

MONTH	SOLAR ENERGY SYSTEM	COLLECTOR SUBSYSTEM	DOMESTIC HOT WATER SOLAR
JAN	16.33	16.39	N.A.
FEB	17.59	18.83	N.A.
MAR	15.85	18.40	N.A.
APR	18.69	19.94	N.A.
MAY	16.46	17.39	N.A.
JUN	*	*	N.A.
JUL	16.84	16.84	N.A.
AUG	15.31	18.67	N.A.
SEP	17.46	19.83	190.03
OCT	20.66	22.75	1,318.77
NOV	22.27	23.06	*
DEC	17.94	18.30	*
WEIGHTED AVERAGE	17.52	19.28	539.17

* DENOTES UNAVAILABLE DATA.
N.A. DENOTES NOT APPLICABLE (UNTIL ADDITION OF SOLAR SPECIFIC PUMP IN SEPTEMBER).

1.3 ENERGY SAVINGS

Solar energy system savings are realized whenever solar energy is used to help supply the hot water load at the site. To determine a net savings, the solar system operating energy required to collect and utilize solar energy is subtracted from the solar energy contribution to the loads.

The energy savings for Forest City Dillon during the 1980 reporting period are presented in Table 3 and shown graphically in Figure 3. The annual fossil fuel savings were 530.45 million BTU or 48.22 million BTU per month. This resulted in a 3,825-gallon reduction of oil consumption during the year or a savings or $3,765.15. These savings represent an annual savings of 1.48 gallons of fuel oil per square foot of gross collector area and 1.73 gallons of fuel oil per square foot of net aperture area.

The auxiliary water heating source at Forest City Dillon consists of an oil-fired boiler. This unit is considered to be 60% efficient for computational purposes.

Table 3. ENERGY SAVINGS

FOREST CITY DILLON
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU)

MONTH	SOLAR ENERGY USED	DOMESTIC HOT WATER		ECSS OPERATING ENERGY	ENERGY SAVINGS	
		ELECTRICAL	FOSSIL FUEL		ELECTRICAL	FOSSIL FUEL
JAN	14.70	N.A.	24.50	0.90	-0.90	24.50
FEB	25.68	N.A.	42.80	1.46	-1.46	42.80
MAR	28.85	N.A.	48.08	1.82	-1.82	48.08
APR	20.00	N.A.	33.33	1.07	-1.07	33.33
MAY	20.24	N.A.	33.73	1.23	-1.23	33.73
JUN	*	*	*	*	*	*
JUL	45.02	N.A.	75.03	2.67	-2.67	75.03
AUG	42.74	N.A.	71.23	2.79	-2.79	71.23
SEP	37.88	-0.20	63.13	1.97	-2.17	63.13
OCT	34.09	-0.03	56.82	1.62	-1.65	56.82
NOV	30.06	0.00	50.10	1.35	-1.35	50.10
DEC	19.02	0.00	31.70	1.06	-1.06	31.70
TOTAL	318.28	-0.23	530.45	17.94	-18.17	530.45
AVERAGE	28.93	-0.06	48.22	1.63	-1.65	48.22

*DENOTES UNAVAILABLE DATA.
N.A. - DENOTES NOT APPLICABLE (UNTIL ADDITION OF SOLAR SPECIFIC PUMP IN SEPTEMBER).

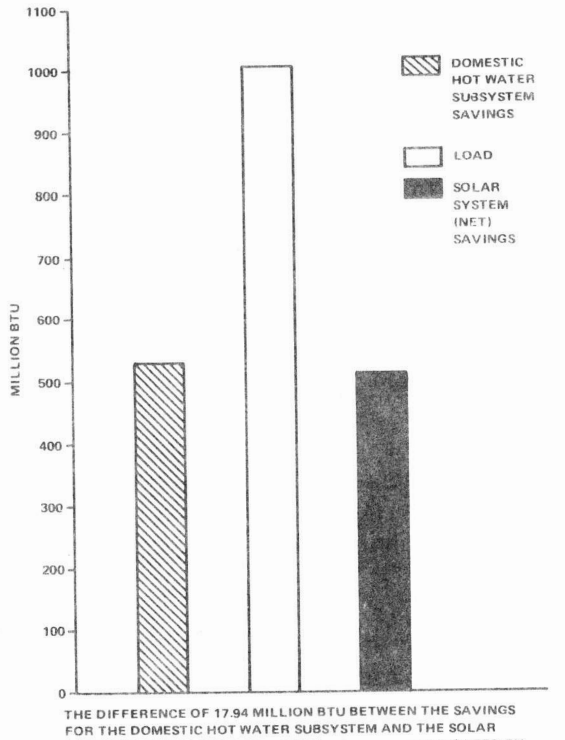


Figure 3. Combined Thermal Energy Savings Compared to Load
Forest City Dillon
January 1980 through December 1980

The monthly energy savings at the site varied from a low of 24.50 million BTU in January to a high of 75.03 million BTU in July. The variation in monthly savings resulted mainly from two factors. First, the site had several modifications during June which improved the system performance. The solar energy system average COP from January through May was only 16.89 compared to 17.86 for the period from July through December. Second, colder ambient temperatures and lower daily insolation levels during the winter months also had a marked effect on the monthly energy savings. Although consumption of hot water varied from 40,014 gallons/month in April to 111,183 gallons/month in August, this had no noticeable effect on energy savings. The reason for a high variation in hot water consumption is unknown at this time, but probably should be expected in large (188-unit) apartment buildings.

1.4 SOLAR ENERGY UTILIZATION

During the reporting period, the solar energy system delivered 92% of the collected solar energy to the hot water subsystem. This shows excellent performance during the year. The collector array captured 29% of the solar energy striking the array during the year. The losses of solar energy at different points in the subsystem are presented in Table 4 and are shown graphically in Figure 4.

Table 4. SOLAR ENERGY LOSSES

FOREST CITY DILLON
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED	SOLAR ENERGY TO STORAGE	LOSS COLLECTOR TO STORAGE (%)	CHANGE IN STORED ENERGY	HOT WATER SOLAR ENERGY FROM STORAGE
JAN	14.80	14.06	5	-0.64	14.70
FEB	27.40	26.03	5	0.35	25.68
MAR	33.56	31.88	5	-0.37	28.85
APR	21.42	20.35	5	1.07	20.00
MAY	21.39	20.32	5	0.29	20.24
JUN	*	*	*	*	*
JUL	48.58	46.15	5	0.29	45.02
AUG	52.03	49.43	5	0.11	42.74
SEP	39.14	37.19	5	-0.69	37.88
OCT	36.88	35.04	5	0.03	34.09
NOV	31.22	29.66	5	-0.40	30.06
DEC	19.38	18.41	5	-0.61	19.02
TOTAL	345.80	328.52	-	-0.57	318.28
AVERAGE	31.44	29.87	5	-0.05	28.93

*DENOTES UNAVAILABLE DATA.

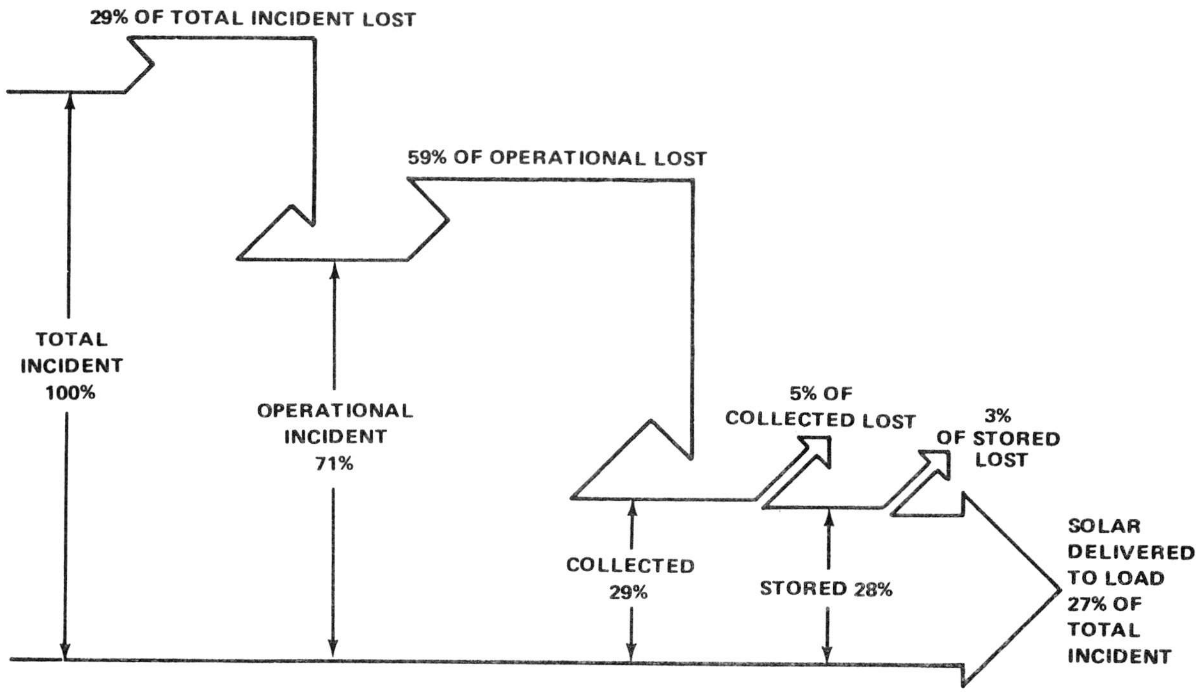


Figure 4. Solar Energy Use
Forest City Dillon
January 1980 through December 1980

Most of the losses in the solar energy system were from the domestic hot water subsystem. These losses were from hot water tank standby losses and recirculation loop losses.

Note that Hot Water Solar Energy from Storage column in Table 4 does not include the storage tank environmental gains. This column shows only the solar energy usage. The environmental storage tank gains are discussed in detail in Section 2.2, Storage.

SECTION 2

SUBSYSTEM PERFORMANCE

2.1 COLLECTOR

The Forest City Dillon collector array consists of 144 single-glazed, liquid medium, flat-plate collectors manufactured by Lennox (LSC-181S). The collectors, which use Brayco 888 for a transfer fluid, have a black chrome selective coating. The glazing, made by Clearlite, is a tempered, low-iron glass with a thickness of 0.125 inch. The collector array is composed of 12 subarrays, all located on the roof of the building. The subarrays all face six degrees East of due South at a tilt of 40 degrees to the horizontal. The collector subsystem performance for Forest City Dillon is presented in Table 5.

Table 5. COLLECTOR SUBSYSTEM PERFORMANCE

FOREST CITY DILLON
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	COLLECTOR ARRAY OPERATIONAL EFFICIENCY (%)	ECSS OPERATING ENERGY	SOLAR ENERGY FROM STORAGE	SOLAR ENERGY TO STORAGE	DAYTIME AMBIENT TEMPERATURE (°F)
JAN	61.85	14.80	24	37.91	39	0.90	14.70	14.06	38
FEB	102.52	27.40	27	74.53	37	1.46	25.68	26.03	37
MAR	104.07	33.56	32	77.86	43	1.82	28.85	31.88	51
APR	110.49	21.42	19	53.66	40	1.07	20.00	20.35	63
MAY	122.40	21.39	18	51.84	41	1.23	20.24	20.32	72
JUN	*	*	*	*	*	*	*	*	*
JUL	143.32	48.58	34	122.21	40	2.67	45.02	46.15	89
AUG	153.28	52.03	34	128.93	40	2.79	42.74	49.43	*
SEP	117.73	39.14	33	96.59	41	1.97	37.88	37.19	81
OCT	111.75	36.88	33	84.39	44	1.62	34.09	35.04	65
NOV	89.13	31.22	35	68.76	45	1.35	30.06	29.66	52
DEC	73.50	19.38	26	49.68	39	1.06	19.02	18.41	41
TOTAL	1,190.04	345.80	-	846.36	-	17.94	318.28	328.52	-
AVERAGE	108.19	31.44	29	76.94	41	1.63	28.93	29.87	59

*DENOTES UNAVAILABLE DATA.

The total incident solar radiation on the collector array for the period from January 1980 through December 1980 (excluding June) was 1,190.04 million BTU. During the time the collector pump was operating, the available solar radiation on the collector array was 846.36 million BTU, or just over 71% of the total solar insolation. Much of the remaining 343.68 million BTU (29%) could have been collected if the control activated the collector pump at the ideal time. Of the 846.36 million BTU of the operational solar insolation, 345.80 million BTU were collected. This resulted in a collector array efficiency of 29% compared to an operational collector efficiency of 41%. The large difference in these efficiencies results from less than optimum collector control operation. Collection of solar energy required 17.94 million BTU (5,253 kwh) of electrical energy for operation of collector pumps P1 and P2.

The collectors were operational throughout the year. On May 4, 7, 11 and 14, the collector subsystem did not start up. This was due to a high temperature limit switch set for 140°F on the storage tank. This limit was raised to 160°F during system changes occurring in June. After June, this was no longer a factor limiting solar collection. Data acquisition problems caused the loss of data for June; therefore, no solar system performance is given for that month. Collector array efficiency also improved after June. This was probably the result of site personnel changing the collector control set temperatures during the system changes. The somewhat lower collector efficiency in December was due to the approximate 14% shading of the collector array.

2.2 STORAGE

The solar energy storage tank at the Forest City Dillon site is a 3,200-gallon cylindrical steel tank manufactured by National Tank and Manufacturing Company (#SW32553). The tank is 13.5 feet high and 6.5 feet in diameter. Four inches of fiberglass (Owens Corning) is used for insulation. Evaluation of the system storage performance under actual solar energy system operation and weather conditions can be performed using the parameters listed in Footnote 1. The utility of these measured data in evaluation of the overall storage design is illustrated in Table 6.

---

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:

STEI = Solar Energy Input + Storage Tank Gain from Environment

STEFF = (STECH + STEO)/STEI

Where:
STEFF = Storage efficiency
STECH = Change in stored energy
STEO = Energy removed from storage
STEI = Energy added to storage
STOGAIN = Environmental gain by storage tank
STLOSS = STEI - STECH - STEO
[(STEI - STOGAIN)/STEI] x STLOSS = Losses from solar
(Solar Energy Input/STEI) x STEO = Solar portion of STEO

Table 6. STORAGE SUBSYSTEM PERFORMANCE

FOREST CITY DILLON
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU, unless otherwise indicated)

MONTH	TOTAL ENERGY TO STORAGE	TOTAL ENERGY FROM STORAGE	CHANGE IN STORED ENERGY	STORAGE EFFICIENCY (%)	AVERAGE STORAGE TEMP. (°F)	LOSS FROM STORAGE	STORAGE TANK GAIN FROM BOILER ROOM	SOLAR ENERGY INPUT	SOLAR ENERGY FROM STORAGE
JAN	16.34	16.93	-0.64	100	64	0.05	2.28	14.06	14.70
FEB	27.07	26.79	0.35	100	83	-0.07	1.04	26.03	25.68
MAR	33.07	29.93	-0.37	92	78	3.51	1.19	31.88	28.85
APR	20.57	20.21	1.07	100	104	-0.71	0.22	20.35	20.00
MAY	20.43	20.35	0.29	100	106	-0.21	0.11	20.32	20.24
JUN	*	*	*	*	*	*	*	*	*
JUL	46.16	45.02	0.29	98	122	0.85	0.01	46.15	45.02
AUG	49.46	42.74	0.11	87	117	6.61	0.03	49.43	42.74
SEP	37.26	38.58	-0.69	100	113	-0.63	0.07	37.19	37.88
OCT	35.25	34.29	0.03	97	108	0.93	0.21	35.04	34.09
NOV	30.76	31.42	-0.40	100	83	-0.26	1.10	29.66	30.06
DEC	20.13	22.38	-0.61	100	73	-1.64	1.72	18.41	19.02
TOTAL	336.50	328.64	-0.57	-	-	8.43	7.98	328.52	318.28
AVERAGE	30.59	29.88	-0.05	97	96	0.77	0.73	29.87	28.93

*DENOTES UNAVAILABLE DATA.

The storage tank at the site is located in the building's boiler room on the eleventh floor. Due to the large amount of heating equipment in this room, boiler room ambient temperatures commonly reach 100°F. Daily average storage temperatures have been as low as 47°F in December and January. The average storage temperature for the year was only 96°F. Because storage temperatures are often less than boiler room ambient temperatures, it is common for the storage tank to gain energy from the storage room. This is actually an advantage for the solar system and resulted in a calculated energy gain of 7.98 million BTU of waste heat in the boiler room (shown on Table 6). However, this auxiliary energy has caused much more difficulty in tracking solar energy through the storage tank. The amount of solar energy entering and leaving storage is shown on Table 6.

Storage performance, based on solar energy plus auxiliary boiler room gains, was over 97% during the year. High storage tank efficiency was expected at Forest City Dillon due to high boiler room temperatures and low average storage temperatures. The low average storage temperatures were the result of the high average daily hot water consumption during the year of 2,519 gallons per day.

2.3 DOMESTIC HOT WATER (DHW)

The domestic hot water subsystem used 328.64 million BTU of energy from storage and 674.92 million BTU of auxiliary thermal energy to satisfy a hot water load of 1,003.59 million BTU. Of the 328.64 million BTU supplied from storage, 318.28 million BTU (97%) were solar energy. The rest was comprised of environmental gains to storage from the boiler room. The solar fraction of this load was 32%. The hot water demand for the year was 551.53 million BTU. The solar fraction of the hot water demand (excluding losses) was 58%. Operating energy for the hot water subsystem was 17.13 million BTU (5,016 kwh). Losses from the domestic hot water system were 469.16 million BTU. Of this, only 8.12 million BTU were from calculated hot water tank standby losses (based on a 106.1 square foot tank surface area, 150°F hot water, 80°F average boiler room temperature, and U = 0.125). The remaining 461.04 million BTU were due mainly to recirculation loop losses. The average daily consumption was 2,519 gallons of water heated to an average temperature of 136°F. The average supply water temperature was 64°F. The domestic hot water subsystem performance for the Forest City Dillon site during the reporting period is shown in Table 7 and by graphic illustration in Figure 5.

Table 7. DOMESTIC HOT WATER SUBSYSTEM PERFORMANCE

FOREST CITY DILLON
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	SUP WATER TEMP (°F)	HOT WATER TEMP (°F)	HOT WATER CONSUMPTION (GAL)
JAN	119.33	12	44.93	14.70	2.43	102.40	170.66	49	125	69,697
FEB	106.09	25	38.31	25.68	2.48	79.30	132.17	46	123	59,345
MAR	111.81	26	61.99	28.85	1.77	81.88	136.47	51	123	104,994
APR	92.42	22	20.89	20.00	2.83	72.21	120.34	63	127	40,014
MAY	80.11	25	18.50	20.24	2.94	59.76	99.59	68	121	42,518
JUN	*	*	*	*	*	*	*	*	*	*
JUL	65.69	69	59.48	45.02	0.35	20.67	34.44	81	159	42,780
AUG	61.42	70	60.27	42.74	0.50	18.65	31.08	83	149	111,183
SEP	61.24	62	55.40	37.88	0.48	22.66	37.77	81	150	97,002
OCT	89.42	38	50.40	34.09	1.26	55.13	91.88	69	143	81,905
NOV	103.52	29	67.20	30.06	0.96	72.10	120.17	58	142	96,206
DEC	112.54	17	74.16	19.02	1.13	90.16	150.26	50	138	100,652
TOTAL	1,003.59	-	551.53	318.28	17.13	674.92	1,124.83	-	-	846,296
AVERAGE	91.24	32	50.14	28.93	1.56	61.36	102.26	64	136	76,936

*DENOTES UNAVAILABLE DATA.

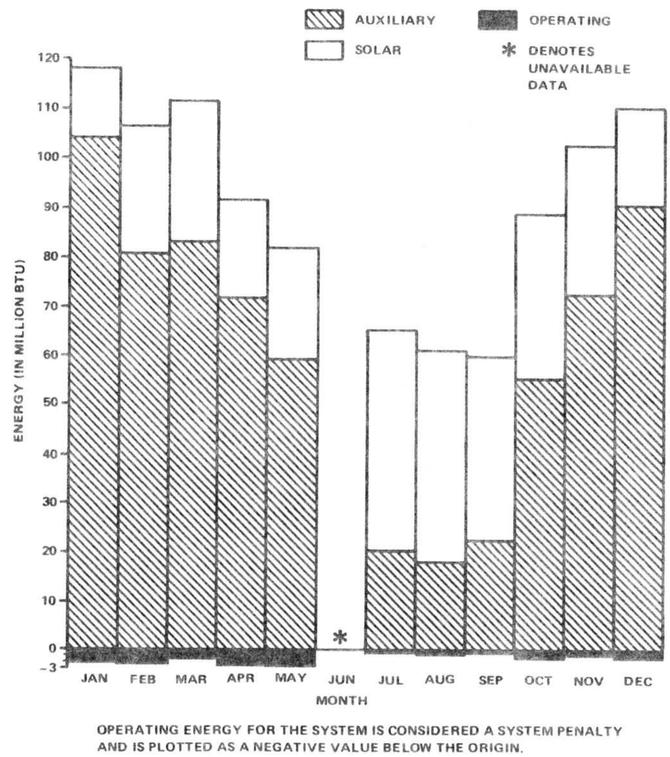


Figure 5. Domestic Hot Water Subsystem Performance
Forest City Dillon
January 1980 through December 1980

Approximately 46% of the total hot water load was composed of recirculation loop losses. The losses from July through September (the assumed cooling season) increased the cooling load by a calculated 12.44 million BTU. The losses during the remainder of the year (excluding June for which no data is available) reduced the heating load by a calculated 453.16 million BTU. Although 97% of the recirculation loop losses occurred during the assumed heating season, the losses in general are too high at 60% boiler efficiency; these losses required using 5,604 gallons of oil. If twice as much insulation had been used on all of the pipe run in the recirculation loop, the recirculation loop losses would be approximately 226.58 million BTU. This reduction of losses is over 71% of the amount of energy the solar system saved during the reporting period. The losses from July through September are low since the coupler on the recirculation loop pump was broken from July 15 until September 16.

The solar heated water rarely meets the entire load at this site. During periods of consumption, all preheated (solar) water from storage passes through the auxiliary heat exchanger en route to the hot water tank. The auxiliary heat exchanger is maintained at a set point of 150°F. Unless the preheated water is hotter than 150°F, some auxiliary heating occurs. Daily peak hot water demand generally occurs about 7:00 a.m. with a second somewhat lower peak about 5:00 p.m. The hot water demand profile for September is presented in Figure 6.

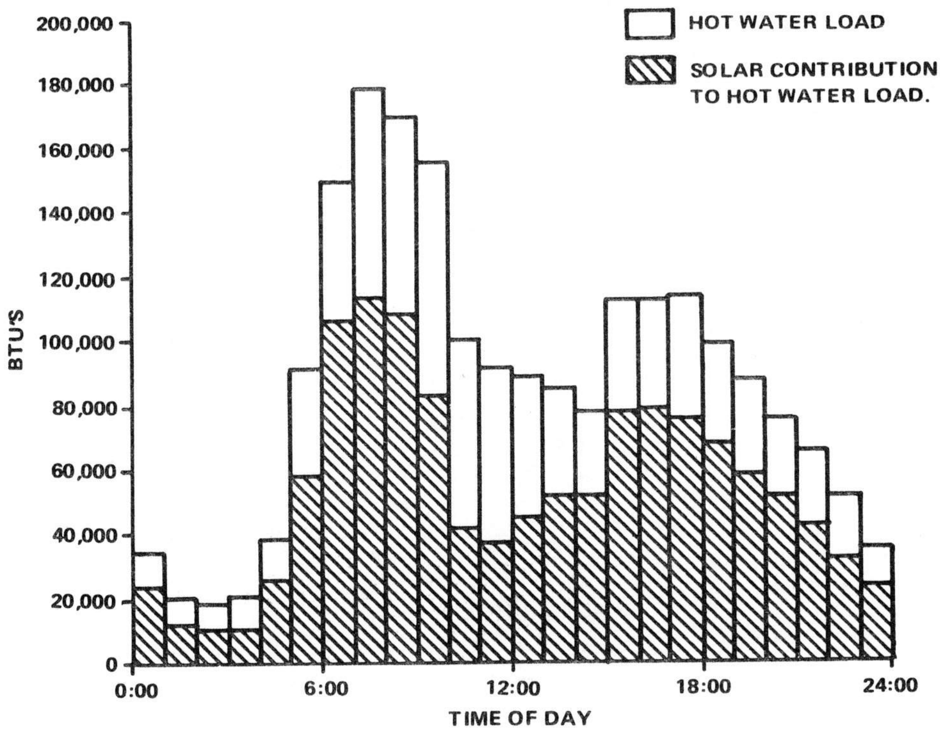


Figure 6. Hot Water Demand Average Hourly Performance
Forest City Dillon
September 1980

The site had several changes made in June. The storage tank high temperature limit was raised from 140°F to 160°F. This allowed more solar energy to be collected during the summer months. A piping modification allowed the recirculation loop return flow to pass through storage whenever storage is at least five degrees warmer than the return water temperature. Finally, an aquastat controller was installed on the recirculation loop pump. The aquastat tempers the hot water leaving the hot water tank when it exceeds 135°F. These modifications improved the system performance during the rest of the year. After the changes were made, the hot water subsystem periodically did route recirculation loop water through the storage tank. When this mode occurred, the hot water subsystem was charged solar unique operating energy due to operation of the recirculation pump.

SECTION 3

OPERATING ENERGY

The solar energy system used 35.07 million BTU of operating energy during the reporting period. Of this, the collector pumps (P1 and P2) used 17.94 million BTU. The remaining 17.13 million BTU were used by the pumps for the domestic hot water subsystem (pumps P4 and P5). Only 0.23 million BTU of hot water subsystem operating energy were solar unique. The solar unique operating energy was used from September through December after system changes allowed solar energy to help supplement the heat lost by the recirculation loop. Storage temperatures were rarely higher than the recirculation loop return temperature, so this mode rarely occurred. Measured monthly values for operating energies are presented in Table 8. The distribution of this energy is shown graphically in Figure 7.

Table 8. OPERATING ENERGY

FOREST CITY DILLON
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU)

MONTH	ECSS OPERATING ENERGY (SOLAR UNIQUE)	DHW OPERATING ENERGY		TOTAL SOLAR UNIQUE OPERATING ENERGY	TOTAL SYSTEM OPERATING ENERGY
		TOTAL	SOLAR UNIQUE		
JAN	0.90	2.43	N.A.	0.90	3.33
FEB	1.46	2.48	N.A.	1.46	3.94
MAR	1.82	1.77	N.A.	1.82	3.59
APR	1.07	2.83	N.A.	1.07	3.90
MAY	1.23	2.94	N.A.	1.23	4.17
JUN	*	*	N.A.	*	*
JUL	2.67	0.35	N.A.	2.67	3.02
AUG	2.79	0.50	N.A.	2.79	3.29
SEP	1.97	0.48	0.20	2.17	2.45
OCT	1.62	1.26	0.03	1.65	2.88
NOV	1.35	0.96	0.00	1.35	2.31
DEC	1.06	1.13	0.00	1.06	2.19
TOTAL	17.94	17.13	0.23	18.17	35.07
AVERAGE	1.63	1.56	0.06	1.65	3.19

* DENOTES UNAVAILABLE DATA.
N.A. DENOTES NOT APPLICABLE (UNTIL ADDITION OF SOLAR SPECIFIC PUMP IN SEPTEMBER).

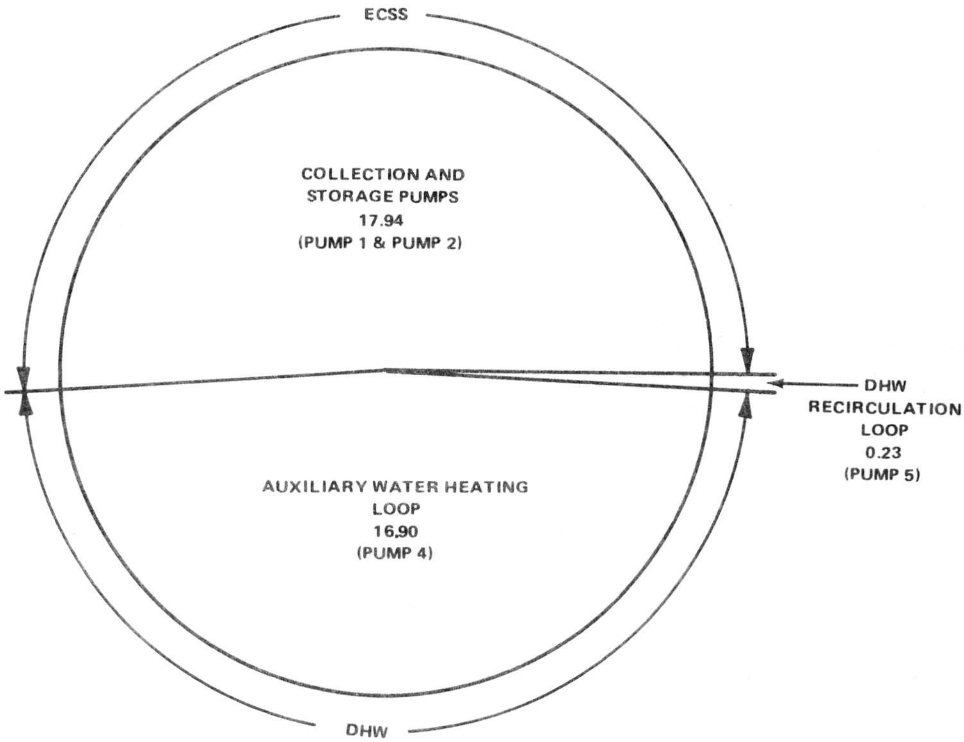


Figure 7. Total Operating Energy
Forest City Dillon
January 1980 through December 1980
(Figures in million BTU)

The overall electrical energy consumption by the pumps in the system is small in relation to the amount of solar energy the system used. The collectors collected over 19 times more energy than the collector pumps consumed.

The components which use operating energy in each subsystem are:

The energy collection and storage subsystem	Pump P1 Pump P2	Collector loop pump. Transfers energy from collector to loop to storage.
DHW (for auxiliary water heating)	Pump P4	Non-solar specific operating energy which transfers energy from boiler to hot water tank.
DHW (for recirculation loop)	Pump P5	Solar specific operating energy for recirculation loop.

SECTION 4

WEATHER CONDITIONS

The Forest City Dillon site 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

FOREST CITY DILLON
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	770	930	35	32	930	1,020	0	0
FEB	1,364	1,149	32	34	957	874	0	0
MAR	1,295	1,339	47	42	558	719	0	0
APR	1,421	1,472	58	53	214	367	4	0
MAY	1,523	1,540	67	63	37	131	63	57
JUN	*	*	*	*	*	*	*	*
JUL	1,784	1,580	81	77	0	0	496	319
AUG	1,908	1,552	81	74	0	0	496	267
SEP	1,514	1,507	73	71	9	14	316	182
OCT	1,391	1,368	57	60	236	192	30	25
NOV	1,146	1,035	46	45	553	609	1	0
DEC	915	805	37	34	845	961	0	0
TOTAL	-	-	-	-	4,339	4,887	1,406	850
AVERAGE	1,366	1,298	56	53	394	444	128	77

*DENOTES UNAVAILABLE DATA.

During the period from January 1980 through December 1980 (excluding June), the average daily total incident solar radiation on the collector array was 1,366 BTU per square foot per day. This radiation was above the estimated average daily solar radiation for this geographical area during the reporting period of 1,298 BTU per square foot per day for a south-facing plane with a tilt of 40 degrees to the horizontal. During the period, the highest monthly average insolation was 1,908 BTU per square foot per day during August. The average ambient temperature during the reporting period was 56°F, three degrees above the long-term average. The highest monthly average ambient temperature was 81°F during July and August. The lowest monthly average ambient temperature was 32°F during February. The number of heating degree-days for the period (based on a 65°F reference) was 4,339 as compared with the long-term average of 4,887. The range of heating degree-days was from a high of 957 heating degree-days during February to a low of zero heating degree-days during 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 61% during February to a low of 42% during January. The lowest monthly average insolation was 770 BTU/square feet/day during January.

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EXTRA-TERRESTRIAL INSOLATION	1,829	2,242	2,738	3,203	3,489	3,591	3,531	3,304	2,899	2,382	1,923	1,709
TTL INS / EXT INS (%)	42	61	47	44	44	*	51	58	52	58	60	54

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 March 1981, Parts 1, 2, and 3, SOLAR/0001-81/15, Vitro Laboratories, Silver Spring, Maryland.

*7. Monthly Performance Report, Forest City Dillon, January 1980, SOLAR/1041-80/01, Vitro Laboratories, Silver Spring, Maryland.

*8. Monthly Performance Report, Forest City Dillon, February 1980, SOLAR/1041-80/02, Vitro Laboratories, Silver Spring, Maryland.

*9. Monthly Performance Report, Forest City Dillon, March 1980, SOLAR/1041-80/03, Vitro Laboratories, Silver Spring, Maryland.

---

* 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, Forest City Dillon, April 1980, SOLAR/1041-80/04, Vitro Laboratories, Silver Spring, Maryland.

*11. Monthly Performance Report, Forest City Dillon, May 1980, SOLAR/1041-80/05, Vitro Laboratories, Silver Spring, Maryland.

*12. Monthly Performance Report, Forest City Dillon, July 1980, SOLAR/1041-80/07, Vitro Laboratories, Silver Spring, Maryland.

*13. Monthly Performance Report, Forest City Dillon, August 1980, SOLAR/1041-80/08, Vitro Laboratories, Silver Spring, Maryland.

*14. Monthly Performance Report, Forest City Dillon, September 1980, SOLAR/1041-80/09, Vitro Laboratories, Silver Spring, Maryland.

*15. Monthly Performance Report, Forest City Dillon, October 1980, SOLAR/1041-80/10, Vitro Laboratories, Silver Spring, Maryland.

*16. Monthly Performance Report, Forest City Dillon, November 1980, SOLAR/1041-80/11, Vitro Laboratories, Silver Spring, Maryland.

*17. Monthly Performance Report, Forest City Dillon, December 1980, SOLAR/1041-80/12, 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 Forest City Dillon site is a high-rise apartment building in Washington, D.C. The building has 188 apartments and a total of 124,000 square feet of living space. Solar energy is used to preheat the domestic hot water (DHW). Six individual apartments are instrumented with flow meters; however, the flow data are not used in the performance evaluation.

The solar energy system has 12 arrays of flat-plate collectors with a gross area of 2,592 square feet. The arrays face south at an angle of 40 degrees to the horizontal. The collectors are manufactured by Lennox, Model LSC-181S. A light hydrocarbon solution is the transfer medium that delivers solar energy from the collector arrays to a hot water heat exchanger. The control system is manufactured by RHO Sigma, Model RS104. Preheated water is stored in a 3,200-gallon storage tank and supplied, on demand, to a conventional 400-gallon hot water tank. When solar energy is insufficient to satisfy the total load, three oil-fired boilers provide auxiliary thermal energy. The system, shown schematically, has only one mode of solar operation.

Mode 1 - DHW Preheating - This mode activates when the temperature of the collector solar fluid exceeds the water temperature of the preheat storage tank by approximately 25 degrees. Pumps P1 and P2 are activated. The solar fluid passes through a heat exchanger, where heat is transferred to circulating water. The preheated water then flows through the storage tank until the preheated water temperature approximates the solar fluid temperature within 10 to 15 degrees. Pumps P1 and P2 then shut off.

As hot water is drawn from the DHW tank, it is replenished with preheated water from the storage tank. When necessary, the water can be heated further by an oil-fired heat exchanger. This conventional heat exchanger is in a DHW circulation loop containing pump P4. Pump P4 is activated when the DHW storage temperature drops below the 135°F service-water temperature requirement.

Pump P5 activates when the recirculation return temperature drops below a nominal 130°F. If the storage temperature is greater than the recirculation return temperature by a nominal 5°F, then recirculation flow is passed through storage to utilize solar energy.

SUBSYSTEM

Collector - The gross collector array area is 2,592 square feet. The collectors face in a southeasterly direction at an azimuth angle of six degrees East of South. The collectors are tilted to an altitude angle of 40 degrees from the horizontal.

The collector panels have one glass cover and a selective absorber surface. The absorber surface has a solar absorptivity of 0.94 and an infrared emissivity of 0.10. Total solar transmissivity of the glazing is 96%. The absorber surface is composed of a steel absorber plate with a black chrome coating. The fluid circulated through the collectors is Brayco 888 oil.

Storage - Solar energy storage is provided by a cylindrical steel storage tank, located in the boiler room of the building. The storage has two inches of fiberglass at the bottom and two inches of fiberglass on the top and side. Water is used as the medium to transfer solar energy to the DHW subsystem.

Hot Water - City water is preheated and stored in a 3,200-gallon storage tank and supplied, on demand, to a 400-gallon DHW tank. When solar energy is insufficient to satisfy the DHW load, the oil-fired boiler provides auxiliary energy for heating the supply water. Solar energy is transferred from the storage to the DHW tank during consumption. Water is used as the transfer medium. The design solar fraction is 59%.

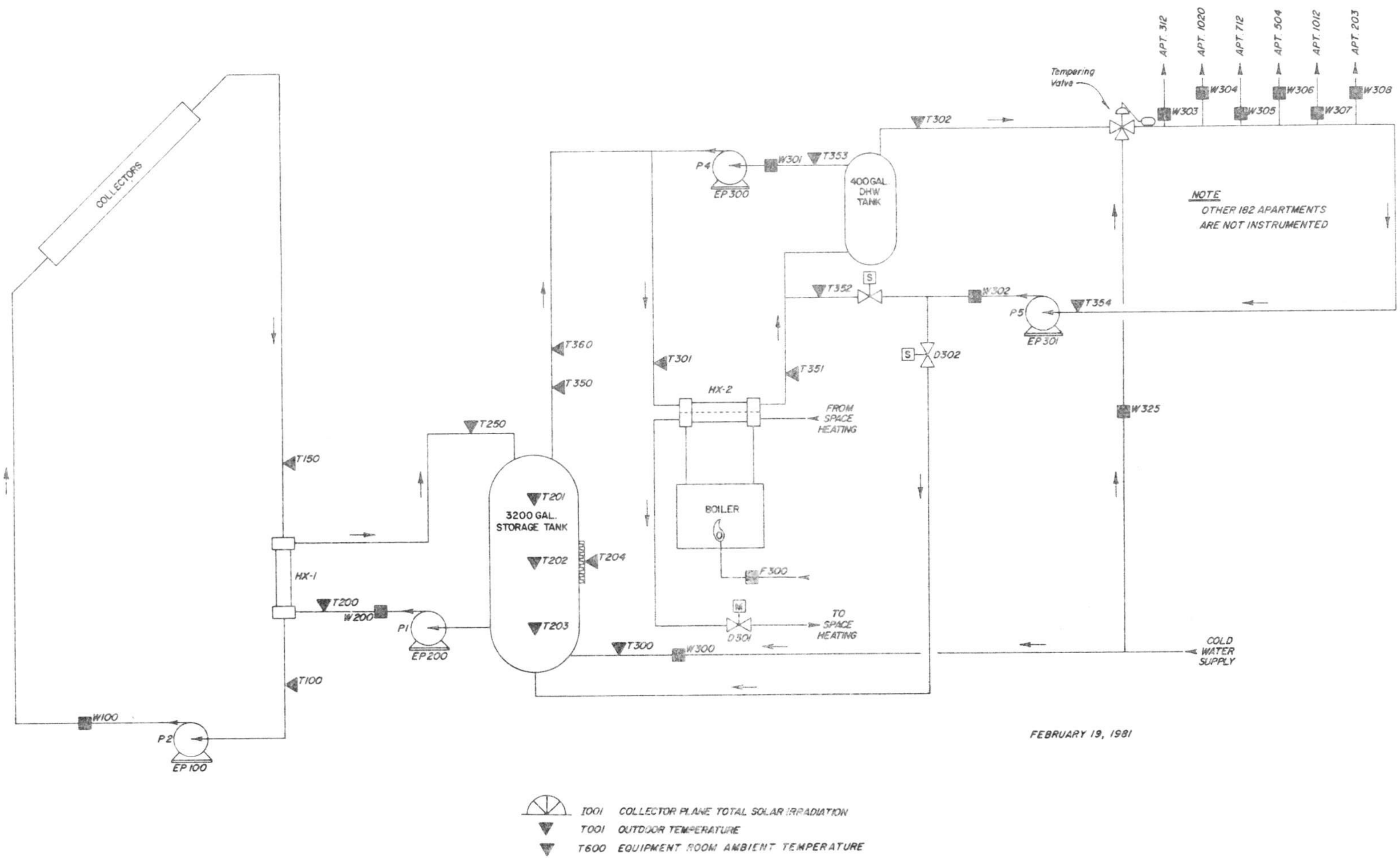


Figure A-1. Forest City Dillon Solar Energy System Schematic

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

The performance of the Forest City Dillon 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.

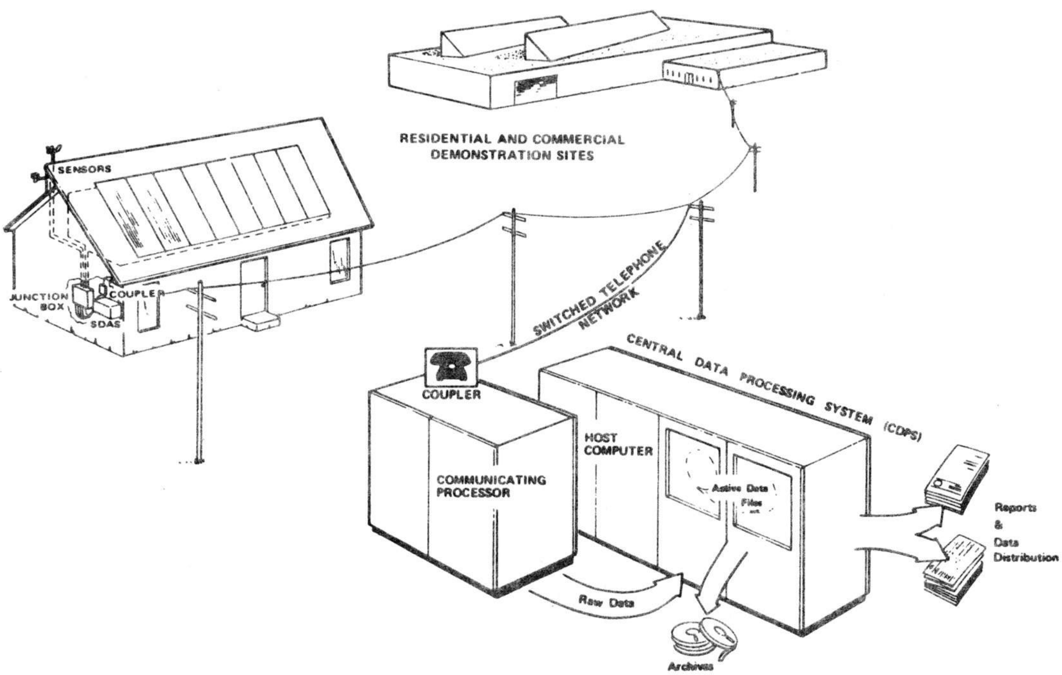


Figure B-1. The National Solar Data Network

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 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 320 second interval, and the average value is recorded in the tape.

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

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

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 data 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 scan interval. 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 computing 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 Forest City Dillon solar energy system from January 1980 through December 1980 (excluding June) was analyzed during the annual reporting season, 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 Report:

July 1979, SOLAR/1041-79/07
October 1979, SOLAR/1041-79/10
November 1979, SOLAR/1041-79/11
December 1979, SOLAR/1041-79/12
January 1980, SOLAR/1041-80/01
February 1980, SOLAR/1041-80/02
March 1980, SOLAR/1041-80/03
April 1980, SOLAR/1041-80/04
May 1980, SOLAR/1041-80/05
July 1980, SOLAR/1041-80/07
August 1980, SOLAR/1041-80/08
September 1980, SOLAR/1041-80/09
October 1980, SOLAR/1041-80/10
November 1980, SOLAR/1041-80/11
December 1980, SOLAR/1041-80/12

* These reports can be obtained (free) by contacting: U.S. Department of 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. Section 1 includes the acronym, 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 general acronyms used in this report.

SECTION 1. PERFORMANCE FACTOR DEFINITIONS AND ACRONYMS

ACRONYM	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.
CLAREA	Collector Array Area	The gross area of one collector panel multiplied by the number of panels in the array.
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.

* Primary Performance Factors

ACRONYM	NAME	DEFINITION
CSE	Solar Energy to SCS	Amount of solar energy delivered to the SCS.
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

ACRONYM	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

ACRONYM	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

ACRONYM	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

ACRONYM	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

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

* Primary Performance Factors

SECTION 2. SOLAR TERMINOLOGY

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

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

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

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

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

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

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

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

SECTION 3. GENERAL ACRONYMS

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

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

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

DHW — Domestic Hot Water.

ECSS — Energy Collection and Storage System.

HWS — Domestic or Service Hot Water Subsystem.

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

FOREST CITY DILLON

INTRODUCTION

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

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

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

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

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

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

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

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

For a liquid system ΔH is generally given by

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

where C_p is the average specific heat, in BTU/lb_m-°F, of the heat transfer fluid and ΔT, in °F, is the temperature differential across the heat exchanging component.

---

* See Appendix B.

For an air system ΔH is generally given by

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

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

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

For electrical power, a general example is

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

where EP100 is the power required by electrical equipment in kilowatts and the two factors (1/60) and 3,413 correct the data to BTU/min.

Letter Designations

C or CP	=	Specific Heat
D	=	Direction or Position
EE	=	Electric Energy
EP	=	Electric Power
F	=	Fuel Flow Rate
H	=	Enthalpy
HR	=	Humidity Ratio
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
_P	=	Appended to a function designator to signify the value of the function during the previous iteration

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

COLLECTOR AND STORAGE SUBSYSTEM OPERATING ENERGY

$$CSOPE = (EP100 + EP200) \times 56.8833$$

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

AVERAGE STORAGE ROOM TEMPERATURE (°F)

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

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

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

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

$$SEOP = SE \times \text{COLLECTOR AREA} \times (1/60) \times \Delta\tau$$

when the collector loop is active

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

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

SOLAR ENERGY TO STORAGE (BTU)

$$STEI = \Sigma\ [M200 \times CP \times (T250 - T200)] \times \Delta\tau$$

SOLAR ENERGY FROM STORAGE (BTU)

$$STEO = \Sigma\ [M300 \times CP \times (T350 - T300)] \times \Delta\tau$$

AVERAGE TEMPERATURE OF STORAGE (°F)

$$TST = (1/60) \times \Sigma\ [T201 + T202 + T203)/3] \times \Delta\tau$$

HOT WATER CONSUMED (GALLONS)

$$HWCSM = \Sigma\ (WD300 + WD325)$$

where WD300 = W300 (current scan) - W300 (previous scan)
and WD325 = W325 (current scan) - W325 (previous scan)

HOT WATER AUXILIARY FOSSIL ENERGY (BTU)

$$HWAF = 1{,}000 \times \Sigma\ FD300$$

where FD300 = F300 (current scan) - F300 (previous scan)

HOT WATER SOLAR ENERGY USED (BTU)

$$M300 \times CP \times (T350 - T300) \times \Delta\tau$$

HOT WATER FOSSIL SAVINGS (BTU)

$$HWSVF = HWSE/0.6$$

HOT WATER OPERATING ENERGY

$$HWOPE = (EP300 + EP301) \times 56.8833$$

HOT WATER SOLAR SPECIFIC OPERATING ENERGY

$$HWOPE1 = EP301 \times 56.8833$$

HOT WATER ELECTRICAL SAVINGS (BTU)

$$HWSVE = -HWOPE1$$

HOT WATER AUXILIARY THERMAL ENERGY (BTU)

$$HWAT = (M300 + M301) \times CP \times (T351 - T301)$$

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

$$SEA = CLAREA \times SE$$

where CLAREA = collector area (ft^2)

COLLECTED SOLAR ENERGY PER SQUARE FOOT OF COLLECTOR (BTU/ft^2)

SEC = SECA/CLAREA

COLLECTOR ARRAY EFFICIENCY (PERCENT)

CLEF = SECA/SEA

OPERATIONAL COLLECTOR EFFICIENCY (PERCENT)

CLEFOP = SECA/SEOP

CHANGE IN STORED ENERGY (BTU)

$STECH = STECH_1 - STECH_{1_p}$

where $STECH_1$ is energy contained in storage and subscript $_p$ refers to a prior reference value.

STORAGE EFFICIENCY

STEFF = (STECH + STEO)/STEI

ENERGY DELIVERED FROM ECSS TO HOT WATER SUBSYSTEM

CSEO = HWSE

SOLAR ENERGY TO LOAD SUBSYSTEMS

SEL = CSEO

ECSS SOLAR CONVERSION EFFICIENCY

CSCEF = SEL/SEA

HOT WATER LOAD

HWL = HWSE x HWAT

HOT WATER DEMAND

HWDM = M300 x CP x (T302 - T300)

HOT WATER SOLAR FRACTION

HWSFR = HWSE/HWL

AUXILIARY THERMAL ENERGY TO LOADS (BTU)

AXT = HWAT

SYSTEM LOAD (BTU)

SYSL = HWL

SOLAR FRACTION OF SYSTEM LOAD (PERCENT)

SFR = HWSFR

SYSTEM OPERATING ENERGY

SYSOPE = CSOPE + HWOPE

AUXILIARY FOSSIL ENERGY TO LOAD (BTU)

AXF = HWAF

TOTAL ENERGY CONSUMED (BTU)

TECSM = SECA + AXT + SYSOPE

TOTAL ELECTRICAL ENERGY SAVINGS (BTU)

TSVE = HWSVE - CSOPE

TOTAL FOSSIL ENERGY SAVINGS (BTU)

TSVF = HWSVF

SYSTEM PERFORMANCE FACTOR

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

APPENDIX E

CALCULATION OF PREDICTED VALUES

The f-Chart 4.0 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.

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)

SYSTEM PERFORMANCE SUMMARY (f-CHART, VERSION 4.0)*
FOREST CITY DILLON
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU, unless otherwise indicated)

MONTH	HT	TA (°F)	HWLOAD	QU	QLOSS	FDHW (%)
JAN	61.87	35	119.33	18.79	-1.46	17
FEB	99.00	32	106.09	26.50	-0.93	26
MAR	104.06	47	111.81	31.86	-0.88	29
APR	110.50	58	92.42	35.29	-0.43	39
MAY	122.38	67	80.11	39.09	0.01	48
JUN	*	*	*	*	*	*
JUL	143.35	81	65.69	47.45	0.98	69
AUG	153.31	81	61.42	49.37	1.45	79
SEP	117.73	75	61.24	39.23	0.66	63
OCT	111.77	58	89.42	37.12	-0.27	42
NOV	89.11	47	103.52	28.60	-0.89	28
DEC	73.52	38	112.54	21.82	-1.27	21
TOTAL	1,186.61	-	1,003.59	374.72	-3.03	-
AVERAGE	98.88	56	83.63	31.23	-0.25	37

*DENOTES UNAVAILABLE DATA.

	GAS	ELECTRIC	OIL	TOTAL
USE (MMBTU)	0.0	0.0	1,048.12	1,048.12
COST ($)	0.0	0.0	7,441.66	7,441.66

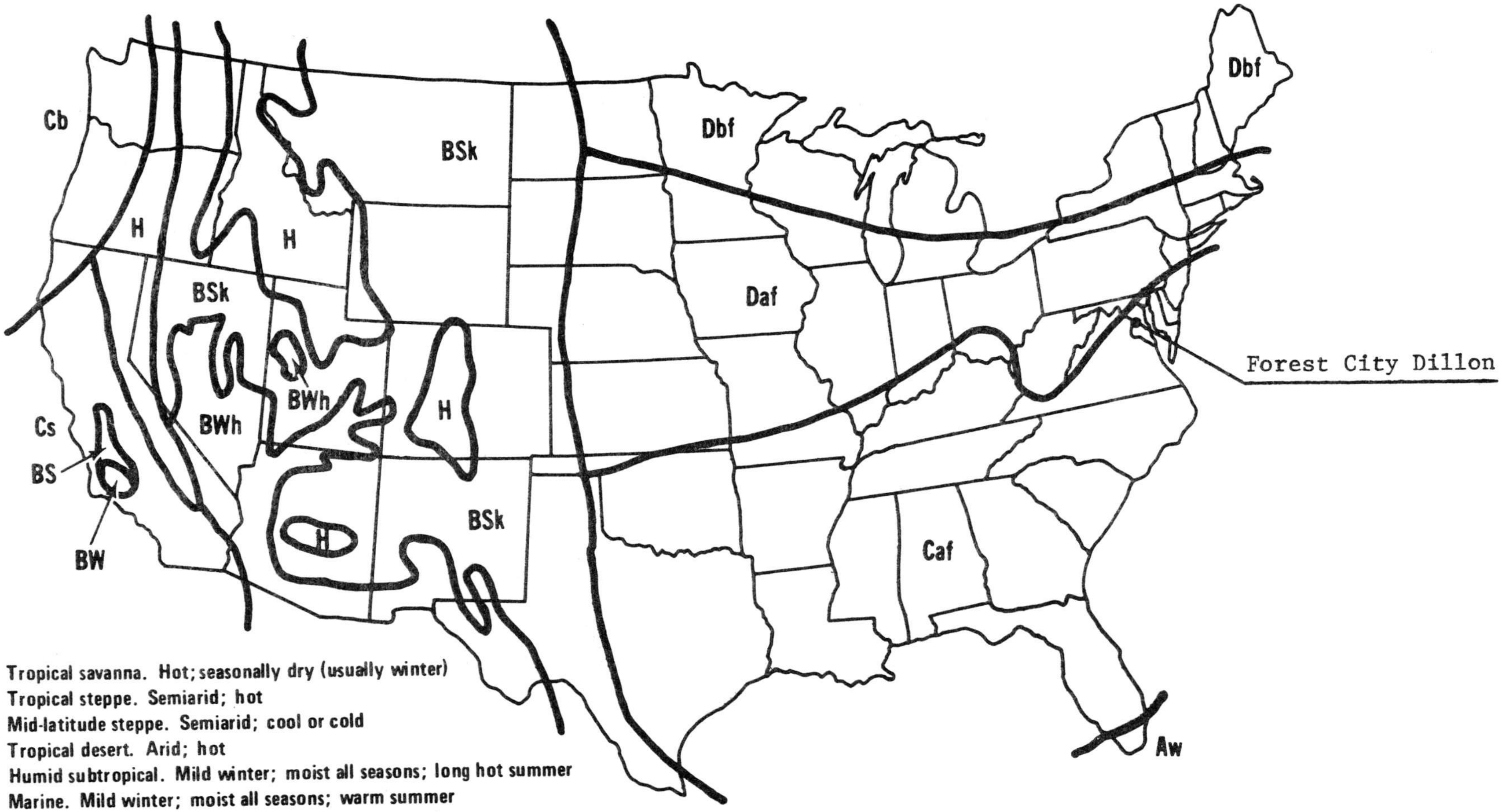
*See next page for glossary of f-Chart version 4.0 terms.

GLOSSARY OF f-CHART VERSION 4.0 TERMS

HT	-	Incident radiation on tilted surface
TA	-	Average ambient temperature
HWLOAD	-	Hot water load
QU	-	Energy collected
QLOSS	-	Energy lost from storage
FDHW	-	Hot water solar fraction

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 Forest City Dillon Location

FOREST CITY DILLON LONG-TERM WEATHER DATA

COLLECTOR TILT: 40 DEGREES
LATITUDE: 39 DEGREES

LOCATION: WASHINGTON, D.C.
COLLECTOR AZIMUTH: 0 DEGREES

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
JAN	1,380	571	0.41409	1.628	930	1,020	0	32
FEB	1,841	815	0.44269	1.410	1,149	874	0	34
MAR	2,432	1,125	0.46234	1.191	1,339	719	0	42
APR	3,043	1,460	0.47987	1.008	1,472	367	0	53
MAY	3,468	1,718	0.49542	0.896	1,540	131	57	63
JUN	3,639	1,902	0.52276	0.848	1,614	5	188	71
JUL	3,548	1,818	0.51230	0.869	1,580	0	319	75
AUG	3,202	1,619	0.50550	0.959	1,552	0	267	76
SEP	2,649	1,342	0.50665	1.123	1,507	43	100	67
OCT	2,011	1,003	0.49861	1.364	1,368	291	9	56
NOV	1,486	653	0.43906	1.587	1,035	609	0	45
DEC	1,254	483	0.38526	1.667	805	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: FOREST CITY DILLON
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	679	37	42
2	1174	35	37
3	1222	37	43
4	136	29	28
5	161	27	28
6	1772	29	36
7	117	34	35
8	1062	38	41
9	390	34	37
10	1130	32	38
11	70	41	40
12	254	37	37
13	420	30	32
14	99	39	39
15	1165	45	49
16	1574	47	57
17	195	39	40
18	55	41	42
19	1572	40	45
20	1601	39	46
21	1837	38	44
22	81	40	42
23	702	37	40
24	888	25	*
25	277	33	34
26	1715	36	40
27	804	32	36
28	321	35	38
29	778	32	36
30	794	24	26
31	818	23	25
SUM	23863	-	-
AVG	770	35	38

* DENOTES UNAVAILABLE DATA.

F-3

MONTHLY REPORT: FOREST CITY DILLON
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	1812	20	*
2	1904	21	*
3	2001	24	28
4	1689	26	*
5	1902	30	35
6	196	26	27
7	1740	30	35
8	1860	33	38
9	326	31	34
10	1709	29	31
11	1740	33	40
12	1956	31	*
13	1980	32	40
14	1723	42	53
15	505	37	38
16	576	34	*
17	2108	25	30
18	1967	30	38
19	1651	38	49
20	*	*	*
21	*	*	*
22	181	43	43
23	673	48	*
24	1526	51	58
25	395	38	39
26	1642	31	34
27	899	33	38
28	209	27	27
29	1955	21	25
SUM	39553	-	-
AVG	1364	32	37

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: FOREST CITY DILLON
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	*	*	*
2	*	*	*
3	*	*	*
4	*	*	47
5	*	*	*
6	2425	43	47
7	907	51	58
8	566	60	65
9	1923	49	*
10	1749	49	60
11	3146	42	40
12	*	*	*
13	44	31	30
14	1231	37	41
15	2273	44	51
16	2178	46	54
17	231	56	55
18	2003	49	49
19	1912	48	60
20	1012	55	*
21	404	53	61
22	748	39	39
23	2324	46	55
24	214	46	50
25	980	47	*
26	2031	42	48
27	2297	48	58
28	407	45	52
29	448	50	53
30	613	52	57
31	312	42	42
SUM	40150	-	-
AVG	1295	47	51

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: FOREST CITY DILLON
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	*	*	*
2	*	*	*
3	*	*	*
4	*	*	*
5	*	*	*
6	*	*	*
7	*	*	*
8	*	*	*
9	*	*	*
10	1309	61	69
11	2279	62	70
12	867	63	72
13	1414	59	64
14	152	58	55
15	1033	54	59
16	1899	47	51
17	2380	47	55
18	2291	55	65
19	2074	63	75
20	2119	69	79
21	2256	64	68
22	2228	64	70
23	1992	63	70
24	1885	63	*
25	1268	61	*
26	146	49	47
27	223	51	51
28	184	52	53
29	1485	58	*
30	354	53	55
SUM	42626	-	-
AVG	1421	58	63

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: FOREST CITY DILLON
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	1022	58	64
2	1733	64	73
3	1996	68	77
4	2226	73	80
5	1933	76	*
6	1641	75	84
7	1984	70	81
8	506	53	52
9	1476	52	59
10	2198	61	72
11	755	65	64
12	1592	75	86
13	1339	76	*
14	1835	69	76
15	*	*	*
16	*	*	*
17	*	*	*
18	614	66	*
19	*	*	*
20	*	*	*
21	*	*	*
22	*	*	*
23	*	*	*
24	*	*	*
25	*	*	*
26	*	*	*
27	*	*	*
28	*	*	*
29	*	*	*
30	*	*	*
31	*	*	*
SUM	47221	-	-
AVG	1523	67	72

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: FOREST CITY DILLON
JUNE 1980
ENVIRONMENTAL SUMMARY

(No data available)

MONTHLY REPORT: FOREST CITY DILLON
JULY 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	*	*	*
2	2122	83	90
3	419	77	*
4	2050	82	91
5	1506	80	92
6	2200	77	82
7	2164	76	85
8	88	69	67
9	1948	80	*
10	1807	80	87
11	1988	84	93
12	1545	81	92
13	2210	76	83
14	2066	80	92
15	2032	83	90
16	1757	87	*
17	1402	83	*
18	2043	84	92
19	1754	86	97
20	1966	91	102
21	2299	92	101
22	*	*	*
23	594	73	76
24	2646	78	84
25	*	*	*
26	1820	83	93
27	*	*	*
28	*	*	*
29	*	*	*
30	*	*	*
31	2380	84	94
SUM	55295	-	-
AVG	1784	81	89

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: FOREST CITY DILLON
AUGUST 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	*	*	*
2	*	*	*
3	*	*	*
4	*	*	*
5	*	*	*
6	1971	83	93
7	2732	86	96
8	*	*	*
9	2291	90	*
10	1927	84	*
11	2598	87	*
12	*	*	*
13	*	*	*
14	*	*	*
15	*	*	*
16	*	*	*
17	*	*	*
18	*	*	*
19	*	*	*
20	*	*	*
21	640	70	74
22	855	69	75
23	1170	75	82
24	1733	78	*
25	2094	80	91
26	2802	84	96
27	*	*	*
28	*	*	*
29	*	*	*
30	2079	83	92
31	*	*	*
SUM	59135	-	-
AVG	1908	81	*

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: FOREST CITY DILLON
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	*	*	*
2	1714	87	*
3	1899	79	*
4	1314	78	88
5	1116	77	*
6	1555	81	*
7	2039	75	82
8	2102	76	83
9	1836	78	87
10	1830	72	78
11	2237	71	80
12	2102	74	86
13	1885	76	90
14	1470	79	91
15	1271	72	*
16	1000	67	*
17	1387	77	86
18	605	72	*
19	1626	72	80
20	886	74	81
21	1640	80	90
22	1905	83	*
23	982	78	85
24	677	67	70
25	218	67	69
26	2176	68	73
27	2056	58	*
28	1801	63	*
29	2029	64	73
30	546	64	67
SUM	45419	-	-
AVG	1514	73	81

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: FOREST CITY DILLON
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	1190	68	77
2	1556	68	81
3	131	55	55
4	1329	57	63
5	1962	58	75
6	2161	56	63
7	1802	56	68
8	1958	63	75
9	1542	68	81
10	209	56	57
11	888	62	69
12	1344	54	59
13	1575	50	59
14	2024	50	57
15	1757	59	72
16	1761	64	80
17	1711	69	78
18	596	67	74
19	1310	63	69
20	1580	55	62
21	1942	61	70
22	1825	58	69
23	1382	48	55
24	1274	50	56
25	297	51	55
26	1243	45	50
27	1385	47	53
28	488	55	59
29	1417	46	50
30	1598	47	56
31	1873	52	63
SUM	43112	-	-
AVG	1391	57	65

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: FOREST CITY DILLON
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	1776	55	65
2	1685	45	52
3	1820	47	59
4	138	52	51
5	1473	50	57
6	1707	49	56
7	1707	61	78
8	1137	62	71
9	1026	55	62
10	1514	52	57
11	1901	40	44
12	1897	42	47
13	1382	52	62
14	840	57	62
15	198	50	51
16	1686	40	46
17	174	33	34
18	281	36	39
19	1628	38	44
20	1720	40	49
21	1636	43	53
22	1659	44	50
23	293	43	50
24	33	45	45
25	1116	44	50
26	1620	39	45
27	347	39	40
28	118	40	39
29	247	39	40
30	1630	47	53
SUM	34385	-	-
AVG	1146	46	52

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: FOREST CITY DILLON
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	1477	56	64
2	1484	55	64
3	1778	37	40
4	1623	35	41
5	1285	38	44
6	1237	47	56
7	490	55	59
8	1133	62	71
9	61	58	55
10	185	45	45
11	386	36	38
12	1076	41	45
13	280	46	51
14	1411	37	46
15	208	30	32
16	252	36	40
17	1638	31	33
18	836	37	42
19	579	38	42
20	1639	19	22
21	1645	20	27
22	787	24	29
23	687	32	35
24	97	31	30
25	1765	15	17
26	1191	19	24
27	362	25	27
28	126	35	35
29	623	42	45
30	1372	40	45
31	643	28	31
SUM	28356	-	-
AVG	915	37	41

* DENOTES UNAVAILABLE DATA.

APPENDIX G

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

Prior to June 1980, the collector subsystem would not initiate if the upper half of the storage tank registered a temperature of 140°F or more. This was a safety feature which prevented the delivery of scalding water to the load. In June 1980, this set point was increased to 160°F and a tempering valve was added to reduce the delivery temperature of the DHW.

Also in June 1980, a bypass line with a temperature actuated valve was added to permit solar energy to compensate for recirculation losses. If the recirculation pump is in operation and if the temperature of storage is greater than the recirculated flow return temperature by a nominal 5°F, then the recirculation flow passes through the storage tank, removing solar energy. In addition, an aquastat controller was installed to control the operation of the recirculation pump.

Other minor problems and changes include the following:

DATE	
3/80 - 4/80	Pump P-4 failed from 3/16/80 - 4/3/80, was replaced 4/3/80.
7/80	The motor for Pump P-5 ran continuously because the motor to pump coupler was broken. Repaired 7/16/80.

APPENDIX H

CONVERSION FACTORS

Energy Conversion Factors

Fuel Type	Energy Content	Fuel Source Conversion Factor
Distillate fuel oil[1]	138,690 BTU/gallon	7.21×10^{-6} gallon/BTU
Residual fuel oil[2]	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] No. 1 and No. 2 heating oils, diesel fuel, No. 4 fuel oils

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

APPENDIX I

SENSOR TECHNOLOGY

Temperature Sensors

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

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

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

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

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

Wind Sensor

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

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

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

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

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

Humidity Sensors

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

This solid-state sensor measures relative humidity over the full range of 0-100%. Response of the sensing element is linear within approximately one percent, 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.

☆U.S. GOVERNMENT PRINTING OFFICE: 1981-740-145/2402