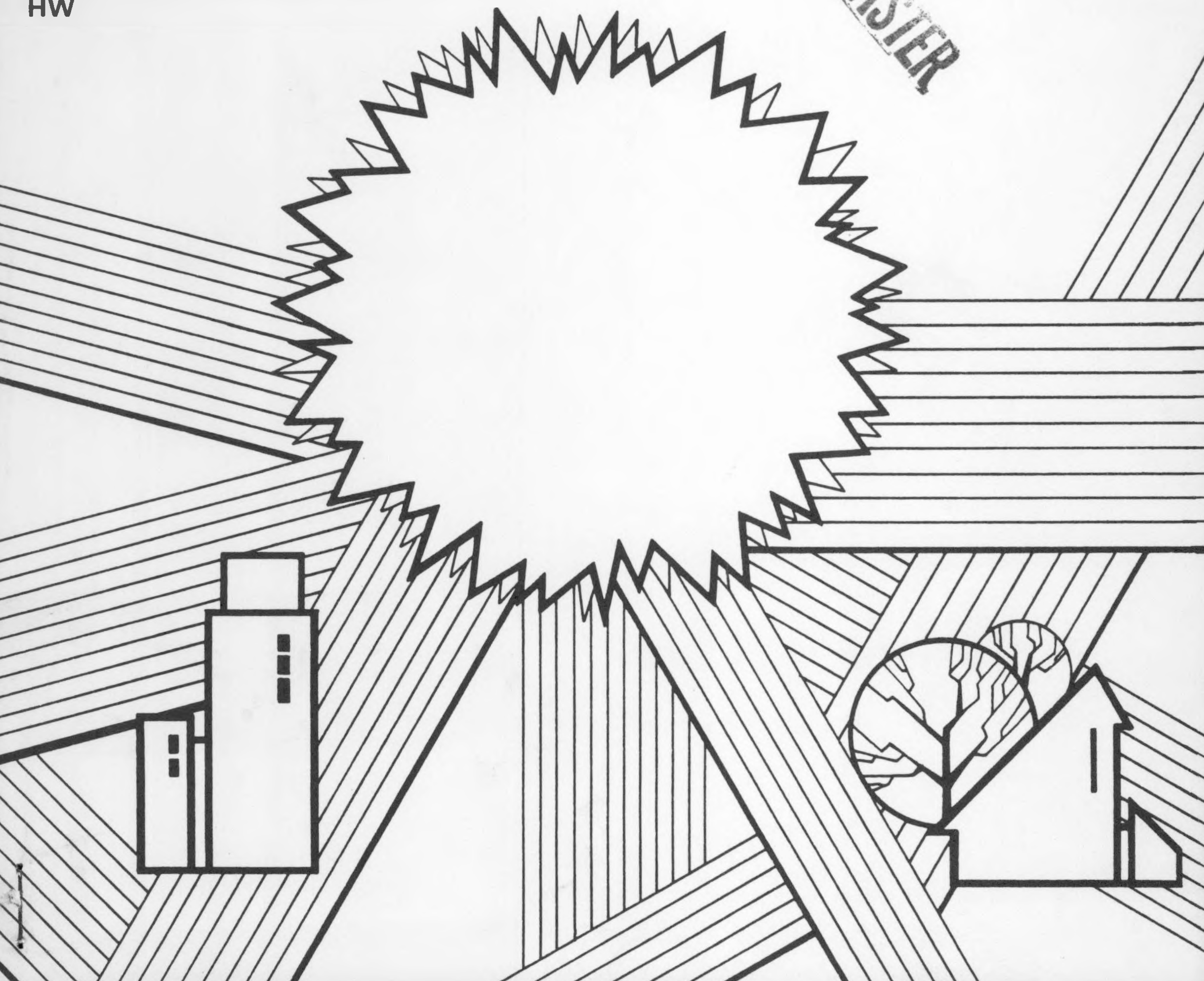
SOLAR/2008-81/14
(DE81029985)

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

ARATEX SERVICES
Fresno, California
December 1979 through November 1980
HW



U.S. DEPARTMENT OF ENERGY

NATIONAL SOLAR DATA PROGRAM

SOLAR/2008-81/14
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ARATEX SERVICES

FRESNO, CALIFORNIA

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

DECEMBER 1979 THROUGH NOVEMBER 1980

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FOREWORD

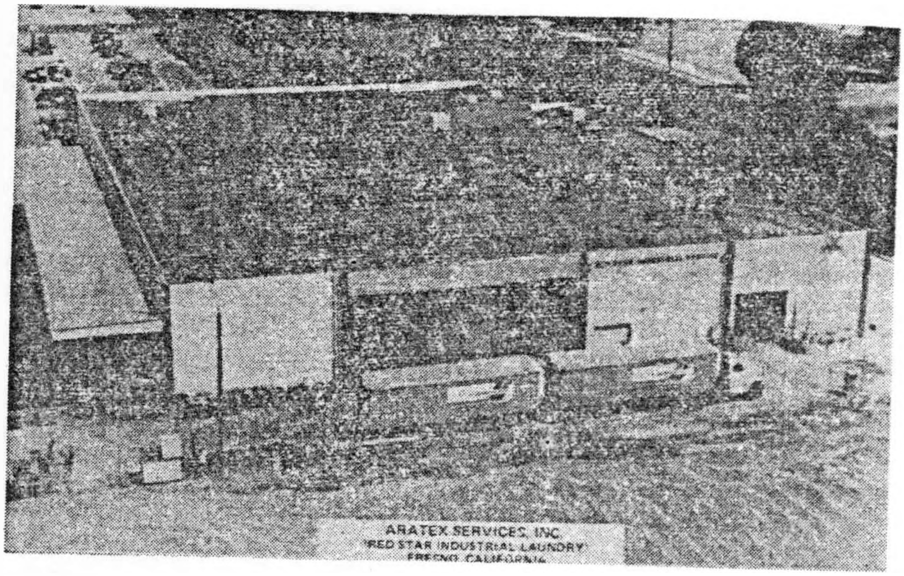
This report is one of a series which describes the performance of solar energy systems in the National Solar Data Network (NSDN) for the entire heating or cooling season. Domestic hot water is also included, if there is a solar contribution. Some NSDN installations are used solely for heating domestic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

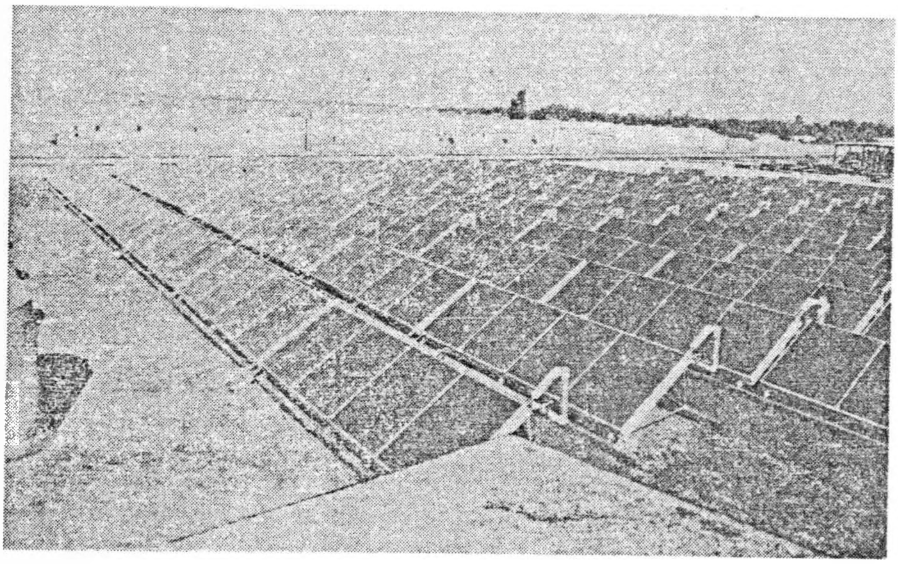
The National Solar Data Network consists of instrumented solar energy systems in buildings selected from among the 5,000 installations built (since early 1977) as part of the National Solar Heating and Cooling Demonstration Program. The overall purpose of this program is to reduce the use of nonrenewable fuels by encouraging the application of solar energy for heating, cooling, and domestic hot water. Vitro Laboratories Division manages 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 are highly automated.

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





ARATEX SERVICES

ARATEX SERVICES

The ARATEX Services solar energy system supplies solar preheated water to a large commercial laundry plant in north central California. The active solar energy system is designed to supply the following:

Annual Design Factors
(Million BTU)

	Total Load	Solar Contribution	% Solar
Hot Water	7,680	1,536	20

It is equipped with:

Collector	6,528 square feet, Ying Manufacturing Company single glazed flat-plate collectors.
Storage	12,500 gallons fiberglass, outside location. R11 insulation.
Auxiliary	Two 235 BHP Babcock and Wilcox steam boilers fired by natural gas with fuel oil for emergency backup.
Heat Recovery	16,500-gallon water pump with tube-shell heat exchanger for feedwater preheat.

TABLE OF CONTENTS

Section	Page
Foreword	iii
Site Summary	v
Table of Contents	vi
List of Illustrations	vii
List of Tables	viii
1. SOLAR SYSTEM PERFORMANCE	1-1
1.1 Summary and Conclusions	1-2
1.2 Overall System Performance	1-3
1.3 Energy Savings	1-6
1.4 Solar Energy Utilization	1-8
1.5 Solar System Availability	1-9
2. SUBSYSTEM PERFORMANCE	2-1
2.1 Collector	2-1
2.2 Storage	2-2
2.3 Laundry Hot Water	2-3
2.4 Heat Recovery	2-5
3. OPERATING ENERGY	3-1
4. WEATHER CONDITIONS	4-1
5. REFERENCES	5-1
Appendices	
A. I. System Description	A-1
II. Typical System Operation	A-4
B. Performance Evaluation Techniques	B-1
C. Performance Factors and Solar Terms	C-1
D. Performance Equations	D-1
E. Meteorological Conditions	E-1
F. Site History, Problems, Changes in Solar System	F-1
G. Conversion Factors	G-1
H. Sensor Technology	H-1

LIST OF ILLUSTRATIONS

Figure Number	Title	Page
1	Energy Flow Diagram, ARATEX Services, December 1979 through November 1980	1-4
2	System Thermal Performance, ARATEX Services, December 1979 through November 1980	1-5
3	Combined Fossil Energy Savings Compared to Load, ARATEX Services, December 1979 through November 1980	1-7
4	Solar Energy Use, ARATEX Services, December 1979 through November 1980	1-8
5	Laundry Hot Water Subsystem Performance, ARATEX Services, December 1979 through November 1980	2-4
6	Total Operating Energy, ARATEX Services, December 1979 through November 1980	3-2
A-1	ARATEX Services Solar Energy System Schematic	A-3
A-2	ARATEX Services Storage Temperature Plot	A-6
A-3	ARATEX Services Weather Conditions Plot	A-6
A-4	ARATEX Services System Temperature Profile	A-7
B-1	The National Solar Data Network	B-1
E-1	Meteorological Map of the United States Showing Location of ARATEX Services	E-2

LIST OF TABLES

Number	Title	Page
1	Solar System Thermal Performance, ARATEX Services, December 1979 through November 1980	1-2
2	Solar Coefficient of Performance, ARATEX Services, December 1979 through November 1980	1-5
3	Energy Savings, ARATEX Services, December 1979 through November 1980	1-6
4	Solar Energy Losses, ARATEX Services, December 1979 through November 1980	1-9
5	Collector Subsystem Performance, ARATEX Services, December 1979 through November 1980	2-1
6	Storage Performance, ARATEX Services, December 1979 through November 1980	2-2
7	Laundry Hot Water Subsystem Performance, ARATEX Services, December 1979 through November 1980	2-4
8	Heat Recovery Subsystem Performance, ARATEX Services, December 1979 through November 1980	2-6
9	Operating Energy, ARATEX Services, December 1979 through November 1980	3-1
10	Weather Conditions, ARATEX Services, December 1979 through November 1980	4-1

SECTION 1

SOLAR SYSTEM PERFORMANCE

ARATEX SERVICES
DECEMBER 1979 THROUGH NOVEMBER 1980

Solar Fraction[1]	18%
Solar Savings Ratio[2]	0.17
Conventional Fuel Savings[3]	1.85 million cubic feet of natural gas
System Performance Factor[4]	1.72
Solar System COP[5]	43.84

Seasonal Energy Requirements
December 1979 through November 1980
(Million BTU)

	Total Load	Solar Contribution	% Solar
Monitored Hot Water	5,111.08	911.84	18
Design Hot Water	7,680.00	1,530.00	20

1. $$\text{Solar Fraction} = \frac{\text{Solar Energy Supplied to Load}}{\text{Hot Water Thermal Demand}}$$

2. $$\text{Solar Savings Ratio} = \frac{\text{Solar Energy Supplied to Load} - \text{Solar Unique Operating Energy}}{\text{Hot Water Thermal Demand}}$$

3. Conventional Fuel Savings = Number BTU saved x 979.43 x 10^{-6} cubic feet/BTU

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

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

1.1 SUMMARY AND CONCLUSIONS

The ARATEX Services solar energy system performed very well throughout the period December 1979 through November 1980. The overall solar energy system performance was slightly below the design expected performance. The occurrence of reduced performance is closely related to the lower than predicted solar energy available to the collector array. The solar energy system supplied 18% of the process hot water required for the laundry load at the plant.

The system thermal performance is summarized in Table 1.

Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

ARATEX SERVICES
DECEMBER 1979 THROUGH NOVEMBER 1980

(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED	SYSTEM LOAD	THERMAL ENERGY RECOVERED	SOLAR ENERGY USED	AUXILIARY ENERGY FOSSIL	OPERATING ENERGY	ENERGY SAVINGS FOSSIL	ENERGY SAVINGS ELECTRICAL	SOLAR FRACTION (%)
DEC	17.39	420.43	229.20	40.19	635.01	13.05	66.98	-0.66	10
JAN	1.95	404.94	267.88	23.72	636.62	12.33	39.54	-0.16	6
FEB	26.35	358.61	252.48	41.25	529.98	22.43	68.76	-0.81	12
MAR	66.81	420.25	279.95	71.93	581.70	25.64	119.89	-1.45	17
APR	85.21	489.64	333.06	88.36	670.14	28.04	147.27	-1.72	18
MAY	105.78	488.21	261.54	101.26	646.21	26.68	168.77	-1.99	21
JUN	119.14	477.28	267.10	110.84	611.96	26.44	184.73	-2.13	23
JUL	104.78	512.46	299.84	101.93	694.04	27.39	169.88	-2.20	20
AUG	132.33	397.87	191.03	87.92	517.62	25.51	146.53	-2.75	22
SEP	143.57	348.99	219.95	103.80	409.46	26.11	173.00	-3.15	30
OCT	124.24	402.13	263.20	89.24	522.53	28.68	148.74	-3.03	22
NOV	60.50	390.27	181.06	51.40	565.92	14.07	85.66	-1.99	13
TOTAL	988.05	5,111.08	3,046.56	911.84	7,021.19	276.37	1,519.75	-22.04	-
AVERAGE	82.34	425.92	253.88	75.99	585.10	23.03	126.65	1.84	18

Available solar energy for collection at the collector array exceeded the hot water demand during two months, August and September of 1980. The heat recovery system provides preheated hot water to the storage, which contains previously utilized solar, auxiliary and recovered energy. Solar energy can exceed new energy collected during low solar insolation months. The combined operation of the heat recovery system and the solar energy system produced a total of 3,958.13 million BTU of thermal energy from nonfossil sources at a total expense of 48.15 million BTU of electrical power to operate both the solar collector pump and the heat recovery pump. This system represents a very impressive coefficient of performance (COP) of 43.84. The COP of the heat recovery system was 107.11, while the COP of the solar collector subsystem was 40.38 or less than half that of the heat recovery system.

The highest collector subsystem efficiency occurred in September and October of 1980, and was due to the installation of a new, larger pump serving the collector array. Operating energy for the solar collector array increased by about one-third but was not very high when compared to the increase in collected solar energy. The new pump was specified by the grantee after examination of the collector array. It was discovered that some of the panels were not filling. The flow rate per square foot of gross collector area was increased from 0.03 to 0.05 gallons per square foot. This strategy yielded an improvement in collector efficiency from 27% to 37% under similar conditions of available solar radiation.

1.2 OVERALL SYSTEM PERFORMANCE

The flow of solar energy for the ARATEX Services site for the 12-month reporting period from December 1979 through November 1980 is presented in Figure 1.

The overall thermal performance presented in Table 1 is shown graphically in Figure 2.

The overall solar fraction of the site, based upon energy delivered to the hot water demand, improved from low values in December 1979 and January 1980 to levels at or above the design expected solar fraction during April through October 1980. The lower performance during the first two months of the reporting period was due to the system being disabled for completion of a 90-panel refurbishment project initiated in September 1979. The overall average solar fraction was 18% while, during the period of April through October, it averaged 23% of the total hot water heating demand.

The heat recovery system operated consistently throughout the period, providing a total of 3,046.29 million BTU which is 37% of the total 8,283.73 million BTU of total fossil energy consumed at the plant for process hot water heating.

Solar energy savings were significant and ranged from 39.27 million BTU in January 1980 (when the system only operated for five days) to 181.18 million BTU in June 1980. Average savings from net solar sources (energy delivered from the storage tank to loads) were 121.34 million BTU per month. The total savings of 1,456.04 million BTU were obtained from operation of the solar energy and heat recovery systems during the period.

The solar energy coefficient of performance (COP) is indicated in Table 2. The COP is an indication of the numerical relationship of solar energy used and the electrical power expended for collection and/or delivery of the solar energy. The greater the COP value the more highly efficient the subsystem or system is. The solar energy system at ARATEX Services functioned with an average COP value of 43.84 for the period December 1979 through November 1980. The high COP in December was due to extensive usage of recovered solar energy at low operating costs for the heat recovery system. The highest COP in normal system configuration was 52.04 in June, the month of highest insolation. The COP was lowest during both January and February during collector refurbishment and an operating error described in this report in the section titled Solar System Availability.

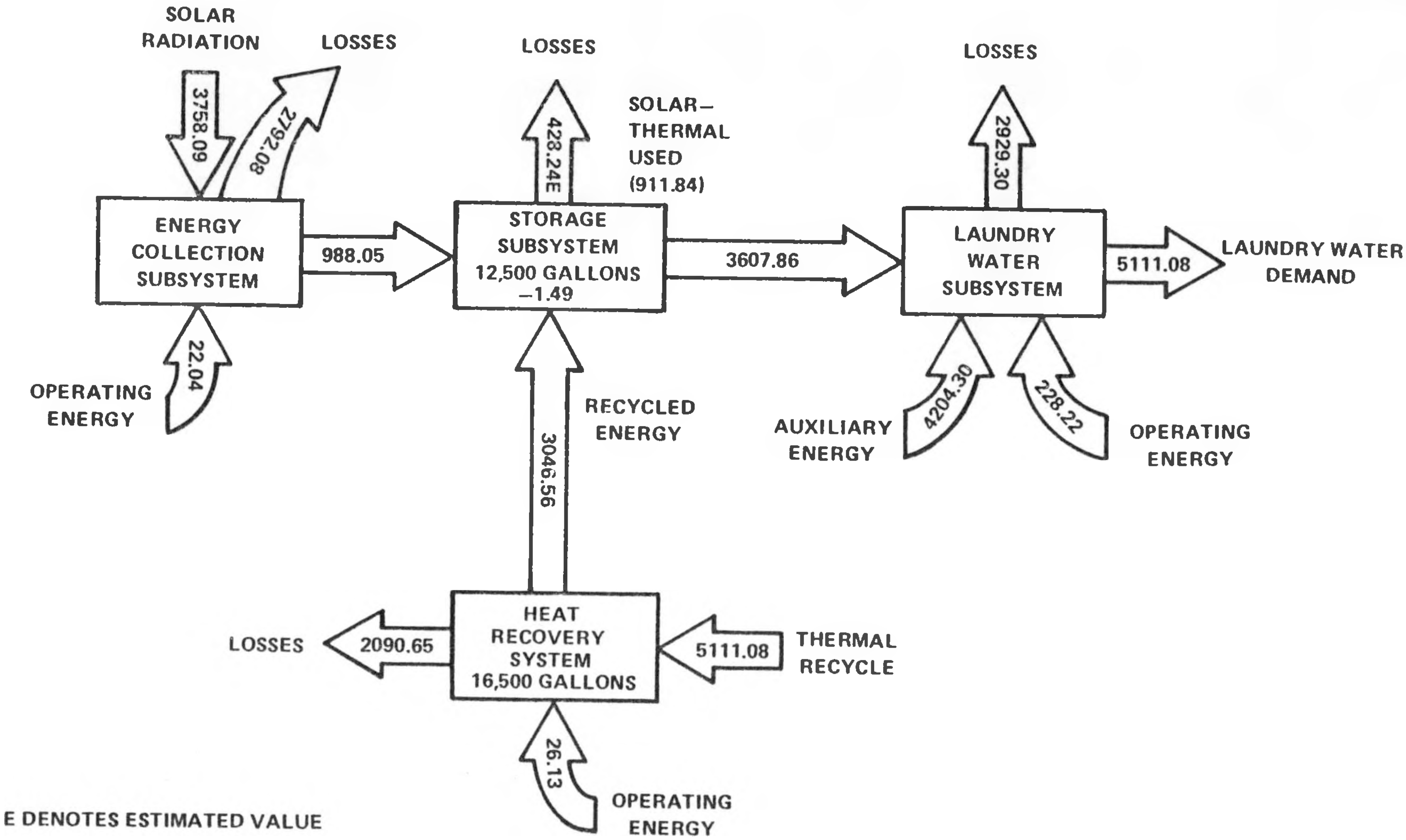


Figure 1. Energy Flow Diagram for ARATEX Services
December 1979 through November 1980
(Figures in million BTU)

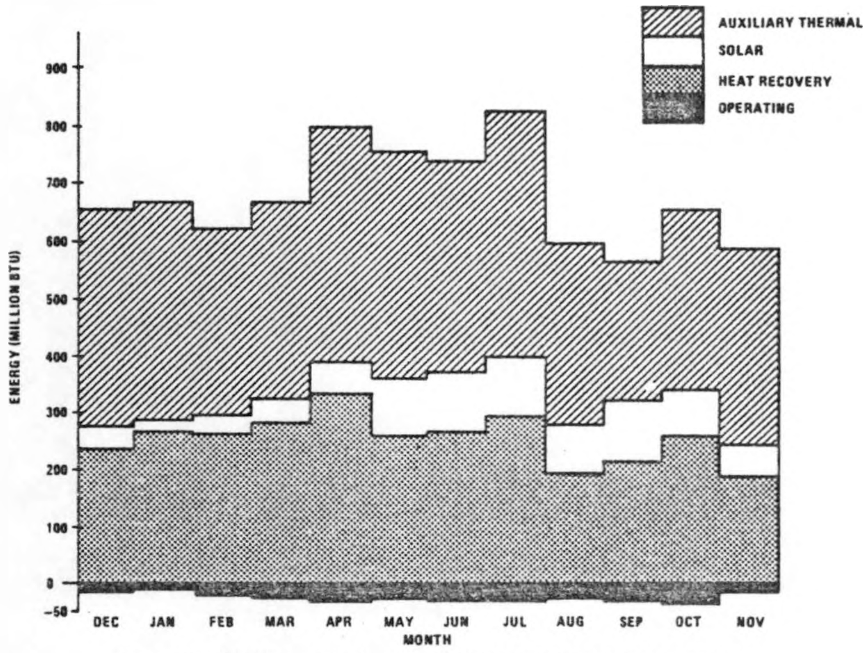


Figure 2. System Thermal Perforamnce
ARATEX Services
December 1979 through November 1980

Table 2. SOLAR COEFFICIENT OF PERFORMANCE

ARATEX SERVICES
DECEMBER 1979 THROUGH NOVEMBER 1980

MONTH	SOLAR ENERGY SYSTEM	COLLECTOR SUBSYSTEM	LAUNDRY HOT WATER SOLAR	HEAT RECOVERY SYSTEM
DEC	60.89	26.43	15.82	*
JAN	*	12.19	9.45	121.92
FEB	50.93	32.41	14.37	111.15
MAR	49.61	46.01	23.43	115.29
APR	51.37	49.57	26.30	117.13
MAY	50.88	53.08	33.20	124.28
JUN	52.04	52.11	33.90	110.35
JUL	46.33	47.67	32.05	103.13
AUG	31.97	48.16	33.81	99.49
SEP	32.95	45.52	*	130.15
OCT	29.45	41.04	34.19	137.37
NOV	25.83	30.37	22.95	116.06
WEIGHTED AVERAGE	43.84	40.38	25.41	107.11

*DENOTES UNAVAILABLE DATA.

The collector subsystem was highly effective, operating with an average COP of 40.38 with the highest values occurring in May and June 1980. The lowest COP value, 12.19, occurred in January when the collector array was inadvertently turned off for three weeks during the month.

The operational COP of the hot water subsystem for solar energy use averaged 25.41 and showed a similar elevation during months with maximum insolation and marked reduction during January and February 1980.

1.3 ENERGY SAVINGS

Energy savings for this site for the reporting period, December 1979 through November 1980, are presented in Table 3 and shown graphically in Figure 3. For this 12-month period, the net total savings after deduction of solar operating energy expenses were 1,456.04 million BTU, for a monthly average of 121.34 million BTU. This is approximately 10,475 gallons of oil (250 bbls oil), or 1.85 million cubic feet of natural gas, or 42,662 kwh of electricity. An electrical energy expense of 21.23 million BTU was incurred during the reporting period for the operation of solar energy components. The expense is very small when compared to savings.

Table 3. ENERGY SAVINGS

ARATEX SERVICES
DECEMBER 1979 THROUGH NOVEMBER 1980

(All values in million BTU)

MONTH	SOLAR ENERGY USED	LAUNDRY HOT WATER		ECSS OPERATING ENERGY	ENERGY SAVINGS		NET HEAT RECOVERY SYSTEM SAVINGS
		ELECTRICAL	FOSSIL FUEL		ELECTRICAL	FOSSIL FUEL	
DEC	40.19	-0.66	66.98	-0.66	-0.66	66.98	227.31
JAN	23.72	-0.16	39.54	-0.16	-0.16	39.54	265.47
FEB	41.25	-0.81	68.76	-0.81	-0.81	68.76	250.29
MAR	71.93	-1.45	119.89	-1.45	-1.45	119.89	277.57
APR	88.36	-1.72	147.27	-1.72	-1.72	147.27	330.38
MAY	101.26	-1.99	168.77	-1.99	-1.99	168.77	259.17
JUN	110.84	-2.13	184.73	-2.13	-2.13	184.73	264.51
JUL	101.93	-2.20	169.88	-2.20	-2.20	169.88	297.34
AUG	87.92	-2.75	146.53	-2.75	-2.75	146.53	189.11
SEP	103.80	-3.15	173.00	-3.15	-3.15	173.00	218.26
OCT	89.24	-3.03	148.74	-3.03	-3.03	148.74	261.27
NOV	51.40	-1.99	85.66	-1.99	-1.99	85.66	179.50
TOTAL	911.84	-22.04	1,519.75	-22.04	-22.04	1,519.75	3,020.18
AVERAGE	75.99	-1.84	126.65	-1.84	-1.84	126.65	251.68

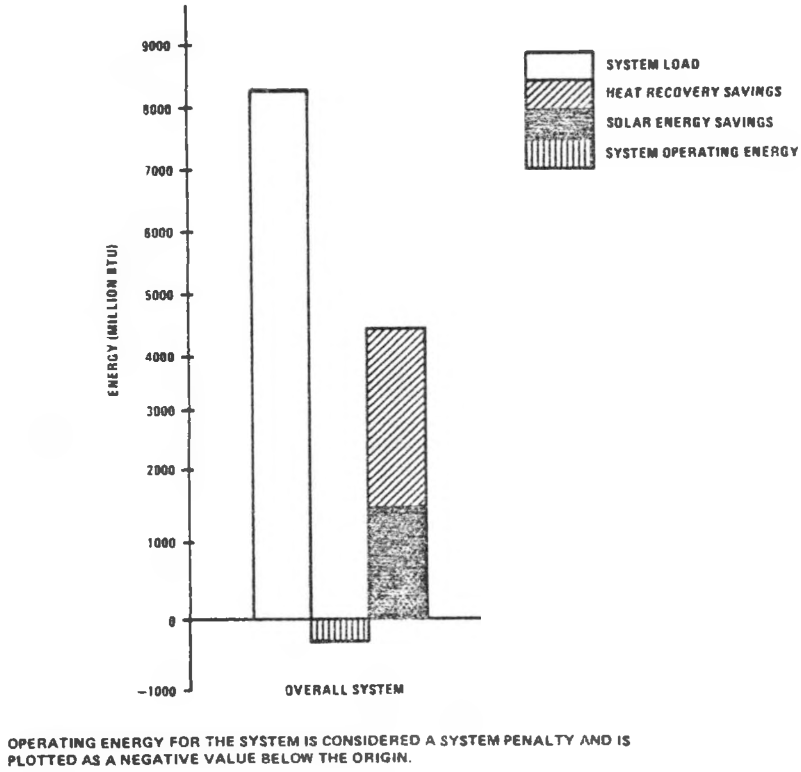


Figure 3. Combined Fossil Energy Savings Compared to Load
ARATEX Services
December 1979 through November 1980

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

Of the total 7,878.91 million BTU supplied by solar, heat recovery, and auxiliary thermal energy sources, 39% was derived from operation of the heat recovery system. The heat recovery system produced 3,046.56 million BTU of available thermal energy at an expense of 26.11 million BTU for operating energy. During the period December 1979 to November 1980, slightly more than three times the net thermal energy collected by the solar collector subsystem was supplied by thermal recycle at very similar operating energy costs. If the net energy delivered to useful purposes is divided by the gross energy available to the subsystem, the results are as follows:

Solar	Thermal Recycle
$(100) \times \frac{988.05}{7,878.91} = 13\%$	$(100) \times \frac{3,046.56}{7,878.91} = 39\%$

The wastewater thermal recycle system is 26% higher than the solar energy system in overall efficiency for this period of monitoring. ARATEX Services is served by a highly integrated alternative energy system comprised of subsystems possessing stand-alone capabilities.

When the solar energy system was out of service for refurbishing in December 1979 and January 1980, the heat recovery system still furnished significant and consistent energy to preheat system feedwaters. In fact, slightly more thermal energy was recycled in January 1980 with 75% less solar participation than in May 1980. The operating energy expended was similar in both months, indicating that the heat recovery system performance is maximized by the control system utilized at the plant.

The auxiliary source at the ARATEX Services site consists of two gas-fired Babcock and Wilcox packaged boilers. These units are considered to be 60% efficient for computational purposes.

1.4 SOLAR ENERGY UTILIZATION

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

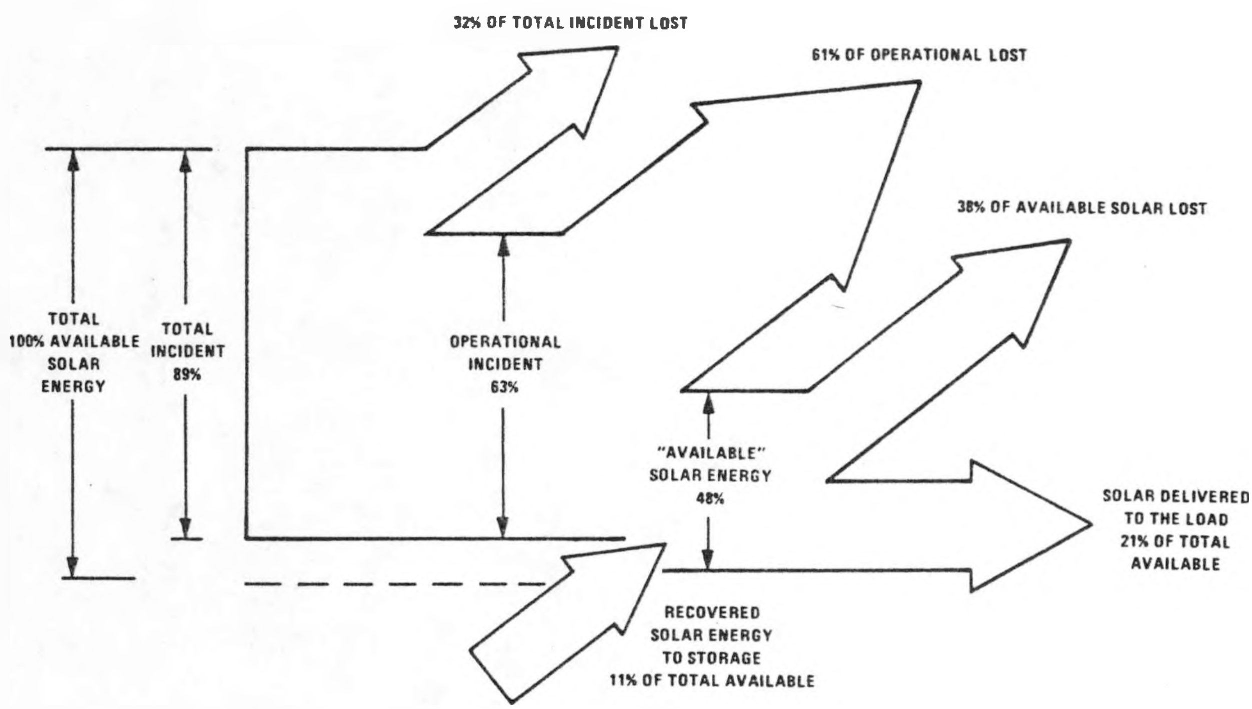


Figure 4. Solar Energy Use
ARATEX Services
December 1979 through November 1980

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

Table 4. SOLAR ENERGY LOSSES

ARATEX SERVICES
DECEMBER 1979 THROUGH NOVEMBER 1980

(All values in million BTU, unless otherwise indicated)

	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	TOTAL	AVERAGE
SOLAR ENERGY COLLECTED	17.39	1.95	26.35	66.81	85.21	105.78	119.14	104.78	132.33	143.57	124.24	60.50	988.05	82.34
SOLAR ENERGY RECYCLED	14.00	11.06	24.75	42.20	52.99	43.58	55.26	54.76	43.77	59.66	56.83	19.14	478.00	39.83
TOTAL SOLAR ENERGY	31.39	13.01	51.10	109.01	138.20	149.36	174.40	159.54	176.10	203.23	181.07	79.64	1,466.05	122.17
CHANGE IN STORED SOLAR ENERGY	-0.08	-0.68	-0.48	-0.89	-0.36	3.56	2.17	-3.72	6.13	-5.20	-1.98	0.04	-1.49	-0.12
COLLECTION TO STORAGE SOLAR ENERGY % LOSS	*	*	20	35	36	30	35	38	47	52	52	35	-	36%
SOLAR ENERGY STORAGE TO HOT WATER LOAD	40.19	23.72	41.25	71.93	88.36	101.26	110.84	101.93	87.92	103.80	89.24	51.40	911.84	75.99

* DENOTES UNAVAILABLE DATA.

Solar energy is collected and stored in the same 12,500-gallon tank into which is introduced preheated system feedwater from the heat recovery heat exchanger. The collector threshold loss, defined as the available solar energy to the collector array while the collector pump was not activated by the control subsystem, is about half the losses from operational solar energy collection. This indicates that the control subsystem is optimizing the collection of solar energy at the lower collector inlet temperatures of this particular collector subsystem.

The addition of about 11% of the total available solar energy to the new collected solar energy through the operation of heat recovery subsystem offsets some of the losses at the site.

1.5 SOLAR SYSTEM AVAILABILITY

The solar system was operational except during the following periods:

1. During December 1979 through February 1980, there were periods of nonoperation due to operator error.

   a. Collector pump was left off for 21 days during January.

   b. During February, the collector was operated for six days to test the installation of the final set of refurbished collectors. The system was then shut down for minor repairs February 13 through February 17. The system was restored to full operation February 18, 1980.

2. Collector threshold control strategy problems were detected in March. However, as the year progressed, these became less evident. Control strategy was improved by the grantee late in April 1980 to reduce energy rejection through the collector array. No further system problems were encountered until July 1980.

3. On July 27 and 28, overheating of storage tank during testing of new valve configurations and a new five hp collector pump led to a rupture in the fiberglass storage tank. This damage was repaired by ARATEX Services and the system continued operation with the solar system in a solar bypass manual mode. Repairs were completed and the system brought on line again August 6, 1980. After two days of operation the storage temperatures rose to nominal levels.

4. A new weekend mode allowed increased collection but eliminated the mode for storage of excess energy in the heat recovery pit. The collector array frequently had to be shut down due to high storage temperatures on weekends. This may have caused overheating of the collectors, damaging the TEDLAR glazing on the refurbished collectors.

The ARATEX Services solar energy system had no further system problems during the period August 8, 1980 through November 30, 1980.

SECTION 2

SUBSYSTEM PERFORMANCE

2.1 COLLECTOR

The collector subsystem performance is presented in Table 5. The performance of the solar collector subsystem was quite good under operational conditions, averaging 39% efficiency. The highest operational efficiency of the collector subsystem was 49% achieved in August, following the fitting of a higher volume replacement circulating pump to the collector loop. The lowest operational collector subsystem efficiency was 17% during January 1980, when the system was undergoing refurbishment testing and the collector controls were disabled for most of the month.

Table 5. COLLECTOR SUBSYSTEM PERFORMANCE

ARATEX SERVICES
DECEMBER 1979 THROUGH NOVEMBER 1980

(All values in million BTU, unless otherwise indicated)

MONTH	INCIDENT SOLAR RADIATION	COLLECTED SOLAR ENERGY	COLLECTOR SUBSYSTEM EFFICIENCY (%)	OPERATIONAL INCIDENT ENERGY	OPERATIONAL SUBSYSTEM EFFICIENCY (%)	DAYTIME AMBIENT TEMPERATURE (°F)	ECSS OPERATING ENERGY
DEC	169.48	17.39	10	74.26	23	57	0.66
JAN	132.16	1.95	2	11.13	17	55	0.16
FEB	193.22	26.35	14	110.56	24	63	0.81
MAR	330.77	66.81	20	216.07	31	63	1.45
APR	337.52	85.21	25	245.44	35	72	1.72
MAY	389.68	105.78	27	276.90	38	78	1.99
JUN	418.80	119.14	28	307.14	39	84	2.13
JUL	405.24	104.78	26	263.67	40	95	2.20
AUG	417.33	132.33	32	271.18	49	93	2.75
SEP	385.66	143.57	37	308.68	47	87	3.15
OCT	335.53	124.24	37	277.49	45	80	3.03
NOV	242.70	60.50	25	174.74	35	66	1.99
TOTAL	3,758.09	998.05	-	2,537.26	-	-	22.04
AVERAGE	313.17	82.34	26	211.44	39	74	1.84

The average collector threshold loss was 33%, indicating that the collector pump may have been turning on at elevated insolation levels and not efficiently collecting available solar energy for part of the year. For operating months without other system problems, collector threshold losses ranged from 56% in December 1979 to a low of 17% in October 1980, after the new collector pump had been installed and some fine tuning of collector activation strategy had been performed.

The collector array effective collection increased greatly towards the end of the year, showing refurbishment and increased flow to the array elements to have improved the overall performance of the subsystem. Operating energy expense increased but is within acceptable limits because the effective collection increases maintained high subsystem COP.

Total collector subsystem efficiency was 26% during the year with most dramatic improvements following the April refurbishment of collector control strategy to reduce the rejection of energy from storage to collectors. A total of 998.05 million BTU of solar energy was collected while only 22.04 million BTU (6,458 kwh) were utilized to operate the collector subsystem. The overall COP of the collector subsystem was 40.38, a very impressive figure of merit.

2.2 STORAGE

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

Table 6. STORAGE PERFORMANCE

ARATEX SERVICES
DECEMBER 1979 THROUGH NOVEMBER 1980

(All values in million BTU, unless otherwise indicated)

MONTH	ENERGY TO STORAGE	ENERGY FROM STORAGE	CHANGE IN STORED ENERGY	STORAGE EFFICIENCY (%)	AVERAGE STORAGE TEMP. (°F)	LOSS FROM STORAGE
DEC	46.54E	41.19	-0.08	86	110	*
JAN	23.75E	23.72	-0.68	*	110	*
FEB	51.10E	41.25	-0.48	80	118	*
MAR	109.01E	71.93	-0.89	65	130	*
APR	138.20E	88.36	-0.36	64	129	*
MAY	151.29E	101.26	3.56	69	131	*
JUN	177.46E	110.84	2.17	64	141	*
JUL	161.45E	101.93	-3.72	61	137	*
AUG	172.13E	87.92	6.13	73	131	*
SEP	198.93E	103.80	-5.20	71	138	*
OCT	177.34E	89.24	-1.98	72	127	*
NOV	77.83E	51.40	0.04	88	119	*
TOTAL	1,485.03	911.84	-1.49	*	*	428.24E
AVERAGE	123.75	75.99	-0.12	66E	127	35.69E

* DENOTES UNAVAILABLE DATA.
E DENOTES ESTIMATED VALUE.

During the reporting period, total solar energy delivered to storage was 981.14 million BTU and recovered solar thermal energy contribution to storage was 503.89 million BTU. There were 911.84 million BTU delivered from storage to the laundry hot water subsystem. Energy loss from storage was 428.24 million BTU. This loss represented 22% of the energy delivered to storage. The calculated storage efficiency based on estimated values was 66%.

The solar thermal storage tank has several functions in the laundry hot water system. These are: 1) solar thermal storage, 2) storage of system makeup water for supply to laundry process hot water load subsystem upon demand, 3) intermediate storage of recycled thermal solar and auxiliary energy in conditions of low solar collection and excess recycled energy available in the heat recovery system, and 4) to maintain normal operations during repairs of problems with the solar energy system.

During months with low contributions of new collected solar energy to the storage tank, operation of valve V3 control strategy maintains the temperature of the solar storage tank at about 30°F higher than system inlet water temperature through recycle of previously collected solar energy and previously utilized auxiliary thermal energy.

The storage subsystem at ARATEX Services acts as a holding mixing tank for both collected solar energy and recycled energy consisting of recovered solar and auxiliary portions. The storage tank is sized to allow approximately three turnovers of tank volume in a typical operating day. While all feedwater to the system is preheated by available recovered energy, not all the system feedwater is delivered to the storage tank. During periods of high demand, water preheated by recovered waste heat is routed through valve V3 direct to the hot water subsystem. During normal operation, inlet waters are made up to the solar storage tank with valve V3 closed. Collection of solar energy occurs without relation to the status of V3 but only contributes energy to the storage tank and not directly to the load under any circumstances. Thus, energy can be contributed from both the heat recovery subsystem and the solar collector subsystem.

Of the total of 1,485.03 million BTU of solar energy available to storage, 911.84 were ultimately provided to the load. A total of 428.24 million BTU is calculated from the subsystem energy balance to have been lost from the storage tank. The computed storage losses, which do not estimate the energy flow to storage due to the operation of valve V3, show that 574.68 million BTU were lost from storage. The difference in these figures is under investigation at Vitro. Sensors have been specified and requested to allow computation of actual recovered energy being introduced to storage, which is now the source of the 146.44 million BTU difference in measured versus calculated energy losses from storage. A high level of confidence exists in the new solar energy collected value and in the value of energy out of storage to the water heating load. The problem is caused by the unmonitored operation of valve V3 and is to be corrected.

2.3 <u>LAUNDRY HOT WATER</u>

The laundry hot water subsystem performance for the ARATEX Services site for the reporting period is shown in Table 7 and graphically illustrated in Figure 5.

Table 7. LAUNDRY HOT WATER SUBSYSTEM PERFORMANCE

ARATEX SERVICES
DECEMBER 1979 THROUGH NOVEMBER 1980

MONTH	HOT WATER DEMAND	SOLAR FRACTION OF DEMAND (%)	SOLAR ENERGY USED	OPER ENERGY	AUX THERMAL USED	AUX FOSSIL FUEL	SUP. WATER TEMP (°F)	HOT WATER TEMP (°F)	AVERAGE DAILY HOT WATER CONSUMPTION (GAL)
DEC	420.43	10	40.19	12.39	380.25	635.01	104	165	26,226
JAN	404.94	6	23.72	12.18	381.21	636.62	109	167	27,440
FEB	358.61	12	41.25	21.62	317.35	529.98	110	164	26,236
MAR	420.25	17	71.93	24.19	348.32	581.70	109	167	28,142
APR	489.64	18	88.36	26.32	401.28	670.14	108	164	35,243
MAY	448.21	21	101.26	24.69	386.95	646.21	106	167	30,731
JUN	477.28	23	110.84	24.32	366.44	611.96	107	165	31,646
JUL	512.46	20	101.93	25.19	415.60	694.04	111	166	34,477
AUG	397.87	22	87.92	22.76	309.95	517.62	107	165	24,908
SEP	348.99	30	103.80	22.96	245.18	409.46	109	160	24,564
OCT	402.13	22	89.24	25.65	312.89	522.53	113	162	28,535
NOV	390.27	13	51.40	12.08	338.88	565.92	105	163	21,762
TOTAL	5,111.08	-	911.84	254.35	4,204.30	7,021.19	-	-	10,339,000
AVERAGE	425.92	18	75.99	21.20	350.36	585.10	108	165	28,326

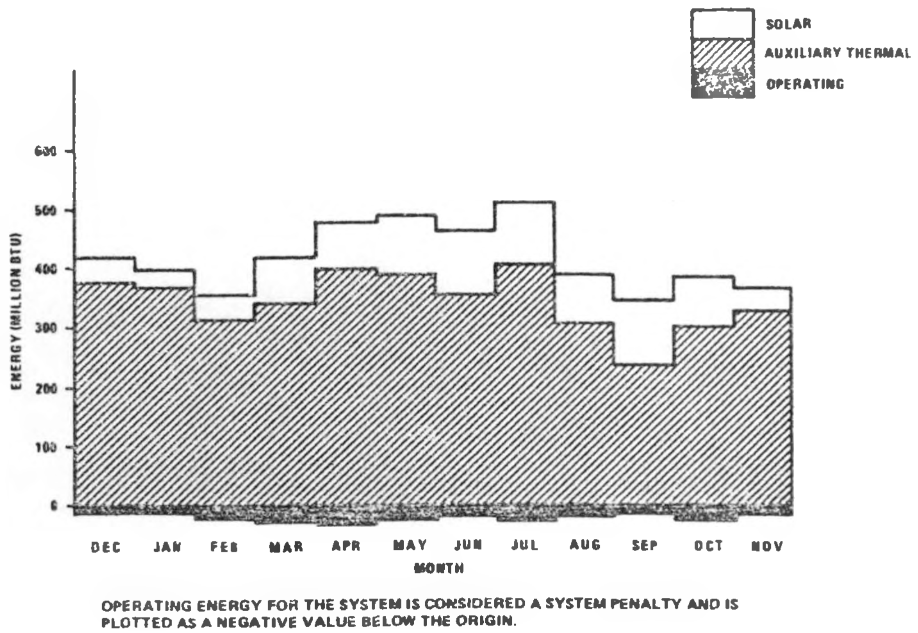


Figure 5. Laundry Hot Water Subsystem Performance
ARATEX Services
December 1979 through November 1980

The laundry hot water subsystem utilized 911.84 million BTU of solar energy and 7,021.19 million BTU of auxiliary fossil fuel energy to satisfy a hot water demand of 5,111.08 million BTU. The solar fraction of the load was 18%, with an operating energy expense of 254.35 million BTU. Losses from the subsystem were estimated at 2,992.68 million BTU. A daily average of 28,326 gallons was consumed at an average temperature of 165°F. This performance was close to predicted design performance values.

The losses from final process heating, while amounting to a great deal of energy on the annual level, have been reduced over time by conservation efforts by ARATEX Services. Despite high losses from the laundry hot water subsystem the subsystem provided adequate and reliable final temperature increase to the laundry process.

The laundry hot water subsystem performed well throughout the year, raising the process hot water temperature to an average operating temperature of 165°F. The heat recovery subsystem provided a boost of 36°F from the inlet water temperature, raising the 72°F city water to a 108°F average temperature. The laundry hot water system inlet water temperature is considered to be the outlet temperature of the heat recovery heat exchanger. The solar collector subsystem provided an additional boost of 19°F to a 127°F average storage temperature. The auxiliary energy applied to the laundry hot water subsystem raised the temperature an additional 38°F to the service temperature of 165°F. Thus, the total increase in temperature provided by the alternative system was 55°F in raising the temperature from 72°F inlet temperature to the storage temperature of 127°F.

2.4 HEAT RECOVERY

The heat recovery subsystem performance for the ARATEX Services site for the reporting period is shown in Table 8.

The heat recovery subsystem provides recovered useful heat from the waste laundry process hot water. The recovered waste heat is routed through waste recovery plumbing to a "pit" of 16,500 gallons capacity. When system controls determine that makeup waters are required by the system, the heat recovery pump routes recovered hot water through the back flush valve to the heat exchanger, preheating the inlet water before it is provided to the solar storage tank or to the laundry hot water subsystem during periods of high demand. Preheated inlet water from the heat recovery heat exchanger can be provided directly to the laundry hot water subsystem through valve V3. Heat recovery occurs in periods of high energy demand when the solar storage tank is not capable of furnishing all the water to the final process. Extended periods of operation in this mode can cause energy imbalance, particularly during months of low insolation.

Table 8. HEAT RECOVERY SUBSYSTEM PERFORMANCE

ARATEX SERVICES
DECEMBER 1979 THROUGH NOVEMBER 1980

(All values in million BTU, unless otherwise indicated)

MONTH	ENERGY RECOVERED	SOLAR ENERGY RECOVERED	SYSTEM FEEDWATER TEMPERATURE (°F)	TEMPERATURE OF PREHEATED WATER (°F)	TOTAL ENERGY[1] CONSUMED (%)	ELECTRICAL OPERATING ENERGY
DEC	229.20	14.00	70	104	34	1.88
JAN	267.88	11.06	70	109	41	2.41
FEB	252.48	24.75	70	110	44	2.19
MAR	279.95	42.20	72	109	42	2.39
APR	333.06	52.99	71	108	43	2.68
MAY	261.54	43.58	73	106	34	2.37
JUN	267.10	55.26	73	107	35	2.59
JUL	299.84	54.76	74	111	36	2.50
AUG	191.03	43.77	74	107	28	1.92
SEP	219.95	59.66	74	109	38	1.69
OCT	263.20	56.83	74	113	39	1.93
NOV	181.06	19.14	72	105	28	1.56
TOTAL	3,046.29	478.00	-	-	-	26.11
AVERAGE	253.86	39.83	72	108	39	2.18

[1] $\frac{\text{ENERGY RECOVERED}}{\text{TECSM}} =$

During January, while the collector array was shut down, the heat recovery subsystem operated for an above average amount of time compared with other months. (The heat recovery subsystem actually provides more energy to the load than the solar collector subsystem at this site and can assume an important role in system operation when the solar subsystem is down for any length of time.) Another example of this system configuration is evident in July when, following the rupture of the solar storage tank, several days had only the heat recovery subsystem preheating inlet feedwaters. The largest net heat recovery energy was obtained during July with a slight decline in operating energy from the previous month.

The temperature boost from the heat recovery subsystem operation is significant, averaging 36°F for the period December 1979 to November 1980. The thermal energy saved by operation of the heat recovery system was 3,046.29 million BTU of which 478.00 million BTU were recycled solar energy, which adds to the solar net efficiency of the system. A total of 26.11 million BTU of electrical energy (7,650 kwh) was expended in operating the heat recovery subsystem. The net fossil savings from the heat recovery subsystem were 5,033.63 million BTU, or 6.39 million cubic feet of natural gas. The savings represent a value of $27,489 worth of natural gas for the period, which is greater than the net value of solar energy savings for the same period.

SECTION 3

OPERATING ENERGY

Measured monthly values of the ARATEX Services solar energy system and subsystem operating energy for the report period are presented in Table 9. A total 276.37 million BTU of operating energy were consumed by the entire system during the reporting period. A distribution of this operating energy among the subsystems is illustrated in Figure 6.

Total system operating energy for ARATEX Services is the electrical energy required to support the process hot water system without affecting its thermal state.

Table 9. OPERATING ENERGY

ARATEX SERVICES
DECEMBER 1979 THROUGH NOVEMBER 1980

(All values in million BTU)

MONTH	ECSS TOTAL (SOLAR UNIQUE)	TOTAL HOT WATER OPERATING ENERGY	HEAT RECOVERY OPERATING ENERGY	TOTAL SYSTEM OPERATING ENERGY
DEC	0.66	10.51	1.88	13.05
JAN	0.16	9.76	2.41	12.33
FEB	0.81	19.43	2.19	22.43
MAR	1.45	21.80	2.39	25.64
APR	1.72	23.64	2.68	28.04
MAY	1.99	22.32	2.37	26.68
JUN	2.13	21.72	2.59	26.44
JUL	2.20	22.69	2.50	27.39
AUG	2.75	20.84	1.92	25.51
SEP	3.15	21.27	1.69	26.11
OCT	3.03	23.72	1.93	28.68
NOV	1.99	10.52	1.56	14.07
TOTAL	22.04	228.22	26.11	276.37
AVERAGE	1.84	19.02	2.18	23.03

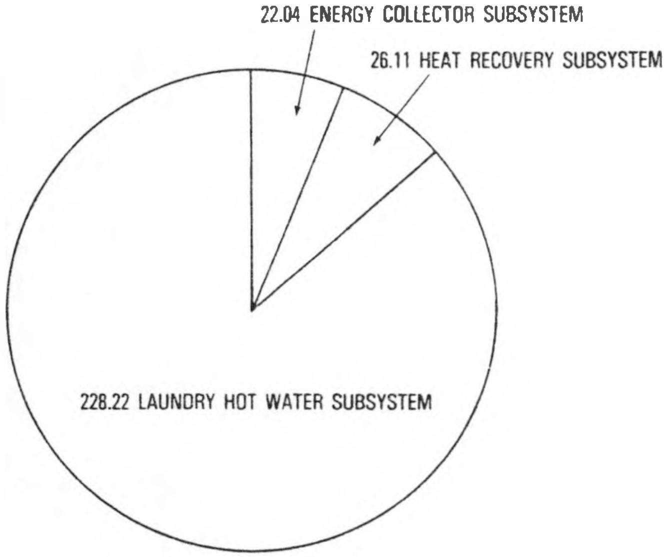


Figure 6. Total Operating Energy
ARATEX Services
December 1979 through November 1980

The operating energy expense at ARATEX Services is very low considering the quantity of energy saved by operation of the solar energy and heat recovery subsystems.

The heat recovery subsystem used only 15% more energy for operation than the energy collector subsystem, while it furnished more than three times the net energy for the satisfaction of water heating demand at the plant. The energy required for heat recovery is directly dependent upon the total consumption of energy at the plant. The consumption was elevated due to increased heat recovery operation during several months when there was elevated average daily hot water consumption.

The solar energy collector subsystem operating energy was lower in the first four months of the season but this was due to reduced operation of the collectors during refurbishment procedures, and below nominal levels of available insolation.

Operation of the process hot water subsystem consumed the greatest amount of operating energy and was also seasonally variable.

The reason for the seasonal variation in total laundry hot water operating energy is unclear at this time and is under investigation but may be related to control functions at the plant.

SECTION 4

WEATHER CONDITIONS

ARATEX Services is located in Fresno, California at 36.46 degrees N latitude and 119.43 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 10. 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 the Fresno SOLMET meteorological station. The long-term average insolation values are total global horizontal radiation converted to collector angle and azimuth orientation, by an algorithm similar to the TRNSYS radiation processor (see Footnote 1).

Table 10. WEATHER CONDITIONS

ARATEX SERVICES
DECEMBER 1979 THROUGH NOVEMBER 1980

MONTH	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT^2-DAY) MEASURED	LONG-TERM AVERAGE	AMBIENT TEMPERATURE (°F) MEASURED	LONG-TERM AVERAGE	AMBIENT TEMPERATURE NEAR SOLAR NOON (°F)
DEC	837	874	49	46	57
JAN	653	971	49	45	55
FEB	1,021	1,367	54	50	63
MAR	1,634	1,884	54	54	63
APR	1,723	2,186	63	60	72
MAY	1,926	2,324	68	67	78
JUN	2,138	2,423	74	74	84
JUL	2,003	2,436	85	81	95
AUG	2,062	2,419	81	78	93
SEP	1,969	2,289	76	74	87
OCT	1,658	1,937	68	64	80
NOV	1,239	1,346	54	54	60
AVERAGE	1,572	1,871	65	62	74

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

During the period from December 1979 through November 1980, the average daily total incident solar radiation on the collector array was 1,572 BTU per square foot per day. This radiation was below the estimated average daily solar radiation for this geographical area during the reporting period of 1,871 BTU per square foot per day for a south-facing plane with a tilt of 30 degrees to the horizontal. During the period, the highest on-site monthly average insolation was 2,138 BTU per square foot per day during June. The average ambient temperature during the reporting period was 65°F as compared with the long-term average for the reporting period of 62°F. The highest monthly average ambient temperature was 85°F during July 1980 and the lowest monthly average ambient temperature was 49°F during December 1979 and January 1980. The same number of heating and cooling degree-days as expected occurred during the reporting period. No space heating system is employed at the site.

Extraterrestrial radiation values are computed and given in the table below for each month during the period. The ratio of total insolation on a tilted surface to extraterrestrial radiation on a parallel surface is an index of atmospheric transmission but may differ from NWS values due to the orientation (tilt) of the pyranometer.

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 67% during June to a low of 24% during January.

	MONTH											
	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
Extraterrestrial Insolation on Tilted Surface (BTU/Ft^2-day)	2,663	2,768	3,042	3,286	3,336	3,259	3,190	3,210	3,284	3,292	3,106	2,823
$\frac{\text{TTL INS}}{\text{ETR INS}}$ (%)	31	24	34	50	52	59	67	62	63	60	53	44

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

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, ARATEX Services, December 1979, SOLAR/2008-79/12, Vitro Laboratories, Silver Spring, Maryland.

*8. Monthly Performance Report, ARATEX Services, January 1980, SOLAR/2008-80/01, Vitro Laboratories, Silver Spring, Maryland.

*9. Monthly Performance Report, ARATEX Services, February 1980, SOLAR/2008-80/02, 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, ARATEX Services, March 1980, SOLAR/2008-80/03, Vitro Laboratories, Silver Spring, Maryland.

*11. Monthly Performance Report, ARATEX Services, April 1980, SOLAR/2008-80/04, Vitro Laboratories, Silver Spring, Maryland.

*12. Monthly Performance Report, ARATEX Services, May 1980, SOLAR/2008-80/05, Vitro Laboratories, Silver Spring, Maryland.

*13. Monthly Performance Report, ARATEX Services, June 1980, SOLAR/2008-80/06, Vitro Laboratories, Silver Spring, Maryland.

*14. Monthly Performance Report, ARATEX Services, July 1980, SOLAR/2008-80/07, Vitro Laboratories, Silver Spring, Maryland.

*15. Monthly Performance Report, ARATEX Services, August 1980, SOLAR/2008-80/08, Vitro Laboratories, Silver Spring, Maryland.

*16. Monthly Performance Report, ARATEX Services, September 1980, SOLAR/2008-80/09, Vitro Laboratories, Silver Spring, Maryland.

*17. Monthly Performance Report, ARATEX Services, October 1980, SOLAR/2008-80/10, Vitro Laboratories, Silver Spring, Maryland.

*18. Monthly Performance Report, ARATEX Services, November 1980, SOLAR/2008-80/11, 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

I. SYSTEM DESCRIPTION
II. TYPICAL SYSTEM OPERATION

APPENDIX A

I. SYSTEM DESCRIPTION

The ARATEX Services (formerly Work-Wear) site is an industrial laundry located in Fresno, California. The system was designed so that collected and recycled solar energy would satisfy 20% of a 30,000-gallon per day hot water laundry process demand. Output waters are designed to be maintained at about 180°F; however, conservation efforts have reduced this temperature to 165°F.

The manufacturers of the major solar system equipment and components are listed below.

Equipment/Components	Manufacturer
Solar Collectors & Control System	Ying Manufacturing Corporation
Solar Hot Water Tank	Century Plastics, Inc.
Solar Pumps ($P2_A$ & $P2_B$)	Grundfos Pump Corporation*
Circulating (Feed) Pump (P1)	Pacific Pumping Company of Canada
Wastewater Pump (P3)	Hydr-O-Matic Pump Division
Heat Reclaimer	Heat Recovery Systems
Diaphragm Control Valves (V_1, V_2, V_B)	ITT Grinnell Valve Division
Pneumatic Control Valves (V_A, V_3, V_4)	DeZurik
Electric Control Valve (V_S)	Automatic Switch Company (ASCO)
Level Controls (L_1, L_2, L_3, L_4)	ASCO
Temperature Controls (T_1 & T_2)	ASCO

*This pump system was replaced by a 5HP Armstrong pump in July 1980.

SUBSYSTEMS

Collector - The solar collector array consists of 140 flat-plate, single-glazed Ying Collectors (Ying Manufacturing Corporation, Gardena, California), 90 of which were reglazed with Tedlar, and recoated during a refurbishment project begun in September 1979.

The collector dimensions are 49.75 x 145.75 x 4 inches, which provide a net collector area of 6,528 square feet which is used in calculation of performance. The collector array faces due south and the collector angle is 30 degrees from the horizontal.

Storage

The ARATEX Services storage tank is composed of a 12,500 gallon, three-fourth inch thick, fiberglass tank with urethane foam insulation three inches in thickness with steel corrugated sheeting attached with metal tiebands at two foot intervals with three bands near the top of the tank. Preheated water can be provided by both the heat recovery system and the solar collector array to the storage tank where the two sources of energy are mixed for delivery to the 4,000-gallon final process heating service tank.

Laundry Hot Water Heating

City water is retained in a fill tank and enters the system through a check valve to the wastewater preheat heat exchanger (HX1). The water is then routed to the solar collector array via the bottom of the 12,500-gallon solar storage tank. Under poor conditions of solar collection, the process water can bypass the solar energy system through V3. Water is final-heated by steam from a natural gas-fired boiler. Operational temperatures across the hot water system for a typical month are City Water Inlet - 72°F; Wastewater - Preheat Out - 108°F; Solar Storage Out - 127°F; Final Heat Out - 165-180°F.

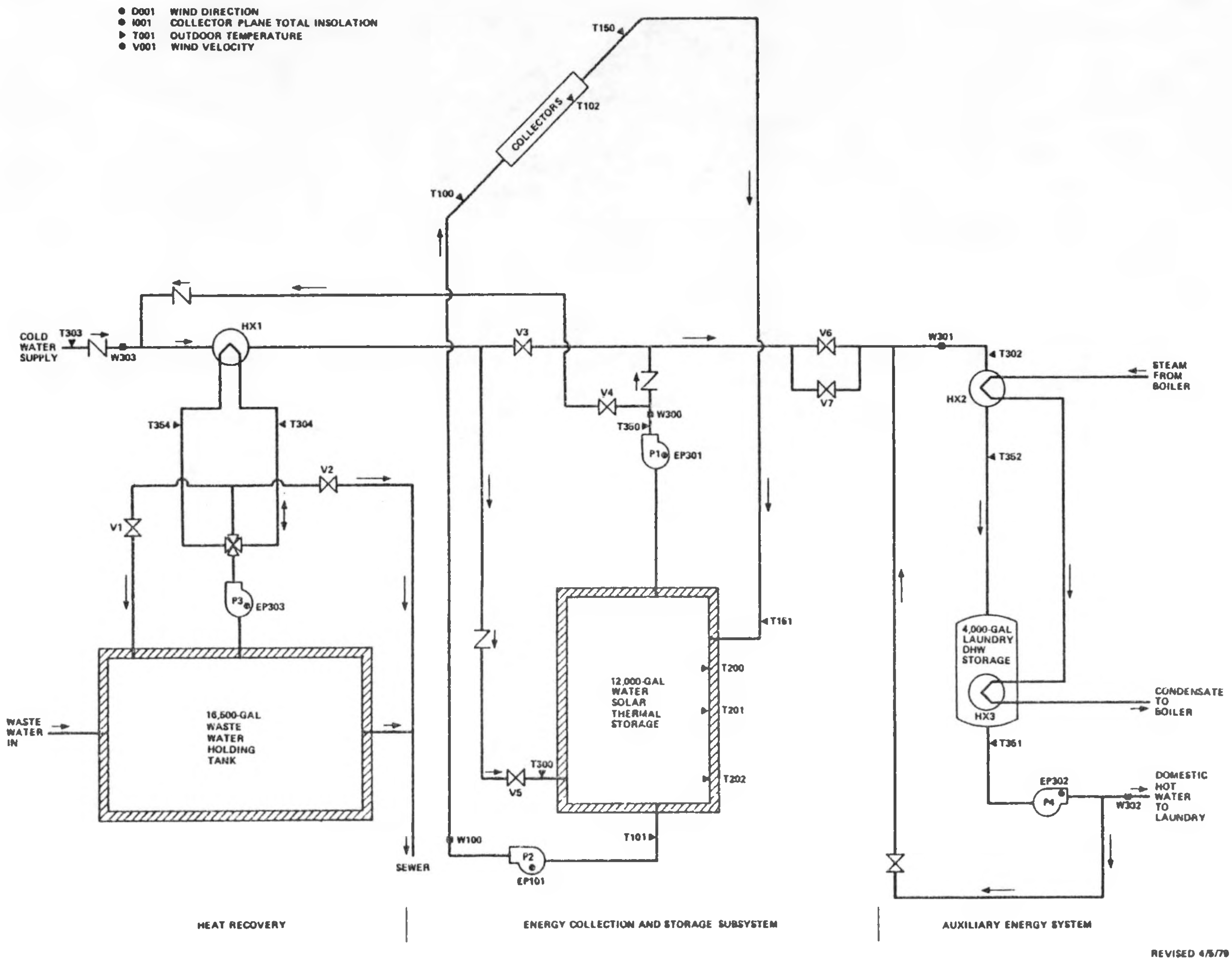


Figure A-1. ARATEX Services Solar Energy System Schematic

The system, shown schematically in Figure A-1, has three modes of operation for process water heating with solar energy and recycled thermal energy.

Mode 1 - Collector-to-Storage - During this mode of operation, water is pumped from solar thermal storage through the collector array and back into storage. This mode is activated when the temperature of the collector array outlet exceeds the storage temperature by 4.5 degrees and continues until this differential temperature drops below 1.5 degrees. There is a 12-minute delay for circulation pump P2 to turn on or off. This control function eliminates sporadic pump operation during fluctuations of insolation, saving electrical operating energy and increasing the life of the collector pump.

Mode 2 - Hot Water Demand - This mode is activated when there is a demand by the laundry for hot water. City water entering the hot water system is preheated using thermal energy from wastewater in the 16,500-gallon holding tank. The temperature of the city water is raised to a range of 95°F to 110°F before entering solar thermal storage. As water is drawn from solar thermal storage, it passes through a steam heat exchanger (HX2) where auxiliary energy is added to maintain the 4,000-gallon laundry hot water service storage tank at about 180°F. Additional energy is supplied from steam condensate flowing through heat exchanger HX3. Under conditions of elevated demand, valve V3 opens to provide inlet water preheated only by the heat recovery subsystem.

Mode 3 - Storage-to-Wastewater - When the water in the solar thermal storage tank reaches 180°F, it can be circulated by reverse flow through heat exchanger HX1 in the heat recovery system, thus storing any excess solar energy in the wastewater holding tank. This mode is used to prevent overheating the 12,500-gallon fiberglass storage tank and allows the wastewater holding tank to be used as a secondary storage tank. Late in the reporting period this mode was eliminated.

II. TYPICAL SYSTEM OPERATION

As shown in Figures A-2 through A-4, typical operation of the ARATEX Services plant integrates the collection of solar energy with recovery of thermal energy from waste laundry process waters retained in a 16,500 gallon holding tank.

At about 5:00 a.m., plant operations staff begin the daily cycle of plant operations by filling the 4,000-gallon laundry service tank and firing the two Babcock & Wilcox gas-fired boilers. As water is drawn from the solar storage tank to the final heating subsystem, stratification in the solar storage tank occurs until about 8:00 a.m. (Figure A-2) when the collector array control logic is satisfied and the collector pumps are activated. By this time, insolation has exceeded 100 BTU/square foot (Figure A-3) and the absorber plates of the collector array are at about 135°F. The collector pump furnishes cooler water via the solar storage tank at about 105°F to the array (Figure A-4).

Referring to the system temperature profile (Figure A-4), the system reaches operating temperature for the provision of hot water to process loads very quickly in the morning. This occurs through the use of auxiliary energy and recovered thermal waste heat as shown by the difference in temperatures between sensors T302 and T351, indicating the final heater loop temperature differential, and between T303 and T300, indicating the recovery of thermal waste heat to the inlet feedwaters.

Before the solar collector subsystem is activated and when only wastewater is available to preheat feedwaters, the difference between T300 and T303 is relatively stable as only a limited quantity of new waste heat is available to the heat recovery subsystem. About 8:00 a.m., the regular employees have arrived and the laundry process system is activated. During operation of the collector subsystem, approximately 18,000 gallons of water per hour is processed through the solar collector array, which boosts the temperature of the water by 4°F - 7°F. On the typical day shown in this section, August 19, 1980 (following installation of the new collector pump and repairs to the ruptured solar storage tank), the array was activated for seven hours during which time about 126,000 gallons of water were circulated. This represents about ten turnovers of storage tank volume while 42,956 gallons of hot water were furnished to the process load. This represents about three loops of each furnished gallon through the array or a two and one-half hour storage residence time. This in turn represents a solar gain of 126.00 BTU per gallon of water drawn through the system and furnished to the final process subsystem and 43.00 BTU per gallon of total daily collector circulation, 126,000 gallons. The calculated all-day collector efficiency was 40%, while, during the operation of the collector pump, 48% of the available solar energy was collected.

The total hot water demand for August 19, 1980 was 22.36 million BTU which represents near-design levels of plant utilization. The overall thermal energy per gallon of water consumed at the plant was 521.00 BTU per gallon for an increase in temperature from 74°F inlet waters to 165°F process water. An additional 10.62 million BTU were applied to the 42,956 gallons of inlet feedwaters through the operation of the heat recovery subsystem. Thus, the total energy provided by thermal energy sources, solar, recycle and auxiliary, was 32.98 million BTU for this typical day.

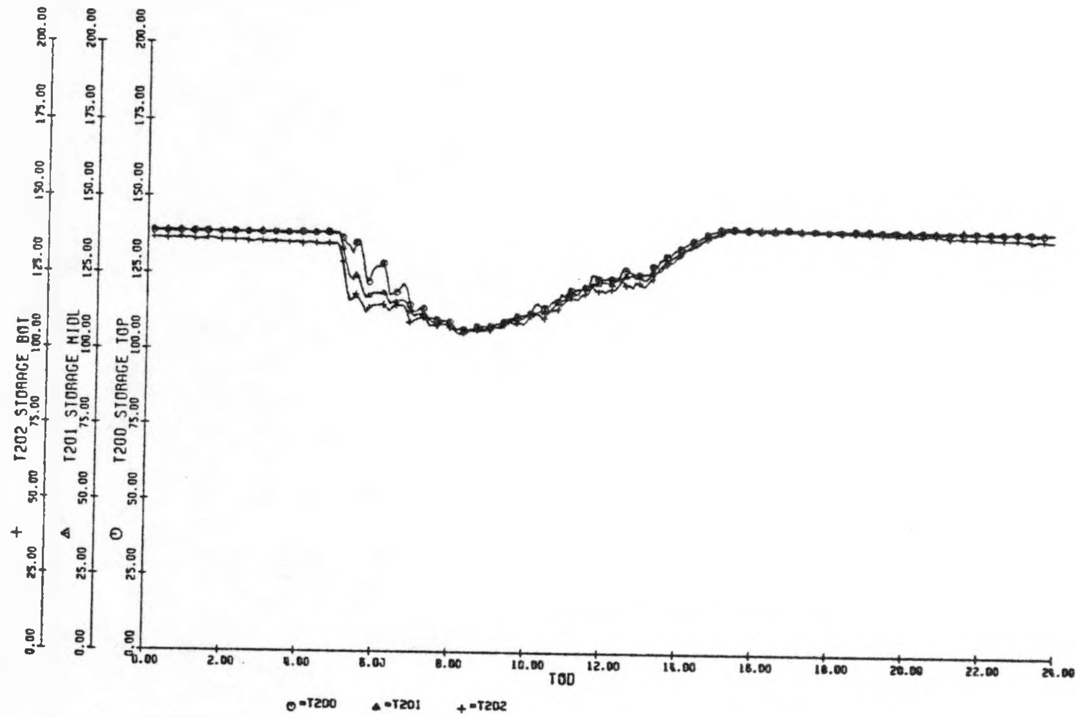


Figure A-2. ARATEX Services Storage Temperature Plot

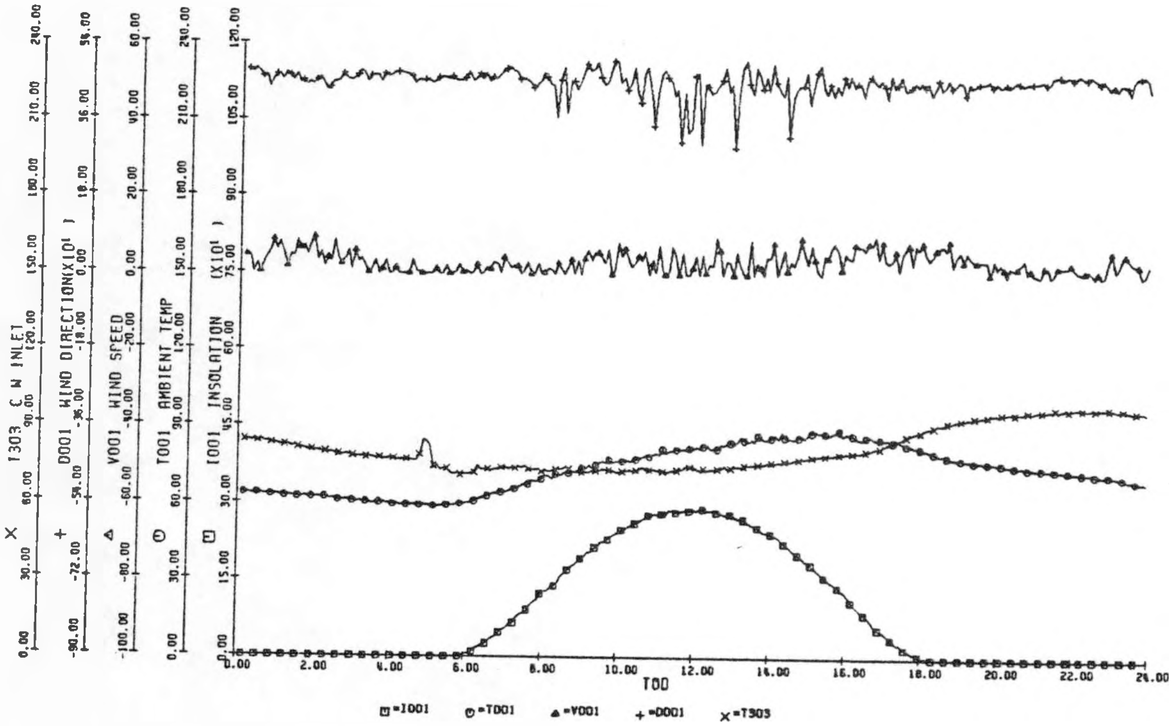


Figure A-3. ARATEX Services Weather Conditions Plot

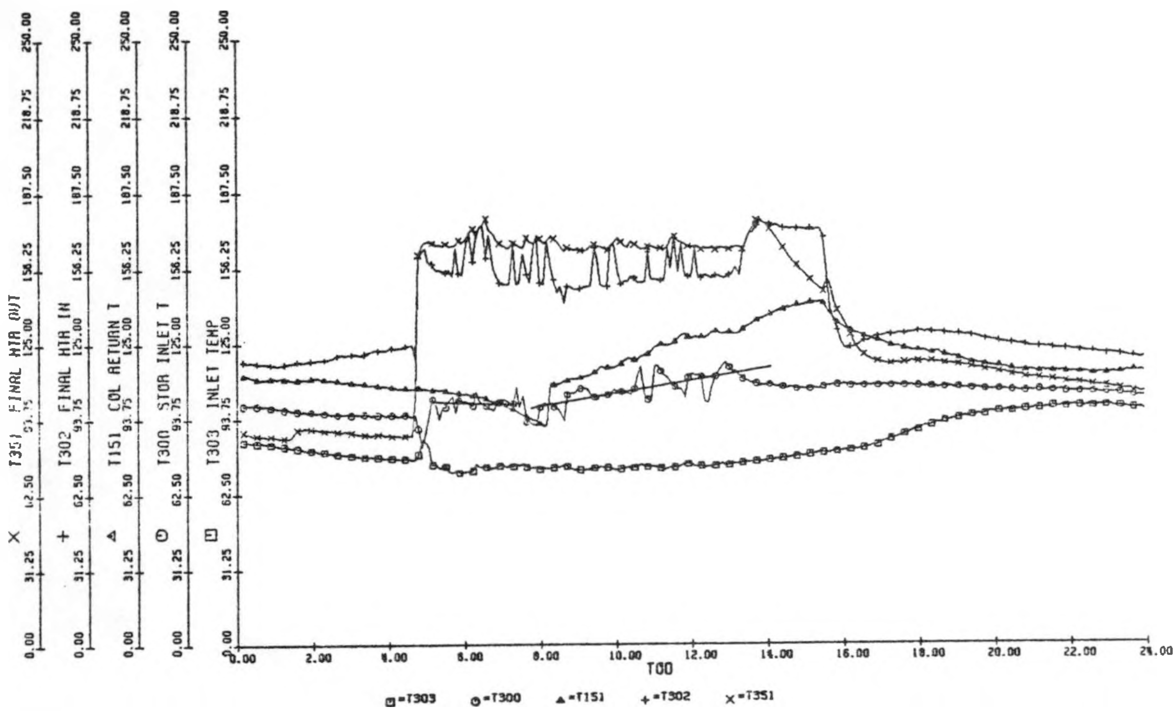


Figure A-4. ARATEX Services System Temperature Profile

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

The performance of the ARATEX Services 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.

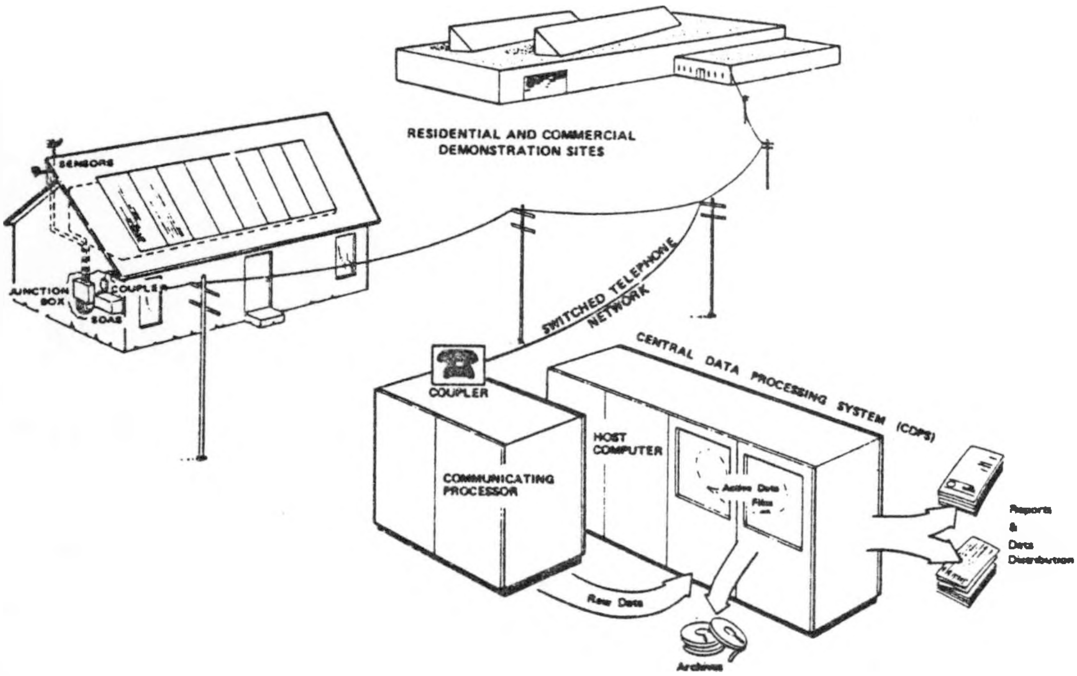


Figure B-1. The National Solar Data Network

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 microprocessor data logger called the Site Data Acquisition Subsystem (SDAS). The SDAS can read up to 96 different channels, one channel for each sensor. The SDAS takes the analog voltage input to each channel and converts it to a 10-bit word. At intervals of 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 realtime 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 ARATEX Services solar energy system from December 1979 through November 1980 was analyzed during the year, and Monthly Performance Reports were published for the months when sufficient valid data were available. See the following page for a list of these reports.

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

OTHER DATA REPORTS ON THIS SITE*

Monthly Performance Reports:

September 1977, SOLAR/2008-77/09
October 1977, SOLAR/2008-77/10
November 1977, SOLAR/2008-77/11
December 1977, SOLAR/2008-77/12
January 1978, SOLAR/2008-77/01
February 1978, SOLAR/2008-78/02
March 1978, SOLAR/2008-78/03
April 1978, SOLAR/2008-78/04
May 1978, SOLAR/2008-78/05
June 1978, SOLAR/2008-78/06
July 1978, SOLAR/2008-78/07
August 1978, SOLAR/2008-78/08
September 1978, SOLAR/2008-78/09
October 1978, SOLAR/2008-78/10
November 1978, SOLAR/2008-78/11
December 1978, SOLAR/2008-78/12
January 1979, SOLAR/2008-79/01
February 1979, SOLAR/2008-79/02
March 1979, SOLAR/2008-79/03
April 1979, SOLAR/2008-79/04
May 1979, SOLAR/2008-79/05
June 1979, SOLAR/2008-79/06
July 1979, SOLAR/2008-79/07
August 1979, SOLAR/2008-79/08
September 1979, SOLAR/2008-79/09
October 1979, SOLAR/2008-79/10
November 1979, SOLAR/2008-79/11
December 1979, SOLAR/2008-79/12
January 1980, SOLAR/2008-80/01
February 1980, SOLAR/2008-80/02
April 1980, SOLAR/2008-80/04
May 1980, SOLAR/2008-80/05
June 1980, SOLAR/2008-80/06
July 1980, SOLAR/2008-80/07
August 1980, SOLAR/2008-80/08
September 1980, SOLAR/2008-80/09
October 1980, SOLAR/2008-80/10
November 1980, SOLAR/2008-80/11
December 1980, SOLAR/2008-80/12

Solar Energy System Performance Evaluations:

July 1978, SOLAR/2008-78/14
September 1978, SOLAR/2008-78/24

Solar Project Description, June 1978, SOLAR/2008-78/50

Solar Cost Report, June 1978, SOLAR/2008-78/60

Thermal Performance of Aratex Services, Inc., Solar Energy System:

July 1978, SOLAR/2008-78/25
November 1978, SOLAR/2008-78/34

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* 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

Section 2. Solar Terminology

Section 3. General Acronyms

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).
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 — Incoming solar radiation.

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.

Microclimate — Highly localized weather features which may differ from long term regional values due to the interaction of the local surface with the atmosphere.

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 ėquipments 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

ARATEX SERVICES

INTRODUCTION

Solar energy system performance is evaluated by performing energy balance computations 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.

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* See Appendix B.

For an air system ΔH is generally given by

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

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

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

For electrical power, a general example is

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

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

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

AVERAGE AMBIENT TEMPERATURE (°F)

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

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

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

for ± three hours from solar noon

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

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

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

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

when the collector loop is active

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

$$SECA = \Sigma\ [M100 \times HWD \times (T150,\ T100)] \times \Delta\tau$$

SOLAR ENERGY TO STORAGE (BTU)

$$STEI = \Sigma\ [M100 \times HWD \times (T151, T101)] \times \Delta\tau$$

SOLAR ENERGY FROM STORAGE

$$STEO = \Sigma\ [M300 \times HWD \times (T350, T300)] \times \Delta\tau$$

AVERAGE TEMPERATURE OF STORAGE (°F)

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

ENERGY DELIVERED FROM ECSS TO PROCESS WATER HEATING SUBSYSTEM (BTU)

$$CSEO = STEO$$

ECSS OPERATING ENERGY (BTU)

$$CSOPE = \Sigma\ EPCONST \times \Sigma\ EP101 \times \Delta\tau$$

when system is in the collector-to-storage mode

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

$$SEA = CLAREA \times SE$$

COLLECTED SOLAR ENERGY (BTU)

$$SEC = SECA/CLAREA$$

COLLECTOR ARRAY EFFICIENCY

$$CLEF = SECA/SEA$$

COLLECTOR ARRAY OPERATIONAL EFFICIENCY

$$CLEFOP = SECA/SEOP$$

CHANGE IN STORED ENERGY (BTU)

$$STECH = STOCAP \times (TSTO \times RHO_p \times CP_p - TST1 \times RHO \times CP) \times \Delta\tau$$

STORAGE EFFICIENCY

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

SOLAR ENERGY TO LOAD SUBSYSTEMS (BTU)

$$SEL = HWSE$$

STORAGE LOSS

$$STLOSS = STEI - STEO - STECH$$

ESCC SOLAR CONVERSION EFFICIENCY

$$CSCEF = SEL/SEA$$

HOT WATER SOLAR ENERGY USED (BTU)

$$HWSE = STEO$$

HOT WATER LOAD (BTU)

$$HWL = HWSE + HWAT$$

HOT WATER DEMAND (BTU)

$$HWDM = \Sigma\ [M302 \times HWD\ (T351,\ T300)] \times \Delta\tau$$

HOT WATER OPERATING ENERGY (BTU)

$$HWOPE = \Sigma\ EPCONST \times (EP301 + EP302 + EP303) \times \Delta\tau$$

HOT WATER CONSUMPTION (GALLONS)

$$HWCSM = \Sigma\ [WD303] \times \Delta\tau$$

HOT WATER TANK TOTAL ENERGY (BTU PER HR)

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

HOT WATER AUXILIARY THERMAL ENERGY (BTU)

$$HWAT = \Sigma\ [M302 \times HWD\ (T351,\ T302)] \times \Delta\tau$$

HOT WATER AUXILIARY FOSSIL ENERGY (BTU)

$$HWAF = HWAT/0.6$$

HOT WATER FOSSIL ENERGY SAVINGS (BTU)

$$HWSVF = HWSE/0.6$$

SUPPLY WATER TEMPERATURE (°F)

$$TSW = \Sigma\ [M300 \times T300)/M300] \times \Delta\tau$$

HOT WATER TEMPERATURE (°F)

$$THW = \Sigma\ (M302 \times T351)/M302] \times \Delta\tau$$

HOT WATER SOLAR FRACTION (PERCENT)

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

HOT WATER PREVIOUS SOLAR FRACTION (PERCENT)

HWSFR_P = HWSFR

HOT WATER DEMAND SOLAR FRACTION (PERCENT)

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

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

ELECTRIC CONVERSION CONSTANT

EPCONST = 56.8833

SYSTEM LOAD

SYSL = HWL

SYSTEM OPERATING ENERGY (BTU)

SYSOPE = CSOPE + HWOPE

AUXILIARY THERMAL ENERGY (BTU)

AXT = HWAT

AUXILIARY FOSSIL ENERGY (BTU)

AXF = HWAF

SYSTEM SOLAR FRACTION

SFR = HWSFR

TOTAL ELECTRICAL ENERGY SAVINGS

TSVE = CSOPE

TOTAL FOSSIL ENERGY SAVINGS

TSVF = HWSVF

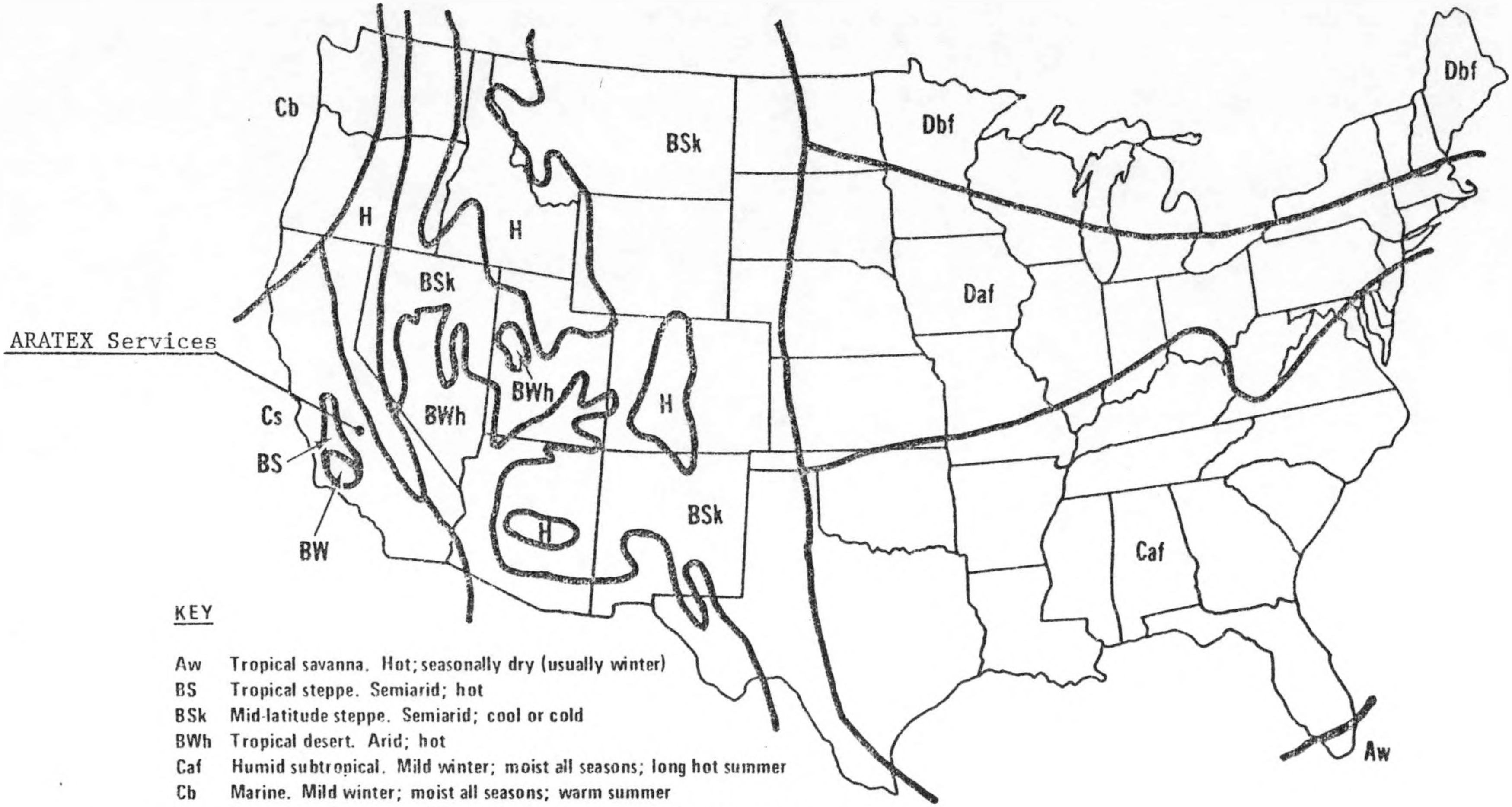
TOTAL ENERGY CONSUMED

TECSM = SYSOPE + SECA + AXF

APPENDIX E

METEOROLOGICAL CONDITIONS

This appendix presents monthly tables of site meteorological conditions of insolation, temperature, and wind by day in the month. The site's location is shown on Figure E-1. Long-term weather data consisting of insolation values for Fresno, California modeled to a tilt of 30° are presented along with values of average temperature and heating or cooling degree-days.



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 E-1. Meteorological Map of the United States Showing Location of ARATEX Services

ARATEX SERVICES LONG-TERM WEATHER DATA

COLLECTOR TILT: 30.00 DEGREES
LATITUDE: 36.46 DEGREES

LOCATION: FRESNO, CALIFORNIA
COLLECTOR AZIMUTH: 0.0 DEGREES

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
DEC	1,391	575	0.41361	1.519	874	595	0	46
JAN	1,516	656	0.43299	1.480	971	611	0	45
FEB	1,965	1,010	0.51424	1.353	1,367	423	0	50
MAR	2,529	1,567	0.61950	1.202	1,884	344	0	54
APR	3,097	2,094	0.67616	1.044	2,186	182	41	60
MAY	3,481	2,485	0.71390	0.935	2,324	51	125	67
JUN	3,631	2,732	0.75246	0.887	2,423	9	276	74
JUL	3,549	2,684	0.75625	0.908	2,436	0	484	81
AUG	3,239	2,422	0.74786	0.999	2,419	0	412	78
SEP	2,730	1,984	0.72662	1.154	2,289	0	267	74
OCT	2,127	1,431	0.67265	1,354	1,937	90	66	64
NOV	1,619	889	0.54885	1,515	1,346	345	0	54

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: ARATEX SERVICES
DECEMBER 1979
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	1382	53	65	0	0
2	1042	57	68	0	0
3	1163	55	*	0	0
4	1480	54	68	0	0
5	1063	49	58	0	1
6	1252	51	64	0	0
7	1323	53	67	0	0
8	980	54	*	0	0
9	1229	54	68	0	0
10	90	47	48	0	0
11	725	45	51	104	2
12	233	42	*	0	0
13	1366	45	58	0	0
14	1654	46	*	0	0
15	223	41	35	0	0
16	1192	47	61	0	0
17	1227	46	*	0	0
18	1434	53	68	0	0
19	225	51	58	0	1
20	811	51	59	0	1
21	451	48	*	0	1
22	872	44	50	0	2
23	84	46	*	256	3
24	93	51	52	251	6
25	958	51	60	*	3
26	91	39	40	113	3
27	1524	44	56	0	0
28	300	38	40	0	1
29	1030	46	53	0	1
30	258	52	*	244	3
31	208	56	62	0	1
SUM	25961	-	-	-	-
AVG	837	49	57	0	1

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: ARATEX SERVICES
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	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	633	52	56	0	1
2	536	53	58	0	0
3	935	49	58	0	0
4	282	46	48	0	1
5	593	47	50	0	1
6	97	48	50	0	1
7	813	51	59	0	0
8	649	50	57	0	1
9	336	54	55	260	5
10	96	50	50	0	1
11	485	59	66	258	6
12	208	61	63	250	4
13	144	62	62	259	6
14	710	59	63	275	3
15	213	54	56	0	2
16	556	55	60	0	1
17	191	52	55	0	1
18	429	46	47	105	5
19	1552	43	54	0	1
20	1784	44	57	0	0
21	1653	47	*	0	0
22	1289	45	*	0	0
23	335	45	*	0	0
24	271	43	45	0	1
25	95	41	*	0	1
26	369	41	44	0	1
27	172	45	46	0	0
28	790	51	57	0	1
29	1449	46	*	108	7
30	1785	47	*	0	1
31	795	48	56	0	1
SUM	20246	-	-	-	-
AVG	653	49	55	0	2

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: ARATEX SERVICES
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	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	939	47	*	0	1
2	205	49	50	0	1
3	142	48	49	0	1
4	326	50	*	0	0
5	374	50	53	117	2
6	210	49	*	0	1
7	1145	50	*	0	1
8	1759	50	63	0	1
9	1787	52	68	0	0
10	1937	53	68	0	0
11	1866	51	66	0	0
12	1768	52	66	0	0
13	403	47	55	0	1
14	162	52	*	251	3
15	637	56	60	244	4
16	105	54	56	245	5
17	179	57	60	254	6
18	1578	63	69	270	7
19	561	55	59	257	6
20	922	53	58	255	5
21	1171	57	65	258	5
22	736	52	60	0	1
23	1729	55	69	0	0
24	1091	57	69	0	0
25	1693	59	74	0	1
26	1597	61	76	0	1
27	626	61	69	*	3
28	2034	57	66	114	4
29	1916	54	66	0	1
SUM	29598	-	-	-	-
AVG	1021	54	63	265	2

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: ARATEX SERVICES
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	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	269	53	57	0	0
2	379	53	57	259	3
3	1021	54	59	235	2
4	2027	57	66	0	2
5	800	54	59	262	4
6	647	50	52	0	1
7	1539	52	60	0	1
8	2114	55	67	0	1
9	2146	57	70	0	1
10	596	55	63	0	0
11	1226	55	61	113	5
12	2166	52	62	111	3
13	2031	53	65	0	1
14	1887	55	68	0	1
15	1613	53	58	111	10
16	2139	51	61	0	2
17	2127	57	72	109	3
18	1389	52	57	116	6
19	2167	56	67	0	1
20	2054	56	69	109	6
21	1930	52	58	108	5
22	2198	55	65	0	2
23	2158	60	75	130	2
24	2205	54	61	109	5
25	262	44	49	0	2
26	1114	51	58	0	0
27	1627	55	63	109	3
28	2182	57	70	0	1
29	2173	62	76	0	1
30	2316	57	65	105	7
31	2167	57	68	93	3
SUM	50669	-	-	-	-
AVG	1634	54	63	98	3

MONTHLY REPORT: ARATEX SERVICES
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	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	2057	55	64	111	3
2	1834	57	67	0	2
3	2128	58	70	0	2
4	946	57	66	0	2
5	776	56	59	233	4
6	2227	57	66	111	8
7	1964	57	67	128	2
8	2095	62	75	0	1
9	2249	63	74	111	7
10	2255	61	72	113	4
11	2198	65	79	0	1
12	2225	71	86	116	2
13	1976	70	84	269	2
14	2180	63	72	111	9
15	1939	63	*	0	2
16	2114	73	86	0	0
17	2139	76	89	100	2
18	1733	65	*	112	4
19	2164	72	84	114	2
20	1756	66	79	111	8
21	2204	55	64	101	4
22	734	51	57	101	2
23	512	52	59	0	1
24	1099	61	67	0	2
25	1954	64	75	107	3
26	1901	67	*	110	3
27	1614	70	82	93	3
28	798	65	74	126	3
29	723	62	64	0	1
30	1210	67	73	0	1
SUM	51704	-	-	-	-
AVG	1723	63	72	102	3

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: ARATEX SERVICES
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	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	1845	69	78	0	2
2	2036	73	84	0	2
3	1745	75	89	116	2
4	2090	77	89	106	4
5	1464	71	83	109	6
6	2159	66	73	111	7
7	2215	68	77	106	4
8	1938	68	81	98	6
9	634	57	63	110	5
10	1994	56	63	107	6
11	1673	57	67	108	3
12	1840	61	69	108	3
13	1293	64	72	106	5
14	1989	63	71	107	6
15	2167	67	76	106	6
16	2068	71	83	104	5
17	2161	75	86	100	2
18	2134	80	96	120	3
19	2109	82	95	111	4
20	1860	83	96	119	4
21	2031	73	85	*	5
22	2125	65	74	104	9
23	1783	55	63	88	8
24	1885	56	65	113	4
25	2052	61	70	106	3
26	2096	65	76	96	3
27	2039	65	75	103	5
28	2037	65	74	108	5
29	2114	68	77	109	6
30	2085	69	80	110	5
31	2033	67	76	106	5
SUM	59694	-	-	-	-
AVG	1926	68	78	105	5

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: ARATEX SERVICES
JUNE 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	2075	70	80	109	4
2	2147	67	75	113	7
3	2125	65	73	107	5
4	1939	68	76	109	6
5	2124	66	75	108	7
6	2115	68	78	105	6
7	2116	71	81	108	5
8	2100	74	86	108	6
9	2155	76	89	109	6
10	2145	76	89	102	6
11	2158	71	82	108	6
12	2152	67	75	107	7
13	2135	68	78	106	8
14	2235	71	81	109	5
15	2218	77	89	99	4
16	2199	80	92	106	4
17	2184	83	95	102	3
18	2150	80	93	105	5
19	2152	78	89	106	4
20	2175	75	86	107	5
21	2236	76	87	108	7
22	2198	73	85	108	7
23	2213	72	81	110	8
24	2154	74	85	107	4
25	2150	75	84	104	7
26	2190	74	84	101	7
27	2020	79	91	0	2
28	1919	88	100	*	2
29	*	*	*	*	*
30	*	*	*	*	*
SUM	64154	-	-	-	-
AVG	2138	74	84	106	5

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: ARATEX SERVICES
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	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	1746	83	95	I	4
2	2120	76	83	I	9
3	1995	78	86	I	5
4	2147	78	88	I	6
5	2096	78	90	I	5
6	2078	78	92	I	5
7	1700	76	85	I	5
8	2152	75	85	I	6
9	2107	73	81	I	6
10	2110	79	89	I	4
11	2111	83	94	I	4
12	2071	79	90	I	6
13	2099	77	88	I	4
14	2117	80	91	I	3
15	2103	85	96	I	2
16	2027	88	100	I	3
17	2150	88	98	I	4
18	2015	86	*	I	4
19	2116	83	94	I	3
20	2106	86	98	I	3
21	2030	88	99	I	4
22	1837	89	*	I	3
23	1968	92	103	I	3
24	1985	92	105	I	3
25	1968	93	106	I	3
26	1990	94	106	I	3
27	1966	94	106	I	2
28	1952	96	105	I	3
29	1973	94	104	I	3
30	1245	89	99	I	2
31	2000	93	103	I	4
SUM	62078	-	-	-	-
AVG	2003	85	95	280	4

I DENOTES INVALID DATA.
* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: ARATEX SERVICES
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	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	2038	93	104	282	4
2	2107	92	106	283	4
3	2164	87	99	274	3
4	2130	84	97	263	3
5	2127	80	92	0	2
6	2035	82	93	271	2
7	2048	87	98	279	3
8	2084	88	99	277	3
9	2119	87	98	267	3
10	1932	88	*	275	3
11	2139	87	100	273	3
12	2137	88	103	287	2
13	2184	82	97	280	4
14	2166	73	85	281	4
15	2085	75	85	0	2
16	2012	81	90	0	2
17	2045	82	94	278	3
18	2026	77	90	279	5
19	2072	74	82	273	3
20	2029	78	88	275	4
21	2030	82	93	279	3
22	1952	79	92	282	4
23	2037	75	85	279	3
24	2039	79	91	272	3
25	1714	75	*	*	2
26	2064	81	93	279	3
27	2113	81	93	284	3
28	1751	76	*	274	3
29	2187	76	89	278	4
30	2175	75	85	284	4
31	2189	77	86	278	2
SUM	63930	-	-	-	-
AVG	2062	81	93	281	3

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: ARATEX SERVICES
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	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	2111	80	93	0	2
2	2122	81	94	281	3
3	2095	81	92	290	3
4	2086	82	94	282	2
5	2010	84	95	269	3
6	2055	78	89	276	4
7	1768	72	*	275	3
8	2133	75	86	276	4
9	2058	78	88	288	3
10	2044	78	90	274	3
11	2043	76	88	273	3
12	2015	79	90	282	2
13	2054	71	83	285	6
14	1871	66	78	0	2
15	1531	68	79	0	1
16	2023	73	85	0	1
17	1676	77	90	0	2
18	1694	73	81	286	7
19	2019	70	79	279	6
20	2081	72	83	279	3
21	2085	70	79	284	3
22	2046	72	86	283	2
23	2031	75	88	0	1
24	1991	78	93	0	1
25	1968	79	94	0	1
26	1839	79	93	0	2
27	1909	72	83	284	3
28	1940	70	81	0	2
29	1937	77	90	0	1
30	1844	79	93	0	0
SUM	59078	-	-	-	-
AVG	1969	76	87	292	3

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: ARATEX SERVICES
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	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	1800	80	95	0	1
2	1794	81	96	0	1
3	1655	82	95	0	1
4	1747	83	97	0	0
5	1730	83	97	0	1
6	1707	80	95	0	1
7	1666	79	92	0	1
8	1724	80	94	0	1
9	1624	79	*	0	1
10	1722	73	86	282	2
11	1731	70	85	0	1
12	1782	67	75	285	7
13	1684	63	73	285	5
14	1736	58	66	279	9
15	1614	56	65	0	2
16	1084	56	68	0	0
17	1813	59	71	0	1
18	1771	61	74	0	1
19	1786	63	78	0	0
20	1788	64	79	0	1
21	1751	66	81	0	1
22	1660	65	79	0	1
23	1735	68	82	0	0
24	1637	70	84	0	1
25	435	59	63	286	3
26	1639	57	67	281	2
27	1772	57	70	0	0
28	1799	61	76	0	1
29	1855	60	76	0	0
30	1524	61	77	0	0
31	1635	65	80	0	1
SUM	51398	-	-	-	-
AVG	1658	68	80	0	1

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: ARATEX SERVICES
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	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	1556	64	80	0	1
2	1554	59	72	0	1
3	1537	62	76	0	1
4	1606	65	79	0	0
5	1538	65	79	283	2
6	1375	59	70	0	1
7	1462	64	77	0	1
8	1548	62	72	286	4
9	1540	58	70	0	1
10	1276	57	68	0	1
11	167	54	56	0	2
12	1612	53	60	292	2
13	1443	51	62	0	0
14	1416	51	63	0	1
15	1398	48	59	0	0
16	1077	50	63	0	1
17	1454	51	64	0	0
18	1493	50	64	0	0
19	1034	49	62	0	1
20	1043	49	60	0	0
21	836	51	63	0	0
22	1387	55	66	0	1
23	645	53	60	0	1
24	220	46	49	0	1
25	1063	46	56	0	0
26	1496	48	63	0	0
27	1381	48	61	0	0
28	1418	50	65	0	0
29	855	53	66	0	0
30	749	53	60	0	1
SUM	37179	-	-	-	-
AVG	1239	54	66	0	1

APPENDIX F

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

The ARATEX Services laundry was retrofitted with the solar energy system described in this report during early 1977. The Ying Manufacturing Company of Gardena, California produced the special light-weight collector panels for the retrofit, designed to minimize roof loading.

The collector panels were damaged in the summer of 1977 due to stagnation effects because the system was not operated.

The site was included in the NSDN in 1977 to monitor performance of the fully-instrumented solar energy system, and to compute the recycled thermal energy returned to the system.

During 1977 through 1979, the ARATEX Services site operated normally but was hindered by what previous analysis described as reduced levels of performance, due to lower levels of insolation than predicted and damaged collector panels.

- During December 1979 through the first week in February 1980, the collector array was not operated normally due to the refurbishment project being completed. During January, the collector pump was shut off by accident for 21 days.

- During February 1980, there were 18 total days of normal controlled operation. During the month, additional adjustments were made to the solar energy system, improving performance.

- Collector threshold control problems were noted in March 1980 but the system maintained automated operation.

- In April 1980, control strategy was improved, reducing inadvertent energy rejection through the collector array.

- No system problems occurred from early April to July 27, 1980 when the storage tank became overpressurized during a system test and was ruptured. The storage subsystem was repaired by August 6, 1980, and was put back on-line. This failure was the result of testing a new five hp collector pump.

- Following repairs to storage, the new collector pump provided a rapid charging cycle of energy to the storage subsystem. Some overheating of storage and elevated collector array inlet temperatures were observed and corrected during September 1980.

- The weekend collection mode was discontinued by the grantee late in August 1980 due to the increased rate of collection overstepping the stand-alone capability of the plant. A major reason was the elimination of weekend plant shifts by ARATEX Services and fears that unattended operation of the solar energy system would result in system failure or damage.

The system operated as controlled for the remainder of this analysis period.

APPENDIX G

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 H

SENSOR TECHNOLOGY

Temperature Sensors

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

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

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

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

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

Wind Sensor

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

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

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

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

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

Humidity Sensors

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

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

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

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

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

Insolation Sensors

Eppley pyranometers and shadowband pyranometers are used to measure the amount of radiant energy incident on a surface. A standard pyranometer measures the total amount of solar energy available, including both the direct beam component and the diffuse component, while the shadowband instrument is designed to measure the diffuse component only. The instruments are calibrated in the horizontal position, with an Eppley thermopile used as the signal generator of the sensor. The heating of the thermopile by the radiation of the sun generates the signal, with the response being linear over the operating range. Measurements are in BTU/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 gage bridge. This strain gage bridge circuit translates the mechanical stress due to the sensor (target) drag into a directly proportional electrical output. Translation is linear, with infinite resolution, and is hysteresis free. The drag force itself is usually proportional to the flow rate squared. The electrical output is unaffected by variations in fluid temperature or static pressure head, within the stated limitations of the unit.

Power Sensors

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

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

The resultant measurements of the wattmeter are summarized below:

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

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

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

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