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1982 Annual Report of the Coolidge Solar Irrigation Project

Dennis L. Larson
The University of Arizona
Soils, Water and Engineering Department
Tucson, AZ 85721

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ABSTRACT

The Coolidge Solar Irrigation Facility at Coolidge, Arizona consists of a 2140.5-m^2 (23 040-ft^2) line-focus collector subsystem, a 13.6-m^2 (30 000 gal) thermal storage subsystem, and a 150-kW_e power generation unit. The purpose of this document is to report the performance of the facility and its operational and maintenance requirements. This document covers the period of time from 1 September 1981 through 30 September 1982. This is the third in a series of annual reports on the operation of the Coolidge Solar Irrigation Facility.

Acknowledgements

The author wishes to acknowledge the following contributions:

Leroy E. Torkelson, Sandia National Laboratories, Albuquerque - developed the facility test and evaluation plan, provided direction and assistance during performance tests and shared in the preparation of the 1980 and 1981 Annual Reports. Tragically, he died of injuries suffered in an accident in Summer 1982. We miss him.

Jack Hoopes, Lee Ballard and Ruben Wood operated the Coolidge Solar Irrigation Facility. Ruben Wood was responsible for maintenance of the solar plant.

Andy Clark and Edie Griffith of the University of Arizona assisted with operation of the facility and processed the facility performance data.

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1. Introduction

This document is a report on the performance of the Coolidge, Arizona, Solar Irrigation Facility during its third and final year of operation.

The facility was the largest operating solar thermal power plant in the United States when it began operation in October 1979. The site, the Dalton Cole farm south of Coolidge, Arizona, was selected in February 1977. A preliminary design study of the facility was undertaken early in 1977 by three contractors and was completed in August 1977. On the basis of the conceptual design competition, Acurex Corporation was selected as the prime contractor for this project as well as the supplier of the solar collectors. The major subcontractors to Acurex were Sundstrand Corporation and Sullivan and Masson Consulting Engineers. Sundstrand was the supplier of the Organic Rankine Cycle (ORC) power generation unit. The team of Sullivan and Masson and Acurex was responsible for the detailed design task.

The solar plant consists of solar collector, energy storage and power conversion subsystems. The facility is arranged around three heat transfer loops. One loop extracts warm heat-transfer oil (Caloria^{TM}) from the bottom of a thermal storage tank, circulates the oil through the collector field, and returns it hot to the top of the thermal storage tank. The second loop extracts hot oil from the top of the storage tank, circulates the oil through a vaporizer heat-exchange unit, and returns it to the bottom of the storage tank or directly to the collector field inlet. The third loop circulates liquid toluene through the vaporizer heat-exchanger unit to vaporize it and then expands the vapor through the turbine in the power conversion module to extract the energy for electrical power generation. The cycle is completed by condensing the expanded vapor in an evaporative cooling tower and pumping the condensed toluene back to the vaporizer. The system flow diagram is shown in Figure 1-1.

The collector field is made up of 2140 m (23040 ft) of line-focusing parabolic trough collectors arranged in eight loops having a north-south orientation. The collector modules are about 1.8 m across by 3 m long and originally had aluminum reflective surfaces. These surfaces were laminated with aluminized acrylic film (FEK-244) in Spring 1981. Caloria^{TM} is pumped thorugh the receiver tube, located at the solar collector focus, at a rate controlled to obtain the desired collector loop outlet temperature. The receiver tubes are coated with a selective black chrome surface and surrounded by a glass tube to increase energy collection. The sun's energy, concentrated about 36 times by the reflectors, is absorbed by the oil heating it to the operating temperature, normally 288°C.

Heated Caloria^{TM} is returned to energy storage or sent directly to the vaporizer heat-exchanger. A 114 m (30,000 gal) insulated tank 4.2 m in diameter by 14.9 m high provides energy storage sufficient for over 5 hours of power conversion subsystem operation. A thermocline separates the heated Caloria^{TM} input at the top of the tank from cooler oil located in the lower part of the tank.

Thermal energy is converted to electrical energy by means of an organic Rankine cycle (ORC) power conversion subsystem. It includes a vaporizer unit consisting of preheater, evaporator and superheater sections, single stage impulse turbine, gear reduction unit, synchronous generator and evaporative cooling tower to recondense toluene. A regenerator stage is included to improve energy conversion efficiency. The electrical generator is interconnected with the local electrical utility company grid.

A control subsystem monitors and controls the collection and storage of solar energy, the supply of hot fluid to the power generation subsystem, and the generation and supply of electric power. In addition, it protects against system-related anomalies such as high temperatures or low flow in the collector field, as well as natural events such as high, gusty winds and external factors such as loss of utility electrical power. The control system also is equipped with manual override options for all control functions to enable greater flexibility for tests and experiments.

An auxiliary heater fired by natural gas was added to the plant to allow experiments which require thermal input equivalent to the output of a larger collector field and enable tests to be performed on the storage and power generation subsystem at times when the insolation level was inadequate. A summary of the major system elements is given in Table 1-1.

For a more complete description of the facility, see Reference 1. The operation, test and evaluation plan is reported in Reference 2. Performance of the facility during its first and second years of operation is documented in References 3 and 4, respectively.

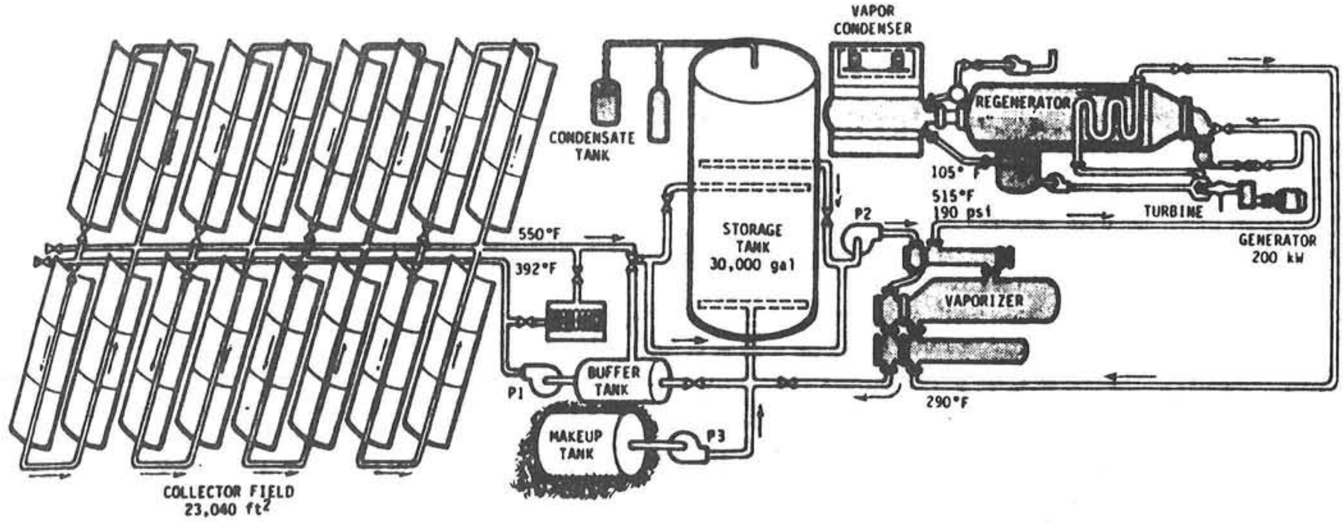


Figure 1-1. 150-kW$_e$ Solar-Powered Irrigation Facility Flow Diagram

Table 1-1. Subsystem Description

Collector Field	
Size:	48 Acurex collector groups with N-S axis orientation = 23 040 ft^2
Fluid:	Caloria® HT-43
Temperatures:	Inlet, 392°F; outlet, 550°F
Thermal Storage	
Type:	Stratified liquid (thermocline)
Tank size:	50 000 gal — 13.67-ft dia by 49-ft length (30 000-gal usable storage)
Storage temperature:	392° to 550°F
Storage medium:	Caloria® HT-43
Insulation:	12-in.-thick fiberglass
Cooling System	
Type:	Vapor condenser
Water (make-up):	10 gal/min
Condensing temperature:	105°F
Power Generation	
Type:	Organic Rankine Cycle
Working fluid:	Toluene
Gross efficiency:	20%

2. Overall Summary

Performance

The plant was operated to maximize operating hours and electrical energy production except during testing periods. The plant operated reliably. Three separate power conversion subsystem equipment problems resulted in a total of 10 days downtime. The collector subsystem operated 93-100 percent of the monthly hours having sufficient insolation.

Electrical energy production in 1981-82 was 178 MWh compared with 162 MWh the previous year. The increase was principally due to the installation of FEK-244 on collector reflector panels, removal of the buffer tank and changes in operating procedures which minimized the use of thermal energy storage.

Figure 2-1 shows the electrical energy generation for September 1981 through September 1982. The line-focus solar collectors were oriented in the north-south direction to maximize the amount of energy collected in the summer when irrigation energy demands are highest. This orientation results in reduced energy collection in the winter.

Automation

A number of equipment and control changes were made in 1981 to permit completely automatic operation of the solar power plant. Beginning in Autumn 1981, the plant opeated unattended part of each day with operator attendance mandated only during PCM startup as a safety precaution. The plant operated automatically on routine, incident free days during 1981-82.

Operating and Maintenance Requirements

Operational tasks required a estimated one hour per day of operator effort. This time was spent monitoring PCM startup, inspecting equipment, and checking and replenishing supplies. Operating supplies cost about $240 per month, about half of which was for purchasing water and water treatment chemicals for the cooling tower.

Maintenance tasks required an average of 3 additional hours of effort per day. About a third of the time was spent cleaning collectors and maintaining site appearance. The rest of the effort was devoted to equipment servicing and adjustment and troubleshooting activities. Maintenance supplies cost about $260 per month with the largest expenditure being for replacement parts and services.

Project Termination

Operational evaluation of the Coolidge solar facility terminated September 30, 1982. The solar power plant became the property of Dalton Cole, Jr., the owner of the farm on which the plant is located, on October 1, 1982. The plant then was decommissioned pending a determination of its future.

Highlights

- The Coolidge solar facility completed three years of daily operation.

- Energy performance characterization was completed.

- The collector field was in operation 97% of the time that adequate sunshine was available in 1981-82.

- Electrical energy generated this fiscal year was 178 MWh.

- The plant operated automatically on routine, incident free days with no operator in attendance during a substantial part of the time.

- The solar power plant became the property of Dalton Cole Jr., at the end of the year. Operational evaluation was terminated; plant disposition is pending.

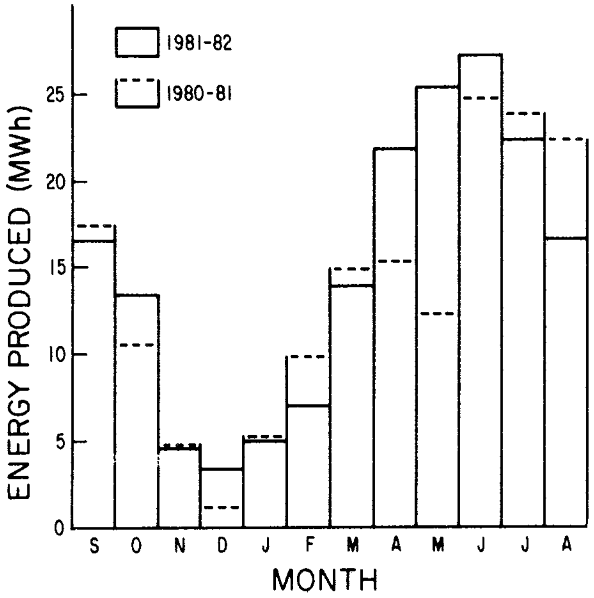


Figure 2-1. Electricity produced in 1981-82 compared with 1980-81 production.

3. Plant Energy Collection, Use, and Production Budgets

The amounts of available solar energy, collected thermal energy, and generated electrical energy have been compiled for September 1981 through September 1982. Available solar energy is the total amount of received direct radiation. The collector subsystem operated whenever direct insolation was greater than 300 W/m^2 (95 $Btu/ft^2 \cdot h$) unless disrupted by maintenance or test activities. That portion of the available solar radiation received during collector subsystem operation is listed as solar energy available during operation. The collected solar energy is the daily thermal energy output of the solar collector subsystem.

Natural gas used by the boiler to provide additional heat for tests also is listed. Since natural gas boiler heating efficiency was found to be about 70%, the total thermal energy input has been computed as solar energy collected plus 70% of the natural gas heating value.

Parasitic electrical energy usage, electricity used by solar plant equipment, is summarized for each day. A more detailed breakdown of parasitic energy use by type of plant equipment is provided in Section 10. For comparison with plant production, the quantity of electricity used by three irrigation pumps located near the solar plant on the Dalton Cole farm is listed. The three pumps require about 150 kW (200 hp) of power.

Energy data for the 13 months are listed in Tables 3-1 through 3-13. When unavailable due to data-gathering problems, the information has been estimated and is so noted. A footnote explains the estimation methods. Monthly totals for available solar energy, collected thermal energy, and generated electrical energy are presented graphically in Figures 3-1 and 3-2.

As expected, more solar radiation was received in June than in any other month, with April and May totals being only slightly less. July had many cloudy days; only four August days were cloudless. Unexpectedly, more solar energy was recorded for October than for August or September. There was mostly clear weather throughout October. Cloudy weather in January and February reduced operating hours to less than 70 percent of that possible with clear conditions.

The amount of solar energy received during operation closely followed the total amount available. Each month the collector subsystem operated 93 to 100 percent of the hours having sufficient insolation. Insolation less than 300 W/m^2 accounted for most of the difference between the total quantity available and that received during operation.

The bars representing of collected thermal energy nearly paralleled the bars depicting available solar energy with two notable exceptions. Less energy was collected in October than in September and less was collected in January than in February even though more solar energy was available in October and January. The reason apparently was the lower solar collector efficiency in October and January as compared with September and February, respectively. The seasonal low efficiencies are due to the lower sun angle and are characteristic of collector arrays oriented in a north-south direction.

The amount of collected thermal energy as a percentage of available direct radiation received during collector operation was 12% in January, 26% in March and 35% in May.

Electrical energy production for 12 months was 178,030 kWh. June production was the highest, 27,350 kWh or an average of 912 kWh per day. Electrical energy production typically was greater than 1000 kWh on a sunny, summer day. The peak daily output was over 1,300 kWh. In January, 5020 kWh of electricity was produced, while September production totals were 16,510 and 17,440 kWh.

Solar energy collection and electrical energy production generally have increased from year to year. Electrical energy production in 1980-81 was 162,020 kWh, about 10% less than in 1981-82. In 1980-81, production was about 10% higher than in 1979-80. This outcome was due to increased operating experience and equipment improvements. The principal equipment improvements were installation of new collector reflective surfaces and achievement of fully automated power conversion subsystem operation. The primary operational change was an adjustment in power conversion subsystem operating time which maximized direct linkage of collector field and power conversion subsystems and minimized use of thermal energy storage.

Note: Superior letters (a through h) on the monthly energy balance summaries (Tables 3-1 through 3-13) refer to the following definitions and assumptions used in the compilation of energy budget information:

a. Direct normal radiation.

b. Solar energy available during collector system operation.

c. Data unavailable; estimate based on hours of operation and seasonal data.

d. Data unavailable; estimate based on seasonal ratio and operating period.

e. Data unavailable; estimate based on seasonal efficiency, operating time, and electrical energy production.

f. Heating value of natural gas used to heat Caloria™.

g. Collected solar energy plus natural gas heating. Boiler efficiency was assumed to be 70%.

h. Measured periodically and apportioned equally to each day within a period.

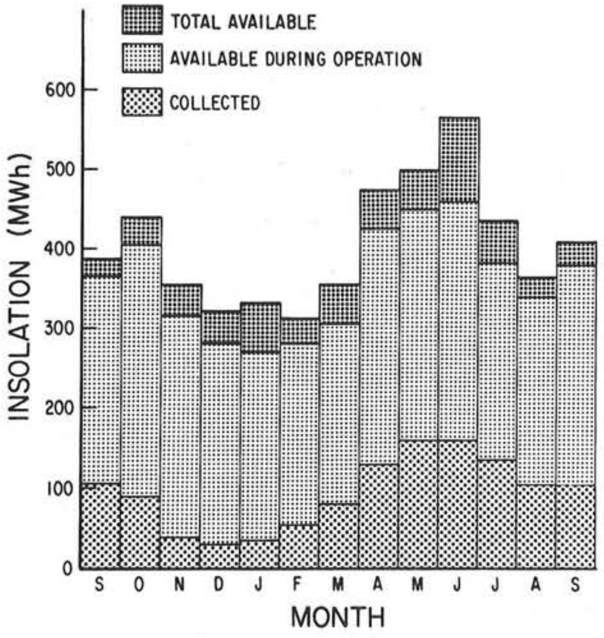


Figure 3-1. Total available solar energy, solar energy received during collector subsystem operation and collected thermal energy for Sept. 1981 - Sept. 1982.

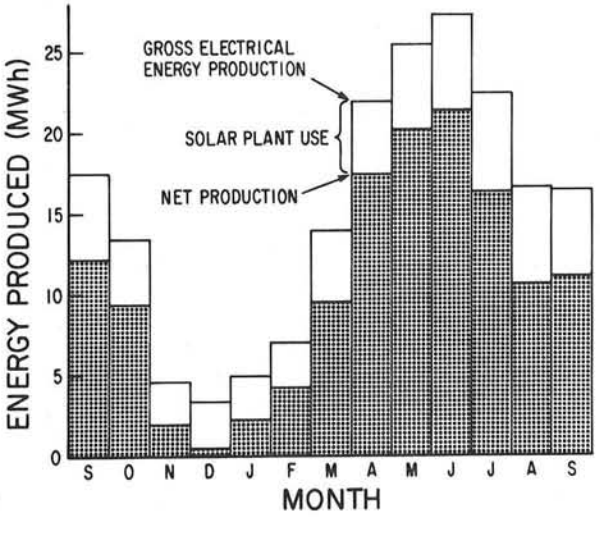


Figure 3-2. Gross and net electrical energy production by the solar power plant from Sept. 1981 through Sept. 1982.

Table 3-1. Coolidge Solar Power Plant
Monthly Energy Balance (September 1981)

Day	OPERATING TIME, Hr.			THERMAL ENERGY, kWh					ELECTRICAL ENERGY,kWh		Irrig.^{h} Pump Energy Usage (kWh)
				SOLAR ENERGY							
	Solar Energy Avail.	Coll. System	Gen. System	Total^{a} Direct	Avail.^{b} During Operation	Collected	Natural^{f} Gas	Total^{g} Input	Generator Output	Plant Usage	
1	10.6	10.6	3.3	17000^{c}	16000^{d}	4800^{e}		4800	600	175	3109
2	10.6	10.6	3.2	17000^{c}	16000^{d}	4800^{e}		4800	570	163	3109
3	8.9	8.9	4.2	13772^{c}	13163^{d}	3456^{e}		3456	800	208	3109
4	10.1	10.1	4.1	16000^{c}	15300^{d}	4600^{e}		4600	760	215	3109
5	5.0	5.0	---	2747^{c}	2610^{d}	685^{e}		685	----	106	3109
6	8.0	9.0	4.8	12969^{c}	12396^{d}	3255^{e}		3255	890	220	3591
7	10.1	10.1	4.4	16800^{c}	16000^{d}	4600^{e}		4600	800	198	3591
8	10.2	10.2	4.2	16800^{c}	16000^{d}	4600^{e}		4600	760	205	3591
9	10.1	10.1	5.0	16800^{c}	16000^{d}	4600^{e}		4600	880	219	3591
10	7.0	7.0	---	11607	11094^{d}	2913^{e}		2913	----	119	3591
11	10.1	10.1	6.1	17830	17412	5271		5271	1200	252	3591
12	9.2	9.2	---	13000^{c}	12000^{d}	3500^{e}		3500	----	119	3591
13	9.9	9.9	5.6	15548	15070	3905		3905	1010	220	2545
14	10.0	10.0	4.4	18965	17892	4817		4817	830	196	2545
15	9.0	9.0	3.7	16947	15320	4256		4256	710	198	2545
16	9.0	9.0	3.5	16606	16059	4140		4140	620	206	2545
17	10.0	10.0	3.7	15599	14785	3870		3870	700	202	2545
18	9.9	9.9	2.9	14176	13715	3226		3226	490	178	2545
19	9.9	9.9	2.5	11638	11249	2699		2699	430	185	2545
20	9.8	9.8	3.1	13459	13000^{d}	3700^{e}		3700	600	142	2545
21	9.0	WASH	---	13896	0	0		0	----	105	2545
22	1.5	1.5	---	6818^{c}	1493^{d}	392^{e}		392	----	101	2545
23	4.5	4.5	---	2565	2481	650		650	----	107	2545
24	9.7	9.7	5.8	10094	9530	3173	2015	4580	1080	245	0
25	9.8	9.8	5.1	15954	15651	5068		5068	980	200	0
26	9.7	9.7	4.7	18000	16981	5400		5400	900	209	0
27	9.5	9.5	4.4	14342	14231	4432		4432	710	206	0
28	9.5	9.5	4.3	16096	14898	4600^{e}		4600	740	230	0
29	8.0	8.0	2.4	9853	8959	2463		2463	380	160	0
30	0.5	0	---	196	0	0		0	----	62	0
TOTAL	259.1	249.6	95.4	386,981	365,289	105,931	2015	107,341	17,440	5351	68,677

Table 3-2. Coolidge Solar Power Plant
Monthly Energy Balance (October 1981)

	OPERATING TIME, Hr.			THERMAL ENERGY, kWh					ELECTRICAL ENERGY,kWh		
				SOLAR ENERGY							
Day	Solar Energy Avail.	Coll. System	Gen. System	Total[a] Direct	Avail.[b] During Operation	Collected	Natural[f] Gas	Total[g] Input	Generator Output	Plant Usage	Irrig.[h] Pump Energy Usage (kWh)
1	6.0	6.0	---	8223	7651	1287		1287	----	105	0
2	7.0	7.0	2.6	8657	7812	1204		1204	370	137	0
3	9.3	9.3	3.9	17920	16677	4711		4711	770	154	0
4	9.3	9.3	4.2	18184	16755	4886		4886	810	136	0
5	9.2	9.2	5.1	15518[c]	15207[d]	4400[e]	1040	5128	910	187	0
6	9.2	9.2	3.7	16399[c]	14975[d]	4300[e]		4300	720	173	0
7	9.1	9.1	3.2	16630[c]	14345[d]	4000[e]		4000	590	165	0
8	9.1	9.1	3.9	13250	12673	3383		3383	730	189	0
9	9.1	9.1	3.7	17849	16270	4188		4188	670	144	0
10	9.1	9.1	3.2	16577	15148	3716		3716	540	152	0
11	5.0	5.0	---	10597	10339	1182		1182	----	76	0
12	8.9	8.9	3.1	15518	15202	3424		3424	550	146	0
13	8.9	8.9	---	11773	11445	2125		2125	----	78	0
14	9.0	9.0	5.9	16939	15883	3765		3765	1030	186	0
15	9.0	9.0	---	8399	7631	893		893	----	73	0
16	8.8	8.8	4.1	18158	16695	3452		3452	710	142	0
17	8.9	8.9	2.9	18232	16693	3431		3431	550	122	0
18	8.7	8.7	2.6	16899	15361	3051		3051	440	120	0
19	9.0	9.0	2.5	17120	15468	3018		3018	470	117	0
20	8.8	8.8	2.5	17413	15474	3003		3003	470	127	0
21	8.5	8.5	---	11034	9733	1601		1601	----	67	0
22	8.8	8.8	3.5	16349	14811	2553		2553	560	137	0
23	8.6	8.6	2.1	16630	14334	2388		2388	350	179	0
24	7.5	7.5	1.9	14425	13452	2386		2386	350	69	0
25	8.8	8.8	2.5	16722	15550	3030		3030	450	115	0
26	8.5	8.5	2.7	16477	15320	2890		1890	400	136	0
27	2.0	2.0	---	3293	2937	91		91	----	76	0
28	1.0	1.0	---	3230	3141	253		253	----	100	0
29	8.0	8.0	1.0	15710	14569	2336		2336	130	106	0
30	8.0	8.0	2.2	12550[c]	11880[d]	2250[e]		2250	390	114	0
31	8.5	8.5	2.7	13235[c]	12750[d]	3393[e]		3393.	400	132	0
TOTAL	249.6	249.6	75.7	439,910	406,081	91,428	1040	92,155	13,380	3,960	0

Table 3-3. Coolidge Solar Power Plant
Monthly Energy Balance (November 1981)

Day	OPERATING TIME, Hr.			THERMAL ENERGY, kWh					ELECTRICAL ENERGY,kWh		Irrig.^{h} Pump Energy Usage (kWh)
	Solar Energy Avail.	Coll. System	Gen. System	Total^{a} Direct	Avail.^{b} During Operation	Collected	Natural^{f} Gas	Total^{g} Input	Generator Output	Plant Usage	
1	8.5	8.5	---	13130^{c}	12645^{d}	2150^{e}		2150	---	95	0
2	8.5	8.5	2.0	13140^{c}	12655^{d}	2155^{e}		2150	360	144	0
3	8.5	8.5	---	12565	12484	2116		2166	---	67	0
4	8.5	8.5	---	15888	13819	2236		2236	---	73	0
5	7.0	7.0	---	13992^{c}	13719^{d}	1000^{e}		1000	---	81	0
6	7.0	7.0	1.2	15148	13213d	1000^{e}		1000	230	89	0
7	6.1	6.1	4.2	9656	8929	1076		1076	710	200	0
8	6.6	6.6	---	6989	6890	495		495	---	63	0
9	8.2	8.2	2.0	15943	14726	1731		1731	300	109	0
10	8.2	8.2	2.0	16995	15456	2114		2114	290	80	0
11	8.0	8.0	1.5	14493	13485	1685		1685	220	160	0
12	8.1	8.1	1.6	15339	14074	1771		1771	240	99	0
13	5.8	5.8	1.6	14135	13054	1638		1638	220	108	0
14	4.5	4.5	0.8	8131	7243	503		503	60	92	0
15	7.5	7.5	1.4	16060	14649	1909		1909	170	104	0
16	8.2	8.2	1.4	15946	14547	1782		1782	250	128	0
17	4.5	4.5	---	11766	10541	1039		1039	---	65	0
18	8.2	8.2	2.5	15146	13768	1630		1630	530	135	0
19	1.0	1.0	---	2915	2111	77		77	---	65	0
20	8.5	8.5	1.5	15210	13738	1668		1668	190	102	0
21	4.5	4.5	---	10100	9323	834		834	---	NA	0
22	0	0	---	1407	0	0		0	---	NA	0
23	8.2	8.2	1.8	15467	13940	1734		1734	150	NA	0
24	8.0	8.0	2.7	15906	14350	1984		1894	230	137	0
25	3.5	3.5	1.4	9115	8501	536	2250	2111	200	91	0
26	3.0	3.0	---	7307	6459	544		544	---	62	0
27	0	0	---	4500^{c}	0	0		0	---	76	0
28	6.0	6.0	---	8141	6954	566		566	---	53	0
29	0	0	---	5970	0	0		0	---	43	0
30	7.9	7.9	1.6	15805	13910	2052		2052	200	82	0
TOTAL	188.5	188.5	31.2	356,304	316,183	37,917	2,250	37,011	4,650	2603	0

Table 3-4. Coolidge Solar Power Plant
Monthly Energy Balance (December 1981)

Day	OPERATING TIME, Hr.			THERMAL ENERGY, kWh					ELECTRICAL ENERGY,kWh		Irrig.[h] Pump Energy Usage (kWh)
				SOLAR ENERGY							
	Solar Energy Avail.	Coll. System	Gen. System	Total[a] Direct	Avail.[b] During Operation	Collected	Natural[f] Gas	Total[g] Input	Generator Output	Plant Usage	
1	7.8	7.8	2.0	15710	14134	1892	4800	1892	200	118	0
2	8.0	8.0	1.9	16487	14529	2192		2192	240	121	0
3	7.9	7.9	1.8	15566	13602	1774		1774	280	123	0
4	2.5	2.5	---	2998	1819	67		67	---	42	0
5	3.0	3.0	---	1595	1192	70		70	---	110	0
6	7.3	7.3	1.2	15148	13447	1852		1852	160	103	0
7	7.7	7.7	1.5	14538	12608	1666		1666	180	94	0
8	7.6	7.6	1.5	15170	13426	1763		1763	200	115	0
9	7.6	7.6	1.7	15555	13764	1680		1680	230	107	0
10	4.0	4.0	---	9342	8218	714		714	---	67	0
11	0.5	0.5	---	568	275[d]	0		0	---	66	0
12	---	---	---	450[c]	0	0		0	---	65	0
13	5.5	5.5	---	11419	9828	788		788	---	78	0
14	6.5	6.5	2.7	8197[c]	3941[d]	709[e]		4069	430	151	0
15	7.5	7.5	1.7	12000[c]	11000[d]	1005[e]		1005	230	116	0
16	7.5	7.5	1.1	12054	11273	1137		1137	90	102	0
17	7.0	7.0	---	11820	10798	893		893	---	74	0
18	7.6	7.6	---	12792	11271	965		965	---	75	0
19	6.0	6.0	---	8241	6972	475		475	---	88	0
20	7.5	7.5	---	14175	12930	1530		1530	---	89	0
21	7.0	7.0	2.7	12894	11544	973		973	360	104	0
22	4.8	4.8	1.1	10788	9555	775		775	110	98	0
23	7.5	7.5	---	12777[c]	10782[d]	923[e]		923	---	73	0
24	7.6	7.6	2.5	15186	13824	1627		1627	320	119	0
25	6.0	6.0	---	5079	4779	252		252	---	59	0
26	7.0	7.0	---	8331	7949	473		473	---	59	0
27	7.5	7.5	---	8090	7391	486		486	---	70	0
28	7.6	7.6	1.2	13629	12730	1351		1351	150	82	0
29	7.6	7.6	1.4	13682	12451	1300		1300	170	88	0
30	1.5	1.5	---	4304	3337	107		107	---	61	0
31	4.5	4.5	---	3673	2545	140		140	---	66	0
TOTAL	195.1	195.1	2.6	322,258	281,914	29,579	4800	32,939	3350	2783	0

Table 3-5. Coolidge Solar Power Plant
Monthly Energy Balance (January 1982)

Day	OPERATING TIME, Hr.			THERMAL ENERGY, kWh					ELECTRICAL ENERGY, kWh		Irrig.[h] Pump Energy Usage (kWh)
				SOLAR ENERGY							
	Solar Energy Avail.	Coll. System	Gen. System	Total[a] Direct	Avail.[b] During Operation	Collected	Natural[f] Gas	Total[g] Input	Generator Output	Plant Usage	
1	0	0	---	2000[c]	0	0		----	---	8	906
2	4.0	4.0	---	10829	4000[d]	458		458	---	82	906
3	5.0	3.0	---	12037	4000[d]	300[e]		300	---	80	906
4	5.0	3.0	---	12907	4143	326		326	---	81	906
5	5.5	5.5	---	12000[c]	5000[d]	500[e]		500	---	81	906
6	2.0	2.0	2.4	1713	1499	177	5700	4107	400	92	906
7	7.0	7.0	---	12368	11116	930		930	---	75	906
8	7.0	7.0	2.2	14099	13150	1254		1254	230	134	906
9	4.0	4.0	---	5000[c]	2000[d]	200[e]		200	---	43	906
10	4.0	4.0	---	4591	2000[d]	200[e]		200	---	44	906
11	7.1	7.1	---	4347	4209	149		149	---	77	906
12	2.0	2.0	---	1395	1300[d]	100[e]		100	---	93	1251
13	7.6	7.6	1.7	16693	14668	2157		2157	220	94	1251
14	8.1	8.1	2.7	13620	12322	985	3340	3323	470	137	1251
15	8.1	8.1	1.9	15739	14156	1912		1912	300	125	1251
16	7.8	7.8	1.7	14644	13313	1894		1894	230	111	1251
17	6.0	6.0	---	10491	9977	1047		1047	---	89	1251
18	7.0	7.0	2.4	12030	11052	1388		1388	300	103	1251
19	0	0	---	300[c]	0	0		----	---	51	445
20	8.1	8.1	1.8	16295	14612	2207		2207	250	105	445
21	2.0	2.0	---	4705	2027	100		100	---	57	445
22	7.5	7.5	2.2	15644[c]	14780[d]	1921[e]	1840	3209	350	137	445
23	8.1	8.1	---	16719[c]	15594[d]	2066[e]		2066	---	86	445
24	8.1	8.1	---	15805[c]	14737[d]	1988[e]		1988	---	87	445
25	8.3	8.3	4.2	15769[c]	14812[d]	2035[e]		2035	720	107	445
26	8.3	8.3	3.3	16002[c]	15085[d]	2109[e]		2109	530	136	0
27	8.4	8.4	2.0	15095[c]	14253[d]	2028[e]		2028	320	83	0
28	0.5	0.5	1.8	3152[c]	2875[d]	416[e]	3800	3076	320	97	0
29	3.7	3.7	---	9842[c]	8987[d]	1323[e]		1323	---	66	0
30	8.4	8.4	2.3	16090[c]	15063[d]	2255[e]		2255	380	110	0
31	6.0	6.0	---	10775[c]	9637[d]	1466[e]		1466	---	93	0
TOTAL	174.6	170.6	22.7	332,696	270,367	33,831	14,680	44,107	5020	2764	21,842

Table 3-6. Coolidge Solar Power Plant
Monthly Energy Balance (February 1982)

Day	OPERATING TIME, Hr.			THERMAL ENERGY, kWh					ELECTRICAL ENERGY, kWh		Irrig.^{h} Pump Energy Usage (kWh)
				SOLAR ENERGY							
	Solar Energy Avail.	Coll. System	Gen. System	Total^{a} Direct	Avail.^{b} During Operation	Collected	Natural^{f} Gas	Total^{g} Input	Generator Output	Plant Usage	
1	8.5	8.5	3.0	16036^{c}	14879^{d}	2300^{e}		2300	440	107	0
2	8.6	8.6	2.7	16276^{c}	15269^{d}	2398^{e}		2398	450	136	0
3	8.5	8.5	2.1	15529^{c}	14511^{d}	2315^{e}		2315	370	108	0
4	7.0	7.0	1.8	14122^{c}	13219^{d}	2141^{e}		2141	280	108	0
5	5.0	5.0	---	11658^{c}	10825^{d}	1780^{e}		1780	---	84	0
6	0	0	---	5557^{c}	0^{d}	0^{e}		----	---	31	0
7	6.0	6.0	---	11888^{c}	10968^{d}	1857^{e}		1857	---	85	0
8	0.5	0.5	1.1	2414^{c}	1877^{d}	322^{e}		322	130	80	0
9	7.0	7.0	3.0	13862^{c}	12816^{d}	2233^{e}	4100	5103	560	131	0
10	1.5	1.5	---	6806^{c}	6293^{d}	1112^{e}		1112	---	67	0
11	3.8	3.8	---	7032^{c}	6279^{d}	1125^{e}		1125	---	70	0
12	6.0	6.0	2.2	12472^{c}	11400^{d}	2071^{e}		2071	260	114	0
13	8.4	8.4	---	14382^{c}	13096^{d}	2411^{e}		2411	---	67	0
14	7.5	7.5	---	11696^{c}	10640^{d}	1985^{e}		1085	---	67	0
15	8.2	8.2	5.6	13089^{c}	11644^{d}	2201^{e}		2201	1020	175	0
16	8.3	8.3	2.7	11788^{c}	10682^{d}	2045^{e}		2045	450	120	3597
17	8.9	8.9	2.7	13416^{c}	11912^{d}	2310^{e}		2301	480	122	3597
18	0.5	0.5	---	2061^{c}	1850^{d}	363^{e}		363	---	61	3597
19	8.9	8.9	2.1	13222^{c}	11886^{d}	2364^{e}		2364	380	109	3597
20	9.0	9.0	3.6	15803	14451	3317		3317	620	146	3597
21	8.0	8.0	---	15594	14132	2938		2938	---	64	3597
22	8.6	8.6	3.4	14239	13407	2536		2536	680	126	3597
23	4.0	4.0	2.2	5897	4000	541	5640	4489	330	116	3597
24	0	0	---	64	0	0		---	---	48	220
25	4.0	4.0	---	5207	4574	785		785	---	69	220
26	9.1	9.1	3.2	13460	12359	3423		3423	580	136	220
27	6.5	6.5	---	11627	10508	2034		2034	---	80	220
28	9.1	9.1	---	16362	15066	3862		3862	---	81	220
TOTAL	171.4	171.4	41.4	311,559	278,543	52,769	9,740	59,587	7,030	2,708	29,876

Table 3-7. Coolidge Solar Power Plant
Monthly Energy Balance (March 1982)

Day	OPERATING TIME, Hr.			THERMAL ENERGY, kWh					ELECTRICAL ENERGY,kWh		Irrig.[h] Pump Energy Usage (kWh)
				SOLAR ENERGY							
	Solar Energy Avail.	Coll. System	Gen. System	Total[a] Direct	Avail.[b] During Operation	Collected	Natural[f] Gas	Total[g] Input	Generator Output	Plant Usage	
1	0	0	4.6	3894	-----	----		0	870	155	220
2	6.5	6.5	---	5800	4619	579		579	----	77	3860
3	9.3	9.3	4.0	19620	16787	4371		4371	790	194	3860
4	9.0	9.0	3.3	18037	16309	4103		4103	640	174	3860
5	8.6	8.6	3.6	17724	16231	4349		4349	700	182	3860
6	9.5	9.5	4.5	17800[c]	16300[d]	4375[e]		4375	850	205	3860
7	9.0	9.0	---	17012	15164	3588		3588	----	64	3860
8	5.0	5.0	3.1	7286	5678	969		969	610	156	3860
9	7.0	7.0	2.4	13779	11907	2936		2936	450	157	3860
10	6.5	6.5	2.6	8336	7175	869	1850	2164	420	137	3860
11	0	0	---	137	-----	----		0	----	34	3812
12	0	0	---	219	-----	----		0	----	37	3812
13	3.0	3.0	---	4236	2896	138		138	----	73	3812
14	3.5	3.5	---	3854	2611	885		885	----	73	3812
15	3.5	3.5	0.6	1456	254	33		33	90	110	3812
16	5.5	5.5	1.5	11403	10211	1901		1901	230	119	3812
17	6.0	6.0	2.1	11148	8977	2137		2137	340	128	6992
18	1.0	1.0	---	3500	1000[d]	24		24	----	69	6992
19	6.0	6.0	2.0	13115	11126	2165		2165	310	138	6992
20	6.9	6.9	---	13605	12658	3750		3750	----	82	6992
21	10.0	10.0	---	18963	17190	4561		4561	----	95	6992
22	10.0	10.0	11.7	19592	18954	5877		5877	2320	402	6992
23	10.0	10.0	5.0	19537	18444	5615		5615	980	244	6992
24	8.5	8.5	2.5	12919	10922	2662		2662	430	148	3840
25	5.5	5.5	2.3	8042	6957	1677	640	2125	380	119	3840
26	1.0	1.0	---	1078	475	47		47	----	59	3840
27	10.3	10.3	4.4	19448	18005	5841		5841	890	235	3840
28	5.5	5.5	---	9326	6829	1429		1429	----	75	3840
29	9.5	9.5	6.7	18853	17838	5398		5398	1170	264	3840
30	10.0	7.5	3.9	17796	16684	3812		3812	710	109	3840
31	8.7	8.2	4.0	16448	14814	4966		4966	770	275	3840
TOTAL	194.8	191.8	74.9	353,963	305,376	79,057	2490	80,800	13,950	4,389	137,497

Table 3-8. Coolidge Solar Power Plant
Monthly Energy Balance (April 1982)

Day	OPERATING TIME, Hr.			THERMAL ENERGY, kWh					ELECTRICAL ENERGY,kWh		Irrig.[h] Pump Energy Usage (kWh)
				SOLAR ENERGY							
	Solar Energy Avail.	Coll. System	Gen. System	Total[a] Direct	Avail.[b] During Operation	Collected	Natural[f] Gas	Total[g] Input	Generator Output	Plant Usage	
1	8.8	4.5	3.3	16032	10473	3071		3071	460	124	3768
2	10.2	10.2	6.3	19152	17586	6844		6844	1150	210	3768
3	8.0	8.0	2.7	9899	9180	2865		2865	460	95	687
4	10.3	10.3	---	20653	18831	6335		6335	----	88	687
5	8.5	8.5	9.5	15288	13616	4446	3110	6623	1900	262	687
6	0.8	0.8	1.3	1553	314	17		17	200	125	687
7	10.0	10.0	5.3	17997	16915	5816		5816	1020	147	687
8	8.5	8.5	4.4	16328	14555	4794		4794	850	154	687
9	0.7	0.7	---	1602	148	10		10	----	88	687
10	10.0	10.0	3.8	17406	15852	5093		5093	690	82	687
11	9.5	9.5	3.3	11349	10075	2732		2732	560	233	687
12	5.0	5.0	1.5	8976	6881	1649		1649	260	123	687
13	4.5	4.5	---	11529	9942	2536		2536	----	69	2490
14	10.1	10.1	6.4	17462	16127	5027		5027	1160	182	2490
15	8.0	8.0	5.2	16631	15357	4867		4867	940	171	2490
16	10.6	10.6	4.8	18557	18285	5476		5476	930	175	2490
17	11.2	11.2	5.1	19335	18136	5938		5938	980	172	2490
18	11.0	11.0	---	20305	19121	6024		6024	----	87	2490
19	10.0	10.0	8.7	15743	13953	4178		4178	1720	248	2490
20	10.5	10.5	5.1	20656	18854	5829		5829	960	200	2490
21	11.0	11.0	5.5	20437	18840	5330		5330	940	163	1042
22	11.0	11.0	4.1	18708	17587	5182		5182	800	190	1042
23	11.0	11.0	4.8	19034	17840	5375		5375	880	142	1042
24	11.0	11.0	4.7	19193	17737	5277		5277	890	129	1042
25	11.0	11.0	4.7	17746	16372	5132		5132	890	129	1042
26	10.0	10.0	2.3	14348	11964	3090		3090	410	212	1042
27	9.8	9.8	3.8	14799	13633	3739		3739	700	108	2185
28	10.1	10.1	4.6	17646	16258	4865		4865	820	196	2185
29	8.0	8.0	3.5	14446	13171	3357		3357	580	133	2185
30	11.0	11.0	4.5	19739	18541	5284		5284	830	191	2185
TOTAL	270.1	265.8	119.2	472,549	426,144	130,178	3110	132,355	21,980	4,628	49,318

Table 3-9. Coolidge Solar Power Plant Monthly Energy Balance (May 1982)

	OPERATING TIME, Hr.			THERMAL ENERGY, kWh					ELECTRICAL ENERGY,kWh		
				SOLAR ENERGY							
Day	Solar Energy Avail.	Coll. System	Gen. System	Total[a] Direct	Avail.[b] During Operation	Collected	Natural[f] Gas	Total[g] Input	Generator Output	Plant Usage	Irrig.[h] Pump Energy Usage (kWh)
1	3.0	3.0	---	5375	3848	340		340	----	92	2186
2	9.9	9.9	4.2	10500[c]	10000[c]	3459		3459	770	181	2186
3	8.4	8.4	4.2	14300[c]	13600[d]	4773		4773	760	150	2186
4	5.0	5.0	2.3	5572	4415	1642		1642	360	113	2186
5	3.5	3.5	---	4705	3300	1000		1000	----	88	2186
6	11.2	11.2	7.7	21900[c]	20800[d]	7248		7248	1480	190	2186
7	11.2	11.2	6.5	22500[c]	21400[d]	7457		7457	1280	196	2186
8	11.2	11.2	5.0	17400[c]	16500[d]	5788		5788	950	146	1844
9	11.2	11.2	4.2	10700[c]	10200[d]	3640		3640	780	196	1844
10	9.0	9.0	4.4	12600[c]	12000[d]	4174		4174	800	192	1844
11	10.0	10.0	5.2	17400[c]	16500[d]	5778		5778	980	174	1844
12	9.2	9.2	3.7	11400[c]	10800[d]	3854	634	4298	710	172	1844
13	11.2	11.2	5.7	17307	16447	5888		5888	1080	153	1844
14	11.2	11.2	4.7	15175	14357	5536		5536	900	151	1267
15	11.3	11.3	4.3	13284	12077	4824		4824	820	157	1267
16	11.5	11.5	4.9	16591	15772	5706		5706	950	228	1267
17	11.5	11.5	5.1	16585	15735	5562		5562	950	191	1267
18	11.0	11.0	4.9	16017	14927	5250[e]	1037	5976	900	208	74
19	11.6	11.6	6.4	20321	19164	6821		6821	1220	188	74
20	12.0	12.0	6.7	21932	20848	7572		7572	1310	203	74
21	11.8	11.8	5.8	19337	18402	6567		6567	1150	203	74
22	11.7	11.7	6.8	21438	20795	7520		7520	1310	225	74
23	11.8	11.8	6.8	21718	20915	7469		7469	1300	230	74
24	11.9	11.9	6.1	19920	18886	6801		6801	1160	225	74
25	12.0	12.0	6.1	20278	19403	6852		6852	1160	202	0
26	11.6	11.6	4.4	15501	14217	4263		4263	810	199	0
27	11.4	11.4	4.1	13300	12100	4800		4800	750	152	0
28	11.3	11.3	2.1	13000[c]	12000[d]	4200[e]		4200	420	191	0
29	11.5	11.5	2.5	21452	20590	7154		7154	460	109	0
30	11.5	6.5	---	22115	21127	5651		5651	----	165	0
31	11.5	----	---	22843	0	0		0	----	49	0
TOTAL	321.1	304.6	134.8	502,466	451,125	157,659	1671	158,759	25,520	5,320	31,956

Table 3-10. Coolidge Solar Power Plant Monthly Energy Balance (June 1982)

Day	OPERATING TIME, Hr.			THERMAL ENERGY, kWh					ELECTRICAL ENERGY,kWh		Irrig.[h] Pump Energy Usage (kWh)
				SOLAR ENERGY							
	Solar Energy Avail.	Coll. System	Gen. System	Total[a] Direct	Avail.[b] During Operation	Collected	Natural[f] Gas	Total[g] Input	Generator Output	Plant Usage	
1	11.8	2.9	6.3	23800	4900	1062		1062	1170	209	399
2	12.1	12.1	6.0	20815	19772	6280		6280	1130	209	399
3	12.0	12.0	5.3	19835	18823	5818		5818	1030	183	399
4	7.0	7.0	3.5	16483	15399	4266		4266	630	155	399
5	7.5	7.5	3.1	12834	11823	3349		3349	540	130	399
6	11.9	11.9	2.5	14455	12838	2911		2911	430	139	399
7	11.9	11.9	4.6	18130	17095	5671		5671	820	172	399
8	12.0	12.0	6.1	21106	20124	7117		7117	1140	226	3290
9	12.1	12.1	6.2	20429	19536	6630		6630	1180	211	3290
10	12.2	12.2	5.3	20369	19531	6722		6722	980	198	3290
11	12.4	12.4	5.6	20685	19539	6741		6741	980	208	3290
12	12.1	12.1	6.6	20531	19510	6537		6537	1160	222	3290
13	12.1	12.1	4.9	21089	19914	6586		6586	870	189	3290
14	12.1	12.1	5.9	19307	18471	6019		6019	1140	246	3290
15	12.0	12.0	3.5	17249	16442	4736		4736	640	146	3290
16	8.0	8.0	3.2	16350	14768	3458		3458	540	154	2884
17	9.9	9.9	3.8	17652	15525	4537		4537	680	167	2884
18	11.2	11.2	5.3	20413	18765	6048		6048	990	214	2884
19	11.4	10.4	5.0	19011	16526	5475		5475	930	195	2884
20	11.7	11.7	6.1	19922	18733	6467		6467	1080	237	2884
21	4.5	4.5	2.5	10808	7778	971	1555	2059	410	145	2884
22	10.7	10.7	6.2	20136	19544	6651		6651	1180	249	2884
23	11.7	11.7	6.2	20816	19626	6852		6852	1180	255	946
24	11.7	11.7	5.9	20065	18909	6533		6533	1090	258	946
25	11.8	11.8	5.3	20800[c]	19500[d]	6350[e]		6350	1020	206	946
26	11.8	11.8	6.2	21352	20110	6269		6269	1120	219	946
27	11.8	11.8	6.5	21098	20139	6815		6815	1160	219	946
28	11.0	11.0	5.4	19660	18538	6145		6145	1030	242	946
29	6.0	6.0	2.9	13466	12177	3386		3386	550	196	4916
30	8.0	8.0	3.2	16369	15531	3673		3673	550	172	4916
TOTAL	322.4	313.5	149.1	565,035	509,886	160,075	1,555	161,163	27,350	5,973	64,809

Table 3-11. Coolidge Solar Power Plant
Monthly Energy Balance (July 1982)

Day	OPERATING TIME, Hr.			THERMAL ENERGY, kWh					ELECTRICAL ENERGY, kWh		Irrig.[h] Pump Energy Usage (kWh)
				SOLAR ENERGY							
	Solar Energy Avail.	Coll. System	Gen. System	Total[a] Direct	Avail.[b] During Operation	Collected	Natural[f] Gas	Total[g] Input	Generator Output	Plant Usage	
1	11.6	11.6	4.8	19014	17695	5480		5480	890	254	4916
2	11.6	11.6	5.3	18553	17558	5705		5705	960	251	4916
3	11.7	11.7	5.1	19064	17933	5765		5765	960	226	4916
4	11.7	11.7	3.3	12892	11586	3312		3312	590	192	4916
5	8.0	8.0	2.1	17934	16640	3221		3221	370	155	4916
6	----	----	3.2	1384	-----	----	4550	3185	530	125	1593
7	6.5	6.5	2.7	11624	9951	2712		2712	500	141	1593
8	11.7	11.7	7.2	21580	20242	8228		8228	1430	295	1593
9	11.7	11.7	7.4	21382	19941	8215		8215	1420	292	1593
10	11.9	11.9	6.9	21928	20682	8489		8489	1200	285	1593
11	11.9	11.9	7.5	21341	20110	8019		8019	1440	284	1593
12	11.8	11.8	6.8	16500[c]	15500[d]	6000[e]		6000	1350	312	1593
13	11.8	10.8	6.1	16500[c]	15500[d]	5500[e]		5500	1160	289	1593
14	11.8	11.8	6.0	18504	17735	6910		6910	1120	294	3171
15	7.5	7.5	2.4	11299	9522	2577		2577	400	171	3171
16	7.0	7.0	0.1	15110	12614	4506		4506	----	125	3171
17	6.5	----	---	3567	-----	----		----	----	57	3171
18	7.0	----	---	5378	-----	----		----	----	57	3171
19	9.5	3.9	---	15760	5321	1612		1612	----	82	3171
20	5.6	5.4	5.0	8980	8270	2607		2607	980	180	3171
21	11.0	11.0	5.2	13610	12576	4466		4466	960	254	3171
22	11.8	11.8	5.0	16336	15497	5878		5878	950	257	3171
23	11.9	11.9	3.1	15870	14826	5571		5571	580	205	3171
24	9.8	9.8	4.3	14800[c]	13750[d]	4900[e]		4900	810	214	3171
25	7.5	7.5	3.6	13764	13288	4567		4567	650	141	3171
26	6.4	6.4	1.7	9642	8842	3234		3234	340	141	3171
27	11.0	11.0	7.0	17985	16935	6739		6739	1330	284	3171
28	10.5	10.5	4.5	15643	13971	4999		4999	850	236	3171
29	3.5	3.5	---	5578	3646	494		494	----	70	3171
30	6.0	6.0	2.8	10029	9610	3114		3114	430	153	3245
31	5.0	5.0	2.3	3962	3660	1360		1360	360	135	3245
TOTAL	281.2	260.9	121.4	435,513	382,901	134,180	4550	137,365	22,560	6,200	94,568

Table 3-12. Coolidge Solar Power Plant
Monthly Energy Balance (August 1982)

Day	OPERATING TIME, Hr.			THERMAL ENERGY, kWh					ELECTRICAL ENERGY,kWh		Irrig.[h] Pump Energy Usage (kWh)
	Solar Energy Avail.	Coll. System	Gen. System	SOLAR ENERGY			Natural[f] Gas	Total[g] Input	Generator Output	Plant Usage	
				Total[a] Direct	Avail.[b] During Operation	Collected					
1	4.5	4.5	2.1	11004	9704	2108	1150	2108	310	130	3254
2	2.0	2.0	---	7159	6232	895		895	---	180	3254
3	10.4	10.4	5.0	17769	17153	5360		5360	850	220	3254
4	10.9	10.9	4.9	18174	17508	5518		5518	870	230	3254
5	2.5	2.5	---	7576	3964	570		570	220	220	3254
6	6.6	6.6	1.8	6177	5075	1122		1122	---	130	2494
7	10.7	10.7	4.1	16856	15985	4897		4897	740	260	2494
8	9.7	5.1	---	8406	9500[d]	2600[e]		2600	---	210	2494
9	11.2	11.2	5.5	12661	12215	4054		4054	970	130	2494
10	9.5	9.5	3.7	13603	12724	3576		3576	650	220	2494
11	7.0	7.0	2.4	10446	10094	2774		2774	420	200	1664
12	4.0	4.0	1.3	4904	3798	598		1403	190	180	1664
13	10.0	10.0	3.7	13335	12647	3865		3865	670	170	1664
14	11.7	11.7	4.8	16309	15467	5432		5432	870	210	1664
15	5.6	5.6	2.2	8225	7594	2536		2536	390	220	1664
16	9.0	9.0	4.2	16682	15649	5056		5056	790	190	1664
17	8.0	8.0	3.6	12658	11283	3608		3608	620	180	1579
18	6.0	6.0	2.3	10993	8818	2380		2380	400	200	1579
19	10.0	10.0	4.1	14879	13641	4421		4421	730	230	1579
20	9.5	9.5	4.0	13127	12164	3900[e]		3900	730	230	1579
21	7.0	7.0	2.8	4079	3774	1327		1327	480	170	1579
22	9.0	9.0	2.9	12745	11759	3409		3409	520	180	1579
23	5.0	5.0	2.3	10076	9593	2666		2666	400	240	1579
24	4.0	4.0	1.7	8642	7291	2033		2033	290	130	1579
25	11.1	11.1	4.7	16682	15740	5285		5285	880	200	1579
26	9.7	9.7	4.0	14744	13615	4506		4506	710	210	3771
27	9.0	9.0	4.5	15314	14226	4939		4939	820	190	3771
28	8.0	8.0	2.4	10152	8608	2676		2676	430	190	3771
29	9.5	9.5	3.0	12648	10785	3211		3211	530	160	3771
30	7.5	7.5	2.6	11514	10099	2657		2657	440	200	3771
31	9.8	9.8	4.4	16511	15776	5195		5195.	810	200	3909
TOTAL	248.4	243.8	95.0	364,050	342,481	103,174	1,150	103,979	16,730	6,010	82,207

Table 3-13. Coolidge Solar Power Plant
Monthly Energy Balance (September 1982)

Day	OPERATING TIME, Hr.			THERMAL ENERGY, kWh					ELECTRICAL ENERGY, kWh		Irrig.[h] Pump Energy Usage (kWh)
				SOLAR ENERGY							
	Solar Energy Avail.	Coll. System	Gen. System	Total[a] Direct	Avail.[b] During Operation	Collected	Natural[f] Gas	Total[g] Input	Generator Output	Plant Usage	
1	10.7	10.7	4.4	16470	15289	4829		4829	800	220	3420
2	10.8	10.8	4.2	16642	15654	4948		4948	760	190	3420
3	6.1	6.1	2.7	12063	11005	2849		2849	490	220	3420
4	9.8	9.8	3.4	15253	14426	4081		4081	580	190	3420
5	8.8	8.8	3.4	13899	12400	3593		3593	580	210	3420
6	10.9	10.9	3.8	15896	15207	4412		4412	690	200	3420
7	5.1	5.1	1.0	9120	8420	1938		1938	170	210	3420
8	2.0	2.0	2.3	5030	4397	635	2880	2651	390	160	2086
9	12.0	12.0	4.3	16205	15326	4351		4351	780	180	2086
10	1.5	1.5	---	3148	2357	264		264	---	140	2086
11	5.0	5.0	1.8	5127	4473	1488		1488	260	150	2086
12	10.5	10.5	4.5	16984	15934	5441		5441	810	100	2086
13	10.1	10.1	4.3	16646	15875	4697		4697	790	210	2086
14	10.1	10.1	4.7	17471	16728	5215		5215	890	200	2086
15	10.1	10.1	4.7	18080	17282	5067		5067	890	180	2086
16	7.0	7.0	2.3	9000[c]	8000[d]	2335[e]		2235	380	210	2086
17	0	0	---	727	0	0		0	---	90	833
18	10.0	10.0	3.7	17070	16215	4476		4476	650	180	833
19	10.0	10.0	4.1	17438	16110	4670		4670	760	200	833
20	10.0	10.0	4.1	17421	16366	4738		4738	770	210	833
21	9.9	9.9	3.8	16545	15336	4294		4294	660	150	833
22	9.9	9.9	3.7	16320	15204	4382		4382	670	230	833
23	9.4	9.4	3.7	16000[c]	15000[d]	4000[e]		4000	660	150	833
24	10.0	10.0	3.5	15803	14806	3957		3957	660	210	833
25	8.2	8.2	2.2	12147	11076	2497		2497	340	180	0
26	9.8	9.8	---	16293	15230	3732		3732	---	190	0
27	3.0	3.0	3.7	10233	8763	712		712	610	140	0
28	9.8	9.8	2.9	15207	14184	3469		3469	540	160	0
29	9.3	9.3	2.6	16027	14678	3496		3496	460	190	0
30	9.8	9.8	2.7	14303	13144	2941		2941	470	140	0
TOTAL	249.6	249.6	92.5	408,568	378,885	103,407	2880	105,423	16,510	5390	52,798

4. Solar Collector Subsystem 1981 Autumnal Equinox Performance

Solar collector subsystem efficiency was determined for operation on September 25, 26 and 28, 1981 (Days 268, 269 and 271). The first two days were mostly clear and collector subsystem outlet oil temperature was maintained at about 282°C. On September 28, the test was conducted with an outlet oil temperature of about 262°C. However, the 28th was hazy and partly cloudy and the results reflect the poorer test conditions. The collector subsystem efficiency ranged from 28 to 39 percent on the 25th, 30-37 percent on the 26th and 23-38 percent on the 27th. The average collection efficiency was about 32 percent on September 25, 33 percent on September 26 and 31 percent on September 27.

Collector subsystem parasitic electrical energy usage was recorded during start-up, the period from collector focusing until flow is diverted to the tank. About 1.0 kWh was used for Caloria pumping; another 1.3 kWh was required for tracking and other controls.

Methods

Collectors were washed with high pressure, deionized water on September 21 by a commercial firm.

Collectors were focused when insolation reached 300 W/m^2. Caloria was recirculated through the collector subsystem until an outlet oil temperature of 215°C was attained. Flow then was directed to the storage tank or vaporizer from that time onward until operation was terminated for the day. During operation, Caloria was circulated through the collector subsystem at a flow rate controlled to maintain the desired, constant outlet temperature.

Collector flow rate was measured with a vortex shedding type instrument, oil temperatures were sensed with RTD's and insolation was measured with a pyrheliometer. Data was digitized and recorded at two minute intervals on magnetic tape.

Collector subsystem efficiency was computed as the thermal energy gained by Caloria during passage from subsystem inlet to outlet manifold locations divided by the total direct normal solar radiation impinging on collector reflective surfaces. Average efficiency was determined for the operating period only.

September 25 (Day 268) Results

Energy was collected at a rate of 550-650 kW, Table 4-1. Collector subsystem efficiency ranged from 28 to 39 percent during the test. The efficiency averaged about 32 percent for the entire day. However, an early morning data gap caused this computation to be only an estimate.

September 25 was mostly clear with peak insolation measured to be 890 W/m^2. Caloria inlet and outlet temperatures were 196-200°C and 280-284°C respectively. The flow rate ranged from 2.9-4.1 liters per second. Just after noon, the flow rate, and associated collector energy production and efficiency, dipped as the power conversion subsystem began operation.

September 26 (Day 269) Results

September 26 was a clear, sunny day with peak insolation of 900 W/m^2. Collector performance again was evaluated with an outlet manifold Caloria temperature of 278-282°C. The inlet oil temperature was 195-200°C. Caloria flow rate ranged from 3.0 to 3.8 l/s to maintain the desired outlet temperature throughout operation.

Thermal energy was collected at a rate of 580-650 kW and the collector subsystem efficiency was 30-37 percent during the test. Collector efficiency averaged about 33 percent over the day.

September 28 (Day 271) Results

An attempt to determine collector performance with Caloria outlet temperature maintained at only 260-262°C was made on September 28. However, haze and partial cloudiness interfered with evaluation. Energy was collected at a highly variable rate of 350-600 kW. Collector efficiency was only 23-38 percent. Results plotted for Day 271 to indicate subsystem response to varying insolation levels.

Parasitic Electrical Energy Use

Electrical energy use by collector subsystem pump and tracking systems was recorded for the start-up period. Start-up lasts from collector focusing until Caloria flow is diverted to storage. Caloria is recirculated through the collector subsystem during warm-up prior to diversion. Electrical energy usage was determined by the difference between operator meter readings taken just before start-up of the collector subsystem and immediately after opening of the flow diversion valve.

The Caloria pump required 0.9-1.1 kWh during the start-up period. Collector subsystem controls and trackers required 1.1-1.5 kWh.

Comments

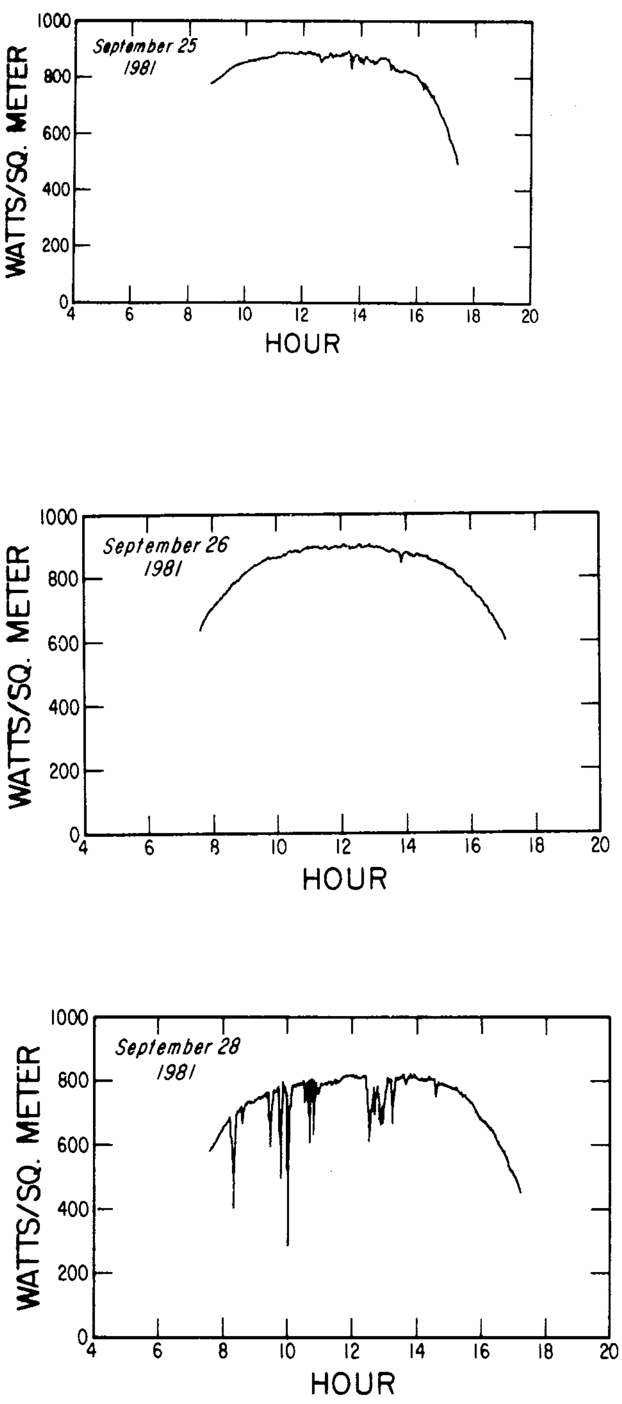
Collector subsystem efficiency was 28-39 percent during clear day operation with outlet Caloria temperature maintained at about 282°C. Average efficiencies for September 25 and 26 operation were 32 to 33 percent. These values were perhaps 2 percent higher than obtained in tests a year earlier when collectors had Coilzak reflective surfaces instead of the present FEK-244 aluminized acrylic surfaces. However, differences in environmental conditions prevent direct comparison of 1981 results with those obtained in 1980.

Table 4-1. Collector subsystem test information.

	Sept. 25 (268)	Sept. 26 (270)	Sept. 27 (271)
Event Times, MST			
Collectors Focused	7:31 AM	7:32 AM	7:34 AM
Flow Diversion	7:55 AM	7:56 AM	8:04 AM
Collectors Defocused	5:57 PM	5:35 PM	5:35 PM
Collector Parameters			
Inlet Temp., °C	196-200	195-200	194-200
Outlet Temp., °C	280-284	278-282	260-262
Flow Rate, l/s	2.9-4.1	3.0-3.8	2.3-4.7
Environmental Conditions			
Peak Insolation, W/m^2	890	900	820
Ambient Temp., °C	30-34		
Wind Speed, Km/h	4-10		
Performance			
Power, kW	550-650	580-650	350-600
Efficiency Range, %	28-39	30-37	23-38
Avg. Efficiency, %	32	33	31

Table 4-2. Parasitic electrical energy use during collector subsystem start-up.

Date	Start-up Period, MST	Collector Field Caloria Pump, kWh	Collector Tracking and Control System, kWh	Total kWh
9/25	7:31-7:55 AM	0.9	1.5	2.4
9/26	7:32-7:56 AM	1.1	1.1	2.2
9/27	7:35-7:57 AM	0.9	1.5	2.4
9/28	7:34-8:00 AM	0.9	1.2	2.1
9/29	7:35-8:06 AM	1.0	1.4	2.4



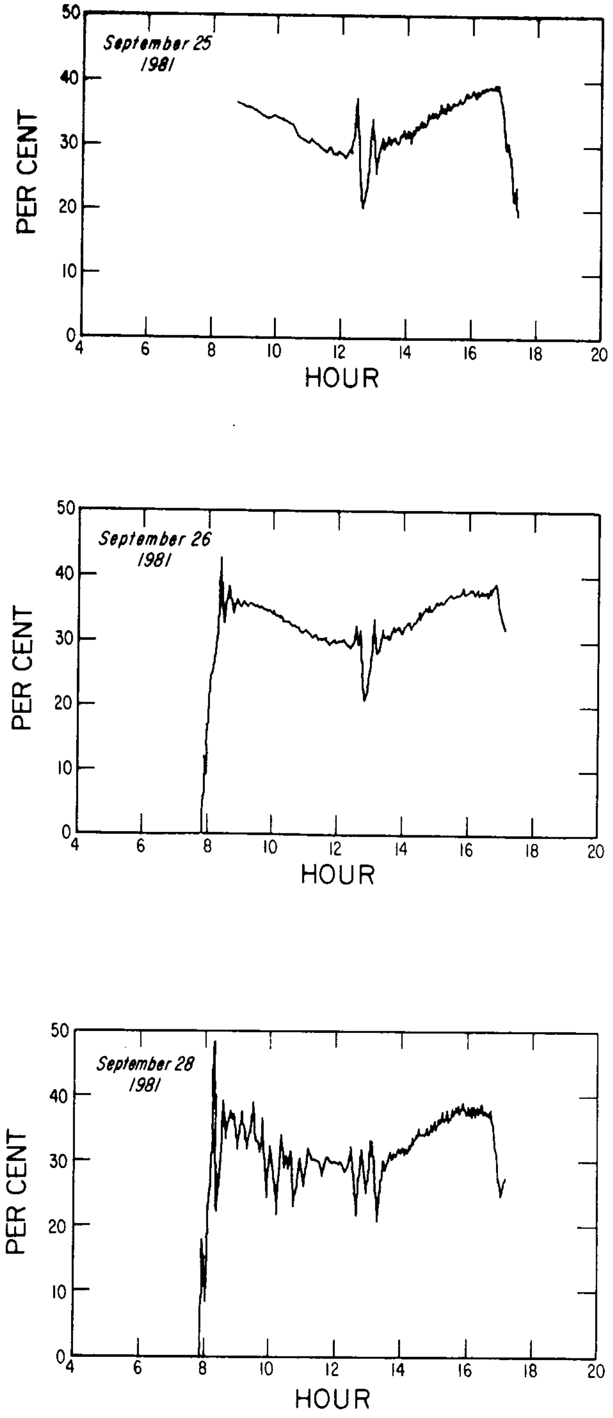


Figure 4-1. Autumnal Equinox, Insolation vs Hour

Figure 4-2. Autumnal Equinox, Efficiency vs Hour

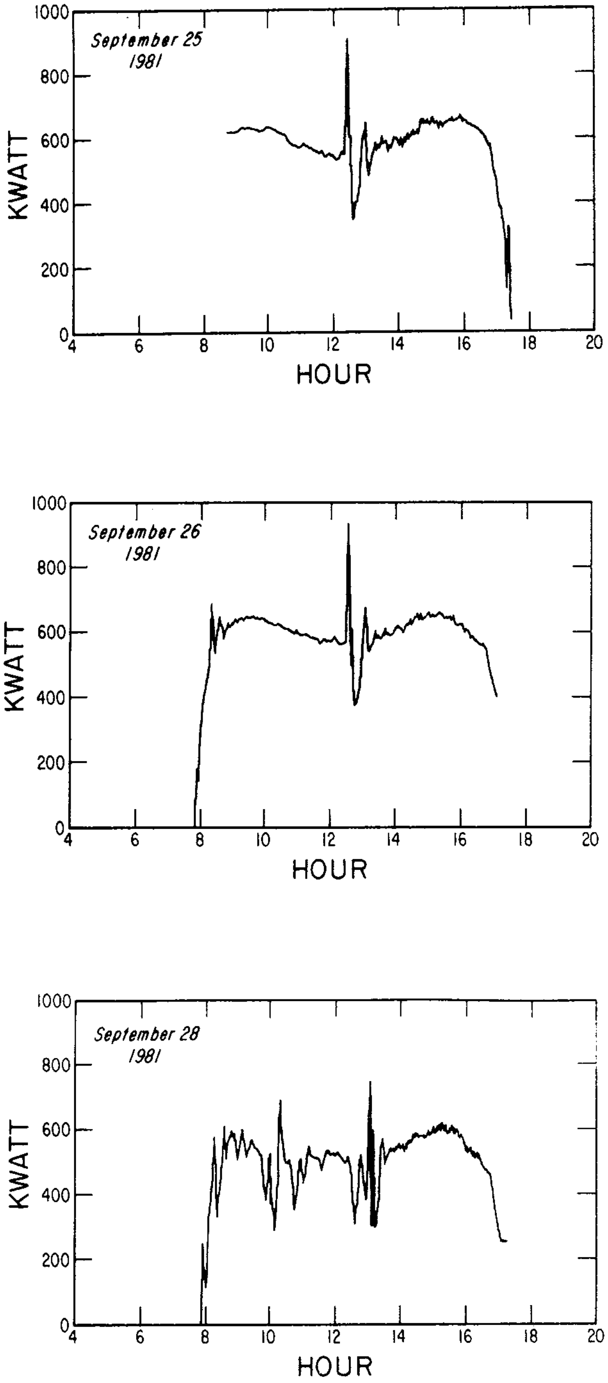


Figure 4-3. Autumnal Equinox, Collected Power vs Hour

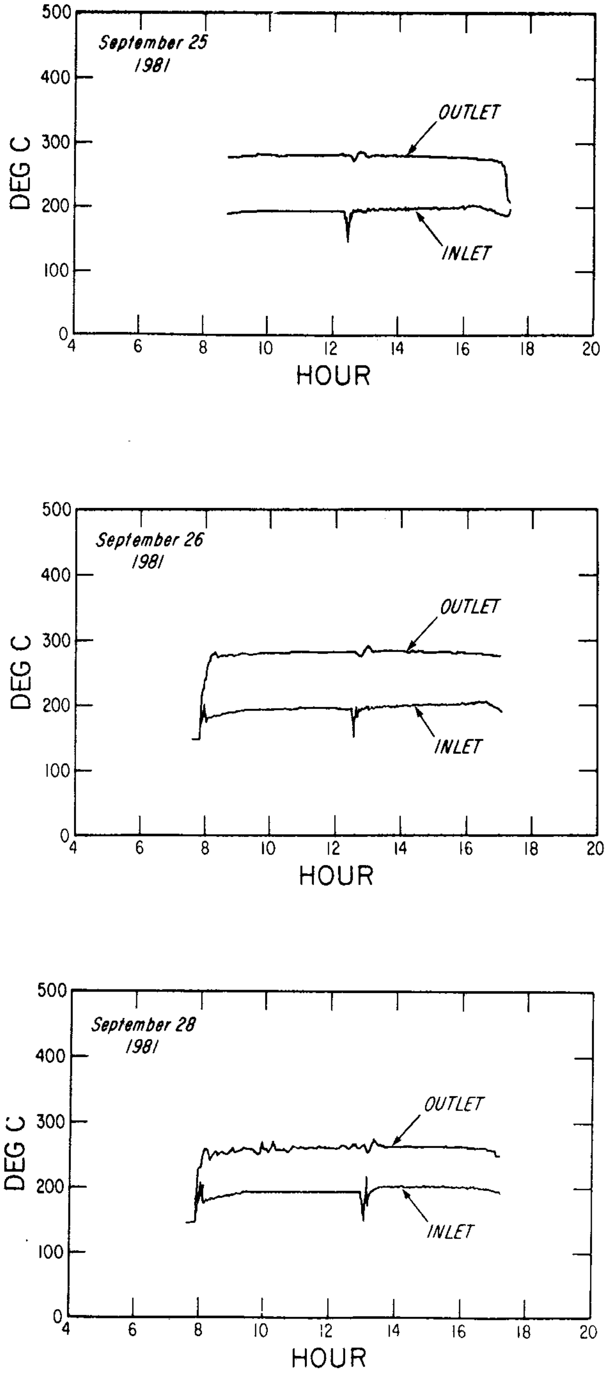


Figure 4-4. Autumnal Equinox, Inlet and Outlet Temperatures vs Hour

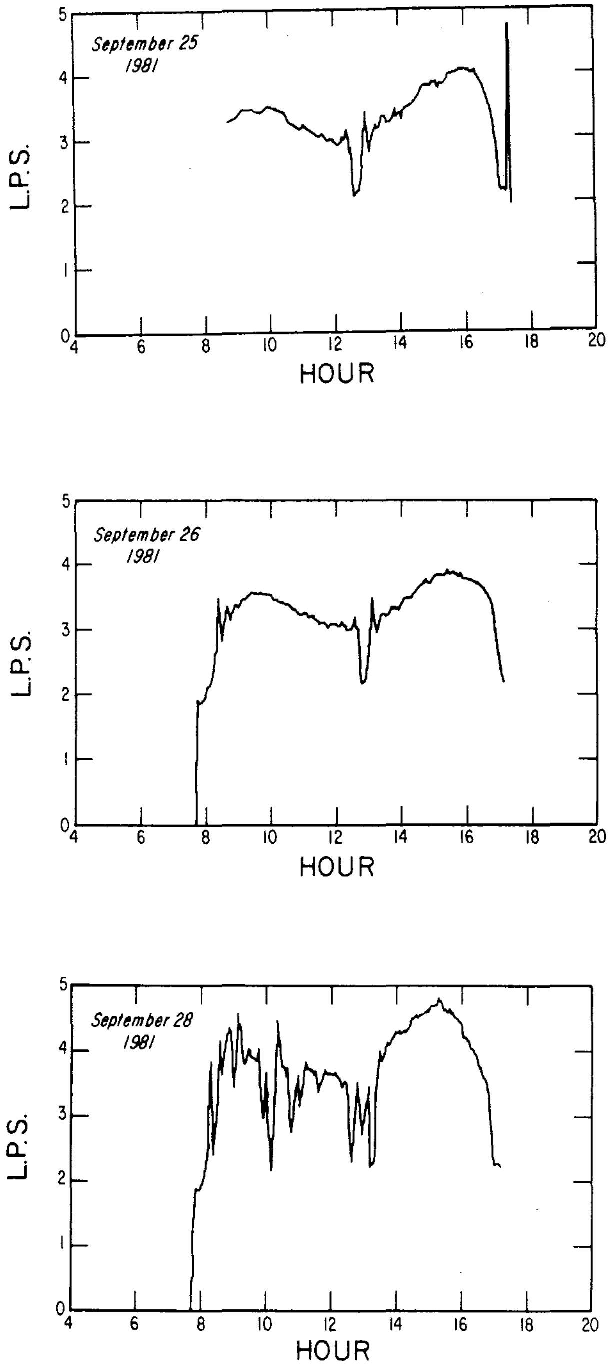


Figure 4-5. Autumnal Equinox, Flow Rate vs Hour

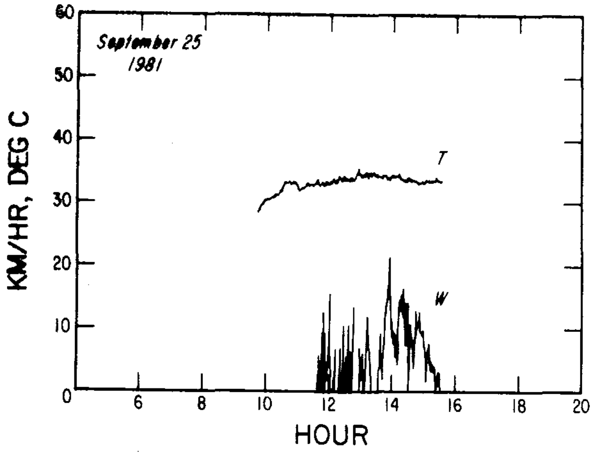


Figure 4-6. Autumnal Equinox, Wind Speed and Ambient Temperature vs Hour

5. Solar Collector Subsystem 1981 Winter Solstice Performance

Solar collector subsystem output and efficiency were computed for operation on December 24, 1981 (Day 358). Collectors had been pressure washed with soft water a few days prior to the test. On December 24, collectors were focused when insolation reached 300 W/m^2. Collector flow rate was set to obtain a collector subsystem fluid outlet temperature of 265°C, with the minimum flow rate set at about 1.5 l/s.

Collector subsystem efficiency was computed as the thermal energy gained by Caloria during passage from subsystem inlet to outlet manifold locations divided by the total direct normal solar radiation impinging on collector reflective surfaces. Average efficiency was computed over the entire operating period.

Results

December 24 was a clear day with peak insolation recorded to be 920 W/m^2. The morning low temperature was near freezing; mid-afternoon temperatures were 16-17°C. There were light afternoon winds of 3-8 km/h.

The outlet temperature did not remain constant, ranging from about 262°C at 10:00 AM to only 238°C at noon to 267°C at 3:00 PM. Collector inlet fluid temperature also varied, from 178°C at 10:00 AM to 184°C at noon to 191°C at 3:00 PM. The flow rate remained at or just above the minimum allowable flow rate quantity throughout the day.

The collector subsystem supplied about 160 kW of thermal energy at mid-day; up to 290 or more kW during mid-morning and mid-afternoon operation. Collection efficiency was about 8 percent at noon, 13-20 percent near 10:00 AM and 17-19 percent near 4:00 PM. Collector efficiency averaged 11.4 percent for the total operational period.

Comments

Collector subsystem performance on December 24, 1981 was substantially better than during a comparable evaluation on December 21-24, 1980. Differences in operating procedures and environmental conditions prevent direct quantifiable comparison of test results among the various test days. However, output was some 60 kW higher and efficiency was about 3-4 percent higher during the 1981 operating day.

It is believed that replacement of Coilzak reflective surfaces with FEK-244 aluminized acrylic reflective collector surfaces was responsible for the bulk of the apparent improvement. Aluminum reflective spill shields, newly installed at the north end of collector groups, also appeared to reflect some sunlight back toward receivers.

Table 5-1 Performance Summary

Event Times, MST	
Collectors Focused	8:34 AM
Flow Diversion	9:18 AM
Generator Start-up	1:47 PM
Collectors Defocused	4:22 PM
Collector Parameters	
Inlet Oil Temp., °C	178-193
Outlet Temp., °C	238-271
Flow Rate, l/s	1.50-1.65
Environmental Conditions	
Description	Clear
Peak Insolation, W/m^2	920
Ambient Temp., °C	0-17
Wind Speed, km/h	3-8
Performance	
Power, kW	160-290
Efficiency Range, %	8.0-19.0
Avg. Efficiency, %	11.4
Electrical Energy Produced, kWh	320

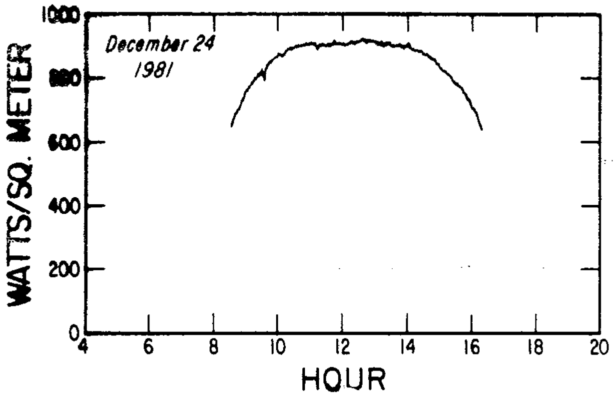


Figure 5-1. Winter Solstice, Insolation vs Hour

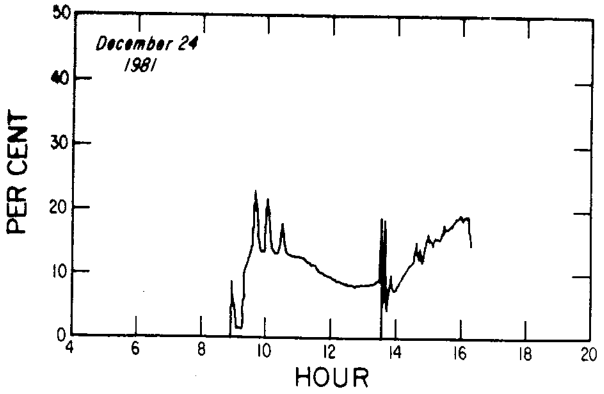


Figure 5-2. Winter Solstice, Efficiency vs Hour

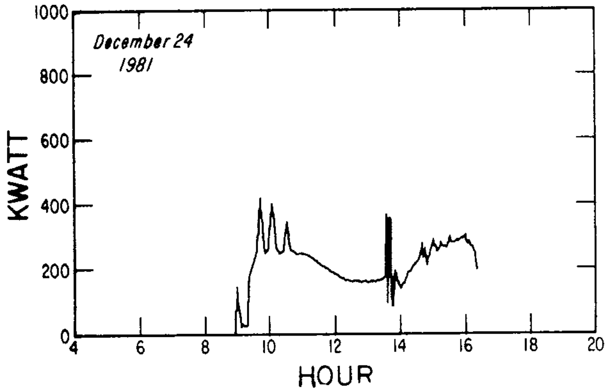


Figure 5-3. Winter Solstice, Collected Power vs Hour

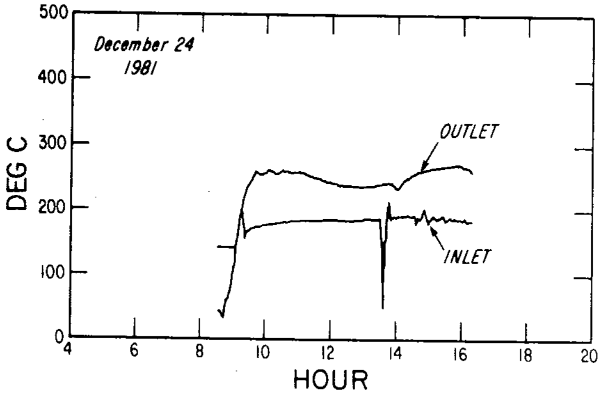


Figure 5-4. Winter Solstice, Inlet and Outlet Temperatures vs Hour

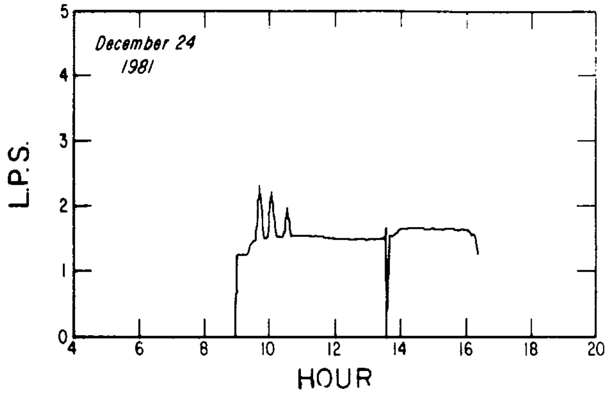


Figure 5-5. Winter Solstice, Flow Rate vs Hour

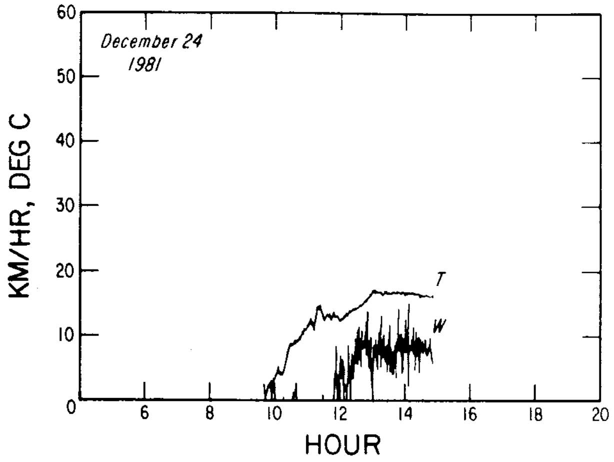


Figure 5-6. Winter Solstice, Wind Speed and Ambient Temperature vs Hour

6. Solar Collector Subsystem 1982 Vernal Equinox Performance

Solar collector subsystem performance was evaluated on 22, 23, and 27 March 1982 to determine collection efficiency during the period near vernal equinox. The average daily collection efficiency was about 31 percent on 22 and 23 March when the subsystem outlet oil temperature was maintained at about 282°C (540°F). With an outlet temperature of 275°C (525°F) on 24 March, daily collection efficiency was 32.5 percent.

Methods

Collector reflective surfaces and receiver tubes were washed by rainfall on 2, 3, and 18 March.

During tests, Caloria flow rate through the collector tubes was controlled to maintain the desired collector subsystem outlet temperature. Inlet oil temperature during operation was about 190°C (374°F). Outlet temperature was 275°C (525°F) on one test day; 282°C (540°F) on the other days.

Collector subsystem flow rates were measured with a vortex shedding type device, temperatures with RTD and thermocouple sensors, and insolation with a pyrheliometer. Data were recorded in digital form on magnetic tape at 2-minute intervals.

Collector system efficiency was computed as thermal energy gained by Caloria in passing from inlet to outlet manifold divided by total direct normal solar radiation incident on the reflector surfaces during collector operation.

22 March Results

Solar collector subsystem efficiency was 33 to 37 percent in midmorning and afternoon. Midday efficiency was about 31 percent. The average collection efficiency during operation was 31.3% on 22 March.

The subsystem collected energy at a rate of 650-710 kW_t. The test day was clear with peak insolation of 980 W/m^2. There was little wind during the test period. Collector inlet oil temperature was 192°C (378°F); outlet temperature was maintained at about 282°C (540°F). Caloria flow rate ranged from 3.6 to 3.8 l/s (57.0 to 60.2 gal/min) during the test.

23 March Results

On March 23, outlet oil temperature from the collector subsystem again was maintained at 280-283°C (536-541°F). Inlet oil temperature was 188-197°C (370-387°F). The flow rate varied considerably, from 2.5 to 3.7 l/s (39.6 to 58.6 gal/min), to maintain the desired outlet oil temperature.

23 March was a hazy day with peak insolation of 970 W/m^2. Low wind speeds and ambient temperatures of 10°C to 24°C (50 - 75°F) were experienced.

Solar subsystem energy collection efficiency was about 30 percent at noon; 36 percent at 9 AM and 4 PM. All-day solar collector subsystem efficiency was 30.8 percent. Energy production ranged from 400 to 700 kW_t, apparently due to solar energy variability.

27 March Results

Collector field outlet temperature was maintained somewhat lower on 27 March, from 273 to 278°C (523-532°F). Inlet oil temperature ranged from 191 to 200°C (376-392°F). The Caloria flow rate therefore was somewhat higher than during the previous tests at 3.8-4.3 l/s (60.2 to 68.1 gal/min).

On March 27, collector subsystem efficiency was up to 39 percent during mid-morning and mid-afternoon, averaging 32.5 percent for the whole day. For much of the day, energy production was 660-740 kW_t. However, occasional cloudiness resulted in varying efficiency and energy production.

Comments

Comparable collector subsystem performance evaluations were conducted in autumn and spring of 1980 and 1981. The earlier tests evaluated performance with Coilzak^{TM} reflective surfaces. Tests since May 1981 have measured performance of the collector subsystem after replacement of Coilzak^{TM} with FEK-244 aluminized acrylic film reflective surfaces.

The all day average collector efficiency on April 3, 1980 was found to be 30.1 percent. On September 24, 1980, the all day efficiency was 31.4 percent. The average collector efficiency on March 22, 1981 was only 26.8 percent. With FEK-244 reflective surfaces, the September 24, 1981 collector subsystem efficiency averaged about 33 percent. Spring 1982 tests resulted in efficiencies of 30.8-32.5 percent.

Since test days were not identical, performance is not directly comparable. However, it appears that collectors having FEK-244 reflective surfaces performed somewhat better than collectors with new Coilzak reflectors. Performance of collectors having older Coilzak reflective surfaces was substantially lower than obtained with either new Coilzak reflectors or with FEK-244 reflective collector surfaces.

Table 6-1 Collector Subsystem Test Events, MST

Event	Date (Julian Date)		
	81 3/22	82 3/23	86 3/27
Sunrise	6:25	6:23	6:21
Sufficient Insolation	7:35	7:34	7:30
Collectors Focused	7:35	7:34	7:30
Flow Diversion	8:15	8:11	8:21
Turbine Start-up	8:25	1:02	1:45
Insufficient Insolation	5:37	5:34	5:49
Collectors Defocused	6:04	6:04	6:39
Sunset	6:37	6:38	6:39

Table 6-2 Collector Subsystem Test Information

Event	Date		
	3/22	3/23	3/27
<u>Collector Parameters</u>			
Inlet Temp. (°C)	192	188-197	191-200
Outlet Temp. (°C)	282	280-283	273-278
Flow rate (l/s)	3.6-3.8	2.5-3.7	3.8-4.3
<u>Environmental Conditions</u>			
Description	Clear	Hazy	Some Clouds
Ambient Temp. (°C)	15-23	10-24	15-24
Wind Speed (km/h)		NOT RECORDED	
Peak Insolation (W/m^2)	980	970	960
<u>Performance</u>			
Power (kW)	650-710	400-700	660-740
Efficiency Range (%)	31-37	25-36	12-39
Avg. Eff., I>300 W/m^3 (%)	31.1	30.8	32.5

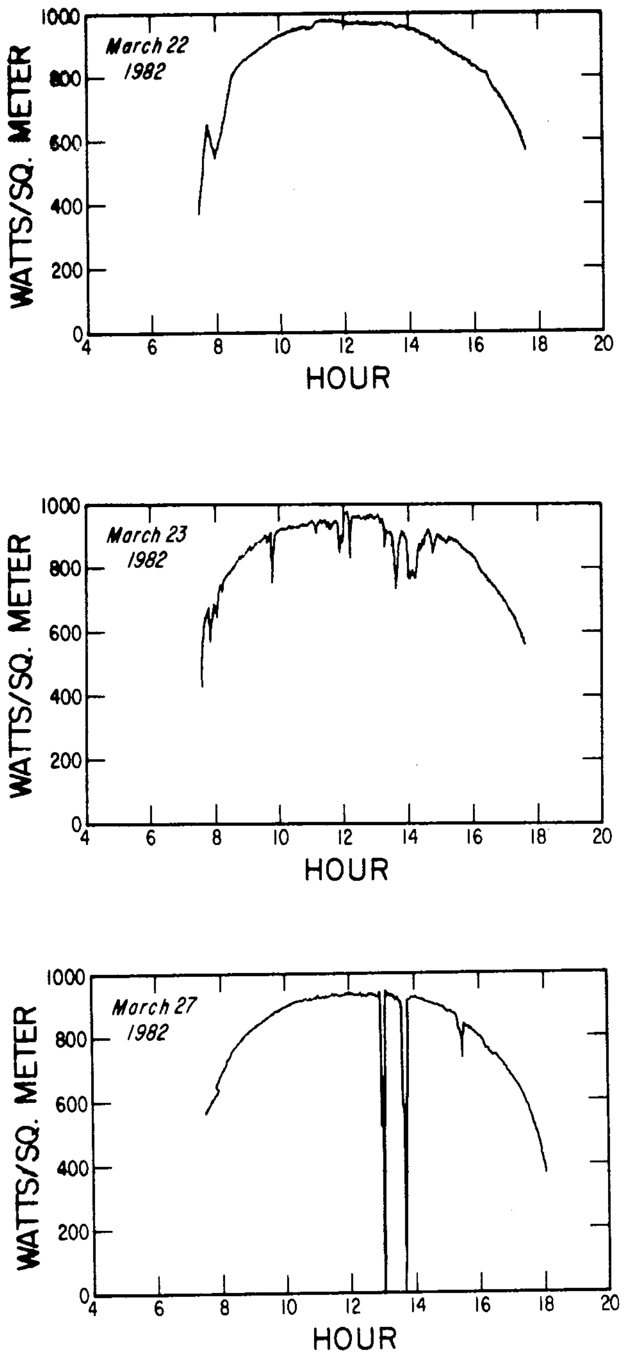


Figure 6-1. Vernal Equinox, Insolation vs Hour

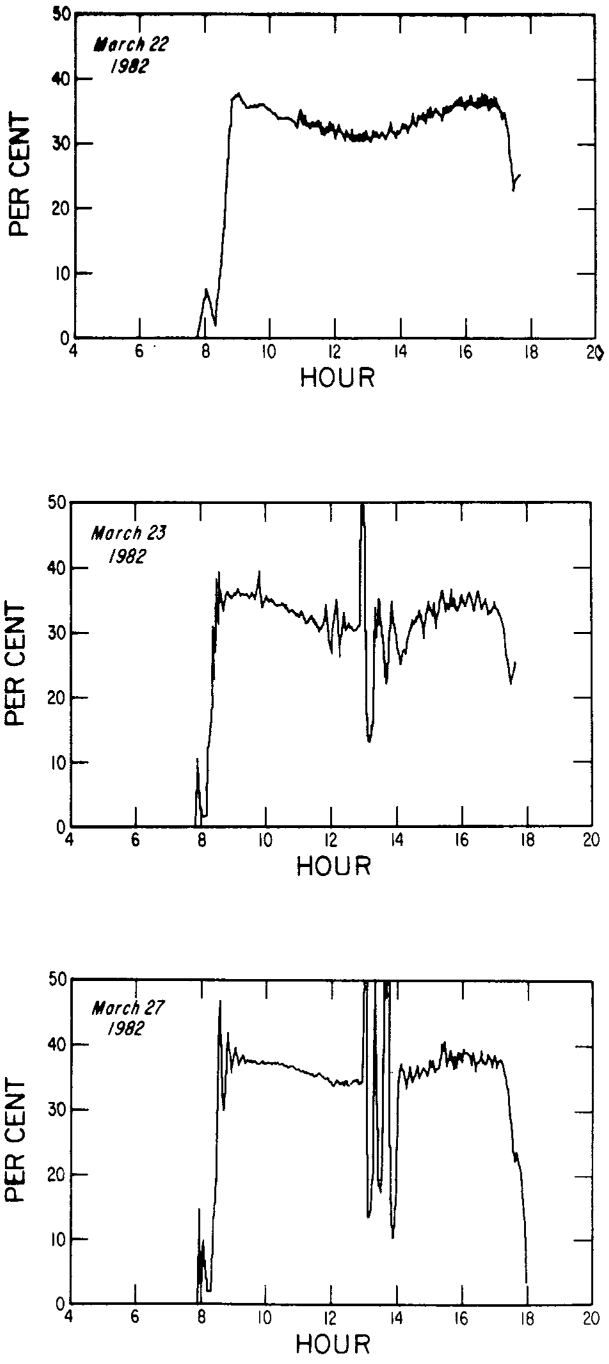


Figure 6-2. Vernal Equinox, Efficiency vs Hour

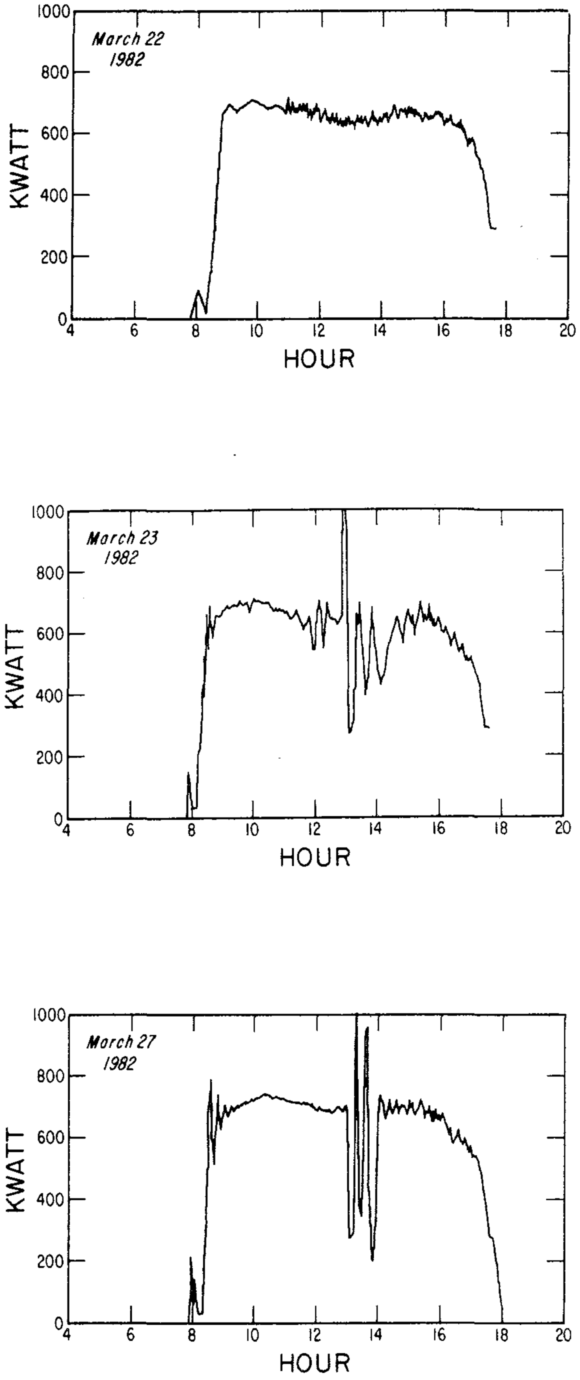


Figure 6-3. Vernal Equinox, Collected Power vs Hour

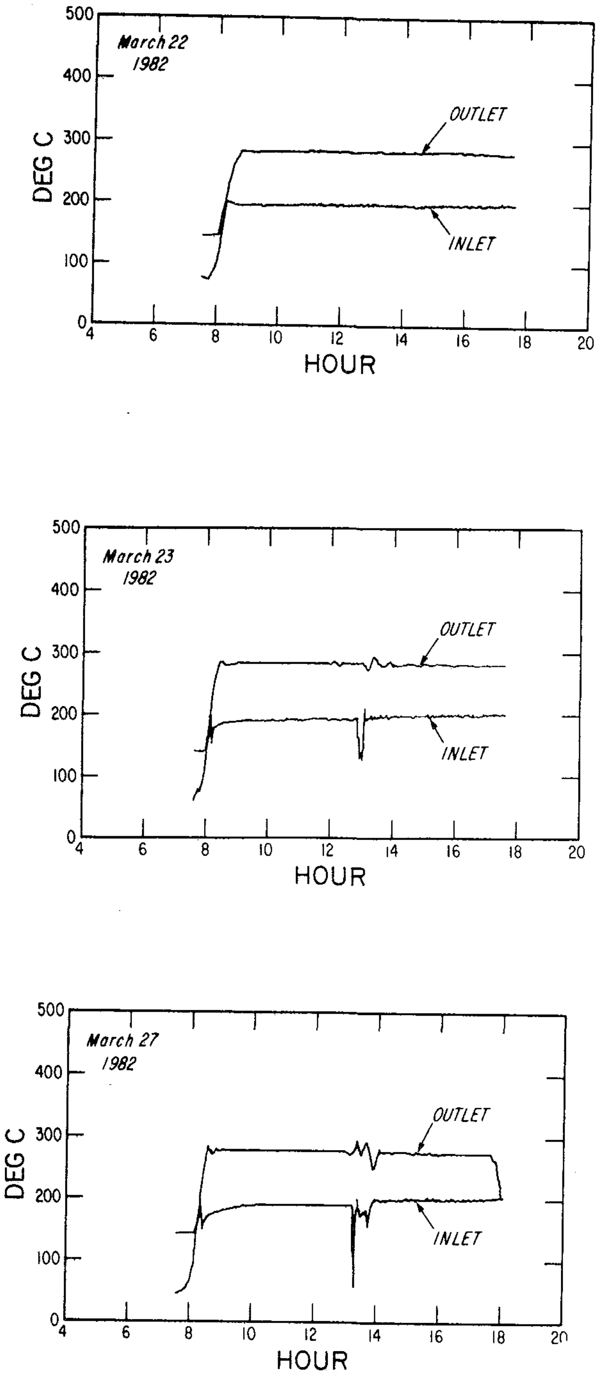


Figure 6-4. Vernal Equinox, Inlet and Outlet Temperatures vs Hour

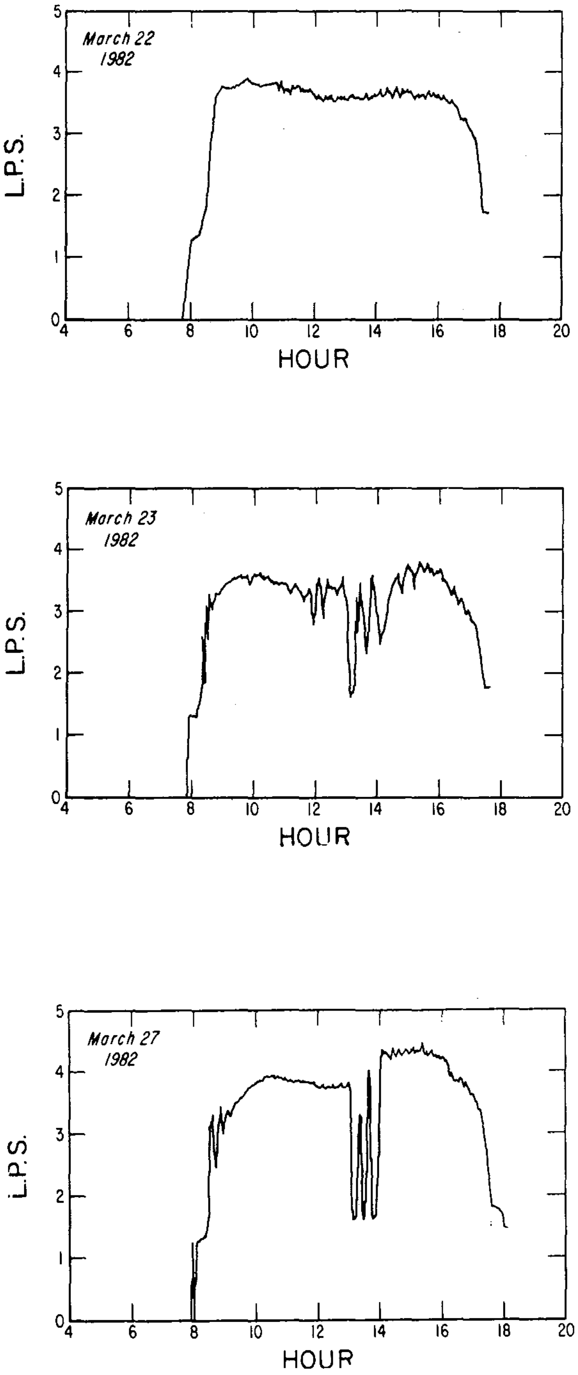


Figure 6-5. Vernal Equinox, Flow Rate vs Hour

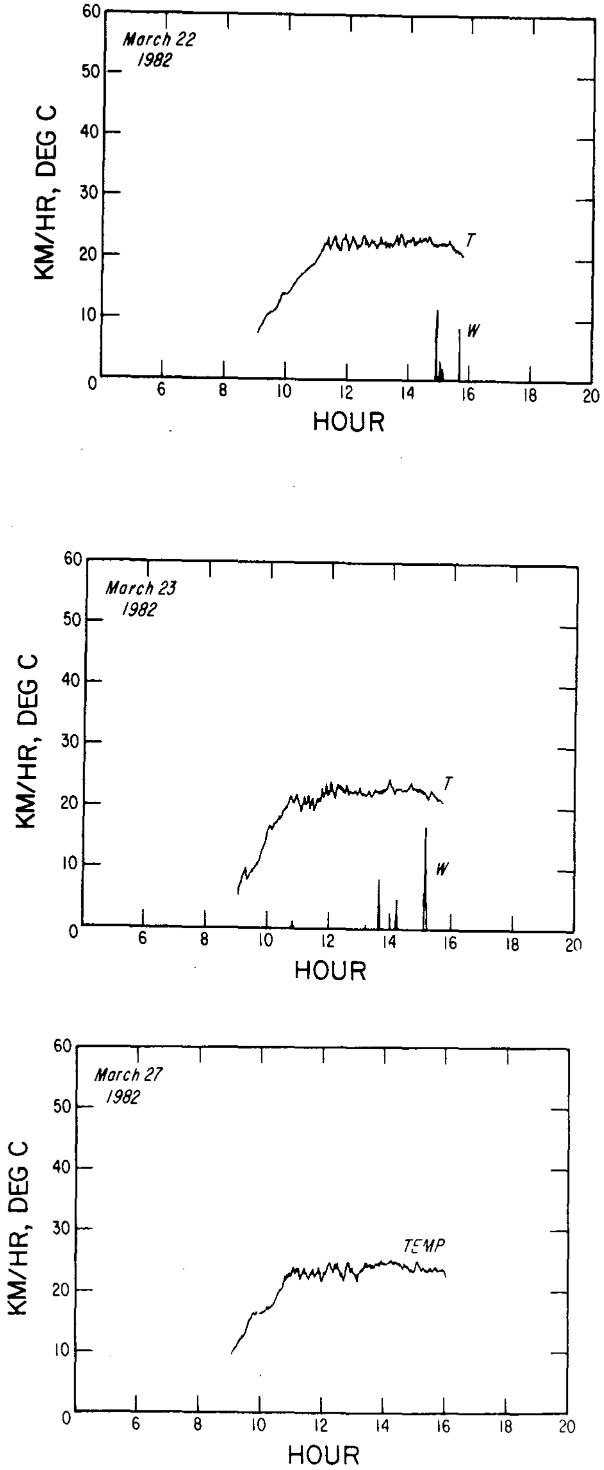


Figure 6-6. Vernal Equinox, Wind Speed and Ambient Temperature vs Hour

7. Solar Collector Subsystem 1982 Summer Solstice Performance

Solar collector subsystem performance was evaluated on 20 and 23 June 1982 to determine collection efficiency during the period near summer solstice. Average daily subsystem efficiency for each day was 35 percent, although the collector subsystem outlet Caloria^{TM} temperature was different during the two days.

Methods

Collectors were focused when insolation reached about 300 W/m^2 (95 Btu/ft^2 h). Caloria^{TM} was recirculated through the collector subsystem until an outlet temperature of 246°C (475°F) was attained. Then flow was diverted into the storage tank. Caloria^{TM} was circulated through the collector subsystem at a flow rate controlled to maintain the desired constant outlet temperature for the remainder of the test day. However at about 12:30 pm, the power conversion subsystem began operation and Caloria^{TM} was redirected from the collector subsystem through the vaporizer heat exchanger instead of to storage. The switchover resulted in a 15-20 minute perturbation in Caloria^{TM} flow rate and temperature while the vaporizer was heated to the operating temperature.

Collector reflectors and receiver tubes were washed with soft water using a portable pressure washer during the week prior to the test. Some windy, dusty conditions were experienced during the week so collectors were not completely clean at the time of performance testing. Moreover, it is felt that the water softening equipment was not adequately treating the wash water. There appeared to be a film on the reflective surfaces after washing was completed. Best collector reflectivity readings before washing were about 65 percent. After pressure washing, reflectivity was measured to be about 80 percent. Collectors were rain washed in early July. After the rain, collector reflectivity was found to be about 83 percent.

Collector system flow rate was measured with a vortex-shedding type instrument, Caloria^{TM} temperatures with resistance temperature detectors (RTDs) and insolation with a pyrheliometer. Data were recorded at 2 minute intervals.

Collector subsystem efficiency was computed as the thermal energy gained by Caloria^{TM} during passage from subsystem inlet to outlet manifold locations divided by the total direct normal solar radiation impinging on the collector reflective surfaces. Average efficiency was computed for the entire period of collector subsystem operation.

20 June Results

The collector subsystem outlet Caloria^{TM} temperature was maintained at about 280°C (536°F). Inlet Caloria^{TM} temperature was 200°C (392°F). The subsystem Caloria^{TM} flow rate was 3.8 to 4.3 l/s (59.7 - 67.6 gpm).

The day was mostly clear with peak insolation of 845 W/m^2 (268 Btu/ft^2 h). Ambient temperature was 30 to 38°C (86 - 100°F). Wind speeds were variable, but were about 4-11 km/h (2.5 - 6.8 mph).

Solar collector subsystem efficiency during mid-day ranged from 36 to 40 percent. Collector efficiency averaged 35 percent for the day. Thermal energy was produced by the collector subsystem at 600 to 720 kW_t (569 - 683 Btu/S) during the central part of the day.

23 June Results

Environmental conditions on 23 June were similar to those on 20 June, except peak insolation was somewhat higher, about 880 W/m^2 (279 Btu/ft^2 h). The outlet Caloria^{TM} temperature was maintained at about 264°C (507°F), about 16°C (29°F) cooler than on 20 June. The inlet Caloria^{TM} temperature was about 200°C (392°F), as on 20 June. The subsystem flow rate, however, was 4.7 to 5.4 l/s (74.5 - 85.7 gpm), about 25 percent greater than on 20 June in order to obtain the lower outlet temperature.

Solar collector subsystem efficiency was 37 to 40 percent during the period from 10 am to 4 pm. Collector efficiency averaged 35 percent over the entire operating period. Thermal energy was produced at a rate of 670 to 750 kW_t from mid-morning to mid-afternoon.

Parasitic Energy Usage

Tracking motors used 22 and 23 kWh_e during the two test days, The Caloria^{TM} pump required 36 kWh_e on 20 June. However on 23 June with lower collection temperatures, higher pump speed and flow rate resulted in the use of 52 kWh_e. Additional electrical energy is required to operate the air compressor and other controls associated with collector subsystem operation. These were previously estimated to be about 32 kWh_e per day. Adding this quantity to tracking motor and Caloria^{TM} pump requirements yields estimated parasitic energy usage totals of 90 kWh_e for 20 June and 107 kWh_e for 23 June.

Thermal energy is converted to electrical energy by the power conversion subsystem at Coolidge with an efficiency of about 20 percent. Using a 20 percent energy conversion value, parasitic energy use of 90 kWh_e reduced the net collector subsystem efficiency from 35.0 percent thermal efficiency to 32.7 percent for 20 June. For 23 June, parasitic energy use reduced the net collector subsystem efficiency to 32.4 percent. The average thermal efficiency on 23 June was 35.0 percent.

Discussion

Collector subsystem solar energy collection efficiency peaked at about 40 percent and averaged about 35.0 percent on both test days. Caloria^{TM} outlet temperatures on the two test days were 280°C and 264°C respectively. Thus these tests confirmed earlier results showing collector subsystem performance not to be very sensitive to the operating temperature range.

Parasitic energy use reduced the average collector subsystem efficiency from 35.0 percent thermal efficiency to net values of 32.4 and 32.7 percent for the two test days. The higher Caloria^{TM} pumping rate required with lower temperature collector operation resulted in the lower net efficiency.

The collection efficiencies were 5 to 7 percent lower than measured during comparable collector subsystem performance tests conducted a year earlier in June 1981. It is believed that reduced collector reflectivity due to a poorer quality washing job was responsible for the reduced performance in 1982. Freshly washed collector panels had a reflectivity of nearly 85 percent on June 18, 1981; about 80 percent before June 1982 tests. This reduction in reflectivity is not believed to be permanent. After rainwashing of collectors in early July 1982, reflectivity of panels was about 83 percent. Additional accumulation of dust within receiver tube glass covers also could account for some of the reduction in collector performance.

Table 7-1. Collector Subsystem Test Events, MST

Event	Date	
	171 6/20	174 6/23
Sunrise	5:18	5:19
Sufficient Insolation	6:25	6:26
Collectors Focused	6:40	6:32
Flow Diversion	7:23	7:17
Turbine Start-up	12:19	12:28
Insufficient Insolation	6:07	6:09
Collectors Defocused	6:55	6:57
Sunset	7:40	7:41

Table 7-2. Collector Subsystem Summary Test Data.

Data	Date	
	6/20	6/23
Collector Parameters		
Inlet Temp (°C)	200	197-202
Outlet Temp (°C)	278-280	264
Flow Rate (l/s)	3.8-4.3	4.7-5.4
Environment Conditions		
Description	Clear	Clear
Ambient Temp (°C)	30-38	29-37
Wind Speed (Km/h)	4-11	6-12
Peak Insolation (W/m^2)	845	880
Collector Performance		
Power (kW$_t$)	600-720	670-750
Eff. Range, 10 am - 4 pm (%)	36-40	37-40
Avg. Eff., $I > 300$ W/m^2 (%)	35.0	35.0
Parasitic Energy Use, kWh$_e$		
Tracking Motors, daily use (use	22	23(2.1)
Pump during warmup)	36	52(1.0)

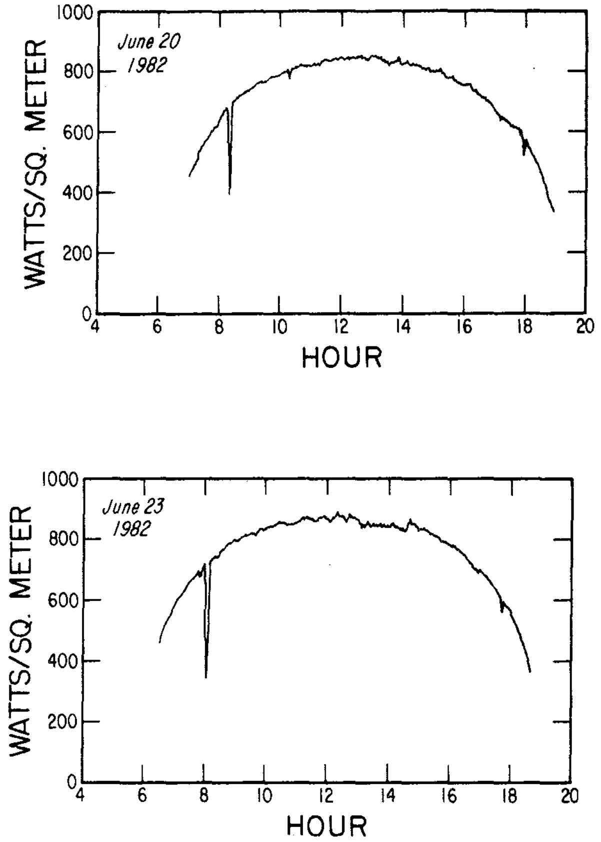


Figure 7-1. Summer Solstice, Insolation vs Hour

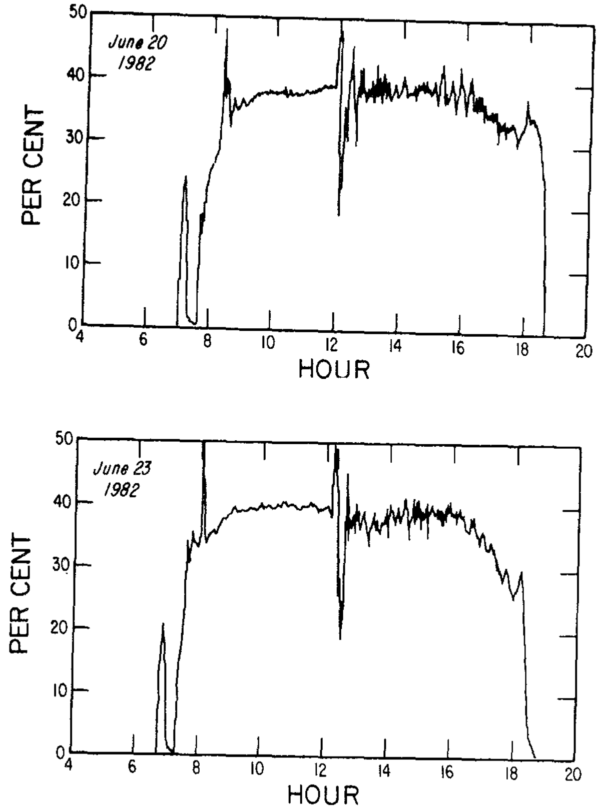


Figure 7-2. Summer Solstice, Efficiency vs Hour

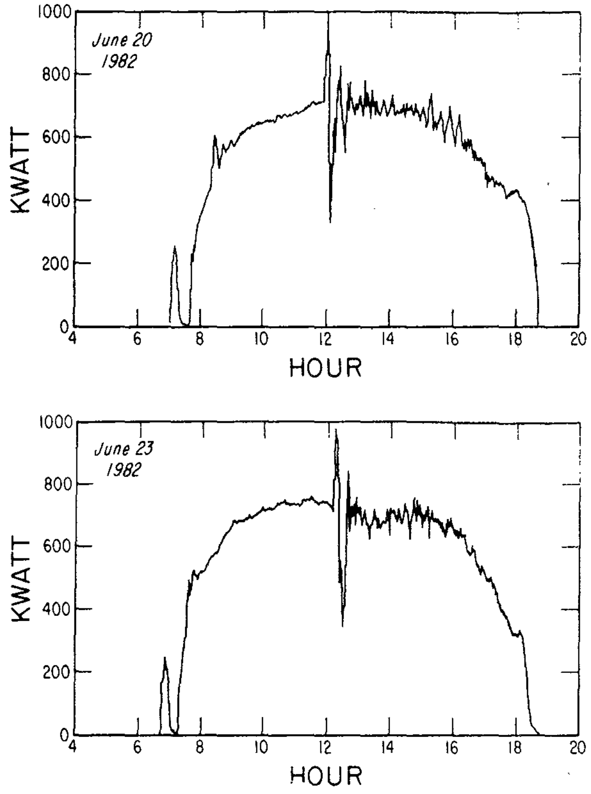


Figure 7-3. Summer Solstice, Collected Power vs Hour

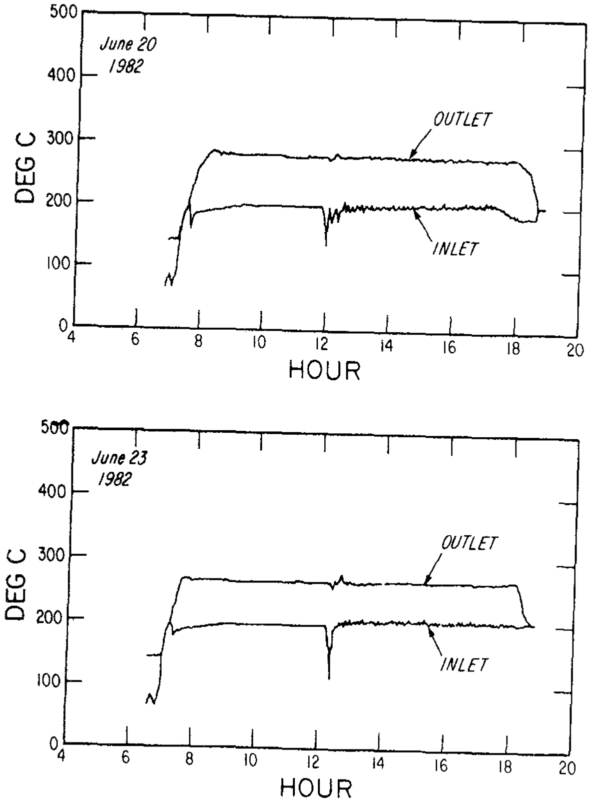


Figure 7-4. Summer Solstice, Inlet and Outlet Temperatures vs Hour

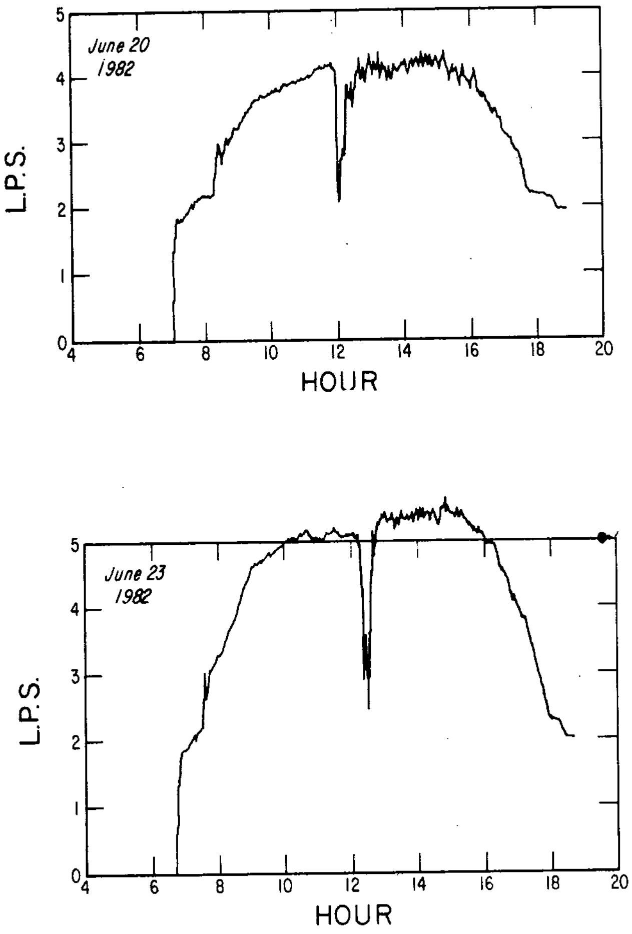


Figure 7-5. Summer Solstice, Flow Rate vs Hour

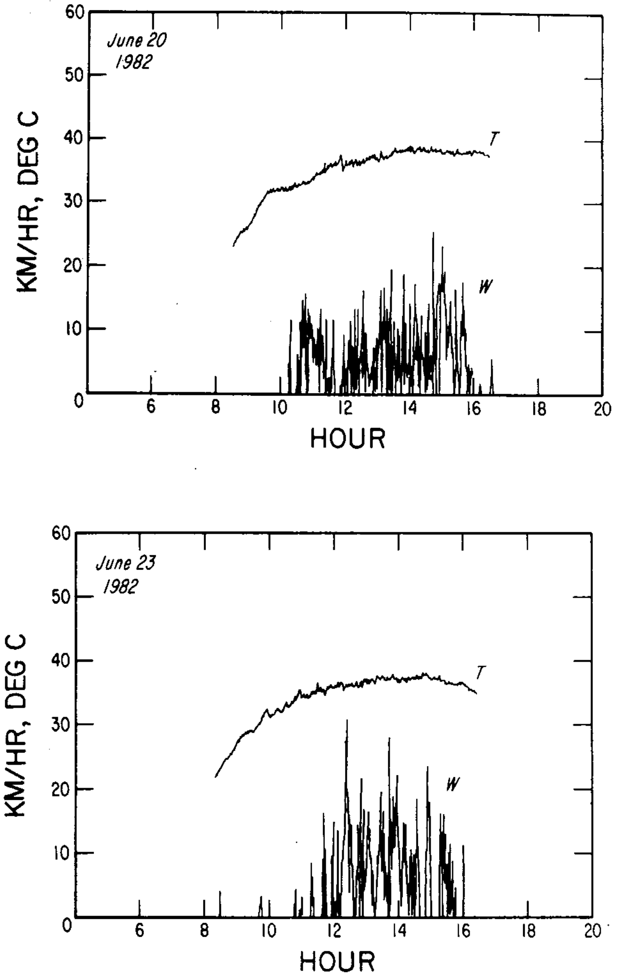


Figure 7-6. Summer Solstice, Wind Speed and Ambient Temperature vs Hour

8. Solar Collector Subsystem 1982 Antumnal Equinox Performance

Solar collector subsystem performance was evaluated on 20 and 22 September, 1982 to determine collection efficiency during the period near the autumnal equinox. Average daily subsystem efficiency for both days was about 29 percent, although the collector subsystem outlet Caloria^{TM} temperature was about 285°C (545°F) on September 20 but only 266°C (510°F) on the 22nd.

Methods

Collectors were focused when insolation reached about 300 W/m^2 (95 Btu/ft^2 h). Caloria^{TM} was recirculated through the collector subsystem until an outlet temperature of 232°C (450°F) was attained. Then flow was diverted into the storage tank. Caloria^{TM} was circulated through the collector subsystem at a flow rate controlled to maintain the desired constant outlet temperature for the remainder of the test day. At about 1:25 PM, the power conversion subsystem began operation and Caloria^{TM} was directed from the collector subsystem through the vaporizer heat exchanger for the remainder of the day. The switchover resulted in a 15-20 minute perturbation of the Caloria^{TM} flow rate and temperature while the vaporizer was heated to the operating temperature.

Collector reflectors and receiver tubes all were washed by rainfall a few days prior to the tests. Some groups also were washed with soft water using a portable pressure washer during the week prior to the tests. However some windy conditions were experienced during the week so collectors were not completely clean at the time of performance testing.

Collector subsystem flow rate was measured with a vortex-shedding type instrument, Caloria^{TM} temperatures with resistance temperature detectors (RTDs) and insolation with a pyrheliometer. Data were recorded at 2 minute intervals.

Collector subsystem efficiency was computed as the thermal energy gained by Caloria^{TM} during passage from subsytem inlet to outlet mainfold locations divided by the total direct normal solar radiation impinging on the collector reflective surfaces. Average efficiency was computed for the entire period of collector subsystem operation.

20 September Results

The collector subsystem outlet Caloria^{TM} temperature was maintained at about 285°C (545°F). Inlet Caloria^{TM} temperature was 190-196°C (374-385°F). The subsystem Caloria^{TM} flow rate was 2.8 to 3.0 l/s (44-47 gpm).

The day was mostly clear with peak insolation of 830 W/m^2 (263 Btu/ft^2 h). Ambient temperature was 30 to 37°C (86-99°F). Wind speeds were variable, but were about 3-14 km/h (3/9 mph).

Solar collector subsystem efficiency during mid-day ranged from 28 to 35 percent. Collector efficiency averaged 29.5 percent for the day. Thermal energy ws produced by the collector subsystem at 520 to 585 kW$_t$ (493-555 Btu/S) during the central part of the day.

22 September Results

September 22 was somewhat hotter and breezier than September 20. The outlet Caloria^{TM} temperature was maintained at about 266°C (510°F), about 19°C (34°F) cooler than on September 20. The inlet Caloria^{TM} temperature was 195-200°C (382-392°F), about the same as on September 20. The subsystem flow rate, however, was 3.4 to 3.9 l/s (54-62 gpm), about 25 percent greater than on 20 September, in order to obtain the lower outlet temperature.

Solar collector subsystem efficiency was 30 to 33 percent during the period from 9 AM to 4 PM. Collector efficiency averaged 29.1 percent over the entire operating period. Thermal energy was produced at a rate of 490 to 530 kW_t (465-503 Btu/S) from mid-morning to mid-afternoon.

Discussion

Collector subsystem solar energy collection efficiency peaked at 33-35 percent and averaged a bit more than 29 percent on the two test days. Caloria^{TM} outlet temperatures on the two test days were 285°C and 266°C respectively. Thus these tests confirmed earlier results showing collector subsystem performance not to be very sensitive to the operating temperature range. However, the higher collection temperature is desirable since higher input temperatures increase energy conversion efficiency.

The collection efficiencies were about 2 to 3 percent lower than measured during comparable collector subsystem performance tests conducted a year earlier in September 1981. March 1982 test results were similar to September 1981 results. It is believed that reduced collector reflectivity, increased amounts of dust within glass receiver tube covers and collector subsystem insulation degradation all contributed to the decline in performance. Reduced reflectivity is due to delamination of FEK-244 on about 10 percent of the collector panels affecting perhaps 1 percent of the collector area.

Table 8-1 Collector Subsystem Test Events, MST

Event	Date	
	263 9/20	265 9/22
Sunrise	6:14	6:16
Sufficient Insolation	7:28	7:31
Collectors Focused	7:28	7:31
Flow Diversion	8:00	8:08
Turbine Start-up	1:23	1:28
Insufficient Insolation	5:30	5:29
Collectors Defocused	5:40	5:40
Sunset	6:28	6:25
Collection Temperature	545°F	510°F
Electricity Producted	770 kWh	670 kWh

Table 8-2 Collector Subsystem Summary Test Data

Data	Date	
	263 9/20	265 9/22
Collector Parameters		
Inlet Temp. (°C)	190-196	195-200
Outlet Temp. (°C)	283-287	265-267
Flow rate (l/s)	2.8-3.0	3.4-3.9
Environmental Conditions		
Description	Clear	Clear
Ambient Temp. (°C)	30-37	30-41
Wind Speed (km/h)	3-14	4-16
Peak Insolation (W/m^2)	830	820
Performance		
Power (kW)	520-585	490-530
Efficiency Range (%)	28-35	30-33
Avg. Eff., $I>300\ W/m^3$ (%)	29.5	29.1

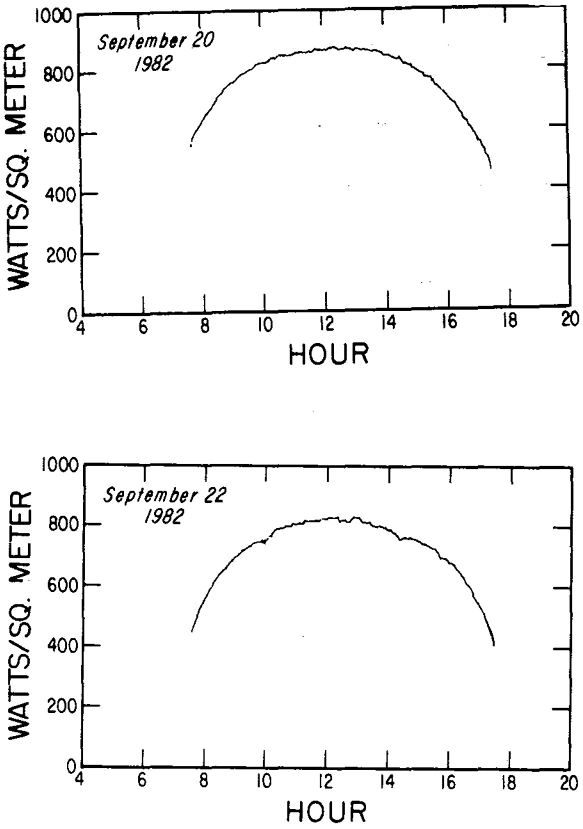


Figure 8-1. Autumnal Equinox, Insolation vs Hour

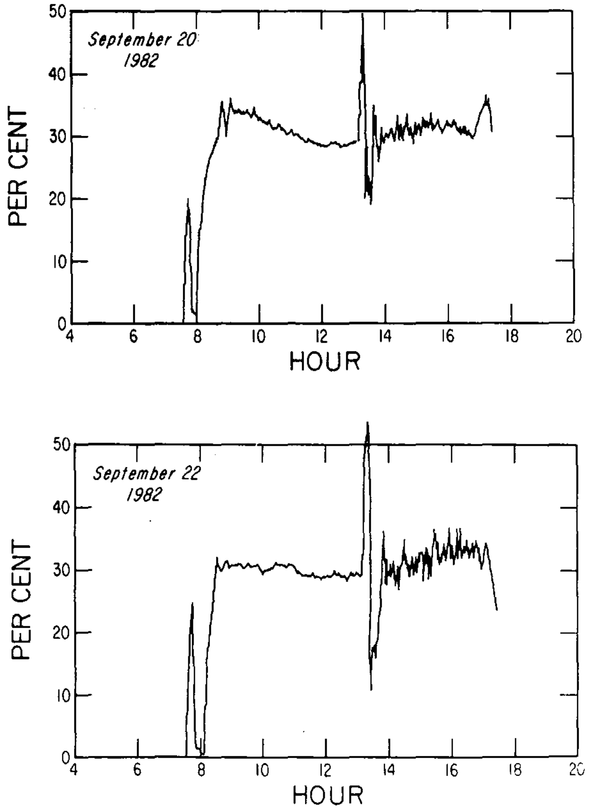


Figure 8-2. Autumnal Equinox, Efficiency vs Hour

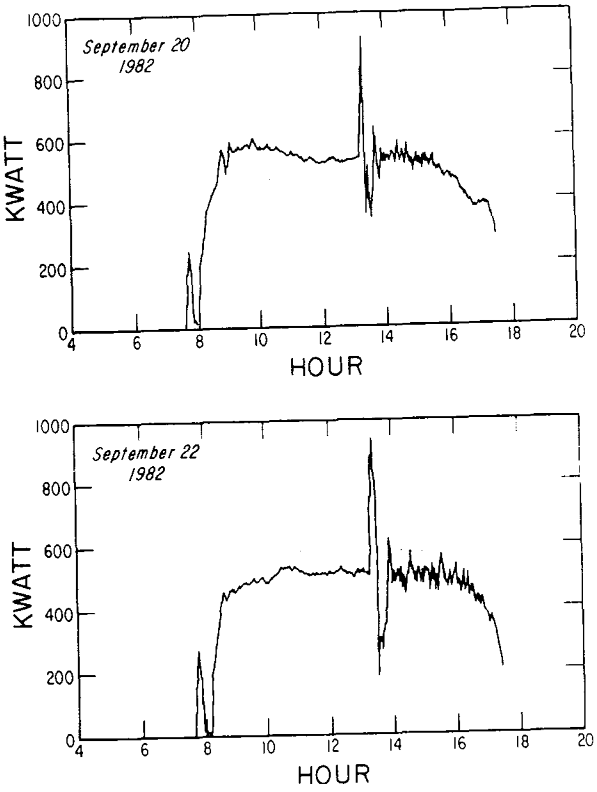


Figure 8-3. Autumnal Equinox, Collected Power vs Hour

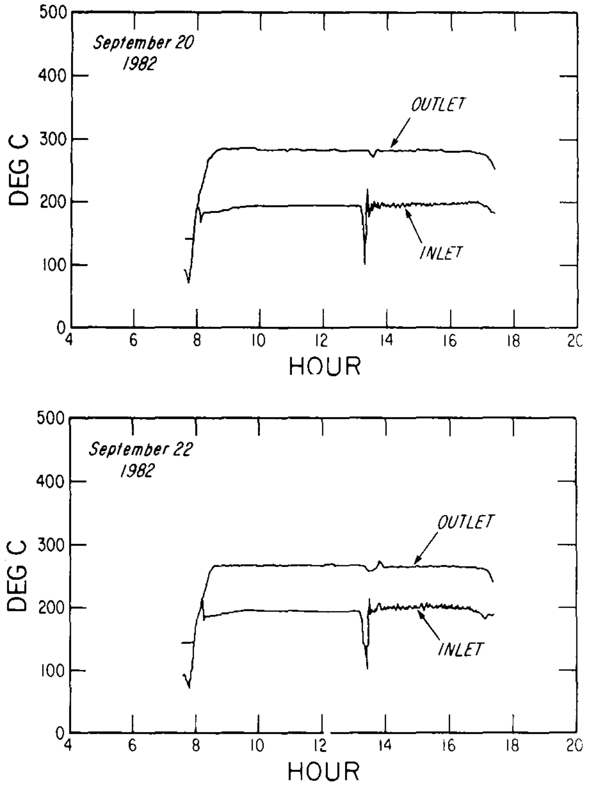


Figure 8-4. Autumnal Equinox, Inlet and Outlet Temperatures vs Hour

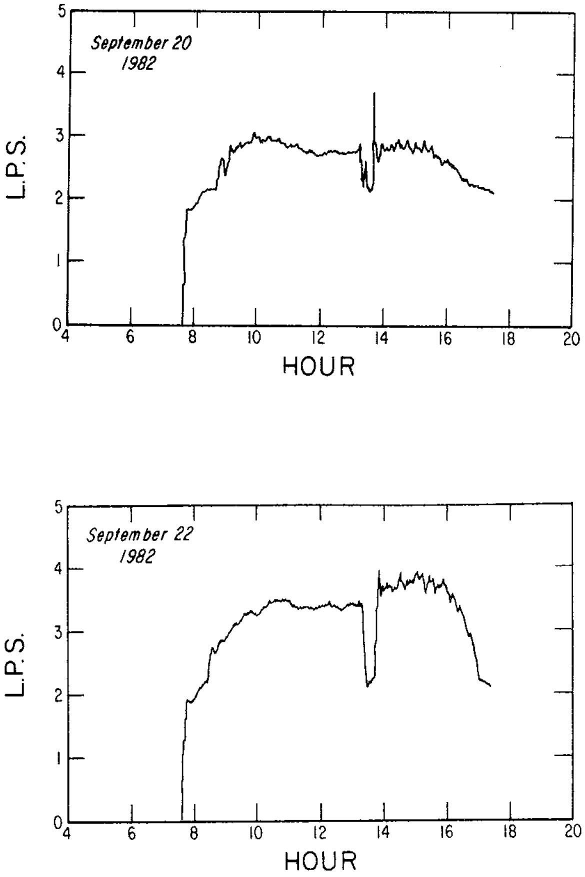


Figure 8-5. Autumnal Equinox, Flow Rate vs Hour

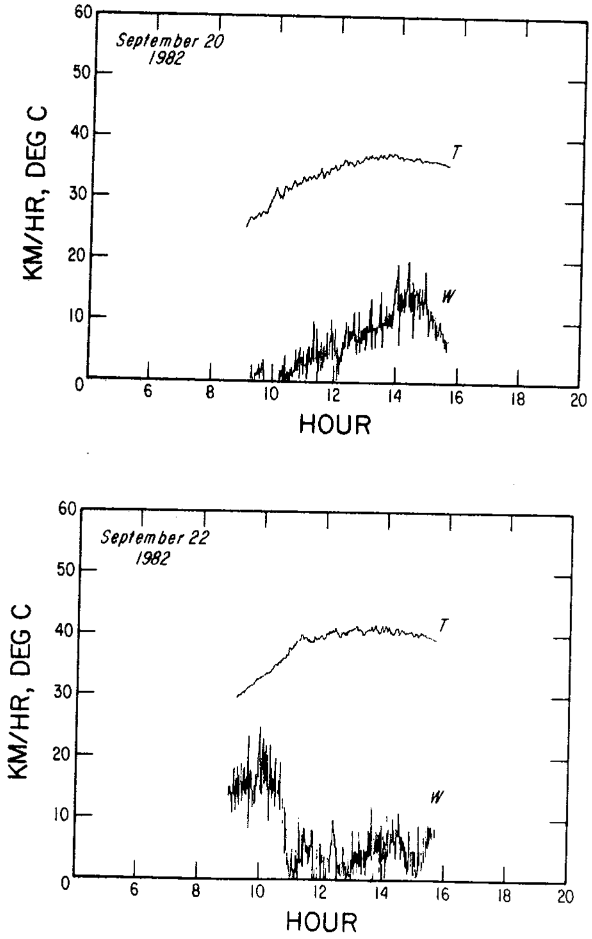


Figure 8-6. Autumnal Equinox, Wind Speed and Ambient Temperature vs Hour

9. Cleaning and Reflectivity of Solar Collector Subsystem Reflector Panels

Solar collectors at the Coolidge facility originally had Coilzak^{TM} reflector panels. However, the reflectivity of clean Coilzak^{TM} refective surfaces was less than 60% after 1 year of service. In Spring 1981, the Coilzak panels were replaced with aluminized acrylic (FEK-244) laminated aluminum panels.

The solar collectors were cleaned periodically to improve energy collection performance. Effectiveness of the cleaning was determined by reflectivity measurements. The three methods used to clean the solar collectors were:

a. Spraying on a mixture of cleaner and deionized water and rinsing with deionized water

b. Pressure spraying with soft water and cleaner, then rinsing with soft water

c. Rain washing.

The hard water available locally precluded use of tap water. Originally, the Coilzak^{TM} reflector panels were cleaned with tap water in combination with a variety of cleaners, mops, and high-pressure spray equipment. The results using these techniques were not very satisfactory. It was determined that the tap water was causing a white film to build up on the Coilzak^{TM}. The cause of the film was apparently the high hardness of the water (1 100 ppm total dissolved solids compared to 200 to 350 ppm for Albuquerque).

It was more cost effective to hire a commercial firm (Coffin Brothers Co., Phoenix, AZ) to perform the deionized water cleaning operations. The contractor brought 7 570 L (2,000 gal) of deionized water and spray equipment to the site. The cleaner used was "Car Wash Soap" from Schrader Chemical Co. The collectors were cleaned every 3 months (for the equinox and solstice tests) at a cost of $500 per cleaning through September 1981.

A less expensive cleaning method was desired. Thus, in Autumn 1981, a water softening system and portable, high-pressure spray equipment were purchased for a study of the use of soft water as a substitute for deionized water.

The portable sprayer was used with soft water and cleaning agent to wash collectors in December 1981 and June 1982. The cleaner used was "Powered Power" made by Cal-Pak for washing cars with softened water in Arizona.

Collectors also were washed by rainfall whenever possible. Collector modules were rotated so as to face the rainfall and drain water from the lower edge.

The effectiveness of cleaning was checked by making reflectivity measurements on the reflector panels using a portable specular reflectometer provided by J.M. Freese of SNLA. A 23.1-mrad (1.32-degree) aperture was used in the reflectometer, which approximates the acceptance window of reflected solar radiation for the Acurex collector. Table 9-1 lists the reflectance data gathered in 1981-82. The reflectance values listed are average values representative of the collector field.

It appears that rain washing is as effective as pressure washing with deionized water. Reflectivity measurements were about 83% after washing with either of these two methods.

Reflectivity measurements after the December 1981 soft water washing were about equal to measurements obtained after washing with rainfall or deionized water. However, collector panel reflectivity was found to be somewhat lower following soft water washing in June 1982. It was determined that soft water treatment equipment was not performing properly and a film had been left on the FEK surface. Subsequent washings by rainfall and with properly softened water resulted in higher reflectivity measurements. Thus, it appears that soft water washing can be as effective as cleaning with rainfall or deionized water. However, soft water quality must be maintained carefully.

Table 9-1. Reflectance data for collector FEK-244 reflector panels.

Date	Reflectance %	Comments
9/4/81	75.8	
9/11/81	73.3	
9/22/81	83.1	Pressure washed with deionized water on 9/21/81
9/25/81	82.1	
10/2/81	82.4	Rain washed on 10/1/81
10/16/81	77.2	
10/24/81	71.7	
11/6/81	75.7	Rain-washed on 10/27/81
11/18/81	68.4	
11/27/81	69.7	
12/4/81	76.2	Rain washed on 11/29 & 30/81
12/17/81	83.8	Pressure-washed with soft water on 12/15
1/11/82	71.9	
1/17/82	75.1	Rain-washed on 1/12/82
1/22/82	76.7	Rain-washed on 1/21/82
1/31/82	72.3	
2/12/82	80.8	Rain-washed on 2/11/82
2/19/82	79.0	Light rain wash on 2/18/82
3/1/82	75.5	
3/11/82	77.2	Rain-washed on 3/3/82
3/15/82	77.4	
4/5/82	79.4	Rain-washed on 3/26/82
4/13/82	76.2	
4/26/82	69.1	Field operations on 4/5 to 20/82 caused dusty conditions
5/3/82	72.6	Rain-washed on 5/1/82
5/5/82	76.6	
5/24/82	69.6	Days 5/8 & 9/82 were windy and dusty
5/23/82	69.2	
5/28/82	72.5	
6/6/82	70.6	
6/12/82	64.1	
6/19/82	80.2	Collectors pressure-washed with soft water on 6/13 to 18/82
7/7/82	83.1	Rain-washed on 7/6/82
7/27/82	81.4	Rain-washed on 7/26/82
8/1/82	80.0	Rain-washed on 7/30/82
8/18/82	79.0	Rain-washed on 8/6/82
8/24/82	80.3	Rain-washed on 8/23/82
8/25/82	80.4	Rain-washed on 8/24/82
9/1/82	78.5	
9/8/82	79.8	

10. Parasitic Electrical Energy Usage

INTRODUCTION

Electrical meters have been used to monitor electrical energy used by various components and subsystems of the solar power plant. Collector subsystem feed pump and tracking motors, control module, power conversion subsystem vaporizer pump, cooling tower, air compressor, and control building were the principal metering divisions. Meter designations and equipment monitored by the meters are summarized in Table 10-1. In some cases, other smaller uses also were monitored by a meter. For example, the control module meter also included data logger and weather station electrical energy usage.

Daily energy usage for these categories is shown in Tables 10-2 through 10-14. Total electrical energy usage by the plant was monitored by another meter. This measurement is listed in the energy budget tables in Section 3 of the report. The total energy-use meter should indicate a somewhat higher value than the total of the seven meters since energy usage by the natural gas boiler, outdoor lights, and make-up pump and that consumed by plant transformers are not metered separately. However, possible differences in meter calibration make comparison valueless.

ENERGY USE

Total parasitic energy use varied considerably from day to day and month to month. Day-to-day energy consumption varied with equipment usage; month-to-month changes were principally due to day length and control building environmental control requirements. Day-to-day energy use data are listed in Tables 10-2 to 10-14. However, the data can be used only with great care since the meters were read by the operator who frequently completed work before plant operation terminated. Thus, meter readings were recorded at different times on different days.

Table 10-1. Identification of Equipment Monitored by Each Meter.

Meter Designation	Equipment Metered
Field pump	Collector subsystem pump motor
Tracking motors	Collector subsystem tracking motors, collector subsystem controls, electrical outlets in collector field
Vaporizer pump	Power conversion subsystem vaporizer Caloria^{TM} pump
Control module	Power conversion subsystem motors and controls, including vacuum pump and toluene feed pumps, data logger, weather station
Cooling tower	Cooling tower water pump and fans, PCM area electrical outlets water treatment system
Air compressors	Air compressors and air dryer
Air conditioner/heater	Control building air conditioner, furnace, lights, and electrical outlets

Unmonitored Usage:
- Natural gas boiler
- Caloria^{TM} make-up pump
- Floodlights
- Transformer losses (480:240/120)

The average daily solar plant parasitic energy use ranged from 89 kWh in January to 154 kWh in April and 200 kWh in July.

In early spring on a day when neither collector nor power conversion subsystems were operated, the plant used 31-37 kWh. The air compressors used about 10 kWh and the control module 12-13 kWh of this amount. Building utilities required a smaller amount. On a sunny spring day when collectors operated but the turbine-generator did not operate, the plant used about 90 kWh. Of this total, the collector subsystem Caloria^{TM} pump and tracking motors required about 50 kWh. The solar plant used about 175 kWh in April on sunny days when the power conversion subsystem operated about 5 hours. Almost 80 kWh of that total was used by the cooling tower and power conversion subsystem vaporizer Caloria^{TM} pump. The greater use of parasitic energy in summer is due, in about equal parts, to increased operation of the power conversion subsystem and building air conditioner.

Collector subsystem energy usage was monitored by field pump and tracking motor meters, Figures 10-1 and 10-2. Field pump energy use depends primarily on flow rate and length of operating period. The pumping power required in January was about 3.1 kW, while in July the pumping power requirement was nearly 4.0 kW due to the higher flow rate. Average daily pumping energy use ranged from 18 kWh in December to 33 kWh in July. Collector tracking motor average energy usage varied from about 21 to 26 kWh per day. The tracking energy use was only modestly greater in summer when operating hours are much longer.

Power conversion subsystem energy consumption was monitored by vaporizer Caloria^{TM} pump and cooling tower electrical meters, Figures 10-3 and 10-5. The vaporizer Caloria pump required about 5 kW of power; the cooling tower used about 11 kW. Energy use varied directly with hours of power conversion subsystem operation, from about 30 kWh for the vaporizer pump and cooling tower on an operational December day to about 80 kWh during a sunny June day.

Other power conversion subsystem equipment, including vacuum and toluene feed pumps, monitored by the control module electrical meter, require an estimated 3 kW of power. Thus, the power conversion subsystem needs about 20 kW of power to support its operation. Original estimates of solar plant performance estimated power conversion subsystem electrical energy output to be 174 kW with 24 kW of that amount being required to drive subsystem equipment. Apportioning commonly metered energy use to power conversion subsystem operation would make actual usage nearly equal the predicted quantity.

The electrical meters monitoring control module and air compressor energy use measured energy use in support of both solar collector and power conversion subsystem operation. Control module energy use ranged from about 10 kWh per day in winter to nearly 50 kWh on a sunny summer day, Figure 10-4. Air compressor energy use was reduced by operational control adjustments in Autumn 1981. Thereafter, air compressor energy use ranged from an average of 11 kWh per day in winter to 16 kWh per day in summer when operating hours are greatest, Figure 10-6.

Control building environmental control and electrical outlets required about 4 kWh per day in winter. Average daily energy consumption increased to about 50 kWh per day in July, Figure 10-7. Some energy usage was unmonitored, principally outdoor night lights and transformer losses. The natural gas boiler and Caloria^{TM} make-up pump were used infrequently. It is believed that the unmonitored energy usage was small.

SUMMARY

The parasitic energy usage study has quantified the primary plant energy requirements and indicated areas of potential conservation. As a result, energy usage by the air compressors and for control building environmental control has been reduced substantially during the past year, as compared with the previous year.

Energy use by collector and power conversion subsystems was found to meet expectations. Power conversion equipment required over 20 kW of power. The collector subsystem used an average of 39 to 59 kWh of energy per day for oil circulation and tracking. The requirement varied with amount of equipment operation.

Thus, on a winter day when the power conversion subsystem operated about one hour, it used about 20 kWh of parasitic energy while the collector subsystem pump and tracking motors used about 40 kWh. On a sunny summer day, the power conversion subsystem used about 120 kWh in 6 hours of operation and the collector subsystem required about half as much, 60 kWh. Other plant requirements increased total parasitic energy use by 30 to 100 kWh per day.

Since the base energy usage by the solar plant is substantial, increased power conversion subsystem operation would increase the ratio of net to gross electrical energy production. Thus it appears that increasing the collector field size would result in a higher ratio of net to gross energy producton.

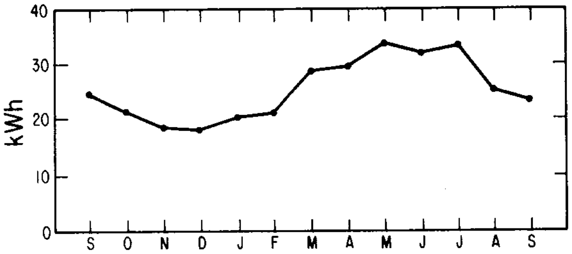


Figure 10-1. Average Daily Energy Usage by the Collector Field Pump. Sept. 1981-Sept. 1982.

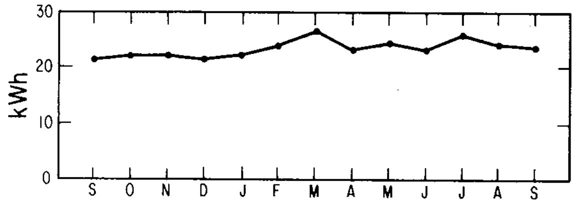


Figure 10-2. Average Daily Energy Usage by Collector Tracking Motors. Sept. 1981-Sept. 1982.

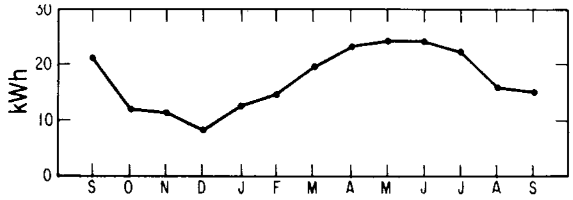


Figure 10-3. Average Daily Energy Usage by the Vaporizer Pump. Sept. 1981-Sept. 1982.

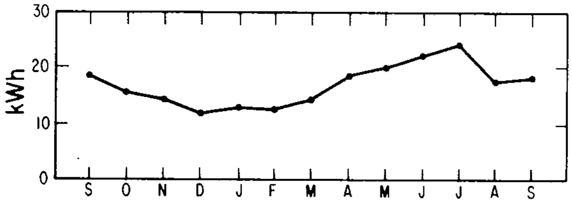


Figure 10-4. Average Daily Energy Usage by the Control Module. Sept. 1981-Sept. 1982.

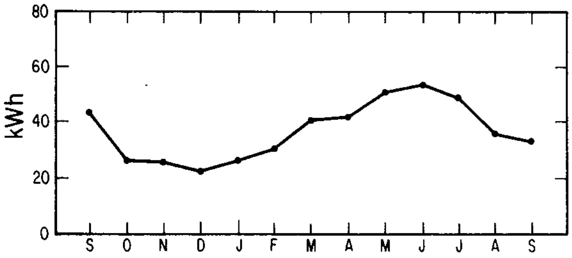


Figure 10-5. Average Daily Energy Usage by the Cooling Tower. Sept. 1981-Sept. 1982.

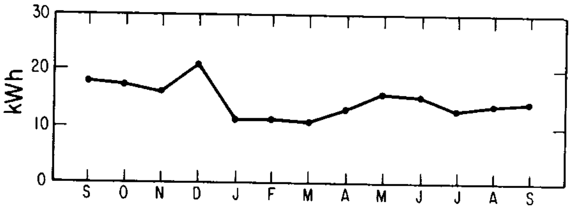


Figure 10-6. Average Daily Energy Usage by Air Compressors. Sept. 1981-Sept. 1982.

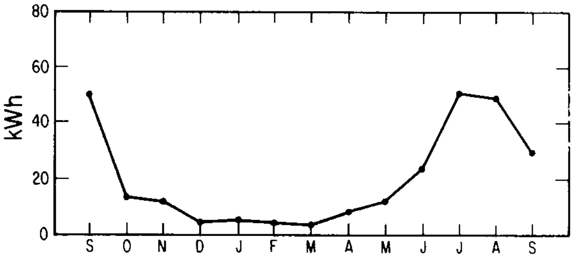


Figure 10-7. Average Daily Energy Usage by the Control Building Air Conditioner/Heater. Sept. 1981-Sept. 1982.

Table 10-2. Parasitic Energy Usage:
September 1981

	ENERGY CONSUMPTION IN KWH							OPERATED HOURS		
Day	Field Pump	Tracking Motors	Control Module	Vaporizer Pump	Cooling Tower	Air Comp.	AC/HEAT	Collectors	Boiler	Generator
1	24	22	70	16	34	13	43	10.6		3.3
2	24	21	63	16	34	16	39	10.6		3.2
3	25	21	81	20	43	16	61	8.9		4.2
4	26	22	78	19	51	18	70	10.1		4.1
5	20	11	20	0	0	13	55	5.0		---
6	27	20	89	26	39	18	58	8.0		4.8
7	24	21	80	22	45	16	51	10.1		4.4
8	27	23	83	22	43	21	50	10.2		4.2
9	29	22	86	23	47	18	59	10.1		5.0
10	21	24	23	0	0	17	51	7.0		---
11	29	21	111	33	65	20	58	10.1		6.1
12	21	25	26	0	0	19	47	9.2		---
13	24	24	98	29	56	19	45	9.9		5.6
14	25	15	82	21	45	16	53	10.0		4.4
15	25	24	75	19	39	20	55	9.0		3.7
16	24	21	71	17	27	17	63	9.0		3.5
17	25	21	75	19	39	18	62	10.0		3.7
18	20	23	69	14	31	20	52	9.9		2.9
19	27	32	58	13	26	18	55	9.9		2.5
20	11	11	68	16	34	17	36	9.8		3.1
21	13	14	23	0	0	14	53	----		---
22	16	22	20	0	0	13	43	1.5		---
23	20	25	24	0	0	17	38	4.5		---
24	42	23	102	29	62	18	51	9.7	2.5	5.8
25	31	21	93	25	52	18	30	9.8		5.1
26	28	21	86	24	48	18	50	9.7		4.7
27	36	21	83	23	47	17	43	8.5		4.4
28	34	22	83	23	45	19	68	9.5		4.3
29	26	20	55	12	26	16	47	8.0		2.4
30	15	19	0	0	0	17	11	----		---
31										
AVG	24.8	21.0	85.8	20.9	43.0	17.3	49.9			

Table 10-3. Parasitic Energy Usage:
October 1981

	ENERGY CONSUMPTION IN KWH							OPERATED HOURS		
Day	Field Pump	Tracking Motors	Control Module	Vaporizer Pump	Cooling Tower	Air Comp.	AC/HEAT	Collectors	Boiler	Generator
1	16	23	45	--	--	14	21	6.0		---
2	19	23	60	14	29	16	21	7.0		2.6
3	34	22	75	19	39	16	4	9.3		3.9
4	16	19	78	20	44	16	3	9.3		4.2
5	40	21	90	26	53	15	10	9.2	1.2	5.1
6	27	22	75	19	41	17	30	9.2		3.7
7	22	22	70	15	34	19	36	9.1		3.2
8	27	31	79	20	42	19	32	9.1		3.9
9	25	12	68	18	37	15	21	9.1		3.7
10	25	23	71	16	35	27	17	9.5		3.2
11	17	20	21	--	--	6	18	8.7		---
12	23	21	70	16	35	19	16	8.9		3.1
13	20	22	25	---	1	17	11	8.9		---
14	24	23	106	30	62	20	3	9.0		5.9
15	19	30	21	--	--	14	3	9.0		---
16	23	13	82	21	43	20	3	8.8		4.1
17	20	20	64	15	32	16	3	8.9		2.9
18	21	22	61	13	30	17	3	8.7		2.6
19	20	20	59	13	27	16	5	9.0		2.5
20	22	22	56	13	28	14	4	8.8		2.5
21	20	23	21	--	1	14	3	8.5		---
22	22	24	58	13	28	15	20	8.8		3.5
23	29	33	77	16	34	22	24	8.6		2.1
24	10	10	37	11	19	8	1	7.5		1.9
25	21	22	57	12	29	15	3	8.8		2.5
26	21	22	58	22	29	16	13	8.5		2.7
27	19	10	30	--	2	16	17	7.0		---
28	20	33	21	--	--	14	26	1.0		---
29	21	21	41	3	14	14	20	8.0		1.0
30	19	22	47	11	24	16	15	8.0		2.2
31	19	20	65	12	27	19	16	8.5		2.7
AVG	21.9	21.6	57.6	12.3	26.4	16.2	13.6			

Table 10-4. Parasitic Energy Usage:
November 1981

Day	ENERGY CONSUMPTION IN KWH							OPERATED HOURS		
	Field Pump	Tracking Motors	Control Module	Vaporizer Pump	Cooling Tower	Air Comp.	AC/HEAT	Collectors	Boiler	Generator
1	18	20	35	3	0	14	19	8.5		---
2	29	21	63	11	37	20	20	8.5		2.0
3	9	21	18	0	0	11	19	8.5		---
4	25	22	19	0	0	12	7	8.5		---
5	28	22	17	0	0	11	14	7.0		---
6	18	23	27	8	15	10	21	7.0		1.2
7	18	23	117	28	63	16	14	6.1		4.2
8	18	24	3	0	1	16	18	6.6		---
9	18	20	47	9	20	15	15	8.2		2.0
10	17	18	26	5	25	13	14	8.2		2.0
11	29	25	73	17	19	17	16	8.0		1.5
12	8	21	46	9	19	15	15	8.1		1.6
13	17	21	48	8	20	14	14	5.8		1.6
14	16	20	38	4	10	15	14	4.5		0.8
15	29	13	41	6	17	16	15	7.5		1.4
16	8	31	63	11	23	16	15	8.2		1.4
17	17	21	13	0	1	16	14	4.5		---
18	18	21	58	13	27	17	25	8.2		2.5
19	17	22	24	0	0	17	1	1.0		---
20	18	21	50	8	18	19	5	8.5		1.5
21	NA	NA	NA	NA	NA	NA	NA	4.5		---
22	NA	NA	NA	NA	NA	NA	NA	---		---
23	NA	NA	NA	NA	NA	NA	NA	8.2		1.8
24	20	20	60	24	29	18	13	8.0		2.7
25	18	24	46	8	19	14	3	3.5	1.9	1.4
26	17	20	20	0	0	13	5	3.0		---
27	17	25	31	0	0	14	3	---		---
28	16	26	8	0	0	11	3	6.0		---
29	13	14	12	0	0	17	4	---		---
30	24	29	7	9	22	23	13	7.9		1.6
31										
AVG	18.4	21.7	77.8	11.4	26	15.3	11.7			

Table 10-5. Parasitic Energy Usage:
December, 1981

Day	ENERGY CONSUMPTION IN KWH							OPERATED HOURS		
	Field Pump	Field Motors	Control Module	Vaporizer Pump	Cooling Tower	Air Comp.	AC/HEAT	Collectors	Boiler	Generator
1	18	20	66	11	24	28	3	7.8		2.0
2	20	22	62	10	20	30	7	8.0		1.9
3	20	22	49	9	20	27	23	7.9		1.8
4	16	20	36	0	0	24	4	2.5		---
5	17	20	36	0	0	22	3	3.0		---
6	19	21	51	6	18	24	6	7.3		1.2
7	17	20	46	7	12	24	4	7.7		1.5
8	17	21	63	11	26	23	3	7.6		1.5
9	19	20	55	10	20	24	3	7.6		1.7
10	16	19	29	0	0	22	3	4.0		---
11	15	23	25	0	0	19	3	0.5		---
12	17	15	30	0	0	22	3	0		---
13	18	27	30	0	0	24	3	5.5		---
14	37	21	76	14	34	25	3	6.5	3.8	2.7
15	18	22	62	10	23	25	4	7.5		1.7
16	18	22	52	7	15	26	3	7.5		1.1
17	18	22	31	0	0	25	3	7.0		---
18	18	21	33	0	0	26	3	7.6		---
19	18	22	45	0	0	25	3	6.0		---
20	18	22	46	0	0	25	3	7.5		---
21	18	22	46	15	31	26	3	7.0		2.7
22	17	20	50	6	15	24	5	4.8		1.1
23	18	23	26	0	0	19	6	7.5		---
24	17	19	57	15	30	12	11	7.6		2.5
25	17	21	18	0	0	11	3	6.0		---
26	17	21	18	0	0	11	3	7.0		---
27	17	22	28	0	0	12	3	7.5		---
28	16	21	34	7	17	13	4	7.6		1.2
29	17	20	38	8	16	12	5	7.6		1.4
30	16	20	20	0	0	10	5	1.5		---
31	19	22	22	0	0	10	3	4.5		---
AVG	18.3	21.1	41.3	7.7	21.4	21.0	4.5			

Table 10-6. Parasitic Energy Usage:
January, 1982

	ENERGY CONSUMPTION IN KWH							OPERATED HOURS		
Day	Field Pump	Field Motors	Control Module	Vaporizer Pump	Cooling Tower	Air Comp.	AC/HEAT	Collectors	Boiler	Generator
1	0	0	5	0	0	5	3	---		---
2	24	26	28	0	0	11	4	4.0		---
3	24	26	29	0	0	11	3	3.0		---
4	24	26	15	0	0	11	3	3.0		---
5	24	26	15	0	0	11	4	5.5		---
6	23	26	53	12	28	12	3	2.0	4.7	2.4
7	27	25	20	0	0	13	3	7.0		---
8	27	25	65	13	32	13	4	7.0		2.2
9	10	20	15	0	0	13	3	4.0		---
10	11	20	15	0	0	13	3	4.0		---
11	11	21	21	0	0	13	4	7.1		---
12	47	26	17	0	0	11	3	2.0		---
13	18	21	52	10	26	12	3	7.6		1.7
14	36	20	58	14	31	12	9	8.1	3.1	2.7
15	19	32	48	11	22	12	15	8.1		1.9
16	19	12	54	9	24	13	17	7.8		1.7
17	17	23	22	0	0	12	12	6.0		---
18	18	23	52	14	29	11	11	7.0		2.4
19	14	16	18	0	0	11	3	---		---
20	20	21	48	9	22	12	7	8.1		1.8
21	13	24	17	0	0	10	3	2.0		---
22	32	24	60	12	29	14	9	7.5	2.1	2.2
23	21	22	20	0	0	12	3	8.1		---
24	21	22	20	0	0	12	4	8.1		---
25	21	20	80	23	49	12	3	8.3		4.2
26	21	20	75	17	37	11	3	8.3		3.3
27	10	21	37	11	22	10	4	8.4		2.0
28	28	9	46	11	24	21	3	0.5	3.3	1.8
29	10	34	19	0	0	11	3	3.7		---
30	29	12	53	12	28	12	4	8.4		2.3
31	19	27	40	0	0	11	7	6.0		---
AVG	20.4	21.7	35.7	12.7	26.9	11.5	5.2			

Table 10-7. Parasitic Energy Usage: February 1982

	ENERGY CONSUMPTION IN KWH							OPERATED HOURS		
Day	Field Pump	Tracking Motors	Control Module	Vaporizer Pump	Cooling Tower	Air Comp.	AC/HEAT	Collectors	Boiler	Generator
1	18	26	50	16	33	12	7	8.5		3.0
2	25	21	59	14	30	14	7	8.6		2.7
3	22	22	44	11	25	14	9	8.5		2.1
4	20	25	47	10	21	12	6	7.0		1.8
5	29	30	20	0	0	14	5	5.0		---
6	0	5	21	0	0	5	5	---		---
7	29	30	20	0	0	15	6	6.0		---
8	8	15	45	7	21	14	5	0.5		1.1
9	29	22	60	16	33	13	4	7.0	3.1	3.0
10	20	25	18	0	0	11	4	1.5		---
11	15	28	17	0	0	10	2	3.8		---
12	20	23	55	12	27	12	4	6.0		2.2
13	22	22	20	0	0	11	3	8.4		---
14	22	22	20	0	0	11	3	7.5		---
15	22	22	97	31	66	11	3	8.2		5.6
16	23	25	56	13	29	10	3	8.3		2.7
17	24	24	57	14	30	12	3	8.9		2.7
18	14	20	22	0	0	10	5	0.5		---
19	21	23	50	12	29	11	3	8.9		2.1
20	26	26	72	18	41	13	4	9.0		3.6
21	20	20	21	0	0	10	3	8.0		---
22	20	21	65	18	40	10	2	8.6		3.4
23	24	26	51	12	26	10	3	4.0	2.0	2.2
24	9	18	17	0	0	10	4	---		---
25	19	30	17	0	0	10	3	4.0		---
26	22	23	70	16	39	12	5	9.0		3.2
27	26	31	20	0	0	10	3	6.5		---
28	27	31	20	0	0	10	3	9.1		---
AVG	20.9	23.5	40.4	14.7	30.6	11.4	4.2			

Table 10-8. Parasitic Energy Usage:
March 1982

Day	ENERGY CONSUMPTION IN KWH							OPERATED HOURS		
	Field Pump	Tracking Motors	Control Module	Vaporizer Pump	Cooling Tower	Air Comp.	AC/HEAT	Collectors	Boiler	Generator
1	0	5	74	24	52	10	4	---		4.6
2	27	30	20	0	0	11	3	6.5		---
3	27	25	76	22	44	12	3	4.3		4.0
4	26	33	63	17	35	10	4	9.0		3.3
5	39	15	70	18	40	12	3	8.6		3.6
6	21	27	83	24	50	13	3	9.5		4.5
7	21	23	20	0	0	10	4	9.0		---
8	21	23	61	17	35	11	3	5.0		3.1
9	23	30	54	12	38	11	3	7.0		2.4
10	31	19	55	13	29	11	3	6.5	2.1	2.6
11	0	18	16	0	0	9	4	---		---
12	0	20	17	0	0	11	4	---		---
13	28	27	18	0	0	11	4	3.0		---
14	29	27	17	0	0	11	3	3.5		---
15	28	27	37	5	13	11	4	3.5		0.6
16	25	27	41	8	18	11	3	5.5		1.5
17	21	23	49	11	24	11	3	6.0		2.1
18	16	34	19	0	0	12	3	1.0		---
19	24	24	54	11	25	13	10	6.0		2.0
20	35	27	20	0	0	13	3	6.9		---
21	50	25	20	0	0	13	7	10.0		---
22	50	24	147	57	124	13	7	10.0		11.7
23	33	23	113	24	51	13	4	10.0		5.0
24	27	23	55	13	30	11	3	8.5		2.5
25	23	21	43	11	21	10	3	5.5	0.9	2.3
26	14	21	24	0	0	11	3	1.0		---
27	42	30	85	24	54	14	4	10.3		4.4
28	35	20	20	0	0	9	4	5.5		---
29	24	24	107	36	73	12	3	9.5		6.7
30	29	22	37	7	14	11	3	7.5		3.9
31	38	23	110	34	70	13	3	8.2		4.0
AVG	28.9	26.5	52.4	19.4	41.5	11.3	3.8			

Table 10-9. Parasitic Energy Usage:
April, 1982

	ENERGY CONSUMPTION IN KWH							OPERATED HOURS		
Day	Field Pump	Tracking Motors	Control Module	Vaporizer Pump	Cooling Tower	Air Comp.	AC/HEAT	Collectors	Boiler	Generator
1	29	24	54	14	30	10	3	4.5		3.3
2	61	23	93	29	57	14	4	10.2		6.3
3	25	21	39	8	8	9	2	8.0		2.7
4	39	25	20	0	0	11	4	10.3		---
5	40	20	148	51	113	13	3	8.5	2.0	9.5
6	20	25	62	15	33	12	3	0.8		1.3
7	33	22	70	19	40	12	3	10.0		5.3
8	21	23	83	24	49	14	3	8.5		4.4
9	18	22	38	7	15	12	3	0.7		---
10	24	21	29	5	10	9	3	10.0		3.8
11	45	43	100	28	58	16	17	9.5		3.3
12	23	22	57	13	27	15	8	5.0		1.5
13	21	20	20	0	0	15	8	4.5		---
14	23	18	100	32	68	8	9	10.1		6.4
15	33	23	80	21	47	13	14	8.0		5.2
16	41	24	75	20	42	14	15	10.6		4.8
17	23	24	86	23	51	15	16	11.2		5.1
18	30	23	20	0	0	14	14	11.0		---
19	29	20	140	45	93	13	14	10.0		8.7
20	31	22	102	31	66	13	14	10.5		5.1
21	28	23	85	24	50	15	3	11.0		5.5
22	29	23	97	58	59	15	3	11.0		4.1
23	28	22	77	11	45	13	4	11.0		4.8
24	25	20	75	16	45	13	3	11.0		4.7
25	25	21	75	16	45	14	2	11.0		4.7
26	29	37	89	33	47	18	4	10.0		2.3
27	25	14	54	12	26	14	3	9.8		3.8
28	29	22	93	26	54	15	26	10.1		4.6
29	25	24	65	14	35	15	5	8.0		3.5
30	28	21	91	29	53	15	22	11.0		4.5
AVG	29.7	23.1	85.3	23.2	42.2	13.3	8.2			

Table 10-10. Parasitic Energy Usage:
May, 1982

	ENERGY CONSUMPTION IN KWH							OPERATED HOURS		
Day	Field Pump	Tracking Motors	Control Module	Vaporizer Pump	Cooling Tower	Air Comp.	AC/HEAT	Collectors	Boiler	Generator
1	22	40	37	0	11	17	3	3.0		---
2	27	26	78	23	45	14	17	9.9		4.2
3	30	20	77	20	45	13	3	8.4		4.2
4	25	28	45	12	18	15	3	5.0		2.3
5	19	35	31	0	8	14	3	3.5		---
6	47	13	98	29	59	17	3	11.2		7.7
7	40	22	97	29	59	15	8	11.2		6.5
8	35	23	68	17	36	15	3	11.2		5.0
9	30	26	106	31	64	17	3	11.2		4.2
10	28	21	108	32	68	17	3	9.0		4.4
11	34	25	89	23	51	17	3	10.0		5.2
12	32	25	88	23	50	17	4	8.2		3.7
13	30	22	76	20	42	15	5	11.2	0.6	5.7
14	31	23	68	17	36	16	12	11.2		4.7
15	27	24	63	15	33	15	28	11.3		4.3
16	34	26	118	35	71	20	15	11.5		4.9
17	27	18	98	26	60	15	22	11.5		5.1
18	38	22	99	29	60	15	20	11.0	2.0	4.9
19	36	22	84	22	49	16	24	11.6		6.4
20	44	23	100	27	60	16	9	12.0		6.7
21	43	23	100	28	61	17	9	11.8		5.8
22	38	23	121	35	77	15	8	11.7		6.8
23	38	21	121	35	77	16	15	11.8		6.8
24	39	24	108	32	69	17	22	11.9		6.1
25	34	22	99	28	61	15	19	12.0		6.1
26	32	24	88	24	51	16	31	11.6		4.4
27	26	28	74	20	41	15	4	11.4		4.1
28	44	25	88	22	48	18	12	11.3		2.1
29	18	16	50	10	29	9	15	11.5		2.5
30	85	36	33	1	5	16	10	6.5		---
31	11	16	16	0	0	20	6	----		---
AVG	33.7	23.9	81.5	23.8	51.5	15.8	11.0			

Table 10-11. Parasitic Energy Usage:
June, 1982

	ENERGY CONSUMPTION IN KWH							OPERATED HOURS		
Day	Field Pump	Tracking Motors	Control Module	Vaporizer Pump	Cooling Tower	Air Comp.	AC/HEAT	Collectors	Boiler	Generator
1	19	26	115	30	67	9	19	2.9		6.3
2	32	21	110	29	64	19	17	12.1		6.0
3	33	21	97	25	57	15	9	12.0		5.3
4	33	24	64	17	37	18	17	7.0		3.5
5	24	22	57	15	33	14	12	7.5		3.1
6	29	26	56	12	27	19	26	11.9		2.5
7	25	19	80	23	52	12	15	11.9		4.9
8	35	22	112	29	65	16	28	12.0		6.1
9	35	23	113	30	66	15	10	12.1		6.2
10	34	23	97	25	57	17	19	12.2		5.3
11	37	23	102	27	60	16	19	12.4		5.6
12	28	20	121	32	70	15	21	12.1		6.6
13	31	23	90	23	52	26	22	12.1		4.9
14	44	29	108	28	63	12	37	12.1		5.9
15	29	18	64	17	37	11	18	12.0		3.5
16	20	26	59	15	34	17	34	8.0		3.2
17	27	23	69	18	41	14	30	9.9		3.8
18	37	22	97	25	57	16	33	11.2		5.3
19	31	21	91	24	53	15	28	10.4		5.0
20	36	22	112	29	65	18	38	11.7		6.1
21	29	26	46	12	27	14	32	4.5	2.1	2.5
22	38	27	113	30	66	22	41	10.7		6.2
23	51	22	113	30	66	15	39	11.7		6.2
24	52	23	108	28	63	15	47	11.7		5.9
25	30	22	97	25	57	14	32	11.8		5.3
26	27	22	113	30	66	11	27	11.8		6.2
27	26	19	119	31	64	11	24	11.8		6.5
28	41	24	99	26	58	16	52	11.0		5.4
29	27	27	53	14	31	14	75	6.0		2.9
30	24	28	59	15	34	13	46	8.0		3.2
AVG	32.1	23.1	90.9	23.8	53.0	15.3	23.1			

Table 10-12. Parasitic Energy Usage:
July, 1982

Day	ENERGY CONSUMPTION IN KWH							OPERATED HOURS		
	Field Pump	Tracking Motors	Control Module	Vaporizer Pump	Cooling Tower	Air Comp.	AC/HEAT	Collectors	Boiler	Generator
1	40	32	94	24	53	14	64	11.6		4.8
2	41	32	104	26	59	14	48	11.6		5.3
3	41	32	100	25	56	11	28	11.7		5.1
4	40	32	65	16	36	13	39	11.7		3.3
5	29	22	41	10	23	16	53	8.0		2.1
6	13	--	63	16	35	20	33	----	3.6	3.2
7	23	18	53	13	30	13	34	6.5		2.7
8	42	32	141	36	80	14	44	11.7		7.2
9	41	32	133	37	82	12	49	11.7		7.4
10	43	32	135	34	76	13	41	11.9		6.9
11	41	32	147	37	83	15	27	11.9		7.5
12	42	32	133	34	75	15	71	11.8		6.8
13	39	29	120	30	67	13	71	10.8		6.1
14	40	32	118	30	66	13	74	11.8		6.0
15	27	20	47	12	27	13	65	7.5		2.4
16	25	19	40	2	25	14	59	7.0		0.1
17	--	--	12	--	--	12	45	---		---
18	--	--	12	--	--	12	45	---		---
19	14	11	12	--	--	12	45	3.9		---
20	19	15	78	23	50	12	45	5.4		5.0
21	39	30	90	26	52	13	69	11.0		5.2
22	42	32	98	25	50	12	60	11.8		5.0
23	41	32	61	15	29	14	56	11.9		3.1
24	35	27	84	21	43	13	47	9.8		4.3
25	27	20	71	18	40	15	48	7.5		3.6
26	23	17	33	8	19	15	60	6.4		1.7
27	39	30	125	35	77	16	55	11.0		7.0
28	38	29	88	22	50	17	59	10.5		4.5
29	13	10	7	--	--	7	47	3.5		---
30	21	16	55	14	31	16	47	6.0		2.8
31	18	14	45	11	25	17	47	5.0		2.3
AVG	33.4	25.4	88.2	22.4	49.7	13.7	50.8			

Table 10-13. Parasitic Energy Usage:
August, 1982

Day	ENERGY CONSUMPTION IN KWH							OPERATED HOURS		
	Field Pump	Tracking Motors	Control Module	Vaporizer Pump	Cooling Tower	Air Comp.	AC/HEAT	Collectors	Boiler	Generator
1	23	25	48	11	21	15	48	4.5		2.1
2	19	26	41	--	--	13	44	2.0		---
3	41	21	65	27	57	15	55	10.4		5.0
4	19	21	86	26	56	14	69	10.9		4.9
5	24	26	58	--	--	15	60	2.5		---
6	22	23	30	10	20	15	53	6.6		1.8
7	32	28	105	24	61	17	58	10.7		4.1
8	20	18	20	--	--	12	55	5.1		---
9	24	20	74	22	44	12	55	11.2		5.5
10	26	23	64	14	32	15	72	9.5		3.7
11	23	21	74	19	41	14	60	7.0	0.1	2.4
12	24	25	55	10	26	15	29	4.0	1.4	1.3
13	22	23	56	11	27	14	30	10.0		3.7
14	29	22	75	20	43	14	45	11.7		4.8
15	25	23	83	21	48	15	48	5.6		2.2
16	27	19	75	19	41	14	38	9.0		4.2
17	26	24	63	13	32	15	51	8.0		3.6
18	25	26	62	14	32	14	46	6.0		2.3
19	28	23	69	17	37	15	74	10.0		4.1
20	27	22	86	22	49	14	64	9.5		4.0
21	21	22	42	12	27	13	54	7.0		2.8
22	27	22	68	12	28	14	46	9.0		2.9
23	23	27	81	14	35	16	60	5.0		2.3
24	21	24	40	11	22	15	31	4.0		1.7
25	27	29	74	18	42	15	26	11.1		4.7
26	29	24	95	26	56	15	34	9.7		4.0
27	29	22	73	18	41	14	38	9.0		4.5
28	25	27	60	13	27	15	40	8.0		2.4
29	23	22	52	11	27	13	35	9.5		3.0
30	23	26	68	16	36	15	46	7.5		2.6
31	26	22	78	20	45	15	49	9.8		4.4
AVG	25.2	23.7	69.7	16.2	36.3	14.4	48.8			

Table 10-14. Parasitic Energy Usage:
September, 1982

Day	ENERGY CONSUMPTION IN KWH							OPERATED HOURS		
	Field Pump	Tracking Motors	Control Module	Vaporizer Pump	Cooling Tower	Air Comp.	AC/HEAT	Collectors	Boiler	Generator
1	26	22	72	21	46	13	49	10.7		4.4
2	35	21	81	17	39	14	40	10.8		4.2
3	16	25	70	18	38	15	60	6.1		2.7
4	23	22	61	13	31	14	51	9.8		3.4
5	27	24	69	16	35	16	49	8.8		3.4
6	22	23	75	20	43	14	44	10.9		3.8
7	22	25	69	15	37	15	58	5.1		1.0
8	19	20	59	12	28	15	18	2.0	2.8	2.3
9	25	24	55	21	47	15	31	12.0		4.3
10	16	37	47	0	0	13	15	1.5		0
11	23	23	51	6	20	19	7	5.0		1.8
12	32	29	53	10	22	16	12	11.5		4.5
13	23	20	100	27	62	15	5	10.1		4.3
14	29	22	98	26	58	16	13	10.1		4.7
15	27	31	92	17	40	15	20	10.1		4.7
16	26	24	69	22	51	15	22	7.0		2.3
17	0	0	27	1	2	14	7	0		---
18	25	25	69	15	34	18	21	10.0		3.7
19	25	23	87	21	51	14	39	10.0		4.1
20	23	19	79	20	45	15	40	10.0		4.1
21	28	21	71	18	39	14	21	9.9		3.8
22	29	22	78	20	44	14	45	9.9		3.7
23	21	20	54	11	27	13	26	9.4		3.7
24	24	23	85	23	49	16	41	10.0		3.5
25	19	23	31	3	11	12	24	8.2		2.2
26	29	30	20	0	0	12	10	9.8		0
27	10	20	74	18	39	17	24	3.0		3.7
28	20	22	71	17	38	15	15	9.8		2.9
29	20	22	79	18	44	16	26	9.8		2.6
30	20	22	41	7	15	14	36	9.3		2.7
AVG	23.4	23.3	66.2	15.1	34.5	14.9	28.97			

11. Incidents

Three incidents which occurred during the last year and a half of plant operation were cause for special concern or attention. These were delamination of collector reflective film, collector loop overheating and a flexhose Caloria^{TM} fire.

FEK Delamination

Collector subsystem Coilzak^{TM} reflective panels were replaced with aluminized acrylic (FEK-244) laminated aluminum panels in Spring 1981. The change was made because the reflectivity of clean Coilzak^{TM} was less than 60 percent after 1 year of service.

Two major FEK-244 delamination incidents occurred since installation. Initial delamination appeared after a rainstorm accompanied by heavy winds in July 1981. Ten to fifteen percent of the panels were affected, but the delaminated area on each affected panel was small. Forty two of the most damaged panels were replaced.

Delamination occurred as tunnel separations of FEK from aluminum backing sheets or within FEK film layers, Figure 11-1. Tunnel separations were initiated at collector edges where the FEK film had been trimmed. Tunnels continued to grow until meeting another FEK edge.

A few new tunnel separations were initiated during the following year and some older tunnels continued to grow. Various methods for preventing and halting tunneling were evaluated, including edge taping. These methods seemed to be beneficial for only a short period of time, perhaps for a few months.

A second major delamination incident occurred after deliberate washing by gentle rainfall in July 1982. Next morning, tunnel delamination appearing similar to that of previous occurrences was discovered to have affected nearly 10 percent of the panels. About half of the newly affected panels previously had not experienced delamination. Edges of affected panels again were sealed or edge taped to limit delamination.

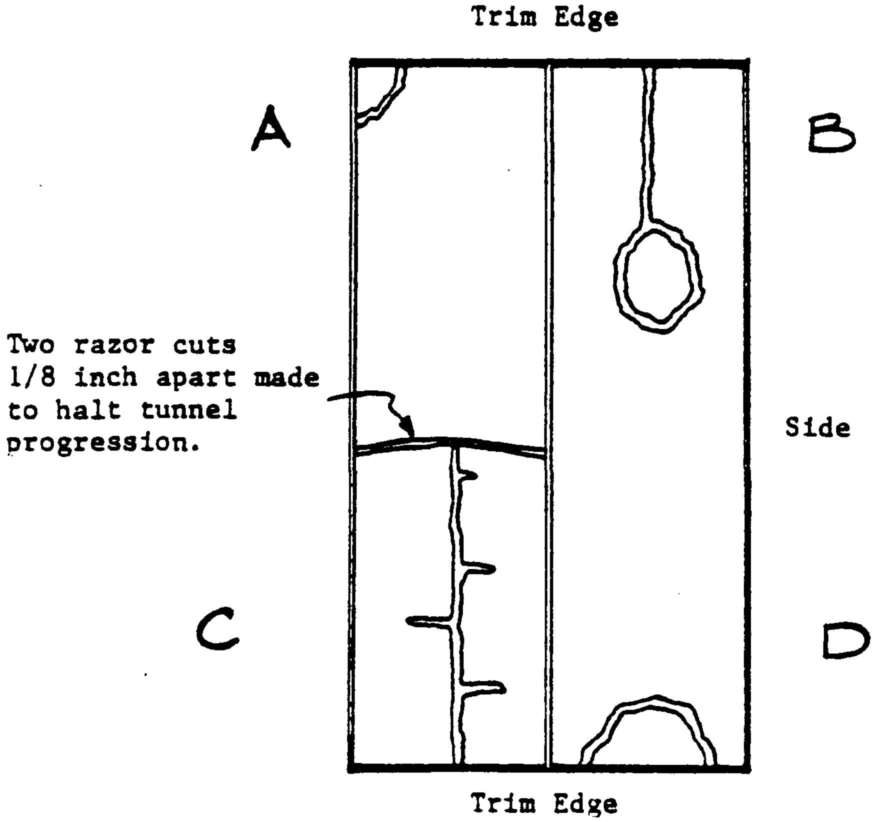


Figure 11-1. FEK-244 Reflective Film Delamination Patterns.

Each reflective panel was laminated with 2 strips of FEK-244 and edges were trimmed. This figure shows four observed delamination patterns. Tunnels are about 1/8-1/4 inch wide. It is expected that all tunnels observed in area "C" would progress until reaching an FEK side or edge. Delamination continued from razor cuts after about one year's service. Tunnels also have been observed to widen somewhat.

Collector No-Flow Overheating

One flexhose ruptured in August 1981, probably due to operator error. The failure was discovered upon operator investigation after noting smoke emanating from the field. One collector loop had been kept inoperative to permit early morning maintenance. The loop was returned to service with the manual flow control valve closed. Collectors began tracking even though Caloria^{TM} flow was restricted or nonexistent. After about an hour of service, one flexhose ruptured. Pressure buildup due to no-flow overheating of trapped Caloria^{TM} was the probable cause of the failure. Collectors did not desteer as expected in an overtemperature situation. Sensors located between collector groups apparently did not sense the temperature rise.

The flexhose was replaced and the collector loop returned to service next day. No other detrimental effects of the incident were observed until June 1982. From June to October 1982, six additional flexhoses in the affected collector loop began leaking Caloria^{TM}. Leaks began as and were limited to seepage or oozing of Caloria^{TM} from a small single crack in the flexhoses. Leaks were indicated by a small amount of smoke emanating from oil soaked flexhose insulation.

Flexhose Leakage and Fire

Two flexhoses located in other flow loops also developed leaks of the oozing or slow leakage type. One leak was detected after noticing a small amount of emanating smoke. The other leak, in June 1982, led to a fire.

The fire was noticed by the operator, who was performing PCM maintenance tasks, and extinguished with a single fire extinguisher. The fire was confined to

Caloria^{TM} soaked insulation surrounding the flexhose. The fire apparently was initiated spontaneously in hot, Caloria soaked insulation or from contact of the insulation cover with the exposed flexhose.

This was the second fire at the Coolidge plant. The first, in February 1980, occurred in the shroud area of the collector field pump. Caloria leaking from the pump seal pooled in the shroud area and apparently auto-ignited. The fire was discovered and extinguished by the operator.

These two incidents led to routine, careful leak inspections and immediate maintenance efforts to halt leakage.

12. Equipment Problems and Solutions

The Coolidge solar power plant was operated on a daily basis from startup in October 1979 to closeout in November 1982. The amounts of collector and power conversion subsystem operation lost in 1981-82 due to tests and equipment problems are listed in Tables 12-1 and 12-2.

Three PCM problems prevented PCM operation for more than one successive day. In November 1981, the PCM was inoperative for 3 days awaiting procurement of a toluene pump seal. Because seal failure occurred in November when thermal energy collection was reduced, little PCM operation was lost. A relay in the generator-utility connection jammed on May 30 and could not be repaired until the next working day, June 1, preventing PCM operation for two days. Failure of a gasket in the vaporizer on Friday, July 16 prevented PCM operation for 4 days. The gasket could not be obtained until Monday the 19th.

Collector subsystem equipment problems prevented operation for part of the day on 4 occasions. On two occasions, the high wind speed/ambient temperature lockout relay failed to reset automatically. The plant operator reset the relay permitting plant startup upon arrival to inspect plant operation or monitor PCM startup. On the other two occasions, collectors were kept inoperative to permit pump motor repair.

A collector or PCM problem did impact an operation of the other subsystem. Naturally when energy was not collected the PCM could not operate. Additionally, on two occasions, PCM equipment problems resulted in terminating operation of the col-

Table 12-1. Amount of lost collector operation in 1981-82

Date	Inoperative Hours	Reason
Sept. 21, 1981	9	Pressure washing for performance tests
Jan. 3, 1982	2	Wind/temp. lockout relay req'd manual reset
March 30, 1982	3	Collector pump motor SCR relay repair
April 1, 1982	4	Collector pump motor SCR relay repair
May 30-June 1, 1982	25	PCM inoperative - thermal storage full
July 17-19, 1982	19	PCM inoperative - thermal storage full
Aug. 8, 1982	6	Wind/temp. relay req'd manual reset

Table 12-2. Amount of PCM operation lost in 1981-82

Date	Hours of Operation Missed	Reason
Sept. 21, 1981	3	Collector test preparations
Nov. 3-5, 1981	4	Toluene pump seal procured and replaced
May 30-31, 1982	12	Generator-utility connection relay malfunction
July 16-19, 1982	7	Vaporizer toluene gasket replacement
Aug. 8, 1982	4	Collectors inoperative - no heat

lector subsystem when the thermal energy storage tank was filled with hot Caloria^{TM}.

A number of other equipment problems reduced plant energy performance, affected operation for short periods of time or stopped operation of only a small part of the plant (for example, one collector group). The principal equipment problems encountered during the year and their solutions, or needs for solutions, are summarized in the following paragraphs.

Collector Subsystem

Reflective Panels

The original Coilzak^{TM} reflective panels were replaced with aluminized acrylic (FEK-244) laminated aluminum panels in Spring 1981. Tunnel separations of FEK film occured, principally in two incidents. These are described in Chapter 11. Reflectivity of sample panels was measured periodically; results are listed in Chapter 9.

Tracking Units

The original collector tracking system required considerable attention to assure proper operation. Malfunctions included failure to track and tracking off-sun. Malfunctions were attributed to moisture, thermal stress and electronic component failures. Redesigned sensors and control boards were installed during the last half of 1981. Modifications included changes in sensor cases to minimize moisture intrusion and changes in photodiode encapsulation to reduce thermal stressing.

Isolated incidences of erratic tracking occured infrequently with the new tracking systems. Moisture collected in four sensor cases in separate occurences, requiring opening and drying of the cases. Relays in three of the new tracker control boards required replacement. An unsecured sensor cable caught and tore loose in a July 1982 wind storm. A few other instances of erratic tracking caused by changing insolation levels required manual resetting of proper tracking operation. On one cloudy but bright day, the collectors wandered in search of the sun and stowed until manually unstowed. One day in June, collectors did not unstow until the operator tapped on the low air pressure sensors. Toward the end of the year, seven collector groups tended to lose the sun at low insolation levels.

Collector Drive Motors

Electric motor failures in 1979-80 resulted in institution of a program whereby all motors were returned to the manufacturer for inspection, and , if required, maintenance or repair. Six motors were exchanged at a time, so the program wasn't completed until February 1982. There have been few problems with motors sent to the manufacturer and returned to service again. Two motors were replaced due to noisy, slow operation in 1982. A capacitor was replaced in another motor. At year's end, two additional motor were operating noisily and hesitantly.

Flexible Hoses

One flexible hose (flexhose) ruptured in August 1981, apparently due to collector loop overheating. Several other flexhoses in that loop and two flexhoses in other collector loops began leaking in Summer 1982. One of the leaks resulted in a fire. Flexhose leakage incidents are described in more detail in Chapter 11.

The top portion of flexhose covers has deteriorated on all hoses located at the north ends of collector groups due to sunlight reflection. Covers also failed on some hoses located at south ends of groups. A number of the covers severed or became detached from collector attachment points permitting cover and insulation to drop down and expose several inches of the flexhose. The result is unsightly, and heat loss is greater due to reduced flexhose insulation.

Sun shields to prevent reflection of concentrated sunlight onto flexhose covers were installed on the north end of the collector group in Fall 1981. A new style flexhose assembly also was installed on one group for evaluation. It performed well after being painted with high temperature aluminum paint to reflect sunlight spilling over the sun shield.

All flexhose-to-receiver tube connection areas have unsightly sags. Relative motion of the receiver tube caused an increasingly larger inside diameter in the surrounding foam glass insulation, allowing the insulation cover to sag. The new style flexhose apparently eliminates this problem.

Receiver Tubes

The discoloration and apparent deterioration of black chrome receiver tube coatings that appeared during the first 6 months of operation seems to have stabilized. The deterioration is substantial in the two highest temperature groups, moderate in the two central groups, and slight in the two lowest temperature groups of collectors within each collector loop.

Receiver Glass Covers

Inadequate end sealing of collector receiver tube glass covers permitted dust intrusion, particularly into tubes at the ends of collector groups. There, sunlight reflection from covers is apparent. Installation of a modified receiver tube insulation cover that abuts the end of the glass cover tube has minimized dust intrusion in a trial conducted on one collector group. The new type flexhose with its modified receiver tube connection also may lessen dirt intrusion.

Caloria^{TM} Pumps

Caloria^{TM} leakage from the shaft seal area of the collector subsystem pump was minimized by seal replacement and installation of a system to purge the seal area with carbon dioxide (CO_2) gas during operation in 1980. However, leakage from the vaporizer Caloria^{TM} pump continued to be substantial. The seal assembly was changed and adjusted, and CO_2 purging was used. However, apparently because hotter oil is being pumped, leakage was a continuing problem. Thus in 1981, a closed system was installed to catch and store oil leaking past the shaft seal of the vaporizer Caloria^{TM} pump.

Collector pump motor brushes required replacement twice during the year. The SCR motor controller also caused the electrical input circuit breaker to trip at high flow in March 1982. The controller was inspected and cleaned and operated satisfactorily thereafter.

Flow Diversion Valve

The collector manifold valve directing Caloria^{TM} to recirculate or go to storage stuck in the recirculation position in November 1982. The valve was programmed to automatically switch from recirculation mode to send oil to storage when the collector outlet oil temperature reached 246°C (475°F). Manual valve switching was required after the failure which apparently was caused by a control module malfunction.

Storage Tank

Caloria^{TM} leakage from flanged manhole covers on the side of the Caloria^{TM} thermal energy tank was sufficient to contaminate local insulation and yield a dirty tank appearance below the covers. In December 1980, the flanged covers were retightened. Since that time, only the lower, larger of the covers has exhibited significant leakage.

A high level signal from the condensate tank shut down the collector subsystem in January 1982. The control module was found to have malfunctioned. Only about 8 liters of condensate were obtained during the year.

Power Conversion Subsystem

Vaporizer

Vaporizer toluene leakage required retightening of flange bolts on three separate occasions. In July, a piece of gasket was blown out from one flanged pipe connection. Gasket replacement required removal of a 6 meter long heat exchange tube bundle. It was found that pipe supports interferred with tube bundle removal. Gasket procurement and installation caused the plant to be inoperative for most of 4 days. Caloria^{TM} leakage from a drain cap also was halted by installation of a new gasket.

The toluene used by the PCM was accidentally contaminated with Caloria^{TM} in early 1980. The Caloria^{TM} was removed from the vaporizer by staged distillation in Summer 1980. Some of the material apparently remained in the system and was removed in periodic draining of the vaporizer in succeeding months. About 80L of dark liquid was removed in two draining operations during this past year.

Caloria^{TM} Flow Controller

The vaporizer Caloria^{TM} flow control valve required maintenance on two occasions. In March, an air leak in the line to the pneumatic controller was halted. In July, the controller was adjusted to steady the control of flow, which had been somewhat erratic and variable.

Cooling Tower

A bolt broke in September, permitting a fan blade to strike the shroud. The bolt was replaced.

The hard water was treated to prevent mineral buildup on cooler tubes. In addition, "Lime-away" was used effectively to remove scale on one occasion.

The valve controlling rate of water treatment chemical disbursement and the cooling tower float valve each became stuck or clogged during the year and had to be cleaned and reset.

The water supply line froze and broke overnight in December 1981.

Regenerator

A capped vent pipe began leaking toluene. The cap was re-sealed and tightened, stopping the leaking.

Vacuum Pump

Vacuum pump packing and seal required replacement to obtain and maintain sufficient vacuum in September 1981.

Toluene Pump

The toluene boost pump seal was replaced twice during the year, in November 1981 and again in July 1982. In both cases, the pump had begun providing inadequate pressure for turbine lubrication, resulting in PCM shutdowns. The seal also was replaced twice during the previous year of operation. In late July, the boost pump drive motor failed and was replaced.

Turbine Gearbox Lubrication

Turbine gearbox overtemperature signals resulted in PCM shutdown on 3 occasions. The temperature sensor was replaced. Overfilling of the oil in the gearbox and inserting an overrestrictive oil filter also resulted in overtemperature conditions during the year.

Turbine Bearing Lubrication

Turbine lubricant underpressure signals also caused PCM shutdown on 3 occasions. The boost pump seal was replaced after 2 of the incidents; the lubricant filter was changed after the other underpressure shutdown. A check valve also was installed to prevent air from entering the top of the backup lubrication cylinders. This eliminated underpressure shutdowns from occurring immediately following startup.

Turbine-Generator Coupling

Sundstrand engineers felt vibrational forces transmitted from the turbine to the generator might reduce component life. This judgment was based primarily on manufacturer (Sundstrand) experiences at other installations. Thus, new turbine-to-gearbox and gearbox-to-generator couplings were procured. The new turbine-to-gearbox coupling was installed in February. Vibration of auxiliary equipment was substantially reduced during subsequent turbine operation. The sound level and pitch emitted during turbine operation also were altered by the coupling change.

The gearbox-to-generator coupling was found to be very difficult to remove and was not replaced. A key was found to have sheared and then wedged itself between shaft and coupling housing.

Generator-Utility Interconnection

Operator activation of generator synchronization and utility connection controls originally was required during PCM startup and occasionally during its operation. Installation of equipment to automatically balance voltage among the three phases produced by the generator in Summer 1981 eliminated the need for operator intervention. However, the automatic voltage balancing equipment stopped operating in April 1982. Thereafter, operator actions occasionally were required to maintain phase voltage balance.

After a PCM shutdown caused by a low generator power signal, the relay connecting the generator with the utility grid would not automatically reset itself. Outside technician assistance was required to reset the relay. This problem never reoccured.

Automation

Power conversion subsystem start-up originally required monitoring and frequently required operator intervention. Thus, a number of start-up function controls were reprogrammed to facilitate automatic operation in Summer 1981. The reprogramming, in conjunction with sealing of vacuum leaks, installation of phase voltage balancing equipment, changes in Caloria™ flow control, and installation of a new vaporizer level sensor, resulted in achieving the capability for automatic operation in August 1981.

Until phase voltage balancing equipment stopped operating in Spring 1982, the PCM started up and operated automatically when operated on a daily basis. When PCM operation was omitted for a day or more, operator assistance with startup usually was required. Assistance was required because input conditions were somewhat different, for example temperatures and vacuum level probably were reduced after an extended inoperative period. The PCM operated automatically on the last 42 days of PCM operation at the end of the year, except for required phase voltage balancing assistance.

Other Equipment

Compressors

The air compressors are outdoors; overnight freezing of water in the dryer delayed startup on one winter morning. The plastic bowl on the air filter was broken during a storm in December. The water bleed-off valve repeatedly stuck in the open position, so was replaced with a valve which functioned reliably. The larger of the two compresors began showing signs of wear during the year and was not operated during the last few months.

Backup Generator

The backup gasoline powered generator was started manually and operated for one half to one hour on a weekly basis to assure automatic operation after a utility outage. The engine failed to start on five occasions; three times during maintenance startups and twice after utility power outages. Those outages occurred during operation in January and early April and there was no apparent collector overheating. Routine maintenance actions, such as cleaning and adjusting distributor points, were needed before the engine would start on each of these occasions.

Pyrheliometer

The pyrheliometer motor failed in September 1981. A new motor was installed. Moisture was removed from the unit twice - in May and June.

Anemometer

The anemometer stopped operating on one occasion. It was cleaned and functioned satisfactorily thereafter.

Flowmeters

The toluene flowmeter sensor/transducer failed during the year and was not repaired. The meter was used only for detailed PCM performance evaluation.

Magnetic Tape Recorder

The tape drive malfunctioned in October 1981. Factory repair required 4 months during which a substitute rental unit was used to record data. The tape drive again failed in October 1982. This was the fifth time that the magnetic tape recorder required repair in three years of plant operation. Data gaps and discrepancies were found when magnetic tapes were removed following tape drive failures. These caused substantial data recovery problems and resulted in some data losses.

Summary

Equipment changes made during the first two years of plant operation increased equipment reliability, improved plant performance, and reduced operator requirements. Collector subsystem changes included lamination of reflective panels with aluminized acrylic film (FEK-244) and procurement of tracker systems of a new design. In the power conversion subsystem, the vaporizer level sensor was replaced, vacuum leakage was stopped and controls were reprogrammed to improve performance and permit automatic operation.

Equipment problems prevented operation on only a few days during the past year. The equipment problems - a toluene pump seal, the generator relay, a vaporizer gasket, the Caloria pump controller - were resolved by plant operators with telephonic assistance from the manufacturers and use of local repair services. Third year operation did result in some new equipment problems, e.g. flow diversion valve control failure, flexhose leakage. These may have been among the first of the "lifetime" type of problems discovered by daily operation for three years.

13. Operating Requirements

Personnel

The Coolidge Solar Irrigation Facility operated on a daily basis throughout the year. During the first two years of plant operation, one or more individuals were in attendance durng all operating hours. These individuals performed operational, repair and maintenance tasks, recorded data and incidents of interest, explained plant operation to visitors and made plant equipment improvements.

The equipment improvements made possible fully automatic operation of the solar facility. Thus during the third year of plant operation described in this report, the facility was operated by one full-time technician with some student assistance. Plant operation was not attended full time, but operator attendance was mandated during PCM startup as a safety precaution. The operator also made a daily inspection of equipment condition and operational supply status and recorded information of interest.

During the past year, the plant operated automatically on routine incident-free days. The collector subsystem operated completely automatically every day except for the few occasions when equipment malfunctions necessitated repair efforts. The PCM also operated automatically when operated every successive day. However when lack of thermal energy prevented operation for a day or more, operator control actions often were required to effect a start-up of PCM operation. These actions usually involved varying the preprogrammed warm-up sequence and reestablishing adequate vacuum.

Therefore, plant operational tasks required an average of only about one hour per day of operator time. The tasks were: monitoring and, if necessary, assisting with PCM start-up, inspecting equipment for changes in condition, checking supply status and replenishing supplies as required, and recording data.

Supplies

Operational supplies included cooling tower water and water treatment chemicals, carbon dioxide to purge Caloria^{TM} pump seal areas, and nitrogen to blanket Caloria^{TM} in the energy storage tank. Toluene was required to replace that lost due to leakage. Electrical energy required to operate plant equipment and condition the control building environment was charged against plant electricity production.

Operational supplies cost about $240 per month, Table 13-1. Cooling tower water was purchased from the municipality. Water and water treatment chemicals each cost about $60 per month, together totalling over 50 percent of the operational supply cost. Carbon dioxide and nitrogen gas cost about $60 per month, largely for the carbon dioxide. Replacement toluene cost $50 per month. Gasoline was used by the backup gasoline-powered electrical generator during occasional utility outage and weekly maintenance operation.

Use of less costly water, elimination of the need for carbon dioxide gas purging of pump seals and decreased toluene loss could reduce operational supply costs substantially. It is estimated that the cost of operational supplies for the Coolidge facility could be reduced to $100-150 per month with implementation of these changes.

Table 13-1. Monthly operational supply cost.

OPERATIONAL SUPPLIES	
Cooling tower water	60
Water treatment chemicals	65
Toluene	50
Nitrogen	2
Carbon dioxide	60
Gasoline	3
TOTAL	$240/mo

14. Maintenance Requirements

Personnel

Maintenance activities included cleaning, lubrication and adjustment efforts required to keep plant equipment in operational condition, help maximize plant energy production, and maintain good site appearance. Maintenance required an average of about 3 hours per day or 15 hours per week, Table 14-1.

Nearly 2/3 of the maintenance effort, or 10 hours per week, was devoted to the collector subsystem. Perhaps half of the collector subsystem maintenance effort was spent washing collectors and maintaining site appearance. Collectors were washed by rainfall when possible and on a quarterly basis by pressure washer. Pressure washing of the collector field required about 4 man-days effort. Weed control was the principal task required to maintain site appearance.

The remaining collector maintenance time was used to inspect equipment and check collector alignment, lubricate equipment, and perform troubleshooting missions. Most troubleshooting efforts involved determination of the cause of a control malfunction and repair or replacement of the identified component. An example problem was the failure to correctly track the sun by a collector group. The problem was caused, at various times, by control relay and motor failures and sun sensor malfunctions. Another problem, caused by a failure in the pump motor controller, was initially indicated by abnormal Caloria^{TM} flow rate readings.

Most of the rest of the solar facility maintenance effort, about an hour a day, was devoted to the power conversion subsystem. The cooling tower required a substantial portion of this time. Cooling tower water was tested periodically and treatment chemical addition adjusted as required. Dirt had to be removed from the tank and scale from the cooling tubes 3-4 times a year. PCM lubrication and filter servicing required a small amount of operator time.

The remaining PCM mainteance time was occupied by troubleshooting efforts. Fluid leakage made ncessary replacement of the toluene pump seal, adjustment of a pneumatic control valve and replacement of a gasket in the vaporizer heat exchange unit during the past year. Other troubleshooting efforts involved the control system. For example, high turbine bearing temperature readings caused automatic PCM shutdown. A malfunctioning temperature sensor and inadequate oil pressure caused this problem.

Air compressors, control building and other equipment common to both collector and power conversion subsystem operation also required some maintenance. This effort was included in the quantification of collector and PCM maintenance activities.

Supplies

Maintenance supplies included lubricants and filters, fuses and lamps, cleansing products, pesticides, and office supplies, Table 14-2. Lubricants were required for collector drive gearboxes and the PCM gearbox; filters were replaced in the PCM, air compressor and data logger. A number of facility control system fuses, relays and lamps required replacement. Toluene boost pump and vaporizer gaskets also were replaced. Herbicides were used to control weeds in the collector field, insecticides to kill insects in the control building. Cleansing products were needed to wash collectors and maintain control building appearance. Office supplies were used to record data.

In addition to the supplies, some maintenance service also was purchased. Electric motor rebuilding and welding services were included in the repair services accounting summarized in Table 14-1. Maintenance supplies and services cost an estimated $260 in 1981-82. It is believed that increased equipment reliability could reduce this cost to less than $200 per month.

Table 14-1. Monthly personnel maintenance effort (hours)

Month	Collector	Power Conversion	Total
September	37	13	50
October	34	8	42
November	51	22	73
December	68	11	79
January	35	16	51
February	43	38	81
March	53	23	76
April	46	19	65
May	11	14	25
June	48	28	76
July	26	104	130
August	27	13	40
September	34	12	46
Average	39	25	64

Table 14-2. Monthly maintenance supply cost.

MAINTENANCE SUPPLIES & SERVICES	
Lubricants & Filters	25
Fire Protection	25
Replacement Parts & Repair Services	200
Office Supplies	10
TOTAL	$260/mo

15. Project Termination

The Coolidge solar power plant was operated for over three years. During that time, subsystem energy performance, equipment reliability and plant operating and maintenance requirements were determined for the solar facility. A number of equipment modifications were made to improve performance and evaluate alternative designs. The changes included replacing reflective panels to improve collector performance, replacing collector tracker systems and vaporizer level sensor to obtain more reliable operation, removing the buffer tank and collector loop flow control valves to evaluate operation of a simpler system and adjusting and changing controls to permit fully automatic operation. The effect of these changes then was evaluated during subsequent operation and testing. Operational experiences and performance data were reported to manufacturers on a monthly basis and summarized in annual reports.

The plant was operational at the time of project termination; continued operation would have obtained additional information of interest to researchers, designers and manufacturers. The additional information could have included discovery of new equipment problems and solutions and a better indication of equipment lifetimes. Some equipment experienced their first problem during the last months of plant operation (for example, the collector flow diversion valve controller) while other equipment had not yet been fully tested (for example, most of the new generation collector tracking systems were installed during the past year). Energy performance changes with age and use could have been monitored with periodic tests. A better indication of operating and maintenance costs also could have been obtained through continued solar facility operation. The plant operated completely automatically for 42 days at the end of the year.

However, operation of Coolidge solar facility is not cost effective. Annual operating and maintenance costs were higher than the return from energy sales. This was expected due to the configuration of the experimental facility - the collector field was undersized relative to the energy storage and power conversion subsystems. Therefore since research support ended, the operational evaluation project was terminated at the end of the third year of solar plant operation.

The Coolidge solar power pant became the property of Dalton Cole, Jr., owner of the farm on which the plant is located, on October 1, 1982. The University of Arizona then decommissioned the plant for Mr. Cole. The mothballing process consisted of cooling Caloria^{TM} and isolating the storage tank, removing toluene from and venting the PCM, lubricating equipment and discontinuing most utility services.

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Attn: J. A. Hutchison

Solar Steam
Suite 400
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Southwest Research Insitute
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J. Weisiger

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Attn: J. Gahimer

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Washington, DC 20585
Attn: G. W. Braun
J. E. Greyerbiehl
C. McFarland
J. E. Rannels
M. Scheve
F. Wilkins

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San Francisco Operations Office
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W. L. Lambert

University of Houston
Houston, TX 77004
Attn: Lorin Vant-Hull

University of New Mexico
Department of Mechanical Eng.
Albuquerque, NM 87113
Attn: M. W. Wilden
W. A. Gross

Institute of Gas Technology
34245 State Street
Chicago, IL 60616

Jacobs Engineering Co.
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Pasadena, CA 91101
Attn: Meyer Schwartz

Jet Propulsion Laboratory (3)
4800 Oak Grove Drive MS 502-419
Pasadena, CA 91103
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J. Lucas
A. Marriott

LaJet Energy Co.
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Abilene, TX 79606
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University of California
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Attn: W. C. Dickinson

Los Alamos National Laboratory (2)
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Attn: J. D. Balcomb

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Attn: P. Brown
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Company (3)
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Attn. H. M. Leibowitz

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Energy Systems Group
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New York, NY 10010
Attn: J. Schrauth

Solar Energy Information Center
1536 Cole Blvd.
Golden, CO 80401
Attn: R. Ortiz

Solar Energy Research Institute (4)
1617 Cole Blvd.
Golden, CO 80401
Attn: B. L. Butler
G. Gross
B. P. Gupta
J. Thornton

Viking
3223 N. Verdugo Road
Glendale, CA 91208
Attn: G. Goranson

Winsmith
Div. of UMC Industries, Inc.
Springville, NY 14141
Attn: R. Bhise

Wyle Laboratory
7800 Governor's Drive West
Huntsville, AL 35807
Attn: R. Losey

400	R. P. Strombert
1510	D. B. Hayes
1520	T. B. Lane
1810	R. G. Kepler
1820	R. E. Whan
1830	M. J. Davis
1840	N. J. Magnani
2540	K. L. Gillespie
2541	J. P. Abbin
3161	J. E. Mitchell
3600	R. W. Hunnicutt
	Attn: K. D. Harper 3640
3700	R. R. Russell
7530	W. E. Caldes
7550	F. W. Neilson
8540	J. B. Wright
8452	A. C. Skinrood
8453	W. G. Wilson
8454	J. B. Woodard
6000	E. H. Beckner
6200	V. L. Dugan
6220	D. G. Schueler
6221	J. F. Banas
6222	J. V. Otts
6223	E. L. Burgess
6224	E. C. Boes
6225	R. H. Braasch
6227	J. A. Leonard
8214	M. A. Pound
3141	L. J. Erickson (5)
3151	W. L. Garner (3)
3154-3	C. Dalin (20) for DOE/TIC