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DOE/CS/31457-T1
(DE84013385)

SOLAR PRODUCTION OF INDUSTRIAL PROCESS STEAM AT
THE HOME CLEANING AND LAUNDRY COMPANY

Final Technical Report

June 1984

Work Performed Under Contract No. AC03-77CS31457

Jacobs Engineering Group Inc.
Pasadena, California

Technical Information Center
Office of Scientific and Technical Information
United States Department of Energy

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DOE/CS/31457-T1
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Distribution Category UC-59b

**SOLAR PRODUCTION OF
INDUSTRIAL PROCESS STEAM
AT
THE HOME CLEANING AND LAUNDRY CO.**

FINAL TECHNICAL REPORT

**Submitted to
The United States Department of Energy
Albuquerque Operations Office**

**Prepared by
Jacobs Engineering Group Inc.
251 South Lake Avenue
Pasadena, California 91101**

June 1984

MASTER

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1.0 SUMMARY

This report presents the results of the operation and performance evaluation period at the Home Laundry Solar Industrial Process Heat Project at Pasadena, California. The installation comprises 6,496 ft² (603.5 m²) of linear parabolic trough concentrating collectors supplying solar thermal energy for use in laundry and dry cleaning processes. The system flow diagram is shown in Figure 1.1. A summary of major system elements is given in Table 1.1.

The solar plant was designed and built by Jacobs Engineering Group, Inc. as part of the U.S. Department of Energy Solar Industrial Process Heat Program. The design phase began in September 1977, and an acceptance test was conducted during the week of April 12, 1982. The plant has been in operation since May 1982, with the 12-month Phase III (operational) period starting in October 1982. The objective of the operational evaluation experiment was to maximize energy delivery to the industrial participant while characterizing system performance. Data were acquired for monthly documentation of system performance, maintenance requirements, and operating costs.

Solar thermal energy is supplied to a standard tube and shell generator to produce 100-110 psig (0.69-0.75 MPa) steam at a design flow rate of 935 lb/hr (424.1 kg/hr) for use in a commercial laundry. Production of domestic hot water at 160°F is an optional operations mode. Water is circulated at a constant flow rate between the collector array and either (1) the domestic hot water tank; (2) the high temperature storage tank, or (3) the steam generator, or any combination of the collector array and the three vessels. The storage tank is used as a buffer tank for closed loop over-temperature protection, or as a storage tank for collector receiver preheating during startup or production of domestic hot water during periods of low insolation. The

system is sized to provide 20 percent of the laundry's annual steam demand.

The Data Monitoring and Control system monitors and controls the collection and delivery of solar thermal energy, and protects against equipment damage due to anomalous conditions such as high pressures or low flow. Manual override options exist for all control functions to enable flexibility of operation and to permit isolation of system components for maintenance purposes. Performance data are acquired from 13 selected sensors at two minute intervals. Data is reduced hourly and stored on magnetic disk. A total error of 6% was found in making the annual energy balance.

Table 1.1 PROJECT DESCRIPTION

Application:	Production of domestic hot water or 100-110 psig (0.69-0.75 MPa) steam for use in a commercial laundry.
Site:	34.2° N Latitude, 118.2° W Longitude
Process Schedule:	7:00 AM to 3:30 PM, Monday-Friday
Process Load Profile:	7,643 MBTU/yr (8,062 GJ/yr)
Auxiliary Fuel:	Natural Gas, boiler efficiency = 70% (assumed)
Collectors:	406 linear parabolic-trough concentrating collectors, mirror reflective surface (Del Manufacturing Company). Total Aperture Area: 6,496 ft ² (603.5 m ²) Total Gross Area: 16,025 ft ² (1,488.8 m ²) North-South orientation; East-West Tracking Packing Factor: 0.405
Fluid Type, Flow Rate:	Water at constant flow rate of 34,847 lb/hr (4.42 x 10 ⁻³ m ³ /s) in collector loop; closed loop pressurized to 240 (1.65 MPa) psig at operating temperature.
Storage:	300 gal (1.13m ³) steel tank, 2" AP jacketed fiberglass blanket insulation.

Solar system availability for the report period was 97.6%. The efficiency of the system for the year was 25.5%. A total of 286.5 MBtu of energy was delivered to process. After application of the insolation correction factor, the energy delivery total represents 76% of the annual energy delivery predicted by the SOLIPH model for steam production (SERI, 1983). The discrepancy between actual and simulated performance can be attributed to collector alignment inaccuracies, collector cleanliness, mirror degradation, and below average mean insolation for the year. Operating experience has demonstrated that steam generation at the winter solstice is not possible for the as-built configuration.

Maintenance activities required a total of 247.6 manhours. Collector subsystem maintenance accounted for 49% of the total monthly average maintenance manpower effort. The most labor intensive collector maintenance tasks were tracker troubleshooting and collector washing. Data acquisition system troubleshooting required 56.4 manhours, or 23% of all maintenance manpower required.

Operating costs required to sustain system operation include purchase of electricity to meet parasitic power demands, steam for boiler feedwater preheating, and labor and materials for performing maintenance tasks. The total operating cost for the report period was \$7,938.14. Fossil fuel savings generated by operation of the solar system totaled \$3,340.95.

Solar system operations were discontinued September 30, 1983. The sale of the property at the 432 South Arroyo Parkway job site address resulted in termination of the project. In accordance with contract provisions, the option to dismantle the facility and return the premises to their original condition was exercised by the Home Laundry management.

CLIMATIC INSTRUMENTATION

- PYROHELIOMETER
- WIND ANEMOMETER
- AMBIENT TEMPERATURE

LEGEND

- 3-WAY VALVE
- CONTROL VALVE
- PRESSURE SENSOR
- PIC PRESSURE INDICATOR CONTROL
- TEMPERATURE SENSOR
- TIC TEMPERATURE INDICATOR CONTROL
- FLOW SENSOR

Figure 1.1: SYSTEM FLOW DIAGRAM

2.0 SCOPE AND ORGANIZATION

This document covers project activities for Phase III, Operation and Performance Evaluation, for the solar energy system at the Home Cleaning and Laundry Co., Pasadena, California. Included are brief reviews of the system application, and the design and construction periods, followed by a report on operational experiences and performance evaluation. Major lessons learned and recommendations for future designs are offered in the closing sections of the report.

The contents of this document are organized in twelve sections:

SECTION 1.0: SUMMARY

SECTION 2.0: SCOPE AND ORGANIZATION

SECTION 3.0: DESCRIPTION OF SYSTEM APPLICATION. A brief introduction to the process to which solar thermal energy is applied is provided.

SECTION 4.0: DESIGN AND CONSTRUCTION. Milestones, objectives, criteria, and problems encountered during Phases I and II are briefly reviewed.

SECTION 5.0: SYSTEM DESCRIPTION. System configuration, control strategy, collector specifications, array specifications, and meteorological data are presented in this section.

SECTION 6.0: OPERATIONAL INFORMATION. System availability, maintenance requirements, and the results of the collector cleaning study are reported.

SECTION 7.0: EVALUATION SYSTEM AND TECHNIQUES. A description of the data acquisition system and instrumentation is provided, followed by an explanation of data acquisition methods.

SECTION 8.0: PERFORMANCE

SECTION 9.0: ANNUAL OPERATING BUDGET. Fossil fuel savings generated from solar operations, and operating costs are presented.

SECTION 10.0: MAJOR LESSONS LEARNED

SECTION 11.0: CONCLUSIONS

SECTION 12.0: RECOMMENDATIONS

3.0 DESCRIPTION OF SYSTEM APPLICATION

The solar energy system installed by Jacobs Engineering Group Inc. at The Home Cleaning and Laundry Company was designed to assist the laundry's existing gas-fired boiler system to furnish 100-110 psig (689.5 - 758.5 kPa) steam for laundry and dry cleaning operations. Located in Pasadena, California, The Home Laundry serves both as a laundry and dry cleaning facility, and uses steam and hot water in these processes. The existing system flow diagram is shown in Figure 3.1.

Steam from the boiler is used to heat water to 160°F (71.1°C) for wash cycles. A 1500 gallon (5,678 liter) tank, located in the boiler room, includes a heat exchanger and a steam injector for heat transfer. A circulating pump circulates the water in the domestic hot water tank to maintain a uniform temperature.

Steam is also distributed throughout the laundry for finishing the process; being used in ironers, presses, dryers, and for dry cleaning. For special applications requiring wash water in the 160°F (71.1°C) to 190°F (87.8°C) range, steam from distribution lines is injected directly into the washers.

The monthly energy demand for laundry and dry cleaning processes, and the utilization efficiency of the existing boiler steam system for a period of one year is presented in Table 3.1.

Figure 3.1: Existing Flow Diagram

TABLE 3.1
MONTHLY UTILIZATION EFFICIENCY OF BOILER STEAM SYSTEM

Month	Process Energy Required (MBtu)				Gas Energy Used (MBtu)	Utilization Efficiency
	Hot Water	Steam	Vacuum Tank	Total		
Jan.	103	504	5	612	1,062	58
Feb.	99	504	5	608	1,004	61
Mar.	117	579	6	702	1,216	58
Apr.	101	529	5	635	1,103	58
May	96	529	6	631	1,061	59
June	96	554	6	656	1,100	60
July	85	504	5	594	1,052	56
Aug.	93	554	6	653	1,061	62
Sept.	90	529	6	625	1,058	59
Oct.	93	529	6	628	897	70
Nov.	97	529	6	632	1,052	60
Dec.	109	554	6	669	1,203	56
TOTAL	1,179	6,398	68	7,645	12,869	59

From Table 3.1, it can be seen that almost 85 percent of the process energy required is for steam generation. Home Laundry uses a higher percentage of steam than most laundries because it does a greater than average amount of dry cleaning. This fact was one of the main criteria for selection of the Home Laundry as the industrial participant in the U.S. Department of Energy Solar Production of Industrial Process Steam program.

The laundry facility employs one 200 h.p. (149 KW) natural gas fired steam generating boiler system, generating steam at 100 psig (689.5 kPa). Peak energy demand occurs at 6:00 a.m., when the boiler is fired and the domestic hot water tank is heated. The laundry process schedule is from 7:00 a.m. to 3:30 p.m., Monday through Friday.

4.0 DESIGN AND CONSTRUCTION

4.1 Background

In 1977, Jacobs Engineering Co. was contracted by the Energy Research and Development Administration for the design, fabrication, testing, and evaluation of a system applying the use of solar energy for the generation and supply of industrial process low pressure steam (14.7-135 psia; 101.4-930.8 kPa). The design phase began in September, 1977, and was completed in January, 1981. Construction was completed in April, 1982, and an Acceptance Test was conducted during the week of April 12, 1982.

To ensure maximum control of the progress of the contracted works by the Government, execution of the project was accomplished in a series of three phases:

Phase I - Analysis and Design

Phase II - Fabrication and Installation, and

Phase III - Operation and Performance Evaluation.

4.2 Design Objectives

In accordance with the proposed statement of work, the objectives of Phase I, Analysis and Design, were to perform an economic analysis and comparison of the existing process and the solar energy augmented process to show potential benefits; to perform a detailed process analysis of the existing energy plant; to produce a conceptual design of the solar energy system; to prepare Environmental Impact Assessments associated with solar plant installation; to prepare a system safety analysis report; and to prepare a detailed design of the solar energy system.

The conceptual design and Environmental Impact Assessment were documented in the Conceptual Design Report, submitted to the Department of Energy (DOE) January 25, 1978. Results of the economic, process, and safety analyses, and the detailed design, plans and specifications were submitted to DOE in the 80 Percent Design Review, dated April 12, 1978.

As a retrofit system, design criteria were established to a large degree by the configuration of the existing facility. The major elements of the design were to include:

- A high temperature solar energy collecting system which will generate high temperature hot water (420°F) in a closed recirculating loop.
- A steam generator.
- A high energy buffer storage system.
- Heat transfer loops to the new and existing plant systems.
- A control system to interface and operate the solar energy system.
- Instrumentation to permit comparative evaluation of the new and existing system after construction.

The solar energy system was to be designed to optimize the usage of available solar energy, and to provide flexibility of operation. Availability of space and structural integrity of the existing building dictated the need for construction of an elevated support structure. The solar collector array area was limited by the dimensions of the support structure. The steam

generator was sized to exceed the calculated maximum heat input from the collector array for generation of 105 psig (0.72 MPa) process steam. A thermal storage tank was included in the design to enable sustained operation of the solar steam generator during short periods of cloudiness. To permit energy delivery during periods of insolation insufficient to support steam production, a heat exchanger was planned for installation in the domestic hot water tank. A compression tank was sized to permit thermal expansion of the heat transfer fluid and maintain adequate pressurization in the closed solar circulation loop. Piping, control valves, and a circulation pump were configured to ensure proper distribution of flow to maintain temperature control and optimize energy delivery. Instrumentation was included to analyze system performance and for system control.

4.3 Construction

The solar IPH system was brought on line in a two-stage construction effort, referred to as installation and startup. Each of these construction stages was executed in compliance with a Management Plan which identified and delineated techniques, implementation schedules, and lines of communication. The Management Plan in essence assured efficient execution of the technical, fiscal, and administrative requirements of the construction contract.

Management procedures included:

- o Scheduling
- o Financing
- o Reporting.

Scheduling procedures for project control included a Master Schedule and a Construction Schedule. The former schedule provided control of milestone events such as commencement and completion of major tasks. The construction schedule, in the form of a bar chart, provided detailed control of each task of the project. These schedules served as major tools for project control by the project manager and the construction superintendent.

Financial control was assured by the opening of a separate project account for construction. All receipts for the payment of the cost of construction, regardless of source, were credited and all disbursements were charged to this account. Documents supporting each entry in the account were kept intact during the period of the project, and will remain in that state until three years following final settlement.

Monthly reports, issued by the 15th calendar day of the month following the reporting period so as to secure their receipt by DOE by the 20th calendar day, included:

- o Contract Management Summary Report
- o Project Status Report
- o Cost Management Report.

In addition, hot-line reports were issued as required.

Professional services during construction were rendered in accordance with Table 4.1

TABLE 4.1

PRO-SERVICES DURING CONSTRUCTION

<u>Category of Service</u>	<u>Description of Service</u>
Design Services	<ul style="list-style-type: none"> o Submittal Approval o Plan and Specification Interpretation o Design Changes o "As Built" Drawings
Inspection	<ul style="list-style-type: none"> o Resident Inspection
Contract Administration	<ul style="list-style-type: none"> o Payment Administration o Change Order Administration
Construction Management	<ul style="list-style-type: none"> o Management Plan and Reports
Financial Administration	<ul style="list-style-type: none"> o Accounting
Operation Services	<ul style="list-style-type: none"> o Equipment Testing o System Startup and Testing o Acceptance Test o O&M Manual

A summary of the construction cost and professional services is presented graphically for each fiscal year in Figures 4.1 through 4.8.

4.3.1 Installation

Site preparation at Home Laundry consisted of construction of foundation piers for support structure columns, and erection of an elevated frame to support the collector array, piping, and walkways. The steam generator, pressure vessel, circulating pump, and associated equipment were installed in the boiler room adjacent to the existing gas fired boiler and domestic

hot water tank. An enclosure was constructed near the boiler room to house the Data Monitoring and Control unit and the computer. The final interface of the solar system with the existing steam and hot water distribution lines was accomplished during non-working hours to avoid disruption of the process schedule.

Milestone events for the installation period are shown in Table 4.2.

TABLE 4.2
MASTER SCHEDULE FOR INSTALLATION

<u>MILESTONE EVENT</u>	<u>STARTED</u>	<u>COMPLETED</u>
Procurement	November 1979	November 1980
Collector Fabrication	December 1979	November 1980
Foundations	April 1979	July 1979
Structure Erection	September 1979	November 1979
Collector Installation	October 1979	March 1980
Piping and Process Equipment Installation	September 1979	April 1980
Operational Tests	May 1980	January 1981

4.3.2 Startup

During the initial startup attempt in June, 1980, numerous design deficiencies were identified. A considerable amount of time and money was expended to remedy the problems. Milestone events during this phase of construction are shown in Table 4.3.

TABLE 4.3
MASTER SCHEDULE FOR FINAL CONSTRUCTION

<u>Milestone Event</u>	<u>Started</u>	<u>Completed</u>
Retrofit of Arrays	October 1981	January 1982
Installation and Calibration of Controls and Instrumentation	November 1981	February 1982
Upgrading of Mechanical Items	October 1981	February 1982
Check Out Data Logger	November 1981	February 1982
Check Out Computer	January 1982	February 1982
Test Equipment	February 1982	February 1982
Start-up and Test System	February 1982	March 1982
"As Built" Drawings, Reporting, O&M Manual	January 1982	March 1982
Inspection and Acceptance Test	March 1982	April 1982

The major deficiencies and the corrective measures implemented during the final construction period are presented in point form below:

- o Circulation Pump Shutdown - caused by the solar fluid temperature control valve throttling excessively. The valve was removed.
- o Overheating Collector Drive Motors - resulted because the motors were undersized for the application. The motors were replaced.

- o Flexhose Leakage - caused by improper installation and rapid corrosion of model selected. The flexhoses were replaced with an upgraded, stainless steel, teflon lined hose.
- o Erratic collector drive operation - determined to be the result of a faulty motor direction control circuit design. Three measures were required to remedy the observed problems. A pneumatic time delay relay was introduced into the circuit to provide a distinct time interval between the activation of direction switching contacts. Separate control relays for stow and unstow commands were implemented. An overtravel limit switch was provided to deactivate the drive motor at the west horizon in the event of control system failure.
- o Inaccurate tracking - resulted from an inability of the Delavan tracker circuits to be adjusted to a universal setting for all possible insolation conditions. The control set point for tracker activation was raised from 50 Btu/ft²-hr (157.6 W/m²) to 100 Btu/ft²-hr (315.2 W/m²). A 90-second time delay relay was employed to impose a wait period between motor operations, enabling the Delavan circuit to be adjusted for maximum sensitivity without excessive motor operation.
- o Inability to achieve steady state operation - resulted primarily from an intermittent boiler feed water (BFW) feed rate. A globe valve was installed to throttle the BFW flowrate to eliminate rapid

cooling of make up water in the steam generator shell.

4.3.3 Lessons Learned

The experiences during the final stages of construction at Home Laundry point out two valuable lessons. First, complexity of system design should be avoided. The complex nature of the system shielded many design errors from early detection. Second, a comprehensive, step by step test and inspection program is essential before initial start up. This is true for any mechanical system, but is even more imperative where developmental technologies are being applied.

Wherever possible, conventional methods and equipment should be used in the design of solar industrial process heat systems. Care should be taken, however, not to assume the applicability of conventional methods with developmental components or subsystems. In the case of the Home Laundry, actions required to correct design errors in most cases involved removal or disconnection of existing system components and not addition of new items.

The use of an elevated support structure complicated the construction effort and resulted in increased cost. Site conditions made the selection of a highly reputable contractor imperative for proper execution of construction.

Figure 4.1: Cumulative Pro-Service Manhours, FY 1979

Figure 4.2: Cumulative Constuction Costs, FY 1979

Figure 4.3: Cumulative Pro-Service Manhours, FY 1980

CUMULATIVE PRO-SERVICE MANHOURS

Figure 4.4: Cumulative Construction Costs, FY 1980

CUMULATIVE CONSTRUCTION COSTS

Figure 4.5: Cumulative Pro-Service Manhours, FY 1981

Figure 4.6: Cumulative Construction Costs, FY 1981

Figure 4.7: Cumulative Pro-Service Manhours, FY 1982

Figure 4.8: Cumulative Pro-Service Manhours, FY 1982

5.0 SYSTEM DESCRIPTION

5.1 General Description

The collector array consists of 406 linear, parabolic-trough, concentrating collector modules oriented in a north-south position to track the sun from east to west. A row of seven modules are connected together in a delta-T string. Four delta-T strings comprise a motor group. A motor group is positioned by a single drive assembly consisting of a 1/6 HP electric motor, a 400:1 gear reducer, a shadow band tracker, drive shafts, and worm gears (see Figure 5.1). The total collector aperture is 6,496 ft² (603.5 m²).

The collector field is divided into two sections, each capable of being isolated from flow by manual gate valves. The south section has 32 rows of modules, and the north section has 26 rows (one motor group consists of only two rows). The collector fluid flows in parallel through 58 delta-T loops. There are two delta-T (ΔT) strings in a row connected by end feed, center return fluid piping. The collectors are mounted on an elevated frame having a total area of 16,025 ft² (1,489 m²) (See Figure 5.2).

The solar array is designed as a closed-circuit loop. The heat transfer fluid flowing through the loop is water, pressurized to 240 psig (1.66 MPa) to prevent boiling. Pressurization is accomplished by using bottled nitrogen to supply a nitrogen blanket in an expansion tank. The tank is sized so that as the heat transfer fluid expands due to a rise in temperature, the fluid compresses the gas, thus raising the pressure of the system. With a drop in temperature, the reverse condition takes place. The pressure is permitted to vary from a minimum point above saturation, to a maximum point determined by the materials used in the system.

Figure 5.1: Del Continuous Tracking System.

Figure 5.2: THE HOME LAUNDRY SOLAR INDUSTRIAL PROCESS HEAT PROJECT

Water is circulated at a constant flow rate of 70 gpm ($0.004 \text{ m}^3/\text{s}$) between the collector array and either, (1) the domestic hot water tank, (2) the steam generator, or (3) the high temperature storage tank, or any combination of the collector array and the three vessels. The system is designed for a maximum outlet temperature from the collector array of 420°F (216°C).

Energy is delivered to laundry processes either as steam at 105 psig (0.73 MPa) or as domestic hot water at 160°F (71°C). The interface with the existing process is through heat exchangers. Steam is produced in a tube and shell steam generator. Solar produced steam is generated at a pressure slightly higher than the 100 psig (0.69 MPa) pressure of the fossil-fired boiler to ensure that it will flow into the plant steam header. The steam generator has a design flow rate of 935 lb/hr (424 kg/h). A heat exchanger is mounted in the laundry's existing 1,500 gal ($5,678 \text{ l}$) domestic hot water tank to allow production of domestic hot water from solar heated water.

The steam generator was manufactured by Ace-Buehler of Orange, California. It is a standard tube and shell type heat exchanger designed to boil the shell side water at approximately 340°F (171°C) at flow rates up to 935 lb/hr (421 kg/h) at 105-115 psig ($0.72 - 0.79 \text{ MPa}$). The shell is rated at 150 psig (1.03 MPa) and 400°F (204°C), and the tubes are rated at 500 psig (3.45 MPa) and 450°F (232°C).

The high temperature storage tank is a 300-gal (1.14 m^3) steel vessel rated at 500 psig (3.45 MPa) and 450°F (232°C). The compression tank is a 150-gal (0.57 m^3) steel tank with the same pressure and temperature ratings as the storage tank. Both vessels are jacketed with 2 in. (5.1 cm) of fiberglass insulation.

The main circulating pump is a horizontal, single stage, end-suction centrifugal type with a graphoil seal which does not require cooling water. The impeller is 6-1/4 in. (15.9 cm) in diameter designed for 50 gpm ($3.15 \times 10^{-3} \text{ m}^3/\text{s}$) at 150 ft (45.7 m) of head. The pump is rated for pressures up to 850 psi (5.86 MPa) and temperatures up to 450°F (232°C). The 230v, 3-phase motor drive is rated at 7-1/2 horsepower at 3600 rpm.

Presented as Figure 5.3 is the piping and instrumentation diagram of the solar energy system. Table 5.1 lists the characteristics of the system.

Solar energy is utilized by laundry processes whenever it is available during the laundry's operating schedule. The process schedule at Home Laundry is from 7:00 a.m. to 3:30 p.m., week days only. The process load profile is such that peak demand occurs between 6:00 a.m. and 8:00 a.m. when the steam distribution system is initially pressurized and the day's first wash loads are begun. Demand typically stabilizes at a reduced level until 11:30 a.m. when the machines are idled during the one-half hour lunch period. Demand resumes at noon, and continues at a steady rate until plant shutdown at 3:30 p.m. Early morning peak demand precedes the startup of the solar energy system. During the months of March through September, the solar day extends beyond plant shutdown at 3:30 p.m., and energy storage is required. When heat collection exceeds storage capacity, solar system operation is discontinued, and solar energy is not utilized.

The predicted percentage of annual energy contribution to the process by the solar energy system is 21.2 percent. Based on a five-day work week, it is estimated that the solar system could provide 1,200 MBtu (1,266 GJ).

Figure 5.3: Piping and Instrumentation Diagram

TABLE 5.1

HOME LAUNDRY SOLAR ENERGY SYSTEM CHARACTERISTICS

General

Site:	Pasadena, California; 34.2°N Latitude, 118.2°W Longitude
Application:	Production of steam at 105 psig/344°F (724kPa (gage)/173°C), 935 lb/hr (424 kg/h) max; or domestic hot water at 160°F (71.1°C).

Collector

Type:	Del Manufacturing Co. parabolic-trough, 2 ft. x 8 ft. (0.61 m x 2.44 m) aperture; pointing slope error - 1.0° and +0.5° or less; figures slope error - 0.30° and ± 0.15° or less.
Array Area:	6,496 ft ² (603.5 m ²)
Mounting:	Elevated support structure, N-S orientation, arranged in two banks
Packing Factor:	0.405
Reflective Surface:	Back-silvered sagged glass; mirror reflectivity - 0.90 minimum; mirror thickness - 0.120 in (3.05 mm)
Receiver - Insulating:	Borosilicate glass tube - 1.5 in (38 mm); outside diameter - 0.008 in. (2mm); emissivity - 0.90; transmissivity of solar flux - 0.90
Receiver - Steel tube:	Plated with black chrome over dull nickel; outside diameter - 0.75 in. (1.9 cm); wall thickness - 0.028 in. (7.1 mm); length - 96 in. (2.43 m); absorbtivity (average) - 0.95; emissivity of 600°F - 0.25; emissivity at 212°F - 0.11
Solar Tracking:	Delavan shadow band sensor, electric motor driven tracking; tracking accuracy - ±1°

Table 5.1 (continued)

Working Fluid

Type:	Pressurized water (pressurized to 240 psig (1.66 MPa (gage)))
Control:	Constant flow rate
Flow rate:	70 gpm ($4.42 \times 10^{-3} \text{ m}^3/\text{s}$)
Outlet Temperature:	420°F (216°C) maximum

System

Interface:	Tube and shell steam generator or heat exchange hot water supply tank (closed loop). Both supply to existing plant steam and hot water lines.
Process Schedule:	7:00 AM - 3:30 PM, Monday-Friday
Auxiliary Fuel:	Natural gas
Thermal Storage:	300 gal (1.14 m^3) steel tank
Design Energy Delivery:	935×10^3 Btu/hr (274 kW) max; 1.2×10^9 Btu/yr (1,266 GJ/yr) or 21.2% of annual steam and hot water requirement for process. (SOLIPH model estimate: 725×10^6 Btu/yr (765 GJ/yr))

5.2 Del Concentrator

The parabolic trough concentrators at Home Laundry were manufactured by the Del Manufacturing Co. of Oxnard, California. The modules have an aperture width of 2 ft (0.61 m) and length of 8 ft (2.44 m).

Each module is a rigid welded structure built from rectangular steel tubing and sheet steel ribs. Within this structure are attached eight sagged glass mirror segments. These segments are sagged from 0.27 in. (69 mm) thick glass sheets at high

temperature into either an inner or outer segment parabolic shape. A second surface silver coating is applied to the back of the panels and then a protective coating. The eight segments are clipped into the frame, two across the aperture and four along the length.

The focal length of the collector is 4.5 in. (114 mm) providing an f/d ratio of 0.188. The collector has a rim angle of 106.4 degrees.

The steel receiver tube has an outside diameter of 3/4 in. (19.1 mm) and is plated with black chrome over dull nickel. It is covered by 1.5 in. (35 mm) o.d. borosilicate glass tubing with 0.8 in. (2 mm) thick walls. The receiver tube is fixed and does not move or rotate with the reflector panels, which rotate about the focal line. Flex hoses are used to compensate for the linear thermal growth of the receiver.

The Del collectors were tested at Sandia National Labs, Albuquerque. Performance results were reported, in part, in SAND79-0515 dated April 1979. Data from these tests predicting noon time performance are presented in Figure 5.4.

5.3 Control Strategy

The startup of the solar thermal system occurs daily whenever sufficient sunlight exists, except on weekends. Depending on process heat requirements and weather variations, startup may occur several times during any one day. The conditions that must be met before a startup begins are:

- o Compression tank level is normal
- o Steam generator shell side pressure is less than 125 psig (0.86 MPa)

Figure 5.4: Generalized Module Performance of the Del Parabolic Trough Concentrator

- o Array outlet temperature is less than 420°F (215.5°C)
- o Solar fluid pressure is greater than 50 psig (0.34 MPa)
- o Insolation is greater than 100 Btu/hr-ft² (315.2 W/m²)

When the solar insolation exceeds 100 Btu/hr-ft² (315.2 W/m²), the pump is turned on. A minimum flow rate of 40 gpm (0.002 m³/s) must be verified within 10 seconds or the system will shut down again. Once flow through the array is verified, the collectors are then unstowed until approximately a 12 p.m. sun position is reached. At that point, a mercury switch in the Delavan tracker sensor head activates the tracking device and the collectors begin to track the sun. The trackers will then readjust the collector position at intervals of 1 to 2 minutes to maintain accurate focus.

Once the collectors come into focus the circulating fluid begins to gain heat in the receiver tubes. In the automatic operations mode, flow is established through the domestic hot water tank and the solar steam generator. Steam generation occurs only after demand for domestic hot water has been satisfied. The domestic hot water tank is then bypassed. Flow through the steam generator is permitted only when the array outlet temperature exceeds the steam generator shell side temperature by 10°F. The flow is then regulated to maintain the shell side pressure at 105-115 psig. (0.73-0.79 MPa).

The solar thermal plant has been designed to react to two off-normal conditions which may frequently occur:

- o Low steam demand
- o Low insolation

Low steam demand may occur during the laundry's lunch period, or after the laundry shuts down in the afternoon. As a result of this low steam usage, the solar fluid temperature will begin to rise. When the temperature reaches 375°F (190.5°C), flow will be modulated through the high temperature storage tank (HTST-1) to maintain an array supply feed temperature of 375°F (190.5°C). When the temperature in HTST-1 reaches about 375°F (190.5°C), flow should be fully established through the tank.

If the temperature then continues to rise, the trackers will be turned off at 400°F (204.4°C). Since the sun will not move out of focus immediately, the temperature will drift upward for a few minutes before beginning to fall. When the temperature falls below 390°F (198.9°C), the trackers will be turned back on.

If the temperature should reach 420°F (215.6°C), in spite of the above controls, an alarm will be sounded, and the system will execute an emergency shutdown.

Low insolation may occur on hazy or smoggy days, or intermittently during periods of broken clouds. If the insolation falls below 80 Btu/hr-ft² (252.2 W/m²), the trackers will be turned off to prevent searching. When the ΔT across the array falls to zero, the array bypass control valve will be repositioned to bypass the array flow to reduce heat losses. The steam generator flow will also be bypassed when the array return temperature falls below the steam generator shell temperature.

The pump will continue to run for 10 minutes after the insolation falls below 80 Btu/hr-ft² (252.2 W/m²). This provision is designed to prevent frequent starting and stopping of the pump during periods of broken clouds. If the sun should come out again at any time during the above shutdown sequence, the shutdown

will be aborted. When the insolation climbs above 100 Btu/hr-ft² (315.2 W/m²), the pump is turned on, flow through the array is re-established, and the trackers are reactivated.

Normal shutdown is initiated by low insolation level as measured by the pyrheliometer. When the pyrheliometer reads less than 80 Btu/hr-ft² (252.2 W/m²), the trackers are stopped. Ten minutes after stopping the trackers, the pump is stopped. One hour after the trackers stop, the collectors are stowed (12 a.m. sun position).

An emergency shutdown will begin if any one of the following conditions occurs:

- o Compression tank liquid level is too low or too high
- o Steam generator shell pressure is greater than 125 psig (0.86 MPa)
- o Array return temperature is above 420°F (215.6°C)
- o Solar fluid pressure is less than 50 psig (0.34 MPa)

When an emergency shutdown has been triggered, the following actions are taken:

- o All collectors are stowed
- o The pump is stopped
- o The array bypass control valve is positioned to flow through the array
- o The steam generator bypass control valve is positioned to bypass the steam generator
- o The alarm horn is turned on
- o The green "System On" panel lamp is turned off
- o The red "Alarm" panel lamp is turned on

5.4 Meteorological Data

The Home Cleaning and Laundry Co. is located in Pasadena, California, U.S.A., at 34.2°N Latitude and 118.2°W Longitude. Pasadena has a Mediterranean climate characterized by long, dry summers and mild, wet winters. No solar insolation data exists for Pasadena. Data for the City of Los Angeles has been adjusted for Pasadena and was used in the design analysis of solar energy available for collection. Meteorological data used during the design of the solar plant are shown in Tables 5.2 and 5.3, and Figure 5.5.

TABLE 5.2

CLIMATIC CONDITIONS LOS ANGELES AREA

Month	Mean Wind Speed MPH**	Mean Sky Cover Tenths**	Mean % of Sunshine*	Mean Daily Solar Radiation Langleys**
Jan	4	4.6	70	248
Feb	5	4.8	69	331
Mar	5	4.8	70	470
Apr	5	5.3	67	515
May	5	4.8	68	572
Jun	5	4.1	69	596
Jul	6	2.8	80	641
Aug	5	2.7	81	581
Sep	5	2.8	80	503
Oct	4	3.9	76	373
Nov	4	3.9	76	373
Nov	4	3.4	79	289
Dec	4	4.5	72	241
Year	5	4	73	463

* U.S. National Weather Service

** United States Department of Commerce

Figure 5.5: Direct Normal Radiation Curves

TABLE 5.3

AMBIENT AIR & COLD WATER TEMPERATURES FOR LOS ANGELES

<u>Month</u>	<u>Highest*</u>	<u>Nor. Max.*</u>	<u>Nor. Aver.*</u>	<u>Nor. Min.*</u>	<u>Lowest*</u>	<u>CW Temps**</u>
Jan	90	64	54	45	28	58
Feb	92	64	55	47	28	61
Mar	99	65	57	49	31	59
Apr	100	67	59	52	36	64
May	103	69	62	55	40	68
Jun	105	71	65	59	46	72
Jul	109	76	69	62	49	74
Aug	106	75	69	63	49	74
Sep	110	76	69	61	44	73
Oct	104	73	65	57	40	71
Nov	96	71	61	51	34	67
Dec	92	67	57	47	30	61

* United States Department of Commerce.

**Re. Uniform Solar Energy Code, Table A Page 55.

6.0 OPERATIONAL INFORMATION

Routine solar energy system operations at Home Laundry began in May 1982 when final modifications required to correct deficiencies identified during the Acceptance Test were completed. An October 1, 1982 start date for the 12-month Phase III (operational) period was authorized by the Department of Energy.

Solar system availability at the Home Laundry has been very good. Few incidents have resulted in system downtime. Utilization is limited by the process schedule.

Availability is meant to be a measure of the mechanical reliability of the solar system, that is, that portion of the time the solar energy system was available to collect energy for the process. (It does not take into account climatic conditions that might render the system unusable.) (SERI, 1980.) Specifically,

$$\text{availability (\%)} = \frac{\text{number of days solar system was not down for repairs}}{\text{total number days in the period of calculation}} \times 100$$

The status codes obtained from the monthly System Operation Summary Tables (Appendix A) are used to define system availability as

$$\text{availability (\%)} = \frac{\text{Sum of number of days with status codes 1, 3, 4, or 6}}{\text{total number of days}} \times 100$$

Utilization is an indication of the extent to which the industrial process made use of the solar system when it was available.

Utilization is defined as:

$$\text{utilization (\%)} = \frac{\text{number of days of actual solar system operation}}{\text{number of days solar system was not down for repairs}} \times 100$$

The status codes from the monthly System Operation Summary Tables can be used similarly to define utilization.

Availability and utilization were calculated on a daily basis from October 1982 until May 1983. From June until September 1983, calculation of availability and utilization was done on an hourly basis, and included consideration of partial array downtime. Availability for the report period was 97.6%, and utilization was 68.9%.

A total of 37.8 hours of system downtime were experienced during the 12-month period ending September 30, 1983. Low compression tank level, resulting primarily from excessive leakage of heat transfer fluid through the circulation pump packing, was the only recurring problem resulting in downtime. Some leakage is required to cool pump packing.

Low utilization generally can be attributed to non-utilization of the solar system during industrial plant idleness (weekends, and after 3:30 p.m.), and after saturation of process demand.

Refer to Table 6.1 for system availability and utilization figures.

TABLE 6.1

**SYSTEM AVAILABILITY AND HOURS OF OPERATION
OCTOBER 1982 THROUGH SEPTEMBER 1983**

<u>Month</u>	<u>Availability (%)</u>	<u>Utilization (%)</u>	<u>Hours of Operation</u>	<u>System Downtime (Hrs)</u>
October	100	64.5	101.4	8.0
November	100	70.0	96.7	4.0
December	100	74.0	94.9	--
January	100	67.7	122.5	--
February	100	71.4	104.3	--
March	100	74.2	127.9	--
April	96.7	69.0	117.5	8.4
May	100	67.7	187.9	6.3
June	96.8	72.2	142.5	4.2
July	95.9	59.4	177.2	6.9
August	99.7	69.2	178.8	--
September	96.5	66.9	102.0	--
ANNUAL	97.6	68.9	1,553.6	37.8

The Phase III Work Plan outlined operations strategies devised to evaluate system performance characteristics. A standard (automatic) mode and four comparative modes of operation were identified. In practice, seven modes were used. Failure of the laundry's in-line direct hot water heat exchanger in August 1982 prompted a request by Home Laundry management to dedicate the system to domestic hot water production. For this reason, system controls were modified to enable DHW production as the first priority for energy delivery under the standard operations mode. Steam production was achieved only after demand for domestic hot water was satisfied. Operation of the solar steam generator was planned at least once each month throughout the year for equipment exercise and to characterize system performance.

An effort was made to operate the system under defined operating modes. This was done to enable easier comparison of performance data between actual data and performance simulations, and between the seven

operating modes themselves. The seven operating modes typically exercised at the Home Laundry are as follows:

- o Steam only - plant operated for steam only.
- o DHW only - plant operated for DHW only.
- o Steam and HTST - plant operated for steam until 3:30 PM, then energy added to storage.
- o DHW and HTST - plant operated for DHW. Energy added to storage during low demand periods.
- o Steam and DHW - plant operated for steam until 3:30 PM, then DHW.
- o Steam/HTST/DHW - plant operated for steam until 3:30 PM, then HTST. DHW after 4:00 PM.
- o All Auto - Automatic operations. Energy delivered as steam and/or DHW as process demands. Energy added to storage during low demand periods.

To a great degree, the selection of each day's operating mode is made by the operator based on prevailing conditions such as insolation availability and process demand. Every effort is made to satisfy the two objectives of the project - to provide the industrial user with the greatest amount of energy possible, and to identify the optimum operating mode(s).

An attempt at steam generation was made December 23, a clear day. From a cold start (initial feedwater temperature at 60°F (15.5°C)), all collected energy was diverted to the steam generator. The maximum

shellside pressure achieved during the day was 75 psig (0.52 MPa) recorded at 3:00 PM, less than that required for delivery of steam to the laundry (105 psig (0.72 MPa)). It is apparent that the as-built array cannot achieve and sustain steam production around the winter solstice from a cold start.

The high temperature storage tank can be included in the loop to increase flexibility of operation. The tank was originally intended as a thermal buffer tank to enable sustained steam production during periods of scattered clouds. However, it has provided more utility as a buffer tank for closed-loop overtemperature protection during periods of low demand, or as a storage tank for receiver preheating at startup or production of domestic hot water during extended periods of cloud cover.

The increase in the length of the solar day and time change to daylight savings were two factors that resulted in an increase during April in the number of operating hours after industrial plant shutdown. After 3:30 PM, energy delivery to the domestic hot water tank took first priority, followed by energy addition to the high temperature storage tank. Typically stored energy was removed the following morning to be delivered to the hot water tank if cloudy conditions prevail, or to "bootstrap" the system at startup. Manual operations were required to remove energy from storage. Energy addition to HTST-1 was automated as a means of overtemperature protection. No automatic control function for removing heat from the tank was provided, however. A control strategy that would automatically deliver stored energy to the domestic hot water tank during periods of cloudiness, after shutdown or before morning startup is recommended.

Insolation availability May 17 was adequate to result in energy collection in excess of industrial plant demand. Once the solar steam generator was brought off-line at 3:30 PM the domestic hot water tank

was thermally charged to its capacity. As the outlet temperature from the collector array rose past the 375° (190.5°C) set point, the high temperature storage tank bypass control valve automatically modulated to the open position. At 4:22 PM the temperature of heat transfer fluid in the solar loop, including the 300 gal. (1.14m³) storage tank, exceeded 400°F (204.4°C), resulting in the commencement of the tracker disable/enable control sequence. The overtemperature control function continued until routine system autosutdown time at 5:36 PM. Similar saturation of process demand was experienced on 11 days during the months of May, June, July, and August.

6.1 Maintenance Experience

A comprehensive record of maintenance tasks performed during Phase III is presented in Table 6.2. A labor rate of \$28.00 per hour was used to compute labor costs for all maintenance activities except collector cleaning. For collector cleaning a rate of \$15.60 was used. The monthly personnel labor effort has been tabulated in Table 6.3.

Most consumable materials used during execution of maintenance tasks are entered as footnotes on Table 6.2. Other consumable materials not listed are printer paper and ribbon, and cleansers and lubricants. Only modest quantities of these supplies were required.

6.1.1 Preventive Maintenance

A preventive maintenance program is required to prevent damage to equipment from wear, weathering, and aging. Table 6.4 lists the periodic preventive maintenance tasks planned for the Home Laundry solar energy system, and the recommended time interval for each. Note that maintenance

TABLE 6.2

**HOME LAUNDRY SOLAR IPH PROJECT MAINTENANCE REVIEW
OCTOBER 1982 THROUGH SEPTEMBER 1983**

<u>Task</u>	<u>Manhours</u>	<u>Materials Cost (\$)</u>	<u>Total (\$)</u>
<u>Preventive Maintenance</u>			
o Tracker inspection and adjustment	17.7	--	495.60
o Receiver glass inspection and adjustment	10.2	--	285.60
o Collector cleaning	76.3	137.00 ^a	1,327.28
o Vent air traps	8.8	--	246.40
o Lubricant level inspection	7.2	--	201.60
o Compression tank pressure and level adjustment	20.4	20.00 ^b	591.20
o SG-1 feedwater treatment	3.5	100.00 ^c	198.00
o Pyrheliometer inspection and adjustment	15.0	--	420.00
o System safeties inspection	4.0	--	112.00
Subtotal	163.1	257.00	3877.68
<u>Corrective Maintenance</u>			
o Tracker troubleshooting	12.6	53.34 ^d	406.14
o Instrument calibration	8.0	438.00 ^e	662.00
o DAS troubleshooting	56.4	--	1,579.20
o Receiver glass replacement	6.0	18.38 ^f	186.38
o Pyrheliometer cable replacement	3.0	9.15 ^g	93.15
o Collector drive shaft repair	0.3	--	8.40
o Leak control	2.6	--	72.80
Subtotal	88.9	518.87	3,008.07
TOTAL	251.6	775.87	6,885.75

^aDeionized water regeneration tanks (2)

^bBottled nitrogen (1)

^cFeedwater treatment chemicals (est.)

^dRelays (3)

^eFactory calibration of anemometer

^fReceiver glass annulus

^gPyrheliometer cable

tasks scheduled annually were not performed due to project status at the end of the first year of operation. Consequently, manpower requirements for these tasks are not reflected in manhour totals for the year.

Preventive maintenance activities included cleaning, lubrication, and adjustment efforts required to keep the plant in operational condition and help maintain plant efficiency. Maintenance required an average of about 0.6 hour per day of personnel effort, for a total of 163.1 manhours for the 12 month period.

Collector washing is required to maintain energy collection performance. Collectors were washed monthly either by a rain rinse or manually using a pressure washer. Collector tubes were wiped bi-monthly. Tracker alignment was inspected and adjusted semi-weekly. Monthly collector subsystem maintenance activities required from 2.4 to 27.5 hours of effort with the greatest effort required during the summer months for spray washing. The average effort was 10.2 hours per month, 49 percent of the total average maintenance effort.

TABLE 6.3

MONTHLY PERSONNEL MAINTENANCE EFFORT - CORRECTIVE AND PREVENTIVE

Month	Collector Subsystem (Manhours)	Transfer and Storage Subsystem (Manhours)	Miscellaneous (Manhours)	Total (Manhours)
October	3.0	2.6	5.0	10.6
November	10.8	1.5	--	12.3
December	4.2	1.6	5.3	11.1
January	3.8	2.8	9.4	16.0
February	2.4	2.2	15.1	19.7
March	5.6	1.7	9.2	16.5
April	3.9	1.9	9.1	14.9
May	4.1	4.7	3.6	12.4
June	27.4	3.9	6.6	37.9
July	27.5	5.0	10.9	43.4
August	16.2	7.4	8.3	31.9
September	13.7	6.7	4.9	25.3
Average (man-hours/month)	10.2	3.5	7.2	21.0

The principal maintenance requirement of the transfer and storage subsystem was leakage inspection and control. Venting of non-condensable gases from system piping was performed semi-weekly. Subsystem maintenance efforts averaged 2.6 hours per month.

Steam generator make-up water was monitored routinely for buildup of precipitates. Feedwater samples obtained from the generator shell were tested approximately every 12 hours of operation. Treatment chemicals were added as required to maintain feedwater conductivity at desired levels. Manual blowdown was performed as required. Supplemental manpower for this task was provided by Home Laundry personnel.

TABLE 6.4 PREVENTIVE MAINTENANCE SCHEDULE

ITEM	Intervals				
	1-WEEK	1-MONTH	6-MONTHS	1-YEAR	2-YEARS
<u>Collector Support Assembly</u>					
o Pylon rollers inspection and lubrication				X	
o Finish inspection				X	
<u>Reflector Panel</u>					
o Reflector panel cleaning		X			
o Panel inspection		X			
o Finish inspection				X	
<u>Receiver Assembly</u>					
o Clean glass envelope		X			
o Assembly inspection	X				
o Finish inspection				X	
<u>Collector Drive Assembly</u>					
o Gearbox lubrication inspection			X		
o Replace lubricant					X
o Wear inspection				X	
o Finish inspection				X	
<u>Tracker Assembly</u>					
o Dead band inspection and adjustment		X			
o Sensor alignment	X				
o Tracker assembly inspection		X			
<u>Pipe Fittings, Valves</u>					
o Leak inspection		X			

TABLE 6.4 (continued)

ITEM	Intervals				
	1-WEEK	1-MONTH	6-MONTHS	1-YEAR	2-YEARS
<u>Flex Hose Assembly</u>					
o Hose assembly inspection		X			
o Compression fitting inspection		X			
<u>Insulation</u>					
o Metal jacketing and insulation inspection			X		
<u>Pump Lubrication</u>					
o Check lubricant level - daily					
o Replace lubricant					X
<u>Packing Inspection</u>	X				
<u>Strainer Cleaning</u>				X	
<u>Pressure Vessels</u>					
o Gasket inspection		X			
<u>Steam Generator</u>					
o Boiler heat loss inspection			X		
o BFW treatment - as required					
<u>System Flush</u>					X
<u>Miscellaneous</u>					
o DAS filter cleaning	X				
o DAS battery replacement				X	
o Nitrogen supply - as required					
o Purge high point vents	X				
o System safeties inspection			X		

The Data Monitoring and Control (DMC) system was also a maintenance concern. Observation of data readouts was made daily to ensure early detection of spurious readings possibly caused by a failing sensor. A complete instrument calibration was performed annually. Other miscellaneous maintenance tasks include pyrhelimeter alignment, draining of condensate from pneumatic system, and site cleanup. Miscellaneous maintenance required an average of 7.2 hours per month.

6.1.2 Corrective Maintenance

Corrective maintenance was required during the report period to repair or replace failed or damaged components. Tracker troubleshooting, data acquisition system (DAS) troubleshooting, and compression tank level adjustment (non-routine) were the corrective maintenance tasks requiring the greatest manpower effort. Corrective maintenance tasks required a total of 88.9 hours of effort for the year.

Tracker troubleshooting included correction of any problem associated with the Delavan shadow band tracker, the drive motor/gearbox assemblies, and associated circuitry. Typical tracker problems were caused by failure or degradation of relays, mercury switches, tracker cables, or phototransistors. Daily inspection of tracking behavior was requisite to ensure optimum performance.

Data acquisition system troubleshooting was the single most labor intensive corrective maintenance task at the Home Laundry. Interruptions in data acquisition resulted from faulty disk drives, faulty magnetic disks, voltage

fluctuations in the DAS power supply, printer failure, and a short in a printed circuit board.

Because the datalogger was used to perform control functions, system downtime resulted with frequency due to DAS failure. Matrix printer replacement, installation of a power conditioner, frequent cycling of floppy disks, and repair of disk drive read/write heads were measures taken to remedy DAS failures.

Emergency autoshutdowns due to low compression tank level were experienced on 5 occasions during May, June, and July. The autoshutdowns were determined to be the result of excessive leakage of water through the circulation pump packing. To ensure cooling and lubrication of the packing, the pump manufacturer specifies a minimum leak rate of 6 drops per minute. With the onset of higher closed loop temperatures in May, difficulty was encountered in establishing a packing gland plate compression setting that would result in a proper leak rate for all temperatures. A setting that permitted a leak rate of 6 drops per minute at startup resulted in little or no leakage when steady state steam production was achieved (closed loop temperature around 360°F). Conversely, a gland plate compression setting that would allow the correct leak rate at higher temperatures would result in excessive leakage during startup and recirculation periods, and overnight. To accommodate the leakage requirement while avoiding downtime due to compression tank low level, three steps were taken. A gland plate setting that would allow adequate leakage at higher temperatures was established. Addition of make up water to the compression tank was performed as required. Whenever possible, the compression tank was isolated from

the system after evening shutdown to avoid overnight leakage. As a result of these measures, excessive leakage at lower temperatures was tolerated, and corrective maintenance manhours were expended periodically to correct the gland plate compression setting and the compression tank level. Although the pump used at Home Laundry was capable of operating as designed under steady state conditions, the diurnal temperature extremes inherent in solar system operation resulted in unexpected difficulty by maintaining proper pump packing cooling and lubrication. Pumps that are provided with sealed, water cooled packing are recommended for future designs.

Manual control of system operation was required during performance of some corrective maintenance tasks. On October 18 and 19, system downtime was avoided by manual control while a failed pyrheliometer cable was replaced. On January 6, DAS and system autosutdowns were experienced. Manual operations were performed while a failed datalogger relay could be isolated and replaced. Buildup of condensate on the inner surface of the pyrheliometer window resulted in inaccurate insolation readings April 6. Manual system operations were required to keep the system on line while the pyrheliometer window was disassembled, dried, and resealed.

Slippage of glass annuli off their O-ring mounts was observed repeatedly during routine inspection of the collector array. Daily expansion and contraction of receiver tubes caused the receiver tubes to slowly shift position relative to the glass annuli. Over a series of days, the glass annuli shifted position until it eventually slipped off the O-ring. The occurrence was especially

prevalent at the outermost receivers from the center pylon in a collector row where thermal expansion is greatest. Once off the O-ring, glass annuli became lodged between a support assembly trunnion on one end and a desiccant chamber on the other. Contraction of the receiver upon cooling resulted in a compression fracture of the glass annuli, usually at the end of the glass tube. To prevent glass receiver annuli from breaking in this way, weekly inspection of all receiver assemblies in the collector array was required. Any glass tubes found slipped off their O-ring mounts were remounted on the O-ring. A design modification is recommended to reduce the incidence of glass breakage.

Refer to Appendix B for the Recommended Spare Parts List.

6.2 Collector Cleaning Study

The efficiency of solar reflecting materials can be expected to degrade over time as a result of environmental conditions. Previous studies of optical performance of reflector materials under different use environments have generally listed the effects of weather, industrial process, soil type and low level water sources as the primary determinants of change in performance. For a commercial/residential location such as the Home Laundry site, climate was considered to have the major effect on reflector performance. Most studies relating to the effect of climate discuss primarily the effects of rainfall and temperature. However, in a temperate, arid, urban environment such as Southern California, the actual level of particulates in the air may be a greater factor in the day to day reflectivity of the surfaces and in the rate of reflectivity loss.

As part of the Home Laundry Solar Project, measurements were taken periodically to determine changes in mirror reflectivity and collector efficiency during periods of operation. In order to determine whether percent reflectivity is affected by day-to-day variations in air quality, values for total suspended particulates (TSP), the pollutant which could directly affect reflectivity at the mirror surface itself, were obtained for the months when reflectivity measurements were taken. Collectors were cleaned periodically during the sampling program with different wash techniques used in order to determine the optimum cleaning method.

The following sections discuss the relationship between air quality and mirror reflectivity, mirror reflectivity and collector efficiency, and the various types of washing methods.

6.2.1 Changes in Reflectivity

Reflectivity measurements were taken at the Home Laundry site during the months of May, June, July, August and September, 1983. Earlier reflectivity measurements were considered invalid because of a faulty reflectometer. Mirror surfaces were cleaned once a month (on 6/11, 7/9, 8/13 and 9/24) during the sampling period.

Measurements of total suspended particulates (24-hr peak) were obtained from the South Coast Air Quality Management District for February through September, 1983. Monthly mean TSP levels for the four major sampling months are as follows: June - 135.0; July - 142.5; August - 130.2; September - 136.0.

Mean TSP levels for each period preceding a reflectivity measurement were calculated in order to determine whether the change in reflectivity between measurements was directly related to the degree of particulate pollution. These values, in addition to reflectivity values, are shown in Table 6.5. No significant correlation was found between change in percent reflectivity and preceding air quality ($r = 0.019$).

TABLE 6.5
REFLECTIVITY MEASUREMENTS AND MEAN AMBIENT TSP LEVELS

<u>Date</u>	<u>Percent Reflectivity</u>	<u>Change in Percent Reflectivity</u>	<u>Preceding Mean TSP Level</u>
5/23/83	76.9		
6/3/83	72.9	-4.0	141.4
6/10/83	69.9	-3.0	130.7
6/13/83*	83.2	+13.3	
6/17/83	81.3	-1.9	168.0
6/22/83	80.3	-1.0	143.8
7/1/83	78.0	-2.3	148.4
7/8/83	74.0	-4.0	139.3
7/11/83*	80.1	+6.1	
7/22/83	75.5	-4.6	147.8
7/29/83	70.3	-5.2	139.0
8/5/83	69.0	-1.35	184.4
8/12/83	68.9	-0.05	136.4
8/16/83*	81.2	+12.3	
8/25/83	79.7	-1.5	94.6
9/12/83	75.1	-4.6	138.4
9/24/83	69.6	-5.5	148.7
9/26/83*	81.4	+11.8	

*Collectors were cleaned immediately preceding this sampling date.

Percent reflectivity values are plotted as a function of time in Figure 6.1. After each cleaning, reflectivity increased in all cases to over 80 percent. Linear regression analysis was performed to determine the rate of reflectivity decrease with time after each cleaning. The rate of percent reflectivity loss was very similar for all four cleaning episodes. Slopes were as follows: -0.387, -0.340, -0.377 and -0.293.

The above results suggest that the levels of particulates in the urban air do not directly affect the percent reflectivity of the mirrors at any one time. It appears, rather, that reflectivity declines with time at a fairly steady rate. The ambient level of particulates may have an indirect effect on reflector performance, however, when viewed on an annual basis. Summer months in Southern California typically experience high levels of TSP in contrast to winter months when TSP values are considerably lower. This variation could likely affect the rate of reflectivity loss with a greater loss rate observed in the summer months. This would correlate with results observed in a recent study, where the degree of mirror soiling was found to be highest during times of high temperature and low rainfall (Sandia, 1984).

6.2.2 Changes in Collector Efficiency

The efficiency of the collector array is defined by:

$$N_c = \frac{\text{energy collected during time } t}{\text{incident solar energy during time } t}$$

Collector efficiency was determined for each day of operation.

Figure 6.1 CHANGE IN PERCENT REFLECTIVITY OVER TIME

* Indicates Wash Date

Collector efficiency values calculated for the months of June-September ranged from a high of 60.6 to a low of 0.0. Collector efficiency values calculated for those dates when reflectivity measurements were taken ranged from 59.8 to 23.2. A positive correlation ($p = 0.01$) exists between collector efficiency and percent reflectivity indicating that the reflectivity of the collector surface is a factor in the overall efficiency of the system. Other factors include tracking accuracy, collector alignment, energy utilization efficiency, and temporal distribution of insolation. Because of the presence of many variables, it is difficult to assert the degree of influence of any one variable as a determinant of change in collector efficiency in an uncontrolled environment.

6.2.3 Collector Wash Methods

As mentioned previously, the collectors were washed once a month. Every effort was made to utilize rain rinsing as a collector cleaning technique whenever possible. On November 12 and 15, adjustments to the collector drive motor controls were made to facilitate automatic positioning of the array in the solar noon orientation for proper drainage during a rain rinse. Judgement was required to determine the adequacy of a given precipitation event for the intended objective. Showers or downpours of short duration were not considered adequate for collector cleaning as particulates in the air would be deposited on mirror surfaces if a rain rinse was attempted. Generally, a rainstorm of at least one-half hour duration would be required, with a forecast for continued precipitation, before a rain rinse would be attempted. No valid data was available for reflectivity change as a result of rain

A high pressure spray washing system was installed at Home Laundry during the construction phase. The system used a 1-1/2 H.P. motor to drive a positive displacement pump with a output volume of 3 gallons per minute (0.68 m³/h). Nozzling at the spray wash wand was adjustable, and could be selected up to 1000 psi (6.89 MPa). A schematic diagram of the spray wash system is presented in Figure 6.2.

Pump - Landa model #PE 3700
3 gpm @ 700 psi

$Z \sim 20 \text{ ft.}$

45° ell

45° ell

$\frac{3}{4}''$

$\frac{1}{2}''$ (typical)

$\frac{3}{8}''$ Hose

D

A

B

C

59

Reflectivity measurements were taken within two or three days of cleaning. Cleaning methods were varied, as described below, in order to determine the most efficient method.

Wash 1

Date Cleaned - 6/20/83

Date Sampled - 6/22/83

Percent Reflectivity - 83.2

Change in Percent Reflectivity - 13.3

Cold water with a hardness of <5 ppm CaCO_3 was used to clean the collectors. Cleaning took place during a light drizzle when collectors would be otherwise inoperative. Gentle contact cleaning of the mirrors was performed using a chamois. Discharge pressure was 850 psig.

Wash 2

Date Cleaned - 7/9/83

Date Sampled - 7/11/83

Percent Reflectivity - 80.1

Change in Percent Reflectivity - 6.1

Wash 2 occurred under hot sunny conditions. Cold water (hardness <5 ppm) was again used. Spotting of the mirrors was observed. Contact cleaning methods and discharge pressure were the same as for Wash No. 1.

Wash 3

Date Cleaned - 8/13/83

Date Sampled - 8/16/83

Percent Reflectivity - 81.2

Change in Percent Reflectivity - 12.3

This wash used warm water at a pressure of 700 psig. Water quality was tested and reported as 10 ppm CaCO_3 . No wiping of mirrors took place. Weather conditions were smoggy, hot and partly cloudy.

Wash 4

Date Cleaned - 9/24/83

Date Sampled - 9/26/83

Percent Reflectivity - 81.4

Change in Percent Reflectivity - 11.8

Collectors were washed with deionized (DI) water. Weather was cloudy in the morning and clear in the afternoon. No contact cleaning was performed. Water pressure was set at 700 psig.

Wash Nos. 1, 3 and 4 resulted in similar percent reflectivity increases, whereas for Wash No. 2 reflectivity increased only half as much. This is attributed in part to the fact that percent reflectivity prior to washing was higher than for the other wash events (74.0 vs. 69.0). This assumes that percent reflectivity after washing reaches a maximum value, probably in the range of 81 to 84 percent. The fact that the hot sunny conditions led to

rapid drying and subsequent spotting of reflectors also is considered to have decreased wash effectiveness.

The most effective wash (Wash No. 1 where percent reflectivity increased from 69.9 to 83.2) took place during a light drizzle. It is assumed that the natural precipitation helped to loosen adhered particulates and that subsequent overcast skies allowed slow drying of the collectors.

Clean reflectivity values for all wash techniques are within a 4 percent range. Economic variables, therefore, become the determinants of wash strategy. Estimated costs of materials and labor for each washing technique are presented in Table 6.6.

TABLE 6.6
COLLECTOR WASHING EXPENSES

	<u>Materials</u>	<u>Labor^a</u>	<u>Total</u>	<u>Comments</u>
Wash No. 1	---	374.40	374.40	Contact cleaning 850 psig
Wash No. 2	---	374.40	374.40	Contact cleaning 850 psig
Wash No. 3	---	187.20	187.20	700 psig
Wash No. 4	137.00	156.00	293.00	D.I. regen. tanks; 700 psig
Rain Rinse	---	7.80	7.80	

^a A labor rate of \$15.60 per hour was used to compute labor costs.

The influence of water softeners and fuel for heating wash water on economic factors is considered negligible for the volumes of water used (£1000 gal).

Contact cleaning methods are labor intensive and do not appear to be economically justifiable. Spray wash pressure does not appear to be a major factor in wash effectiveness in this study. However, a low limit for wash pressure below which effectiveness would be reduced is believed to exist.

Performance data were analyzed to determine the extent of the increase in fossil fuel savings resulting from collector washing. Savings for a ten day period before a collector wash were compared to savings for the ten days following a wash, except in September. In September, only two days of energy delivery followed the wash date. The difference in dollars saved per MBTU delivered for ten days before and after a wash event is as follows: June = 0.18; July = 0.27; August = 0.39; and, September = 0.06. For the amounts of energy delivered during the ten days following a wash, this difference results in an increase in fossil fuel savings of \$2.80, \$8.33, \$6.51, and \$0.06 for the months of June, July, August, and September, respectively. Considering the costs of collector washing (see Table 6.6), the benefit derived from washing on a monthly period does not appear to be justified.

Although the wash data are limited, the results suggest that washing should be avoided during hot sunny periods and that the most cost-effective and efficient methods can be ranked as follows: natural precipitation events (of storm rather than drizzle intensity); light precipitation coupled with cold wash water; warm wash water; and deionized water wash.

7.0 EVALUATION SYSTEM AND TECHNIQUES

7.1 Data Acquisition System

System evaluation was performed by using a Consolidated Control Corporation mode 90 MC1-111 datalogger feeding an Industrial Systems Micro 5000 computer (see Figure 7.1).

Figure 7.1: DATA MONITORING AND CONTROL SYSTEM SCHEMATIC DIAGRAM

The datalogger was set for continuous scanning and was interrogated every two minutes to read the status of all data inputs into computer memory. The Alarm Relay Module, 70 MC2, provided output controls to the plant for shutdown if any operation exceeded safe conditions.

7.2 Scanning Information

Data acquisition software was written to obtain and reduce data according to the following schedule:

- Scanning interval - 120 seconds
- Accumulation and averaging period - 1 hour
- Data storage - 1 hour
- Evaluation Summary - daily; monthly

Reliable data reduction was possible beginning in January 1983. Routine data acquisition and reduction was performed from January 20, 1983, until September 30, 1983.

7.3 Monitoring Instrumentation

RADIATION: Eppley Model NIP Pyrheliometer mounted on an Eppley Solar Tracker Model ST1. Output is 9.03×10^{-6} volts/watt meter⁻².

Calibration: Traceable to standard self-calibrating cavity pyrheliometer.

Accuracy: $\pm 0.5\%$.

FLOW: Daniel #520 Concentric Orifice Plate with Taylor 3300T Series Electronic Differential Pressure Transmitter.

Calibration: W&T Pressure Standard.

Accuracy: $\pm 0.5\%$ of Span.

PRESSURE: Taylor 3300T Series Electronic Pressure Transmitter.

Calibration: W&T Pressure Standard.

Accuracy: $\pm 0.5\%$ of Span.

ANEMOMETER: Weather Measure Corporation Model W102-P/DC Skyvane I Sensor with Model WTB-DC/360 Wind Translator.

Calibration: Factory.

Accuracy: $\pm 1\%$ below 25 MPH
 $\pm 3\%$ above 25 MPH.

TEMPERATURE: 100 Ω Platinum, DIN Curve Alpha = .00385, mounted in CRES Thermowell.

Calibration: Temperature bath & Resistance Standard.

Accuracy: Element, 0.05°C
Overall, $\pm 0.1\%$ of Span.

PARASITIC ENERGY: Ohio Semitronics Model PC5-Series Watt Transducer

Calibration: Factory

Accuracy: $\pm 0.5\%$

The locations of measurement sensors are shown in Figure 7.2.

7.4 Data Processing Methodology

Data inputs from 13 sensors were scanned at two-minute intervals between the hours of 5:00 a.m. and 8:00 p.m., Monday through Friday. Instantaneous data readings were stored on floppy disk and displayed on a CRT. Every hour on the hour data were reduced by the master program and written on floppy disk. An option to print reduced data automatically on the matrix dot line printer as soon as it was available was typically exercised. Instantaneous data were discarded following the hourly data reduction and storage.

Hourly records of reduced data were totalized and averaged nightly by the master program to provide a daily report. The daily report was recorded on floppy disk and printed on the line printer as soon as it was produced.

Accumulated data were copied from the data disk to a backup disk on a daily basis by the solar plant operator as a precaution against inadvertent erasure of the data record.

Upon command by the operator, daily reports were compiled to generate a monthly report. This was performed after operating hours or on a weekend early in the month following the period being compiled. Data disks were never recycled; a new disk was used for each month and the data disk for the previous month was saved for data retrieval at a later date.

The error due to limitations of the data processing methodology and instrument accuracy is estimated at ± 4 percent.

Figure 7.2: SIMPLIFIED SCHEMATIC DIAGRAM WITH KEY DATA SENSOR LOCATIONS

7.5 Special Measurements

Reflectivity data were collected as part of a collector cleaning study. Measurements were obtained weekly from May 23 to September 26, 1983. Earlier measurements were considered unreliable. A portable specular reflectometer manufactured by Devices and Services Co., Dallas, Texas, and supplied by Sandia National Laboratories, Albuquerque, New Mexico was used. The mean value of measurements taken at six randomly selected locations throughout the collector array was considered representative of the reflectivity of the array. The data are presented in Section 6.2.1.

7.6 Lost Data Replacement

Data not accumulated during DAS downtime was replaced whenever possible by examining the raw data printout available from the datalogger printer, extracting pertinent data, and performing manual data reduction. Insolation and steam flow totalizers were also used as a backup record for data entries during DAS downtime. Data were entered onto the data disk for the missing period through the use of an editor feature in the master program.

Data inaccuracies resulted as a result of the limitation of the position switch used to indicate bypass valve positioning. The position switch on the high temperature storage tank flow control valve tripped when the valve was fully open. The valve was capable of modulating flow through the vessel; however, partial stroking of the valve did not result in a change in position switch contact status. Switch contact status was used to indicate whether heat was being added or removed from storage for data monitoring purposes. Manual calculation of energy transfer was required to document observed temperature changes resulting from partial flow through the storage tank.

8.0 PERFORMANCE

Data acquisition software was completed in January, with automatic DAS operation begun January 20. Performance data reports were formatted as closely as possible after the example formats presented by the Solar Energy Research Institute (SERI, 1980). Hourly performance data were compiled to produce the Clear Day Performance Tables. Daily totals and averages were assembled to produce monthly performance summaries. Monthly summaries for the period from January 20 to September 30, 1983 are shown in Table 8.1.

Table 8.1: Performance Data - January 20 to September 30, 1983

MONTH	AMB TEMP F	WIND VEL MPH	DIR INSOL MBTU	INC INSOL MBTU	ENER COLL MBTU	COLL EFF %	ENER DEL'V MBTU	PIPE LOSS MBTU	STOR LOSS MBTU	ADD STOR MBTU	REN STOR MBTU	AVE STOR F	SYS EFF %	PARA ENER MM
JAN	55.6	1.16	29.8	20.1	5.2	25.7	5.0	0.56	0.03	0.0	0.0	76.2	24.7	0.241
FEB	63.2	1.08	68.4	50.9	16.7	32.8	15.6	1.56	0.06	0.3	0.2	84.9	30.6	0.641
MAR	61.4	2.00	109.6	93.4	31.0	33.2	26.4	2.87	0.36	3.5	1.7	130.0	28.3	0.921
APR	62.9	1.72	122.2	115.4	39.3	34.1	36.2	3.27	0.31	2.0	1.3	123.0	31.4	0.968
MAY	71.7	1.06	146.8	146.0	46.6	31.9	37.4	3.77	0.55	5.8	4.6	189.7	25.6	0.958
JUN	72.2	1.07	129.8	124.3	44.6	35.9	36.2	4.20	0.72	15.6	11.4	179.6	29.1	1.139
JUL	82.3	1.27	251.3	246.6	70.6	28.6	59.4	5.87	0.62	6.3	5.2	193.6	24.1	1.234
AUG	83.5	1.10	221.7	215.8	60.4	28.0	48.3	5.84	1.01	8.5	6.3	245.0	22.4	1.295
SEP	79.9	0.94	121.3	110.7	27.9	25.2	22.0	3.48	0.62	50.9	33.9	185.7	19.9	0.875
TOT/AVE	70.3	1.63	1201	1123	342.3	30.5	286.5	31.4	4.3	94.9	64.6	156.4	25.5	8.27

Due to the necessity of using pyrheliometer output for system control, insolation was monitored only during operating hours. Blinders were mounted on the pyrheliometer platform to create a false horizon at 17° elevation above the horizon. This was required to avoid attempts at system startup before the sun's elevation was high enough to minimize row to row shading effects. Insolation data therefore are reported only for periods of system operation. Solar energy received during inoperative periods was not monitored.

An error was discovered late in the report period in the equation for incident insolation used in data reduction algorithms. The angle of incidence calculation for a horizontal surface at 0° slope was misapplied for the calculation used at Home Laundry. Data reported in the Clear Day Performance Tables (Tables 8.11 to 8.16) have been corrected using the incidence angle equation for tracking collectors mounted in a North-South orientation (Appendix C).

Corrections were not made for data reported in the Monthly Performance Summary Tables, Tables 8.2 to 8.10. Based on manual calculation of hourly data for clear day reports (Tables 8.11-8.16), values reported for incident insolation can be expected to average 24.4 percent low with a standard deviation (σ) of 3.8%. The range of error was from 31.6 percent in December to 19.9 percent in June. As a result of the erroneous equation, reported efficiency values are higher than was actually experienced. Reported collector efficiency figures are about 9.6 percent higher than corrected figures ($\sigma = 3.1\%$). System efficiency figures are about 8.1 percent high ($\sigma = 2.0\%$). Data reported in Table 8.1 were adjusted based on errors observed in calculating corrected values for the clear day data.

Energy collected was measured by monitoring the temperature differential across the collector array and the heat transfer fluid flow rate.

Energy delivery was measured by monitoring the steam flow rate from the solar steam generator and/or the temperature differential across the domestic hot water tank heat exchanger and the heat transfer fluid flow rate.

Static heat losses from piping and the high temperature storage tank were experimentally determined by monitoring fluid temperature and ambient temperature and plotting temperature decay. Operating losses

Table 8.2: Monthly Performance Summary Table, January 1983

JULIAN	DATE	AMB TEMP F	WIND VEL MPH	DIR INSOL MBTU	INC INSOL MBTU	ENER COLL MBTU	COLE EFF %	ENER DEL'V MBTU	PIPE LOSS KBTU	STOR LOSS KBTU	ADD STOR MBTU	REN STOR MBTU	AVE STOR F	SYS EFF %	PARA ENER KWH	OPER- ATIONS	MODE
20	20-JAN	57.5	0.85	11.34	5.34	1.91	35.7	1.73	170.5	5.1	0.00	0.00	85.3	32.4	62.6		DHW
21	21-JAN	50.6	0.48	0.26	0.11	0.00		0.00	49.8	6.7	0.00	0.00	83.1		12.0		DHW
24	24-JAN	53.2	1.12	0.01	0.00	0.00		0.00	6.9	5.4	0.00	0.00	73.9		11.5		DHW
25	25-JAN	60.4	0.52	8.30	4.15	1.84	44.3	1.92	142.7	2.9	0.00	0.00	74.2	46.2	57.3		DHW
26	26-JAN	59.4	1.04	5.59	2.52	0.56	22.2	0.48	65.7	3.1	0.00	0.00	73.1	19.0	38.2		DHW
27	27-JAN	52.8	2.46	0.21	0.08	0.00	0.0	0.00	29.6	5.0	0.00	0.00	72.5	0.0	15.1		DHW
28	28-JAN	55.5	1.68	4.05	1.93	0.86	44.5	0.84	90.4	4.1	0.00	0.00	71.3	43.5	44.5		DHW
TOT/AVE		55.6	1.16	29.76	14.13	5.17	36.6	4.97	556	32.3	0.00	0.00	76.2	35.2	241		

Table 8.3: Monthly Performance Summary Table, February 1983

JULIAN	DATE	AHB TEMP F	WIND VEL MPH	DIR INSOL MBTU	INC INSOL MBTU	ENER COLL MBTU	COLL EFF %	ENER DEL'V MBTU	PIPE LOSS KBTU	STOR LOSS KBTU	ADD STOR MBTU	REN STOR MBTU	AVE STOR F	SYS EFF %	PARA ENER KM	OPER- ATIONS	MODE
32	01-FEB	60.4	0.37	1.57	0.73	0.43	58.9	0.41	38.7	0.4	0.00	0.00	70.0	56.1	19.1		DHW
33	02-FEB	45.7	3.38	0.00	0.00	0.00		0.00	4.4	1.6	0.00	0.00	69.8		5.0		DHW
34	03-FEB	56.5	0.70	3.19	1.45	0.57	39.3	0.56	50.9	2.2	0.00	0.00	69.0	38.6	36.1		DHW
35	04-FEB	62.1	1.33	9.08	4.75	0.91	19.1	0.62	199.1	0.9	0.00	0.00	68.4	13.0	47.6		DHW
38	07-FEB	53.6	0.13	0.00	0.00	0.00		0.00	1.6	0.4	0.00	0.00	66.7		2.1		DHW
39	08-FEB	62.7	2.58	5.97	3.28	1.31	39.9	1.23	103.7	0.4	0.00	0.00	66.1	37.5	45.3		DHW
40	09-FEB	65.1	1.17	N.A.	N.A.	2.03	N.A.	2.18	131.3	0.1	0.00	0.00	66.0	N.A.	61.3		DHW
41	10-FEB	65.3	1.16	8.06	4.24	1.25	29.4	0.93	201.1	0.0	0.00	0.00	66.2	21.9	54.9		DHW
42	11-FEB	73.0	0.52	2.42	1.09	0.38	34.8	0.34	75.2	-0.6	0.00	0.00	66.8	31.1	33.6		DHW
45	14-FEB	70.2	1.10	4.30	2.45	1.07	43.6	1.01	100.8	0.0	0.01	0.00	71.0	41.2	29.4		DHW
46	15-FEB	70.5	1.06	5.31	2.91	1.18	40.5	1.12	106.6	0.4	0.00	0.00	74.4	38.4	48.2		DHW
47	16-FEB	67.3	1.14	9.32	5.21	2.72	52.2	2.61	145.0	1.0	0.00	0.00	74.2	50.0	63.1		DHW
48	17-FEB	72.4	0.56	8.21	5.04	1.99	39.4	1.71	104.6	0.1	0.00	0.00	73.9	33.9	42.8		DHW
49	18-FEB	70.0	1.18	0.00	0.00	0.00		0.00	1.6	0.4	0.00	0.00	73.8		7.0		DHW
52	21-FEB	76.6	1.00	6.82	4.27	2.14	50.1	2.06	133.5	3.7	0.06	0.00	98.5	48.2	53.6		DHW
53	22-FEB	65.3	0.00	0.81	0.37	0.12	32.4	0.08	4.6	0.5	0.19	0.00	145.2	21.6	7.5		DHW
54	23-FEB	61.1	1.14	0.10	0.05	0.00	0.0	0.00	5.7	14.8	0.00	0.00	177.6	0.0	8.1		DHW
55	24-FEB	54.8	1.16	2.97	1.76	0.57	32.3	0.73	103.6	22.2	0.00	0.14	127.2	41.4	54.1		DHW
56	25-FEB	53.1	1.12	0.26	0.14	0.00	0.0	0.04	44.9	7.7	0.00	0.06	93.0	28.5	20.7		DHW
59	28-FEB	58.0	0.83	0.00	0.00	0.00		0.00	0.1	0.1	0.00	0.00	79.8		1.6		DHW
TOT/AVE		63.2	1.08	68.4	37.7	16.7	44.2	15.6	1557	56.3	0.3	0.2	84.9	41.3	641.1		

Table 8.4: Monthly Performance Summary Table, March 1983

JULIAN	DATE	AMB TEMP F	WIND VEL MPH	DIR INSOL MBTU	INC INSOL MBTU	ENER COLL MBTU	COLL EFF %	ENER DEL'V MBTU	PIPE LOSS KBTU	STOR LOSS KBTU	ADD STOR MBTU	REN STOR MBTU	AVE STOR F	SYS EFF %	PARA ENER KW	OPER- ATIONS	MODE
60	01-MAR	51.9	3.14	0.00	0.00	0.00		0.00	5.4	5.4	0.00	0.00	78.3		12.5		
61	02-MAR	51.3	1.41	0.00	0.00	0.00		0.00	5.2	7.2	0.01	0.00	77.0		15.6		
62	03-MAR	50.7	0.28	0.10	0.03	0.00	0.0	0.00	6.1	6.4	0.00	0.00	75.6	0.0	16.6		
63	04-MAR	60.1	1.94	9.68	5.87	2.29	39.0	1.08	291.4	39.7	0.66	0.00	187.7	18.3	65.7	DHW	HTST
66	07-MAR	61.7	0.85	2.85	1.69	0.65	38.4	1.00	92.6	26.1	0.00	0.31	146.8	59.1	55.0		DHW
67	08-MAR	68.1	0.75	9.29	5.97	2.85	47.2	2.02	274.4	36.1	0.17	0.07	192.2	33.8	56.3	DHW	HTST
68	09-MAR	72.3	1.03	11.02	7.18	2.88	40.1	1.90	347.9	71.1	1.61	0.20	261.7	26.4	63.0	DHW	HTST
69	10-MAR	67.1	1.25	4.49	2.84	1.00	35.2	1.22	129.7	14.0	0.00	0.36	133.2	42.9	64.2		DHW
70	11-MAR	64.6	1.05	2.01	1.20	0.40	33.3	0.51	58.1	12.0	0.00	0.00	118.3	42.5	31.8		DHW
73	14-MAR	63.7	2.31	9.82	6.38	3.09	48.4	2.83	238.1	5.8	0.00	0.09	82.3	44.3	64.8		DHW
74	15-MAR	69.3	1.67	9.06	6.16	2.39	38.7	1.96	250.8	3.8	0.00	0.00	93.0	31.8	46.3	ALL	AUTO
75	16-MAR	71.8	1.98	11.23	7.88	3.10	39.3	2.46	203.7	7.2	0.00	0.00	122.4	31.2	47.7	ALL	AUTO
76	17-MAR	64.9	7.82	0.17	0.11	0.00	0.0	0.00	11.2	1.4	0.14	0.00	140.8	0.0	7.1	ALL	AUTO
77	18-MAR	48.8	4.22	0.00	0.00	0.00		0.00	0.1	1.6	0.00	0.00	128.0		1.0	ALL	AUTO
80	21-MAR	59.4	2.47	0.97	0.62	0.00	0.0	0.00	-0.5	6.1	0.00	0.00	107.7	0.0	7.1	ALL	AUTO
81	22-MAR	51.1	1.42	0.00	0.00	0.00		0.00	4.0	6.2	0.00	0.13	87.7		7.3	ALL	AUTO
82	23-MAR	61.4	1.10	4.60	3.53	2.00	56.6	1.92	124.3	6.3	0.00	0.00	87.0	54.3	43.7		DHW
83	24-MAR	56.2	4.24	3.83	2.46	0.69	28.2	0.64	87.9	9.1	0.00	0.00	94.0	25.9	56.9		DHW
84	25-MAR	61.6	4.77	6.34	4.26	2.47	57.9	1.42	172.0	16.1	0.32	0.00	140.4	33.3	51.8		DHW
87	28-MAR	58.3	0.51	1.53	1.26	0.34	26.9	0.61	22.2	13.5	0.01	0.22	115.8	48.4	42.3		DHW
88	29-MAR	67.1	0.94	10.03	7.10	3.52	49.6	2.82	206.2	19.8	0.33	0.00	152.9	39.7	72.9	ALL	AUTO
89	30-MAR	74.1	0.77	11.73	8.33	3.27	39.2	2.45	312.4	33.9	0.00	0.07	209.1	29.4	74.2	STEAM	DHW
90	31-MAR	57.7	0.13	0.81	0.41	0.07		1.55	32.3	9.8	0.24	0.24	157.8		17.1	STEAM	HTST
TOT/AVE		61.4	2.00	109.6	73.3	31.0	42.2	26.4	2875	358.6	3.5	1.7	130.0	36.0	920.9		

Table 8.5: Monthly Performance Summary Table, April 1983

JULIAN	DATE	AHB TEMP F	WIND VEL MPH	DIR INSOL MBTU	INC INSOL MBTU	ENER COLL MBTU	COLL EFF %	ENER DEL'V MBTU	PIPE LOSS KBTU	STOR LOSS KBTU	ADD STOR MBTU	REN STOR MBTU	AVE STOR F	SYS EFF %	PARA ENER KW	OPER- ATIONS	MODE
91	01-APR	80.2	1.16	12.03	8.97	3.99	44.4	3.54	279.1	32.0	0.13	0.00	233.9	39.4	65.0	STEAM	DHW HTST
94	04-APR	65.8	1.91	10.26	7.42	3.62	48.7	3.19	256.1	13.0	0.00	0.18	118.0	42.9	71.9	ALL	AUTO
95	05-APR	57.1	1.53	4.60	3.76	1.69	44.9	1.53	110.1	9.5	0.00	0.00	113.7	40.6	29.0		DHW
96	06-APR	N.A.	1.50	1.98	1.61	1.32	81.9	2.23	159.2	10.4	0.00	0.03	99.5	138.5	44.1		DHW
97	07-APR	67.1	2.76	7.91	5.74	4.35	75.7	3.77	328.1	29.0	0.34	0.00	161.7	65.6	67.1		DHW
98	08-APR	66.4	1.40	12.94	9.37	4.01	42.7	3.28	307.9	45.3	0.24	0.00	250.8	35.0	69.2	ALL	AUTO
101	11-APR	59.1	3.17	5.70	4.29	1.85	43.1	2.05	136.3	8.5	0.03	0.32	93.9	47.7	54.4		DHW
102	12-APR	63.8	4.78	7.83	6.55	3.12	47.6	2.67	147.8	3.6	0.02	0.00	99.2	40.7	42.1	STEAM	DHW
103	13-APR	62.4	2.30	6.86	5.18	2.43	46.9	2.74	231.3	9.9	0.03	0.00	112.0	52.8	52.7	STEAM	DHW
104	14-APR	63.7	1.41	12.93	9.56	4.63	48.4	3.58	347.5	27.6	0.39	0.01	153.3	37.4	73.1	ALL	AUTO
105	15-APR	68.7	1.21	12.50	9.33	4.26	45.6	3.04	382.4	51.0	0.71	0.21	233.0	32.5	73.0	ALL	AUTO
108	18-APR	58.5	1.67	1.26	0.88	0.33	37.4	0.59	52.7	22.0	0.09	0.43	155.9	67.0	38.4	STEAM	DHW
109	19-APR	59.6	2.46	1.88	1.47	0.48	32.6	0.54	63.3	8.9	0.00	0.11	104.2	36.7	44.8		
110	20-APR	52.4	0.98	0.03	0.02	0.00	0.0	0.00	8.3	6.0	0.00	0.00	99.3	0.0	7.9		
111	21-APR	60.9	0.94	2.03	1.47	0.44	29.9	0.42	67.3	11.0	0.00	0.00	96.3	28.5	35.7		DHW
112	22-APR	63.9	0.99	1.16	0.95	0.22	23.1	0.35	53.7	6.1	0.00	0.03	83.8	36.8	44.4		DHW
115	25-APR	63.2	1.47	7.09	5.11	0.00	0.0	0.00	-10.8	3.8	0.00	0.00	76.4	0.0	15.7	ALL	AUTO
116	26-APR	59.9	0.87	1.04	0.68	0.13	19.1	0.12	22.3	4.8	0.00	0.00	75.5	17.6	28.2		
117	27-APR	63.8	1.24	8.18	5.59	2.10	37.5	2.03	185.1	3.4	0.00	0.00	74.6	36.3	65.1	ALL	AUTO
118	28-APR	57.2	0.62	0.01	0.00	0.00		0.00	63.6	5.2	0.00	0.00	74.0		15.2	ALL	AUTO
119	29-APR	60.7	1.70	3.99	2.42	0.33	13.6	0.54	84.7	3.6	0.00	0.00	73.4	22.3	31.2	ALL	AUTO
TOTAL AVE		62.9	1.72	122.2	90.4	39.3	43.5	36.2	3276	308.5	1.98	1.32	123.0	40.0	968.2		

Table 8.6: Monthly Performance Summary Table, May 1983

JULIAN	DATE	AMB TEMP F	WIND VEL MPH	DIR INSOL MBTU	INC INSOL MBTU	ENER COLL MBTU	COLL EFF %	ENER DEL'V MBTU	PIPE LOSS KBTU	STOR LOSS KBTU	ADD STOR MBTU	REN STOR MBTU	AVE STOR F	SYS EFF %	PARA ENER KW	OPER- ATIONS	MODE
122	02-MAY	69.0	1.21	8.12	6.09	3.50	57.4	2.79	239.3	19.5	0.75	0.25	148.9	45.8	70.1	ALL	AUTO
123	03-MAY	70.0	1.09	13.86	10.42	5.28	50.6	4.57	367.0	37.4	0.38	0.10	193.8	43.8	76.4	ALL	AUTO
124	04-MAY	59.9	0.53	1.12	1.05	0.27	25.7	0.30	39.1	25.6	0.00	0.00	279.7	28.5	22.6	ALL	AUTO
125	05-MAY	64.1	0.91	0.70	0.65	0.14	21.5	0.29	10.0	3.0	0.00	0.40	187.9	44.6	12.1		DHW
132	12-MAY	75.8	1.56	11.34	8.87	3.95	44.5	3.18	307.2	24.0	0.28	0.01	176.3	35.8	72.7		DHW
133	13-MAY	60.5	0.84	0.03	0.02	0.01	50.0	0.02	55.5	17.4	0.08	0.43	117.0	100.0	16.5	ALL	AUTO
136	16-MAY	68.0	1.07	3.73	3.45	1.21	35.0	1.16	58.7	3.3	0.10	0.07	85.8	33.6	40.4	ALL	AUTO
137	17-MAY	80.4	1.31	16.30	12.51	5.61	44.8	3.99	376.7	41.4	0.66	0.01	214.1	31.8	81.8	STEAM	DHW
138	18-MAY	82.1	1.73	11.80	9.63	4.05	42.0	3.60	295.2	54.1	0.29	0.49	256.7	37.3	71.8	ALL	AUTO
139	19-MAY	77.4	1.29	14.81	11.48	4.85	42.2	3.45	376.0	52.3	0.75	0.09	246.6	30.0	79.1	ALL	AUTO
140	20-MAY	79.3	1.01	14.49	11.02	2.52	22.8	1.96	287.5	55.6	0.13	0.38	259.2	17.7	58.6	ALL	AUTO
143	23-MAY	73.5	0.99	10.00	7.65	2.96	38.6	3.13	271.1	36.5	0.33	0.42	192.1	40.9	63.8	ALL	AUTO
144	24-MAY	74.9	1.11	10.73	8.26	2.27	27.4	1.44	309.1	46.3	0.25	0.14	234.4	17.4	56.7	ALL	AUTO
145	25-MAY	73.6	0.89	8.00	6.28	2.84	44.2	2.26	203.3	35.8	0.36	0.04	189.1	35.9	65.0	ALL	AUTO
146	26-MAY	73.8	0.97	8.66	6.75	3.13	46.3	2.49	199.8	37.4	0.66	0.39	194.5	36.8	68.3	ALL	AUTO
147	27-MAY	78.7	1.04	12.84	9.94	4.01	40.3	2.34	369.6	46.0	0.74	0.37	226.7	23.5	76.5	ALL	AUTO
150	30-MAY	70.7	1.14	0.18	0.06	0.00	0.0	0.45	7.5	13.2	0.00	0.52	113.4	750.0	15.0	ALL	AUTO
151	31-MAY	58.3	0.45	0.00	0.00	0.00		0.03	-4.0	6.1	0.00	0.08	96.4		10.9	ALL	AUTO
TOT/AVE		71.7	1.06	146.8	144.1	46.6	40.8	37.4	3768	554.9	5.8	4.6	189.7	32.8	958.3		

Table 8.7: Monthly Performance Summary Table, June 1983

JULIAN	DATE	AMB TEMP F	WIND VEL MPH	DIR INSOL MBTU	INC INSOL MBTU	ENER COLL MBTU	COLL EFF %	ENER DEL'V MBTU	PIPE LOSS KBTU	STOR LOSS KBTU	ADD STOR MBTU	REN STOR MBTU	AVE STOR F	SYS EFF %	PARA ENER KW	OPER--	ATIONS	MODE
152	01-JUN	63.9	2.00	0.60	0.50	0.15	29.9	0.24	21.2	4.8	0.00	0.00	83.3	47.9	39.0		DHW	
153	02-JUN	61.4	0.61	0.01	0.01	0.00	0.0	0.00	4.7	6.4	0.00	0.00	82.2	0.0	16.0			
154	03-JUN	65.2	1.08	0.65	0.52	0.19	36.5	0.21	38.3	2.3	0.00	0.05	73.5	40.3	25.6		DHW	
157	06-JUN	75.4	1.04	0.80	7.18	3.22	44.8	2.24	209.9	24.0	0.50	0.01	152.8	31.1	71.7		DHW	
158	07-JUN	72.9	1.41	6.02	4.62	1.78	38.5	1.63	148.2	24.5	0.18	0.42	165.9	35.2	65.7		DHW	
159	08-JUN	70.4	1.10	7.57	5.58	2.31	41.3	1.74	216.3	43.8	0.45	0.54	179.2	31.1	63.2		DHW	
160	09-JUN	68.1	0.91	5.32	3.40	1.85	54.4	1.47	174.9	39.0	0.66	0.97	203.9	43.2	67.2	DHW	HTST	
161	10-JUN	73.6	1.22	11.55	8.69	3.16	36.3	2.07	335.4	62.2	1.02	0.92	275.2	23.8	80.4	DHW	HTST	
164	13-JUN	79.1	0.42	14.10	14.10	4.12	29.8	2.53	295.6	46.2	0.74	0.40	230.0	17.9	61.0	DHW	HTST	
165	14-JUN	84.8	1.05	14.87	11.18	5.37	48.0	5.10	400.5	42.5	0.66	0.22	243.2	45.6	86.5	STEAM	DHW	HTST
166	15-JUN	78.3	0.92	9.70	7.34	2.98	40.5	2.31	340.9	50.4	0.48	0.61	240.3	31.4	74.9	STEAM	DHW	HTST
167	16-JUN	77.3	1.00	10.09	7.99	3.07	38.4	2.20	282.3	48.7	0.78	0.49	234.1	27.5	70.5	DHW	HTST	
168	17-JUN	77.3	1.14	8.51	7.37	2.59	35.1	2.10	335.9	73.8	0.85	0.33	311.4	28.4	49.1	DHW	HTST	
171	20-JUN	69.8	0.99	4.88	2.97	1.80	60.6	1.30	165.7	40.1	0.62	0.59	194.2	43.7	52.8	DHW	HTST	
172	21-JUN	72.4	1.11	8.35	6.12	3.44	56.2	2.91	274.9	58.6	0.89	0.45	262.0	47.5	62.3	DHW	HTST	
173	22-JUN	75.0	1.38	9.87	7.53	2.76	36.7	3.02	248.1	49.0	0.51	4.33	220.8	40.1	53.3	DHW	HTST	
174	23-JUN	75.1	1.28	12.35	9.56	3.24	33.9	2.54	328.1	55.2	0.41	0.50	253.2	26.6	56.1	DHW	HTST	
175	24-JUN	74.6	1.33	5.89	5.29	1.87	35.3	1.65	264.6	37.7	0.15	0.44	196.0	31.2	55.5	ALL	AUTO	
178	27-JUN	66.5	0.83	0.14	0.06	0.00	0.0	0.19	16.7	11.1	0.00	0.14	104.6	316.6	19.0	ALL	AUTO	
179	28-JUN	69.8	0.97	2.41	1.84	0.61	33.1	0.69	59.2	5.4	0.00	0.00	87.7	37.4	37.4		DHW	
180	29-JUN	70.0	0.54	0.82	0.44	0.03	6.8	0.08	19.9	4.3	0.00	0.00	86.6	18.1	20.7	ALL	AUTO	
181	30-JUN	67.3	1.12	0.00	0.00	0.00		0.00	8.8	3.5	0.00	0.00	85.3		11.3	ALL	AUTO	
TOT/AVE		72.2	1.07	129.8	99.6	44.6	44.7	36.2	4190	722.5	15.6	11.4	194.0	36.3	1139			

Table 8.8: Monthly Performance Summary Table, July 1983

JULIAN	DATE	AIR TEMP F	WIND VEL MPH	DIR INSOL MBTU	INC INSOL MBTU	ENER COLL MBTU	COLL EFF %	ENER DEL'V MBTU	PIPE LOSS KBTU	STOR LOSS KBTU	ADD STOR MBTU	REN STOR MBTU	AVE STOR F	SYS EFF %	PARA ENER KH	OPER- ATIONS	MODE
182	01-JUL	73.8	1.26	0.14	0.12	0.01	8.3	0.05	7.4	2.2	0.00	0.00	84.2	41.6	25.9	DHW	
185	04-JUL	77.8	1.03	0.50	0.40	0.00	0.0	0.00	-4.9	7.0	0.00	0.00	80.4	0.0	15.0	PLANT HOLIDAY	
186	05-JUL	78.7	1.14	10.40	7.87	2.61	33.4	1.26	304.7	20.5	0.84	0.00	146.8	12.1	61.1	STEAM HTST	
187	06-JUL	78.0	1.30	13.64	10.57	3.49	33.1	3.18	350.1	57.1	0.74	0.64	266.7	29.6	62.5	STEAM HTST	
188	07-JUL	79.1	1.04	16.30	12.43	5.01	40.9	4.35	345.7	68.4	0.40	0.38	279.8	35.0	79.4	STEAM HTST	DHW
189	08-JUL	82.1	1.12	16.21	12.43	4.43	36.0	4.06	378.9	46.2	0.60	0.60	239.5	32.7	72.7	STEAM HTST	DHW
192	11-JUL	92.1	1.23	16.22	12.29	3.41	27.9	2.59	252.2	29.9	0.72	0.43	210.2	21.0	74.9	STEAM HTST	DHW
193	12-JUL	94.6	1.09	15.99	12.06	5.01	41.7	5.90	361.8	15.2	0.01	0.41	159.8	48.9	70.2	STEAM	DHW
194	13-JUL	92.4	1.58	15.45	11.49	4.41	38.6	3.84	356.1	16.7	0.00	0.00	145.9	33.4	65.6	ALL AUTO	
195	14-JUL	82.4	1.02	7.44	6.12	2.28	37.2	1.82	131.0	9.4	0.00	0.00	140.2	29.8	41.4	ALL AUTO	
196	15-JUL	79.5	1.58	9.54	7.45	2.26	30.3	1.73	225.4	11.4	0.00	0.00	133.0	23.2	42.2	ALL AUTO	
199	18-JUL	82.9	1.53	9.42	7.07	2.81	39.7	2.28	228.3	6.8	0.00	0.00	265.0	32.2	45.9	ALL AUTO	
200	19-JUL	84.5	1.37	16.86	12.52	4.11	32.8	3.63	391.2	10.2	0.00	0.00	117.7	28.9	65.7	ALL AUTO	
201	20-JUL	88.6	1.11	16.76	12.88	4.63	36.3	4.36	298.5	11.2	0.00	0.00	129.5	33.9	64.0	ALL AUTO	
202	21-JUL	87.3	1.91	4.45	2.89	1.53	51.9	0.97	77.0	7.6	0.43	0.00	188.5	33.5	30.7	ALL AUTO	
203	22-JUL	80.7	1.07	15.84	11.92	4.71	40.1	3.74	379.0	54.9	0.76	0.24	257.3	31.3	78.3	ALL AUTO	
206	25-JUL	76.5	1.19	12.95	9.94	4.44	44.6	3.78	348.5	47.6	0.73	0.53	229.9	38.0	70.3	STEAM HTST	DHW
207	26-JUL	76.5	1.17	12.27	9.41	3.67	39.0	2.99	376.1	49.4	0.53	0.48	235.9	31.7	71.5	STEAM HTST	DHW
208	27-JUL	78.7	1.11	11.89	9.04	3.29	35.3	2.48	324.7	33.4	0.64	0.35	217.8	27.4	61.5	STEAM HTST	DHW
209	28-JUL	79.2	1.16	14.54	11.14	4.45	39.9	3.78	392.0	50.9	0.63	0.41	243.9	33.9	74.4	STEAM HTST	DHW
210	29-JUL	82.2	0.88	14.49	11.45	3.81	33.2	2.78	346.4	65.7	1.24	0.71	294.4	24.2	61.0	STEAM HTST	DHW
TOT/AVE		82.3	1.27	251.3	191.5	70.5	36.9	59.4	5870	615.4	8.27	5.18	193.6	31.0	1234		

Table 8.9: Monthly Performance Summary Table, August 1983

JULIAN	DATE	AMB TEMP F	WIND VEL MPH	DIR INSOL MBTU	INC INSOL MBTU	ENER COLL MBTU	COLL EFF %	ENER DEL'V MBTU	PIPE LOSS KBTU	STOR LOSS KBTU	ADD STOR MBTU	REN STOR MBTU	AVE STOR F	SYS EFF %	PARA ENER KW	OPER- ATIONS	MODE
213	01-AUG	81.8	1.07	10.89	8.34	3.51	42.0	2.81	302.5	22.6	0.59	0.65	196.8	33.6	67.8	STEAM	DHW
214	02-AUG	83.2	0.92	12.69	9.45	3.62	38.3	3.16	362.8	40.8	0.55	0.33	222.9	33.4	74.8	STEAM	DHW
215	03-AUG	83.3	1.06	12.86	9.38	3.46	36.8	2.64	333.4	61.8	0.83	0.26	312.4	28.1	72.8	STEAM	DHW
216	04-AUG	90.2	1.49	12.38	9.14	3.67	40.1	3.24	348.6	59.5	0.65	0.21	354.9	35.4	56.5	STEAM	DHW
217	05-AUG	91.7	1.37	13.58	10.27	3.46	33.6	2.88	337.1	73.2	0.78	0.45	334.0	28.0	73.9	STEAM	DHW
220	08-AUG	89.3	1.15	11.89	8.94	3.30	36.9	2.01	315.8	34.8	0.59	0.43	202.5	22.4	70.8	STEAM	DHW
221	09-AUG	81.9	0.62	0.14	0.12	0.00	0.0	0.27	54.0	21.0	0.00	0.48	166.6	225.0	24.3	E'DELV	HTST
222	10-AUG	86.2	1.11	11.06	8.13	3.43	42.1	2.59	241.6	22.1	0.57	0.01	160.3	31.8	73.7	DHW	HTST
223	11-AUG	84.7	1.22	13.77	10.23	3.37	32.9	2.72	317.7	52.0	0.23	0.19	253.7	26.5	64.3	ALL	AUTO
224	12-AUG	88.4	1.07	12.52	9.46	2.20	23.2	1.79	306.4	66.9	0.63	0.34	309.5	18.9	60.9	DHW	HTST
227	15-AUG	92.9	1.25	4.39	2.64	1.56	59.0	0.89	130.7	13.4	0.40	0.53	186.6	33.7	31.6	DHW	HTST
228	16-AUG	86.8	0.88	5.63	4.60	1.63	35.4	1.88	172.1	29.9	0.04	0.50	182.7	40.8	56.8	DHW	
229	17-AUG	84.8	1.64	6.66	5.60	2.05	36.6	1.53	171.6	39.1	0.34	0.07	222.0	27.3	56.3	DHW	
230	18-AUG	68.0	0.26	0.00	0.00	0.00		0.00	3.1	19.0	0.00	0.00	247.2		6.4		
231	19-AUG	67.5	0.73	0.02	0.01	0.00	0.0	0.00	12.9	49.3	0.00	0.00	226.4	0.0	15.6		
234	22-AUG	73.5	0.97	7.76	5.23	2.36	45.1	1.58	206.5	32.6	0.52	0.18	178.7	30.2	68.3	DHW	
235	23-AUG	77.0	1.23	12.34	8.94	3.24	36.2	2.64	383.8	74.7	0.88	0.61	324.2	29.5	72.3	DHW	HTST
236	24-AUG	76.4	1.14	12.13	8.90	3.74	42.1	2.77	386.1	75.1	0.91	0.47	319.8	31.1	71.1		HTST
237	25-AUG	79.9	1.16	12.68	9.01	3.42	37.9	3.11	275.3	30.1	0.00	0.57	184.9	34.5	63.2	ALL	AUTO
238	26-AUG	91.4	1.17	14.12	10.23	3.40	33.2	2.51	330.4	37.8	0.00	0.00	244.3	24.5	53.1	ALL	AUTO
241	29-AUG	88.8	1.03	13.99	10.02	3.97	39.6	3.34	323.4	50.5	0.00	0.00	252.4	33.3	62.5	ALL	AUTO
242	30-AUG	87.3	1.56	5.98	4.36	1.65	38.0	1.57	186.6	41.5	0.00	0.00	253.1	36.0	41.0	ALL	AUTO
243	31-AUG	84.9	1.14	14.19	10.08	3.36	33.3	2.36	334.1	66.1	0.01	0.03	298.0	23.4	57.1	ALL	AUTO
TOT/AVE		83.5	1.1	221.7	163.1	60.4	37.0	48.3	5836	1013	8.5	6.3	245.0	29.6	1295		

Table 8.10: Monthly Performance Summary Table, September 1983

JULIAN	DATE	AMB TEMP F	WIND VEL MPH	DIR INSOL MBTU	INC INSOL MBTU	ENER COLL MBTU	COLL EFF %	ENER DEL'V MBTU	PIPE LOSS KBTU	STOR LOSS KBTU	ADD STOR MBTU	REM STOR MBTU	AVE STOR F	SYS EFF %	PARA ENER KW	OPER- ATIONS	MODE
244	01-SEP	91.9	1.36	10.06	7.37	2.58	35.1	2.38	250.0	27.1	0.01	0.44	203.7	32.3	55.1	ALL	AUTO
245	02-SEP	89.2	1.10	13.22	9.31	2.54	27.2	2.02	333.1	43.3	0.00	0.00	229.3	21.6	54.0	ALL	AUTO
248	05-SEP	91.2	0.00	0.00	0.00	0.00		0.00	33.6	25.9	0.00	0.00	205.0		11.0	PLANT	HOLIDAY
249	06-SEP	87.2	0.97	12.15	8.63	3.66	42.4	3.17	28.8	27.1	0.00	0.00	186.5	36.7	59.0	ALL	AUTO
250	07-SEP	81.5	1.03	11.34	7.84	3.03	38.6	2.63	309.7	31.3	0.00	0.00	183.8	33.5	62.8	ALL	AUTO
251	08-SEP	84.5	1.10	13.33	9.24	3.16	34.1	1.94	357.7	51.4	0.04	0.00	252.5	20.9	62.2	ALL	AUTO
252	09-SEP	84.7	0.97	2.06	1.61	0.40	25.1	1.49	98.3	35.9	0.08	1.00	217.3	92.5	41.8	ALL	AUTO
255	12-SEP	94.8	1.25	10.10	6.99	2.84	40.6	2.11	259.5	23.2	0.48	0.04	209.1	30.1	50.9	ALL	AUTO
256	13-SEP	78.5	0.64	2.54	1.72	0.57	33.1	0.65	60.4	16.2	0.00	0.27	190.0	37.7	23.5	ALL	AUTO
257	14-SEP	86.0	1.03	10.28	7.11	2.18	30.6	1.13	326.4	23.5	1.37	0.00	180.1	15.8	66.0	ALL	AUTO
258	15-SEP	79.6	0.76	6.63	4.60	1.37	29.7	0.70	273.5	38.9	0.21	0.00	241.2	15.1	46.3	ALL	AUTO
259	16-SEP	82.4	0.93	7.15	4.75	1.38	29.0	0.76	217.4	37.6	0.51	0.33	251.9	15.9	63.2	DHW	HTST
262	19-SEP	85.0	0.80	0.15	0.10	0.01	9.9	0.01	22.2	3.1	0.00	0.00	108.5	9.9	9.6	DHW	
263	20-SEP	75.6	0.56	0.70	0.47	0.06	12.7	0.07	52.8	9.5	0.00	0.00	105.8	14.8	25.1	DHW	
264	21-SEP	82.2	1.10	7.46	4.65	1.83	39.3	1.29	143.0	22.5	0.91	0.31	127.9	27.7	64.6	DHW	
265	22-SEP	76.9	0.83	0.76	0.24	0.00	-4.1	0.11	36.2	9.2	0.01	0.31	125.2	45.8	17.3	DHW	HTST
266	23-SEP	74.9	1.05	4.94	2.89	0.77	26.6	0.57	61.4	16.3	0.32	0.08	136.4	19.7	35.3	DHW	HTST
269	26-SEP	70.5	1.25	2.44	1.07	0.64	59.8	0.49	63.7	13.9	0.38	0.26	122.8	45.7	30.5	DHW	HTST
270	27-SEP	71.4	1.24	4.44	3.01	0.88	29.2	0.43	212.8	40.7	0.77	0.35	202.7	14.2	54.8	DHW	HTST
271	28-SEP	69.5	1.18	1.00	0.63	0.00	0.0	0.00	64.2	47.7	0.00	0.00	222.7	0.0	15.0	NO	OPER- ATION
272	29-SEP	62.3	0.35	0.54	0.30	0.00	0.0	0.00	16.3	42.3	0.00	0.00	200.2	0.0	15.3	NO	OPER- ATION
273	30-SEP	58.5	1.21	0.02	0.01	0.00	0.0	0.00	5.5	30.5	0.00	0.00	183.1	0.0	12.0	NO	OPER- ATION
TOT/AVE		79.9	0.94	121.3	82.5	27.9	33.8	22.0	3485	617.1	50.9	33.9	185.7	26.7	875.3		

were quantified by integrating static losses over the operating period. Thermal losses between the hours of 8:00 PM and 5:00 AM were not monitored.

No measurement of energy inputs by the circulating pump was made.

Equations used in determining performance data are presented in Appendix C.

8.1 Clear Day Performance

Performance data for selected days are presented in Tables 8.11 through 8.16. Insolation, collected energy, and delivered energy are shown graphically in Figures 8.1 through 8.11. A brief description of prevailing conditions on each clear day is presented in the following paragraphs.

Day 350 - December 16, 1982

Data for December were calculated manually from data logger printouts. Wind velocity was not monitored. Light winds were observed throughout the day. High thin clouds prevailed during Day 350. System operation was for domestic hot water production.

Day 20 - January 20, 1983

Clear skies and light winds prevailed on Day 20. Data collection was manually initiated at 8:00 AM. Automatic system startup occurred at 8:23 AM. Operation for domestic hot water was performed. The recirculation period before energy delivery is very short under the DHW operations mode. Manual flow through the domestic hot water tank was controlled after 3:30 PM to extend the length of the operating day. Routine shutdown occurred at 4:10 PM.

Table 8.11: Clear Day Performance, Day 350 and Day 20

HOOR	DATE	AMB TEMP F	WIND VEL MPH	DIR INSOL MBTU	INC INSOL MBTU	LOOP FLOW KID/HR	COLL INLET F	COLL OUT F	ENER COLL MBTU	COLL EFF %	ENER DEL'V MBTU	PIPE LOSS KBTU	STOR LOSS KBTU	ADD STOR MBTU	REN STOR MBTU	AVE STOR F	SYS EFF %	PARA ENER KW
9	16-DEC	56.5	0.00	0.886	0.638	35.3	79.5	80.9	0.037	5.8	-0.15	2.7	0.3	0.000	0.000	74.2	-23.5	8.1
10	16-DEC	67.6	0.00	1.212	0.766	33.9	129.2	136.5	0.245	32.0	0.147	9.7	0.1	0.000	0.000	74.2	19.2	7.6
11	16-DEC	74.1	0.00	1.562	0.800	33.6	149.9	157.8	0.269	30.6	0.194	12.0	0.0	0.000	0.000	74.2	22.0	7.5
12	16-DEC	73.6	0.00	1.414	0.759	33.5	151.6	158.1	0.219	28.8	0.128	12.0	0.0	0.000	0.000	74.2	16.9	7.4
13	16-DEC	73.5	0.00	1.196	0.673	33.3	147.0	152.9	0.195	28.9	0.158	11.3	0.0	0.000	0.000	74.2	23.5	7.4
14	16-DEC	75.6	0.00	1.498	0.947	33.1	157.5	165.5	0.266	28.1	0.096	12.8	0.0	0.000	0.000	74.2	10.1	7.3
15	16-DEC	74.6	0.00	1.246	0.899	33.1	169.9	179.0	0.303	33.7	0.198	14.9	-0.0	0.000	0.000	74.2	22.0	7.3
16	16-DEC	68.5	0.00	0.601	0.467	32.3	148.3	151.2	0.081	16.6	0.046	12.0	0.1	0.000	0.000	74.2	9.4	7.6
350	16-DEC	70.5	0.00	9.62	6.05	DHW	ONLY		1.62	26.8	0.95	87.4	0.5	0.000	0.000	74.2	15.7	60.2
9	20-JAN	48.2	0.28	0.784	0.589	25.3	79.2	79.2	0.034	5.8	0.038	3.8	0.7	0.000	0.000	85.6	6.4	6.0
10	20-JAN	58.2	1.01	1.456	0.973	33.6	142.5	150.1	0.252	25.9	0.205	12.9	0.6	0.000	0.000	85.5	21.1	7.3
11	20-JAN	60.1	0.96	1.625	0.983	32.9	179.9	189.5	0.318	32.3	0.293	18.4	0.5	0.000	0.000	85.4	29.8	7.2
12	20-JAN	58.7	1.15	1.636	0.949	32.7	188.1	196.7	0.276	29.1	0.257	19.0	0.5	0.000	0.000	85.4	27.1	7.3
13	20-JAN	59.9	1.43	1.739	1.051	32.5	192.7	202.0	0.311	29.6	0.298	20.8	0.5	0.000	0.000	85.3	28.4	7.2
14	20-JAN	61.8	1.12	1.561	1.043	32.2	198.1	207.0	0.281	26.9	0.256	20.1	0.5	0.000	0.000	85.2	24.5	7.1
15	20-JAN	61.8	0.50	1.401	1.052	32.4	218.0	224.9	0.239	22.7	0.180	23.7	0.5	0.000	0.000	85.2	17.1	7.2
16	20-JAN	59.2	0.60	0.984	0.821	31.9	256.6	261.7	0.158	19.2	0.140	27.9	0.5	0.000	0.000	85.1	17.1	7.2
17	20-JAN	55.2	0.73	0.157	0.142	20.5	194.9	197.5	0.009	6.3	0.008	12.4	0.4	0.000	0.000	85.1	5.6	5.0
18	20-JAN	51.7	0.68	0.000	0.000	0.0	181.7	181.5	0.000		0.000	11.5	0.4	0.000	0.000	85.0		1.1
20	20-JAN	57.5	0.85	11.34	7.60	DHW	ONLY		1.91	25.1	1.73	170.5	5.1	0.000	0.000	85.3	22.8	62.6

Table 8.12: Clear Day Performance, Day 47 and Day 88

HR	DATE	AMB TEMP F	WIND VEL MPH	DIR INSOL MBTU	INC INSOL MBTU	LOOP FLOW KIB/HR	COLL INLET F	COLL OUT F	ENER COLL MBTU	COLL EFF %	ENER DEL'V MBTU	PIPE LOSS KBTU	STOR LOSS KBTU	ADD STOR MBTU	REN STOR MBTU	AVE STOR F	SYS EFF %	PARA ENER KW
9	16-FEB	60.5	0.13	0.474	0.388	33.9	97.6	102.5	0.071	18.3	0.053	2.6	0.1	0.000	0.000	74.2	35.6	7.4
10	16-FEB	65.4	1.06	1.290	0.969	33.6	146.3	156.4	0.347	35.8	0.312	13.2	0.2	0.000	0.000	74.2	32.2	7.3
11	16-FEB	68.1	0.92	1.378	0.964	33.0	175.6	187.9	0.399	41.4	0.378	16.7	0.1	0.000	0.000	74.2	39.2	7.2
12	16-FEB	70.6	1.00	1.421	0.967	32.8	188.9	200.3	0.375	38.8	0.355	18.3	0.1	0.000	0.000	74.2	36.7	7.2
13	16-FEB	71.0	0.80	1.158	0.810	32.6	191.5	200.9	0.313	38.6	0.305	18.6	0.1	0.000	0.000	74.2	37.7	7.1
14	16-FEB	72.4	1.05	1.286	0.967	32.6	190.2	201.9	0.381	39.4	0.369	18.4	0.0	0.000	0.000	74.2	38.2	7.1
15	16-FEB	72.4	1.48	1.182	0.969	32.7	190.5	202.4	0.391	40.3	0.382	18.5	0.0	0.000	0.000	74.2	39.4	7.1
16	16-FEB	68.6	1.29	0.963	0.855	32.6	183.0	193.5	0.355	41.5	0.357	17.9	0.1	0.000	0.000	74.2	41.8	7.3
17	16-FEB	63.3	1.19	0.163	0.154	16.5	172.4	178.3	0.092	59.7	0.100	13.8	0.2	0.000	0.000	74.2	64.9	4.3
18	16-FEB	60.6	2.47	0.000	0.000	0.1	153.5	154.7	0.000		0.000	7.0	0.1	0.000	0.000	74.2		1.1
47	16-FEB	67.3	1.14	9.32	7.04	DHW	ONLY		2.72	38.6	2.61	145.0	1.0	0.000	0.000	74.2	37.1	63.1
8	29-MAR	55.3	0.70	0.360	0.349	34.9	90.3	94.0	0.047	13.4	0.03	1.6	0.2	0.000	0.000	80.7	8.6	7.4
9	29-MAR	62.6	0.32	0.851	0.795	34.3	135.4	143.2	0.273	34.3	0.245	11.0	0.4	0.000	0.000	80.6	30.8	7.3
10	29-MAR	66.9	0.33	1.037	0.928	33.6	167.6	178.2	0.355	38.2	0.310	14.9	0.3	0.000	0.000	80.6	33.4	7.3
11	29-MAR	69.6	0.68	1.427	1.235	32.9	207.5	222.6	0.497	40.3	0.462	20.9	0.2	0.000	0.000	80.5	37.4	7.2
12	29-MAR	69.9	0.79	1.409	1.203	32.6	219.8	234.6	0.488	40.6	0.437	22.4	0.2	0.000	0.000	80.5	36.3	7.2
13	29-MAR	73.2	1.13	1.405	1.216	32.3	239.9	253.8	0.453	37.2	0.415	24.4	0.2	0.000	0.000	80.5	34.1	7.1
14	29-MAR	74.4	1.60	1.005	0.899	33.2	189.8	203.0	0.363	40.3	0.136	16.0	1.1	0.205	0.010	181.4	15.1	7.1
15	29-MAR	73.4	1.92	1.224	1.143	32.6	218.1	231.3	0.435	38.0	0.290	21.3	3.3	0.122	0.000	229.8	25.4	7.2
16	29-MAR	71.7	1.10	1.169	1.135	32.5	222.1	234.2	0.404	35.6	0.368	21.6	3.4	0.000	0.000	236.6	32.4	7.2
17	29-MAR	67.5	1.32	0.150	0.149	24.2	210.3	216.9	0.208	139.6	0.124	19.6	3.5	0.000	0.000	235.7	83.2	5.9
18	29-MAR	62.7	1.07	0.000	0.000	0.0	185.2	185.4	0.000		0.000	15.8	3.6	0.000	0.000	234.7		1.0
19	29-MAR	59.3	0.34	0.000	0.000	0.0	174.8	176.7	0.000		0.000	16.7	3.4	0.000	0.000	233.8		1.0
88	29-MAR	67.1	0.94	10.03	9.05	ALL	AUTO		3.52	38.9	2.82	206.2	19.8	0.33	0.00	152.9	31.2	72.9

Table 8.13: Clear Day Performance, Day 89 and Day 104

HOUR	DATE	AMB TEMP F	WIND VEL MPH	DIR INSOL MBTU	INC INSOL MBTU	LOOP FLOW KIB/HR	COLL INLET F	COLL OUT F	ENER COLL MBTU	COLL EFF %	ENER DEL'V MBTU	PIPE LOSS KBTU	STOR LOSS KBTU	ADD STOR MBTU	REN STOR MBTU	AVE STOR F	SYS EFF %	PARA ENER KW
8	30-MAR	61.5	0.00	0.287	0.279	23.4	123.5	127.7	0.033	11.8	0.000	1.9	0.8	0.000	0.000	220.6	0.0	7.3
9	30-MAR	69.8	0.53	1.402	1.313	31.6	202.2	209.7	0.246	18.7	0.000	19.7	3.2	0.000	0.000	220.0	0.0	7.1
10	30-MAR	73.9	0.89	1.491	1.339	29.3	308.6	317.8	0.270	20.2	0.085	32.9	3.0	0.000	0.000	219.1	6.3	6.8
11	30-MAR	77.4	0.46	1.579	1.372	28.7	333.3	347.4	0.422	30.8	0.387	36.7	2.9	0.000	0.000	218.3	28.3	6.8
12	30-MAR	80.2	0.65	1.529	1.311	28.5	333.5	346.6	0.389	29.7	0.252	36.4	2.8	0.000	0.000	217.4	19.2	6.8
13	30-MAR	84.4	0.83	1.493	1.297	28.7	333.6	346.3	0.382	29.4	0.298	36.0	2.7	0.000	0.000	216.6	23.0	6.8
14	30-MAR	85.4	1.43	1.258	1.130	28.8	332.5	342.7	0.312	27.6	0.156	35.2	2.7	0.000	0.000	215.8	13.8	6.7
15	30-MAR	84.4	1.93	1.272	1.191	28.9	332.9	343.9	0.331	27.8	0.122	35.2	2.7	0.000	0.000	215.0	10.2	6.8
16	30-MAR	80.6	1.77	1.228	1.194	30.2	306.3	324.4	0.558	46.7	0.572	32.6	2.8	0.000	0.000	214.2	47.9	6.9
17	30-MAR	73.9	0.74	0.186	0.185	33.3	214.7	224.4	0.338	182.6	0.367	19.5	2.9	0.000	0.000	213.4	198.3	7.4
18	30-MAR	68.1	0.51	0.000	0.000	10.1	177.3	164.7	0.000		0.211	11.8	2.4	0.000	0.071	184.7		2.8
19	30-MAR	62.9	0.22	0.000	0.000	0.0	152.8	136.3	0.000		0.000	8.6	2.5	0.000	0.000	181.9		1.0
20	30-MAR	60.4	0.00	0.000	0.000	0.0	128.6	114.6	0.000		0.000	5.9	2.5	0.000	0.000	181.4		1.0
89	30-MAR	74.1	0.77	11.73	10.61	STEAM	DHW	HTST	3.27	30.8	2.45	312.4	33.9	0.00	0.07	209.1	23.1	74.2
6	4-APR	42.7	0.21	0.000	0.000	0.0	100.9	113.1	0.000		0.000	8.4	1.4	0.000	0.000	111.6		1.0
7	4-APR	48.2	0.02	0.038	0.037	0.0	97.2	109.4	0.000	0.0	0.000	7.5	1.3	0.000	0.000	111.3	0.0	1.0
8	4-APR	56.9	0.04	1.085	1.073	33.8	107.4	113.8	0.215	20.0	0.151	6.9	1.1	0.000	0.000	111.1	14.1	7.6
9	4-APR	64.3	0.42	1.344	1.297	31.2	182.9	200.2	0.539	41.6	0.439	18.3	1.0	0.000	0.000	110.9	33.8	7.2
10	4-APR	70.1	0.60	1.489	1.394	30.6	219.0	238.4	0.601	43.1	0.527	23.4	0.8	0.000	0.000	110.8	37.8	7.1
11	4-APR	71.5	0.97	1.562	1.427	30.3	243.5	260.3	0.522	36.6	0.381	26.0	0.8	0.009	0.000	110.6	26.7	7.0
12	4-APR	71.9	1.01	1.623	1.469	28.8	317.8	333.6	0.459	31.2	0.352	35.9	0.9	0.043	0.000	114.3	24.0	6.9
13	4-APR	73.7	1.07	1.559	1.425	28.9	323.8	342.1	0.527	37.0	0.524	36.7	1.2	0.025	0.000	132.4	36.8	6.8
14	4-APR	73.6	2.34	1.431	1.340	29.3	303.2	314.6	0.370	27.6	0.214	32.6	1.4	0.000	0.000	142.8	16.0	6.7
15	4-APR	71.7	3.78	1.354	1.307	29.6	296.3	312.8	0.545	41.7	0.483	32.9	1.5	0.002	0.000	143.8	37.0	6.8
16	4-APR	69.9	3.43	1.188	1.175	30.2	314.0	331.2	0.531	45.2	0.511	35.4	1.5	0.001	0.000	144.5	43.5	6.9
17	4-APR	66.0	3.68	0.255	0.255	18.9	233.3	241.0	0.160	126.6	0.000	23.1	3.4	0.306	0.010	234.2	0.0	4.6
18	4-APR	61.7	2.53	0.000	0.000	0.0	227.7	228.8	0.000		0.000	21.8	3.7	0.000	0.000	241.5		1.3
19	4-APR	57.5	1.00	0.000	0.000	0.0	209.8	214.1	0.000		0.000	20.1	3.8	0.000	0.000	240.5		1.0
20	4-APR	55.6	0.03	0.000	0.000	0.0	191.3	199.8	0.000		0.000	18.5	3.8	0.000	0.000	239.5		1.0
104	4-APR	63.7	1.41	12.93	12.20	ALL	AUTO		4.63	38.0	3.58	347.5	27.6	0.39	0.01	153.3	29.3	73.1

Table 8.14: Clear Day Performance, Day 137 and Day 174

HR	DATE	AMB TEMP F	WIND VEL MPH	DIR INSOL MBTU	INC INSOL MBTU	LOOP FLOW KID/HR	COLL INLET F	COLL OUT F	ENER COLL MBTU	COLL EFF %	ENER DEL'V MBTU	PIPE LOSS KBTU	STOR LOSS KBTU	ADD STOR MBTU	REM STOR MBTU	AVE STOR F	SYS EFF %	PARA ENER KW
6	17-MAY	53.0	0.12	0.000	0.000	0.0	120.6	135.9	0.000		0.000	10.5	1.2	0.000	0.000	112.9		1.0
7	17-MAY	55.8	0.07	0.008	0.007	0.0	116.3	129.7	0.000	0.0	0.000	9.2	1.2	0.000	0.000	112.7	0.0	1.0
8	17-MAY	62.8	0.69	0.665	0.664	21.6	99.7	105.5	0.031	4.6	0.044	5.0	1.0	0.000	0.000	112.6	6.6	5.6
9	17-MAY	76.8	0.52	1.401	1.393	34.1	169.0	182.2	0.443	31.8	0.373	14.5	0.7	0.000	0.000	112.4	26.8	7.5
10	17-MAY	84.0	1.08	1.639	1.610	32.1	222.6	246.2	0.749	46.5	0.545	23.1	0.6	0.000	0.000	112.2	33.9	7.3
11	17-MAY	89.6	1.14	1.768	1.716	30.5	237.6	260.8	0.712	41.5	0.594	24.4	0.5	0.000	0.000	112.1	34.6	7.2
12	17-MAY	89.4	1.74	1.727	1.668	29.9	278.4	294.8	0.515	30.9	0.284	28.8	0.5	0.000	0.000	112.0	17.0	7.2
13	17-MAY	88.7	1.47	1.786	1.734	28.7	334.7	355.2	0.613	35.3	0.335	37.2	1.4	0.108	0.000	157.2	19.3	6.9
14	17-MAY	89.9	1.45	1.802	1.770	29.0	311.3	333.4	0.711	40.2	0.550	33.9	2.6	0.139	0.000	215.0	31.1	6.9
15	17-MAY	92.4	1.84	1.681	1.672	28.7	303.6	325.1	0.660	39.5	0.582	32.5	3.1	0.069	0.000	243.7	34.8	6.9
16	17-MAY	91.7	1.33	1.632	1.631	28.9	342.4	359.8	0.528	32.4	0.253	37.0	4.1	0.114	0.000	291.2	15.5	7.0
17	17-MAY	88.8	2.80	1.402	1.388	28.8	376.2	382.8	0.217	15.6	0.058	40.1	6.0	0.227	0.011	381.3	4.2	7.0
18	17-MAY	86.7	3.27	0.791	0.760	30.5	288.8	300.6	0.422	55.5	0.371	29.1	6.2	0.000	0.000	381.6	48.8	7.4
19	17-MAY	80.5	1.88	0.000	0.000	3.2	275.4	281.7	0.006		0.000	26.5	6.1	0.000	0.000	378.3		1.8
20	17-MAY	75.8	0.32	0.000	0.000	0.0	242.7	262.9	0.000		0.000	24.9	6.2	0.000	0.000	376.1		1.1
137	17-MAY	80.4	1.31	16.30	16.01	STEAM	DHW		5.61	35.0	3.99	376.7	41.4	0.66	0.01	214.1	24.9	81.8
6	23-JUN	58.5	0.15	0.000	0.000	0.0	119.8	145.9	0.000		0.000	10.7	5.2	0.000	0.000	307.3		1.0
7	23-JUN	58.9	0.19	0.000	0.000	0.0	114.7	138.4	0.000		0.000	9.5	5.1	0.000	0.000	305.5		1.0
8	23-JUN	60.1	0.08	0.000	0.000	0.0	111.4	132.5	0.000		0.000	8.4	5.0	0.000	0.000	303.8		1.0
9	23-JUN	65.5	0.44	0.279	0.278	11.3	126.9	132.9	0.000		0.128	8.2	4.3	0.078	0.498	268.2	46.0	3.4
10	23-JUN	73.4	0.14	1.269	1.260	33.4	190.9	206.0	0.503	39.9	0.398	17.7	2.3	0.062	0.000	186.5	31.6	7.2
11	23-JUN	80.4	0.69	1.429	1.408	32.4	235.1	253.8	0.615	43.7	0.570	24.0	2.3	0.000	0.000	189.2	40.5	7.1
12	23-JUN	83.9	0.95	1.438	1.412	31.5	290.9	300.7	0.337	23.9	0.199	29.8	2.2	0.000	0.000	188.7	14.1	7.0
13	23-JUN	85.9	1.32	1.355	1.335	11.6	356.3	375.9	0.178	13.3	0.114	40.2	2.1	0.000	0.000	188.7	8.5	3.7
14	23-JUN	86.8	2.14	1.434	1.404	32.1	245.3	264.7	0.639	44.9	0.612	24.2	2.4	0.037	0.000	204.3	43.0	7.0
15	23-JUN	85.7	2.66	1.339	1.338	32.0	248.1	265.3	0.561	41.9	0.521	24.4	2.4	0.000	0.000	203.7	38.9	7.0
16	23-JUN	84.1	2.32	1.334	1.330	29.9	295.6	307.3	0.371	27.9	0.000	30.2	3.6	0.139	0.000	261.7	0.0	6.5
17	23-JUN	81.4	2.34	1.244	1.219	0.0	293.1	294.9	0.000	0.0	0.000	29.1	4.5	0.092	0.000	300.0	0.0	1.2
18	23-JUN	80.6	1.81	0.985	0.930	0.0	252.5	271.9	0.000	0.0	0.000	26.1	4.5	0.000	0.000	298.5	0.0	1.0
19	23-JUN	74.1	1.99	0.016	0.000	0.0	213.5	252.1	0.000		0.000	23.7	4.6	0.000	0.000	297.0		1.0
20	23-JUN	67.2	2.01	0.000	0.000	0.0	191.6	235.3	0.000		0.000	21.9	4.7	0.000	0.000	295.5		1.0
174	23-JUN	75.1	1.28	12.12	11.93	DHW	HTST		3.20	32.0	2.54	328.1	55.2	0.41	0.50	253.2	21.3	56.1

Table 8.15: Clear Day Performance, Day 189 and Day 222

HR	DATE	AMB TEMP F	WIND VEL MPH	DIR INSQL MBTU	INC INSQL MBTU	LOOP FLOW KID/HR	COLL INLET F	COLL OUT F	ENER COLL MBTU	COLL EFF %	ENER DEL'V MBTU	PIPE LOSS MBTU	STOR LOSS KBTU	ADD STOR MBTU	REN STOR MBTU	AVE STOR F	SYS EFF %	PARA ENER KW
6	8-JUL	56.3	0.00	0.000	0.000	0.0	127.7	145.5	0.000		0.000	10.1	4.9	0.000	0.000	302.7		1.0
7	8-JUL	60.2	0.19	0.036	0.035	0.0	121.4	135.4	0.000	0.0	0.000	9.1	5.0	0.000	0.000	301.0	0.0	1.0
8	8-JUL	65.5	0.00	0.693	0.691	20.6	166.9	158.7	-0.200	-28.9	0.000	10.4	3.6	0.136	0.526	238.3	0.0	5.2
9	8-JUL	77.0	0.00	1.473	1.471	31.1	263.7	268.3	0.429	29.2	0.000	4.3	0.4	0.000	0.000	193.4	0.0	6.9
10	8-JUL	84.1	0.51	1.681	1.666	29.3	320.1	335.8	0.479	28.7	0.383	37.3	2.4	0.000	0.000	196.4	23.0	6.7
11	8-JUL	90.3	0.95	1.463	1.438	28.8	337.9	356.6	0.490	34.1	0.487	32.2	1.8	0.000	0.000	192.2	33.9	6.7
12	8-JUL	92.0	1.20	1.521	1.489	28.9	337.1	353.5	0.493	33.1	0.465	36.2	2.0	0.000	0.000	191.7	31.2	6.7
13	8-JUL	92.6	0.99	1.616	1.588	28.8	336.6	354.1	0.535	33.7	0.530	36.5	2.1	0.000	0.000	191.1	33.4	6.7
14	8-JUL	93.6	1.48	1.670	1.655	28.4	337.2	355.8	0.551	33.3	0.542	36.1	2.0	0.000	0.000	190.6	32.7	6.6
15	8-JUL	92.7	1.84	1.685	1.682	28.1	337.9	356.5	0.550	32.7	0.503	36.2	2.0	0.000	0.000	190.0	29.9	6.7
16	8-JUL	90.8	2.44	1.691	1.688	27.1	332.9	342.1	0.288	17.1	0.394	34.5	2.0	0.000	0.000	189.5	23.3	7.1
17	8-JUL	89.0	2.15	1.685	1.657	30.4	286.3	312.4	0.768	46.3	0.582	30.8	4.1	0.285	0.037	294.7	35.1	7.1
18	8-JUL	89.7	2.12	1.000	0.948	4.6	258.4	263.2	0.099	10.4	0.176	23.8	4.5	0.000	0.000	308.3	18.5	2.0
19	8-JUL	83.0	2.08	0.000	0.000	0.0	240.2	245.9	0.000		0.000	21.6	4.6	0.000	0.000	306.8		1.3
20	8-JUL	75.3	0.82	0.000	0.000	0.0	219.8	229.7	0.000		0.000	19.8	4.8	0.000	0.000	305.4		1.0
189	8-JUL	82.1	1.12	16.21	16.01	STEAM	-HTST	--DHW	4.48	28.0	4.06	178.9	46.2	0.60	0.60	239.5	25.4	72.7
6	10-AUG	68.4	0.03	0.000	0.000	0.0	94.8	91.3	0.000		0.000	2.1	1.0	0.000	0.000	116.8		1.1
7	10-AUG	70.2	0.29	0.000	0.000	0.0	92.4	91.6	0.000		0.000	1.9	0.9	0.000	0.000	116.6		1.0
8	10-AUG	73.5	0.00	0.133	0.132	0.0	92.7	91.0	0.000	0.0	0.000	1.3	0.9	0.000	0.000	116.5	0.0	1.0
9	10-AUG	81.5	0.16	0.664	0.655	20.3	94.9	94.3	0.009	1.4	0.011	1.3	0.7	0.000	0.000	116.5	1.7	5.2
10	10-AUG	87.3	0.48	0.818	0.792	31.8	159.5	168.8	0.172	21.7	0.000	11.8	0.6	0.000	0.000	157.5	0.0	7.1
11	10-AUG	92.2	0.77	1.068	1.017	31.6	221.6	234.7	0.420	41.3	0.371	20.6	0.5	0.000	0.000	116.3	36.5	7.0
12	10-AUG	93.9	1.27	1.144	1.082	32.5	200.9	214.4	0.436	40.3	0.426	16.7	0.5	0.000	0.000	116.2	39.4	7.1
13	10-AUG	95.2	1.42	1.323	1.260	32.0	222.8	237.0	0.458	36.3	0.437	19.6	0.4	0.000	0.000	116.1	34.7	7.0
14	10-AUG	95.7	2.09	1.394	1.350	31.6	227.1	242.4	0.492	36.4	0.474	20.3	0.4	0.000	0.000	116.0	35.1	7.0
15	10-AUG	96.6	1.98	1.388	1.369	31.6	233.0	249.0	0.511	37.3	0.494	21.0	0.4	0.000	0.000	115.9	36.1	7.0
16	10-AUG	94.7	2.46	1.316	1.314	30.4	272.3	279.6	0.248	18.9	0.208	25.1	0.7	0.070	0.000	128.1	15.8	6.8
17	10-AUG	92.6	2.18	1.213	1.209	31.4	245.5	261.4	0.504	41.7	0.173	23.1	2.2	0.361	0.007	202.4	14.3	7.2
18	10-AUG	90.7	1.46	0.600	0.585	30.6	282.2	287.6	0.176	30.1	0.000	26.3	4.0	0.141	0.000	282.5	0.0	7.0
19	10-AUG	83.2	1.16	0.000	0.000	0.0	284.0	284.2	0.000		0.000	26.6	4.4	0.000	0.000	294.2		1.2
20	10-AUG	77.7	0.95	0.000	0.000	0.0	249.4	262.0	0.000		0.000	23.9	4.5	0.000	0.000	292.9		1.0
222	10-AUG	86.2	1.11	11.06	10.76	DHW	HTST		3.43	31.9	2.59	241.6	22.1	0.57	0.01	160.3	24.1	73.7

Table 8.16: Clear Day Performance, Day 250

HR	DATE	AMB TEMP F	WIND VEL MPH	DIR INSOL MBTU	INC INSOL MBTU	LOOP FLOW KIB/HR	COLL INLET F	COLL OUT F	ENER COLL MBTU	COLL EFF %	ENER DEL'V MBTU	PIPE LOSS KBTU	STOR LOSS KBTU	ADD STOR MBTU	REN STOR MBTU	AVE STOR F	SYS EFF %	PARA ENER KW
6	7-SEP	62.3	0.03	0.000	0.000	0.0	120.1	143.4	0.000		0.000	9.9	2.6	0.000	0.000	187.0		1.0
7	7-SEP	61.1	0.00	0.000	0.000	0.0	114.2	135.7	0.000		0.000	8.9	2.6	0.000	0.000	186.3		1.0
8	7-SEP	64.1	0.00	0.001	0.000	0.0	112.1	130.3	0.000		0.000	7.7	2.5	0.000	0.000	185.7		1.0
9	7-SEP	70.6	0.09	0.627	0.594	25.6	115.6	119.3	0.001	0.1	0.070	4.2	1.7	0.000	0.000	185.1	11.8	6.2
10	7-SEP	82.7	0.18	1.204	1.100	31.9	177.1	190.1	0.423	38.4	0.319	15.2	2.2	0.000	0.000	184.6	29.0	6.9
11	7-SEP	88.9	1.21	1.290	1.144	31.2	216.6	231.2	0.459	40.1	0.390	19.7	2.0	0.000	0.000	184.1	34.1	6.9
12	7-SEP	91.2	0.57	1.303	1.142	30.7	232.3	247.2	0.452	39.6	0.432	21.7	1.9	0.000	0.000	183.5	37.8	6.9
13	7-SEP	92.8	1.08	1.247	1.106	30.1	248.3	258.7	0.323	29.2	0.229	22.9	1.9	0.000	0.000	183.0	20.7	6.8
14	7-SEP	94.1	1.43	1.381	1.262	28.9	313.3	324.5	0.323	25.6	0.262	31.8	1.8	0.000	0.000	182.5	20.8	6.6
15	7-SEP	95.0	1.64	1.450	1.375	29.7	264.6	283.0	0.566	41.2	0.565	26.1	1.8	0.000	0.000	182.0	41.1	6.7
16	7-SEP	94.0	1.55	1.475	1.444	28.7	322.9	333.8	0.316	21.9	0.203	32.6	1.8	0.000	0.000	181.5	14.1	6.6
17	7-SEP	90.5	2.68	1.327	1.324	10.4	316.5	340.8	0.169	12.7	0.162	34.3	1.9	0.000	0.000	183.6	12.2	3.2
18	7-SEP	84.3	1.99	0.033	0.032	0.0	281.3	301.4	0.000	0.0	0.000	29.3	2.1	0.000	0.000	183.4	0.0	1.0
19	7-SEP	77.0	2.03	0.000	0.000	0.0	246.3	262.6	0.000		0.000	24.4	2.2	0.000	0.000	182.9		1.0
20	7-SEP	72.5	0.94	0.000	0.000	0.0	222.7	235.2	0.000		0.000	21.0	2.3	0.000	0.000	182.4		1.0
250	7-SEP	81.5	1.03	11.34	10.52	ALL--	AUTO-		3.03	28.8	2.63	309.7	31.3	0.00	0.00	183.8	25.0	62.8

FIGURE 8.1: CLEAR DAY PERFORMANCE

FIGURE 8.2: CLEAR DAY PERFORMANCE

FIGURE 8.3: CLEAR DAY PERFORMANCE

FIGURE 8.4: CLEAR DAY PERFORMANCE

FIGURE 8.5: CLEAR DAY PERFORMANCE

FIGURE 8.6: CLEAR DAY PERFORMANCE

FIGURE 8.7: CLEAR DAY PERFORMANCE

FIGURE 8.8: CLEAR DAY PERFORMANCE

FIGURE 8.9: CLEAR DAY PERFORMANCE

FIGURE 8.10: CLEAR DAY PERFORMANCE

FIGURE 8.11: CLEAR DAY PERFORMANCE

Day 47 - February 16, 1983

Domestic hot water production was the operating mode on Day 47. Hot water demand by the laundry was high on this day, resulting in the best overall system efficiency to date. Insolation greater than 100 Btu/ft²-hr (315.2 W/m²) (collector start-up threshold) was recorded from 8:12 AM to 4:07 PM. Energy delivery was logged from 8:12 AM until 4:32 PM. Insolation recorded from the pyrheliometer on Day 47 was 1527 Btu/ft² (17.3×10^6 J/m²).

Demand for hot water on Day 47 was sufficient to warrant the extension of system operation for 15 minutes beyond normal shutdown time by manual control. As a result, collector and system efficiency values for the 17th hour report are inaccurate

as insolation less than 80 Btu/ft²-hr was not recorded during this period.

Day 88 - March 29, 1983

The Clear Day Performance Table is presented for two days in March to enable comparison of two operating modes under similar insolation conditions.

On Day 88, March 29, automatic system operation for domestic hot water was performed. Collector outlet temperatures did not exceed 260°F on this day. Low demand at mid-afternoon resulted in the addition of energy to storage. Insolation totalized from the pyrheliometer for Day 88 was 1,633 Btu/ft² (18.5×10^6 J/m²). Thirteen minutes of data were lost between 7:23 and 7:36 AM, and ten minutes of data are missing between 1:21 and 1:31 PM, due to improper data transfer between the data logger and the computer.

Day 89 - March 30, 1983

Fair skies and ambient air temperatures in the 80's (29.4°C) were recorded on Day 89, March 30. Startup was logged at 7:19 AM. Data acquisition was begun at 7:44 AM. Performance data for the 8th hour report includes manually calculated data for the 23 minute data gap. During industrial plant operations, the solar system was dedicated to steam generation. Steam production was achieved at 9:45 AM, 2.4 hours after start-up. Energy delivery to the domestic hot water tank was manually controlled after industrial plant shutdown at 3:30 PM. Manual control of solar system shutdown was performed to prolong energy input to the domestic hot water tank. Insolation was not monitored during the period of manual control between 4:38 PM and 5:18 PM. This accounts for the high efficiencies shown in the 17th hour report.

Day 104 - April 14, 1984

Routine automatic system operation was performed on Day 104. Startup was recorded at 6:59 AM. Energy was delivered to the DHW tank until 10:42 AM. Steam production was achieved intermittently between 10:42 AM and 3:30 PM, with a total of 370 pounds (167.8 kg) produced. After 3:30 PM, the DHW tank was charged, followed by energy addition to storage from 4:00 PM until autosutdown at 4:14 PM. System shutdown was extended 17 minutes by manual control of the solar fluid pump to maximize the addition of energy to storage.

Day 137 - May 17, 1983

Clear skies and ambient temperatures in the upper 80's (31.7°C) prevailed on Day 137, May 17. Automatic system operation was performed. Most of the collected energy was delivered to the domestic hot water tank. A total of 520 pounds (235.9 Kg) of steam was produced. System startup occurred at 7:24 AM. Saturation of process demand was observed at 4:22 PM when tracker disable/enable control cycling commenced (see Section 6.0). Shutdown was logged at 5:36 PM.

Day 174 - June 23, 1983

Early morning clouds were experienced on Day 174, with hazy sunshine for the remainder of the day. Startup occurred at 8:41 AM. Flow through the storage tank was established manually for 15 minutes at startup. Energy was delivered to the domestic hot water tank until 3:30 PM, when heat was added to storage. The system was shutdown at 4:56 PM by Home Laundry personnel, approximately 1.5 hours before insolation was no longer available. Day 174 represents a typical day of operation by Home Laundry personnel.

Day 189 - July 8, 1983

Smoggy sunshine and light winds prevailed on Day 189, July 8. Collector reflective surfaces were relatively dirty, with a reflectivity value of 74.0 percent obtained during morning hours. Flow through HTST-1 was established for 0.4 hours at startup to shorten the recirculation period. The system was operated for steam generation until industrial plant shutdown at 3:30 PM. Energy addition to storage was then begun, followed by production of domestic hot water after 4:00 PM. Energy delivery values for Day 189 are for steam generation through the 16th hour report, and for domestic hot water production thereafter. A system shutdown due to a high compression tank level was experienced at 3:26 PM. The level was corrected and the system was reset at 3:38 PM for a total of 0.2 hours downtime. The system was shutdown by Home Laundry personnel at 5:00 PM, approximately 45 minutes before solar energy was no longer available.

Day 222 - August 10, 1983

Hazy sunshine and high humidity were recorded on Day 222, August 10. The system was operated for domestic hot water production. Startup was recorded at 7:50 AM. Energy was added to the high temperature storage tank late in the operating day. Shutdown occurred at 5:33 PM.

Day 250 - September 7, 1983

Routine automatic system operations were conducted on Day 250. Generally, fair, hazy skies were recorded with a few scattered clouds in the morning. Collector washing was performed more than three weeks before the clear day study. Reflectivity efficiency was recorded at 79.7 percent on August 25.

Energy delivery as domestic hot water is favored under the automatic operating mode. Steam production was sustained for about 0.7 hours on Day 250 out of a total of 8.0 hours of operation. Automatic system shutdown was initiated by a low air pressure signal resulting from shutdown of the air compressor by Home Laundry personnel around 3:45 PM. Shutdown was completed at 4:23 PM, approximately 0.6 hours before insolation was no longer available.

8.2 Analysis of Results

Monthly data for energy delivery, parasitic energy demands, available insolation, and energy collected are depicted graphically in Figures 8.12 and 8.13. An error of 6% was found in determining the annual energy balance.

Data for January were available for the latter part of the month only, from January 20 through 31. An unusually cloudy late spring for Southern California resulted in reduced availability of solar energy for June. Performance data were not available for some periods of DAS downtime.

Energy flow diagrams for July (noon, one-day, month) and January 20 through September 30 are shown in Figures 8.14 through 8.17. Insolation available before solar plant startup and after shutdown is not monitored, and is estimated at 8% of the total insolation available during operation. Energy in megawatt-hours and in relative units are indicated.

A reduction in emission of pollutants resulted from operation of the solar plant. Based on published air pollution emission factors (EPA, 1982), emission of the following quantities of pollutants was avoided as a result of solar system operation: particulates -

FIGURE 8.12: ENERGY DELIVERED

JANUARY 20-SEPTEMBER 30, 1983

FIGURE 8.13: ENERGY COLLECTED

JANUARY 20-SEPTEMBER 30, 1983

Figure 8.14: ENERGY FLOW DIAGRAM FOR THE NOON HOUR JULY 8, 1983

Figure 8.15: ENERGY FLOW DIAGRAM FOR JULY 8, 1983 - DAY 189

Figure 8.16: ENERGY FLOW DIAGRAM FOR JULY, 1983

Figure 8.17: ENERGY FLOW DIAGRAM FOR JANUARY 20 - SEPTEMBER 30, 1983

2.47 lbs; sulfur dioxide - 0.29 lb; nitrogen oxides - 49.48 lbs; carbon monoxide - 9.90 lbs; volatile organics, non-methane - 2.62 lb; volatile organics, methane - 1.34 lb.

8.2.1 Comparative Operating Modes

To evaluate overall system performance characteristics, the system was operated under the seven operating modes identified in Section 6.0. A total of 75 days between March 30 and September 27 were analyzed to determine the most efficient operations mode. Mean system efficiency figures for each mode were determined. The results are shown in Table 8.17, with the operating modes ranked from most to least efficient.

TABLE 8.17
SYSTEM EFFICIENCY UNDER DIFFERENT OPERATING MODES

<u>Operations Mode</u>	<u>Mean Sys. Eff.</u>	<u>Std. Dev.</u>	<u>No. of Data Points</u>
DHW and Steam	40.6	7.70	6
DHW only	37.6	9.46	25
Steam/DHW/HTST	31.1	4.31	7
DHW and HTST	29.7	12.33	10
All Auto	29.5	6.82	24
Steam only	29.4	--	1
Steam and HTST	29.1	16.76	3

The validity of specific conclusions regarding operations modes is questionable when the influence of uncontrolled variables such as fluctuating demand, DAS downtime, or insolation quality (e.g. scattered clouds vs. hazy sunshine) is considered. This is especially true for the four operations modes with less than ten data points.

However, the general conclusion that domestic hot water production is the most efficient operating mode appears to be supported by the data.

Two factors further support this conclusion. First, all energy delivered by the solar system is credited towards a reduction in steam production by the existing system regardless of the type of energy delivered. This does not take into account the efficiency of the method used by the existing system to produce domestic hot water. Second, energy inputs to exceed the latent heat of evaporation are not required for domestic hot water production. Energy delivery can commence almost immediately after startup under the DHW operations mode. Recirculation before steam production requires at least 45 minutes under optimum conditions based on operating experience.

8.2.2 Directed Studies

The performance data were reviewed to determine the benefit of two control functions, "bootstrapping" the closed solar loop upon startup with stored thermal energy to decrease the recirculation period, and the array and steam generator bypass control functions. Flow through the storage tank requires manual control; array and steam generator bypass controls are automated.

Flow through the high temperature storage tank was manually controlled at startup on 31 days between March 30 and September 27 over 75 entries. On each day, circulation through the tank was maintained until the addition of energy to storage was observed (positive ΔT across HTST-1). Depending upon insolation conditions, operating mode, and

the quality of thermal energy stored in the tank prior to start up, duration of flow through the tank was 10 to 40 minutes. "Bootstrapping" was performed under all seven operating modes.

The mean system efficiency for days when flow through the storage tank was established at startup was 32.3%, with a standard deviation of 7.87% over 31 data points. Mean system efficiency on days without flow through the storage tank at startup was 32.4%, with a standard deviation of 8.19% over 75 entries. It is apparent that no benefit is derived from the "bootstrapping" operations procedure.

On July 8, both the array and steam generator automatic bypass control functions were defeated. This measure was taken to permit a comparison of system performance with and without these control functions in force. The bypass control functions were included in the design of the control system to eliminate heat losses resulting from (1) flow through the collector array when no insolation was present; or (2) flow through the steam generator when energy was being added to the closed solar loop by make up water in the steam generator shell. These conditions were rarely observed by the operator, primarily because circulation of the solar fluid was discontinued ten minutes after a low insolation condition was sensed. Pump shutdown typically occurred before heat losses from the array or the steam generator were experienced.

The period from March 30 through September 27 was analyzed to determine the impact of disconnecting the array and steam generator bypass controls. Prior to July 8, mean daily system efficiency was 34.1%, with a standard

deviation of 9.10% over 54 entries. After July 8, mean daily system efficiency was 29.9%, with a standard deviation of 7.67% over 50 data points. The data suggest that no benefit was derived from inclusion of the bypass controls in the control circuitry. It can be argued that their inclusion introduces unnecessary complexity into the system, and requires additional expense for equipment monitoring and calibration.

8.3 Performance Simulation

Modeling of solar energy system performance at Home Laundry was done by the Solar Energy Research Institute using the SOLIPH computer program. Two operating modes were considered, operation for domestic hot water production, and operation for steam production. Performance simulation in each mode was for weekdays only, from 7:00 AM until 3:30 PM. Results of the SOLIPH modeling are presented as Tables 8.18 and 8.19.

Comparison of actual to simulated performance is complicated by the fact that routine operation at Home Laundry included the application of many operating modes in any given period. For example, under the automatic operations mode, energy delivery as domestic hot water and steam can occur over as short a period as 2 or 3 hours. On many summer days, energy addition to storage was a routine late afternoon operations practice. An effort was made in July to control system operations in a specified operations mode for discreet periods to ease comparison of actual and predicted performance.

SOLIPH output for both operating modes, and actual performance results for the months of February through September are shown graphically in Figure 8.18. The SOLIPH data has been adjusted for

HOME LAUNDRY (DHW)
ANNUAL PERFORMANCE SUMMARY TABLE

MONTH	INCIDENT SOLAR ENERGY			COLLECTOR EFFICIENCY BASED ON		ENERGY DELIVERED GJ	PIPING			SYSTEM EFFICIENCY BASED ON		PARASITIC ENERGY GJ
	HORIZONTAL SURFACE (1) GJ	COLLECTOR PLANE (2) GJ	ENERGY COLLECTED GJ	(1) %	(2) %		OPERATING LOSSES GJ	NON-OPERATING LOSSES GJ	STORAGE LOSSES GJ	(1) %	(2) %	
JANUARY	144.7	137.0	66.7	46.1	48.7	54.4	7.1	4.3	.0	37.6	39.7	3.7
FEBRUARY	171.2	145.0	74.1	43.3	51.1	59.8	8.1	5.5	.0	34.9	41.2	3.3
MARCH	248.0	192.0	101.6	41.0	52.9	81.1	11.2	8.3	.0	32.7	42.2	3.9
APRIL	276.0	204.1	110.1	39.0	53.9	87.3	12.1	9.3	.0	31.5	42.7	3.5
MAY	343.7	237.2	130.0	37.8	54.8	103.9	14.2	10.7	.0	30.2	43.8	4.1
JUNE	308.4	192.6	106.4	34.5	55.3	83.9	11.5	9.9	.0	27.2	43.6	3.3
JULY	362.6	295.2	162.2	44.7	54.9	131.6	18.0	11.1	.0	36.3	44.6	4.7
AUGUST	343.3	285.1	154.9	45.1	54.3	125.2	16.8	11.5	.0	36.5	43.9	4.7
SEPTEMBER	241.8	197.3	105.7	43.7	53.6	84.9	11.3	8.6	.0	35.1	43.1	3.7
OCTOBER	205.5	164.7	85.6	41.7	52.0	68.4	9.0	7.3	.0	33.3	41.5	3.6
NOVEMBER	151.5	132.9	65.8	43.4	49.5	54.0	6.9	4.3	.0	35.6	40.6	3.5
DECEMBER	120.1	108.4	52.0	43.3	48.0	42.3	5.3	3.8	.0	35.2	39.1	3.3
TOTALS/AVERAGES	2917.5	2291.5	1215.1	41.7	53.0	976.7	131.5	94.5	.0	33.5	42.6	45.2

Table 8.18: Simulated Performance by SOLIPH Model for DHW Production

HOME LAUNDRY (STEAM)
ANNUAL PERFORMANCE SUMMARY TABLE

MONTH	INCIDENT SOLAR ENERGY			COLLECTOR EFFICIENCY BASED ON		ENERGY DELIVERED GJ	PIPING			SYSTEM EFFICIENCY BASED ON		PARASITIC ENERGY GJ
	HORIZONTAL SURFACE	COLLECTOR PLANE	ENERGY COLLECTED GJ	(1) %	(2) %		OPERATING LOSSES GJ	NON-OPERATING LOSSES GJ	STORAGE LOSSES GJ	(1) %	(2) %	
	(1) GJ	(2) GJ										
JANUARY	144.7	137.0	61.5	42.5	44.9	31.4	16.3	11.6	.0	21.7	22.9	3.7
FEBRUARY	171.2	145.0	69.6	40.6	48.0	41.0	15.4	11.5	.0	23.9	28.3	3.3
MARCH	248.0	192.0	96.7	39.0	50.4	62.5	18.4	14.1	.0	25.2	32.5	3.1
APRIL	276.8	204.1	106.4	38.4	52.1	74.1	17.2	13.2	.0	26.8	36.3	3.5
MAY	343.7	237.2	125.7	36.6	53.0	88.2	20.2	15.4	.0	25.7	37.2	4.1
JUNE	308.4	192.5	103.1	33.4	53.6	71.4	16.1	14.0	.0	23.1	37.1	3.3
JULY	362.6	295.2	157.7	43.5	53.4	117.6	23.9	14.1	.0	32.4	39.8	4.7
AUGUST	343.3	285.1	150.1	43.7	52.7	109.2	23.4	15.5	.0	31.8	38.3	4.7
SEPTEMBER	241.8	197.3	101.4	41.9	51.4	68.7	17.7	13.4	.0	28.4	34.8	3.7
OCTOBER	205.5	164.7	81.0	39.4	49.2	48.6	16.4	13.8	.0	23.6	29.5	3.6
NOVEMBER	151.5	132.9	61.0	40.3	45.9	32.4	15.6	11.2	.0	21.4	24.4	3.5
DECEMBER	120.1	108.4	47.7	39.7	44.0	20.0	13.8	11.9	.0	16.7	18.5	3.3
TOTALS/AVERAGES	2917.5	2291.6	1161.9	39.8	50.7	765.1	214.6	159.8	.0	26.2	33.4	45.2

Table 8.19: Simulated Performance by SOLIPH Model for Steam Production

the difference between statistical insolation data used to model performance and the insolation actually received. The insolation correction factor was derived by multiplying the SOLIPH energy delivery values by the ratio of actual to statistical insolation data. System efficiency based on incident solar energy in the collector plane is plotted in Figure 8.19.

From Figure 8.18 it can be seen that actual performance fell short of simulated results. Offered as possible explanations for this fact are the following points:

- o Mirror reflectivity was lower than that of new mirrors used to develop collector efficiency curves. Reflectivity of new mirrors was measured at 95.5%. Field measurements show a peak reflectivity for clean mirrors of 83.2%.
- o Mirror cleanliness is a factor to be considered in the performance of solar systems using concentrating collectors.
- o Tracking accuracy and collector alignment are not controlled as carefully in a field environment as they are in a test park environment.
- o Insolation availability in Southern California was lower than average for the period. Although adjustments for the discrepancy between actual and predicted insolation were made, the temporal distribution of insolation has an effect on steady state operation of the solar energy system, especially if operation is for steam production.

FIGURE 8.18

ACTUAL VS. SIMULATED ENERGY DELIVERY

FIGURE 8.19

ACTUAL VS. SIMULATED SYSTEM EFFICIENCY

Many of the above factors may have been considered in the configuration of the SOLIPH code for Home Laundry. It is assumed in this discussion that the reasons for the discrepancy between actual and simulated performance are due primarily to the influence of the field environment, and not to the model itself.

9.0 ANNUAL OPERATING BUDGET

For the period from January 20 through September 31, a total of 494,851 ft³ (14,013 m³) of natural gas was offset by operation of the solar energy system. The value of this fuel is \$ 3,340.95. A combustion efficiency of 80% and a gas-fired boiler efficiency of 70% was used in the fossil fuel savings computation. A summary of fossil fuel savings is presented in Table 9.1.

Expenses incurred for purchase of electricity to meet parasitic energy demand, production of steam for boiler feedwater preheating, labor for maintenance and operations monitoring, and consumable materials for the year totaled \$7,938.14. A monthly breakdown of operating expenses is shown in Table 9.2. A labor rate of \$28.00 per hour was used to compute labor costs, except for collector cleaning. The cost of labor for collector cleaning was calculated using a rate of \$15.60 per hour.

Property taxes levied by the County of Los Angeles for the solar energy system were \$6,000.00 annually.

TABLE 9.1 FOSSIL FUEL SAVINGS

Month	Energy Delivered (MBTU)	Natural Gas Offset ^a (FT ³)	Billing Rate (¢/Therm)	Value (\$)
January ^b	5.0	8,585	0.62036	53.26
February	15.6	26,948	0.62036	167.17
March	26.4	45,604	0.62036	282.91
April	36.2	62,532	0.62036	378.92
May	37.4	64,605	0.62036	400.78
June	36.2	62,532	0.71810	449.04
July	59.4	102,608	0.71810	736.83
August	48.3	83,434	0.71810	599.14
September	22.0	38,003	0.71810	272.90
TOTAL	286.5	494,851	--	<u>3,340.95</u>

^a Assumes 80% combustion efficiency, and 70% gas-fired boiler efficiency.

^b Partial month only - Jan 20 to Jan 31.

TABLE 9.2 COST-TO-OPERATE, OCTOBER 1982 THROUGH SEPTEMBER 1983

Month	Electricity (\$)	Steam (\$)	Labor (\$)	Materials (\$)
October	70.00 ^a	--	284.40	9.15
November	65.00 ^a	--	341.92	30.72
December	60.00 ^a	--	295.92	479.00 ^b
January	54.10	--	429.40	--
February	65.91	--	544.16	--
March	94.67	6.30	452.08	6.16
April	81.33	6.13	412.24	5.99
May	80.50	8.63	339.76	8.46
June	95.68	7.11	763.60	26.95
July	103.66	49.58	917.60	48.49
August	108.78	22.72	744.40	22.22
September	<u>73.52</u>	<u>1.77</u>	<u>584.40</u>	<u>138.73</u>
Totals (\$)	950.15	102.24	6,109.88	775.87
GRAND TOTAL (\$)				<u><u>7,938.14</u></u>

^a Estimated.

^b Includes calibration services.

No savings were derived from operation of the solar energy system at Home Laundry. For the period from February through September, the cost to operate the plant totaled \$5,821.53, and property taxes for the same period were \$4,000.00. Fossil fuel savings for the period were \$3,287.69. Fossil fuel savings resulting from energy delivery during periods of DAS downtime have not been accounted for.

10.0 MAJOR LESSONS LEARNED

Design: The inclusion in the design of both high and low temperature energy delivery options proved to be very useful in allowing flexibility of operation under a wide range of conditions.

Complexity in the design of solar energy systems is unnecessary and hinders detection of problems during startup and initial operation.

The datalogger should not be used to perform control functions. Data acquisition should be accomplished by a stand alone subsystem to permit independent operation and manipulation.

Construction: A requirement for an elevated support structure results in increased cost and complicates the construction effort.

Operation: The reliability of the system was high, with only minor downtime experienced. Most downtime resulted from two recurring problems - compression tank low level resulting from excessive leakage through the circulation pump packing, and data acquisition system related shutdowns.

Although the system was designed for stand-alone operation, the attention of a qualified individual to monitor system operation and troubleshoot failures was required. An operating budget should include a conservative allowance for manpower to operate and maintain the plant.

Frequent collector washing using manual spray washing techniques is not economically justifiable. Collector cleaning should be performed whenever possible by rain rinsing.

Performance: The influence of environmental factors and manpower availability in an industrial application should be considered in making performance predictions.

Savings generated by solar plant operation at Home Laundry were not sufficient to offset operating costs.

Analysis: The capability of on site data reduction provides a useful tool for diagnosis of anomalous system conditions and identification of performance trends. A backup source of raw data is required to enable manual calculation of performance data during any DAS downtime.

11.0 CONCLUSIONS

The solar energy system at Home Laundry operated reliably once deficiencies identified during the construction phase were rectified. Energy was delivered routinely to industrial processes during periods of available insolation. System performance fell below design predictions primarily due to lower than expected insolation, mirror degradation, and tracking inaccuracies. Energy savings were not substantial enough to offset operating costs.

The Del concentrating collector proved to be adequate for production of low pressure steam. Control functions implemented to limit collector outlet temperatures were exercised regularly, demonstrating the capability of the as-built array to sustain temperatures in excess of 400°F (204°C). The amounts of solar energy available at winter solstice, however, were not sufficient for steam production to be achieved. The alternate operations mode for energy delivery to the domestic hot water tank was a valuable option during periods of reduced solar energy availability.

Operations monitoring and maintenance manpower requirements were greater than anticipated by system designers. The greatest effort was required for tracker troubleshooting, collector cleaning, and data acquisition system debugging. Despite a successful redesign of collector drive motor control circuitry, tracker inaccuracies resulted from failed relays, switches, and photodiodes. The Delavan shadow band tracker operates well under optimum conditions (bright sunshine), but its performance is marginal under hazy skies (insolation levels between 100 Btu/ft²-hr and 125 Btu/ft²-hr (315 W/m²-395 W/m²)). Collector washing by manual methods was not economically justified on the basis of relative energy production before and after a wash. The complex nature of the Data Monitoring and Control system resulted in lost data and system downtime, and required frequent operator attention. This

requirement can be expected to be substantially less when monitoring for experimental purposes is not essential.

With the exception of a fundamental error in the equation for calculating incidence angle effects on solar availability, the analytical techniques used to document system performance were effective. On site data reduction is preferred from the operator's standpoint, as it allows quick assessment of operational trends that develop from such conditions as tracking errors or demand fluctuations. A substantial amount of time and effort was required to develop and debug software to meet data acquisition and reduction needs for the Home Laundry solar experiment.

Analysis of performance data has confirmed the assumption that low temperature energy delivery applications yield higher efficiencies than other modes of operation. Energy required during recirculation to elevate operating temperatures for steam generation can be delivered to the domestic hot water tank, resulting in better utilization of solar energy. "Bootstrapping," or using stored solar thermal energy to shorten the recirculation period at startup, was found to be of little benefit overall, especially in view of the requirement for manual control to achieve flow through the storage tank.

Natural gas not consumed as a result of solar plant operations was of less value than the resources required to run the experiment. Manpower devoted to operations monitoring to ensure proper execution of experimental procedures would not be required in commercial application of solar energy. Manpower requirements for maintenance are not considered to be directly proportional to the size of a solar system. Reductions in staffing requirements in a commercial operation, coupled with increased design energy delivery, would improve the cost effectiveness of a solar plant.

12.0 RECOMMENDATIONS

- o Design instrumentation and monitoring equipment such that data acquisition can be accomplished independently of control functions.
- o Incorporate optional low temperature energy delivery application into the design of solar thermal plants primarily intended for steam or electric power production.
- o Attempt to maintain simplicity in the design of solar thermal systems. Eliminate unnecessary valves, bypass loops, or control functions not essential for plant operation. Keep control logic simple.
- o Establish contract mechanisms for experimental government funded solar installations that safeguard against project termination before the full research value of the project is realized.
- o Encourage development of non-optical, microprocessor-based tracking systems to enable these systems to compete with optical tracking devices on a cost basis.
- o Schedule long lead times prior to commencement of the operations monitoring and evaluation period for shakedown of the facility and debugging of data acquisition software.
- o Plan for a liberal allowance for manpower to perform operations monitoring and maintenance tasks. Ensure operator involvement early in the project.

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APPENDIX A

THE HOME LAUNDRY CO.

SYSTEM OPERATION SUMMARY TABLE

OCTOBER, 1982

DATE	JULIAN DAY	STATUS CODE	WEATHER	COMMENTS
10/1	274	1	F	DHW production
10/2	275	6	-	Weekend
10/3	276	6	-	Weekend
10/4	277	3	P	No solar system operator
10/5	278	1	P	DHW production
10/6	279	1	F	DHW production
10/7	280	1	P	DHW production
10/8	281	1	F	DHW production
10/9	282	6	-	Weekend
10/10	283	6	-	Weekend
10/11	284	1	F	DHW production
10/12	285	1	F	DHW production
10/13	286	1	F	DHW production
10/14	287	1	F	DHW production
10/15	288	1	F	DHW production
10/16	289	6	-	Weekend
10/17	290	6	-	Weekend
10/18	291	1	P	DHW production
10/19	292	1	P	DHW production
10/20	293	1	C	DHW production
10/21	294	1	C	
10/22	295	1	C	T.E. comparison test
10/23	296	6	-	Weekend
10/24	297	6	-	Weekend
10/25	298	1	C	
10/26	299	1	R	Rain rinse
10/27	300	1	F	DHW production, P.F. test 11:30 a.m.
10/28	301	1	F	DHW production
10/29	302	1	F	DHW production
10/30	303	6	-	Weekend
10/31	304	6	-	Weekend

Status Code Key

Status Code	Solar System	Industrial Plant
1	Up	Up
2	Down	Up
3	Idle	Up
4	Up	Down
5	Down	Down
6	Idle	Down

Weather Key

F = Fair
P = Partly Cloudy
C = Fog or Overcast
R = Rain

APPENDIX A (continued)

THE HOME LAUNDRY CO. SYSTEM OPERATION SUMMARY TABLE NOVEMBER, 1982

DATE	JULIAN DAY	STATUS CODE	WEATHER	COMMENTS
11/1	305	1	F	DHW production
11/2	306	1	F	DHW production. Motorgroup #9 down for tracker repair.
11/3	307	1	F	DHW production
11/4	308	1	F	DHW production
11/5	309	3	F	DHW production. System idle P.M. due to operator error.
11/6	310	6	-	Weekend
11/7	311	6	-	Weekend
11/8	312	1	P	DHW production
11/9	313	1	C	Motor group #9 tracker replaced
11/10	314	1	C	
11/11	315	1	F	DHW production
11/12	316	1	F	DHW production
11/13	317	6	-	Weekend
11/14	318	6	-	Weekend
11/15	319	1	F	DHW production
11/16	320	1	C	
11/17	321	1	F	DHW production. N ₂ array down 8-11 am for receiver replacement
11/18	322	1	C	Rain rinse late P.M. N ₂ array down 8-11 am for receiver replacement.
11/19	323	1	P	DHW production
11/20	324	6	-	Weekend
11/21	325	6	-	Weekend
11/22	326	1	C	
11/23	327	1	C	
11/24	328	1	F	DHW production
11/25	329	6	-	Holiday
11/26	330	1	F	DHW production
11/27	331	1	F	DHW production
11/28	332	6	-	Weekend
11/29	333	1	C	
11/30	334	1	P	

APPENDIX A (continued)
The Home Laundry Co.
System Operation Summary

December, 1982

Date	Julian Day	Status Code	Weather	Comments
1	335	1	F	
2	336	1	F	
3	337	1	F	Startup delayed 45 min. for D.A.S. work.
4	338	6	-	Weekend
5	339	6	-	Weekend
6	340	1	F	D.A.S. on line.
7	341	1	C	
8	342	1	C	
9	343	1	C	
10	344	1	P	
11	345	6	-	Weekend
12	346	6	-	Weekend
13	347	1	P	
14	348	1	F	
15	349	1	P	
16	350	1	P	
17	351	1	F	
18	352	6	-	Weekend
19	353	6	-	Weekend
20	354	1	P	
21	355	1	C	
22	356	1	R	Rain rinse
23	357	1	F	Attempted steam prod.
24	358	1	F	Winds >40 mph. System shutdown at NOON.
25	359	6	-	Holiday
26	360	6	-	Weekend
27	361	1	C	
28	362	1	C	
29	363	1	F	D.A.S. idled.
30	364	1	F	D.A.S. idled.
31	365	1	F	Process shutdown at NOON.

APPENDIX A (continued)

THE HOME LAUNDRY SOLAR I.P.H. PROJECT
SYSTEM OPERATIONAL SUMMARY

January, 1983

Date	Julian Day	Status Code	Weather	Comments
1	1	6	-	
2	2	6	-	
3	3	1	F	DAS down.
4	4	1	F	
5	5	1	F	
6	6	1	F	Two hours data lost.
7	7	1	F	DAS down 1 p.m. on.
8	8	6	-	
9	9	6	-	
10	10	1	F	Data logged 2 hrs only.
11	11	1	F	DAS down. Printer replaced.
12	12	1	F	DAS down.
13	13	1	F	DAS down. Datalogger relay replaced.
14	14	1	F	DAS on line.
15	15	6	-	
16	16	6	-	
17	17	1	P	
18	18	1	P	
19	19	1	P	
20	20	1	F	
21	21	1	C	
22	22	6	R	Rain rinse.
23	23	6	-	
24	24	1	R	Rain rinse.
25	25	1	P	
26	26	1	P	Three hours data lost.
27	27	1	R	Rain rinse.
28	28	1	P	
29	29	6	-	
30	30	6	-	
31	31	1	F	DAS down.

APPENDIX A (continued)

THE HOME LAUNDRY SOLAR I.P.H. PROJECT
SYSTEM OPERATIONAL SUMMARY

February 1983

Date	Julian Day	Status Code	Weather	Comments
1	32	1	F	D.A.S. off-line 6 hrs.
2	33	1	R	Rain rinse.
3	34	1	P	
4	35	1	F	No demand p.m.
5	36	6	-	Weekend.
6	37	6	-	Weekend.
7	38	1	R	Rain rinse.
8	39	1	C	
9	40	1	P	Pyrheliometer down. Manual system operation.
10	41	1	P	Pyrheliometer on-line. Low demand p.m.
11	42	1	F	D.A.S. off-line 3 hrs.
12	43	6	-	Weekend.
13	44	6	-	Weekend.
14	45	1	F	D.A.S. off-line a.m.
15	46	1	F	
16	47	1	F	
17	48	1	F	D.A.S. down 2 hrs late p.m.
18	49	1	C	
19	50	6	-	Weekend.
20	51	6	-	Weekend.
21	52	1	F	
22	53	1	F	D.A.S. off-line 6 hrs.
23	54	1	C	
24	55	1	C	E Del'v from storage.
25	56	1	P	D.A.S. off-line 5 hrs.
26	57	6	-	Weekend.
27	58	6	-	Weekend.
28	59	1	R	Rain rinse. D.A.S. off-line 2 hrs.

APPENDIX A (continued)

THE HOME LAUNDRY SOLAR I.P.H. PROJECT
SYSTEM OPERATIONAL SUMMARY

March 1983

Date	Julian Day	Status Code	Weather	Comments
1.	60	1	R	Rain rinse.
2	61	1	R	
3	62	1	R	Rain rinse.
4	63	1	P	
5	64	6	-	Weekend.
6	65	6	-	Weekend.
7	66	1	P	
8	67	1	P	
9	68	1	F	
10	69	1	P	D.A.S. down 1 hr.
11	70	1	C	
12	71	6	-	Weekend.
13	72	6	R	Weekend. Rain rinse.
14	73	1	P	
15	74	1	F	Power failure. D.A.S. down 2 hrs.
16	75	1	F	Steam production.
17	76	1	C	
18	77	1	R	
19	78	6	-	Weekend.
20	79	6	-	Weekend.
21	80	1	C	
22	81	1	C	
23	82	1	R	Rain rinse.
24	83	1	P	
25	84	1	P	D.A.S. down 3 hrs.
26	85	6	-	Weekend.
27	86	6	-	Weekend.
28	87	1	C	
29	88	1	F	0.4 hrs. data lost.
30	89	1	F	Steam production.
31	90	1	F	Steam production. D.A.S. down 6.5 hrs.

APPENDIX A (continued)

THE HOME LAUNDRY SOLAR I.P.H. PROJECT
SYSTEM OPERATIONAL SUMMARY

April 1983

Date	Julian Day	Status Code	Weather	Comments
1	91	1	F	33 min. data not collected
2	92	6	-	
3	93	6	-	
4	94	1	P	30 min. data not collected, pyrheliometer misaligned
5	95	1	P	Rain rinse P.M.
6	96	1	F	DAS down 'til 10:24 A.M. for report prep.
7	97	1	F	DAS down 'til 9:05 A.M. for report prep; manual operation
8	98	1	F	33 min. data not collected
9	99	6	-	
10	100	6	-	
11	101	1	C	
12	102	1	P	DAS down P.M.
13	103	1	F	D.A.S. down 1.7 hrs for program mod.
14	104	1	F	
15	105	1	F	Early shutdown 1:40 P.M. by Home Laundry
16	106	6	-	
17	107	6	-	
18	108	1	P	Manual operation required
19	109	1	C	
20	110	1	R	Rain rinse
21	111	1	C	
22	112	1	C	
23	113	6	-	Power failure
24	114	6	-	
25	115	2	P	
26	116	1	C	
27	117	1	P	Early shutdown 3:30 P.M. by Home Laundry
28	118	1	C	
29	119	1	C	
30	120	6	-	

APPENDIX A (continued)

THE HOME LAUNDRY SOLAR I.P.H. PROJECT
SYSTEM OPERATIONAL SUMMARY

May 1983

Date	Julian Day	Status Code	Weather	Comments
1	121	6	-	
2	122	1	F	Manual startup. Pyrheliometer not aligned until 9:10 a.m.
3	123	1	F	D.A.S. down 35 min. a.m. for April report preparation
4	124	1	C	D.A.S. down from 1:15 p.m. for inspection
5	125	1	C	D.A.S. down from noon for disk drive repair
6	126	1	P	D.A.S. down
7	127	6	-	
8	128	6	-	
9	129	1	P	D.A.S. down
10	130	1	P	D.A.S. down
11	131	1	F	D.A.S. down
12	132	1	F	D.A.S. returned to service 8:45 a.m.
13	133	1	C	
14	134	6	-	
15	135	6	-	
16	136	1	P	D.A.S. down from 2:00 p.m.; printer programming error
17	137	1	F	
18	138	1	P	20 min. downtime due to low compression tank level
19	139	1	F	
20	140	1	F	3.8 hrs downtime due to low compression tank level
21	141	6	-	
22	142	6	-	
23	143	1	F	
24	144	1	F	2.3 hrs downtime due to low compression tank level
25	145	1	P	
26	146	1	P	
27	147	1	F	
28	148	6	-	
29	149	6	-	
30	150	6	-	Plant holiday
31	151	1	C	

APPENDIX A (continued)

THE HOME LAUNDRY SOLAR I.P.H. PROJECT
SYSTEM OPERATIONAL SUMMARY

June 1983

Date	Julian Day	Status Code	Weather	Comments
1	152	1	P	
2	153	1	C	
3	154	1	P	D.A.S. down 3.8 hours
4	155	6	—	
5	156	6	—	
6	157	1	F	Clouds AM
7	158	1	F	Clouds AM
8	159	1	F	Clouds AM; SG-1 high level alarm
9	160	1	F	Clouds AM
10	161	1	F	System saturated at 4:30 PM
11	162	6	P	Collector washing
12	163	6	—	
13	164	1	F	System down 1.1 hr, CT-1 level; system saturated by 4:00 PM
14	165	1	F	
15	166	1	F	Clouds early AM; system down 0.2 hr, SG-1 pressure
16	167	1	F	Clouds early AM; system not available 1.5 hr, operator error, trackers not enabled
17	168	1	F	Clouds early AM; 10th hr data not collected. System saturated at 3:27 PM
18	169	6	—	
19	170	6	—	
20	171	1	P	
21	172	1	P	
22	173	1	P	System down 1.4 hr; CT-1 level
23	174	1	P	
24	175	1	P	
25	176	6	—	
26	177	6	—	
27	178	1	C	
28	179	1	P	Clouds AM
29	180	1	C	
30	181	1	C	

APPENDIX A (continued)

THE HOME LAUNDRY SOLAR I.P.H. PROJECT
SYSTEM OPERATIONAL SUMMARY
July 1983

Date	Julian Day	Status Code	Weather	Comments
1	182	1	C	
2	183	6	--	
3	184	6	--	
4	185	6	--	Plant holiday
5	186	1	F	0.3 hrs system downtime high CT-1 level
6	187	1	F	Clouds AM; system saturated at 4:39 PM
7	188	1	F	
8	189	1	F	0.2 hrs system downtime, high CT-1 level
9	190	6	F	Collector washing
10	191	6	--	
11	192	1	F	3.0 hrs system downtime; low flow; 0.5 hrs D.A.S downtime.
12	193	1	F	System saturated 4:37 PM
13	194	1	F	3:30 PM shutdown
14	195	1	F	3:30 PM shutdown; 2.6 hrs D.A.S. downtime
15	196	1	F	3:30 PM shutdown; 2.9 hrs D.A.S. downtime
16	197	6	--	
17	198	6	--	
18	199	1	F	3:30 PM shutdown; 2.5 hrs D.A.S. downtime
19	200	1	F	3:30 PM shutdown
20	201	1	F	3:30 PM shutdown
21	202	1	F	2.1 hrs. system downtime, low flow; MG#6 down; 3:30 PM shutdown.
22	203	1	F	MG#6 down; system saturated at 4:36 PM.
23	204	6	--	
24	205	6	--	
25	206	1	F	Clouds early AM; pyrheliometer down until 9:30 AM
26	207	1	F	Clouds early AM; 10 min. system downtime, low flow.
27	208	1	F	Clouds early AM.
28	209	1	F	Clouds early AM.
29	210	1	F	1.3 hrs. system downtime; low CT-1 level; system saturated at 4:44 PM
30	211	6	--	

APPENDIX A (continued)

THE HOME LAUNDRY SOLAR I.P.H. PROJECT SYSTEM OPERATIONAL SUMMARY AUGUST 1983

Date	Julian Day	Status Code	Weather	Comments
1	213	1	F	DAS down 0.4 hrs
2	214	1	F	
3	215	1	F	
4	216	1	F	DAS down until 10:20 A.M. for July report prep
5	217	1	F	DAS and system down 0.4 hrs
6	218	6	-	
7	219	6	-	
8	220	1	F	
9	221	1	C	
10	222	1	F	
11	223	1	F	System shutdown at 3:55 P.M. by H. L. personnel
12	224	1	F	DAS down 0.6 hrs; system saturated 3:30 P.M.
13	225	6	P	Collector washing
14	226	6	-	
15	227	1	C	DAS down 0.8 hrs
16	228	1	C	
17	229	1	P	
18	230	1	C	
19	231	1	C	
20	232	6	-	
21	233	6	-	
22	234	1	P	
23	235	1	F	DAS down 0.6 hrs; system saturated 3:39 P.M.
24	236	1	F	System saturated 4:19 P.M.
25	237	1	F	DAS down 3.0 hrs; 4:00 P.M. shutdown
26	238	1	F	4:00 P.M. shutdown
27	239	6	-	
28	240	6	-	
29	241	1	F	4:00 P.M. shutdown
30	242	1	P	
31	243	1	F	4:00 P.M. shutdown

APPENDIX A (continued)

THE HOME LAUNDRY SOLAR I.P.H. PROJECT
SYSTEM OPERATIONAL SUMMARY
SEPTEMBER 1983

Date	Julian Day	Status Code	Weather	Comments
1	244	1	P	
2	245	1	F	
3	246	6	-	
4	247	6	-	
5	248	6	-	
6	249	1	F	
7	250	1	F	
8	251	1	F	Motor Group #15 down
9	252	1	P	Motor Group #15 down
10	253	6	-	
11	254	6	-	
12	255	1	F	
13	256	1	F	4.0 hrs D.A.S. downtime
14	257	1	F	
15	258	1	F	1.5 hrs D.A.S. downtime
16	259	1	P	
17	260	6	-	
18	261	6	-	
19	262	1	C	
20	263	1	C	
21	264	1	P	
22	265	1	P	
23	266	1	P	3.0 hrs system downtime
24	267	6	P	Collector washing
25	268	6	-	
26	269	1	P	
27	270	1	P	
28	271	6	C	
29	272	6	R	
30	273	6	C	

APPENDIX B

HOME LAUNDRY SOLAR I.P.H. PROJECT

Recommended Spare Parts List

Item No.	Quantity	Unit	P/N	Item	Vendor	Unit Price (\$)
I. COLLECTOR SUBSYSTEM						
1	2	ea	40952	Phototransistor	Delavan Electronics	8.00
2	2	ea	40592	Quad I.C. w/socket	Delavan Electronics	1.09
3	2	ea	40475-1	5 ASPST Relay	Delavan Electronics	12.00
4	2	ea	27238	PNP Transistor	Delavan Electronics	0.50
5	2	ea	30274	NPN Transistor	Delavan Electronics	0.50
6	2	ea	31780	L.E.D.	Delavan Electronics	0.85
7	2	ea	40073-1	Diode	Delavan Electronics	0.50
8	2	ea	40869	Merc. Sw.	Delavan Electronics	10.00
9	1	set	SUN-LOC 1	Complete SUN-LOC 1 Board and Sunshade.	Delavan Electronics	525.00
10	1	box	1009	Jacket - Glass (20)	Del Manufacturing	183.80
11	6	ea	1025	Receiver Tube Ass'y	Del Manufacturing	25.00
12	25	ea	2-316	O-rings	Del Manufacturing	0.50
13	2	ft	189	Mirror Cushion Strips	Del Manufacturing	1.50
14	1	ea	1440	Gearbox Ass'y	Del Manufacturing	325.00
15	2	ft	1617	Phenolic Insulating Tube Ass'y	Del Manufacturing	2.00
16	1	ea	1034	Bulkhead Union & Receiver Tube Point Roller Ass'y	Del Manufacturing	16.00
17	2	ea	1029	Bulkhead Union & Receiver Tube Roller Ass'y	Del Manufacturing	12.00
18	3	ea	132	Pylon Ass'y	Del Manufacturing	12.00
19	2	ea	1303-03	Washer	Del Manufacturing	0.50
20	2	ea	1319	Adapter plate	Del Manufacturing	6.00
21	2	ea	NTA 3244	Thrust bearing	Del Manufacturing	2.50
22	2	ea	TRE 3244	Thrust race	Del Manufacturing	1.00
23	10	ea		.156" diam x 1.125" long Crescent Roll Pin	Del Manufacturing	0.20

APPENDIX B(continued)

Recommended Spare Parts List

Item No.	Quantity	Unit	P/N	Item	Vendor	Unit Price (\$)
I. COLLECTOR SUBSYSTEM - continued						
24	6	ea	1109-02	Collector Clamp	Del Manufacturing	4.50
25	6	ea	1465	3/4" U-joint	Del Manufacturing	35.00
26	6	ea	1466	1/2" U-joint	Del Manufacturing	32.00
27	3	ea	1468	Shear Pin	Del Manufacturing	0.50
28	3	ea	1664	Adapter plate, w/hex nuts	Del Manufacturing	NA
29	2	ea	1461-30	Drive Shaft Ass'y	Del Manufacturing	7.00
30	2	ea	1462-03	Drive Shaft	Del Manufacturing	7.00
31	2	ea	1467	Key	Del Manufacturing	5.00
32	1	ea	34-4207-3899	Baldor Motor, Class F	Baldor Co.	113.00
33	1	ea	1804	Hub City Gear Reducer	Hub City Co.	241.00
34	20	ea	DEL #1210	Sagged glass, back silvered parabolic mirrors	Schott Glass	20.00
II. TRANSFER AND STORAGE SUBSYSTEM						
1	2	ea	Titeflex #WHV815F-00008BC	Flex hoses, w/fittings	Westward Hose Co.	29.95
2	1	ea	10	Shaft Sleeve	Paul L. Armstrong Co.	217.00
3	1	box	9405295	Set Graphoil Packing (9 rings)	Paul L. Armstrong Co.	97.00
4	1	box		Small parts kit:	Paul L. Armstrong Co.	
			10K	Shaft Sleeve Key		1.60
			77	Casing Gasket		6.80
			77B	Bearing end cover gasket		1.50
			12	Impeller bolt		0.95
			12A	Impeller washing		9.15

APPENDIX B(continued)

Recommended Spare Parts List

Item No.	Quantity	Unit	P/N	Item	Vendor	Unit Price (\$)
II. TRANSFER AND STORAGE SUBSYSTEM - continued						
			76	Front oil seal		7.90
			76A	Rear oil seal		18.00
			18	Splash Collar		10.00
5	1	ea		BS+B Rupture Disk, 3" Type S-90. Rupture pressure 162 psig.	Tom Ponton Ind.	187.20
6	1	ea		1/4" Rubber gasket mat'l for SG-1 handhole	Local Hardware Store	NA
7	1	ea	30066954-859	Body gasket	Honeywell	1.35
8	1	ea	30066954-859	Seat ring gasket	Honeywell	1.35
9	1	ea	30066954-859	Tailpiece gasket	Honeywell	1.35
10	1	ea	30042563-840	TFE/ASB packing	Honeywell	3.05
11	1	ea	30029934-322	Pins	Honeywell	1.20
12	1	ea	30685491-001	Direct diaphragm	Honeywell	34.65
13	1	ea	30685491-004	Rev diaphragm	Honeywell	42.55
14	1	ea	1601	2" 3-way valve	Honeywell	
15	2	ea		Solid grafoil gasket, 1/16" thick with 3/16" wire insert, sized to fit HTST-1 handhole (✓ 4" x 6" oval)	Power Engr. Co.	22.92
16	1	ea	910H122	1-1/2" Kunkle pressure relief valve, set pressure at 500 psig	Fred McCoy Co.	604.39
17	1	ea	R434	High Temp. Hot Water Pump	Paul L. Armstrong Co.	1,712.00

APPENDIX B(continued)

Recommended Spare Parts List

Item No.	Quantity	Unit	P/N	Item	Vendor	Unit Price (\$)
III. MISCELLANEOUS						
1	1	ea	1 LS 2	Limit Sw.	Microswitch	32.53
2	1	ea	700-CR5	Contacts	Allen Bradley Co.	9.07
3	1	ea	700 CR6	Contacts	Allen Bradley Co.	11.34
4	1	ea	7022AB	Agastat TD relay	R. B. Clapp	70.57
5	1	ea	SSC12AAA	Agastat TD relay	R. B. Clapp	35.35
6	1	ea	SSC12AFA	Agastat TD relay	R. B. Clapp	69.00
7	1	ea	GVTPDT120A	MEC relay	Master Distr.	15.60
8	1	ea	GVDPDT120A	MEC relay	Master Distr.	12.60
9	1	ea	6PA63	Microswitch	Elec. Sw. Co.	8.81
10	1	ea	A5408A25	Microswitch	Elec. Sw. Co.	2.55
11	1	ea	600-TOX4	A-B Manual Starter	Allen Bradley Co.	12.47
12	1	ea	26	Heater	Allen Bradley Co.	2.25
13	1	ea	9998SL3	P-1 Motor Starter Contacts	Square D Co.	34.52
14	1	ea	ST-1	Eppley Solar Tracker, motor only	Eppley Labs	75.00
15	1	ea	8222A5	Asco Solenoid valve	Nelson Dunn Inc.	125.00
16	2	ea	TR133	Mallory 4.2V DAS battery	Local Hardware Store	8.00

Total Priced Parts \$6,232.07

NOTE: A tooling charge of \$400 is required for production of Del Manufacturing components. All prices subject to change.

APPENDIX (C).

HOURLY HEAT AND MASS BALANCE EQUATIONS

Equation

Description

A

Ambient Temperature - DAS CH. 14; TE-13

$$\bar{T}_{13} (^{\circ}\text{F}) = \frac{\sum(T_{13})}{n}$$

Where n is the number of data inputs over one hour.

B

Wind Velocity - DAS CH. 32; XE-2

$$\bar{V}_{32} (\text{mi/hr}) = \frac{\sum(V_{32})}{n}$$

C

Direct Insolation - DAS CH.49; XE-1

$$\bar{I}_{\text{DIR}} (\text{MBTU/HR}) = \frac{\sum(I_{\text{DIR}} * 6496)}{n} * 10^{-6}$$

APPENDIX (C) - continued

Equation

Description

D

Incident Insolation

$$\bar{I}_{INC} \text{ (MBTU/HR)} = \bar{I}_{DIR} \text{ (MBTU/HR)} * \text{COSZ}$$

X.XXX

Where:

$\bar{I}_{DIR}$ as found in E

$$\text{COSZ} = ((\sin \ell \sin d + \cos \ell \cos d \cos a)^2 + \cos^2 \delta \sin^2 w)^{\frac{1}{2}}$$

Where:

$$a = 180 - 15t_h$$

$$d = 23.45 \sin \{0.9863 (284 + J)\}$$

$$\ell = 34.2$$

Where:

J = Julian day

t_h = t_s converted to decimal hours

Where:

$$t_s = (t_{\text{clock}} - 30_{\text{min}}) + \{7.2 + 8 \sin (1.06J - 48) + 10 \sin (1.9(1.1 J - 30))\}$$

t_{clock} = time of hourly data reduction

NOTE: See text for comments on I_{INC} calculation.

APPENDIX (C) - continued

Equation

Description

E

Loop Flow - DAS CH.25; FT-3

$$\dot{W}_{3i} \text{ (KLB/HR)} = q_i \text{ (GAL/MIN)} \times M_i \text{ (LBS/FT}^3\text{)} \times \frac{8.02}{1000} \text{ (MIN} \cdot \text{FT}^3\text{/GAL} \cdot \text{HR)}$$

Where:

$$M_i \text{ (LB/FT}^3\text{)} = (100 \text{ } 34.96 e^{6.889 \times 10^{-4} T_2})$$

Where:

$$T_2 = \text{temp. (}^\circ\text{F)} \text{ from CH.26}$$

Thus:

$$\dot{W}_3 = \frac{\sum (\dot{W}_{3i})}{n}$$

APPENDIX (C) - continued

Equation

Description

F

Collector Inlet Temperature - DAS CH.20; TE-1

$$\bar{T}_1 (^{\circ}\text{F}) = \frac{\sum (T_1)}{n}$$

G

Collector Outlet Temperature - DAS CH.26; TE-2

$$\bar{T}_2 (^{\circ}\text{F}) = \frac{\sum (T_2)}{n}$$

APPENDIX (C) - continued

Equation

Description

H

Energy Collected

$$\bar{Q}_{\text{Coll}} \text{ (MBTU)} = \frac{\sum (W_{3i} * C_i * (T_2 - T_1)_i)}{n}$$

Where:

$$W_{3i} \text{ (KLB/HR)} = q_i * m_i * 8.022 * 10^{-3}$$

$$q_i \text{ (GAL/MIN)} = \text{CH.25 reading}$$

M_i as found in G above.

$$C_i = 1.0025 + 2 * 10^{-12} T_2^{4.07} \text{ (BTU/LB.°F)}$$

$$T_2 \text{ (°F)} = \text{Ch.26 reading}$$

$$T_1 \text{ (°F)} = \text{Ch.29 reading}$$

I

Collector Efficiency

$$E_c \text{ (\%)} = \frac{\text{Energy Collected as in K (hourly total)}}{\text{Incident Insolation as in F (hourly total)}} * 100$$

APPENDIX (C) - continued

Equation

Description

J

Energy Delivered

$$\bar{Q}_{DEL} \text{ (MBTU)} = \frac{\sum (W_{1i} * 1190)}{n}$$

$$\frac{\sum (W_{3i} * C_i * (T_3 - T_4)_i)}{n}$$

Where:

W_{1i} (LB/HR) = Ch.31 reading

W_{3i} (KLB/HR) as found in K above

C_i as found in G above

T_3 (°F) = Ch.7 reading

T_4 (°F) = Ch.8 reading

K

Pipe Loss - DAS CH.26; TE-2
DAS CH.14, TE-13

$$Q_{LPi} \text{ (KBTU/HR)} = 142.4 * (T_2 - T_{13}) * 10^{-3}$$

$$\bar{Q}_{LP} \text{ (KBTU)} = \frac{\sum (Q_{LPi})}{n}$$

APPENDIX (C) - continued

Equation

Description

L

Storage Loss - DAS CH.1; TE-14
DAS CH.14; TE-13

$$Q_{LSi} \text{ (KBTU/HR)} = 20.75 * (T_{14} - T_{13}) * 10^{-3}$$

$$\bar{Q}_{LS} \text{ (KBTU)} = \frac{\sum(Q_{LSi})}{n}$$

M

Storage Heat Added - DAS CH.4; TE-5
DAS CH.0; TE-6

$$Q_{STOi} \text{ (MBTU)} = (\dot{W}_{3i} * C_i * (T_5 - T_6) * C)$$

Where:

C = 1 if CH.59 ≠ 0.0, else C = 0.

W_{3i} as in K above

C_i as in K above

$$\bar{Q}_{STOADD} \text{ (MBTU)} = \sum(Q_{STOi} \geq 0)n$$

APPENDIX (C) - continued

Equation	Description
N	<p>Storage Heat Removed - DAS CH.4; TE-5 DAS CH.0; TE-6</p> <p>If Q_{STO_i} as in Q < 0, then</p> $\bar{Q}_{STO_{REM}} \text{ (MBTU)} = \sum (Q_{STO_i} < 0)_n$
O	<p>Average Storage Temperature - DAS CH.1; TE-14</p> $\bar{T}_{14} \text{ (°F)} = \frac{\sum (T_{14})}{n}$
P	<p>System Efficiency</p> $E_s \text{ (\%)} = \frac{\text{Energy Delivered as in M (hourly total)}}{\text{Incident Energy as in F (hourly total)}} \times 100$
Q	<p>Parasitic Energy - DAS CH.23; XT-4</p> $W_L \text{ (WATTS} \times 10) = (X_4)$ $\bar{W} \text{ (KW)} = \frac{\sum (W_i)}{n} \times 10^{-2}$