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**SOLAR PRODUCTION OF INDUSTRIAL PROCESS HOT WATER: OPERATION AND
EVALUATION OF THE CAMPBELL SOUP HOT WATER SOLAR FACILITY**

Final Report for the Period September 1, 1979—December 10, 1980

By
John I. Kull
William N. Niemeyer
Stanley B. Youngblood

December 1980

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Work Performed Under Contract No. AC03-76CS31218

Acurex Corporation
Mountain View, California

U.S. Department of Energy

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December 1980

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Prepared for

U.S. Department of Energy
San Francisco Operations Office
Under Contract DE-AC03-76CS31218

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SECTION 1

EXECUTIVE SUMMARY

This report summarizes the operation and evaluation of a solar hot water facility designed by Acurex Corporation and installed (November 1977) at the Campbell Soup Company Sacramento, California canning plant. The period of evaluation was for 12 months from October 1979 through September 1980. The work was performed under Contract DE-AC03-76CS31218 to the U.S. Department of Energy. This work was a continuation of an earlier contract that concluded in June 1979. The objective of the work reported here was to obtain additional, long term data on the operation and performance of the facility. Minor modifications to the facility were completed and the system was operated and evaluated for 1 additional year to obtain performance data. Appendix A contains the full contract statement of work (SOW) for this period.

All but one of the objectives of this SOW were accomplished. The system was operated for 15 months and 12 months of detailed data were evaluated. The facility was available for operation 99 percent of the time during the last 8 months of evaluation. Delivery of a system operation and maintenance manual, however, was deferred pending final direction by DOE with respect to an upgrade program for first generation field experiments sponsored by DOE. The Campbell Soup facility has been selected for this program. Consequently, modifications to the facility

based on the results of this contract are under consideration by DOE (see Section 2.2). As of this date (December 1980) it is anticipated that the upgrade program will be in place in early 1981.

This report is organized into five major sections. Section 1, the executive summary, contains a summary of operational experience (Section 1.1), a summary of system performance (Section 1.2), and conclusions (Section 1.3). Section 2 presents a detailed description of the solar facility and of the operating experience. Section 3 provides a summary of system performance for the 12 month operation/evaluation period. Section 4 gives recommendations for large-scale solar facilities based on this project's experience, and Section 5 provides an environmental impact assessment for the Campbell Soup solar facility.

1.1 SYSTEM OPERATION

The solar facility at Campbell Soup's Sacramento, California plant supplies hot water for washing empty soup cans before they are filled. A schematic of the hot water system is shown in Figure 1. The design is simple: water passes through the collector field once, without recirculation. Well water enters the flat-plate collectors for preheating, passes through the concentrators for final heating, and is sent to a storage tank. Hot water is pumped from the storage tank to the plant upon demand. Additional heating as required is provided by a steam heat exchanger operating from the plant steam supply.

Key features of the system are:

- Flat-plate collectors are used for preheating in the lower temperature range where they are most efficient. They are installed on existing skylights eliminating the expense of additional structural support. The Acurex Model 3001-2

Figure 1. Campbell Soup Solar Hot Water System Schematic

concentrating parabolic troughs provide final heating in the temperature range where they are most efficient.

- The storage tank accumulates collector energy when the can lines are inactive and over weekends when the plant is shut down. Table 1 is a summary of key system parameters.

Table 1. Summary of the Campbell Soup Solar Facility

Collectors:	414 m ² (4,455 ft ²) Solargenics flat plate (inclined 25° to south), single glazed, nonreflective coating
	268 m ² (2,880 ft ²) Acurex Model 3001-2 line focus parabolic trough concentrators (east/west orientation)
Storage:	64,900 liters (17,150 gal) working volume
Flowrates:	113 LPM (30 gpm) collector field flowrate
	47 LPM (12.5 gpm) flowrate to can lines
Load temperature:	345° to 350°K (180° to 195°F)
Control mode:	Constant flowrate

The facility was operated and evaluated over the October 1979 through September 1980 period. Figure 2 illustrates the availability of the solar facility for operation and the percentage of time the plant process (can washer) was operating, which is a measure of the utilization by the plant of the solar supplied hot water. Solar facility availability was quite low during November, December, and January as a result of operational problems summarized in Table 2. These were corrected (see Table 2) and 100 percent operation was achieved during the last 6 months

Figure 2. System and Process Percent of Time Available

Table 2. Major Operation Problems and Solutions

Item	Effect	Correction
1. Control program	Incorrect or nonoptimum sequencing of system controls resulted in system downtime or reduced system operation	Control program was reprogrammed for simpler system operation (January 1980)
2. Jamming of flow control valve, strainers, etc. by inert solids in supply water	System downtime and reduced data accuracy	Frequent blowdown of strainers, regular cleaning of valve, and installation (November 1980) of blowdown water separator on inlet water supply
3. Reduced steam flow through auxiliary heat exchanger	System downtime if minimum can line supply temperature (180°F) cannot be provided	Plant maintenance of steam heat exchanger and controls

of evaluation. Maximum energy delivery, however, was not achieved during most of this latter period because the can washers were not operating continuously while the solar facility was operating. Consequently, the storage tank would fill with water and the collector field would shut down early in the day.

As a result of the experience gained during the 12 months of evaluation, several recommendations for the facility have been identified and are under consideration by DOE as part of a general upgrade program for the first cycle of field experiments. These recommendations are summarized in Table 3. The first recommendation, revising the plant interface, is the most significant in terms of improving the overall performance of the solar facility. The other recommendations are

Table 3. Recommendations Based on Operating Experience

Item	Comment	Recommendation
Plant interface <ul style="list-style-type: none"> ● Can line washers 	Operation is irregular resulting in less than full utilization of the solar-supplied water	Revise plant interface; tie into plant water main to achieve 100 percent utilization
Controls <ul style="list-style-type: none"> ● Field flowrate ● System control panel ● Control hardware 	<p>Fixed flowrate resulted in simpler, reliable operation and maximized energy collection</p> <p>A simple, central control panel with auto/manual switches and an annunciator panel with system indicators, alarms, and mode status is preferred by plant operators</p> <p>Although the programmable controller has provided design flexibility and reliability, the user prefers conventional relay-logic hardware for ease of service</p>	<p>Retain constant field flowrate. Use a self-powered flow control valve to regulate flow</p> <p>Revise control panel for easier use by plant operators and maintenance personnel</p> <p>Replace programmable controller with relays; specify equipment commonly used by Campbell maintenance personnel</p>
Collector field <ul style="list-style-type: none"> ● Solargenics Series 75 flat-plate collectors ● Acurex Model 3001-2 concentrator ● Concentrator tracker system 	<p>Flat-plate panels developed large leakage of water past glazing seal resulting in corrosion of absorber plate</p> <p>Original receiver support does not provide adequate support resulting in sagging of tube and inadequate expansion provided for Pyrex glass tube resulting in glass breakage</p> <p>Although sun sensors have worked reliably, they are one-of-a-kind prototypes developed 3 years ago</p>	<p>Replace seals and damaged absorber plates or replace entire unit</p> <p>Replace existing receivers with current 3001 receiver assembly</p> <p>Replace trackers with current sensors which are a commercial product with standard repair/service procedures. Also, use direct insolation monitor rather than total horizontal pyrometer for concentrator wake-up and stow commands</p>

Table 3. Concluded

Item	Comment	Recommendation
<p>Date acquisition</p> <ul style="list-style-type: none"> ● Mag tape/line printer ● Data sensors <p>System documentation</p> <ul style="list-style-type: none"> ● O and M manual and as-built drawings 	<p>Line printer is redundant with mag tape, but has proven a valuable backup to tape due to tape failures</p> <p>Data sensors should not be used as control signals. Sensors should be easily calibrated and simple, gage sensors should be installed to verify electronic instrumentation</p> <p>Documentation for the system was deferred pending direction by DOE regarding the above recommendations</p>	<p>Provide a redundant data recording device to ensure data collection</p> <p>Use three-wire RTD's for temperature measurement, provide bulb thermometers and pressure gages in key locations</p> <p>System documentation is essential for the facility owner to assume operation and maintenance of the facility</p>

primarily due to the facility's first-of-a-kind nature and can be easily implemented based on the current status of the solar industry.

1.2 SYSTEM PERFORMANCE

Data collected and evaluated during the reporting period demonstrated that:

- The solar facility performed with excellent reliability, being available for operation 99 percent of the time during the last 8 months of the period
- Low utilization by the process restricted the solar facility operation to the extent that overall energy collection would have been two times greater with full utilization
- The thermal performance of the solar energy system was good, being in agreement with predictions when utilization effects are included (see Section 3.1.2)

Figure 3 illustrates the daily average energy collection by the solar facility and shows the low utilization by the plant of the solar facility, especially during the summer which was potentially a peak energy collection period. Table 4 summarizes these measured values and shows that measured energy collection would double with 100 percent availability of the system and 100 percent utilization, both achievable in practice.

Economic analyses were performed based on these results (see Section 3.2) and indicated that solar hot water facilities are competitive with \$30/bbl oil escalating in cost at 15 percent per year.

1.3 CONCLUSIONS

The experience gained from this project has provided valuable insights for the application of large-scale solar process heat facilities

Figure 3. Daily Average Energy Volumes

Table 4. Capsule Summary, October 1979 Through September 1980

<u>Measured</u>	
Days system available and data taken	257
Average daily energy to storage	2.9×10^6 Btu
Average daily efficiency	48%
Energy to storage	749×10^6 Btu
Equivalent barrels of oil displaced	210
Value of fuel displaced (at \$30/bbl)	\$6,300
 <u>Estimated for 100 Percent Availability, 100 Percent Utilization, and 100 Percent Availability</u>	
Days system available and data taken	366
Average daily energy to storage	5.0×10^6 Btu
Average daily efficiency	48%
Energy to storage	1843.6×10^6 Btu
Equivalent barrels of oil displaced	516
Value of fuel displaced (at \$30/bbl)	\$15,480

to industries for supplementing the consumption of fossil fuels.

Section 4 reviews these in detail. Overall approaches include:

Performance Considerations

- The design of the solar facility should be simple to ensure maximum availability for energy collection. Modifications that simplified the operation of the Campbell Soup solar facility at the outset of this project demonstrated this.
- The interface of the solar facility with the plant should be simple and should provide for full utilization of solar energy collected and delivered to the plant. Large, continuous thermal loads ensure the most cost-effective use of the solar facility.

- Current investments in large-scale solar facilities are competitive with current fossil fuel costs that are assumed to escalate at 15 percent per year

Operation and Maintenance Considerations

- Plant personnel should be consulted during the design phase of the project to ensure compatibility of solar hardware and design with plant hardware and practices. Specified hardware should be nationally serviceable and industrial grade. Experimental or one-of-a-kind designs must be avoided if the plant maintenance personnel are to assume responsibility for the facility.
- Complete documentation of the facility is essential for plant maintenance personnel. This includes system O and M manuals and as-built drawings.
- Current state-of-the-art solar hardware is of industrial quality and has benefitted from the experience gained from initial field experiments

SECTION 2

SYSTEM OPERATION

This section describes the system operation for the period from September 1979 to December 1980. Section 2.1 gives a brief description of the solar hot water facility including the collector field, control system, piping and storage, and the data acquisition system. Section 2.2 summarizes the operational experience, outlines operation and maintenance requirements, and presents recommendations for the facility based on 1 year of operating experience.

2.1 SYSTEM DESCRIPTION

The solar system at the Campbell Soup Company plant in Sacramento, California heats potable water for washing cans on two soup can filler lines. The solar hot water system consists of a collector field to heat the potable water, a storage tank to store the hot water for second shift operation and to collect energy during weekends, a control system, and a data acquisition and recording system. Figure 4 shows the process flow diagram and data sensor locations, control signals, and control interlocks.

In this simple configuration, water passes through the collector field at a fixed flowrate of 30 gal/min without recirculation. Well water enters the flat-plate collectors for preheating, passes through the concentrators for final heating, and is sent to a 19,200-gal storage tank. When either of the can lines are operating, hot water is pumped

Figure 4. System Schematic and Control Interlocks

from the storage tank to the can-line washers. When the tank outlet temperature is below the required 195°F limit, plant steam is supplied to a heat exchanger to increase the water temperature to the required 195°F.

Water is supplied to the can washers via either of two can wash lines. Can-line load patterns were not as regular or as continuous as originally anticipated; consequently, a priority switching control was added to permit maximum water usage from the solar field. When either can line is operating, the can line supply pump is automatically started, supplying water at a controlled flowrate. The flowrates are fixed at 12 and 8 gal/min for the V and U can lines, respectively. If both lines are operating, the V line is given priority.

A solid-state programmable controller automatically controls the daily system operation and provides the safety interlocks for protection against high wind, freezing weather, and low flowrate. When the collector field operation permissive control is satisfied, the main field solenoid valve opens, initiating flow into the storage tank and the concentrating collectors move into focus.

An automated data acquisition system is employed to sense all system performance parameters and record them on both magnetic tape and line printer paper. Temperatures, insolation, system operating status, and weather data are continuously recorded at 15-minute intervals.

The collector field is located on the roof of the finished products warehouse of the Campbell Soup Sacramento plant (Figure 5). Water first flows through two parallel rows of Solargenics flat-plate collectors where it is preheated to 140°F. The output of the 4,455 ft² of flat-plate collectors is fed to six parallel groups of Acurex concentrating

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Figure 5. Collector Field

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collectors where it is heated to 200°F. Each group consists of eight 6- by 10-ft modules connected in series, yielding a total of 2,880 ft² of concentrators. The water from these units is then transported to the storage tank along an existing pipe run via the can-washing building. In addition to storage capability, the tank allows the collector field to operate independently from the can line supply system.

2.1.1 Collector Field

The collector field is designed to heat well water from 70° to 200°F on an average June day. The collector field is a combination of flat-plate and single-axis tracking parabolic trough concentrating collectors. A hybrid collector field was selected as the cost-optimum manner to provide 195°F water to the soup can line washers. The flat plates are used for preheating in the lower temperature range where they are most efficient. They are installed on existing skylights eliminating the expense of additional structural support. The Acurex Model 3001 concentrators provide final heating in the temperature range where they are most efficient. More detail on this design rationale and selection is given in Reference 1.

Flat-Plate Collectors

The field contains 4,455 ft² of flat-plate collectors, mounted facing due south and inclined 25° from the horizontal. There are two rows of flat-plate collectors each containing 54 panels. The panels in the front row are 16.5 ft long by 3 ft wide, and those in the second row are 11 ft long by 3 ft wide. Figure 6 shows the 11-ft panel installation. The collectors were manufactured by Solargenics, Inc., of Chatsworth, California. They have a single glazing of low iron tempered glass and a nonselective absorber coating. The collectors were mounted to

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Figure 6. 11-ft Flat-Plate Collector Row and Concentrator Row

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the existing roof skylights with a steel structure supporting the collectors between the skylights. The rationale for selection of these collectors is given in Reference 1. Additional details of the collector construction and performance are given in Appendix B.

Concentrating Collectors

The field contains 2,880 ft² of Acurex Model 3001-2 parabolic trough, single-axis tracking, concentrating collectors mounted in an east-west orientation.

The Model 3001-2 concentrating collector is a reflecting parabolic trough solar collector designed to heat fluids to temperatures between 140° and 600°F. The collector is assembled in modules 10 ft in length and 6 ft wide. Eight modules are coupled together to form a group with a common tracker and drive at the center. There are six groups of concentrators that are fed preheated water from the flat plates.

The concentrators are equipped with a 1-1/4-in diameter copper receiver tube. Copper was specified for this installation because the working fluid is potable water. Each concentrator group has a continuous 80-ft receiver with fittings at either end. The receiver is supported at 10-ft intervals between each module.

The receiver tubes were originally coated with a black chrome over nickelplate selective coating and enclosed with a Pyrex glass jacket to reduce convective heat losses from the tube. Degradation of this coating, however, was experienced during the first year of operation on half (three) of the concentrator groups. In addition, breakage of the Pyrex glass covers was experienced due to inadequate expansion allowance at the tube support collars. Consequently, the glass covers were removed from the receivers and the tubes were recoated with nonselective nextel paint.

The Pyrex covers were not replaced on these concentrators. An analysis was performed prior to this change and indicated that there would be a negligible effect on performance. This is because the concentrators are operating at a relatively small fluid parameter where the convective heat loss from the receiver tube is of the same magnitude as the optical transmission loss from the Pyrex glass covers. Temperature data from both concentrator configurations do not indicate any significant difference in thermal performance.

Each 10-ft collector module is mounted on a tubular steel triangular support. The triangular supports are mounted to the parapet wall of the building and to the steel roof support structure. A flexible hose and swivel connection is provided at the ends of each receiver tube to connect the piping and allow the receiver tube to expand during temperature cycling.

The concentrating collector drive system consists of a shadow band tracker, a fractional horsepower gear motor, and a worm drive gear assembly. The motor turns a large reduction worm and gear set through a chain to yield an overall gear reduction of 1900:1. The drive slew rate is 180° in 15 minutes. The active sun-seeking tracker uses the imbalance at the output of two phototransistors in the shadowband sensor to switch on the drive motor. The motor then drives the collector back into focus, rebalancing the shadow on the phototransistors.

Each concentrator group tracking system is also capable of "desteering" the group (continue tracking the sun 5° out of focus to an overtemperature signal) to protect the concentrator receivers from excessive temperatures.

Additional details of the concentrator specifications and performance are given in Appendix C.

2.1.2 CONTROLS

The control system performs three major functions. It controls: (1) collection and storage of solar-heated water, (2) supply of hot water to the canning line; and (3) protection of the collector field from environmental damage.

The control philosophy is based on a maximum amount of local autonomous control in each of the can line and collector field areas. Functions that can be controlled completely within the field or other areas are handled locally. For example, the concentrator fluid temperature sensor is interlocked to the drive in the collector field to trigger the "desteer" function of the tracking concentrators, without involving the central console. Similarly, the control of process steam for additional water heating in the heat exchanger is self-contained and does not involve central control action to activate the steam supply.

Central Control Console

The central control console (Figure 7) contains the main operating and control components, the data logging system, and the control panel.

The control panel contains indicator lights showing operating modes, the status of system components, various possible malfunctions, and several operating controls.

The heart of the control system is the Texas Instruments 5TI Programmable Controller. This is an all solid-state controller that stores the control program or ladder diagram input by the user. It contains switching input and output modules that facilitate the interface with the overall system. Since the controller is programmable, additional

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Figure 7. Control Console and Data Acquisition System

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delays and safety interlocks can be added as required. The 5TI controller handles the operations of the collector field and can line subsystems. The ladder diagram of these operation and safety interlocks is given in Appendix D.

Collector Field Operation

These are the series of conditions that must be satisfied to allow the collector field to operate. They are designed to ensure that there is sufficient insolation to add energy to the water and to protect the concentrators from damage by high fluid temperatures or winds.

1. Wind -- Must be less than 30 mph; otherwise the concentrators stow in a protective position
2. Flat-Plate Surface -- Must be over 100°F; if less, main flow solenoid will not open
3. Overtemperature Protection -- Built-in concentrating collector protection to desteer if exiting water temperature exceeds 215°F
4. Flat-Plate Insolation -- Must be greater than 300 W/m² at the collector aperture plane before field flow will be allowed. This will be followed by a concentrator "track permissive" signal.
5. Flow -- Must be greater than 6 gpm or concentrators remain in stow or go to stow. Low flow would cause overheating in concentrators.
6. Tank Level -- Must not be full (dumping water from the tank is not permitted)

The following sequence protects the collector field from damage by freezing:

1. Ambient Air Temperature -- If the ambient air temperature is less than 34°F, the system goes into the freeze protect mode

2. Freeze Protect Solenoid -- This solenoid is deenergized to allow 5 gpm flow-through field
3. Freeze Protect Flow Switch -- Verifies flow in protect mode, if not verified main flow solenoid is opened

The collector field junction boxes are connection points for all field data and control signals. Each concentrator contains a Resistance Temperature Detector (RTD) temperature sensor conditioned to a 0 to 1 volt signal representing 0° to 250°F. Each temperature sensor is connected to an overtemperature transmitter that will desteer that concentrator group if 215°F is reached or exceeded. The wind velocity sensor is also equipped with upper limit alarms so that the concentrators will move to the "stowed" position during high winds.

When a possible field freezing condition exists with either of two redundant sensors below 34°F, a signal is sent to the central control console. This will trigger a controlled water flow through the collector field to prevent freezing.

A centrifugal boost pump at the field inlet is activated by a local flow switch with its outlet pressure regulated to 40 psig by a self-contained regulator. Flow is balanced in the field by Bell & Gossett circuit setter valves, with the overall field flow controlled by a Kates pressure compensating flow control valve. This valve yields a flowrate control of $\pm 1\frac{1}{2}$ percent at the 30-gpm fixed setting. A main flow solenoid valve is activated by the 5TI controller to allow field flow.

Can Line Operation

This sequence permits flow to the can lines from the storage tank. Line U or V can line will be supplied by solar if:

1. The tank is not empty
2. The pump is operating as verified by a flow switch
3. One can line is running

U and V can lines operate at a flowrate of 8 and 12 gpm, respectively. These flowrates are controlled locally by Griswold self-contained flow control valves. These valves maintain the specified flowrate to within ± 5 percent. Since V line operates at a higher flowrate, V line is given operating priority over U line. This is facilitated by the controller setting V line when both can lines are operating.

The temperature of the water leaving the heat exchanger is measured by a liquid-filled thermal bulb that directly actuates a control valve on the steam line into the heat exchanger. A SARCO Model 25TE temperature control valve is used to control the final water temperature delivered to the can lines.

A water flow switch interlock is used to detect when the can line flow is shut off for any reason. This signal causes the central control console to shut off the steam and can line feed pump after a short time delay.

Solenoid valves at the can lines are actuated by the programmable controller to select either solar or plant-heated water for each can line. During summer operation, if the heat exchanger inlet temperature exceeds 170°F, both can lines will be fed by solar-heated water.

The tank level is sensed by several DeLaval float-type switches located on a support frame that is inserted into both the top and bottom of the tank. These float switches signal tank level either high, full,

low, or empty. These signals are processed by the 5TI controller to control the can line pump, steam, and water supply solenoid valves.

2.1.3 Piping Design and Storage

The process piping for the collector field connects to the existing water supply in the finished products warehouse, Building W8. From there the pipe is routed through the roof directly above the connection point and into the collector field. Scheduled 40 galvanized pipe with jacketed fiberglass insulation was used throughout for the process piping.

The flat-plate collectors are divided into four arrays. Each row contains two arrays of 14 collectors each. As a result of the unequal collector area in these two arrays, flowrate was adjusted to equalize the outlet temperatures. The array sizes were selected to keep the water velocity in the risers within acceptable limits for efficient heat transfer.

The flat-plate collectors are connected to each other with 3/4-in U-shaped copper tubes. The connections were sized to accommodate the differential thermal growth that occurs when the collectors are heated, and they were insulated to reduce heat loss.

The preheated water from the flat-plate collectors flows to the concentrator inlets. The flow through the concentrators is balanced at 5 gpm per group with all outlets tied together at the field outlet. The field outlet piping follows other process plant piping along the wall of the canning building to the storage tank.

Storage Tank

The water storage system consists of the accumulator tank, pump, and associated equipment and piping. The system was designed to store the

output of the solar collector field and supply the hot water to the can lines on demand. The collector field will operate 7 days a week and the can washer line 5 days, except during high demand months.

The storage tank working volume is based on a process demand (output) of 12.5 gpm of potable water for two shifts, 5 days a week, and an input from the field spread over 7 days a week.

The total volume of the tank is a nominal 19,200 gal. This size is based on a working capacity of 17,150 gal of water. The total height of the tank is 22 ft 6 in with a straight height of 22 ft and a conical cover, 6 in high, welded to the shell.

The tank is equipped with an overflow pipe, drain, inlet, and outlet which are connected at the tank bottom. The tank has a manway and is insulated with 6 in of jacketed fiberglass insulation. The tank rests on an insulated pad to minimize heat loss to the foundation.

A centrifugal pump with check valve are mounted at the base of the storage tank to supply water to the second floor can-line area.

Can Washing Interface

The can washer interface section consists of the heat exchanger and associated steam line and the connection to can lines U and V.

The heater exchanger is a shell-and-tube type designed using the following parameters:

- Heat exchanged -- 960,200 Btu/hr
- Water temperature rise -- 130°F
- Water flowrate -- 15 gpm
- Water pressure drop -- 1 psi
- Steam pressure -- 20 psig

The heat exchanger is located near the ceiling on the second floor of Building 4, above can lines U and V. An existing steam main close to the heat exchanger supplies the steam to the unit. The steam heat exchanger tops off and controls the water temperature to 195°F. The water then flows through a check valve, a solenoid valve, and a Griswold flow control valve to the can washer.

The can-washing device used on lines U and V is a sheet metal enclosure, approximately 8 ft long, with a water supply tube feeding a row of eight 1/4-in spray nozzles. When the empty cans travel through the washer, they rotate to expose all surfaces to the fixed streams of hot water. The water is supplied to the empty can washer through a 3/4-in schedule 40 pipe.

2.1.4 Data Sensors

The collector field instrumentation is summarized in Table 5. Figure 8 shows the location of the instruments in the field. The field temperature sensors are RTD's, with Action Pak signal conditioners. These signal conditioners produce a 0 to 1 volt signal which are converted and displayed as temperature of 0° to 250°F. The ambient temperature is measured using a mast-mounted Weather-Measure Model T621 thermosensor with a radiation shield. Wind speed and direction are sensed by a Weather-Measure W101-0-DC/540 Skyvane I system mounted on a 10-ft mast. Four Eppley SBS pyranometers are also mounted in the field. These units measure insolation in the following four separate modes:

1. Total horizontal insolation
2. Total insolation at tracking angle
3. Diffuse insolation at tracking angle
4. Total insolation at 25° from the horizontal

Table 5. Data Acquisition Channels

A-9 Channel	Transmitter	Parameter
0	TY-16	Field inlet
1	TY-34	F. P. absorber, 11 ft
2	TY-36	F. P. absorber, 16.5 ft
3	TY-33	F. P. outlet, 11 ft
4	TY-18	F. P. outlet, 11 ft
5	TY-35	F. P. outlet, 16.5 ft
6	TY-19	F. P. outlet, 16.5 ft
7	TY-20	Inlet CC No. 5
8	TY-27	Outlet CC No. 5
9	TY-24	Outlet CC No. 6
10	TY-22	Outlet CC No. 3
11	TY-25	Outlet CC No. 4
12	TY-23	Outlet CC No. 1
13	TY-26	Outlet CC No. 2
14	TY-28	Field outlet
15	IY-1	F. P. insolation
16	IY-2	Total insolation CC No. 6
17	IY-3	Diff. insolation CC No. 4
18	IY-4	Total horizontal insolation
19	WT	Wind speed
20	WT	Wind direction
21	--	--
22	μ	Tank inlet
23	TY-37	Tank outlet
24	TY-55	Line U temperature
25	--	U solar open
26	--	U house open
27	TY-51	Line V temperature
28	--	V solar open
29	--	V house open
30	TY-63	Ambient temperature tank
31	--	System status
32	--	High tank
33	--	Low tank
34	--	Field flow
35	--	Can line flow
36	--	Freeze protection
37	TY-42	Hx inlet
38	TY-41	Hx outlet
39	--	Ambient temperature RTD

Figure 8. Field Schematic Showing Sensor Locations With Data Channel Numbers

To accomplish this, the first unit was mounted horizontally, the second and third on separate tracking concentrators, and the fourth unit was installed on a flat-plate collector.

Table 5 lists the data acquisition channels and sensor descriptions for the system. As shown in Table 6 and Figure 8, RTD temperature sensors are located at all critical points in the collector field, storage tank, and can-line areas. Each RTD has a 0° to 250°F output. Status signals are sensed by 115 VAC to 5 VDC signal conditioning and displayed on the data logging and recording equipment.

Table 6. Data System Sensor Types

Sensor Numbers	Variables	Sensor
00, 03-14, 22-24, 27, 37, 38	Water temperature	RDF 21B10A4B resistance temperature device with signal cond. via Action Pak
01, 02	Flat-plate surface temperature	Mical RTX-4568-D2-F72 resistance temperature device with signal cond. via Action Pak
15, 16, 18	Insolation	Eppley PSP Pyranometer
17	Insolation	Eppley SBS Pyranometer
19, 20	Wind speed and direction	Weather-Measure W101-P-DC/540 Skyvane I
30, 39	Ambient temperature	Weather-Measure W101-P-DC/540 Skyvane I, RTD as above
25-29, 31-36	Various system and support statuses	Hi/low voltage signal to Autodata 9

Digital Hardware

- Acurex Autodata 9 data logger: scans the data sensors, converts their information to engineering units and controls the output of this information to peripheral devices
- Kennedy 9-track magnetic tape deck: for transfer of data for later reduction and analysis
- Decwriter II 30 CPS printer/terminal: for on-site output of data sensor information and backup for transfer of data

DAS Operation

The Autodata 9 is responsible for controlling the scanning of the data channels, converting the information to engineering units, and inputting the data to peripheral devices.

Data scans are made every 15 minutes over the day. Upon scanning the data, the Autodata 9 outputs the values, converted into engineering units, on the magnetic tape deck and the on-site line printer. The magnetic tape is used to transfer the system data to the Acurex Mountain View offices, where it is reduced and analyzed via a computer code. The line printer provides on-site records of system data and a backup means of data transfer.

2.2 OPERATING HISTORY

The objectives during this operating period were to operate the solar hot water facility for 12 months and evaluate its daily, weekly, and monthly performance. To accomplish this, several modifications were made to the facility at the outset of the project to simplify its operation and improve system reliability. Table 7 summarizes key changes to the facility as of October 1979. These changes were consistent with a general shift in approach for the project. Initially in 1976, the solar facility

Table 7. Modifications to the Campbell Soup Solar Hot Water System
as of October 1979

From	To	Comment
1. Digital flow valve	Analog flow controller (Kates valve)	Original flow control device required feedback from a flowmeter. The accumulated errors of each caused instabilities resulting in water hammer. Direct reading from flow controller eliminated need for main flowmeter.
2. Direct feed from waterline	Booster pump on water inlet	The system is supplied by a waterline which does not supply pressure as originally specified.
3. Temperature control mode after tank was full	Remove T.C.M. Close supply and stow collectors upon full tank	Campbell Soup Company policy would not allow water to be dumped to support temperature control mode.
4. Flowmeters on each can line	Flow regulators	Pressure surges due to intermittent can fillers operation caused major damage to pressure meters and flowmeters. New regulators fix flow under wide pressure variation, are standard hardware.
5. Closed control area (no ventilation)	Install exhaust fan and open windows	High temperature and humidity caused malfunctions of data logger and ultimate failure of the mag tape unit. Mag tape unit required replacement.
6. Voltage calibration of RTD's amplifiers	In-situ calibration with ice and boiling water baths	Two-wire RTD's do not compensate for wide variation in lead length, require in-situ calibration.
7. Clock in L and N curve follower (flowrate control)	Add standard AC clock timer option	Timing was based on a gear driving a paper chart, requiring at least weekly adjustment. Also, switch in L and N has malfunctioned many times. Clock timer is simple and reliable.
8. Can-line select switch, set to supply flow to either line	Selector switch-bypassed for priority switching	Can-line loads pattern not as regular as originally provided information. One line can be off for weeks. Priority switching allows maximum water usage by directing water to either of operating can lines.
9. Glass covering on all receiver tubes	One-half field with glass covers, one-half without	Investigate benefit of glazed receiver tube for this type of application
10. Surface temperature measurement on all flat plates	Surface temperature on one flat plate in front row and one in back row.	Reduce control circuit complexity by eliminating redundant measurements.

Table 7. Concluded

From	To	Comment
11. Freeze protect sensing from numerous flat-plate panel sensors	Freeze protect sensing on air temperature measurement with bimetallic switch (in air) backup	Reduce control complexity, improve reliability using nonelectronic backup device. Air temperature monitoring will prevent localized freezing which water temperature sensors, affected by thermal inertia, might allow.
12. Baseline data system	Added various ^a system states to data channels	The states data will allow determination of system conditions for data reduction.
13. Special stow microswitch assembly	Separate feeler assemblies	Some special assemblies failed due to dirt entering the mechanisms. New units are fully sealed, standard industrial hardware.
14. North stow at full north position	North stow at 50° beyond vertical	Extra stow travel not required for proper operation. System less likely to follow bright clouds on cloudy day.
15. Can-line flow switch location near heat exchanger on can-line floor	Flow switch location outside by pump	Flow switch location difficult to service. High temperature and humidity caused rapid failure of flow switch.

^aCan-line flow, tank level, system on/off

was designed as an experiment and, as such, had a considerable amount of control flexibility and options incorporated in the design to permit optimization of its performance. Based on the experience gained during the operation of the facility from April 1978 through June 1979, many of these options were eliminated and emphasis was placed on improving the utilization of the solar hot water by the plant can-line operation (e.g., see item 8 of Table 7). This approach proved successful and resulted in high system availability (reliability) during the evaluation period. The following Section, 2.2.1, summarizes the operating experience during the project period. Operation and maintenance requirements are given in Section 2.2.2 and recommendations based on operating experience are given in Section 2.2.3.

2.2.1 Operating Experience

Operation of the hot water facility for this evaluation was from October 1979 through September 1980. Figure 9 illustrates the percentage of days, by month, that the hot water facility was available for operation. This graph also shows the percentage of time the can washers were operating, which is a measure of the utilization by the plant of the solar supplied hot water. Solar facility availability was quite low during November and December 1979 and January 1980 as a result of operational problems. These were corrected in early 1980 and 100 percent operation was achieved during the last 6 months of evaluation. Maximum energy delivery, however, was not achieved during most of this latter period because the can washers were not operating continuously while the solar facility was operating. Consequently, the storage tank would fill with water and the collector field would shut down early in the day. (Recommendations to correct this problem are given in Section 2.2.3.)

Figure 9. System and Process Percent of Time Available

Major operational problems encountered and corrected are summarized in Table 8. Item 2, jamming of flow components by inert solids, had the greatest effect on system operation and data acquisition (since field flow was inferred from the flow control valve setting -- see Section 2.1.4). Regular cleaning of system flow components was initiated in early 1979 to correct this problem, and, concurrently, analyses of water samples were undertaken by Campbell Soup personnel. Based on these analyses, an inline water separator was installed and has corrected the frequent clogging of flow components. Appendix G provides a detailed summary, by month, of the operating problems and corrective actions during the entire year of operation. In general, operation of the facility became routine and trouble-free during the last 6 months of the evaluation period.

2.2.2 Operations and Maintenance Requirements

Operation and maintenance records for the system were maintained to characterize the types and level of the effort required to operate the system. This effort does not reflect initial startup, checkout, calibration, or modifications required to bring the system into full, reliable operation. It does, however, include any repair, calibration, lubrication, washing, etc., required to keep the system in routine working order. Table 9 summarizes the annual requirements for the facility. In addition to these requirements, a system operations and maintenance manual, and as-built drawings are essential for plant maintenance personnel.

2.2.3 Recommendations

The objective of this contract was to operate the facility and obtain 12 months of performance data. This objective was accomplished. As a result of this experience, several actions have been identified that

Table 8. Major Operational Problems and Solutions

Item	Effect	Correction
1. Control program	Incorrect or nonoptimum sequencing of system controls resulted in system downtime or reduced system operation	Control program was reprogrammed for simpler system operation (January 1980)
2. Jamming of flow control valve, strainers, etc. by inert solids in supply water	System downtime and reduced data accuracy	Frequent blowdown of strainers, regular cleaning of valve, and installation (November 1980) of blowdown water separator on inlet water supply
3. Reduced steam flow through auxiliary heat exchanger	System downtime if minimum can-line supply temperature (180°F) cannot be provided	Plant maintenance of steam heat exchanger and controls

Table 9. Operation and Maintenance Requirements

Item	Frequency	Labor	Other Direct Costs
Monitor system performance	15 min/day	65 hr	\$3,070*
Parts replacement and repair	As required	72 hr	
Collector washing	16 hr/wash Once/4 months	48 hr	
Lubrication and other cleaning	Once/yr 0.5 hr/wk	34 hr	\$50
Calibration and adjustments	Once/yr Once/3 months	33 hr	
Total		252 hr	\$3,120

*Other direct costs for routine replacement and repair

<u>Item</u>	<u>Quantity</u>	<u>Cost</u>
● Motors		\$ 450
● Transmitters	2	470
● RTD's	2	50
● TMC board	1	75
● Control modules	2	50
● SARCO valve	2	400
● Pressure gages	2	50
● Line printer repair	1	325
● Repair mag tape	1	900
● Miscellaneous	1	300

would improve the system operating reliability and result in a facility which is easier to maintain by Campbell Soup personnel. These recommended changes reflect a shift away from the original contract approach, which viewed the solar facility as a research experiment, to an approach that will provide a reliable, trouble-free, industrial-grade facility to the plant owner. This approach emphasizes operation and control simplicity and the selection of industrial-grade, nationally serviceable hardware. Table 10 summarizes, by categories, the recommendations that Acurex and Campbell Soup propose to accomplish these objectives based on the 15 months of operating experience.

The first and most significant recommendation concerns the interface of the solar facility with the plant can washing process. Since the operation of the can washers has been (and will continue to be) irregular, full utilization of the solar facility is not possible. Consequently, it is recommended that the solar supplied water be provided to the plant service hot water main, upstream of the plant stream heat exchanger, which heats the service water to 190° to 200°F. This approach utilizes the existing plant controls to provide any required auxiliary heating of the solar supplied water and ensures that all of the solar supplied water is used as it is collected.

With respect to controls, it is recommended that the existing control panel be modified to permit easier use by the plant operator and maintenance personnel. This includes an annunciator panel for system status and alarms and auto/manual system operating switches. Key process indicators (i.e., temperatures and flowrate) for all subsystems should also be provided on easy-to-read panel meters.

Table 10. Recommendations Based on Operating Experience

Item	Comment	Recommendation
Plant interface		
<ul style="list-style-type: none"> Can line washers 	Operation is irregular resulting in less than full utilization of the solar-supplied water	Revise plant interface; tie into plant water main to achieve 100 percent utilization
Controls		
<ul style="list-style-type: none"> Field flowrate 	Fixed flowrate resulted in simpler, reliable operation and maximized energy collection	Retain constant field flowrate. Use a self-powered flow control valve to regulate flow
<ul style="list-style-type: none"> System control panel 	A simple, central control panel with auto/manual switches and an annunciator panel with system indicators, alarms, and mode status is preferred by plant operators	Revise control panel for easier use by plant operators and maintenance personnel
<ul style="list-style-type: none"> Control hardware 	Although the programmable controller has provided design flexibility and reliability, the user prefers conventional relay-logic hardware for ease of service	Replace programmable controller with relays; specify equipment commonly used by Campbell maintenance personnel
Collector field		
<ul style="list-style-type: none"> Solargenics Series 75 flat-plate collectors 	Flat-plate panels developed large leakage of water past glazing seal resulting in corrosion of absorber plate	Replace seals and damaged absorber plates or replace entire unit
<ul style="list-style-type: none"> Acurex Model 3001-2 concentrator 	Original receiver support does not provide adequate support resulting in sagging of tube and inadequate expansion provided for Pyrex glass tube resulting in glass breakage	Replace existing receivers with current 3001 receiver assembly
<ul style="list-style-type: none"> Concentrator tracker system 	Although sun sensors have worked reliably, they are one-of-a-kind prototypes developed 3 years ago	Replace trackers with current sensors which are a commercial product with standard repair/service procedures. Also, use direct insolation monitor rather than total horizontal pyrometer for concentrator wake-up and stow commands

Table 10. Concluded

Item	Comment	Recommendation
<p>Date acquisition</p> <ul style="list-style-type: none"> ● Mag tape/line printer ● Data sensors <p>System documentation</p> <ul style="list-style-type: none"> ● O and M manual and as-built drawings 	<p>Line printer is redundant with mag tape, but has proven a valuable backup to tape due to tape failures</p> <p>Data sensors should not be used as control signals. Sensors should be easily calibrated and simple, gage sensors should be installed to verify electronic instrumentation</p> <p>Documentation for the system was deferred pending direction by DOE regarding the above recommendations</p>	<p>Provide a redundant data recording device to ensure data collection</p> <p>Use three-wire RTD's for temperature measurement, provide bulb thermometers and pressure gages in key locations</p> <p>System documentation is essential for the facility owner to assume operation and maintenance of the facility</p>

In the collector field, two major actions are recommended. These include: (1) repair or replacement of the leaking flat-plate panels (about 25 percent have damaged absorber plates) and (2) replacement of concentrator receiver tubes. These and the other actions recommended in Table 10 are currently under consideration by DOE and it is anticipated that an upgrade project will be underway in early 1981.

SECTION 3

SYSTEM PERFORMANCE

This section summarizes the thermal and economic performance of the solar facility during the period of October 1979 through September 1980. Section 3.1 discusses measured system performance, system availability and utilization by the plant, data measurement error, and conclusions based on the evaluation period. Section 3.2 presents an economic analysis including fuel savings, operation and maintenance costs, and projected costs for large-scale systems.

3.1 THERMAL PERFORMANCE

This section presents the thermal performance for the solar facility and shows the breakdown of availability and utilization records for the facility. This data shows that:

- The solar facility performed with excellent reliability, being available for operation 99 percent of the time during the last 8 months of the period
- Low utilization by the process restricted the solar facility operation to the extent that overall energy collection would have been two times greater with full utilization
- The thermal performance of the solar energy system was good, being in agreement with predictions when utilization effects are included

The following data is presented to conform with the SERI Data Acquisition System Guideline (Reference 2) as much as possible using the installed data system. Definitions of the energy values presented are listed in Table 11.

Table 11. Definitions of Energy Values

Values	Definition
(1) Total horizontal insolation	Total insolation on horizontal surface over entire day
(2) Insolation to collector aperture	Insolation (total at 25° plane for flat plates and direct on concentrator plane) on collector aperture during operation
Energy to storage	Energy to tank as measured by temperature rise from collector field inlet to tank inlet
Electrical energy	Calculated electrical energy use by pumps, concentrator drives, and controls, averaged over 24 hr
Fossil fuel saved	Energy to storage divided by 65 percent (relative efficiency of storage tank to plant steam system)
Efficiency (based on (1))	Energy to storage divided by total horizontal insolation times the collector aperture area (7335 ft ²)
Efficiency (based on (2))	Energy to storage divided by insolation to collector aperture

Table 12 shows a capsule summary of the performance and operation information presented later in this section.

3.1.1 Measured System Performance

Table 13 shows measured performance data for the solar facility, by month, for the reporting period. This data is for days on which the solar

Table 12. Capsule Summary, October 1979 Through September 1980

<u>Measured</u>	
Days system available and data taken	257
Average daily energy to storage	2.9×10^6 Btu
Average daily efficiency	48%
Energy to storage	749×10^6 Btu
Equivalent barrels of oil displaced	210
Value of fuel displaced (at \$30/bbl)	\$6,300
 <u>Estimated for 100 Percent Data System Availability</u>	
Days system available and data taken	293
Average daily energy to storage	2.8×10^6 Btu
Average daily efficiency	48%
Energy to storage	831×10^6 Btu
Equivalent barrels of oil displaced	232
Value of fuel displaced (at \$30/bbl)	\$6,960
 <u>Estimated for 100 Percent Data Availability and 100 Percent Utilization</u>	
Days system available and data taken	293
Average daily energy to storage	5.3×10^6 Btu
Average daily efficiency	48%
Energy to storage	1561.2×10^6 Btu
Equivalent barrels of oil displaced	437
Value of fuel displaced (at \$30/bbl)	\$13,110
 <u>Estimated for 100 Percent Data Availability, 100 Percent Utilization, and 100 Percent Availability</u>	
Days system available and data taken	366
Average daily energy to storage	5.0×10^6 Btu
Average daily efficiency	48%
Energy to storage	1843.6×10^6 Btu
Equivalent barrels of oil displaced	516
Value of fuel displaced (at \$30/bbl)	\$15,480

Table 13. Measured System Performance

Month	Total Horizontal Insolation (Btu/ft ²) (1)	Insolation to Collector Aperture During Operation (10 ⁶ Btu) (2)	Insolation to Flat Plates During Operation (10 ⁶ Btu)	Insolation to Concentrator During Operation (10 ⁶ Btu)	Energy to Storage (10 ⁶ Btu)	Daily Efficiency, Percent (Based on (1))	Daily Efficiency, Percent (Based on (2))	Fossil Fuel Displaced (10 ⁶ Btu)	Electrical Energy ^a (10 ⁶ Btu)	Days of Data ^b
October 1979	25,900	147.7	104.9	42.8	82.1	42	56	126.3	2.2	23
November ^c	12,858	67.4	47.9	19.5	35.7	38	53	54.4	1.1	17
December	1,484	6.0	5.7	2.3	4.6	47	58	7.1	0.1	2
January 1980	4,145	25.4	15.9	9.5	12.9	42	51	19.8	0.4	6
February	22,009	109.7	85.3	23.9	54.7	34	50	84.2	1.8	27
March	28,083	148.6	103.2	45.4	73.4	26	49	113.1	2.1	26
April	45,915	59.9	41.3	18.6	30.7	9	51	47.2	1.2	24
May ^c	54,491	87.3	63.5	23.8	43.4	11	50	66.8	1.5	24
June ^c	72,353	132.3	86.3	45.4	66.2	12	50	101.8	2.0	28
July ^c	75,335	196.7	151.0	45.7	78.5	14	40	120.8	2.3	31
August ^c	90,520	268.8	201.2	67.6	107.6	29	40	165.5	2.7	22
September ^c	46,216	319.5	211.5	108.0	159.6	47	50	245.5	3.9	27
Total	462,983	1571.3	1118.8	452.5	749.4	23	48	1152.5	21.3	257

^aCalculated^bDays solar system was available and data was taken^cSystem data taken during these months indicated higher than normal efficiencies.

This was due to various problems with flow components causing lower than normal flowrates (see text, Operational Experience). Average efficiencies for each month were estimated based on performance data when flowrates were at proper levels and the temperatures at which the collectors were operating in these months. The data for these months were modified to reflect the estimated efficiency. The estimated efficiencies used for each of the months were: November, 53 percent; May, 50 percent; June, 50 percent; July, 40 percent; August, 40 percent; September, 50 percent.

facility was available and data was taken. Days on which the solar facility was not available are not included as this table is intended to show the performance of the system when operational. (Information on the availability of the system is shown later in this section.)

This data shows the effect on system performance of low utilization of the facility by the process (can washers). Beginning in February and continuing through August, plant operations were reduced and the operating time of the two can lines that use the solar supplied hot water was decreased significantly. Water demand was so reduced during these months that often the solar facility was available to operate but could not because the storage tank was already full.

This effect appears as a reduction in the value of daily efficiency relative to total horizontal insolation, the available solar resource. Nominally, this value should be approximately 45 percent for this system. However, during the reduced plant operations period the values are significantly less, as low as 9 percent during April. This reflects the fact that the solar system was sitting idle most of April because its storage tank was full. Over the year, the value of this efficiency was 23 percent, indicating that total energy collection could have been twice as much with full utilization.

This table shows also the low parasitic power consumption of the system relative to fossil fuel displaced. Using a net generation efficiency of 30 percent, the equivalent fossil fuel used to generate the electrical power used is only 6 percent of the fuel displaced.

Daily Average Performance by Month

Table 14 shows the daily averages of the performance values by month. These once again indicate how the lack of demand by the can lines

Table 14. Daily Average Performance by Month

Month	Total Horizontal Insolation (Btu/ft ²) (1)	Insolation to Collector Aperture During Operation (10 ⁶ Btu) (2)	Insolation to Flat Plates During Operation (10 ⁶ Btu)	Insolation to Concentrator During Operation (10 ⁶ Btu)	Energy to Storage (10 ⁶ Btu)	Daily Efficiency, Percent (Based on (1))	Daily Efficiency, Percent (Based on (2))	Fossil Fuel Displaced (10 ⁶ Btu)	Electrical Energy ^a (10 ⁶ Btu)	Days of Data ^b
October 1979	1,170	6.4	4.6	1.9	3.6	42	56	5.5	0.10	23
November ^d	756	4.0	2.8	1.1	2.1	38	53	9.2	0.07	17
December	572 ^c	4.0	2.9	1.2	2.3	47	58	3.5	0.07	2
January 1980	691	4.2	2.5	1.6	2.2	42	51	3.3	0.07	6
February	815	4.1	3.2	0.9	2.0	34	50	3.1	0.07	27
March	1,464	5.7	4.0	1.7	2.8	26	49	4.4	0.08	26
April	1,913	2.5	1.7	0.8	1.3	9	51	2.0	0.05	24
May ^d	2,270	3.6	2.5	1.0	1.8	11	50	2.8	0.06	24
June ^d	2,584	4.7	3.8	1.6	2.4	12	50	3.6	0.07	28
July ^d	2,430	6.3	4.9	1.5	2.5	14	40	3.9	0.08	31
August ^d	2,296	12.2	9.1	3.1	4.9	29	40	7.5	0.12	22
September ^d	1,711	11.8	7.8	4.0	5.9	47	50	9.1	0.14	27
Total	1,635	6.1	4.4	1.8	2.9	23	48	4.5	0.08	257

^aCalculated

^bDays solar system was available and data was taken

^cBased on 30 days of data

^dSystem data taken during these months indicated higher than normal efficiencies.

This was due to various problems with flow components causing lower than normal flowrates (see text, Operational Experience). Average efficiencies for each month were estimated based on performance data when flowrates were at proper levels and the temperatures at which the collectors were operating in these months. The data for these months were modified to reflect the estimated efficiency. The estimated efficiencies used for each of the months were: November, 53 percent; May, 50 percent; June, 50 percent; July, 40 percent; August, 40 percent; September, 50 percent.

restricted system operation. In the summer months when energy values should be high, they are low, not because of low system thermal efficiency, but due to reduced demand for hot water.

Figure 10 shows the low utilization problem graphically. Shown are daily average values by month for total horizontal insolation, insolation to collector aperture, and energy to storage. As the low utilization period occurred during the peak insolation summer months, it has a large effect on energy collection. Appendix G contains a monthly summary table for each of the 12 months evaluated.

Hourly System Performance

Hourly graphs and tables are included for two typical clear days. The first set (Figure 11, Table 15), for a day in September, shows a normal operating day. The second set (Figure 12, Table 16), for an April day, shows how the system may run for only 4 hours in the morning during periods of low utilization. Appendix F contains an hourly summary table for a typical day in each of the 12 months evaluated.

3.1.2 System Availability and Utilization

Data on solar facility, data system, and process (can washer) availability and system utilization is shown in Table 17. The number of days of freeze protection is also shown. Figure 13 shows a graph of the percent of time the solar system and the process were available.

This information again illustrates the low use of the solar facility by the plant process. This data does not fully show the effect of low utilization since any day in which the process allowed the solar facility to run, even for a short time only, is considered a "process available" day.

Figure 10. Daily Average Energy Values

Figure 11. Single Day Graph
Day 257, 9/13/80
Campbell Soup

Table 15. Single Day Table
Day 257, 9/13/80
Campbell Soup

(Hourly Averages)

Hour	8tu/ft ² /hr	In 10 ⁶ 8tu/hr						Eff., Percent (Based on (1))	Eff., Percent (Based on (2))	In °F			In mph
	Total Horiz. Insol. (1)	Insol. to Coll. Plane (2)	Insol. to Flat Plates	Insol. to Conc.	Energy to Storage ^a	Elect. Energy ^b	Fossil Fuel Saved			Field Inlet	Tank Inlet	Ambient	Wind Speed
1	—	—	—	—	—	—	—	—	—	—	—	70.1	0.0
2	—	—	—	—	—	—	—	—	—	—	—	68.2	5.9
3	—	—	—	—	—	—	—	—	—	—	—	67.0	0.7
4	—	—	—	—	—	—	—	—	—	—	—	66.4	4.2
5	—	—	—	—	—	—	—	—	—	—	—	66.3	0.0
6	—	—	—	—	—	—	—	—	—	—	—	69.4	0.5
7	16	—	—	—	—	—	—	0	—	—	—	64.7	0.0
8	73	—	—	—	—	—	—	0	—	—	—	67.2	7.7
9	128	0.7	0.5	0.2	0.2	—	0.3	21	29	71.0	85.6	70.4	7.8
10	176	1.4	0.9	0.5	0.6	—	0.9	46	43	71.0	109.6	73.0	11.8
12	213	1.7	1.1	0.6	0.8	—	1.2	51	47	71.2	126.4	76.4	4.3
12	237	1.9	1.2	0.7	1.0	—	1.5	58	53	71.3	137.9	78.8	8.5
13	248	2.0	1.3	0.7	1.1	—	1.7	60	55	71.5	143.3	80.0	14.9
14	237	1.9	1.2	0.7	1.0	—	1.5	58	53	71.5	140.4	80.6	11.8
15	208	1.7	1.1	0.6	0.9	—	1.4	59	53	71.5	131.3	83.3	8.4
16	162	1.2	0.8	0.4	0.7	—	1.1	59	58	71.4	117.0	83.4	8.2
17	106	0.8	0.5	0.3	0.4	—	0.6	51	50	71.3	98.0	82.7	14.6
18	50	0.3	0.2	0.1	0.2	—	0.3	55	67	71.3	81.7	79.3	13.6
19	—	—	—	—	—	—	—	—	—	—	—	77.2	8.9
20	—	—	—	—	—	—	—	—	—	—	—	75.0	1.7
21	—	—	—	—	—	—	—	—	—	—	—	70.7	7.6
22	—	—	—	—	—	—	—	—	—	—	—	68.3	12.8
23	—	—	—	—	—	—	—	—	—	—	—	65.5	0.4
24	—	—	—	—	—	—	—	—	—	—	—	64.8	5.2
Total	1857	13.8	9.0	4.8	6.9	0.16	10.6	51	50	—	—	—	—

^aBased on 30 gpm flowrate

^bCalculated as daily total only

Figure 12. Single Day Graph
Day 107, 4/16/80
Campbell Soup

Table 16. Single Day Table
Day 107, 4/16/80
Campbell Soup

Hour	Btu/ft ² /hr	In 10 ⁶ Btu/hr						Eff. (Based on) (1)	Eff. (Based on) (2)	In °F			In mph
	Total Horiz. Insol. (1)	Insol. to Coll. Plane (2)	Insol. to Flat Plates	Insol. to Conc.	Energy to Storage	Elect. Energy	Fossil Fuel Saved			Tank Inlet	Field Inlet	Ambient	Wind Speed
0	--	--	--	--	--	0.006	--	--	--	--	--	62.1	2.5
1	--	--	--	--	--	0.006	--	--	--	--	--	61.4	2.1
2	--	--	--	--	--	0.006	--	--	--	--	--	61.0	2.2
3	--	--	--	--	--	0.006	--	--	--	--	--	60.0	0.5
4	19	--	--	--	--	0.006	--	--	--	--	--	61.0	0.0
5	77	--	--	--	--	0.006	--	--	--	--	--	68.3	0.0
6	140	0.7	0.5	0.2	0.3	0.006	0.4	29%	40%	68.4	89.2	73.0	0.8
7	195	1.1	0.9	0.2	0.6	0.006	0.9	42%	54%	69.5	111.1	80.9	0.4
8	240	1.6	1.1	0.5	0.8	0.006	1.3	45%	50%	69.6	125.1	85.1	1.5
9	264	1.7	1.1	0.5	0.9	0.006	1.4	46%	55%	69.7	132.2	89.7	0.5
10	260 ^a	--	--	--	--	0.006	--	--	--	--	--	91.5	1.6
11	260	--	--	--	--	0.006	--	--	--	--	--	92.9	2.7
12	236	--	--	--	--	0.006	--	--	--	--	--	95.7	1.0
13	179	--	--	--	--	0.006	--	--	--	--	--	95.9	2.5
14	136	--	--	--	--	0.006	--	--	--	--	--	95.3	2.8
15	73	--	--	--	--	0.006	--	--	--	--	--	92.4	4.2
16	20	--	--	--	--	0.006	--	--	--	--	--	89.7	1.1
17	--	--	--	--	--	0.006	--	--	--	--	--	85.4	1.1
18	--	--	--	--	--	0.006	--	--	--	--	--	81.9	0.0
19	--	--	--	--	--	0.006	--	--	--	--	--	80.6	0.0
20	--	--	--	--	--	0.006	--	--	--	--	--	77.9	3.8
21	--	--	--	--	--	0.006	--	--	--	--	--	74.1	2.4
22	--	--	--	--	--	0.006	--	--	--	--	--	70.4	3.0
23	--	--	--	--	--	0.006	--	--	--	--	--	68.0	3.7
Total	2101	5.1	3.6	1.4	2.6	0.15	3.9	16%	50%	--	--	--	--

^aSystem shut down due to tank fill-up

Table 17. System/Process Availability and Utilization Breakdown

	Solar System Available	Process Available	Availability	Utilization	Data System Operation	Freeze Protection
October 1979	77% (24 days)	100% (31 days)	77% (24/31)	100% (24/24)	97% (30 days)	0 days
November	67% (20 days)	100% (30 days)	67% (20/30)	100% (20/20)	93% (28 days)	1 day
December	6% (2 days)	61% (19 days)	11% (2/19)	100% (2/2)	97% (30 days)	6 days
January 1980	19% (6 days)	71% (22 days)	18% (4/22)	67% (4/6)	26% (8 days)	2 days
February	93% (28 days)	72% (21 days)	95% (20/21)	71% (20/28)	100% (29 days)	0 days
March	97% (30 days)	87% (27 days)	96% (26/27)	87% (26/30)	100% (31 days)	0 days
April	100% (30 days)	40% (12 days)	100% (12/12)	40% (12/30)	100% (30 days)	0 days
May ^a	100% (24 days)	46% (11 days)	100% (11/11)	46% (11/24)	77% (24 days)	0 days
June ^a	100% (29 days)	55% (16 days)	100% (16/16)	55% (16/29)	97% (29 days)	0 days
July	100% (31 days)	74% (23 days)	100% (23/23)	74% (23/31)	100% (31 days)	0 days
August	100% (31 days)	100% (31 days)	100% (31/31)	100% (31/31)	71% (22 days)	0 days
September	100% (30 days)	100% (30 days)	100% (30/30)	100% (30/30)	90% (27 days)	0 days
Total	80% ^b (285 days)	76% ^b (273 days)	80% (219/273)	77% (219/285)	87% ^c (319 days)	9 days

^aBased only on days data system operated because no site observations available

^bBased on 358 days observations available

^cBased on 366 days

Figure 13. System and Process Percent of Time Available

The high reliability of the system during the last 8 months of the year is also shown in Figure 13. The system experienced its low availability period during the low insolation winter months. Work performed on the facility during this period resulted in the 99 percent availability record during the remaining 8 months of the year (refer to Section 2.2.1).

Predicted Vs Measured Vs Potential Performance

A comparison of predicted, measured, and potential daily averages for insolation and energy collected is shown in Table 18. Insolation on the flat-plate collectors and the concentrators was estimated using a Liu and Jordan model modified as indicated on the table. This was used to predict system energy collection based on an average daily efficiency of 45 percent.

The table shows that measured total horizontal insolation values are close to the predictions, indicating the reporting period was an "average" year. The large reduction of measured values from those predicted is due to the low utilization of the solar supplied water by the can washers.

To quantify the impact of low utilization on the system, the last two columns of Table 18 show potential energy values, assuming full utilization of the solar system. The potential values show a large increase over the measured values in the high insolation summer months and agree well with the predicted values over the year. The net effect is to almost double the year-long daily average insolation and energy collected values.

Potential Energy to Storage Breakdown

Table 19 shows a monthly breakdown of three estimated energy collection approaches which assess the impact of data system, process, and

Table 18. Predicted, Measured, and Potential Performance of Current Campbell Solar Facility

Month	Predicted Insolation			Predicted Energy Delivered		Measured Values October 1979 Through September 1980			Potential Estimated With 100% Utilization	
	Long Term Average ^a L&J, Total Horizontal (Btu/ft ² /day)	Modified L&J ^b Total at 20° (10 ⁶ Btu/day)	Modified L&J Direct at Trough (10 ⁶ Btu/day)	Energy at Total Field Aperture Over Day (10 ⁶ Btu/day)	Energy to ^c Storage (10 ⁶ Btu/day)	Horizontal Insolation (Btu/ft ² /day)	Energy at Field Aperture During Operation ^d (10 ⁶ Btu/day)	Energy to Storage (10 ⁶ Btu/day)	Energy at Field Aperture During Operation ^d (10 ⁶ Btu/day)	Energy to Storage (10 ⁶ Btu/day)
1	607	3.48	2.05	5.52	2.49	691	4.2	2.2	4.5	2.4
2	977	5.11	2.67	7.78	3.50	815	4.1	2.0	5.4	2.6
3	1519	7.26	3.42	10.7	4.82	1464	5.7	2.8	9.9	4.8
4	1942	8.83	3.78	12.4	5.58	1913	2.5	1.3	12.5	6.5
5	2323	9.83	4.48	14.3	6.44	2270	3.6	1.8	14.7	7.4
6	2544	10.80	5.01	15.6	7.02	2584	4.7	2.4	17.6	9.0
7	2459	10.40	4.87	15.3	6.89	2430	6.3	2.5	16.2	6.4
8	2166	9.85	4.44	14.1	6.35	2296	12.2	4.9	15.1	6.1
9	1689	8.17	4.05	12.2	5.49	1711	11.8	5.9	11.8	5.9
10	1193	6.40	3.61	10.0	4.50	1170	6.4	3.6	6.9	3.9
11	699	4.28	2.52	6.60	2.97	756	4.0	2.1	4.7	2.5
12	529	3.24	2.05	5.29	2.38	572	4.0	2.3	4.0	2.3
Year total	5.67×10^5 /yr	2.64×10^9 Btu/yr	1.3×10^9 Btu/yr	3.95×10^9 Btu/yr	1.78×10^9 /yr					
Average daily	1554	7.23	3.58	10.8	4.88	1635	6.1	2.9	11.9	5.7

Table 19. Potential Energy to Storage Breakdown

Month	Predicted (10 ⁶ Btu)	Measured (10 ⁶ Btu)	Estimated Measured With 100% Data System Availability (10 ⁶ Btu)	Potential Estimated Measured With 100% Utilization	
				With Actual Availability (10 ⁶ Btu)	With 100% Availability (10 ⁶ Btu)
October 1979	139.5	82.1	84.6	90.6	117.7
November	89.1	35.7	38.4	45.5	67.9
December	73.8	4.6	4.6	4.6	76.7
January 1980	77.2	12.9	12.9	13.8	67.9
February	101.5	54.7	54.7	72.4	77.8
March	149.4	73.4	73.4	127.0	130.9
April	167.4	30.7	30.7	153.5	153.5
May	199.6	43.4	56.4	230.7	230.7
June	210.6	66.2	68.2	255.8	255.8
July	213.6	78.5	78.5	201.9	252.3
August	196.9	107.6	151.5	188.1	235.1
September	164.7	159.6	177.3	177.3	177.3
Total	1783.3	749.4	831.2	1561.2	1843.6

solar system downtime on measured energy collection. Figure 14 displays the Table 19 information in graphical form. Data system downtime reduces the measured energy because some solar system generation goes unmonitored. If 100 percent data system availability had been achieved, the average monthly energy collection would have been 831 million Btu, or 11 percent higher than the measured value. Using observed availability and 100 percent utilization, the energy collected increases by an additional 88 percent to 1561 million Btu. Finally, applying 100 percent system availability, the energy collected increases 18 percent to 1844 million Btu.

3.1.3 Data Measurement Error Analysis

Error in system measurements and performance calculations will be present in any solar system data analysis due to inherent data system inaccuracies. In a document prepared by the National Bureau of Standards (Reference 3), 6 percent is recommended as an error criterion for calculated overall values, such as efficiencies, for solar energy systems.

The methodology presented in that report was used in conducting an error analysis for the Campbell Soup solar facility. The results of this analysis are shown in Table 20. The highlights of the methodology are:

- Sensor measurement error and sampling rate error are included
- RMS error calculation method was used, assumes errors are random and uncorrelated
- Manufacturer's data and Acurex engineering judgment was used to estimate information needed for the error analysis

Table 20 shows that the dominant uncertainty in system calculations is the flowrate error. This flowrate error is due mainly to the control error in the field flow control valve (estimated to be 10 percent) and in

Figure 14. Potential Energy Collection

Table 20. Measurement Error Analysis for the Campbell Soup Solar Facility

	Daily	Monthly
Total horizontal insolation (1)	$\pm 2.0\%$ ($\pm 1.4\%$) ^a	$\pm 1.0\%$ ($\pm 1.0\%$)
Insolation to collector aperture during operation (2)	$\pm 1.7\%$ ($\pm 1.3\%$)	$\pm 1.1\%$ ($\pm 1.0\%$)
Insolation to flat plates during operation	$\pm 2.1\%$ ($\pm 1.4\%$)	$\pm 1.0\%$ ($\pm 1.0\%$)
Insolation to concentrator during operation	$\pm 1.6\%$ ($\pm 1.6\%$)	$\pm 1.6\%$ ($\pm 1.6\%$)
Flowrate	$\pm 12.8\%$ ($\pm 2.6\%$)	$\pm 10.1\%$ ($\pm 1.5\%$)
Field inlet to tank inlet ΔT	$\pm 2.0\%$ ($\pm 1.9\%$)	$\pm 1.9\%$ ($\pm 1.9\%$)
Energy to storage	$\pm 13.0\%$ ($\pm 3.2\%$)	$\pm 10.3\%$ ($\pm 2.4\%$)
Efficiency based on (1)	$\pm 13.2\%$ ($\pm 3.8\%$)	$\pm 10.3\%$ ($\pm 2.6\%$)
Efficiency based on (2)	$\pm 13.1\%$ ($\pm 3.6\%$)	$\pm 10.4\%$ ($\pm 2.6\%$)

^aValues in parentheses are error values assuming proper functioning of the facility flow control valve

smaller part to the 15 minute data system scanning rate (the field flow is inferred from the valve flowrate setting). This worst case error in the valve can occur when material in the field supply water causes the valve to jam (and behave as a fixed orifice with a varying head due to tank level fluctuations). Final resolution of this problem involved the installation of a water treatment system, but other actions that were taken to lessen the flowrate error were:

- Biweekly calibration and inspection of the field flow control valve
- Regular (weekly) blowdown of inline water supply strainers
- Periodic cleaning of the flow control valve and main field solenoid valve

The error analysis was also computed assuming the water treatment system was in place. These results are indicated in parentheses in Table 20. As the table shows, the overall error is within the NBS 6 percent criterion with the proper functioning of the flow control valve.

3.1.4 Conclusions

The thermal performance of the Campbell Soup system has been good. Measured energy collection is in agreement with predicted values by accounting for three well defined and specific effects (which are not a result of the solar facility as it is presently configured). These are:

- Low utilization of solar supplied water by the can washers accounting for an 88 percent decrease in energy collection. This is due to the process running unexpectedly short hours during the summer and is not caused by any inability of the system to produce hot water.

- Data system downtime accounting for an 11 percent decrease in measured energy collection. This is due to energy collection which took place but was not measured.
- Solar system downtime accounting for an 18 percent decrease in energy collection. In its present configuration the system has demonstrated high reliability, running at 99 percent availability for the last 8 months of the period. Therefore, it is likely that in its present state, the system's availability losses will be negligible.

3.2 ECONOMIC PERFORMANCE

This section presents the economic performance of the solar system. Fuel savings, O and M costs, and an economic analysis are given.

3.2.1 Fuel Savings

Table 21 shows fuel savings for the system: predicted, measured, and potential. these were calculated based on a 65 percent relative efficiency of the boiler system to the storage tank and fuel oil with an energy content of 5.5×10^6 Btu/bbl.

3.2.2 Operation and Maintenance Costs

Table 22 presents O and M costs for the system. These costs are based on actual hours and equipment recorded for the reporting period. Labor and loading rates were chosen that are typical for industry. These are 1.75 overhead factor applied to \$8/hr labor to yield \$14/hr loaded maintenance labor and 1.15 purchasing rate applied to equipment purchases.

3.2.3 Economic Analysis

A simple economic analysis has been performed for the Campbell Soup solar energy system. Two cases were considered. One was performed using

Table 21. Fossil Fuel Savings

	bbls Saved	\$ Saved
Measured	210	6,300
Measured with 100% data system availability	232	6,960
Potential with 100% utilization and actual availability	437	13,110
Potential with 100% utilization and 100% availability	516	15,480

Table 22. O and M Costs

	Labor	Equipment	Total
Monitor system performance	\$ 910	\$ --	\$ 910
Parts replacement and repair	1,008	3,530	4,538
Collector washing	672	--	672
Lubrication and other cleaning	476	58	534
Calibration and adjustments	462	--	462
Total	\$3,528	\$3,588	\$7,116

original construction costs and potential system performance. A second was performed based on present estimated system construction costs and potential system performance.

The cost factors used in the first case were:

Capital cost (1978) (\$79/ft ²)	580,000
Annualized capital cost (using 20% CRF)	116,000
Annual O and M cost	7,116
Annual parasitic power cost	250
Total annual cost	123,000
Measured fuel displaced \$/bbl	210 bbls 585/bbl

This value is very high relative to current oil prices, but several factors account for this. The capital cost reflects a first of its kind, experimental field test. The system experienced high initial maintenance requirements and costs and had a low utilization year. Also, no tax benefits are shown in this analysis.

To account for these effects, a record analysis was performed using the following cost factors reflecting current estimated costs and potential energy collection.

Capital cost (1980) (\$45/ft ²)	330,000
Present value of solar tax credits and depreciation (68%)	224,000
Net initial cost	106,000
Annualized initial cost (25% CRF)	26,500
Annual O and M cost (as 1% capital cost)	3,300
Annual parasitic power cost	614
Total annual cost	30,400
Potential fuel displaced \$/bbl	516 bbls 58.9/bbl

This levelized value of solar energy is competitive with current oil prices (\$30/bbl) escalating at 15 percent per year over the next

20 years. Moreover, additional reductions in installed solar costs will favor the solar energy alternative.

SECTION 4

RECOMMENDATIONS FOR LARGE-SCALE SYSTEMS

This section presents design approaches for full-scale systems based on experience gained with the present Campbell Soup solar system. Overall design approaches will be outlined as well as details of system design, including reevaluation of the original design decisions.

4.1 OVERALL APPROACHES

The following are general design approaches for solar industrial process heat systems which Acurex has developed through its experience on the Campbell Soup project and other solar industrial process heat systems:

1. The thermal load should be a large, continuous process. this will minimize the need for thermal storage and maximize the energy supplied by the solar investment. At Campbell Soup this could be accomplished by switching from supplying water to particular can lines to supplying water to the plant mains. This would minimize the utilization problems which were experienced.
2. To minimize system downtime and system costs, the solar system and its interface should be as simple as possible. At Campbell Soup, the storage tank could be eliminated if the solar system were to supply water to the plant mains. This would simplify the hardware and control system.

3. Collector design has been standardized and modularized to reduce production and installation costs. Standard industrial components are used in the system where possible to improve durability, reliability, and repairability by plant personnel. Plant personnel should be consulted in selection of components so that solar system equipment will be compatible with plant equipment. At Campbell Soup, some of the original system equipment has been replaced with more standard industrial hardware.
4. Careful consideration should be given during design of the data system to what performance calculations shall be made for the solar system. Location and type of sensors and choice of monitoring and recording equipment will have a great effect on the information that can be calculated, the degree of accuracy, and the cost.
5. Planning for O and M procedures is vital to keep the system long-running. Documentation is provided which is used by plant personnel to maintain the system. This includes an O and M manual, all vendor literature, and a set of as-built drawings. Field activities will include collector washing (possibly using automatic equipment), inspection, and lubrication. The system will be designed to run under its own control, with little operator attention, and to be easily maintained by plant personnel.

4.2 SYSTEM DESIGN

This section reviews the key design trade-offs and selections that were made during the initial design phase and evaluates them relative to

full-scale systems which can be applied in various industries. Although many options exist for the design of industrial process heat solar systems, only those options that were considered initially will be discussed here. For that reason, although solar energy could supply high temperature pressurized water or steam, only supply of unpressurized hot water will be considered here.

Collector Field Selection

Three primary collector field design choices were made for the Campbell Soup system. First, a decision was made to use a mixed field of flat-plate and parabolic trough collectors. This was done to utilize each collector in the temperature range where it is most cost-effective. Experience with this system has shown that this approach has no inherent operational problems. The decision to use mixed or single type fields is then a cost-effectiveness consideration.

A sharp variation in cost vs performance is not apparent in a comparison of field options. Therefore, site specific cost or performance considerations might dominate the selection which would make specification of a general approach difficult. In conclusion, the mixed field approach is operationally sound and may be valid in many applications, but this would depend on site specific cost-effectiveness factors.

The second decision regarding the collector field was siting. Three sites were considered at the plant, two on roofs, and one on the ground. One roof site was rejected because of shading; the ground site was rejected on the basis of cost. In retrospect, this may have been an error, considering the extensive work necessary to retrofit the collectors onto the existing roof. Operationally, there have been no problems having the collectors on the roof, although their east-west mounting, dictated by

the roof orientation, has reduced their performance by approximate 15 percent compared to a north-south mounting. (A ground installation, however, would have incurred higher piping losses since the collector field would have been farther from the can washers.) Generally, retrofit of collectors onto existing buildings will be more expensive than installation on the ground or inclusion in the design of a new building.

The third choice involved field size. This was determined by load matching considerations and the capital available for the project. In large-scale projects, these factors and available collector mounting area will dictate the field size.

Plant Interface

The original design choice, to deliver solar heated water to two specific can lines, has been demonstrated to be a poor approach even with priority switching controls. If a solar energy system is tied into one specific plant process, downtime in that process can keep the solar system from functioning. Larger-scale systems should be tied into main plant energy supplies to assure availability of large, continuous energy demand.

Storage

Storage for the system was included because of the interface with the two can lines and a reported regular weekday-only, two-shift operation schedule. The actual operating pattern turned out to be very irregular, ranging from long periods of inactivity to 7 day-a-week, 20 hours a day operation during harvest season. In the case where the system supplies a large, continuous load, storage is not necessary because collected energy is used immediately. This improves thermal efficiency, reduces costs, and simplifies the system.

Flow Control

The original design used a programmed variable flowrate to achieve a constant outlet temperature. This approach was changed to a constant flowrate system due to the failure of components in the original, nonstandard, variable flow control system. The change to a constant flow simplified the system and raised thermal efficiency as the collectors operated at lower temperatures. As long as an auxiliary heat source is available to control final delivery temperatures, a variable flowrate is not necessary and increases cost and complexity.

Control Hardware

Because the system was experimental and first-of-a-kind, the control system was designed to have great flexibility to allow alternate modes of system operation. As a result, nonstandard hardware was used and the system was complicated. Consequently, maintenance and repair were difficult for plant personnel. It is advantageous for the control system of a large-scale, commercial system to be as simple as possible and to use standard hardware. This improves reliability and reduces cost.

SECTION 5

ENVIRONMENTAL IMPACT ASSESSMENT

The industry-wide implementation of full-scale solar systems similar to the Campbell Soup solar system will have a net positive environmental impact primarily through the reduction of air emissions from fossil fuel combustion. The following paragraphs summarize the environmental considerations for installing and operating such systems.

5.1 PROPOSED ACTION

Solar energy systems to heat water in a range from 140° to 212°F would be installed and operated at industrial plants throughout the country to displace the use of fossil fuel or electricity as an industrial heat source. Earlier sections of this report describe a pilot plant version of these systems. Solar energy would be collected by flat-plate and concentrating collectors to directly heat water in a once-through process before it is used in the plant.

5.2 DESCRIPTION OF THE SITE

This assessment is for an industry-wide implementation, therefore a particular site is not being considered. Solar systems could be installed at industrial plants in all areas of the United States, although the majority will be installed in the high insolation areas of the Southwest and South. The systems may be installed on roofs or on land. The solar systems may experience wide ranges of climates, temperatures, and

inclement weather, including high winds. At any particular site, an environmental impact will be required as a result of the industrial plant. The solar system will have similar impacts on land, minerals, animals, and historical sites.

5.3 POTENTIAL IMPACTS

The system installer and operator will comply with all applicable laws, regulations, codes, and standard engineering practices. Our preliminary environmental assessment of the design indicates that a positive impact will be caused by development of the solar system. The following is an account of the environmental issues considered. (The impact of solar system manufacturing is not considered here.)

Construction

- Construction activities will be confined to an area within the plant boundaries or, if it is installed on the ground, adjacent to the plant
- Only minor, temporary soil and biological disturbances are expected from the placement of concrete supports and/or pilings for the collectors, storage tank, and control building. The surface will largely be left undisturbed.
- No increase in rain runoff or sedimentation loading is expected, since paving, building construction, and earth-moving will be minor
- Air and noise contamination from construction-related traffic will be temporary
- Any subsurface archaeological sites, if discovered, will be handled according to federal guidelines

- Construction debris will be handled by suitable waste disposal methods
- Land may be removed from other uses for the solar system

Operation

- Operation of the solar system will reduce the combustion of fossil fuel, which is a positive impact
- Potential emissions from the facility will consist of treated potable water. This water contains no toxic agents and poses no harm to the environment.
- The system is closed and should experience only temporary drainage or emissions
- Any system drainage will return to the plant's existing water treatment facilities
- A soapy water solution will be used occasionally for cleaning collectors. This runoff will be insignificant. This is the only additional water use.
- The potential for exposure to harmful glare is small. Access to the field will be limited.
- A minimum of offsite utility resources will be required for circulating pumps and control instrumentation
- System safety and engineering will minimize the possibility of product contamination
- There will be no thermal effects on local meteorology since heat transport fluid systems do not reject significant amounts of heat to the external environment

5.4 COORDINATION WITH FEDERAL, STATE, REGIONAL, OR LOCAL PLANS

Since the proposed solar system is in line with the current national energy plan, it is unlikely that existing federal, state, regional, or local plans would hinder the construction of the proposed action. The U.S. already has a number of large solar energy conversion systems operational, and the responses of the state, regional, and local government officials has been very supportive for these types of projects.

5.5 DESCRIPTION OF ALTERNATIVE

The alternative to the proposed system is to continue to use existing fossil fuel or electric heat sources. The alternative does not have a more positive impact on the surrounding environment than does the proposed solar steam system, therefore, the current proposed action would be the most environmentally advantageous selection.

APPENDIX A
CONTRACT STATEMENT OF WORK
CONTRACT DE-AC03-76CS31218

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STATEMENT OF WORK
PHASE III

The Phase III operation and evaluation of the solar water heating system will be a 15-month program. The work has been broken down into four tasks. The actual system operation and data acquisition will last 12 months, with most of the analysis and evaluation occurring in the last 5 months. A brief description of each task is given below.

This program will be run by the same personnel as in Phases I and II to ensure continuity. Mr. Jorgen Vindum will continue as Program Manager and Mr. Jerry Litzinger as Project Engineer. The other team members from the first two phases will be available as needed. Acurex will carry out all tasks without subcontracts or external support.

Task .10 - Program Management

This task will provide program planning, internal direction and control, travel, reports and meetings. The Contractor shall participate in quarterly reviews and make presentations at DOE approved workshops or conferences, as directed by DOE, not to exceed two such events in any twelve (12) month period. The Contractor shall complete reports as set forth in Exhibit II, Reports and Deliverables.

Task .20 - System Operation

The Contractor shall operate, maintain, and monitor the complete system for a period of 12 months. Solar heated water will be provided for can washing line U and compared to the normally operated V line. Operation will include routine monitoring, checking and adjustment. Maintenance will be both preventive (scheduled) and corrective (as required). Data will be acquired to allow a complete operational analysis during Task .30, and will consist of both automatic data acquisition and operator entries, including:

- Inlet and outlet water temperatures for flat-plate collectors, concentrating collectors, overall collector field, storage tank, auxiliary heat exchanger, and both can washers

- Flowrates through flat plates, concentrators, storage tank and both can washers
- Ambient temperature, wind speed and direction, and total and diffuse solar radiation
- Collector absorber and receiver temperatures
- Time history of operations including solar system and both can washers
- Maintenance, repair and adjustment records

An operations and maintenance manual covering all aspects of the solar energy system shall be prepared within 90 days from the start of Phase III. The Contractor shall train the plant owner's personnel to operate and maintain the solar system.

Task .30 - Data Reduction

The Contractor shall process the raw data gathered during the 12-month operation into easily usable forms for the Operational Analysis task. This will consist of conversion, integration, performance of basic calculations, verification of consistency, etc. Data reduction will be performed on a continuous basis throughout the 12-month operation.

Task .40 - Operational Analysis

The Contractor shall perform a complete analysis of system operations to allow evaluation of energy, environmental and economic benefits. Using reduced data from the previous task, the performance of the solar water heating system will be evaluated periodically, and the energy contribution to the U line can washer will be compared to the conventional energy required for the V line can washer. System performance will be evaluated on a daily, seasonal and annual basis, and comparisons will be made for transient conditions, periods of low and high diffuse radiation, flat plates versus concentrators, and varying storage times. An economic evaluation will be performed using final installed costs from Phase II, and operating costs and system performance data from this phase. Problems in operation of the system will be tabulated based on detailed maintenance records,

and analyzed in order to identify desirable design modifications. Based on the performance, economic and operational problems analyses, design trade-offs will be reevaluated to allow further optimization of the system. This optimization will be directed primarily to full-scale systems for the near term. Finally, an environmental impact assessment will be prepared, assuming industry-wide implementation of full-scale solar systems.

U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

FORM ERDA 537
2/1/77

REPORTING REQUIREMENTS CHECKLIST

(See Instructions on Reverse)

EXHIBIT II

1. IDENTIFICATION	Solar Production of Industrial Process Hot Water	2. OBLIGATION INSTRUMENT:	EY-76-C-03-1218
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3. REPORTING REQUIREMENTS

A. PROJECT MANAGEMENT	Frequency	A. PROJECT MANAGEMENT (CONT.)	Frequency
a. ☐ Management Plan		k. ☒ Conference Record	A
b. ☐ Milestone Plan and Management Report		l. ☒ Hot Line Report	A
c. ☐ Cost Plan		m. ☐ PMS (Earned Value)	
d. ☒ Manpower Plan	M	B. TECHNICAL INFORMATION REPORTING	
e. ☐ Contract Management Summary Report		a. ☒ Energy RD&D Work - In Progress (SSIE)	O
f. ☐ Major Milestone Status Plot		b. ☐ Technical Progress Report	
g. ☒ Technical Status Report	M	c. ☐ Topical Report	
h. ☒ Cost Management Report	M	d. ☒ Final Technical Report	F
i. ☐ Manpower Management Report		C. OTHER	
j. ☐ Funds Reconciliation Report		a. ☐ Travel Plan	

FREQUENCY CODES: A - As Required Q - Quarterly
C - Contract Change S - Semi-Annually
F - Final (End of Contract) X - Mandatory for Delivery with Proposals/Bid.
M - Monthly Y - Yearly or Upon Contract Renewal
O - One Time (Soon After Contract Award)

4. SPECIAL INSTRUCTIONS:

Monthly reports at DOE by the 20th calendar day of the month following the reporting period.

The Cost Management Report shall show fee and cost separately by at least Budget and Reporting Category (B&R).

During Phase III, the monthly status reports should evaluate the performance of the solar system and state the maintenance requirements and the problems encountered during operation.

A draft Operations and Maintenance Manual covering all aspects of the solar energy system is required not later than 90 days after the start of Phase III. The final Operations and Maintenance Manual shall be submitted as part of the Phase III Final Report, but will be a separately bound document.

A draft Phase III Final Report is due one month after the 12 month operational period. It shall summarize the overall performance, maintenance, problems, suggestions for improving the system, system economics, environmental considerations, and other pertinent information regarding the final analysis of the project.

5. ATTACHED HEREWITH:

☒ Report Distribution List
☐

☐
☐

6. PREPARED BY (Signature and date):

D. Nettleton, Jr. *D. Nettleton* 4/17/78

7. REVIEWED BY (Signature and date):

Mike Hall 4/19/78

APPENDIX B

FLAT PLATE COLLECTOR SPECIFICATIONS AND PERFORMANCE

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FLAT PLATE COLLECTOR SPECIFICATIONS AND PERFORMANCE

The flat-plate collectors are constructed as follows:

- Absorber plate -- 10 copper tubes, (1/2-in I.D.) sandwiched between two formed aluminum plates
- Header -- copper tube, 1-in I.D.
- Frame and backplate -- aluminum extrusion and plate
- Glazing -- single sheet of low iron tempered glass, 1/8-in thick, installed at factory
- Bottom insulation -- 1-in fiberglass insulation and isocyanrate foam
- Absorber coating -- 3M brand nextel black velvet coating (nonselective)
- Fluid entrance/exit -- 3/4-in copper tubing, located at ends and staggered to facilitate short intercollector connections

Figure B-1 shows the performance of a single panel of the Solargenics flat-plate Series 75.

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SOLARGENICS, INC.

SOLAR COLLECTOR SUBSYSTEM

Specification:

The basic Solargenics™ solar collector subsystem is sized to provide 100,000 to 1 million Btu's per day. The subsystem is built to yield fluid temperatures up to 220°F with high efficiency.

1. GENERAL

The solar collector subsystem uses up to 10 Solargenics Series 75-20, structurally contained, high efficiency, selectively coated, flat plate collector panels. The subsystem is provided complete with supply and return manifolds, flow balancing valves, glass, control sensors, and basic mounting hardware. The subsystem is ready for attachment to the structure, heat transfer fluid and electrical connections.

9713 LURLINE AVENUE CHATSWORTH, CALIFORNIA 91311 (213) 998-0806

SOLARGENICS, INC.

B-5

2. SERIES 75 SOLAR COLLECTOR

Size	20'x3'x3½"
Piping	All copper
Supply/Return Connection	¾" type "L" copper
Absorber Plate	Aluminum with selective coating
Active Collector Area	53.4 square feet
Housing	Corrosion resistant structural aluminum designed for 4 point mounting
Insulation	High temperature foam and fiberglass
Control Sensor	Direct mount to absorber plate
Venting	Automatic air vent
Glazing	Sunadex glass
Pressure	125psi working; 250 psi test

3. SOLAR COLLECTOR SUBSYSTEM

Array Size	1 to 10 Series 75-20 collectors
Manifolding	1½" type "L" copper supply and return assemblies, complete with flow balancing valves and ¾" stubouts
Mounting Hardware	2 ea., 1½"x1½"x¼" aluminum angle end mounts per collector; 1 ea., pair of aluminum cover and support plates for inter-collector mounting

4. INSTALLATION OPERATION AND MAINTENANCE INSTRUCTIONS

Complete instructions provided,

5. GUARANTEES AND TESTS

Efficiency Guarantee

The complete subsystem is guaranteed to operate with an efficiency equal to or greater than the published efficiency curve.

Factory Test

The complete solar collector subsystem receives factory tests to check construction, operation, and function of all components. Factory testing may be witnessed by the purchaser at his own expense and upon sufficient notice to the company.

B-7

Figure B-1. Solar Collector Test Facility

APPENDIX C

MODEL 3001-2 CONCENTRATOR SPECIFICATION AND PERFORMANCE

Table C-1 -- Specification

Figure C-1 -- Performance

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Table C-1. Acurex Parabolic Trough Concentrating Solar Collector
Model 3001 Specifications

● Module size (nominal)	6-ft aperture x 10-ft length
● Collection area per module (plain reflector area less receiver shadow)	58.3 ft ²
● Rotational axis above ground	3.5 ft
● Nominal assembled length of standard group of eight modules (includes allowance for support posts)	84 ft 7-1/4 in
● Reflector reflectance	0.70 to 0.75
● Rim angle	90°
● Nominal receiver area per module	1.64 ft ²
● Geometric concentration ratio	36
● Receiver data	
-- Receiver absorptance	0.93
-- Receiver emittance	0.15
-- Fluid temperature operating range	140° to 600°F
-- Fluid flowrate range	1 to 15 gpm
-- Pressure drop range (per standard 84-ft row)	2 to 10 psi
● Module weight (each)	275 lb
● Motor/gear weight (at center of 84-ft row)	144 lb
● Distributed weight per group	5.6 lb/ft ²
● Sun tracker system	
-- Tracking accuracy	±0.25°
-- Desteer mode	5° off focus
-- Stow (fast mode)	Clockwise or counterclockwise
-- Tracking motor	1/8 hp gear motor at 10 duty cycle or less

C-4

Figure C-1. Acurex Efficiency Versus Delta Temperature/Insolation

APPENDIX D
SYSTEM CONTROL LADDER DIAGRAM AND CONTROLLER INPUTS

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LOW X0	FIELD < 34" F NEW BIPOLAR SWITCH OR TY-36
LOW X1	WIND > 30 MPH WVA
HIGH X2	PLAT PLATE TEMPERATURE > 110°F TY-34 OR TY-36
HIGH X3	INSULATION > 800 W/H ² AT PLAT-PLATE APERTURES IT-1
LOW X4	TANK FULL LSH-31
ON 15	
HIGH X5	CLOCK TIMER
ON 15	
HIGH X6	SYSTEM ACTIVE/INACTIVE SWITCH
LOW X7	FIELD FLOW-SIGNAL FROM FLOW SWITCH FS-31
HIGH X8	TANK LOW LSH-31
HIGH X9	CAN LINE FLOW-SIGNAL FROM FLOW SWITCH FS-41
LOW X10	FREEZE PROTECT FLOW FROM FLOW SWITCH FS-55
HIGH X11	TANK WATER > 70°F (EXPAND WATER USAGE)
HIGH X12	'U' LINE ACTIVE
HIGH X13	SOLAR SELECT
HIGH X14	'V' LINE ACTIVE
X15	NOT USED

0-3

	Y	OUTPUTS FROM CONTROLLER
Y0		NOT USED
Y1		FREEZE PROTECT
Y2		FIELD FLOW TO TANK
Y3		WIND PROTECT (TO YELLOW LIGHT ON FRONT PANEL)
Y4		FREEZE PROTECT FAILURE
Y5		NOT USED
Y6		PUMP ON
Y7		'U' LINE SELECTED FOR SOLAR
Y8		NORTH DRIVE TO FIELD
Y9		'V' LINE SELECTED FOR SOLAR
Y10		CAN LINE OPERATION READY
Y11		STEAM ON
Y12		LINETOW PERMISSIVE
Y13		FIELD FLOW FAILURE
Y14		LOSS OF INSULATION
Y15		FIELD SYSTEM READY

1. NUMBERS 1-16 IDENTIFY PROGRAM STEP NUMBERS FOR
FTI PROGRAMMABLE CONTROLLER.

2. STEP NUMBERS NOT USED ARE: 108, 110.

										DATE <u>11-1-64</u> BY <u>AS</u> CDR <u>AS</u> GDS ENG <u>1</u> APP'D <u>AS</u> <u>11-1-64</u>		A SOURCE CONTROL LADDER DIAGRAM CAMPBELL SOUP SOLAR FACILITY			
DESCRIPTION	DATE	APPRO	BY	DESCRIPTION	DATE	APPRO	BY	TITLE	REFERENCE	DRAWINGS	TITLE	SCALE	SHEET NO.	DRAWING NO.	REV
REVISIONS															
FT. SASSO															

APPENDIX E
LOG OF OPERATIONS EXPERIENCE

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LOG OF OPERATIONS EXPERIENCE

The following log sheets summarize the operations experience gained during the period from October 1979 through December 1980. The following code was used to designate types of actions required:

- F -- collector field
- C -- controls
- P -- piping and storage
- D -- data acquisition

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Sub-system	Work Required -- November 1979	Comments
C	Added freeze protection sensing redundancy (freeze protection was required during one night in November)	Clean strainers once/wk, monitor pressures
D	A replacement magnetic tape deck was installed to replace the previous one which had a failed servo motor	
D	An interface problem between the datalogger and the mag tape recorder was encountered, which prevented reading the data on the mag tape	
P	Late in the month it was discovered that the pressure regulator at the inlet of the field was not maintaining adequate supply pressure. Strainers were clogged with solids.	
C	Campbell plant maintenance personnel continued work to repair the steam regulator. The temperature control valve on the steam heat exchanger continues to leak and fails to regulate steam flow to maintain the correct outlet water temperature.	
P	Site work was performed to address problems with tank outlet pump priming, control system operation, and can line status	
	December 1979	
C	Calibration was performed for the collector field flow control valve	Campbell personnel can access much of the system, but without instruction
C	The system control program was found to be scrambled (as of December 13, 1979). The control system program was reinstated and operation was checked and found to be correct.	
P	A closed hand valve in the line going to the can lines was identified as the source of operational problems	
C	The temperature control valve on the steam heat exchanger failed completely. Work began to repair the valve.	
D	Work continued to resolve problem with the mag tape interface	
P	Work continued to resolve problem with tank outlet pump priming	

Sub-system	Work Required -- January 1980	Comments
D	The mag tape interface problem was corrected. The problem was due to an incompatibility between the new mag tape drive and the existing data logger software. New software was installed in the data logger and this solved the problem.	
D	The apparent "scrambling" of the data logger program which caused the line printer output to be unreadable was found to be actually caused by an incorrect BAUD rate switch setting on the printer. This was corrected.	CSC operator error
P	The tank outlet pump was repaired to solve its cavitation and priming problems	
C	A sight gage was added to the tank for calibration of flowrate measurements	Required by continued jamming of flow control by inert solids in supply water
C	The collector field flow control valve was inspected and it was found that a coupling pin within had rusted and broken, causing inaccurate valve flowrate setting. This was repaired and debris found inside the valve was removed. Pressure gages were installed on the inlet and outlet of the valve to monitor supply and delivery pressures.	
C	Flowrate control was transferred to the valve controller near the valve to resolve inaccuracies caused by controlling flowrate from the control cabinet. Flowrate will be set manually using the local controller.	Fixed flowrate. Manual control established.
C	The steam heat exchanger temperature control valve was repaired by Campbell maintenance staff	

Sub-system	Work Required -- February 1980	Comments
D	A detailed analysis of the data tapes revealed an intermittent, random error making the tape data unreadable. The data logger/mag tape interface is being corrected by Autodata personnel.	
C	The local controller for the field flow control valve failed and was disconnected from the system	
F	An interconnecting piping loop on the flat-plate collectors broke loose and was reconnected	
C	The temperature bulb sensing tube on the steam heat exchanger was discovered to have been kinked during maintenance of the steam flow control valve and a new tube was ordered. (The kinked sensing bulb was believed to be responsible for the slow response of the steam flow in the heat exchanger.)	
C	<p>The following actions were taken on the control system:</p> <ul style="list-style-type: none"> ● Input and output signals were identified and tagged ● The control ladder diagram was verified and updated ● The can-line pump flow switch was reconnected ● Various changes were made to the control logic to improve system operation 	
P	Pressure gages were installed on the house hot water lines. Readings on these lines indicated that the can line solenoid valves were allowing backflow into the house water system. It is recommended that check valves be installed at the can lines.	Solenoid valves used originally were specified by Campbell Soup

Sub-system	Work Required -- March and April 1980	Comments
C	The field flow control valve was cleaned, repaired, and calibrated	Solids at field inlet continue to jam regulator and FCV
C	A new temperature sensing bulb was installed in the heat exchanger control valve	
P	Water samples were collected and sent to Campbell Soup, Camden, New Jersey headquarters	
C	Changes were made to the control logic to improve system operation	
D	Work continued to resolve the mag tape interface problem	
D	The mag tape interface problem was resolved and the mag tape was used to record and transfer data to the Acurex offices for reduction	
C	System operation was changed to being controlled by insolation and temperature levels rather than a timer, thereby allowing longer system operation A safety inspection of the system was made by an Acurex safety engineer	
C	The field flow control valve was cleaned and calibrated	
P	Check valves were installed on the solar waterlines to the can lines	

Sub-system	Work Required -- May and June 1980	Comments
<p>C D</p> <p>C</p> <p>C</p> <p>D</p> <p>C P</p> <p>F</p>	<p>The data system clock and the control system timer were reset after they lost 3 hours due to a power failure. This power failure occurred late April. System operation was not affected, but data time tags were incorrect.</p> <p>The field flow control valve became jammed due to material in the supply water. This did not significantly affect system operation but it did cause inaccuracies in data reduction (see note on the monthly summary table).</p> <p>A calibration was performed for the field flow control valve</p> <p>Mag tape interface problems reoccurred. The mag interface board and mag tape drive were replaced and test tapes indicated this resolved the problem.</p> <p>The field flow control valve and inlet pressure regulator were cleaned. The regulator was jammed with material in the supply water. This did not significantly affect system operation, but did cause inaccuracies in data reduction.</p> <p>Collectors washed and trackers aligned</p>	<p>CSC plant continues to have periodic power outages at the control console</p>
	July 1980	
<p>P</p> <p>C</p> <p>C</p> <p>P</p>	<p>A means of water treatment was evaluated and selected. A cyclone water separator was ordered and will be installed to remove the inert material which has been clogging strainers and jamming the field flow control valve and the main field solenoid valve.</p> <p>A precision pressure gage was installed on the tank to provide an indication of calibration of the flow control valve</p> <p>This gage did not meet specification and will be replaced by a unit which is on order</p> <p>Routine maintenance and data reduction was performed on the system</p> <p>Efforts were continued to keep flow components clean (i.e., routine blowdown of strainers). Nevertheless, the field flow rate control valve, the field solenoid valve, and the strainers became clogged or jammed by the inert material in the inlet water, thereby reducing flowrates. This did not prevent system operation, but did cause concentrator desteeering due to high temperatures, reduce collector efficiencies, and affect data reduction accuracy.</p>	<p>Replaces plastic sight tube</p> <p>A cyclone separator was recommended to Campbell Soup for order</p>

Sub-system	Work Required -- August 1980	Comments
C D P C	<p>A new precision pressure gage was installed on the storage tank to enable volumetric calibration of the flow control valve by measuring the height of the tank</p> <p>The magnetic tape drive was removed and sent to the manufacturer for repair</p> <p>The field flow solenoid and control valves were cleaned, but still became rejammed by the inert material in the inlet water, thereby reducing flowrates. This did not prevent system generation, but did cause concentrator destearing due to high temperatures, reduce collector efficiencies, and affect data reduction accuracy.</p>	
	September and October 1980	
P D P C F F F C D	<p>The cyclone separator was delivered onsite. This device will remove the inert material present in the inlet water, which has been affecting system operation and data system accuracy. This device will be installed when present high plant activity is reduced.</p> <p>The mag tape drive was repaired by the manufacturer and returned to Acurex</p> <p>The field flow solenoid and control valves were cleaned, but became rejammed by the inert material in the inlet water, thereby reducing flowrates. This did not prevent system operation, but did reduce collector efficiencies and affect data reduction accuracy.</p> <p>Collectors were washed and checked</p> <p>Three collector motors failed and were evaluated for replacement (cause unknown)</p> <p>Collectors were lubricated</p> <p>Solenoid and flue were cleaned and checked</p> <p>Repaired mag tape drive was installed</p>	

Sub-system	Work Required -- November 1980	Comments
P F C	Cyclone separator was installed and system strainers blown down. Flowrate remains normal for much longer periods. New motors were ordered for the concentrators The tank high-level switch stuck in the high position, preventing field operation	
	December 1980	
F C C P	Concentrator motors were replaced The tank lever switch was repaired The system was thoroughly flushed to remove the final residue from the piping system	

APPENDIX F
SINGLE DAY PERFORMANCE TABLES
FOR OCTOBER 1979 THROUGH SEPTEMBER 1980

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SINGLE DAY TABLE

Day 278, 10/5/79, CAMPBELL SOUP

Hour	Btu/ft ² /hr	In 10 ⁶ Btu/hr				Eff. (based on (1))	Eff. (based on (2))	In °F			In M.P.H.
	Total horiz. insol. (1)	Insol. to coll. range (2)	Energy to storage	Elect. energy	Fossil fuel saved			Tank Inlet	Field Inlet	Ambient	Wind Speed
0	--	--	--	0.006	--	--	--	--	--	61.4	1.0
1	--	--	--	0.006	--	--	--	--	--	60.7	0.4
2	--	--	--	0.006	--	--	--	--	--	59.7	0.0
3	--	--	--	0.006	--	--	--	--	--	57.8	3.1
4	--	--	--	0.006	--	--	--	--	--	57.3	4.4
5	--	--	--	0.006	--	--	--	--	--	57.5	3.0
6	--	--	--	0.006	--	--	--	--	--	57.2	3.6
7	27	--	--	0.006	--	0%	--	--	--	61.1	0.0
8	82	--	--	0.006	--	0%	--	--	--	64.1	1.2
9	134	--	--	0.006	--	0%	--	--	--	69.0	0.0
10	176	1.6	0.80	0.006	1.2	62%	50%	133.2	69.3	74.9	4.4
11	202	1.8	0.92	0.006	1.4	62%	51%	142.9	69.4	76.8	4.2
12	214	1.9	1.03	0.006	1.6	66%	54%	151.8	69.5	80.4	3.6
13	203	1.8	1.05	0.006	1.6	71%	58%	153.6	69.7	86.4	0.3
14	188	1.6	0.94	0.006	1.5	68%	59%	144.8	69.7	89.7	0.0
15	144	1.0	0.58	0.006	0.9	55%	58%	116.2	69.8	90.4	3.3
16	95	--	--	0.006	--	0%	--	--	--	86.5	9.2
17	37	--	--	0.006	--	0%	--	--	--	81.2	8.8
18	--	--	--	0.006	--	--	--	--	--	75.0	0.0
19	--	--	--	0.006	--	--	--	--	--	72.2	3.8
20	--	--	--	0.006	--	--	--	--	--	69.7	4.5
21	--	--	--	0.006	--	--	--	--	--	67.8	2.3
22	--	--	--	0.006	--	--	--	--	--	67.2	2.9
23	--	--	--	0.006	--	--	--	--	--	63.8	2.2
Total	1502	9.7	5.3	0.15	8.2	48%	55%	--	--	--	--

SINGLE DAY TABLE

DAY 384, 11/20/79, CAMPBELL SOUP

Hour	Btu/ft ² /hr	In 10 ⁶ Btu/hr				Eff. (based on (1))	Eff. (based on (2))	In °F			In M.P.H.
	Total horiz. insol. (1)	Insol. to coll. plane (2)	Energy to storage	Elect. energy	Fossil fuel saved.			Tank Inlet	Field Inlet	Ambient	Wind Speed
0	--	--	--	0.006	--	--	--	--	--	50.4	0.0
1	--	--	--	0.006	--	--	--	--	--	48.3	0.0
2	--	--	--	0.006	--	--	--	--	--	48.3	1.1
3	--	--	--	0.006	--	--	--	--	--	46.7	3.1
4	--	--	--	0.006	--	--	--	--	--	45.5	1.0
5	--	--	--	0.006	--	--	--	--	--	46.8	3.8
6	--	--	--	0.006	--	--	--	--	--	48.3	6.0
7	51	--	--	0.006	--	0%	--	--	--	52.7	4.1
8	102	--	--	0.006	--	0%	--	--	--	54.8	7.7
9	146	1.6	0.7	0.006	1.1	65%	44%	112.2	68.1	60.1	7.2
10	172	1.9	1.1	0.006	1.7	87%	58%	144.5	68.3	63.1	9.6
11	178	1.9	1.4	0.006	2.2	107%	74%	164.6	68.5	65.7	5.7
12	163	1.7	1.4	0.006	2.2	117%	82%	164.3	68.5	69.0	2.6
13	139	1.6	1.1	0.006	1.7	108%	69%	143.8	68.6	68.8	5.2
14	90	1.1	0.9	0.006	1.4	135%	82%	126.0	68.6	70.8	2.8
15	25	--	--	0.006	--	0%	--	--	--	67.2	4.2
16	--	--	--	0.006	--	--	--	--	--	60.6	2.9
17	--	--	--	0.006	--	--	--	--	--	57.5	2.6
18	--	--	--	0.006	--	--	--	--	--	54.7	3.9
19	--	--	--	0.006	--	--	--	--	--	53.0	0.0
20	--	--	--	0.006	--	--	--	--	--	49.2	0.0
21	--	--	--	0.006	--	--	--	--	--	46.9	1.6
22	--	--	--	0.006	--	--	--	--	--	45.6	2.3
23	--	--	--	0.006	--	--	--	--	--	44.7	0.1
Total	1066	9.8	6.7	0.15	10.3	86%	68%	--	--	--	--

SINGLE DAY TABLE

DAY 340, 12/06/79, CAMPBELL SOUP

Hour	Btu/ft ² /hr	In 10 ⁶ Btu/hr				Eff. (based on (1))	Eff. (based on (2))	In °F			In M.P.H.
	Total horiz. insol. (1)	Insol. to coll. plane (2)	Energy to storage	Elect. energy	Fossil fuel saved			Tank Inlet	Field Inlet	Ambient	Wind Speed
0	--	--	--	0.006	--	--	--	--	--	43.0	0.2
1	--	--	--	0.006	--	--	--	--	--	42.1	0.0
2	--	--	--	0.006	--	--	--	--	--	40.6	0.0
3	--	--	--	0.006	--	--	--	--	--	39.6	0.0
4	--	--	--	0.006	--	--	--	--	--	40.1	0.0
5	--	--	--	0.006	--	--	--	--	--	40.1	0.0
6	--	--	--	0.006	--	--	--	--	--	38.6	0.0
7	32	--	--	0.006	--	--	--	--	--	40.7	0.0
8	81	--	--	0.006	--	--	--	--	--	46.8	0.0
9	117	--	--	0.006	--	--	--	--	--	54.5	0.0
10	138	--	--	0.006	--	--	--	--	--	57.7	1.2
11	144	1.2	0.75	0.006	1.2	71%	63%	66.4	126.0	63.0	0.7
12	128	1.4	0.89	0.006	1.4	95%	64%	69.0	139.9	65.8	0.0
13	96	1.1	0.69	0.006	1.1	98%	63%	69.1	124.3	67.4	0.0
14	55	0.7	0.28	0.006	0.4	69%	40%	69.1	91.2	65.8	4.0
15	13	--	--	0.006	--	--	--	--	--	61.5	3.0
16	--	--	--	0.006	--	--	--	--	--	58.1	0.0
17	--	--	--	0.006	--	--	--	--	--	56.5	0.0
18	--	--	--	0.006	--	--	--	--	--	53.4	0.0
19	--	--	--	0.006	--	--	--	--	--	52.6	0.0
20	--	--	--	0.006	--	--	--	--	--	50.1	0.0
21	--	--	--	0.006	--	--	--	--	--	47.9	3.0
22	--	--	--	0.006	--	--	--	--	--	47.3	1.0
23	--	--	--	0.006	--	--	--	--	--	44.6	0.0
Total	803	4.4	2.6	0.15	4.0	59%	48%	--	--	--	--

SINGLE DAY TABLE

DAY 29, 1/29/80, CAMPBELL SOUP

Hour	Btu/ft ² /hr	In 10 ⁶ Btu/hr						Eff. (based on (1))	Eff. (based on (2))	In °F			In M.P.H.
	Total horiz. insol. (1)	Insol. to coll. plane (2)	Insol. to flat plates	Insol. to conc.	Energy to storage	Elect. energy	Fossil fuel saved			Tank Inlet	Field Inlet	Wind Ambient	Speed
0	--	--	--	--	--	0.006	--	--	--	--	--	43.0	0.0
1	--	--	--	--	--	0.006	--	--	--	--	--	42.1	0.0
2	--	--	--	--	--	0.006	--	--	--	--	--	39.6	0.0
3	--	--	--	--	--	0.006	--	--	--	--	--	40.0	1.6
4	--	--	--	--	--	0.006	--	--	--	--	--	38.4	0.0
5	--	--	--	--	--	0.006	--	--	--	--	--	38.2	0.0
6	--	--	--	--	--	0.006	--	--	--	--	--	37.4	0.0
7	32	--	--	--	--	0.006	--	--	--	--	--	41.7	1.6
8	89	--	--	--	--	0.006	--	--	--	--	--	46.7	7.6
9	136	0.92	0.29	0.63	0.42	0.006	0.65	42%	46%	111.9	67.3	50.0	8.1
10	168	1.73	0.70	1.03	0.76	0.006	1.17	62%	44%	128.1	67.3	53.0	6.9
11	186	1.89	0.77	1.12	0.85	0.006	1.31	62%	45%	135.7	67.5	54.5	3.8
12	182	1.78	0.72	1.06	0.86	0.006	1.32	64%	48%	136.7	67.8	58.3	7.8
13	150	1.62	0.67	0.95	0.80	0.006	1.23	65%	49%	131.5	67.8	59.1	7.5
14	113	1.28	0.54	0.74	0.59	0.006	0.91	71%	46%	114.8	67.7	59.4	7.1
15	60	0.53	0.23	0.30	0.26	0.006	0.40	55%	49%	108.6	67.6	58.9	6.9
16	5	--	--	--	--	0.006	--	--	--	--	--	55.1	7.4
17	--	--	--	--	--	0.006	--	--	--	--	--	51.7	3.3
18	--	--	--	--	--	0.006	--	--	--	--	--	49.2	2.5
19	--	--	--	--	--	0.006	--	--	--	--	--	47.0	2.9
20	--	--	--	--	--	0.006	--	--	--	--	--	45.1	2.3
21	--	--	--	--	--	0.006	--	--	--	--	--	45.0	3.1
22	--	--	--	--	--	0.006	--	--	--	--	--	43.3	4.5
23	--	--	--	--	--	0.006	--	--	--	--	--	42.5	5.5
Total	1143	9.8	3.9	5.9	4.5	0.15	6.9	54%	46%	--	--	--	--

SINGLE DAY TABLE
DAY 60, 2/29/80, CAMPBELL SOUP

Hour	Btu/ft ² /hr	In 10 ⁶ Btu/hr						Eff. (based on (1))	Eff. (based on (2))	In °F			In mph
	Total horiz. insol. (1)	Insol. to coll. plane (2)	Insol. to flat plates	Insol. to conc.	Energy to storage	Elect. energy	Fossil fuel saved			Tank Inlet	Field Inlet	Ambient	Wind Speed
0	--	--	--	--	--	0.006	--	--	--	--	--	53.8	0.0
1	--	--	--	--	--	0.006	--	--	--	--	--	53.0	0.0
2	--	--	--	--	--	0.006	--	--	--	--	--	51.3	0.0
3	--	--	--	--	--	0.006	--	--	--	--	--	50.3	0.3
4	--	--	--	--	--	0.006	--	--	--	--	--	50.9	4.8
5	--	--	--	--	--	0.006	--	--	--	--	--	51.3	0.0
6	14	--	--	--	--	0.006	--	0%	--	--	--	52.2	0.4
7	67	--	--	--	--	0.006	--	0%	--	--	--	57.9	1.5
8	146	0.7	0.5	0.2	0.3	0.006	0.5	28%	43%	68.0	97.3	64.0	1.8
9	185	1.6	1.0	0.6	0.7	0.006	1.1	52%	44%	68.0	142.5	65.6	0.9
10	221	1.9	1.2	0.7	1.0	0.006	1.5	62%	53%	68.3	169.8	69.0	5.5
11	225	1.9	1.2	0.7	1.2	0.006	1.9	73%	63%	68.5	184.0	70.8	3.7
12	215	1.8	1.1	0.7	1.2	0.006	1.9	76%	67%	68.8	192.5	73.4	1.6
13	209	1.8	1.1	0.7	1.1	0.006	1.7	72%	61%	68.9	180.5	73.4	6.5
14	166	1.5	0.9	0.6	0.9	0.006	1.4	74%	60%	69.0	159.2	75.4	5.9
15	107	0.7	0.4	0.3	0.5	0.006	0.8	63%	71%	69.0	119.2	73.6	8.6
16	44	--	--	--	--	0.006	--	0%	--	--	--	75.3	0.0
17	--	--	--	--	--	0.006	--	--	--	--	--	68.0	0.0
18	--	--	--	--	--	0.006	--	--	--	--	--	65.9	0.0
19	--	--	--	--	--	0.006	--	--	--	--	--	63.9	0.0
20	--	--	--	--	--	0.006	--	--	--	--	--	64.1	4.5
21	--	--	--	--	--	0.006	--	--	--	--	--	58.3	0.2
22	--	--	--	--	--	0.006	--	--	--	--	--	57.6	0.0
23	--	--	--	--	--	0.006	--	--	--	--	--	54.6	2.3
Total	1598	11.9	7.7	4.6	7.0 ^a	0.15	10.8	60%	57%	--	--	--	--

^aBased on 20 gpm flowrate

Single Day Table

Day 79, 3/19/80, Campbell Soup

Hour	Btu/ft ² /hr	In 10 ⁶ Btu/hr						Eff. (Based on) (1)	Eff. (Based on) (2)	In °F			In mph
	Total Horiz. Insol. (1)	Insol. to Coll. Plane (2)	Insol. to Flat Plates	Insol. to Conc.	Energy to Storage	Elect. Energy	Fossil Fuel Saved			Tank Inlet	Field Inlet	Ambient	Wind Speed
0	--	--	--	--	--	0.006	--	--	--	--	--	56.8	10.1
1	--	--	--	--	--	0.006	--	--	--	--	--	54.4	4.9
2	--	--	--	--	--	0.006	--	--	--	--	--	53.3	7.8
3	--	--	--	--	--	0.006	--	--	--	--	--	53.3	6.9
4	--	--	--	--	--	0.006	--	--	--	--	--	52.7	3.1
5	--	--	--	--	--	0.006	--	--	--	--	--	49.4	0.0
6	42	--	--	--	--	0.006	--	0%	--	--	--	53.3	4.7
7	108	--	--	--	--	0.006	--	0%	--	--	--	58.9	14.1
8	167	--	--	--	--	0.006	--	0%	--	--	--	64.5	6.7
9	216	1.7	1.1	0.6	0.7	0.006	1.1	44%	41%	68.6	132.2	70.4	5.5
10	247	2.0	1.2	0.8	0.9	0.006	1.4	49%	45%	69.0	150.1	72.9	4.8
11	261	2.1	1.3	0.8	1.1	0.006	1.7	57%	52%	69.2	157.0	76.3	7.3
12	254	2.0	1.3	0.7	1.1	0.006	1.7	59%	55%	69.3	157.7	78.4	6.0
13	231	1.9	1.2	0.7	0.9	0.006	1.4	53%	47%	69.4	152.2	83.2	7.7
14	184	1.5	1.0	0.5	0.8	0.006	1.2	59%	53%	69.4	135.3	82.3	3.2
15	123	0.5	0.5	0.0	0.4	0.006	0.6	44%	80%	69.4	100.2	77.3	2.1
16	58	--	--	--	--	0.006	--	0%	--	--	--	75.2	6.4
17	50	--	--	--	--	0.006	--	0%	--	--	--	70.0	4.2
18	--	--	--	--	--	0.006	--	--	--	--	--	66.8	3.4
19	--	--	--	--	--	0.006	--	--	--	--	--	65.5	5.3
20	--	--	--	--	--	0.006	--	--	--	--	--	59.1	1.6
21	--	--	--	--	--	0.006	--	--	--	--	--	57.9	6.5
22	--	--	--	--	--	0.006	--	--	--	--	--	57.2	5.1
23	--	--	--	--	--	0.006	--	--	--	--	--	56.0	3.4
Total	1941	11.6	7.5	4.1	5.9	0.15	9.1	41%	51%	--	--	--	--

Single Day Table
Day 107, 4/16/80, Campbell Soup

Hour	Etu/ft ² /hr	In 10 ⁶ Btu/hr						Eff. (Based on) (1)	Eff. (Based on) (2)	In °F			In mph
	Total Horiz. Insol. (1)	Insol. to Coll. Plane (2)	Insol. to Flat Plates	Insol. to Conc.	Energy to Storage	Elect. Energy	Fossil Fuel Saved			Tank Inlet	Field Inlet	Ambient	Wind Speed
0	--	--	--	--	--	0.006	--	--	--	--	--	62.1	2.5
1	--	--	--	--	--	0.006	--	--	--	--	--	61.4	2.1
2	--	--	--	--	--	0.006	--	--	--	--	--	61.0	2.2
3	--	--	--	--	--	0.006	--	--	--	--	--	60.0	0.5
4	19	--	--	--	--	0.006	--	--	--	--	--	61.0	0.0
5	77	--	--	--	--	0.006	--	--	--	--	--	68.3	0.0
6	140	0.7	0.5	0.2	0.3	0.006	0.4	29%	40%	68.4	89.2	73.0	0.8
7	195	1.1	0.9	0.2	0.6	0.006	0.9	42%	54%	69.5	111.1	80.9	0.4
8	240	1.6	1.1	0.5	0.8	0.006	1.3	45%	50%	69.6	125.1	85.1	1.5
9	264	1.7	1.1	0.5	0.9	0.006	1.4	46%	55%	69.7	132.2	89.7	0.5
10	260 ^a	--	--	--	--	0.006	--	--	--	--	--	91.5	1.6
11	260	--	--	--	--	0.006	--	--	--	--	--	92.9	2.7
12	236	--	--	--	--	0.006	--	--	--	--	--	95.7	1.0
13	179	--	--	--	--	0.006	--	--	--	--	--	95.9	2.5
14	136	--	--	--	--	0.006	--	--	--	--	--	95.3	2.8
15	73	--	--	--	--	0.006	--	--	--	--	--	92.4	4.2
16	20	--	--	--	--	0.006	--	--	--	--	--	89.7	1.1
17	--	--	--	--	--	0.006	--	--	--	--	--	85.4	1.1
18	--	--	--	--	--	0.006	--	--	--	--	--	81.9	0.0
19	--	--	--	--	--	0.006	--	--	--	--	--	80.6	0.0
20	--	--	--	--	--	0.006	--	--	--	--	--	77.9	3.8
21	--	--	--	--	--	0.006	--	--	--	--	--	74.1	2.4
22	--	--	--	--	--	0.006	--	--	--	--	--	70.4	3.0
23	--	--	--	--	--	0.006	--	--	--	--	--	68.0	3.7
Total	2101	5.1	3.6	1.4	2.6	0.15	3.9	16%	50%	--	--	--	--

^aSystem shut down due to tank fill-up

Single Day Table

Day 137, 5/16/80, Campbell Soup

Hour	Btu/ft ² /hr	In 10 ⁶ Btu/hr						Eff. (Based on (1))	Eff. (Based on (2))	In of			In mph
	Total Horiz. Insc ^l . (1)	Insol. to Coll. Plane (2)	Insol. to Flat Plates	Insol. to Conc.	Energy to Storage*	Elect. Energy	Fossil Fuel Saved			Field Inlet	Tank Inlet	Ambient	Wind Speed
0	--	--	--	--	--	0.006	--	--	--	--	--	60.3	5.8
1	--	--	--	--	--	0.006	--	--	--	--	--	61.3	3.7
2	--	--	--	--	--	0.006	--	--	--	--	--	61.8	4.5
3	--	--	--	--	--	0.006	--	--	--	--	--	60.8	2.1
4	--	--	--	--	--	0.006	--	--	--	--	--	60.3	3.7
5	--	--	--	--	--	0.006	--	--	--	--	--	59.1	4.8
6	12	--	--	--	--	0.006	--	0%	--	--	--	61.9	4.2
7	69	--	--	--	--	0.006	--	0%	--	--	--	66.5	0.6
8	133	--	--	--	--	0.006	--	0%	--	--	--	68.8	7.2
9	192	0.3	0.2	0.1	0.1	0.006	0.2	7%	33%	69.2	75.9	74.1	0.0
10	244	1.6	1.0	0.6	0.6	0.006	0.9	34%	38%	69.2	112.1	78.4	0.0
11	277	1.9	1.2	0.7	1.0	0.006	1.5	49%	53%	69.2	134.9	82.3	2.0
12	300	2.1	1.3	0.8	1.1	0.006	1.7	50%	52%	69.4	143.8	88.1	0.0
13	305	1.9	1.3	0.6	0.9	0.006	1.4	40%	47%	69.5	131.9	92.2	0.0
14	278	1.8	1.2	0.6	1.0	0.006	1.5	49%	56%	69.5	137.3	92.7	4.2
15	260	1.7	1.1	0.6	1.0	0.006	1.5	52%	59%	69.6	137.7	93.5	2.5
16	182	0.9	0.8	0.1	0.6	0.006	0.9	45%	57%	69.6	108.3	95.3	0.0
17	163	0.8	0.7	0.1	0.5	0.006	0.8	42%	53%	70.0	106.0	94.7	3.6
18	98	0.5	0.4	0.1	0.3	0.006	0.5	42%	50%	70.0	86.7	93.2	4.1
19	21	--	--	--	--	0.006	--	0%	--	--	--	86.1	2.7
20	--	--	--	--	--	0.006	--	--	--	--	--	81.3	5.4
21	--	--	--	--	--	0.006	--	--	--	--	--	75.5	1.0
22	--	--	--	--	--	0.006	--	--	--	--	--	72.2	0.8
23	--	--	--	--	--	0.006	--	--	--	--	--	69.4	0.0
Total	2532	13.6	9.3	4.3	7.2	0.15	11.1	39%	53%	--	--	--	--

*Based on field flowrate of 29.9 gpm

Single Day Table
Day 178, 6/26/80, Campbell Soup

Hour	Btu,ft ² /hr	In 10 ⁶ Btu/hr						Eff. (Based on (1))	Eff. (Based on (2))	In °F			In mph
	Total Horiz. Insol. (1)	Insol. to Coll. Plane (2)	Insol. to Flat Plates	Insol. to Conc.	Energy to Storage ^a	Elect. Energy	Fossil Fuel Saved			Field Inlet	Tank Inlet	Ambient	Wind Speed
0	--	--	--	--	--	0.006	--	--	--	--	--	62.9	4.6
1	--	--	--	--	--	0.006	--	--	--	--	--	61.8	4.4
2	--	--	--	--	--	0.006	--	--	--	--	--	62.3	3.7
3	--	--	--	--	--	0.006	--	--	--	--	--	61.0	5.2
4	--	--	--	--	--	0.006	--	--	--	--	--	59.9	2.5
5	--	--	--	--	--	0.006	--	--	--	--	--	59.2	1.8
6	48	--	--	--	--	0.006	--	0%	--	--	--	63.1	0.0
7	69	--	--	--	--	0.006	--	0%	--	--	--	68.8	0.0
8	178	0.6	0.6	--	0.3	0.006	0.5	23%	50%	68.7	85.9	74.1	0.0
9	226	1.4	0.9	0.5	0.6	0.006	0.9	36%	43%	68.6	108.0	77.2	9.9
10	267	1.8	1.1	0.7	0.9	0.006	1.4	46%	50%	68.6	126.4	78.9	2.0
11	295	2.1	1.3	0.8	1.1	0.006	1.7	51%	52%	68.7	139.7	83.1	5.0
12	312	2.1	1.3	0.8	1.1	0.006	1.7	48%	52%	69.0	144.2	87.4	2.4
13	310	2.0	1.4	0.6	1.1	0.006	1.5	48%	55%	70.6	143.8	90.1	3.8
14	281	1.9	1.2	0.7	0.9	0.006	1.4	44%	47%	69.6	131.5	93.9	3.8
15	254	1.6	1.0	0.6	0.7	0.006	1.1	38%	44%	69.7	118.7	94.9	4.8
16	197	0.9	0.6	0.3	0.4	0.006	0.6	28%	44%	69.5	98.0	95.5	10.8
17	145	--	--	--	--	0.006	--	0%	--	--	--	95.1	9.7
18	85	0.5	0.5	--	0.3	0.006	0.5	48%	60%	69.8	87.8	96.2	4.2
19	22	--	--	--	--	0.006	--	0%	--	--	--	91.2	5.6
20	--	--	--	--	--	0.006	--	--	--	--	--	84.0	4.6
21	--	--	--	--	--	0.006	--	--	--	--	--	79.9	3.2
22	--	--	--	--	--	0.006	--	--	--	--	--	77.3	2.5
23	--	--	--	--	--	0.006	--	--	--	--	--	74.3	0.4
Total	2736	15.1	10.1	5.0	7.4	0.15	11.2	37%	49%	--	--	--	--

^aBased on 29.9 gpm flowrate

Single Day Table
Day 191, 7/9/80, Campbell Soup

Hour	Btu/ft ² /hr	In 10 ⁵ Btu/hr						Eff., % (Based on (1))	Eff., % (Based on (2))	In °F			In mph
	Total Horiz. Insol. (1)	Insol. to Coll. Plane (2)	Insol. to Flat Plates	Insol. to Conc.	Energy to Storage ^a	Elect. Energy	Fossil Fuel Saved			Field Inlet	Tank Inlet	Ambient	Wind Speed
0	--	--	--	--	--	0.006	--	--	--	--	--	64.4	2.4
1	--	--	--	--	--	0.006	--	--	--	--	--	63.5	2.4
2	--	--	--	--	--	0.006	--	--	--	--	--	62.0	0.0
3	--	--	--	--	--	0.006	--	--	--	--	--	63.0	0.0
4	--	--	--	--	--	0.006	--	--	--	--	--	61.9	0.0
5	--	--	--	--	--	0.006	--	--	--	--	--	60.3	0.0
6	46	--	--	--	--	0.006	--	0	--	--	--	65.3	0.0
7	108	--	--	--	--	0.006	--	0	--	--	--	67.8	5.1
8	174	0.3	0.3	--	0.2	0.006	0.3	16	67	69.8	83.4	74.2	0.0
9	224	1.3	0.9	0.4	0.6	0.006	0.9	37	46	69.7	110.0	76.7	0.0
10	265	1.8	1.1	0.7	1.0	0.006	1.5	51	56	69.8	134.8	79.8	0.0
11	302	2.2	1.3	0.8	1.2	0.006	1.8	54	57	69.8	150.3	83.3	0.0
12	316	2.2	1.4	0.8	1.3	0.006	2.0	56	59	70.0	157.2	84.3	0.0
13	313	2.0	1.4	0.6	1.3	0.006	2.0	57	59	70.0	155.4	86.2	3.3
14	288	1.9	1.3	0.7	1.2	0.006	1.8	57	60	70.1	152.1	91.8	4.7
15	250	1.6	1.0	0.6	1.1	0.006	1.7	60	69	70.2	140.8	90.0	12.9
16	200	0.3	0.3	--	0.2	0.006	0.3	14	67	70.0	86.6	92.0	4.4
17	138	--	--	--	--	0.006	--	0	--	--	--	92.1	3.0
18	78	--	--	--	--	0.006	--	0	--	--	--	90.2	5.1
19	20	--	--	--	--	0.006	--	0	--	--	--	84.1	10.6
20	--	--	--	--	--	0.006	--	--	--	--	--	77.2	5.9
21	--	--	--	--	--	0.006	--	--	--	--	--	72.5	5.7
22	--	--	--	--	--	0.006	--	--	--	--	--	69.6	6.8
23	--	--	--	--	--	0.006	--	--	--	--	--	67.7	6.1
Total	2721	13.7	8.9	4.6	8.1	0.15	12.5	41	59	--	--	--	--

^aBased on 30 gpm flowrate

Single Day Table
Day 228, 8/15/80, Campbell Soup
(Hourly Averages)

Hour	Btu/ft ² /hr	In 10 ⁶ Btu/hr						Eff., Percent (Based on (1))	Eff., Percent (Based on (2))	In °F			In mph
	Total Horiz. Insol. (1)	Insol. to Coll. Plane (2)	Insol. to Flat Plates	Insol. to Conc.	Energy to Storage ^a	Elect. Energy	Fossil Fuel Saved			Field Inlet	Tank Inlet	Ambient	Wind Speed
1	--	--	--	--	--	0.006	--	--	--	--	--	65.9	5.4
2	--	--	--	--	--	0.006	--	--	--	--	--	65.8	6.1
3	--	--	--	--	--	0.006	--	--	--	--	--	65.1	2.0
4	--	--	--	--	--	0.006	--	--	--	--	--	64.8	3.8
5	--	--	--	--	--	0.006	--	--	--	--	--	64.1	7.0
6	--	--	--	--	--	0.006	--	--	--	--	--	63.9	5.3
7	21	--	--	--	--	0.006	--	0	--	--	--	65.1	0.0
8	79	--	--	--	--	0.006	--	0	--	--	--	68.3	4.2
9	139	0.4	0.3	0.1	0.1	0.006	0.2	10	25	71.0	80.6	72.5	4.7
10	191	1.0	0.8	0.2	0.5	0.006	0.8	36	50	70.9	106.5	77.9	0.0
11	235	1.7	1.1	0.6	0.8	0.006	1.2	46	47	70.8	125.7	81.9	0.0
12	260	1.8	1.2	0.6	1.0	0.006	1.5	52	56	70.8	137.9	85.4	8.9
13	272	2.0	1.3	0.7	1.1	0.006	1.7	55	55	70.9	146.2	90.1	3.1
14	261	1.7	1.1	0.6	1.1	0.006	1.7	57	64	70.9	145.3	93.2	4.5
15	218	1.5	1.0	0.5	1.0	0.006	1.5	63	66	70.9	138.3	94.0	6.4
16	169	1.2	0.8	0.4	0.8	0.006	1.2	65	67	71.0	122.3	97.3	0.0
17	137	0.9	0.6	0.3	0.5	0.006	0.8	50	56	71.1	107.2	96.9	4.3
18	83	0.4	0.3	0.1	0.3	0.006	0.5	49	75	71.1	90.5	96.8	3.1
19	29	--	--	--	--	0.006	--	0	--	--	--	93.6	0.0
20	--	--	--	--	--	0.006	--	0	--	--	--	85.4	7.1
21	--	--	--	--	--	0.006	--	--	--	--	--	78.9	7.3
22	--	--	--	--	--	0.006	--	--	--	--	--	75.7	4.8
23	--	--	--	--	--	0.006	--	--	--	--	--	73.2	2.4
24	--	--	--	--	--	0.006	--	--	--	--	--	71.8	0.0
Total	2094	12.6	8.6	4.0	7.4	0.15	11.4	48	59	--	--	--	--

^aBased on 30 gpm flowrate

Single Day Table
Day 257, 9/13/80, Campbell Soup
(Hourly Averages)

Hour	Btu/ft ² /hr	In 10 ⁶ Btu/hr						Eff., Percent (Based on (1))	Eff., Percent (Based on (2))	In °F			In mph
	Total Horiz. Insol. (1)	Insol. to Coll. Plane (2)	Insol. to Flat Plates	Insol. to Conc.	Energy to Storage ^a	Elect. Energy ^b	Fossil Fuel Saved			Field Inlet	Tank Inlet	Ambient	Wind Speed
1	--	--	--	--	--	↓	--	--	--	--	--	70.1	0.0
2	--	--	--	--	--		--	--	--	--	--	68.2	5.9
3	--	--	--	--	--		--	--	--	--	--	67.0	0.7
4	--	--	--	--	--		--	--	--	--	--	66.4	4.2
5	--	--	--	--	--		--	--	--	--	--	66.3	0.0
6	--	--	--	--	--		--	--	--	--	--	69.4	0.5
7	16	--	--	--	--		--	0	--	--	--	64.7	0.0
8	73	--	--	--	--		--	0	--	--	--	67.2	7.7
9	128	0.7	0.5	0.2	0.2		0.3	21	29	71.0	85.6	70.4	7.8
10	176	1.4	0.9	0.5	0.6		0.9	46	43	71.0	109.6	73.0	11.8
12	213	1.7	1.1	0.6	0.8		1.2	51	47	71.2	126.4	76.4	4.3
12	237	1.9	1.2	0.7	1.0		1.5	58	53	71.3	137.9	78.8	8.5
13	248	2.0	1.3	0.7	1.1		1.7	60	55	71.5	143.3	80.0	14.9
14	237	1.9	1.2	0.7	1.0		1.5	58	53	71.5	140.4	80.6	11.8
15	208	1.7	1.1	0.6	0.9		1.4	59	53	71.5	131.3	83.3	8.4
16	162	1.2	0.8	0.4	0.7		1.1	59	58	71.4	117.0	83.4	8.2
17	106	0.8	0.5	0.3	0.4		0.6	51	50	71.3	98.0	82.7	14.6
18	50	0.3	0.2	0.1	0.2		0.3	55	67	71.3	81.7	79.3	13.6
19	--	--	--	--	--		--	--	--	--	--	77.2	8.9
20	--	--	--	--	--		--	--	--	--	--	75.0	1.7
21	--	--	--	--	--		--	--	--	--	--	70.7	7.6
22	--	--	--	--	--		--	--	--	--	--	68.3	12.8
23	--	--	--	--	--		--	--	--	--	--	65.5	0.4
24	--	--	--	--	--		--	--	--	--	--	64.8	5.2
Total	1857	13.8	9.0	4.8	6.9	0.16	10.6	51	50	--	--	--	--

^aBased on 30 gpm flowrate

^bCalculated as daily total only

APPENDIX G
MONTHLY PERFORMANCE TABLES
FOR OCTOBER 1979 THROUGH SEPTEMBER 1980

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CAMPBELL SOUP

MONTHLY SUMMARY TABLE: OCTOBER 1979

Day	Total horiz. insol. (Btu/ft ²)	Insol. to coll. aperture during oper. (10 ⁶ Btu)	Energy to storage (10 ⁶ Btu)	Daily eff. (based on (1))	Daily eff. (based on (2))	Fossil fuel displaced (10 ⁶ Btu)	Electrical energy (10 ⁶ Btu)
10/1 (274)							
10/2 (275) ^a	1579	7.0	3.3	28%	47%	5.0	0.15
10/3 (276)	1164	4.3	2.4	28%	56%	3.6	0.15
10/4 (277)	1483	8.7	4.8	44%	55%	7.3	0.15
10/5 (278)	1502	9.7	5.3	48%	55%	8.2	0.15
10/6 (279)	936	4.0	2.1	31%	53%	3.2	0.15
10/7 (280)	1481	8.9	4.8	44%	54%	7.4	0.15
10/8 (281)	819	3.3	2.1	35%	64%	3.2	0.15
10/9 (282) ^b	1468	6.9	4.0	37%	58%	6.2	0.15
10/10 (283)	1516	9.6	5.3	48%	55%	8.2	0.15
10/11 (284)	1367	8.7	5.1	51%	59%	7.8	0.15
10/12 (285)	1298	7.3	4.4	46%	60%	6.8	0.15
10/13 (286)	926	3.7	2.3	34%	62%	3.5	0.15
10/14 (287)	1026	5.4	3.4	45%	63%	5.3	0.15
10/15 (288)	1117	7.0	4.1	50%	59%	6.3	0.15
10/16 (289)	1351	9.2	5.4	54%	59%	8.3	0.15
10/17 (290)	1445	9.5	5.2	49%	55%	8.0	0.15
10/18 (291)	407	0.0	0.0	0%	--	0.0	0.15
10/19 (292) ^c	465	0.5	0.2	6%	40%	0.3	0.15
10/20 (293)	653	1.0	0.5	10%	50%	0.8	0.15
10/21 (294)	1391	9.9	5.4	53%	55%	8.3	0.15
10/22 (295)	1206	8.4	5.2	59%	62%	8.0	0.15
10/23 (296)	1104	5.8	3.7	46%	64%	5.7	0.15
10/24 (297)							
10/29 to 10/30 (302) ^d							
10/30 (303)							
10/31 (304) ^e	1206	8.9	3.1	35%	35%	5.4	0.15
Total	26,900	147.7	82.1	42%	56%	126.3	3.45
Average ^f daily	1,170	6.4	3.6	42%	56%	5.5	0.15

^aConcentrators down after 11:30 due to maintenance

^bSystem off for one hour during day for maintenance

^cField flow increased to 30 G.P.M. from 25 G.P.M.

^dCollectors washed

^eField flow decreased to 15 G.P.M. from 30 G.P.M.

^fBased on days (23) on which system operated and data was taken

CAMPELL SOUP

MONTHLY SUMMARY TABLE: NOVEMBER 1979

Day	Total horiz. insol. (Btu/ft ²) (1)	Insol. to coll. aperture during oper. (10 ⁶ Btu) (2)	Energy to storage (10 ⁶ Btu)	Daily eff. (based on (1))	Daily eff. (based on (2))	Fossil fuel displaced (10 ⁶ Btu)	Electrical energy (10 ⁶ Btu)	
11/1 (305)	}	SYSTEM SHUT DOWN FOR STEAM HX MAINTENANCE						
11/6 to (310)								
11/7 (311)		919	6.2	4.5	67%	73%	6.9	0.15
11/8 (312)		SYSTEM OPERATED, DATA SYSTEM DOWN FOR MAG TAPE INST.						
11/9 (313)		SYSTEM OPERATED, DATA ERRATIC DUE TO PUMP CHECKOUT						
11/10 (314)		758	4.6	3.1	56%	67%	4.8	0.15
11/11 (315)		SYSTEM OPERATED, PRINTER ACCIDENTALLY TURNED OFF						
11/12 (316)		SYSTEM SHUT DOWN FOR STEAM HX REPAIR						
11/13 (317) ¹		1026	5.0	3.1	41%	62%	4.8	0.15
11/14 (318)		1013	8.5	5.4	73%	64%	8.3	0.15
11/15 (319)		723	4.0	3.1	58%	78%	4.8	0.15
11/16 (320)		412	0.4	0.2	7%	50%	0.3	0.15
11/17 (321) ²		841	4.4	3.1	50%	70%	4.8	0.15
11/18 (322) ²		1086	6.9	4.4	55%	64%	6.8	0.15
11/19 (323)		1044	9.7	6.6	86%	68%	10.2	0.15
11/20 (324)		1066	9.8	6.7	86%	68%	10.3	0.15
11/21 (325) ³		865	2.3	1.9	30%	82%	2.9	0.15
11/22 (326)		223	0.0	0.0	0%	--	0.0	0.15
11/23 (327)		347	0.1	0.1	4%	100%	0.2	0.15
11/24 (328)		347	0.3	0.2	8%	66%	0.3	0.15
11/25 (329)		427	0.6	0.3	10%	55%	0.5	0.15
11/26 (330) ^{2,4}		1001	2.3	1.8	25%	78%	2.8	0.15
11/27 (331) ^{2,4}		760	2.3	1.7	30%	74%	2.6	0.15
11/28 (332)	}	SYSTEM SHUT DOWN PENDING REPAIR OF CONTROL SYSTEM						
11/30 to (334)								
Total		12,858	67.4	46.2	49%	69%	71.1	2.55
Average ⁵ daily		756	4.0	2.7	49%	69%	4.2	0.15

¹System shut down at 12:00 for steam HX repair

²Concentrators not operated due to overheating caused by flow restriction

³Concentrators operated but de-steering due to overheating

⁴System operated manually from 11:00 a.m. to 2:00 p.m. only, due to control system problem

⁵Based on days (17) on which system operated and data was taken

Important Note: Energy to storage and the efficiencies calculated using it are too high due to errors in flow rate indication caused by clogging of collector field inlet strainers (i.e., actual flow less than indicated flow). Experience with the system indicates these values are overstated by 25 to 33 percent.

CAMPBELL SOUP

MONTHLY SUMMARY TABLE: DECEMBER 1979

Day	Total horiz. insol. (Btu/ft ²) (1)	Insol. to coll. aperture during oper. (10 ⁶ Btu) (2)	Energy to storage (10 ⁶ Btu)	Daily eff. (based on (1))	Daily eff. (based on (2))	Fossil fuel displaced (10 ⁶ Btu)	Electrical energy (10 ⁶ Btu)
12/1 (335)	769	SYSTEM SHUT DOWN					
12/2 (336)	488						
12/3 (337)	857						
12/4 (338)	760						
12/5 (339)	913						
12/6 (340) ¹	803	4.4	2.6	59%	48%	4.0	0.15
12/7 (341)	739	SYSTEM SHUT DOWN					
12/8 (342)	686						
12/9 (343)	596						
12/10 (344)	616						
12/11 (345)	914						
12/12 (346)	779	SYSTEM SHUT DOWN					
12/13 (347)	716						
12/14 (348) ¹	681	3.6	2.0	56%	45%	3.1	0.15
12/15 (349)	716	SYSTEM SHUT DOWN					
12/16 (350)	610						
12/17 (351)	607						
12/18 (352)	390						
12/19 (353)	203						
12/20 (354)	155	SYSTEM SHUT DOWN					
12/21 (355)	532						
12/22 (356)	850						
12/23 (357)	59						
12/24 (358)	75						
12/25 (359)	423	SYSTEM SHUT DOWN					
12/26 (360)	887						
12/27 (361)	598						
12/28 (362)	336						
12/29 (363)	160						
12/30 (364)	232	DATA LOGGER PROGRAMMING ERASED BY POWER FAILURE					
12/31 (365)							
Total	17,151 ²	8.0	4.6	58%	47%	7.1	0.30
Average daily ³	572 ²	4.0	2.3	58%	47%	3.5	0.15

¹System operated manually for 4 hours

²Based on days (30) of horizontal insolation data

³Based on days (2) when system operated and data was taken

CAMPELL SOUP

MONTHLY SUMMARY TABLE: JANUARY 1980

Day	Total horiz. insol. (Btu/ft ²) (1)	Insol. to coll. aperture during oper. (10 ⁶ Btu) (2)	Insol. to to flat plates during oper.	Insol. to conc. during oper.	Energy to storage ³ (10 ⁶ Btu)	Daily eff. (based on (1))	Daily eff. (based on (2))	Fossil fuel displaced (10 ⁶ Btu)	Electrical energy (10 ⁶ Btu)
1/1 (1) } to 1/23 (23) } 1/24 (24) } 1/25 (25) } 1/26 (26) } 1/27 (27) } 1/28 (28) } 1/29 (29) } 1/30 (30) } 1/31 (31) }	SYSTEM SHUT DOWN, DATA SYSTEM DOWN DUE TO PRINTER SWITCH ERROR ¹								
	WORK ON SYSTEM								
	165	--	--	--	--	0%	--	--	0.15
	244	--	--	--	--	0%	--	--	0.15
	1050	7.7	4.8	2.9	4.5	58%	58%	6.9	0.15
	1143	9.8	5.9	3.9	4.5	54%	46%	6.9	0.15
	1126	7.9	5.2	2.7	3.9	47%	49%	6.0	0.15
	417	--	--	--	--	0%	--	--	0.15
Total	4145	4.2	15.9	9.5	12.9	42%	51%	19.8	0.9
Average daily ²	691	4.2	2.6	1.6	2.2	42%	51%	3.3	0.15

¹Weather data for all of January for Sacramento indicates:

14 cloudy days
10 partly cloudy days
7 clear days

²Based on days (6) when system operated and data was taken

³Performance based on 25 gpm flowrate

CAMPBELL SOUP
MONTHLY SUMMARY TABLE: FEBRUARY 1980

Day	Total horiz. insol. (Btu/ft ²) (1)	Insol. to coll. aperture during oper. (10 ⁶ Btu) (2)	Insol. to to flat plates during oper.	Insol. to conc. during oper.	Energy to storage ³ (10 ⁶ Btu)	Daily eff. (based on (1))	Daily eff. (based on (2))	Fossil fuel displaced (10 ⁶ Btu)	Electrical energy (10 ⁶ Btu)
2/1 (32)	779	2.4	2.4	0.0	1.0	18%	43%	1.6	0.15
2/2 (33)	565	0.0	0.0	0.0	0.0	0%	--	0.0	0.15
2/3 (34)	371	0.0	0.0	0.0	0.0	0%	--	0.0	0.15
2/4 (35)	392	0.0	0.0	0.0	0.0	0%	--	0.0	0.15
2/5 (36)	219	0.0	0.0	0.0	0.0	0%	--	0.0	0.15
2/6 (37)	1017	7.2	4.8	2.4	2.8	38%	39%	4.3	0.15
2/7 (38)	1257	8.7	5.4	3.4	4.6	50%	53%	7.1	0.15
2/8 (39)	WORK ON SYSTEM								
2/9 (40)	1224	5.9	5.9	0.0	3.0	33%	51%	4.6	0.15
2/10 (41)	1260	5.1	5.1	0.0	2.6	28%	51%	4.0	0.15
2/11 (42)	972	3.0	3.0	0.0	2.1	29%	70%	3.2	0.15
2/12 (43)	1182	7.0	5.6	1.4	3.7	43%	53%	5.7	0.15
2/13 (44)	1146	8.1	5.5	2.6	3.8	45%	47%	5.8	0.15
2/14 (45)	154	0.0	0.0	0.0	0.0	0%	--	0.0	0.15
2/15 (46)	493	1.1	1.0	0.1	0.8	21%	68%	1.2	0.15
2/16 (47)	183	0.0	0.0	0.0	0.0	0%	--	0.0	0.15
2/17 (48)	173	0.0	0.0	0.0	0.0	0%	--	0.0	0.15
2/18 (49)	994	3.9	3.4	0.5	2.0	27%	51%	3.1	0.15
2/19 (50)	679	2.6	2.2	0.4	2.0	40%	77%	3.1	0.15
2/20 (51)	648	2.5	2.5	0.0	1.0	21%	40%	1.5	0.15
2/21 (52)	995	5.5	4.2	1.3	3.2	44%	58%	4.9	0.15
2/22 (53)	608	2.8	2.0	0.8	1.5	34%	54%	2.3	0.15
2/23 (54)	1119	6.4	4.7	1.7	3.1	38%	48%	4.8	0.15
2/24 (55)	SYSTEM DOWN								
2/25 (56)	990	3.6	3.6	0.0	2.0	28%	56%	3.1	0.15
2/26 (57)	1121	4.8	4.7	0.1	2.7	33%	56%	4.2	0.15
2/27 (58)	360	0.2	0.2	0.0	0.1	4%	48%	0.2	0.15
2/28 (59)	1500	11.8	7.2	4.6	5.7	52%	48%	8.8	0.15
2/29 (60)	1598	12.3	7.7	4.6	7.0	60%	57%	10.8	0.15
Total	22,009	109.7	85.8	23.9	54.7 ^b	34%	50%	84.2	4.1
Average daily ^a	815	4.1	3.2	0.9	2.0 ^b	34%	50%	3.1	0.15

^aBased on days (27) on which system operated and data was taken

^bBased on 20 gpm flowrate

Campbell Soup

Monthly Summary Table: FEBRUARY 1980

Date, Julian Day	Total Horiz. Insol. (Btu/ft ²) (1)	Insol. to Coll. Aperture During Oper. (10 ⁶ Btu) (2)	Insol. to Flat plates During Oper.	Insol. to Conc. During Oper.	Energy to Storage ^c (10 ⁶ Btu)	Daily Eff. (Based on) (1)	Daily Eff. (Based on) (2)	Fossil Fuel Displaced (10 ⁶ Btu)	Electrical Energy (10 ⁶ Btu)
3/1, 61	449	0.5	0.5	--	0.3	8%	51%	0.5	0.15
3/2, 62	525	1.7	1.7	--	0.7	18%	42%	1.1	0.15
3/3, 63	641	2.1	2.1	--	0.7	15%	34%	1.1	0.15
3/4, 64	1330	7.6	5.6	2.0	2.7	28%	36%	4.2	0.15
3/5, 65	723	2.4	2.4	--	1.2	23%	50%	1.8	0.15
3/6, 66	1263	4.5	4.1	0.8	2.4	26%	49%	3.7	0.15
3/7, 67	1119	3.6	2.8	0.8	1.7	21%	47%	2.6	0.15
3/8, 68	1698	10.4	6.5	3.9	4.7	38%	45%	7.2	0.15
3/9, 69	1758	11.2	7.1	4.2	5.4	31%	48%	8.3	0.15
3/10, 70 ^a	1756	4.2	3.2	1.0	2.5	14%	60%	3.8	0.15
3/11, 71 ^a	1551	4.3	3.0	1.3	1.8	15%	16%	2.8	0.15
3/12, 72 ^a	1769	0.6	0.6	--	0.5	4%	4%	0.8	0.15
3/13, 73 ^a	1644	2.9	1.9	1.0	1.2	12%	41%	1.8	0.15
3/14, 74	532	0.4	0.4	--	0.2	4%	41%	0.3	0.15
3/15, 75	1799	7.5	6.0	1.5	3.9	32%	52%	6.0	0.15
3/16, 76	1881	11.6	7.3	4.3	5.3	33%	46%	8.2	0.15
3/17, 77	1513				System down, tank full				
3/18, 78 ^a	1843	3.8	3.2	0.6	2.2	15%	58%	3.4	0.15
3/19, 79	1941	11.6	7.5	4.1	5.9	41%	51%	9.1	0.15
3/20, 80 ^b	1755				System down, testing				
3/21, 81	1855	9.5	6.2	3.3	4.8	35%	51%	7.4	0.15
3/22, 82	1775	10.1	6.4	3.7	4.8	37%	48%	7.4	0.15
3/23, 83	1790	8.2	5.2	3.0	4.4	34%	54%	6.8	0.15
3/24, 84	2005	10.7	6.8	3.9	5.1	35%	48%	7.8	0.15
3/25, 85	563	1.6	1.1	0.5	0.5	13%	33%	0.8	0.15
3/26, 86	1786	6.9	6.1	0.8	3.8	29%	55%	5.8	0.15
3/27, 87 ^a	2015	1.6	1.2	0.4	0.8	5%	50%	1.2	0.15
3/28, 88	2072	11.8	7.5	4.3	5.9	39%	50%	9.1	0.15
3/29, 89	1997				System down, tank full				
3/30, 90	2133				System down, tank full				
3/31, 91					System down for Easter vacation				
Total	38,083	148.6	103.2	45.4	73.4	26%	49%	113.1	3.9
Daily Average ^d	1,464	5.7	4.0	1.7	2.8	26%	49%	4.4	0.15

^aSystem operated for only part of day due to tank becoming full (6 days in total)^bSystem down for flat plate absorber testing^cBased on 20 gpm flowrate, 3/1-6, 23.6 gpm 3/7-30^dBased on days system operated (26 days)

Campbell Soup
Monthly Summary Table: April 1980

Date, Julian Day	Total Horiz. Insol. (Btu/ft ²) (1)	Insol. to Coll. Aperture During Oper. (10 ⁶ Btu) (2)	Insol. to Flat plates During Oper. (10 ⁶ Btu)	Insol. to Conc. During Oper.	Energy to Storage ^b (10 ⁶ Btu)	Daily Eff. (Based on) (1)	Daily Eff. (Based on) (2)	Fossil Fuel Displaced (10 ⁶ Btu)	Electrical Energy (10 ⁶ Btu)
4/1, 92	System down for Easter vacation								
4/6, 97									
3/7, 98	1933	Tank full, system down				0%	--	--	0.15
4/8, 99	1813	2.1	1.5	0.6	1.4	11%	66%	2.2	0.15
4/9, 100	1591	6.0	3.8	2.2	3.0	26%	51%	4.7	0.15
4/10, 101	2153	Tank full, system down				0%	--	--	0.15
4/11, 102	2035	7.1	4.9	2.2	3.8	26%	54%	5.9	0.15
4/12, 103	2256	14.2	9.7	4.5	6.0	36%	42%	9.2	0.15
4/13, 104	1924	Tank full, system down				0%	--	--	0.15
4/14, 105	2176	3.3	2.7	0.6	2.1	13%	63%	3.2	0.15
4/15, 106	2229	5.5	4.4	1.2	3.5	21%	63%	5.4	0.15
4/16, 107	2101	5.1	3.6	1.4	2.6	16%	50%	3.9	0.15
4/17, 108	2209	Tank full, system down				0%	--	--	0.15
4/18, 109	2066	2.6	1.8	0.8	1.3	6%	51%	2.0	0.15
4/19, 110	2300	2.4	1.5	0.9	1.0	4%	42%	1.5	0.15
4/20, 111	884	Tank full, system down				0%	--	--	0.15
4/21, 112	1695	Tank full, system down				0%	--	--	0.15
4/22, 113	385	Tank full, system down				0%	--	--	0.15
4/23, 114	715	Tank full, system down				0%	--	--	0.15
4/24, 115	1920	5.7	3.5	2.1	3.0	21%	53%	4.6	0.15
4/25, 116	2188	3.9	2.6	1.3	1.9	9%	49%	2.9	0.15
4/26, 117	2338	2.0	1.3	0.7	1.1	5%	53%	1.7	0.15
4/27, 118	2237	Tank full, system down				0%	--	--	0.15
4/28, 119	2906	Tank full, system down				0%	--	--	0.15
4/29, 120	2210	Tank full, system down				0%	--	--	0.15
4/30, 121	2461	Tank full, system down				0%	--	--	0.15
Total	45,915	59.9	41.3	18.6	30.7	9%	51%	47.2	3.6
Daily Average ^a	1,913	2.5	1.7	0.8	1.3	9%	51%	2.0	0.15

NOTE: System operation restricted due to tank fill-up on every day but 4/12.

^aBased on days system operated (24 days)

^bBased on 28.8 gpm flowrate 4/1-23; 29.9 gpm 4/24-30

Campbell Soup

Monthly Summary Table: May 1980

Date, Julian Day	Total Horiz. Insol. (Btu/ft ²) (1)	Insol. to Coll. Aperture During Oper. (10 ⁶ Btu) (2)	Insol. to to Flat plates During Oper. (10 ⁶ Btu)	Insol. to Conc. During Oper.	Energy to Storage ^b (10 ⁶ Btu)	Daily Eff. (Based on (1))	Daily Eff. (Based on (2))	Fossil Fuel Displaced (10 ⁶ Btu)	Electrical Energy (10 ⁶ Btu)
5/1, 122	2,394	--	--	--	--	0%	--	--	0.02
5/2, 123	2,300	--	--	--	--	0%	--	--	0.02
5/3, 124	2,423	--	--	--	--	0%	--	--	0.02
5/4, 125	2,407	--	--	--	--	0%	--	--	0.02
5/5, 126	2,173	4.4	3.5	0.9	3.3	21%	76%	5.1	0.15
5/6, 127	2,445	14.6	9.7	4.9	13.1	73%	90%	20.1	0.15
5/7, 128	2,497	--	--	--	--	0%	--	--	0.02
5/8, 129	1,631	3.9	3.7	0.2	2.3	19%	58%	3.5	0.15
5/9, 130	Data system down, printer problem								
5/10, 131	2,298	11.3	8.7	2.6	8.7	52%	77%	13.4	0.15
5/11, 132	1,314	3.2	3.0	0.2	3.3	34%	103%	5.1	0.15
5/12, 133	1,716	--	--	--	--	0%	--	--	0.02
5/13, 134	1,514	--	--	--	--	0%	--	--	0.02
5/14, 135	2,080	--	--	--	--	0%	--	--	0.02
5/15, 136	2,525	--	--	--	--	0%	--	--	0.02
5/16, 137	2,532	13.6	9.3	4.3	7.2	39%	53%	11.1	0.15
5/17, 138	2,566	13.1	8.5	4.6	7.9	42%	60%	12.2	0.15
5/18, 139	2,571	--	--	--	--	0%	--	--	0.02
5/19, 140	2,581	--	--	--	--	0%	--	--	0.02
5/20, 141	Data system down, printer problem								
5/24, 145	Data system down, printer problem								
5/25, 146	2,247	10.8	7.3	3.5	6.0	36%	55%	9.2	0.15
5/26, 147	2,510	--	--	--	--	0%	--	--	0.02
5/27, 148	2,424	--	--	--	--	0%	--	--	0.02
5/28, 149	2,362	8.2	5.7	2.5	5.4	23%	66%	8.3	0.15
5/29, 150	2,531	2.0	1.9	0.1	1.2	5%	60%	1.8	0.15
5/30, 151	Data system down, printer problem								
5/31, 152	2,450	2.2	2.2	--	1.5	8%	67%	2.3	0.15
Total	54,491	87.3	63.5	23.8	59.9	25%	69%	92.2	1.78
Daily Average ^a	2,270	3.6	2.6	1.0	2.5	25%	69%	3.8	0.07
Modified Total	54,491	87.3	63.5	23.8	43.4	18%	50%	66.8	1.78
Modified Daily Average ^a	2,270	3.6	2.6	1.0	1.8	18%	50%	2.8	0.07

^aBased on days system operated and data was taken (24 days)^bBased on 29.9 gpm

NOTE: System data taken during May indicates that the field flow control valve was probably jammed and acting as a fixed orifice instead of modulating the field flow. Consequently, the flow rate was probably less than the indicated 29.9 gpm at times. This accounts for the abnormally high daily efficiencies shown for May. Previous months data shows that the system operated at a nominal daily efficiency of 50% with respect to insolation available at the aperture. Therefore, the summary data for May will be presented as modified to show a daily efficiency of 50%. The summary values for May are therefore shown as the "modified" values. The flow control valve will be cleaned and calibrated during June.

Table 3. Campbell Soup
Monthly Summary Table: May 1980

Date, Julian Day	Total Horiz. Insol. (Btu/ft ²) (1)	Insol. to Coll. Aperture During Oper. (10 ⁶ Btu) (2)	Insol. to Flat plates During Oper. (10 ⁶ Btu)	Insol. to Conc. During Oper.	Energy to Storage ^b (10 ⁶ Btu)	Daily Eff. (Based on (1))	Daily Eff. (Based on (2))	Fossil Fuel Displaced (10 ⁶ Btu)	Electrical Energy (10 ⁶ Btu)
6/1, 153	1,942	--	--	--	--	0%	--	--	0.15
6/2, 154				Data System Down, printer problem					
6/3, 155	2,481	3.4	2.5	0.9	2.0	11%	59%	3.1	
6/4, 156	1,858	6.9	4.5	2.4	4.9	36%	71%	7.5	
6/5, 157	2,248	9.3	6.0	3.3	6.0	37%	65%	9.2	
6/6, 158	2,718	9.2	5.9	3.3	6.1	31%	66%	9.4	
6/7, 159	2,690	11.9	7.6	4.3	7.4	38%	62%	11.4	
6/8, 160	2,724	2.7	1.8	0.9	1.8	9%	67%	1.8	
6/9, 161	2,695	4.7	3.2	1.5	3.3	17%	70%	5.1	
6/10, 162	2,734	12.1	7.7	4.4	7.4	37%	61%	11.4	
6/11, 163	2,500	8.9	5.7	3.2	5.4	29%	61%	8.3	
6/12, 164	2,217	--	--	--	--	0%	--	--	
6/13, 165	2,515	--	--	--	--	0%	--	--	
6/14, 166	2,567	--	--	--	--	0%	--	--	
6/15, 167	2,698	0.9	0.7	0.2	0.4	2%	43	0.6	
6/16, 168	2,682	--	--	--	--	0%	--	--	
6/17, 169	2,634	11.7	7.5	4.2	7.7	40%	65%	11.8	
6/18, 170	2,664	11.8	7.6	4.2	7.1	37%	61%	10.9	
6/19, 171	2,568	10.4	7.3	3.1	7.0	37%	67%	10.8	
6/20, 172	2,640	--	--	--	--	0%	--	--	
6/21, 173	2,681	--	--	--	--	0%	--	--	
6/22, 174	2,725	--	--	--	--	0%	--	--	
6/23, 175				Plant power off for maintenance					
6/24, 176	2,511	--	--	--	--	0%	--	--	
6/25, 177	2,736	8.5	5.0	3.5	1.3	6%	15% ^c	--	
6/26, 178	2,736	15.1	10.1	5.0	7.4	37%	49%	11.2	
6/27, 179	2,570	4.9	3.8	1.1	2.9	15%	59%	4.5	
6/28, 180	2,716	--	--	--	--	0%	--	--	
6/29, 181	1,591	--	--	--	--	0%	--	--	
6/30, 151	2,159	--	--	--	--	0%	--	--	
Total	72,359	132.3	86.9	45.4	78.1	15%	59%	120.0	4.2
Daily Average ^a	2,584	4.7	3.1	1.6	2.8	15%	59%	4.3	0.15
Modified Total	72,359	132.3	86.9	45.4	66.2	12%	50%	101.8	4.2
Modified Daily Average ^a	2,584	4.7	3.1	1.6	2.4	12%	50%	3.6	0.15

^aBased on days system was available and data were taken (28 days)

^bBased on 29.9 gpm

^cLow daily efficiency due to work on system

Note: System data taken during June indicates higher than anticipated efficiencies. This was due to the field flow control valve on the pressure regulator being jammed with material present in the inlet water. This caused lower flowrate values than the indicated 29.9 gpm. Previous months data shows that the system operated at a nominal daily efficiency of 50% with respect to insolation available at the aperture. Therefore, the summary data for June will be presented as modified to show a daily efficiency of 50%. The summary values for June are therefore shown as the "modified" values. The valve and regulator were cleaned on June 25.

Table 3. Campbell Soup
Monthly Summary Table: July 1980

Date, Julian Day	Total Horiz. Insol. (Btu/ft ²) (1)	Insol. to Coll. Aperture During Oper. (10 ⁶ Btu) (2)	Insol. to Flat plates During Oper. (10 ⁶ Btu)	Insol. to Conc. During Oper.	Energy to Storage ^b (10 ⁶ Btu)	Daily Eff., % (Based on (1))	Daily Eff., % (Based on (2))	Fossil Fuel Displaced (10 ⁶ Btu)	Electrical Energy (10 ⁶ Btu)
7/1, 183	1,743	--	--	--	--	0	--	--	0.15
7/2, 184	688	--	--	--	--	0	--	--	0.15
7/3, 185	2,453	--	2.5	0.9	--	0	--	--	0.15
7/4, 186	2,779	--	4.5	2.4	--	0	--	--	0.15
7/5, 187	2,716	10.0	10.0	--	6.7	34	67	10.3	0.15
7/6, 188	2,416	--	--	--	--	0	--	--	0.15
7/7, 189	2,730	--	--	--	--	0	--	--	0.15
7/8, 190	2,666	7.7	6.9	0.8	5.2	27	68	8.0	0.15
7/9, 191	2,721	13.7	8.9	4.8	8.1	41	59	12.5	0.15
7/10, 192	2,667	10.5	6.7	3.9	6.4	33	60	9.8	0.15
7/11, 193	2,677	3.3	3.3	--	2.8	14	85	4.3	0.15
7/12, 194	2,644	4.7	3.0	1.7	2.6	13	55	4.0	0.15
7/13, 195	2,617	--	--	--	--	0	--	--	0.15
7/14, 196	2,637	3.3	2.8	0.5	2.2	11	66	3.4	0.15
7/15, 197	2,626	5.6	3.6	2.0	3.5	18	63	5.4	0.15
7/16, 198	2,560	1.5	1.3	0.2	1.4	7	93	2.2	0.15
7/17, 199	2,593	7.4	6.6	0.8	7.4	39	100	11.4	0.15
7/18, 200	2,656	10.2	9.0	1.2	9.6	49	94	14.8	0.15
7/19, 201	2,484	13.1	8.5	4.6	9.6	53	73	14.8	0.15
7/20, 202	2,579	--	--	--	--	0	--	--	0.15
7/21, 203	2,563	0.6	0.5	0.1	0.5	3	83	0.8	0.15
7/22, 204	2,537	12.3	8.4	3.9	11.5	62	93	17.7	0.15
7/23, 205	2,545	9.3	8.6	0.7	13.7	73	147	21.1	0.15
7/24, 206	2,604	12.1	9.1	3.0	9.8	51	81	15.1	0.15
7/25, 207	2,571	15.4	10.0	5.4	13.0	69	84	20.0	0.15
7/26, 208	2,460	14.1	9.3	4.8	13.2	73	94	20.3	0.15
7/27, 209	2,450	7.0	6.0	1.0	9.3	52	133	14.3	0.15
7/28, 210	889	0.5	0.4	0.1	0.8	12	160	1.2	0.15
7/29, 211	2,316	11.2	9.0	2.2	15.1	89	135	23.2	0.15
7/30, 212	2,411	11.9	9.8	2.1	16.4	93	138	25.2	0.15
7/31, 213	2,338	11.2	9.3	1.9	13.7	80	122	21.1	0.15
Total	75,336	196.7	151.0	45.7	182.5	33	93	280.8	4.65
Daily Average ^a	2,430	6.3	4.9	1.5	5.9	33	93	9.1	0.15
Modified Total	75,336	196.7	151.0	45.7	78.5	14	40	120.8	4.65
Modified Daily Average ^a	2,430	6.3	4.9	1.5	2.5	14	40	3.9	0.15

^aBased on days system was available and data were taken (31 days)

^bBased on 30 gpm

Note: System data taken during July indicates abnormally high efficiencies. This was due to the field flow solenoid control valve being jammed with inert material present in the inlet water. This caused significantly lower flowrates than the indicated 30 gpm. (A separator to remove this material will be ordered during August.) The estimated actual average efficiency for the system during July is 40 percent. This was estimated based on previous months collector performance and the temperature in which the collectors were operating. Therefore, the summary data for July will be presented as modified to show a daily efficiency of 40 percent.

Campbell Soup
Monthly Summary Table: August 1980

Date, Julian Day	Total Horiz. Insol. (Btu/ft ²) (1)	Insol. to Coll. Aperture During Oper. (10 ⁶ Btu) (2)	Insol. to Flat Plates During Oper. (10 ⁶ Btu)	Insol. to Conc. During Oper. (10 ⁶ Btu)	Energy Storage ^b (10 ⁶ Btu)	Daily Eff., Percent (Based on (1))	Daily Eff., Percent (Based on (2))	Fossil Fuel Displaced (10 ⁶ Btu)	Electrical Energy ^c (10 ⁶ Btu)
8/1, 214	2,494	12.0	9.8	2.2	15.0	68	125	23.1	
8/2, 215	2,499	14.5	9.6	4.9	14.4	79	99	22.2	
8/3, 216	2,476	10.9	9.5	1.4	16.1	89	148	24.8	
8/4, 217	2,459	12.8	9.9	2.9	15.3	85	120	23.5	
8/5, 218	2,414	12.2	9.8	2.4	14.7	83	120	22.6	
8/6, 219	2,185	10.7	8.5	2.2	13.5	84	126	20.8	
8/7, 220	2,320	11.3	9.5	1.8	15.5	91	137	23.8	
8/8, 221	2,415	12.4	9.7	2.7	16.4	93	132	25.2	
8/9, 222	2,441	12.4	9.7	2.7	15.9	89	128	24.5	
8/10, 223	2,398	11.1	9.7	1.4	17.0	97	153	26.2	
8/11, 224	2,374	12.5	9.4	3.1	16.2	93	130	24.9	
8/12, 225	2,330	13.1	9.6	3.5	16.0	94	122	24.6	
8/13, 226	2,346	12.4	9.4	3.0	15.7	91	127	24.2	
8/14, 227	2,229	7.8	6.0	1.8	9.0	55	115	13.8	
8/15, 228	2,094	12.6	8.6	4.0	7.4	48	59	11.4	
8/16, 229	2,159	13.4	9.0	4.4	9.2	58	69	14.2	
8/17, 230	2,173	13.6	9.0	4.6	10.2	64	75	15.7	
8/18, 231	2,337	13.8	9.3	4.5	13.5	79	98	20.8	
8/19, 232	2,171	12.8	9.3	3.5	15.4	97	120	23.7	
8/20, 233	2,131	12.9	9.2	3.6	14.5	93	112	22.3	
8/21, 234	2,129	13.4	9.0	4.4	14.4	92	107	22.2	
8/22, 235	1,946	10.2	7.6	2.6	11.4	80	112	17.5	
8/23, 236									
↓									
8/31, 244	Printer down								
Total	50,520	268.8	201.2	67.6	306.7	83	114	471.8	4.3
Daily Average ^a	2,296	12.2	9.1	3.1	13.9	83	114	21.4	0.2
Modified Total	50,520	268.8	201.2	67.6	107.6	29	40	165.5	1.9
Modified Daily Average ^c	2,296	12.2	9.1	3.1	4.9	29	40	7.5	0.09

^aBased on days system was available and data were taken (22 days)

^bBased on 30 gpm

^cMonthly total and average calculated

Note: System data taken during August indicates abnormally high efficiencies. This was due to the field flow solenoid control valve and piping in-line strainers being clogged with inert material present in the inlet water. This caused significantly lower flowrates than the indicated 30 gpm. (A separator to remove this material was ordered during August and will be installed during September.) The estimated actual average efficiency for the system during August is 40 percent. This was estimated based on previous month's collector performance and the temperature at which the collectors were operating. Therefore, the summary data for August will be presented as modified to show a daily efficiency of 40 percent.

Campbell Soup Monthly Summary Table: September 1980

Date, Julian Day	Total Horiz. Insol. (Btu/ft ² (1))	Insol. to Coll. Aperture During Oper. (10 ⁶ Btu) (2)	Insol. to Flat Plates During Oper. (10 ⁶ Btu)	Insol. to Conc. During Oper. (10 ⁶ Btu)	Energy Storage ^b (10 ⁶ Btu)	Daily Eff., Percent (Based on (1))	Daily Eff., Percent (Based on (2))	Fossil Fuel Displaced (10 ⁶ Btu)	Electrical Energy ^c (10 ⁶ Btu)
9/1, 245 } 9/2, 246 } 9/3, 247 }	Printer down								
9/4, 248	1,980	13.6	9.1	4.5	8.0	58	59	12.3	
9/5, 249	1,331	13.2	8.8	4.5	7.9	56	60	12.2	
9/6, 250	2,029	13.6	9.2	4.5	8.9	60	65	13.7	
9/7, 251	1,911	13.2	8.8	4.4	11.8	84	89	18.2	
9/8, 252	1,891	13.4	8.8	4.6	7.5	54	56	11.5	
9/9, 253	1,866	13.4	8.7	4.7	8.2	60	61	12.6	
9/10, 254	1,856	13.4	8.7	4.7	8.5	62	63	13.1	
9/11, 255	1,819	12.9	8.6	4.3	12.5	94	97	19.2	
9/12, 256	1,859	13.5	8.8	4.7	8.3	61	59	12.8	
9/13, 257	1,857	13.8	9.0	4.8	6.9	51	50	10.6	
9/14, 258	1,166	2.2	2.1	0.1	1.2	14	55	1.8	
9/15, 259	1,823	4.0	3.0	1.0	2.3	17	58	3.5	
9/16, 260	1,820	13.6	8.7	4.9	11.6	87	85	17.8	
9/17, 261	1,518	6.8	5.9	0.9	7.2	65	106	11.1	
9/18, 262	1,093	4.2	4.1	0.1	4.4	55	105	6.8	
9/19, 263	1,742	13.0	8.4	4.6	8.9	70	68	13.7	
9/20, 264	1,709	12.6	8.4	4.2	6.3	50	50	9.7	
9/21, 265	1,775	14.0	8.8	5.2	7.2	55	51	11.1	
9/22, 266	1,738	13.9	8.7	5.2	11.1	85	80	17.1	
9/23, 267	1,720	13.8	8.6	5.2	10.3	82	75	15.8	
9/24, 268	1,669	13.3	8.4	4.9	7.2	59	54	11.1	
9/25, 269	1,602	12.1	7.9	4.2	6.7	57	55	10.3	
9/26, 270	1,631	12.6	8.4	4.2	7.5	63	60	11.5	
9/27, 271	1,619	13.1	8.3	4.8	8.2	69	63	12.6	
9/28, 272	1,604	13.1	8.4	4.7	10.1	86	77	15.5	
9/29, 273	1,540	11.9	7.6	4.3	9.0	80	76	13.8	
9/30, 274	1,548	11.3	7.4	3.9	9.4	83	83	14.5	
Total	46,216	319.5	211.5	108.0	217.1	64	68	334.0	5.3
Daily Average ^a	1,711	11.8	7.8	4.0	8.0	64	68	12.4	0.2
Modified Total	46,216	319.5	211.5	108.0	159.6	47	50	245.5	4.3
Modified Daily Average ^a	1,711	11.8	7.8	4.0	5.9	47	50	9.1	0.16

^aBased on days system was available and data were taken (27 days)

^bBased on 30 gpm

^cCalculated as monthly total and daily average only

Note: System data taken during September indicates abnormally high efficiencies. This was due to the field "low solenoid control valve and piping in-line strainers being clogged with inert material present in the inlet water. This caused significantly lower flowrates than the indicated 30 gpm. (A separator to remove this material was ordered during August and will be installed as soon as plant operations are reduced.) The estimated actual average efficiency for the system during September is 50 percent. This was estimated based on previous month's collector performance and the temperature at which the collectors were operating. Therefore, the summary data for September will be presented as modified to show a daily efficiency of 50 percent.

REFERENCES

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3. Stread, E., et al., "Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program," National Bureau of Standards, NBSR 76-1137, August 1976, p. 64.