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Solar Industrial Process Heat (IPH) Project Technical Report October 1982-September 1983

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SOLAR INDUSTRIAL PROCESS HEAT (IPH) PROJECT TECHNICAL REPORT

October 1982-September 1983

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ABSTRACT

This document contains a report of the work performed in the Solar Industrial Process Heat Project during FY 1983. The work involved eighteen industrial process heat experiments originally funded by the Department of Energy (DOE) under two separate programs. During FY 1983, eight of the experiments were in the operational phase directly supported by the DOE, seven had been completed previously and the solar equipment had been transferred to the plant owners for continued operation, and three had been discontinued.

The report contains a description of each of the active experiments and a discussion of their system performance, operation, and maintenance experience. It also contains a brief statement of the status of the solar equipment for experiments completed in prior years.

The project is sponsored by the Systems Test and Evaluations Branch of the Division of Solar Thermal Technology, Department of Energy.

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SUMMARY

The Solar Industrial Process Heat (IPH) Project was initiated in 1976 to evaluate solar energy systems in industrial applications. Seventeen experiments were conducted in four cycles that started one year apart. Each experiment consisted of three phases: (1) design, (2) construction, and (3) operation. Upon completion of the experiments, ownership of the solar energy systems is transferred to the owners of the industrial plants where the systems are located. An additional experiment, Capitol Concrete Products, Topeka, KS, initiated as the "Thermal System Engineering Experiment" by the Jet Propulsion Laboratory, has been included in the project. The purpose of the experiments was to measure energy production over the long term and to assess operation and maintenance requirements.

This report is an account of operations during FY 1983 for seven of the experiments from the original IPH project and for the Capitol Concrete experiment, all of which were funded by the Department of Energy (DOE) for all or part of FY 1983. In addition, brief descriptions are included for the remaining IPH experiments that have been completed and are no longer funded by DOE. The seven experiments from the original IPH project are:

Caterpillar Tractor Co, San Leandro, CA
Dow Chemical Co., Dalton, GA
Home Laundry, Pasadena, CA
Lone Star Brewery, San Antonio, TX
Ore-Ida Foods, Ontario, OR
Southern Union Refining Co., Lovington, NM
USS Chemicals Co., Haverhill, OH

The solar energy systems for these experiments use parabolic-trough, single-axis tracking collectors to produce hot water or steam for their respective industrial processes. The collector fields for these systems vary in size from 600 m^2 to 4,700 m^2 (6,500 ft^2 to 50,400 ft^2) of collector aperture area. The Capitol Concrete experiment uses a point-focus collector with an aperture of 80 m^2 (860 ft^2).

Data were obtained for periods of 7 to 12 months for six of the experiments. Energy production for these experiments, extrapolated to full-year operation, ranged from 387 GJ/yr (367 MBtu/yr) for Home Laundry, with a collector area of 604 m^2 (6,500 ft^2), to 4,270 GJ/yr (4,047 MBtu/yr) for USS Chemicals Co., with a collector area of 4,682 m^2 (50,400 ft^2). The systems converted from 6% to 27% of the maximum collectible solar radiation to thermal energy. Operation and maintenance costs ranged from $1,449 per year at Southern Union Refining Co., with a collector area of 937 m^2 (10,000 ft^2), to $64,244 per year at USS Chemicals Co. A detailed analysis of energy losses and clear-day system performance is reported. Both long-term and clear-day performances are compared with predictions for system models developed by the Solar Energy Research Institute (SERI).

Conclusions

From operations during FY 1983, the following conclusions can be drawn:

1. Long-term energy production for Cycle 2, Cycle 3, and Cycle 4 solar IPH systems in the DOE experimental phase increased over previous years' production, maintenance problems decreased, and operation in general approached routine.
2. After systems were modeled "as built," system performance was less than predicted. Reasons include system downtime because of equipment malfunction, reduced operating efficiency because of tracking inaccuracies, degradation in optical properties, etc., and inability to precisely model the systems.
3. By the end of FY 1983, four years after operation began, seven out of ten Cycle 1 and Cycle 2 IPH systems were being operated by their respective owners. Owner's attitudes ranged from "marginally satisfied" to "pleased" with energy production.

SOLAR INDUSTRIAL PROCESS HEAT (IPH) PROJECT
TECHNICAL REPORT

October 1982 - September 1983

CHAPTER 1. PROJECT DESCRIPTION

Introduction

This report describes the work accomplished during FY 1983 for eight Solar Industrial Process Heat (IPH) projects supported by the Department of Energy (DOE) and also summarizes the status of completed experiments.*

The IPH Project was begun in 1976 for the purpose of evaluating the use of solar energy in industrial applications. The project consisted of 17 experiments initiated in 4 cycles, with each cycle beginning one year apart. The cycles were for applications using (1) hot air or hot water up to 100°C (212°F), (2) low-temperature steam up to 176°C (349°F), (3) mid-temperature steam up to 268°C (514°F), and (4) hot water at 112°C (235°F) and steam at 218°C (425°F). Cost of Cycle 4 projects was shared by plant owners. Collectors used in the project included flat plates, evacuated tubes, parabolic troughs, and multiple reflectors. Milestones for the project are shown in Figure 1-1.

In 1982, responsibility for administration of these experiments was transferred from the DOE, San Francisco Operations

*Work accomplished during FY 1982 was reported in Reference 1.

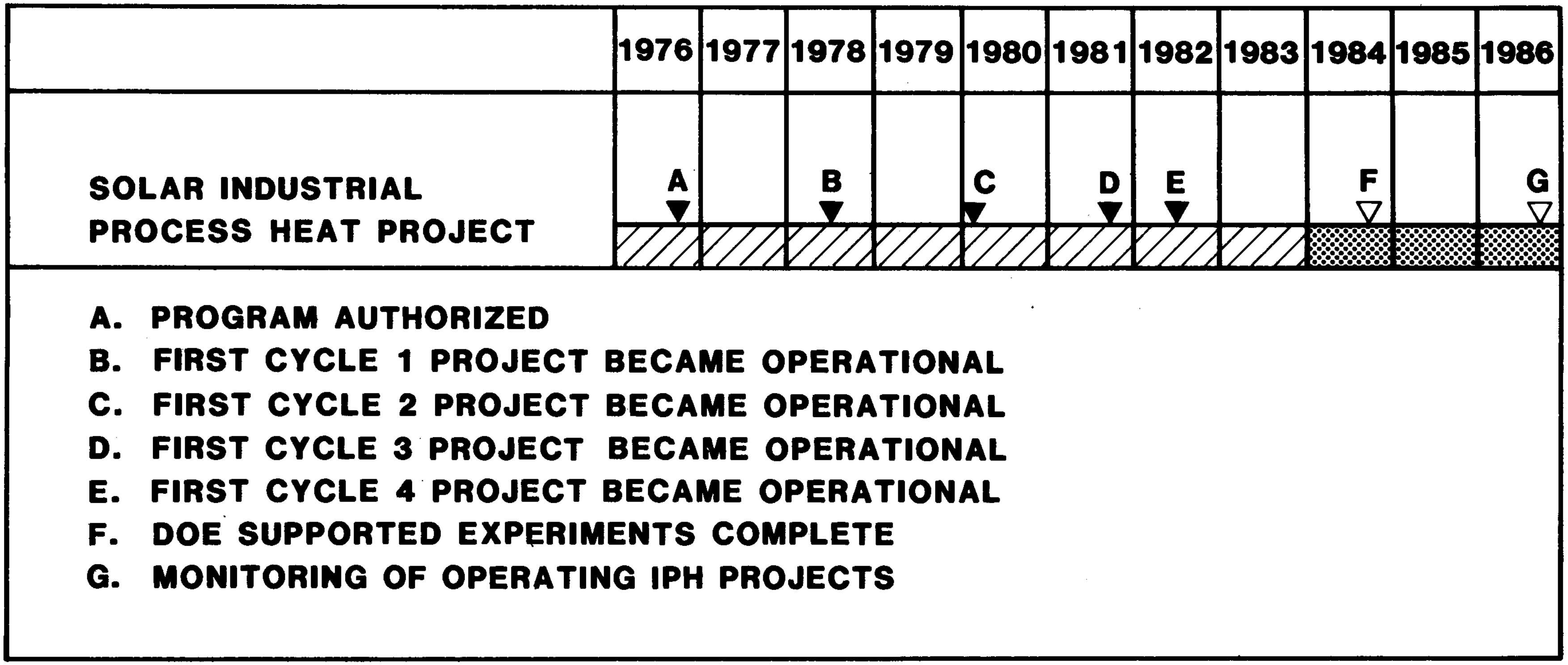

Figure 1-1. Multiyear Milestone Chart

Office (DOE/SAN) to the DOE's Albuquerque Operations Office (DOE/ALO). At the same time, responsibility for the "Thermal System Engineering Experiment," conducted by the Jet Propulsion Laboratory (JPL), California Institute of Technology, under the sponsorship of the National Aeronautics and Space Adminstration, was also transferred to DOE/ALO. This experiment begun in 1980, used a Power Kinetics, Inc. (PKI) 80-m^2 (860-ft^2) square dish collector to generate steam for a concrete block plant. It has been included with the solar IPH project for further followup and reporting purposes.

The experiments, located at industrial sites throughout the country, were to be performed in three phases: design, construction, and operation. Upon completion of the operating phase, normally one or two years, ownership of the solar energy systems was to be transferred to the industrial participants. The systems were to become a continuing source of energy for the industrial plants and to serve as examples of solar energy applications for other prospective users if operation were continued.

Of the 18 experiments, 8 were in the operational phase under DOE funding during part or all of FY 1983, 7 had been completed and the solar equipment transferred to the industrial plant owners who were continuing to operate the systems, and 3 had been discontinued.

FY 1983 was a full year of operation following a year of transition from construction to operation for Cycle 3 and 4 IPH experiments. Emphasis was placed on achieving reliable operation, recording and reporting performance in terms of energy production, and on recording and reporting operating and maintenance (O&M) experience. Equipment problems continued to limit long-term energy production. However, manufacturers worked to solve these problems by improving designs and fabrication processes. Long-term performance increased, maintenance problems decreased, and operation in general approached routine. In addition, a significant effort went into upgrading early prototype equipment to further improve performance and reliability.

Objectives

The objective of the Solar IPH Project is to evaluate the technical feasibility of solar thermal energy for industrial process heat applications. To accomplish this objective, solar IPH systems have been installed at industrial sites and are being operated in experiments to provide long-term (at least one year) data on performance, operation, and maintenance. The objectives of these experiments are to evaluate actual performance against predicted performance and to determine the extent and cost of their operation and maintenance. Additional objectives include the following:

(1) to evaluate solar energy systems in an industrial environment

(2) to assist in the establishment of an engineering and manufacturing base in solar energy in the private sector, and

(3) to gain experience in the application of solar energy to industrial processes

These objectives have been partially achieved. First, systems have been evaluated in an industrial environment. However their performance is lower than predicted. Energy production was less than originally predicted because (1) collector field performance was lower than expected and (2) system downtime caused by equipment malfunction, both solar and nonsolar, was substantial. Also, early performance prediction techniques were inadequate. The lessons learned from this work indicate that continued research in system engineering, design, and production control is necessary.

Second, a private sector base for marketing industrial solar energy systems has been established. At least one privately funded system has been installed and is operating. Not all of the companies that formed this base, however, have survived, and as experimental projects wind down, the ability of those that have survived to continue becomes more tenuous.

Finally, experience has been gained in the application of solar energy to industrial processes. It has been confirmed that solar energy can be applied to industrial processes but that to gain acceptance, long-life, low-cost, reliable systems are needed.

Since 1976, the immediate or short-term need for solar energy has been lessened by a general reduction in energy usage through conservation measures and by an increased availability of fossil fuels. However, as stocks of fossil fuels are depleted, the long-range need for solar energy remains unchanged. Administration policies bringing the development of solar energy systems back into the laboratory at a considerable savings in money make sense. Gaging their development to a longer term when solar energy will be able to compete in the energy market provides time to be more thorough and complete in the development process.

Experiment Descriptions

The experiments break down into three categories: (1) projects operated during the year under DOE sponsorship, (2) projects completed previously that are continuing to be operated by their industrial owners, and (3) projects completed previously that have been terminated for various reasons.

A brief description and status are provided in this summary for each of the experiments. Experimental results are provided in subsequent chapters for those experiments that were active under DOE funding during FY 1983. Because performance data and O&M cost data are not maintained for the experiments that have been completed, no further information on them is provided in subsequent chapters.

DOE-Sponsored Experiments

Operation, data collection, and reporting improved during FY 1983 for the projects supported by DOE funding. During the year, equipment problems were being solved and corrective action was being initiated. Upgrades were negotiated with contractors for the purpose of correcting equipment problems by the time DOE participation ends. However, only those systems were upgraded that were justified by a potential for economical system operation and by an indication from the industrial participants of a willingness to continue operating their systems. Two of the projects, Capitol Concrete Products and Ore-Ida Foods, were completed during the year.

The eight solar industrial process heat experiments discussed in this section are first compared and then briefly described. A detailed description of the solar energy systems used in the experiments and performance predictions for each may be found in Reference 1.

The experiments are located throughout the United States in different climatic regions and at different latitudes. The experiment at Lone Star Brewery in San Antonio, TX, 29°32'N, is located at the most southern latitude of all the experiments. The one at Ore-Ida Foods, located in Ontario, OR, 44°01'N, is at the northernmost latitude.

Caterpillar Tractor in San Leandro, CA and Home Laundry in Pasadena, CA represent Pacific coast climates; Dow Chemical (Dalton, GA) and USS Chemicals (Haverhill, OH) represent climates typical to the eastern part of the country. Southern

Union Refining Co. in Lovington, NM is located in the high insolation, southwestern desert region; Capitol Concrete, representing a midwestern climate, is located in Topeka, KS.

Steam for an industrial process is the output of most of these experiments. The steam conditions range from 380 kPa/ 150°C (55 psia/302°F) to 2,100 kPa/214°C (305 psia/417°F). The exceptions are Caterpillar Tractor, which produces slightly pressurized process hot water at 113°C (235°F), and Home Laundry, which is configured to produce either steam or domestic hot water.

All of the collectors are line-focus parabolic troughs except for the Capitol Concrete collector, which is a point-focus square dish. Most of the collector fields have total collector aperture areas of approximately 900 m^2 (10,000 ft^2). Two systems are smaller--the Capitol Concrete collector, which is 80 m^2 (860 ft^2) and the Home Laundry system, which is 604 m^2 (6,501 ft^2). Two larger systems are at Caterpillar Tractor and USS Chemicals, both having approximately 4,700 m^2 (50,400 ft^2) of aperture area.

The collector fields have their tracking axes aligned in a north-south direction except for the Southern Union Refining field, which has an east-west orientation. Slight deviations from a true north-south field are found at Ore-Ida Foods, Caterpillar Tractor, and USS Chemicals where the systems are aligned with the industrial plant layout. All collector fields are located at ground level except for the Capitol Concrete, Caterpillar Tractor, and Lone Star Brewery systems, which are roof-mounted. Elevated structures were built for the Capitol Concrete and Home Laundry systems.

For half of the experiments, the heat-transfer fluid in the collector field is oil. It is used in a closed-loop configuration at Dow Chemicals, Lone Star Brewery, Southern Union

Refining Co., and USS Chemicals. The oil transfers heat to unfired steam generators in each case.

The others use pressurized water as the collector-field heat-transfer fluid. Home Laundry circulates water in a closed loop through the collector field to an unfired boiler where water from a second loop is heated to produce either steam or hot water. The remaining water systems are open-loop configurations. Ore-Ida Foods uses boiler feedwater in the collector loop, and steam is produced in a flash tank steam generator. At Capitol Concrete, process steam is produced directly in the collector receiver. At Caterpillar Tractor hot water is produced directly in the solar field and then returned to the plant hot water supply system.

Status and descriptions of these experiments are contained in the following sections. The sizes and operating temperatures of six of the experiments that operated throughout the year are shown in Figure 1-2.

<u>Capitol Concrete Products</u> -- The solar IPH experiment at Capitol Concrete Products, Topeka, KS, initiated by JPL as the "Thermal System Engineering Experiment" (see Introduction) was completed in December 1982. The solar equipment was transferred to the site owner, and a final report was issued during FY 1983. The system uses a PKI 80-m^2 (860-ft^2) square dish collector to generate steam for a concrete block company. After the system was transferred to the owner, it was damaged by freezing and was shut down. In the spring of 1983, the system was repaired and put back into operation. A low-cost contract was negotiated with the owner to report monthly energy production and operation and maintenance data. Energy production for the last quarter of FY 1983, limited by weather and some downtime for maintenance, was 13,600 kg (30,000 lb) of steam. Based on measured data from the verification test performed in 1981, the system should have an average thermal

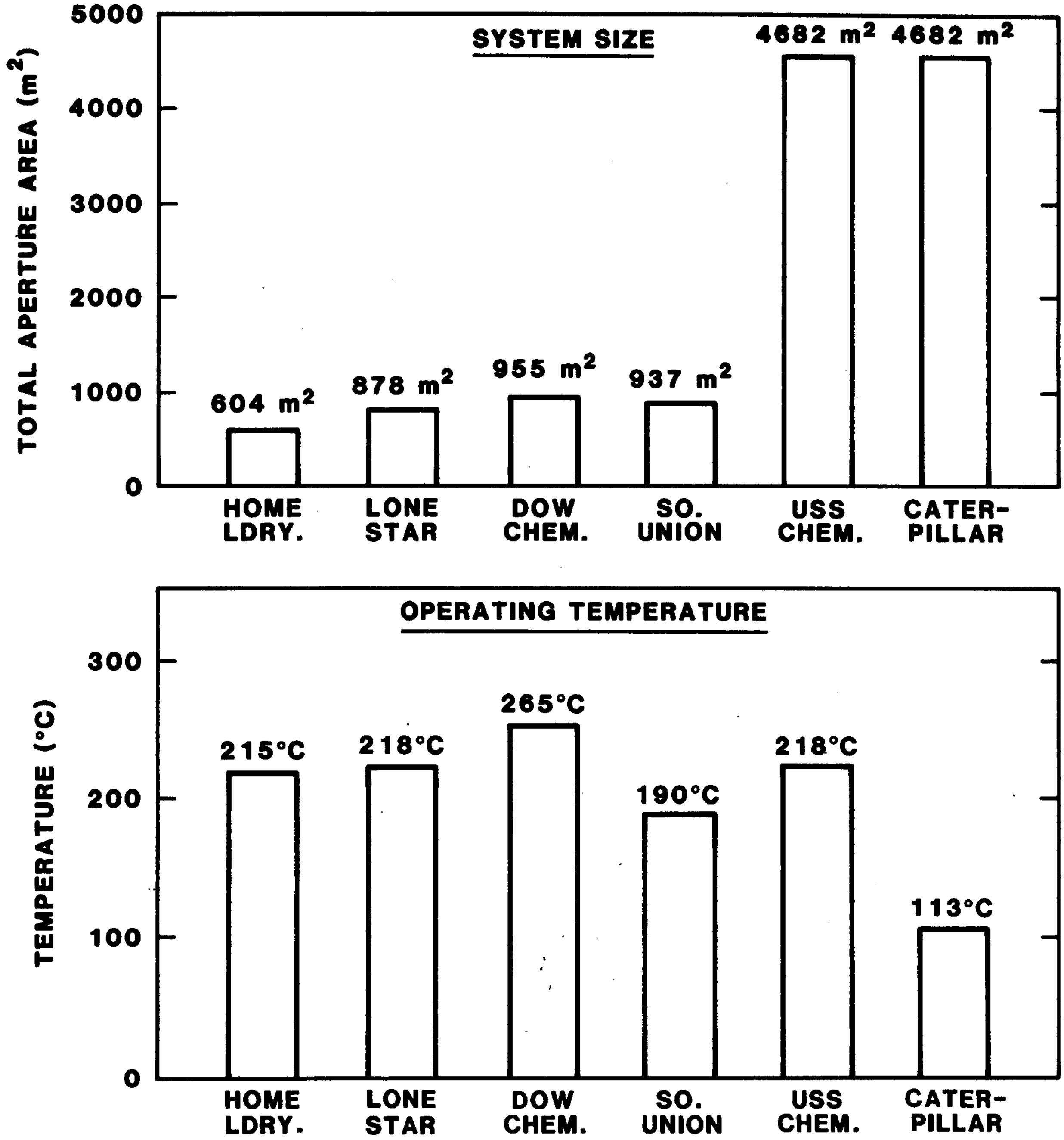

Figure 1-2. IPH Experiments Size and Operating Temperature

efficiency of 69% and should produce 495 kg (1,100 lb) of steam per 10-hour day for insolation levels above 0.6 kW/m^2 (190 Btu/ft^2 hr).

The experiment was operated by Applied Concepts Corporation, in conjunction with PKI and Capitol Concrete Products, Inc. It involves a single PKI collector that provides industrial process steam for the plant (Figure 1-3). The steam is supplied to an autoclave used to produce masonry block. The plant is in operation 5 days per week, 50 weeks per year.

Steam is supplied from the collector to the process at 207 to 414 kPa (30 to 60 psig) at a maximum rate of 0.025 kg/s (200 lb/h). This steam augments that supplied from a 250 hp or 1.06 kg/s (8,400 lbm/h) fossil-fuel boiler that operates on natural gas or oil at an 80% efficiency. There is no thermal energy storage.

The collector and associated flow and control system were designed by PKI. It consists of 864 flat, 0.09 m^2 (1-ft^2), second-surface, silvered glass mirrors. The mirrors are affixed to rows of movable curved supports. Each mirror assembly rotates about a horizontal axis through its center of gravity to provide elevation tracking. The collector has a total aperture area of 80.2 m^2 (864 ft^2).

The collector is supported by a lightweight spaceframe structure. The base of the structure is a circular track, inverted to eliminate problems of dirt and ice build-up. The track rests on wheels mounted on concrete piers and is motor-driven by a simple sprocket-and-roller chain assembly. The rotation of the entire collector on its base provides azimuthal tracking.

A well-insulated galvanized steel receiver is mounted on a boom at the focal point of the concentrator. Boiling takes

Figure 1-3. Solar Energy Collector at Capitol Concrete Products Inc., Topeka, Kansas

place within the receiver. A variety of receivers appropriate for specific applications has been tested including monotube and parallel-tube configurations. The entire collector system is located on top of a storage shed adjacent to the autoclave.

The Capitol Concrete system is a single-fluid system passing boiler feedwater directly to the receiver and extracting process steam at its outlet. The typical operating temperature of the receiver is 140°C (285°F). The annual energy delivery goal of the system is 106 GJ/yr (100 MBtu/yr).

Table 1-1 is a summary of the design characteristics of this system. A schematic of the system is shown in Figure 1-4. The system is described in detail in Reference 2.

Table 1-1

Capitol Concrete Products Characteristics

Application:	Steam for autoclaves or boiler preheat.
Site:	Topeka, KS; 39°04'N latitude, 95°40'W longitude.
Process schedule:	Variable shift, 5 days/wk, 50 wk/yr.
Process load profile:	79.2 GJ/h (75 MBtu/h) (est. max)
Fuel:	Natural gas, boiler efficiency 80%.
Collector:	PKI 80-m^2 square dish; collector area = 80 m^2 (860 ft^2)
Fluid type, flow rate:	Water on demand (level switch) from boiler/receiver.
Storage:	None. Conventional boiler acts as storage in preheat mode.
Design energy delivery:	Experimental plant. Goal = 106 GJ (100 MBtu) per year annual rate.
Cost:	Design and construction: $527,000; plant cost not considered as separate item.

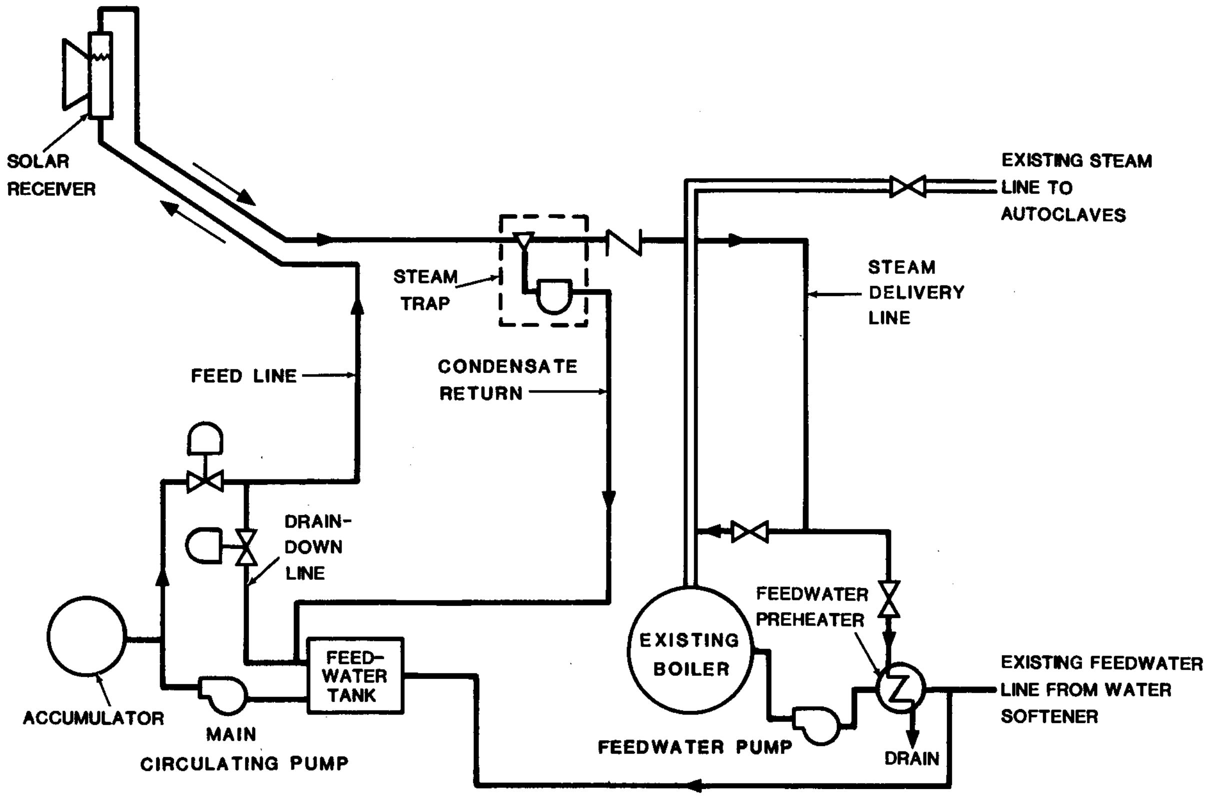

Figure 1-4. Schematic of the Solar Energy System - Capitol Concrete Products

Caterpillar Tractor Co. -- The solar IPH experiment at Caterpillar Tractor Co., San Leandro, CA, a Cycle 4 project conducted under a cooperative agreement with Southwest Research Institute, was nonoperative at the beginning of FY 1983 while awaiting modifications to the solar equipment. The system, which uses Solar Kinetics, Inc. (SKI) T-700 parabolic-trough collectors, was accepted in February 1983. Subsequent to acceptance, the system operated consistently throughout the rest of FY 1983 with an average thermal efficiency of 34%.*

*Energy delivered to the plant divided by the beam component of the solar energy incident in the plane of the collectors when the system is operating. Efficiency numbers shown in this section are based on data reported by the prime contractors. They are averages for periods of operation. System efficiencies are discussed fully in Chapter 2.

During much of the year, however, the capacity of the solar energy system exceeded the demand from the plant as a result of production cutbacks. During this period, as little as one-third of the solar field was able to meet plant energy demand.

The system (Figure 1-5) is one of two large-scale solar energy industrial process heat systems. It was designed and built by Southwest Research Institute and is operated by Caterpillar Tractor personnel. The system supplies solar-heated process hot water for washing tractor parts.

The system was originally designed to provide 55% of the plant's 7 day/wk energy requirements. As a result of production cutbacks, the time and amount of energy usage have been considerably reduced for the last year. Therefore only part of the solar energy system is used at one time. It supplies most of the process heat required by the plant.

The system supplies hot water to supplement a natural gas-fired boiler. No thermal energy storage is incorporated in the system. Its potential annual output as predicted by computer modeling is 11,430 GJ/yr (10,830 MBtu/yr).

The solar field consists of 4,700 m^2 (50,400 ft^2) of SKI T-700 parabolic-trough collectors. The collectors are mounted with their tracking axes oriented 22° east of north on the roof of the building in which the collected energy is used.

Feedwater enters the collector field at 91°C (195°F) and leaves at 113°C (235°F). After leaving the collector field, the water passes through a fossil-fired boiler for additional heating when necessary.

The design characteristics of this sytem are summarized in Table 1-2. A schematic diagram of the system is shown in Figure 1-6.

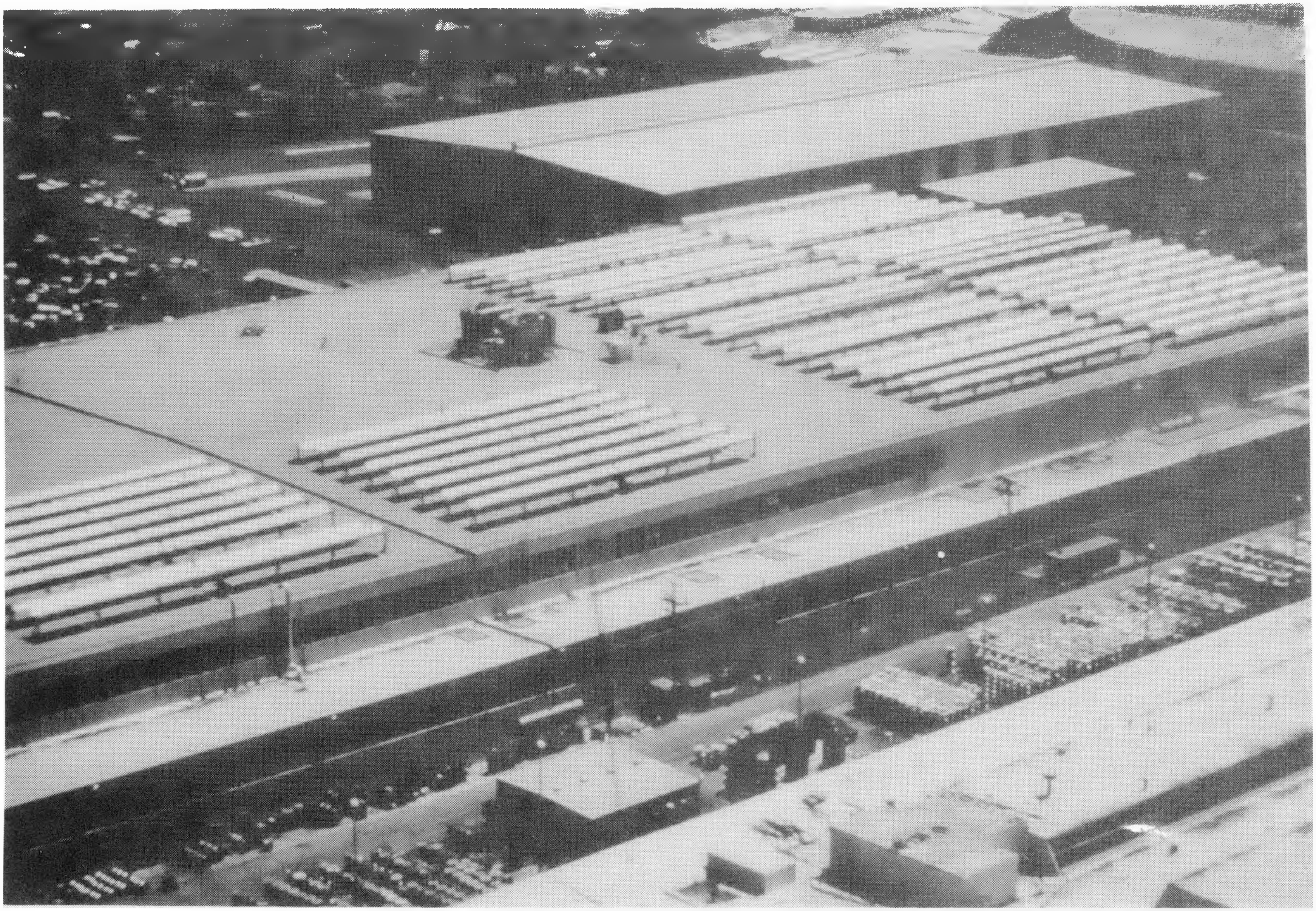

Figure 1-5. Solar Collector Array at Caterpillar Tractor Company, San Leandro, California

Table 1-2

Design Characteristics - Caterpillar Tractor Co.

Application:	Preheat of process hot water for parts washing.
Site:	San Leandro, CA; 37°44'N latitude, 122°15'W longitude, Elevation = 33 m (108 ft).
Process schedule:	Peak energy requirement is 9.5 GJ/h (9×10^6 Btu/h) of hot water at 113°C (235°F). The solar system will deliver a maximum of 9.08 GJ/h (8.6 MBtu/hr).
Auxiliary fuel:	Natural gas.
Collectors:	4,700 m^2 (50,400 ft^2) of SKI tracking, parabolic line focus, T-700 collectors. Roof mounted, horizontal on axis 22° east of north. 30 ΔT strings @ 73 m (240 ft) per string. 60 drive strings (2 per row). (North field, 1,250 m^2 [13,440 ft^2]; south field, 3,437 m^2 [36,960 ft^2]).
Fluid type, flow rate:	Treated water, north field - 2.05×10^{-2} m^3/s (330 GPM), south field - 7.57×10^{-3} m^3/s (120 GPM).
Design energy delivery:	12,239 GJ/yr (11.6×10^9 Btu/yr), 78.2 GJ/day (74.1 MBtu/day), 8.7 GJ/hr (8.2 MBtu/hr) (updated).
Phase 1 cost (design):	$143,045
Phase 2 cost (construction):	$2,827,680

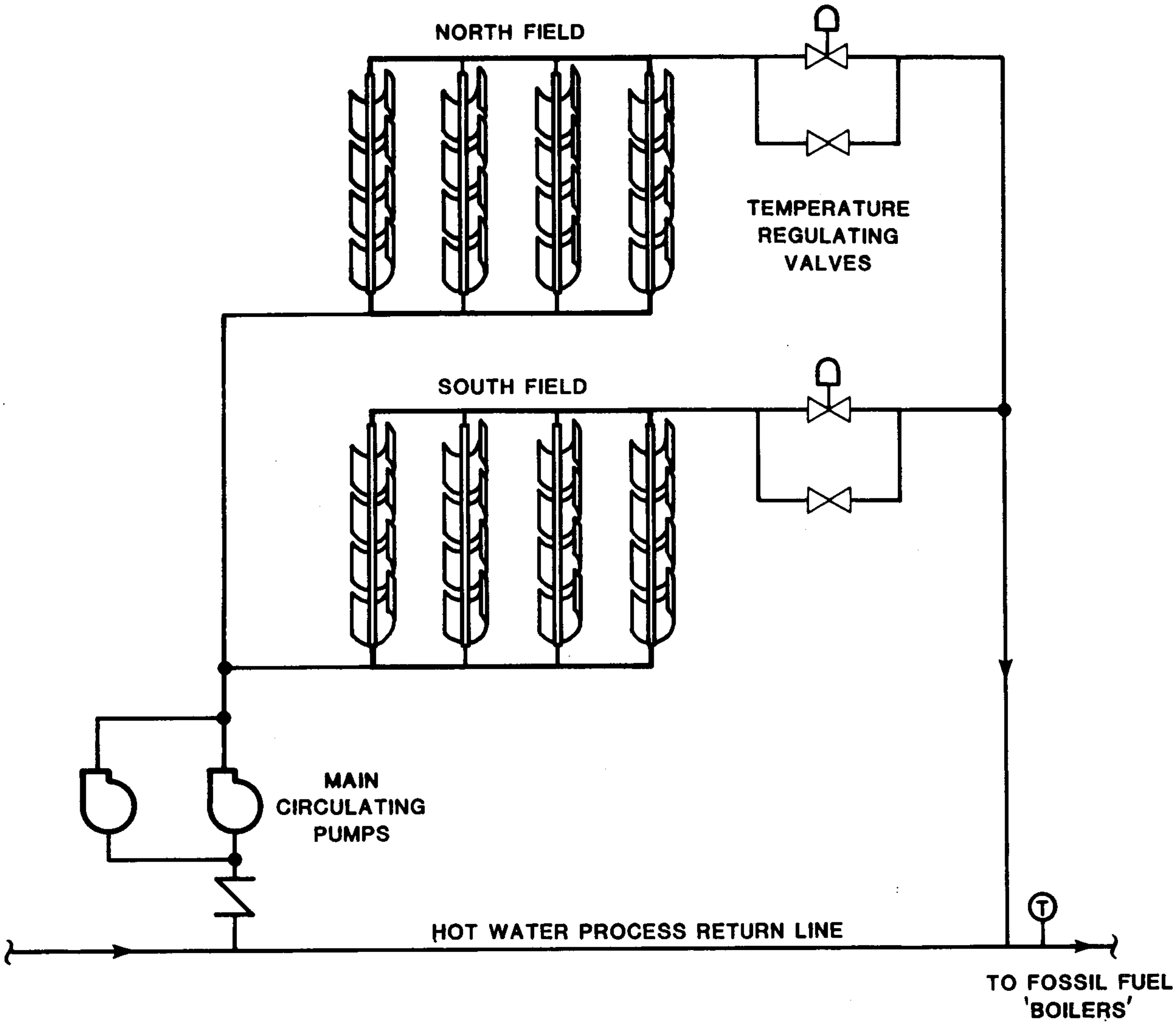

Figure 1-6. Schematic of the Solar Energy System - Caterpillar Tractor Co.

Dow Chemical Co. -- The solar IPH experiment at Dow Chemical Co., Dalton, GA, a Cycle 3 project, was in the operational phase throughout FY 1983. Problems with the data acquisition system prevented collecting and reporting performance until January 1983. Performance was measured and reported from February through August 1983. Average system thermal efficiency for this period was 19%. In September 1983 the system was shut down to replace the piping insulation and to modify the pipe supports. These modifications were made to reduce thermal losses.

Foster Wheeler Development Corporation operates the system (Figure 1-7) at Dow Chemical Co. The system provides process steam for latex production at the plant. Solar-produced steam supplements an existing boiler supplying a 24 h/day, 365 days/yr demand.

The system provides 1,034-kPa (150-psig) steam at a maximum rate of 684 kg/h (1,500 lb/h). It was designed to provide 5% of the energy required for the plant's stripping process. The remainder is supplied by boilers fired with natural gas or fuel oil. No thermal energy storage was included in the system design. Computer simulation studies indicate that the system will produce 4,755 GJ/yr (4,455 MBtu/yr) when operated every day.

The collector field consists of 929 m^2 (10,000 ft^2) of Suntec Systems, Inc. parabolic-trough collectors. They are located in a 10° sloping field with their tracking axes oriented in the north-south direction.

The heat-transfer fluid is Dowtherm LF. It is circulated through the collector field at a rate of 3.28×10^{-3} m^3/s (52 GPM). Under maximum insolation conditions the fluid leaves the collector field at 240°C (464°F). The heat-transfer fluid is then passed through an unfired kettle boiler where the process steam is generated.

A summary of the system design characteristics is presented in Table 1-3. A schematic is shown in Figure 1-8.

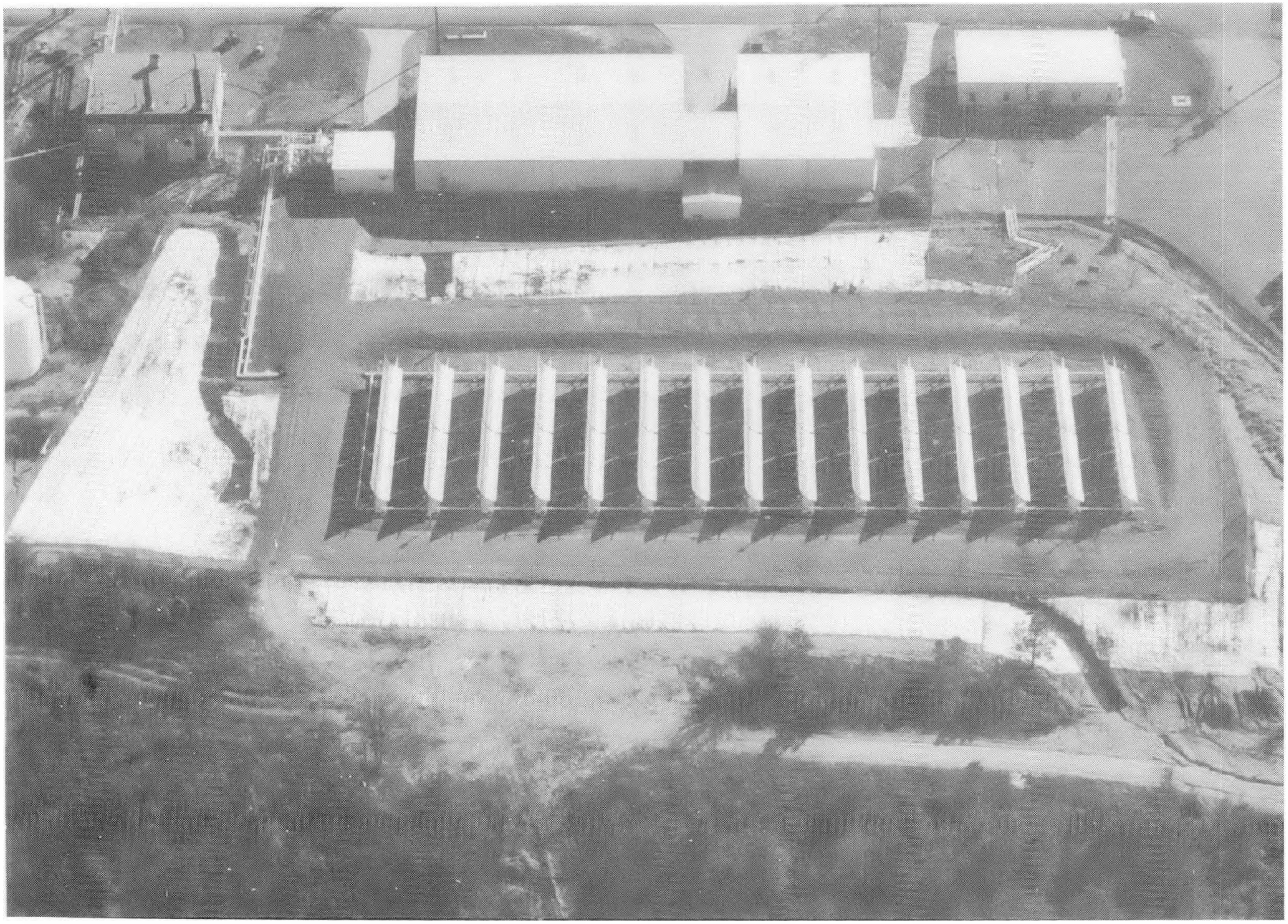

Figure 1-7. Solar Collector Array at Dow Chemical Company, Dalton, Georgia

Table 1-3

Design Characteristics - Dow Chemical Co.

Application:	Generation of process steam for latex production
Site:	Dalton, GA; 34° 43' N latitude, 84° 53' 6" W longitude, elevation = 37 m (122 ft)
Process schedule:	24 h/day; 365 day/yr
Process load profile:	Average steam consumption is 5,004 kg/h (11,000 lb/h). The maximum steam rate is 9,080 kg/h (20,000 lb/h) with intermittent peaks to 11,350 kg/h (25,000 lb/h). The solar steam system will produce a maximum of 684 kg/h (1500 lb/h).
Auxiliary fuel:	Natural gas and No. 2 fuel oil; boiler efficiency = 70%
Collectors:	15 rows of Suntec Systems, Inc., parabolic-trough, line-focus concentrating collectors. North-south orientation with a 10° tilt to the south. Collector total aperture area = 929 m^2 (10,000 ft^2). Field gross area = 2,093 m^2 (22,525 ft^2). Packing factor = 0.44.
Fluid type, flow rate:	Dowtherm LF at constant flow rate of 3.28×10^{-3} m^3/s (52 GPM)
Design energy delivery:	2677 GJ/yr (2536 MBtu/yr)
Phase 1 cost (design):	$190,389
Phase 2 cost (construction):	$993,912

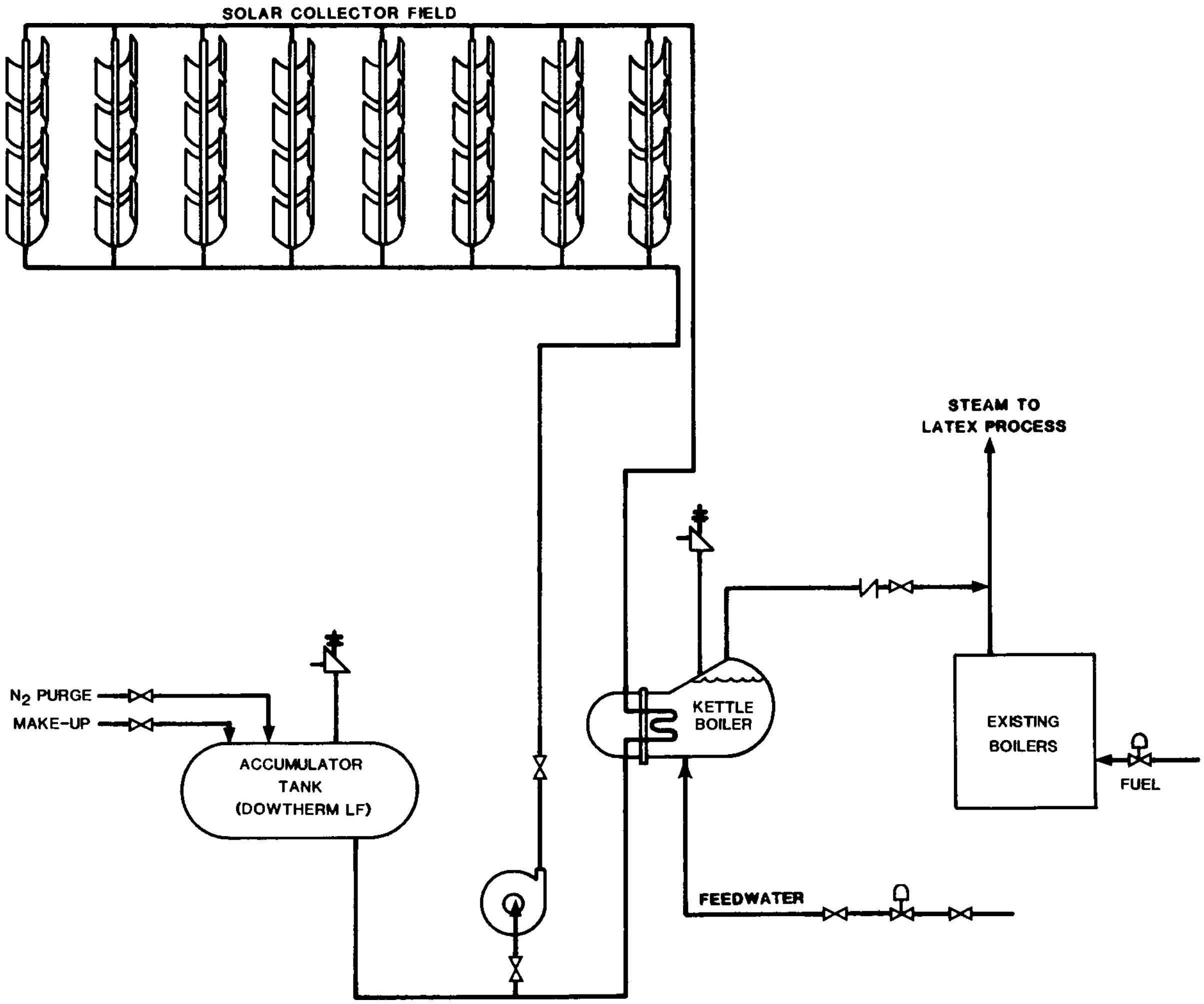

Figure 1-8. Schematic of the Solar Energy System - Dow Chemical Co.

Home Laundry -- The solar IPH experiment at Home Laundry, Pasadena, CA, (Figure 1-9) a Cycle 2 project, began its operational phase in October 1982. At that time the system, which uses Del Manufacturing Co. parabolic-trough collectors, was operating well. However, problems with the data acquisition system prevented collecting and reporting good performance data until February 1983. The system operated throughout the year producing hot water and steam, the choice depending on demand from the laundry. During this period, the thermal efficiency for the system averaged 32%. The DOE contract expired in September 1983, the laundry moved to a different building, and operation of the IPH system was discontinued.

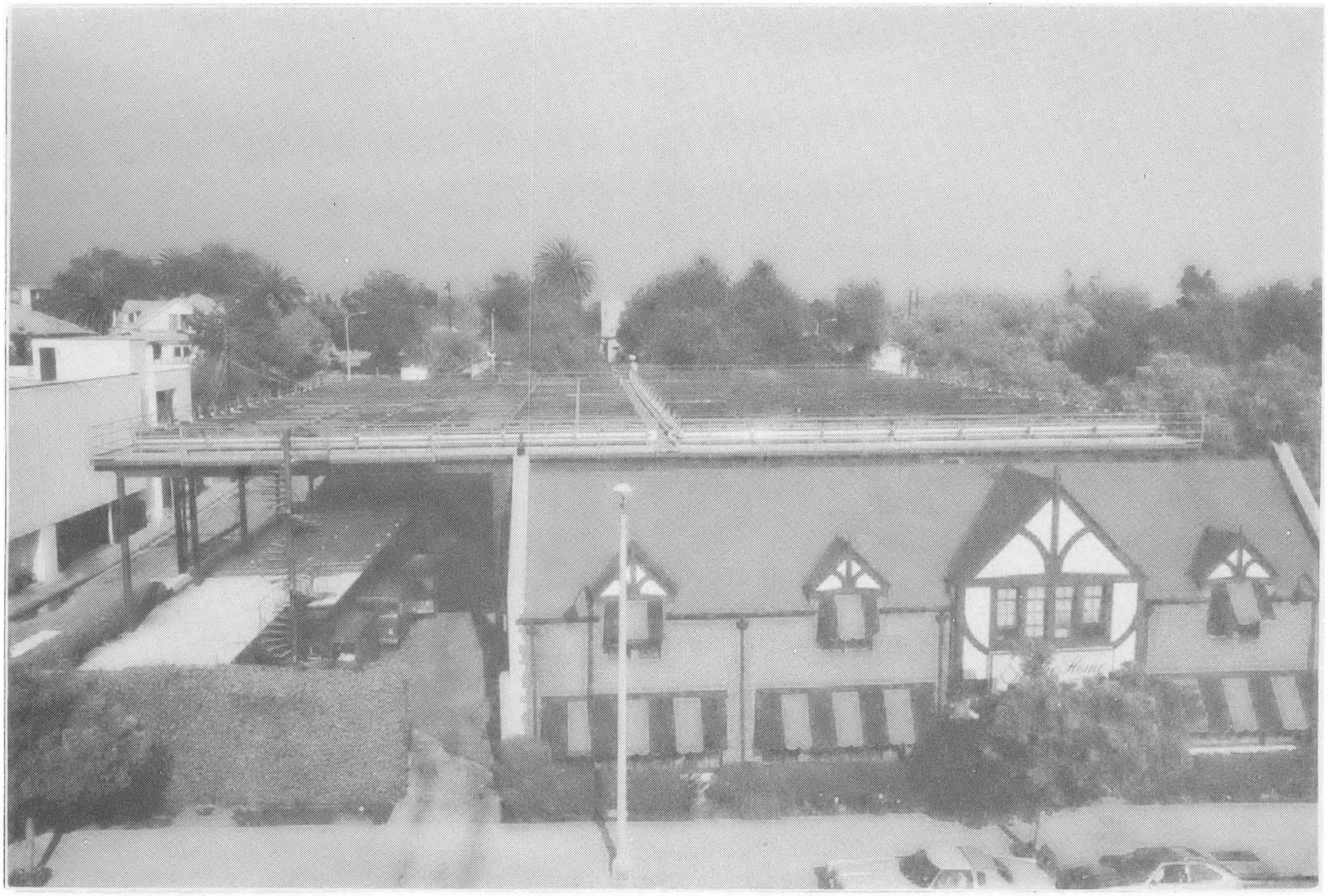

Figure 1-9. Solar Collector Array at Home Laundry, Pasadena, California

The IPH system was operated by Jacobs Engineering Group Inc. It was designed to supply either steam or hot water. The steam was used by Home Laundry for pressing clothes, the hot water for laundering operations. The plant operated from 7 a.m. to 3:30 p.m., Monday through Friday.

The system was sized to supply 20% of the laundry's thermal energy demand. The design flow rate was 424 kg/h (935 lb/h) of 758 kPa (110 psig) steam under maximum insolation conditions. In the hot water mode, it produced 71°C (160°F) water. A small, 1.13-m^3 (300-gal) thermal storage tank was provided as a buffer storage providing some preheating energy for early morning operations. When fully charged, the storage supplied about one hour's demand.

Small, sagged-glass mirror collectors manufactured by Del Manufacturing Company were used. The collector field contained 406 collector modules for a total aperture area of 604 m^2 (6,496 ft^2). The field was mounted at roof height on a steel frame structure, with the collector tracking axes in the north-south direction.

The Home Laundry system is a closed-loop system that used pressurized water as a heat-transfer fluid in a loop separate from the boiler steam loop. Water in the collector loop is pressurized to 1,655 kPa (240 psig) and flows at a constant rate of 4.4×10^{-3} m^3/s (69 GPM). It attains a maximum temperature of 210°C (410°F) in the collector loop. Computer simulations show that the total amount of energy delivered by this system in a year should be 776 GJ/yr (736 MBtu/yr) when producing steam, and 980 GJ/yr (929 MBtu/yr) when providing hot water.

The design characteristics of the system are summarized in Table 1-4. A schematic of the system is shown in Figure 1-10. The system and its operation are described in Reference 3.

Table 1-4

Design Characteristics - Home Laundry

Application:	Production of domestic hot water or 689 to 758 kPa (100 to 110 psig) steam for use in a commercial laundry.
Site:	Pasadena, CA; 34.2°N latitude, 118.2°W longitude
Process schedule:	7 a.m. to 3:30 p.m., Monday-Friday
Process load profile:	8,062 GJ/yr (7,634 MBtu/yr)
Auxiliary fuel:	Natural gas, boiler efficiency = 65%
Collectors:	406 linear parabolic-trough concentrating collectors, second-surface glass mirror reflective surface (Del Manufacturing Company). Total aperture area = 603.5 m^2 (6494 ft^2); Field gross area = 1,489 m^2 (16,019 ft^2); North-south orientation; east-west tracking. Packing factor: 0.405
Fluid type, flow rate:	Water at constant flow rate of 4.4 x 10^{-3} m^3/s (70 GPM) in collector loop; closed loop pressurized to 1.65 MPa (240 psig) at operating temperature.
Storage:	1.13-m^3 (39.9-ft^3) steel tank, 2-in. (5-cm) AP jacketed fiberglass blanket insulation.
Design energy delivery:	1,267 GJ/yr (1,199 MBtu/yr)
Phase 1 cost (design):	$194,000
Phase 2 cost (construction):	$1,351,000

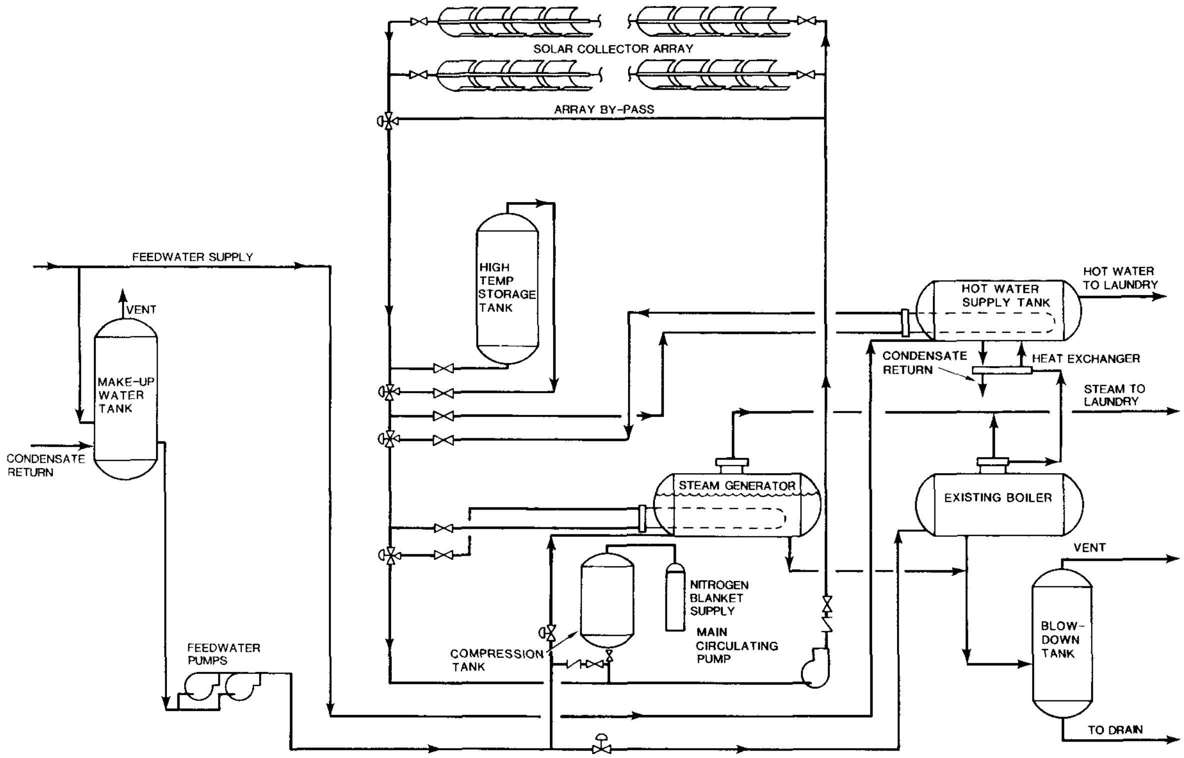

Figure 1-10. Schematic of the Solar Energy System - Home Laundry

Lone Star Brewery -- The solar IPH system at Lone Star Brewery, San Antonio, TX, (Figure 1-11) a Cycle 3 project, operated at reduced capacity from October 1982 through May 1983 with an average thermal efficiency of 17%. Two of fifteen rows of collectors were shut down because of oil leaks and subsequent damage from overheating. The system was shut down completely when additional oil leaks developed and when the DOE contract with Southwest Research Institute, the prime contractor, expired. A final Phase III (Operations) report was issued. Subsequently, the contract was reinstated, and an extensive upgrade was authorized. The upgrade includes converting from an oil-based heat-transfer fluid operating at high temperature to a lower temperature water system and generally improving the solar equipment.

During FY 1983 the IPH system was configured to generate steam used in the manufacturing and bottling of beer. The

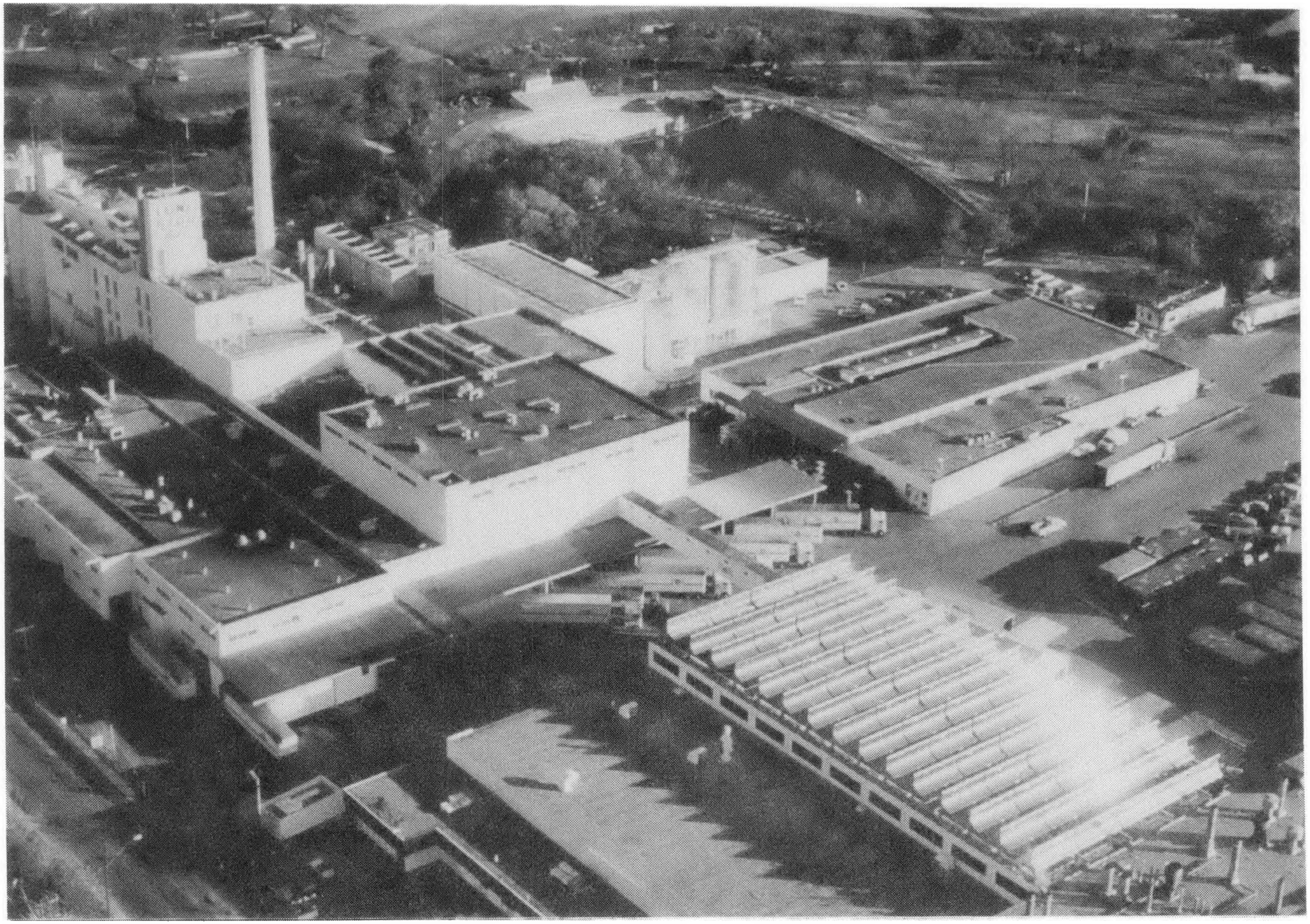

Figure 1-11. Solar Collector Array at Lone Star Brewery, San Antonio, Texas

steam is fed directly into the plant steam header and supplements that produced by natural gas boilers. Steam is required 24 hours per day, all year long.

Originally, the system was designed to produce 862 kPa (125 psig) steam at a maximum flow of 545 kg/h (1200 lb/h), which is about 2% of the maximum plant steam load. There is no thermal energy storage provided in this system.

The collector field consists of 878 m^2 (9,450 ft^2) of SKI T-700 parabolic-trough collectors. These collectors are mounted on the roof of the brewery with their tracking axes oriented in the north-south direction.

Therminol 55 is the heat-transfer fluid in this closed-loop system. It flows through the collector loop at 3.76×10^{-3} m^3/s (75 GPM) and attains a maximum temperature of 218°C (425°F) under maximum insolation conditions. The heat-transfer fluid was subsequently changed to water to eliminate concerns about leakage of heat-transfer oil leaking on the roof.

Computer simulation studies indicate that the annual energy contribution should be approximately 1,378 GJ/yr (1,306 MBtu/yr).

The design characteristics and flow paths are summarized in Table 1-5 and Figure 1-12, respectively. The system and its operation are described in Reference 4.

Table 1-5

Design Characteristics - Lone Star Brewery

Application:	Generation of steam to supplement existing facility.
Site:	San Antonio, TX; 29° 32' N latitude, 98° 28' W longitude; Elevation = 794 ft.
Process schedule:	Average steam requirement is 22,700 kg/h (50,000 lb/h) of which the solar system will provide a maximum of 545 kg/h (1,200 lb/h).
Auxiliary fuel:	Natural gas; boiler efficiency = 70%.
Collectors:	878 m^2 (9,450 ft^2) of Solar Kinetics tracking, parabolic, T-700 collectors. Roof mounted: horizontal with N-S axis of rotation; 15 rows at 27.4 m (90 ft) per row; Packing factor = 0.46.
Fluid type, flow rate:	Therminol flowing at a fixed rate of 4.74×10^{-3} m^3/s (75 GPM) generating steam which flows into an existing main steam header.
Design energy delivery:	3,379 GJ/yr (3.2×10^9 Btu/yr)
Phase 1 cost (design):	$107,795
Phase 2 cost (construction):	$690,900

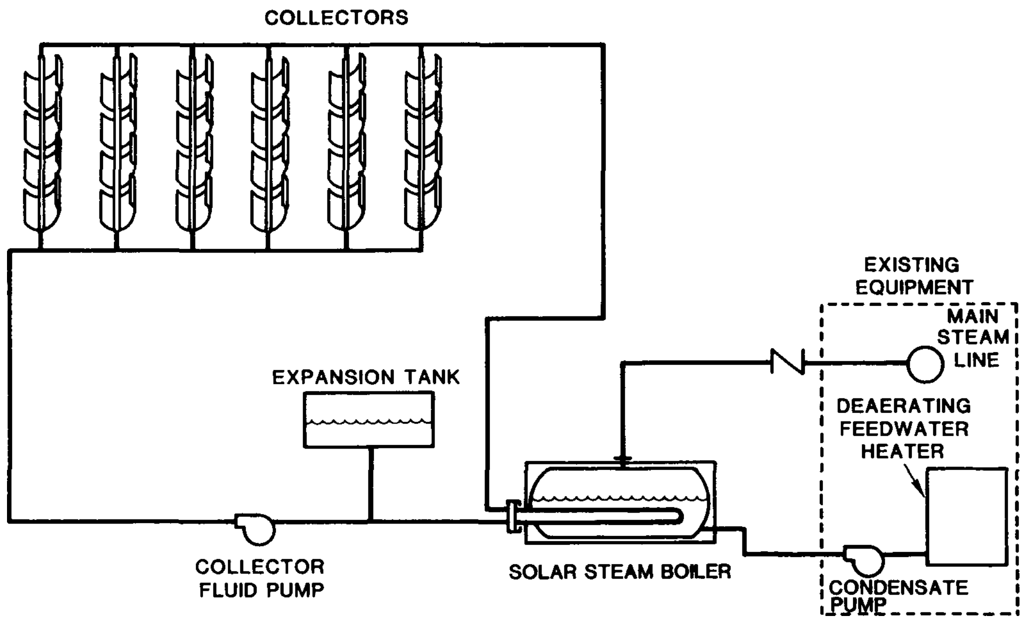

Figure 1-12. Schematic of Solar Energy System - Lone Star Brewery

Ore-Ida Foods -- The solar IPH system at Ore-Ida Foods, Ontario, OR, (Figure 1-13) a Cycle 3 project, used parabolic-trough collectors to generate steam to provide heat for frying onions and potatoes. The acceptance test was performed in June 1981. Subsequently, it operated sporadically until the project was discontinued in March 1983. Problems with the main circulating pump and a flex-hose failure caused the system to be shut down for long periods. When the Phase III contract expired in March 1983, upgrade was considered but was declined because the value of the energy savings did not justify the cost of repairs.

TRW Energy Development Group built the solar process heat system at Ore-Ida Foods, Inc. The system provides high-temperature steam that is used to heat frying oil in a potato fryer. The fryer is operated intermittently, 24 hours per day, 5 or 6 days per week.

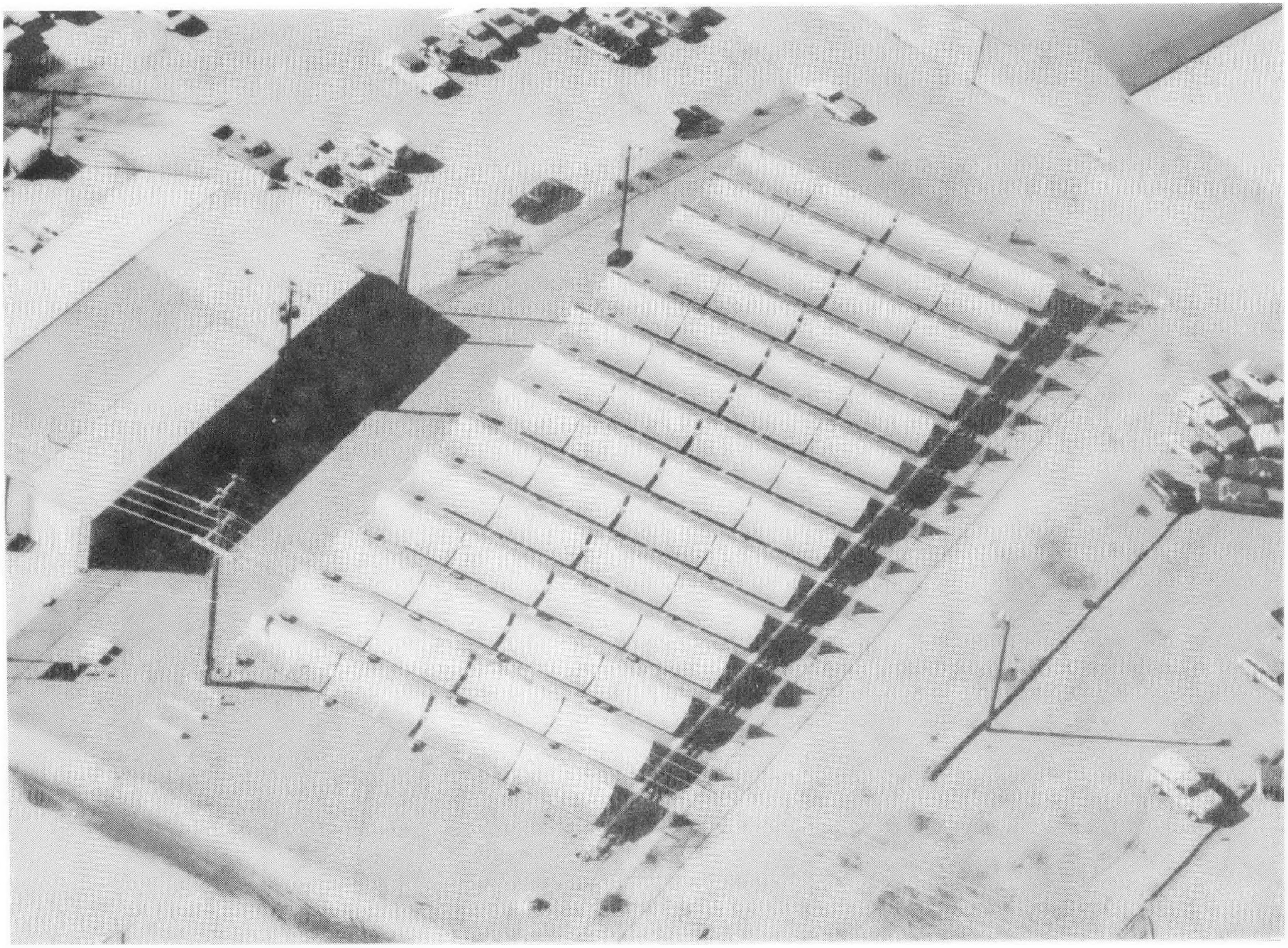

Figure 1-13. Solar Collector Array at Ore-Ida Foods, Ontario, Oregon

The maximum output of the solar energy system is 0.243 kg/s (1,930 lb/h) of 2,069-kPa (300-psig) steam. The estimated annual output of the system is 1,131 GJ/yr (1,072 MBtu/yr) based on computer model studies. There is no storage incorporated into the system.

Suntec Model SH1655 collectors with a total aperture area of 929 m^2 (10,000 ft^2) are used in the system. The collector field is at ground level with the tracking axes oriented 11° west of north.

The system is open-loop with water pressurized to 4137 kPa (600 psig) used as the heat-transfer fluid. After being heated to a maximum temperature of 250°C (480°F) in the collector field, the water is flashed to 2069 kPa (300 psig) steam at a flash tank steam generator.

A summary of the design characteristics is given in Table 1-6. A system schematic is shown in Figure 1-14. The system and its operation are described in Reference 5.

Table 1-6

Design Characteristics - Ore-Ida Foods

Application:	Steam at 2.069 MPa (300 psia) to heat cooking oil in a heat exchanger. The cooking oil is used to fry potatoes.
Site:	Ontario, OR; 44°01' N latitude, 116°58' W longitude.
Process schedule:	24 h/day, 6 days/wk, August to December; 5 days/wk, January to July.
Process load profile:	869 kg/h (1,930 lbm/h) steam at 2.069 MPa (300 psia), 214°C (417°F).
Auxiliary fuel:	Natural gas
Collectors:	Fourteen rows of Suntec Model SH1655 parabolic trough collectors with a gross aperture area of 929 m^2 (10,000 ft^2) and an effective area of 856 m^2 (9,212 ft^2). Mounted on ground, rotation axis 11° ccw of north-south.
Fluid type, flow rate:	Pressurized water at 4.137 MPa (600 psia); 10,433 kg/h (23,000 lbm/h).
Storage:	None
Design energy delivery:	2,743 GJ/yr (2.6 x 10^9 Btu/yr) or 1% of annual process demand
Phase I cost (design):	$239,000
Phase II cost (construction):	$1,350,000

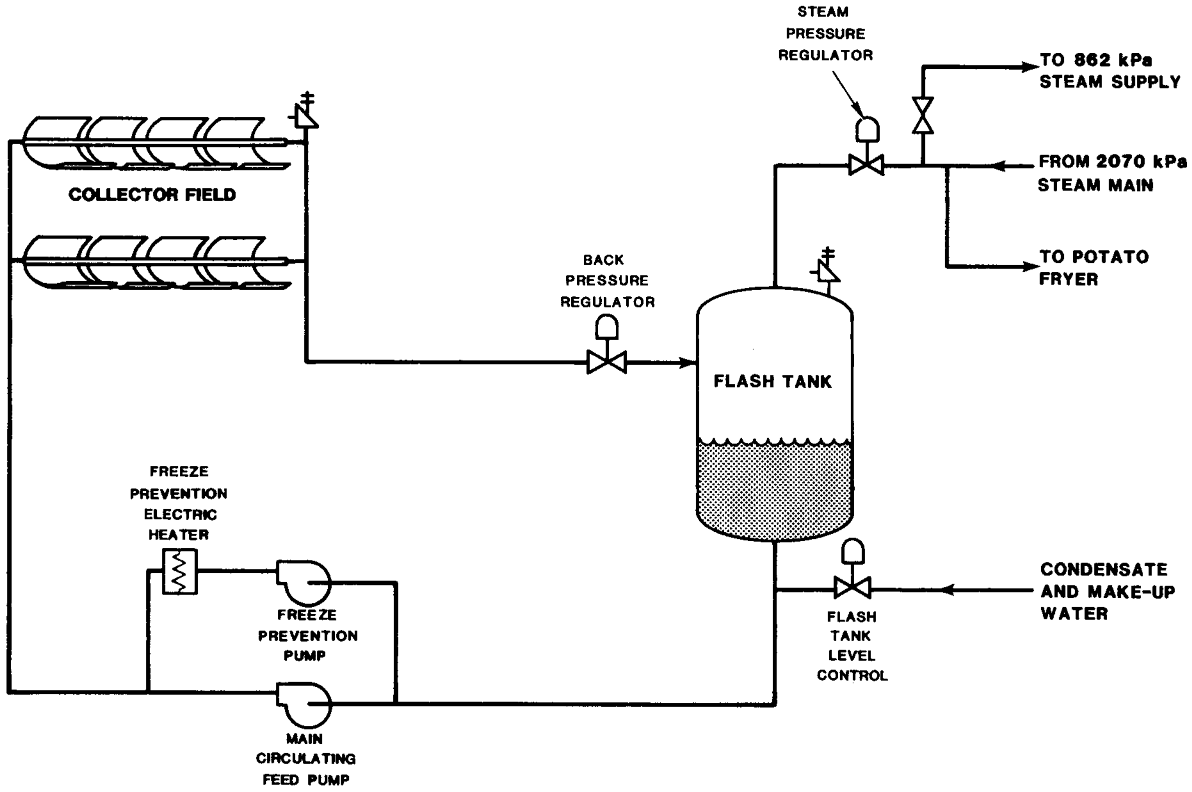

Figure 1-14. Schematic of Solar Energy System - Ore-Ida Foods

Southern Union Refining Co. -- The solar IPH system at Southern Union Refining Co., Lovington, NM, (Figure 1-15) a Cycle 3 project, was in the operational phase throughout the year. The system experienced many equipment problems, but energy production was reported from October 1982 to August 1983. During this period, the average system thermal efficiency was 19%. In September, the system was shut down for an extensive revision to the collector field piping. A system upgrade was authorized to correct solar equipment problems. The upgrade was in process at the end of the fiscal year.

The Energetics Corporation operated the solar steam system at the Southern Union Refining Company. The steam is supplied to the refinery processes, forming a small portion of the total steam used in the petroleum refining operations.

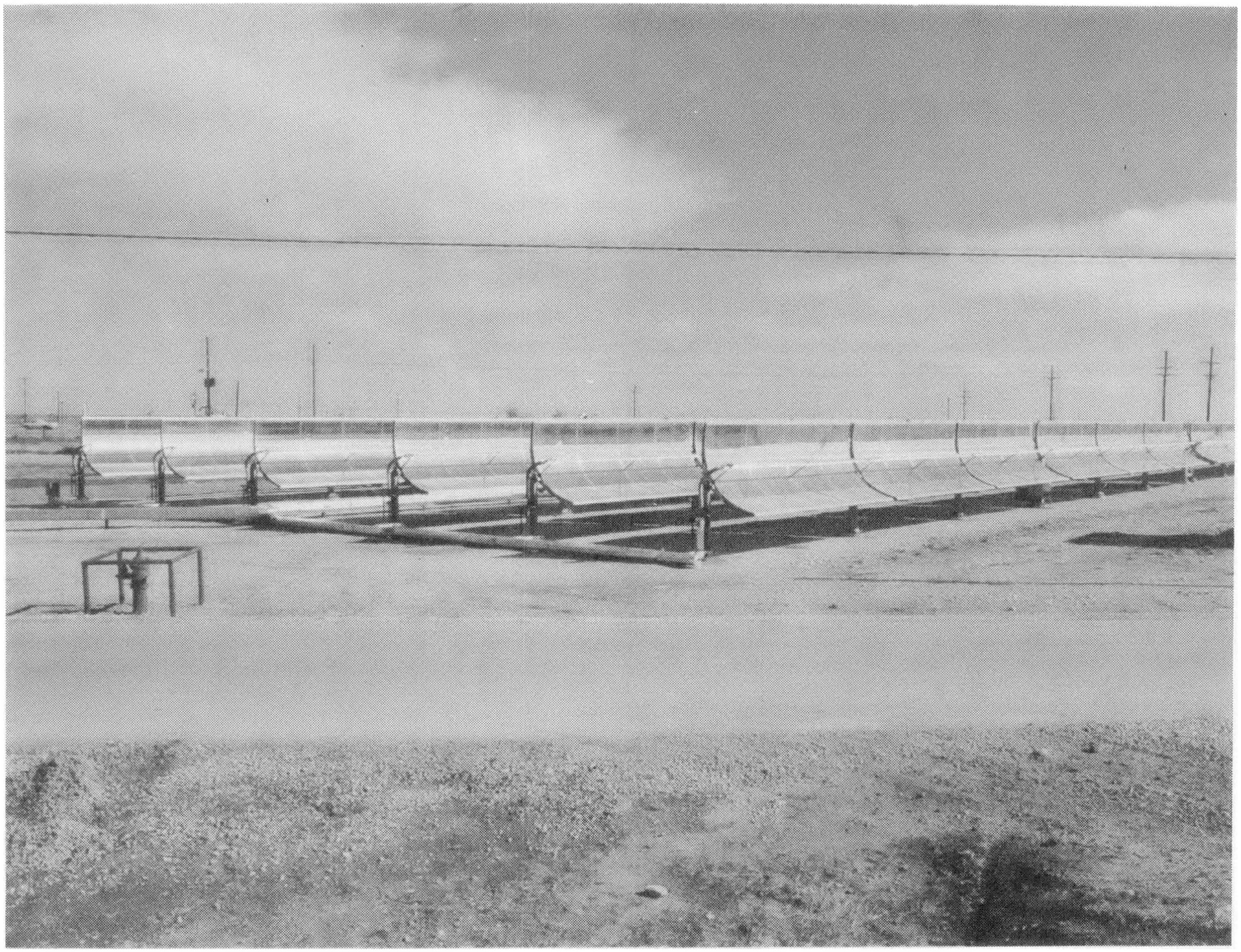

Figure 1-15. Solar Collector Array at Southern Union Refining Company, Lovington, New Mexico

At maximum operating conditions, the solar steam system produces 816 kg/h (1,800 lb/h) of 1,207-kPa (175-psig) saturated steam. The primary steam supply is generated by a natural gas-fired boiler. Thermal storage is not provided in the system.

Solar Kinetics T-700 parabolic-trough collectors are used in the collector field, which has a total aperture area of 937 m^2 (10,800 ft^2). The collectors are located at ground level with their tracking axes aligned in the east-west direction.

The system is dual-loop and uses Texatherm, a petroleum-based fluid, as heat-transfer fluid. The fluid is circulated through the collector loop at 4.5 kg/s (98 GPM) and attains a maximum temperature of 228°C (442°F). Computer studies show that this system should produce 2,048 GJ/yr (1,939 MBtu/yr).

A schematic of the system is shown in Figure 1-16. The design characteristics for this system are summarized in Table 1-7. The system and its operation are described in Reference 6.

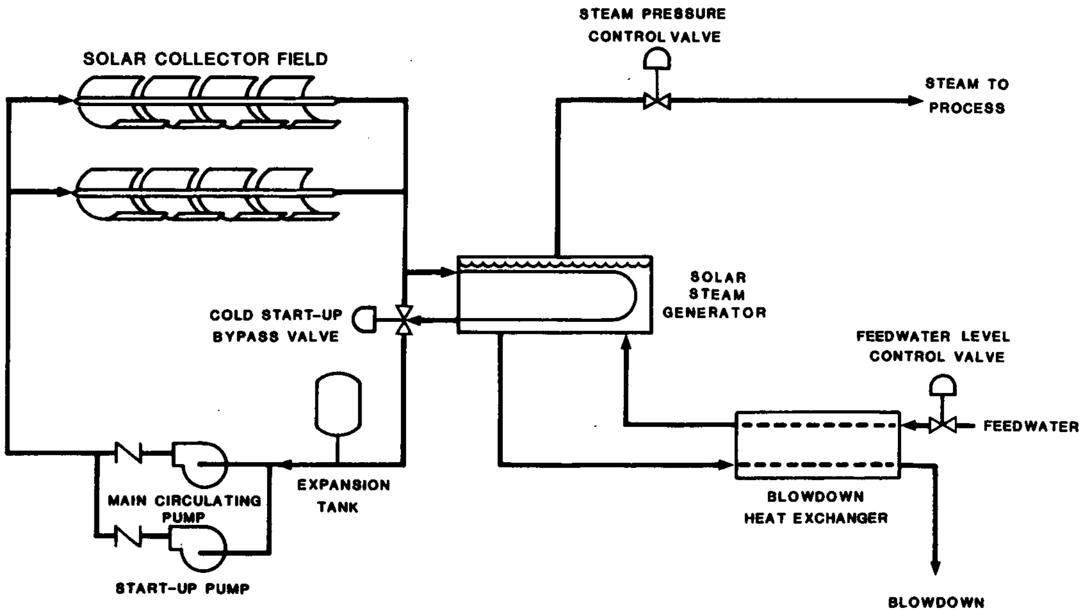

Figure 1-16. Schematic of Solar Energy System - Southern Union Refining Co.

Table 1-7

Design Characteristics - Southern Union Refining Co.

Application:	Solar production of process steam at 375°F for processing crude oil at the Southern Union Refining Company near Hobbs, NM.
Site:	Lovington, NM; 32°45'N latitude, 103°15'W longitude. Elevation = 1,112 m (3,650 ft).
Process schedule:	24-h operation, 7 days/wk, 50 wk/yr.
Process load profile:	9,070 to 13,603 kg/h (20,000 to 30,000 lbm/h) of 191°C (375°F) saturated steam.
Auxiliary fuel:	Natural gas, boiler efficiency and line losses = 65%.
Collectors:	SKI T-700 parabolic troughs. Total aperture area = 937 m^2 (10,080 ft^2); Field gross area = 2157 m^2 (23,205 ft^2). Mounted on ground, horizontal, east-west axis. Packing factor = 0.434.
Fluid type, flow rate:	Oil - Texatherm; Startup pump = 2.02 x 10^{-3} (32 GPM); Operational pump = 6.19 x 10^{-3} m^3/s (98 GPM).
Storage:	None
Design energy delivery:	3,466 GJ/yr (3,285 MBtu/yr) - Includes 7.2% energy reduction for collector site relocation.
Phase I cost (design):	$215,000
Phase II cost (construction):	$1,069,000

USS Chemicals -- The solar IPH experiment at United States Steel Chemicals Co., Haverhill, OH, (Figure 1-17), a Cycle 4 project conducted under a cooperative agreement with Columbia Gas System Service Corp., was operational throughout FY 1983. At the beginning of the year, problems with the data acquisition system precluded measurement and reporting of energy production. These problems were cleared up by January 1983. Subsequently, system thermal efficiency averaged 43%.

Columbis Gas System Service Corporation and USS Chemicals Division of United States Steel operate the system, which provides industrial process steam for the production of phenol. The phenol plants are operated 24 hours per day, 7 days per week, and 51 weeks per year. Phenol plant maintenance, requiring 1 week, is scheduled once each year.

The phenol process loads exceed the maximum solar energy system steam output of 4,536 kg/h (10,000 lb/h) at all times that the phenol plants are in operation. No solar energy storage system is required at this site. Steam is supplied at a pressure of 379 kPa (55 psig). Steam for the USS Chemicals plant complex is generated with steam generators using primarily natural gas, although portions of the plant's total steam requirements can be produced with oil and coal.

The solar energy system uses 360 SKI T-700 solar collectors with a total aperture area of 4,682 m^2 (50,400 ft^2). The collectors track about a single axis and are mounted on the ground with an an orientation that conforms to the axis of the roads and streets within the plant compound. The solar collector axis runs 25° west of true north.

A heat-transfer fluid, Monsanto Therminol 60, is pumped through the solar collector array at a nominal flow rate of 14.5 kg/s (320 GPM). Solar collector outlet temperature after initial warmup is nominally 204°C (400°F), but actual outlet

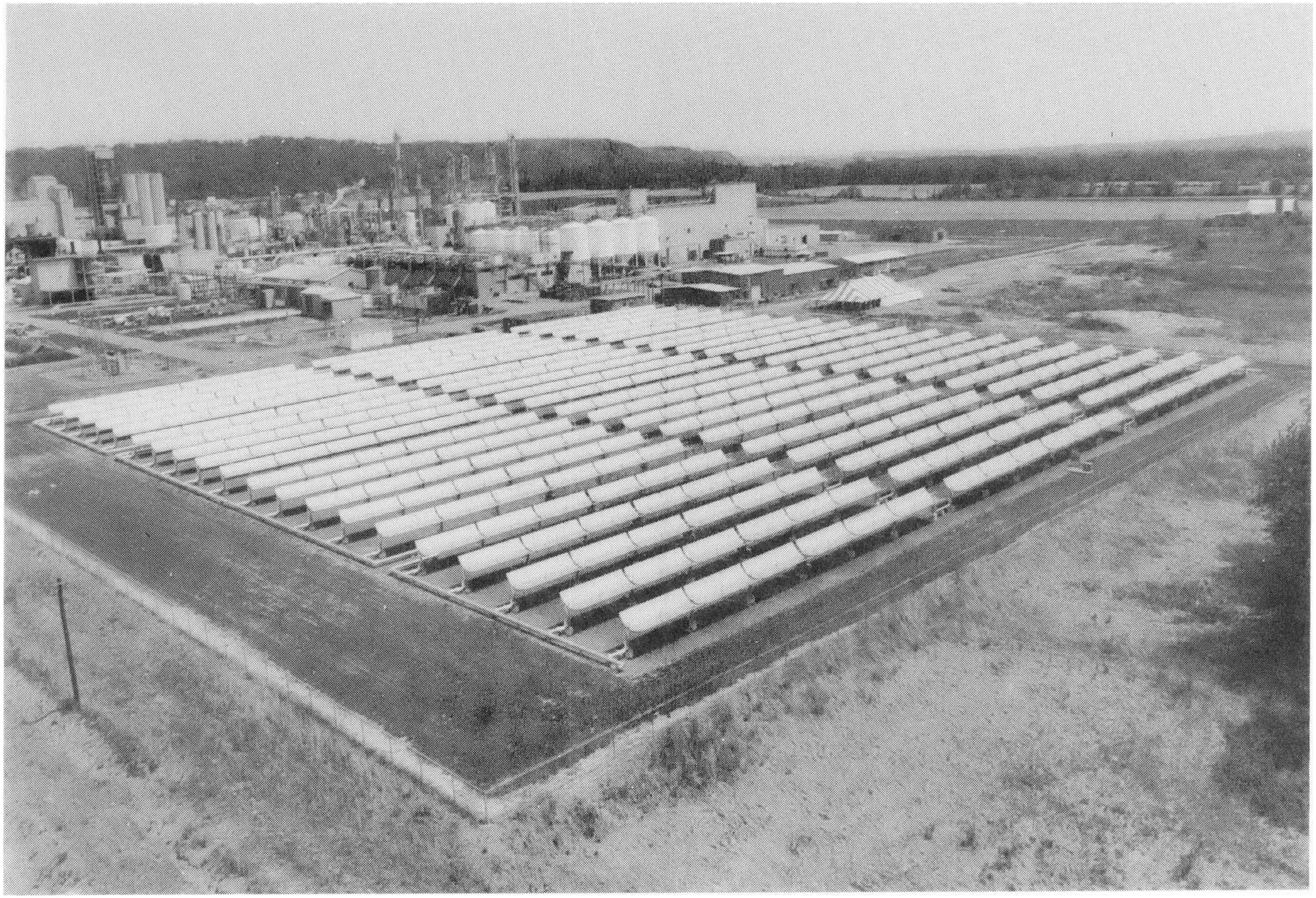

Figure 1-17. Solar Collector Array at USS Chemicals Company, Haverhill, Ohio

temperature ranges from 177°C to 232°C (350°F to 450°F) depending on solar radiation, steam generator pressure, and actual solar-collector loop-flow rate. Based on computer studies, it is estimated that the solar energy system will deliver 4,752 GJ/yr (4,504 MBtu) annually.

The design characteristics of this system are summarized in Table 1-8. A schematic of the system is shown in Figure 1-18. The system and its performance are described in Reference 7.

Table 1-8

Design Characteristics - USS Chemicals Co.

Application:	Steam used in the production of phenol.
Site:	Haverhill, OH; 38°36' N latitude, 82°50' W longitude; Elevation 169 m (553 ft).
Process schedule:	24 h/day, 7 days/wk, 51 wk/yr.
Process load profile:	4,536 kg/h (10,000 lbm/h) constant solar steam demand. Steam is 380 kPa (55 psia), 150°C (303°F).
Auxiliary fuel:	Natural gas, oil, coal.
Collectors:	Solar Kinetics T-700 parabolic dish concentrators having a total aperture area of 4,682 m^2 (50,400 ft^2). Mounted on the ground with tracking 25° west of true north.
Fluid type, flow rate:	Therminol 60 (Monsanto) at nominal rate of 2.02×10^{-2} m^3/s (320 GPM) with a nominal temperature of 204°C (400°F).
Storage:	None
Design energy delivery:	8,440 GJ/yr (8×10^9 Btu/yr)
Phase I cost (design):	$237,000
Phase II cost (construction):	$2,983,000

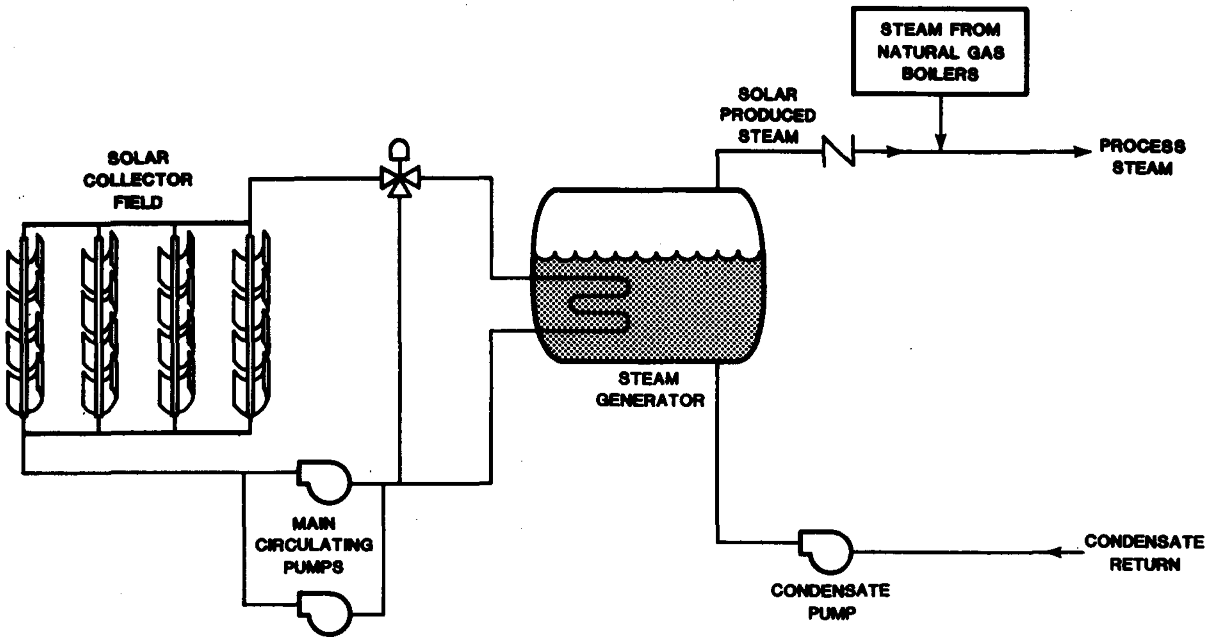

Figure 1-18. Schematic of the Solar Energy System - USS Chemicals Co.

Owner-Operated Systems

A number of solar IPH experiments were completed prior to FY 1983. The solar equipment from these experiments was transferred to the plant owners, who have continued to operate it. During FY 1983, the plant owners were interviewed to obtain their thoughts on the experiments. The status of their equipment, as derived from the interviews, is summarized below. Detailed results of the interviews are contained in Reference 8.

A new plan to maintain close contact with the plant owners for monthly reports of energy output and operation and maintenance data was initiated during FY 1983. An effort is being made to assure that performance data and operating experience from these projects is properly and widely disseminated.

The owner-operator experiments are summarized in Table 1-9.

Table 1-9

Operating IPH Systems Transferred to Owners

Project	Cycle	Status
1. Campbell Soup Co. Sacramento, CA	1	Upgrade complete, operating routinely. ETEC* contract for spares in process.
2. J. A. La Cour Kiln Service Canton, MS	1	Upgrade complete, operating routinely.
3. Lamanuzi and Pantaleo Fresno, CA	1	Upgrade complete, operating routinely. Operates August through October.
4. Goldkist (Bunge Corp.) Decatur, AL	1	Only operated during drying season.
5. Riegel Textile Corp. La France, SC	1	Upgrade complete, operating routinely.
6. York Building Products Middletown, PA	1	Operating routinely, needs repairs. ETEC contract for repairs in process.
7. Johnson and Johnson Sherman, TX	2	Operating routinely. ETEC contract for spares in process.
8. Capitol Concrete Products Topeka, KA	Point-Focus	Experiment completed 12/82; operating routinely.

*Energy Technology Engineering Center, Rockwell International

Campbell Soup -- The solar energy system at Campbell Soup, Sacramento, CA, a Cycle 1 project, producing hot water for sterilizing cans, was upgraded under DOE sponsorship and was transferred to the owner during FY 1983. Since it was put back into operation, it has been performing well and has had an availability of 95%. The system is a combination of flat-plate collectors and Acurex parabolic troughs.

J. A. LaCour Kiln Services -- The system at J. A. LaCour Kiln Services, Canton, MS, a Cycle 1 project, uses Chamberlain flat-plate collectors to supply hot air to kilns for drying lumber. The solar energy system operates through a heat exchanger to preheat water that is circulated through the boiler. During February 1983, one kiln operated 100% on solar energy. Later in the year, a boiler fired by wood chips was added to the system to eliminate the need for natural gas.

Lamanuzi and Pantaleo Foods -- At Lamanuzi and Pantaleo Foods, Fresno, CA, a Cycle 1 project, single-glazed flat-plate collectors are used to supply hot air for drying raisins and prunes. The system is operated from August through mid-October. The original fiberglass glazing experienced substantial yellowing and was subsequently replaced with glass, which is working well. The system has been subject to vandalism, i.e., children gouging the insulation with sticks, but damage was not significant. In FY 1983, use of the system approached 100 days, an increase in usage resulting from a greater need for drying because of extensive rains.

Goldkist -- The solar IPH system at Goldkist (Bunge Corp.), Decatur, AL, a Cycle 1 project, uses Solaron single-glazed flat-plate collectors to heat air for drying soybean products. The system is readied just before each drying season by washing the collectors with detergent and repairing duct work. The system is controlled so that it is activated only when the collectors can supply heat and there is a demand for drying. Plant officials commented that once the system is activated "it just sits there and supplies hot air."

Riegel Textiles -- Construction activities to upgrade the Solar IPH system at Riegel Textiles, La France, SC, a Cycle 1 project, were completed during FY 1983, and the system was put back into operation. The system, which uses Sunworks flat-plate collectors, provides preheated boiler feedwater for production of steam for textile-dying operations.

York Building Products, Inc. -- The solar IPH system at York Building Products, Inc., York, PA, a Cycle 1 project, operates routinely producing hot water for a 190 m^3 (50,000 gal) rotoclave used for curing concrete blocks. It has been operating at a reduced level because of broken reflector glass on one of seven rows of collectors. The system, which uses collectors with moveable linear facets focusing on a fixed overhead receiver, was damaged when it was struck by a crane boom. York plans to repair the broken mirrors.

Johnson and Johnson -- The system at Johnson and Johnson, Sherman, TX, a Cycle 2 project, operated reliably throughout the year but was damaged by freezing in January and had some glass breakage and flex hose problems. The system uses Acurex parabolic-trough collectors. The actual performance was about 5% below predicted, based on steam meter readings.

Discontinued Projects

Three projects from Cycles 1 and 2 were discontinued because of solar energy system equipment problems. Upgrades were proposed to industrial participants but were declined because of potentially unfavorable operating economics. These projects are summarized below.

Gilroy Foods -- The system at Gilroy Foods, Gilroy, CA, a Cycle 1 project, began operation in July 1979 and operated until 1981. The system used GE evacuated-tube collectors mounted in racks on the roof of a building. Operation was discontinued when about 500 tubes broke and replacement was required. The cost of repairs was estimated to be $30,000 while the net annual savings in energy was estimated to be $3,000.

Tropicana Products -- The solar IPH system at Tropicana Products, Bradenton, FL, was removed by the prime contractor in 1982 before the system became operational and before the system was accepted by DOE and Tropicana. Tropicana was a Cycle 2 project that used evacuated-tube collectors. The system was subject to many equipment problems that included (1) an unreliable pump, (2) insufficient and incorrectly protected insulation, (3) inadequate manifold joints, (4) broken tubes, and (5) delaminated reflectors. Vandalism was a serious problem. Modification of the system to place it in operation was not considered justified.

Westpoint Pepperell -- The IPH system at Westpoint Pepperell, Fairfax, AL, a Cycle 2 project that used parabolic-trough collectors, was removed before it reached capacity in terms of operation and steam production. Problems included tracking, brake motors, and controls. Upgrade of the system was discussed but was declined because there were too many serious problems.

A summary of projects that have been discontinued is shown in Table 1-10.

Table 1-10

Solar IPH Projects Discontinued

Project	Cycle	Status
1. Gilroy Foods Gilroy, CA	1	Operated last in 1981, 500 tubes need replacement. Estimated cost: $30,000
2. Tropicana Products, Inc. Bradenton, FL	2	System removed in 1982
3. Westpoint Pepperell Fairfax, AL	2	Equipment removed; roof restored.

57,58

CHAPTER 2. SYSTEM PERFORMANCE, FY 1983

Solar energy system performance is determined by the amount of energy delivered as steam or hot water compared to the amount of solar energy incident on the solar collectors of a solar collector field. This chapter reports on the performance of six of the experiments supported by DOE during FY 1983. Data submitted by the prime contractors for the experiments have been analyzed and evaluated. The solar resource and its measurement are discussed first. Next, long-term energy production data and efficiencies are presented, followed by a detailed evaluation of long-term system losses. Finally, short-term performance is described in terms of clear-day operation.

The effects of data loss during the experimental period have been compensated for in estimating long-term energy production. For short periods (less than one month) when data was lost for any reason, it was assumed that values would be similar to those measured and recorded during the remainder of the month. For longer periods, gaps in the data were filled by deriving incident energy values from Typical Meteorological Year (TMY) weather data[9] and by obtaining the effects of angle of incidence from computer models. System operation and efficiency data were assumed to be similar to the periods when operational data were reported. The results from data sets completed in this manner were used to evaluate system performance.

Solar Resource

The sites selected for the solar IPH projects receive significantly different amounts of solar irradiation over the year. They represent almost the full range of availability of solar energy in the United States. The amount of energy available at the highest insolation site (Southern Union Refining Co. at Lovington, NM) is over twice the amount available at the lowest insolation site (USS Chemicals at Haverhill, OH). Figure 2-1 shows the yearly average direct normal solar irradiation for weather stations near the IPH sites. The locations of the sites are shown on an insolation map of the United States in Figure 2-2.

Average daily direct normal solar irradiation values in Figure 2-1 were taken from TMY data rather than from values measured at the IPH sites during FY 1983. The latter measurements were incomplete and also were not measured in a consistent manner at the different sites. TMY data appeared to provide a more consistent insolation base for evaluating system performance.

In a study performed for the DOE Solar Heating and Cooling Project to evaluate the TMY data for six weather stations, the analyst concluded: "...yearly and seasonal results are acceptably close to long-term for most practical purposes."[10] In this study TMY data were compared with long-term SOLMET data collected over a period of 23 years. For the six weather stations the absolute differences between the long-term and the TMY monthly radiation averaged about 3% with a 10% maximum difference. The analyst qualified his conclusions by noting that TMY data were constructed around the total horizontal and that the diffuse fraction (and consequently the beam fraction) varied to a greater extent. He also commented that although the TMY data were typical of the 23 years of the SOLMET data, there is no assurance that the weather will be the same for the next 20 years.

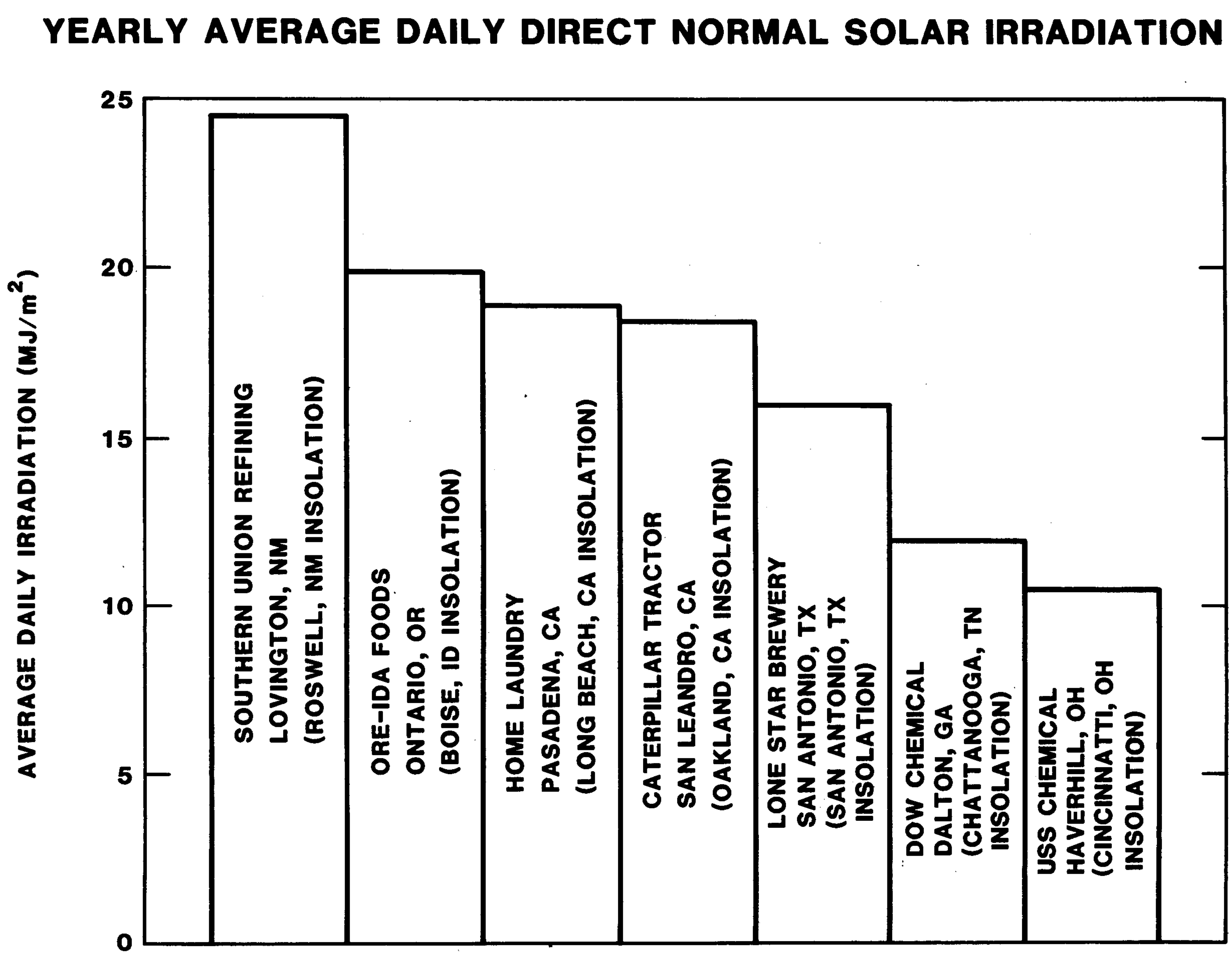

Figure 2-1. Average Daily Direct Normal Irradiation at the Solar Industrial Process Heat Sites (Adjacent TMY site is noted in parenthesis.)

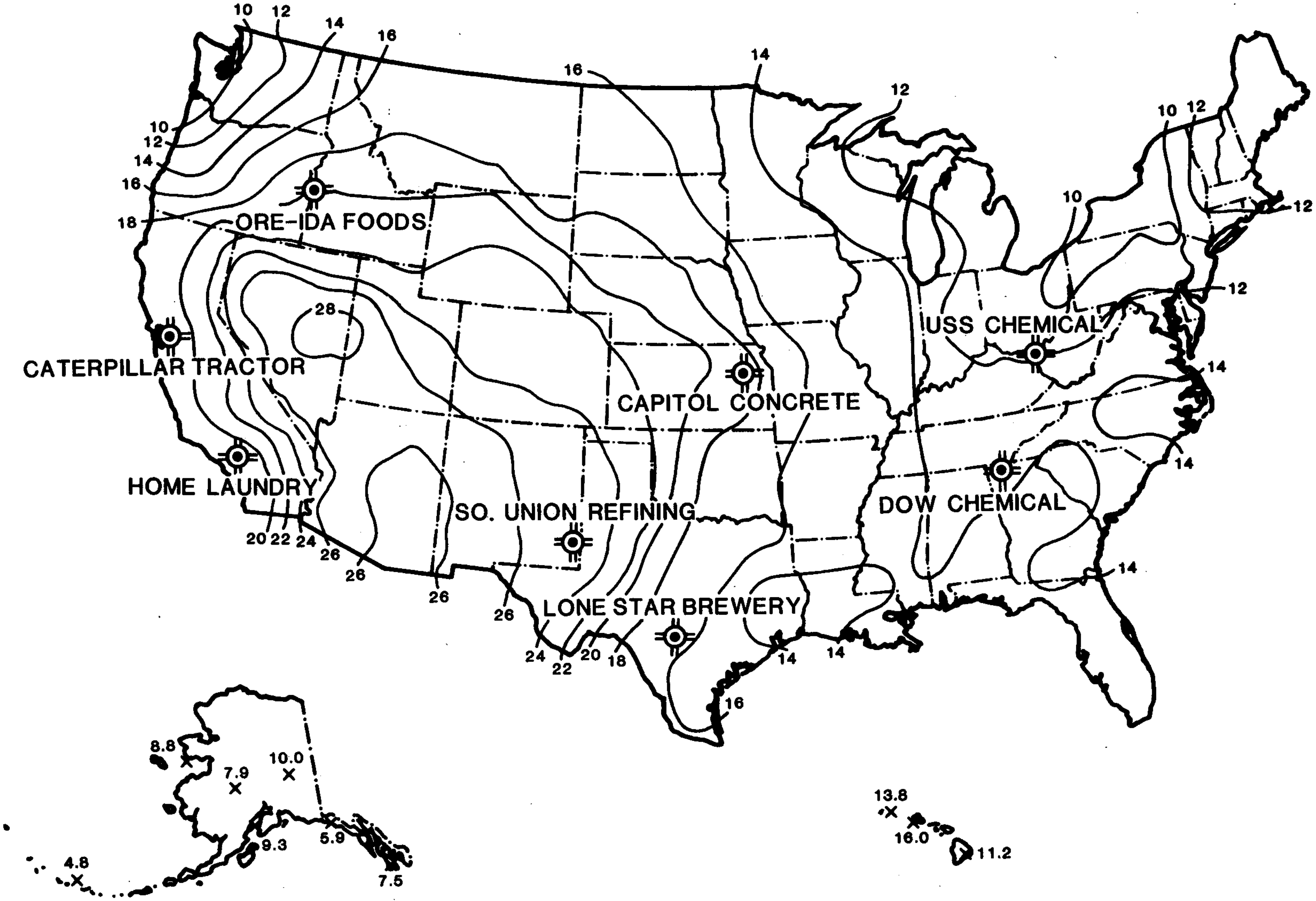

Figure 2-2. Yearly Average Daily Solar Irradiation for the United States (MJ/m^2)

A method to estimate direct insolation from total horizontal values was developed by The Aerospace Corporation.[11] This method gave values within 4% of observed values for four SOLMET locations with diverse climates. The method was then applied to data for all 26 SOLMET locations so that, according to the authors, the annual average direct insolation was expected to be within 4% of the SOLMET data. These values were used for generation of TMY data. At IPH sites where insolation was measured, TMY average insolation values did not vary to a large extent from FY 1983 weather when averaged over the entire year.

At some of the sites, direct normal insolation was measured using normal incidence pyrheliometers (NIP). However, in many cases, because of data acquisition system malfunctions and problems with adjustment and calibration, the yearly averages of these measurements are not considered reliable and are not presented. Sites that used pyrheliometers are listed in Table 2-1.

Table 2-1

Direct Normal Insolation Instruments

Capitol Concrete	Eppley NIP and tracker
Dow Chemical	Eppley NIP and tracker
Home Laundry	Eppley NIP and tracker with blinders (used as part of control system)
Ore-Ida Foods	Eppley NIP and tracker
USS Chemicals	Eppley NIP-LiCor tracker*

*This tracker has a self-adjusting declination axis in addition to the usual polar-axis clock drive.

Long-Term Energy Production

Energy production during FY 1983, extrapolated over a full year, ranged from 12% to 34% of the original design predictions. The design predictions were based, in most cases, upon meager weather data and upon very optimistic operation of the solar equipment. Subsequently the systems were modeled by the Solar Energy Research Institute (SERI),[12] and new predictions were made using TMY weather data and estimates of system characteristics as the systems were built. These predictions (see Chapter 3) were 30% to 80% of the original design values.

The differences between the SERI predictions and the original design predictions are attributed primarily to the development and use of annual weather data and more detailed modeling techniques. The cause for the differences between the measured values and values predicted by SERI is probably a combination of modeling inaccuracies, tracking errors, implementation of operational strategies, and instrument errors. The spread between actual energy production and the SERI model seems to be a function of the care with which the solar energy systems were engineered and with which the experiments were performed. When equipment was better engineered and experiments were given more attention, energy production was closer to the SERI predictions.

Actual long-term energy production measured during FY 1983 for the different projects is summarized in Table 2-2. Values are extrapolated to full-year energy production, and predicted values are shown.

Solar Efficiencies

Efficiencies describing system performance have been defined for the purpose of evaluating the IPH experiments. These efficiencies are as follows:

Table 2-2

Long-Term Energy Production

Project	Actual Period	Actual Energy Produced (GJ)	Full-Year Extrapolation (GJ)	Design Prediction (GJ)	SERI Prediction (GJ)	Comments
Caterpillar Tractor Co.	Feb-Sept	1158	1747	14800	11426	Acceptance test in January; solar output voluntarily reduced so as not to exceed plant load (plant production cutback because of slow economy); plant down most of July
Dow Chemical Co.	Feb-Aug	323	496	2676	794	DAS inoperative through Jan.; shut down for upgrade - Sept.
Home Laundry	Feb-Sept	298	387	1266	776 (steam) 980 (water)	DAS inoperative through Jan.; laundry shutdown at 3:30 p and on weekends; operation predominately hot water.
Lone Star Brewery	Oct-May	215	457	3376	1379	Two of 15 rows inoperative; system shut down in May because of HTF leaks.
Southern Union Refining Co.	Oct-Aug	383	416	3481	2046	One of 6 rows damaged by wind in April; shut down for upgrade in Sept.
USS Chemicals Co.	Feb-Sept	3919	4270	12661	4752	DAS inoperative through Jan.

Subsystem Efficiencies

1. Operational Efficiency
2. Collector Field Efficiency
3. Delivery Efficiency

System Efficiencies

1. System-Operation Efficiency
2. System Thermal Efficiency

"Operational Efficiency" is the ratio of the energy incident on an operating collector to the energy that would be incident on the collector if the collector were up and operating any time that insolation is available. The operational efficiency represents how reliably the system operated over the period of interest (a year in this case), how well it was matched with its load, and how well the system collected low levels of insolation.

"Collector Field Efficiency" is the ratio of the thermal energy transferred to the heat-transfer fluid coming from the collector field to the radiant energy incident on the collector when the system is operating. It is a measure of how well the collector field collects solar energy and converts it into thermal energy.

"Delivery Efficiency" is the ratio of energy delivered to the industrial process (or steam header) to the energy coming from the solar collector field. The difference between the two energies is the thermal loss between the collector field and the industrial process.

Subsystem efficiencies for the six experiments for which there is long-term data are shown in Table 2-3. These numbers are based on the year-long estimates discussed earlier.

Of the three efficiencies tabulated below, operational efficiency is the major factor affecting performance of the

Table 2-3

Subsystem Efficiencies

Project	Operational Efficiency (%)	Collector Field Efficiency (%)	Delivery Efficiency (%)
Dow Chemical	73	28	68
USS Chemicals	62	51	85
Lone Star Brewery	59	33	52
Home Laundry	32	40	82
Southern Union Refining Co.	31	33	59
Caterpillar Tractor	18	35	100

systems. Low operational efficiency is caused by system failures and load mismatch. To obtain maximum operational efficiency of a solar energy system, the system must be kept operating and the load must be available whenever the sun is shining.

The two system efficiencies were computed to describe overall performance of the IPH systems. "System-Operation Efficiency" is the ratio of actual energy delivered to the process to the maximum available energy in the plane of the collector. This efficiency is a measure of both the ability of the solar energy system to operate and to provide thermal energy, and also of how well it matches its load. The system thermal efficiency is a measure of the system's ability to provide thermal energy when it is operating. System efficiencies for the six experiments are shown in Table 2-4. These numbers are based on the year-long estimates discussed earlier.

The System-Operation efficiency of the USS Chemicals system is almost twice that of the next most efficient system

Table 2-4

Annual System Efficiencies

Project	System-Operation Efficiency (%)	System Thermal Efficiency (%)
USS Chemicals	27	43
Dow Chemical	14	19
Home Laundry	10	32
Lone Star Brewery	10	17
Caterpillar Tractor Co.	6	34
Southern Union Refining Co.	6	19

and almost 5 times that of the lowest. This system also delivered the most energy per unit area of collector. The reasons that the USS Chemicals system performed this well, although located in the lowest insolation region, are that the system was kept operating most of the time, the collector field was well tuned and kept clean, and the insulation and interconnecting piping between the field and the process were well designed and properly installed. These factors, combined with a north-south orientation, resulted in a system with high operating efficiency.

System Losses

Solar energy system performance depends upon and is reduced by a summation of many energy losses. These losses result from (1) design considerations such as choosing a single-axis collector so that the direction of the sun is not normal to the aperture at all times, (2) operational limitations such as operating thresholds and mismatch of the load with the availability of solar energy, (3) optical and thermal inefficiencies in the collector field, and (4) thermal and parasitic losses in the nonsolar portion of the system. In this section, we will consider the data reported from each of the experiments and will categorize these losses to provide an insight into the mechanisms that affect solar energy system performance. These losses are shown graphically for each of the IPH experiments in Figures 2-3 through 2-9. The figures also show energy available (direct normal insolation) and the energy delivered to the industrial plant (energy to process).

Cosine Losses

The systems described in this report use single-axis tracking of the aperture. Therefore, the sun is not always normal to the collector aperture and the energy incident on the aperture area is reduced by the cosine of the angle of incidence. This reduced available energy is referred to as the "energy in the plane of the collector."

If a horizontal collector is oriented with its tracking axis in the north-south direction, cosine losses are small in the summer and large in the winter. If the tracking axis is oriented in the east-west direction, winter cosine losses are less and summer losses are greater than for the north-south orientation. During the day, the east-west axis tracking aperture is normal to the sun at noon but has considerable cosine losses in the morning and the afternoon. The yearly average of these effects depends upon the weather patterns at a particular location. Studies of TMY data for a number of sites indicate that, over the year, the north-south oriented single-axis tracking collector provides 5% to 10% more energy than the east-west oriented collector.[13] A summary of the orientation of the systems discussed here is given in Table 2-5.

The yearly average percentage reduction in available energy because of cosine effect was computed for each IPH system by assuming that the IPH data would be similar to the

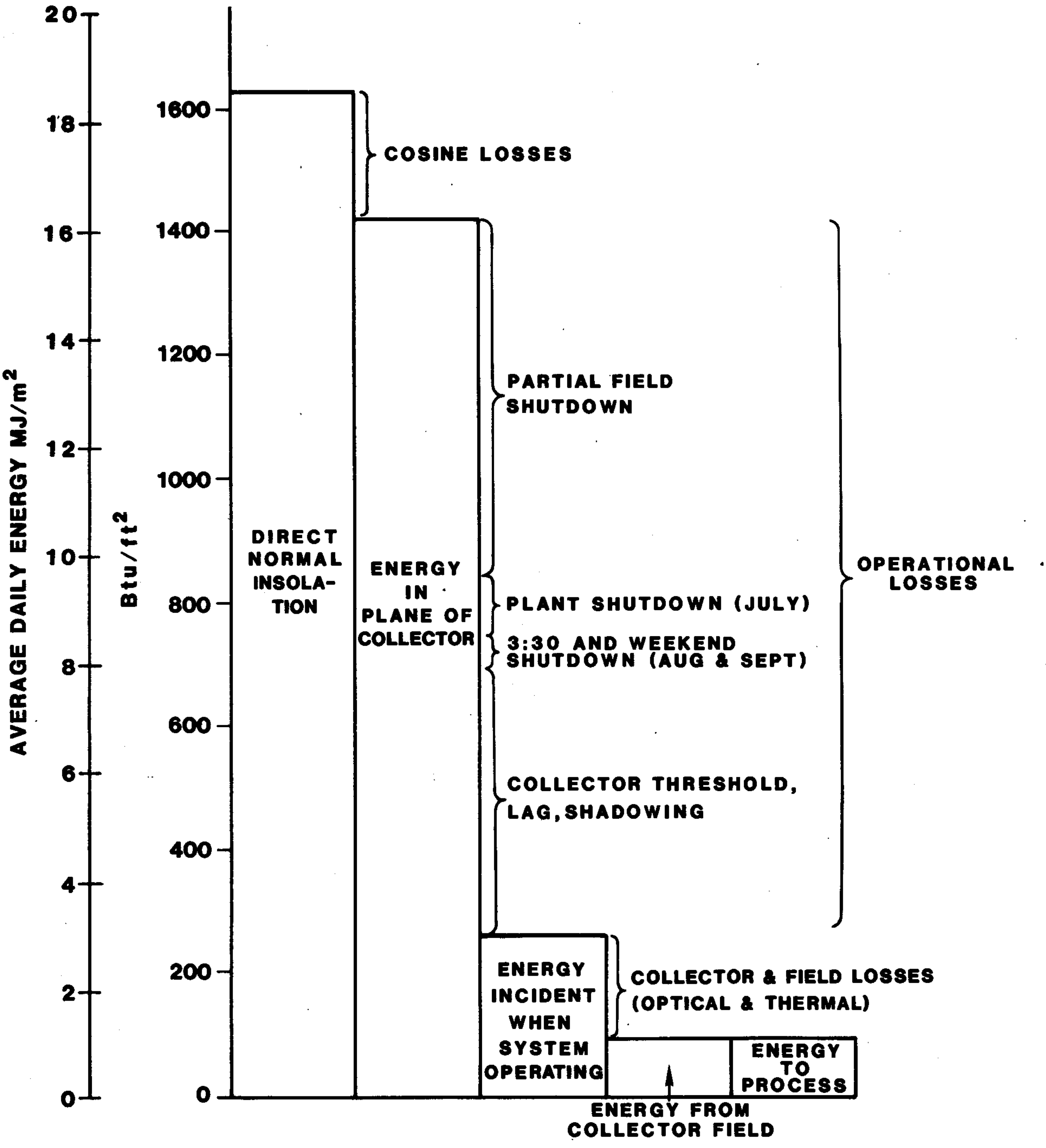

Figure 2-3. System Losses - Caterpillar Tractor Co.

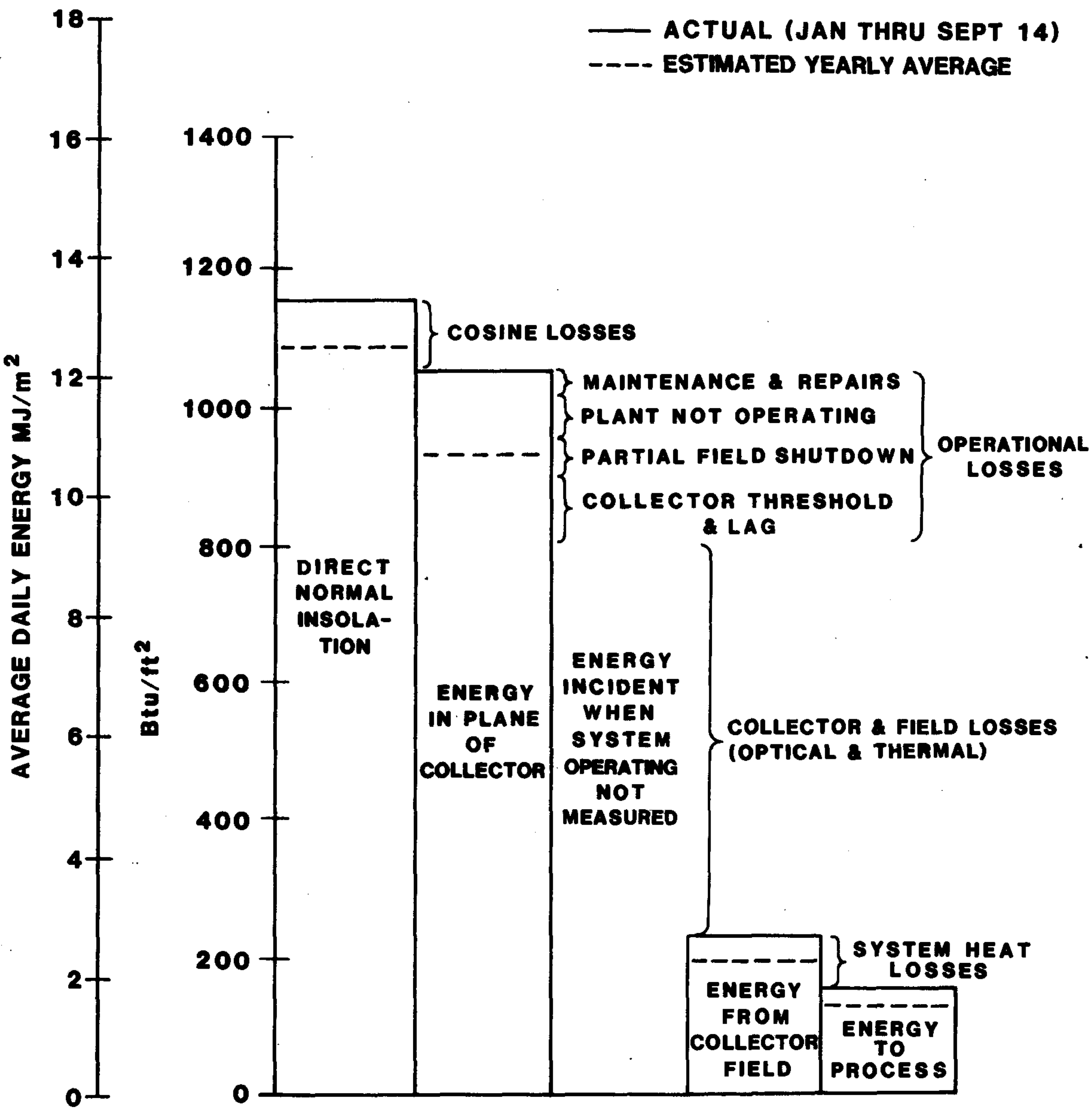

Figure 2-4. System Losses - Dow Chemical Co.

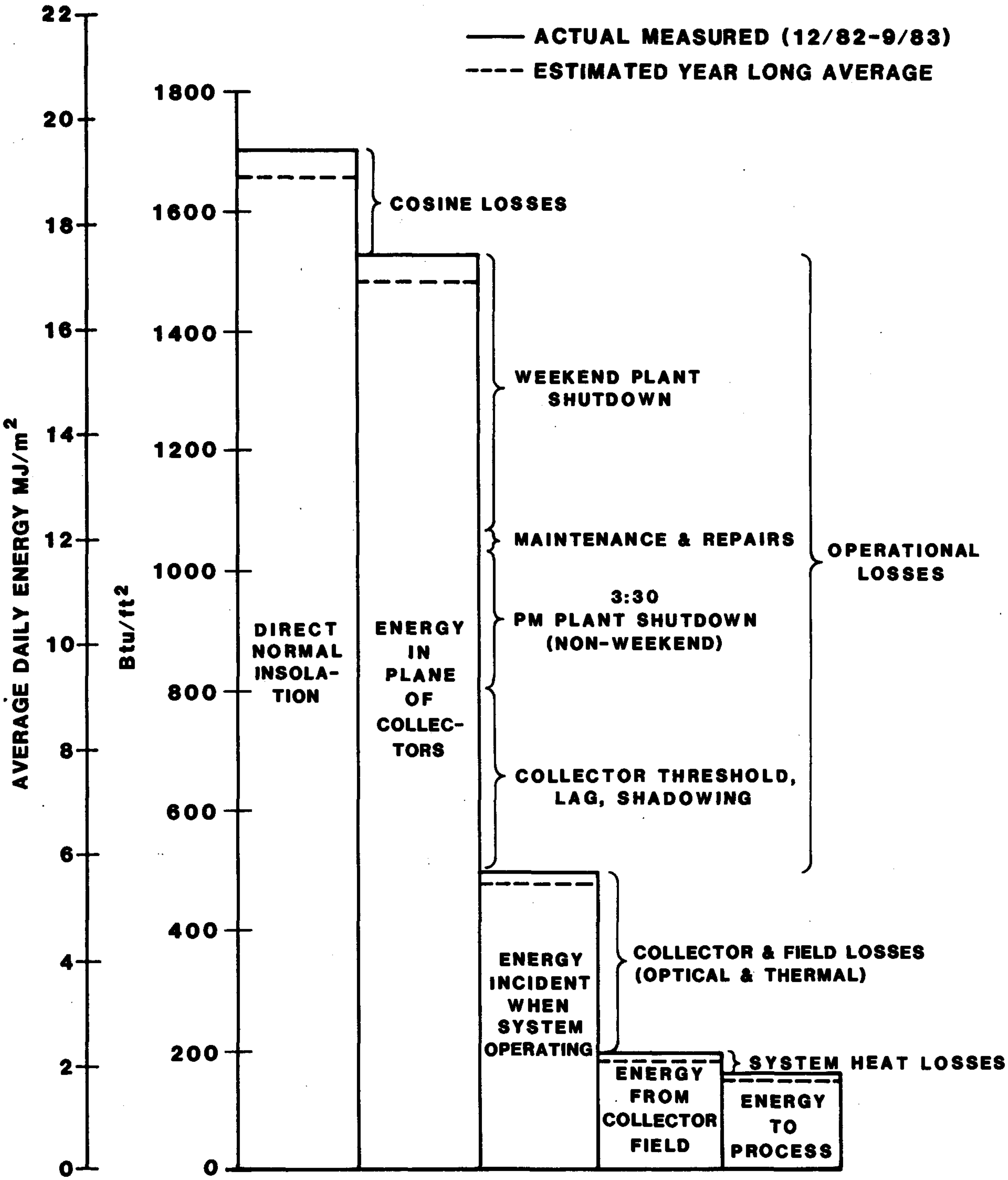

Figure 2-5. System Losses - Home Laundry

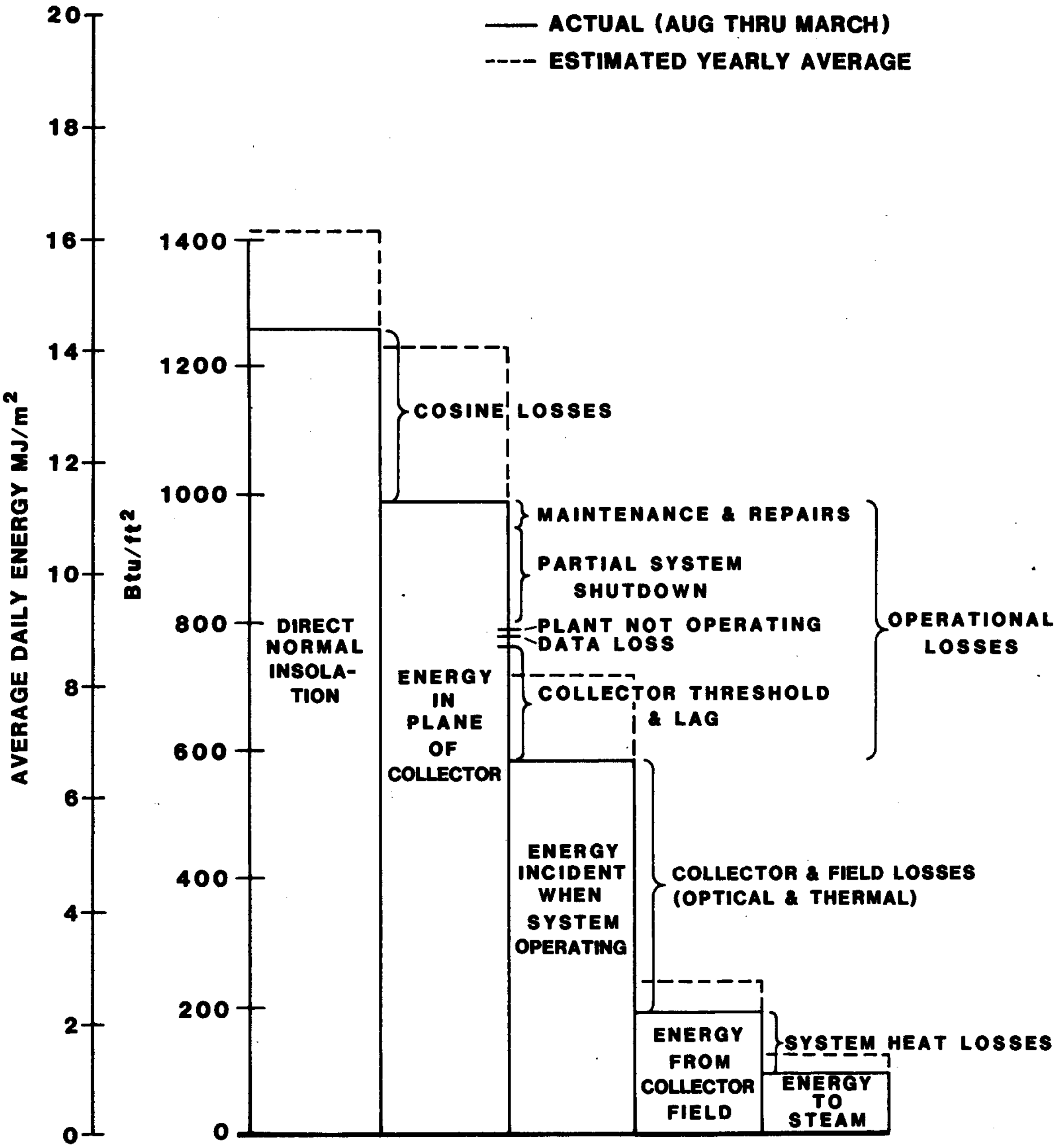

Figure 2-6. System Losses - Lone Star Brewery

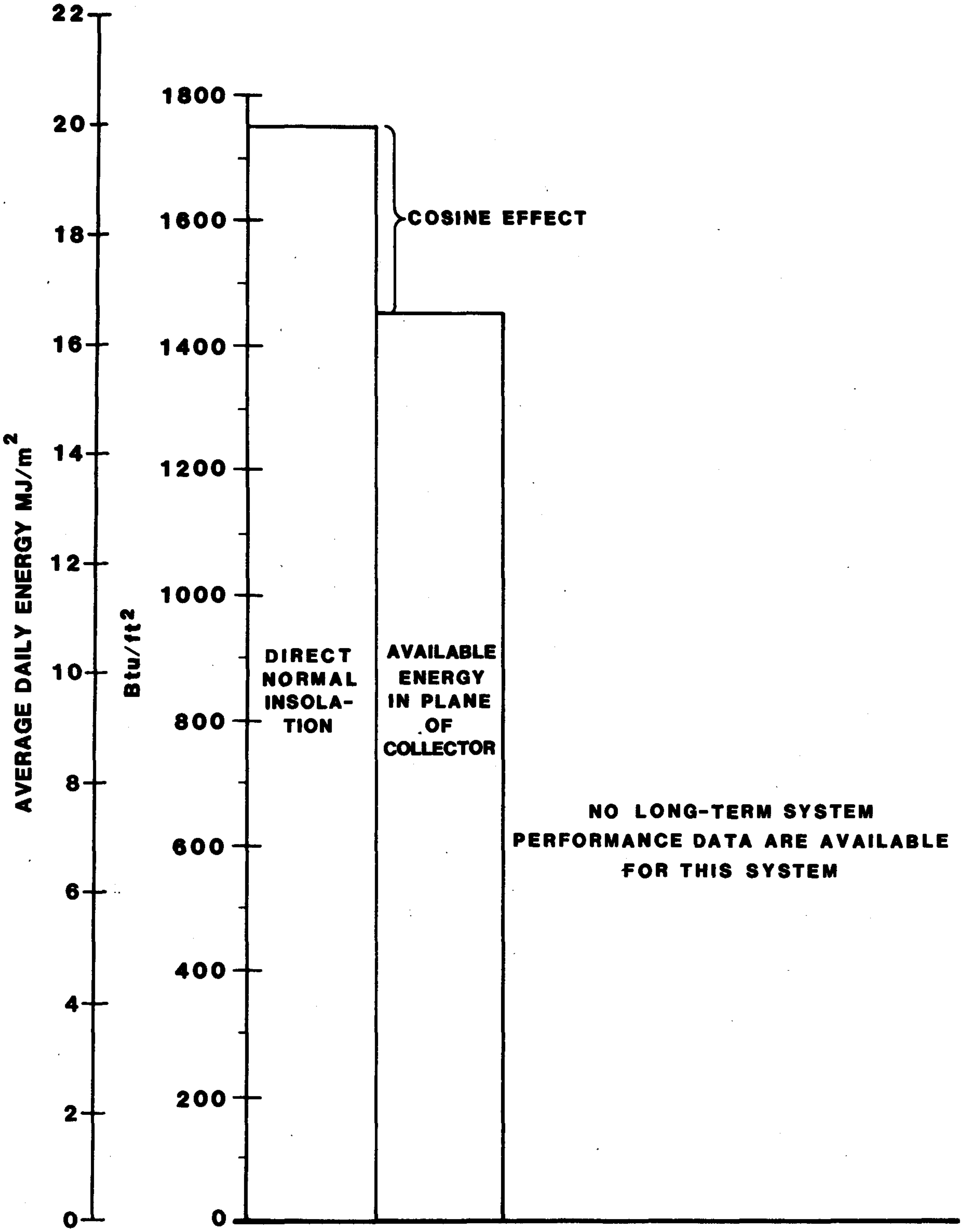

Figure 2-7. System Losses - Ore-Ida Foods

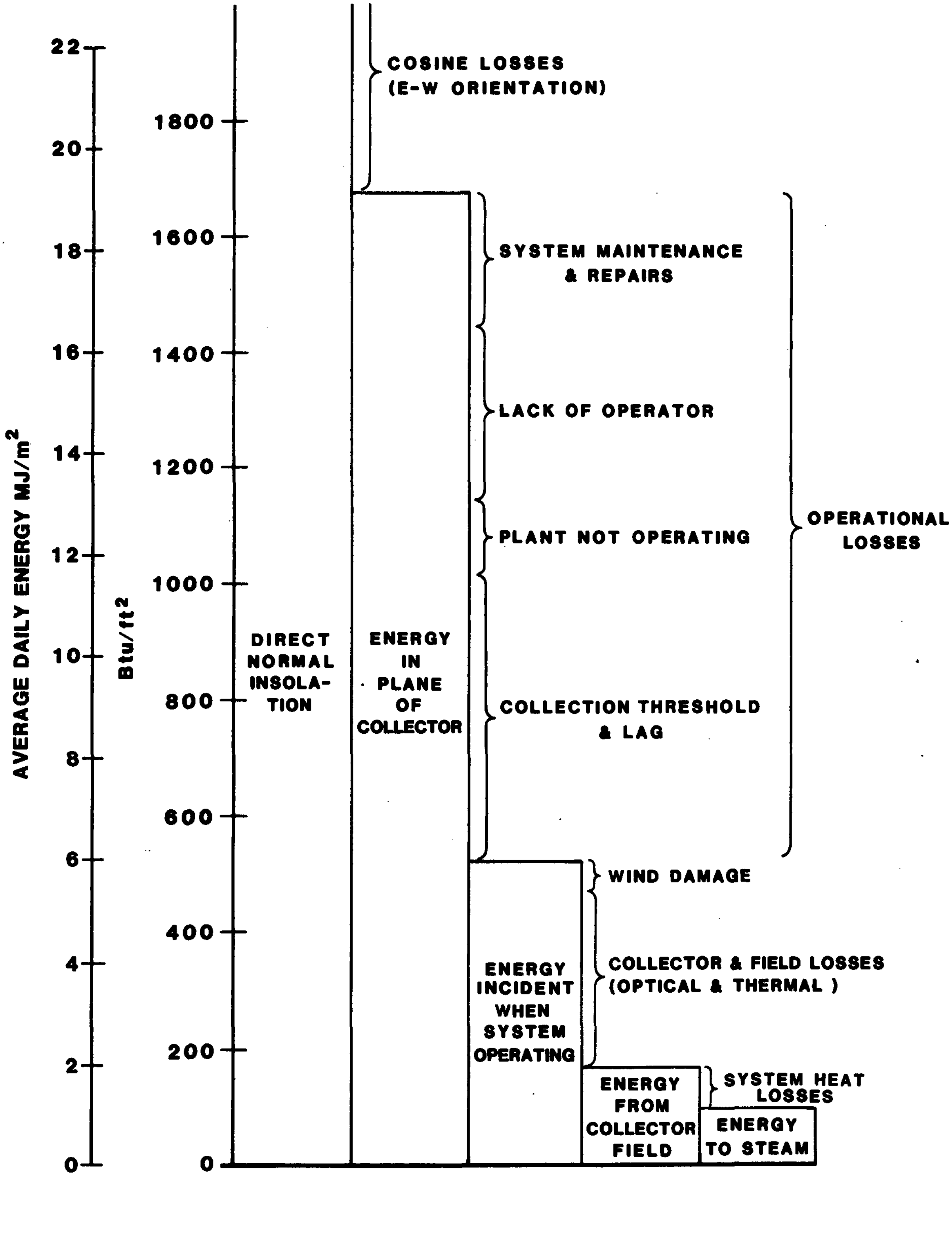

Figure 2-8. System Losses - Southern Union Refining Co.

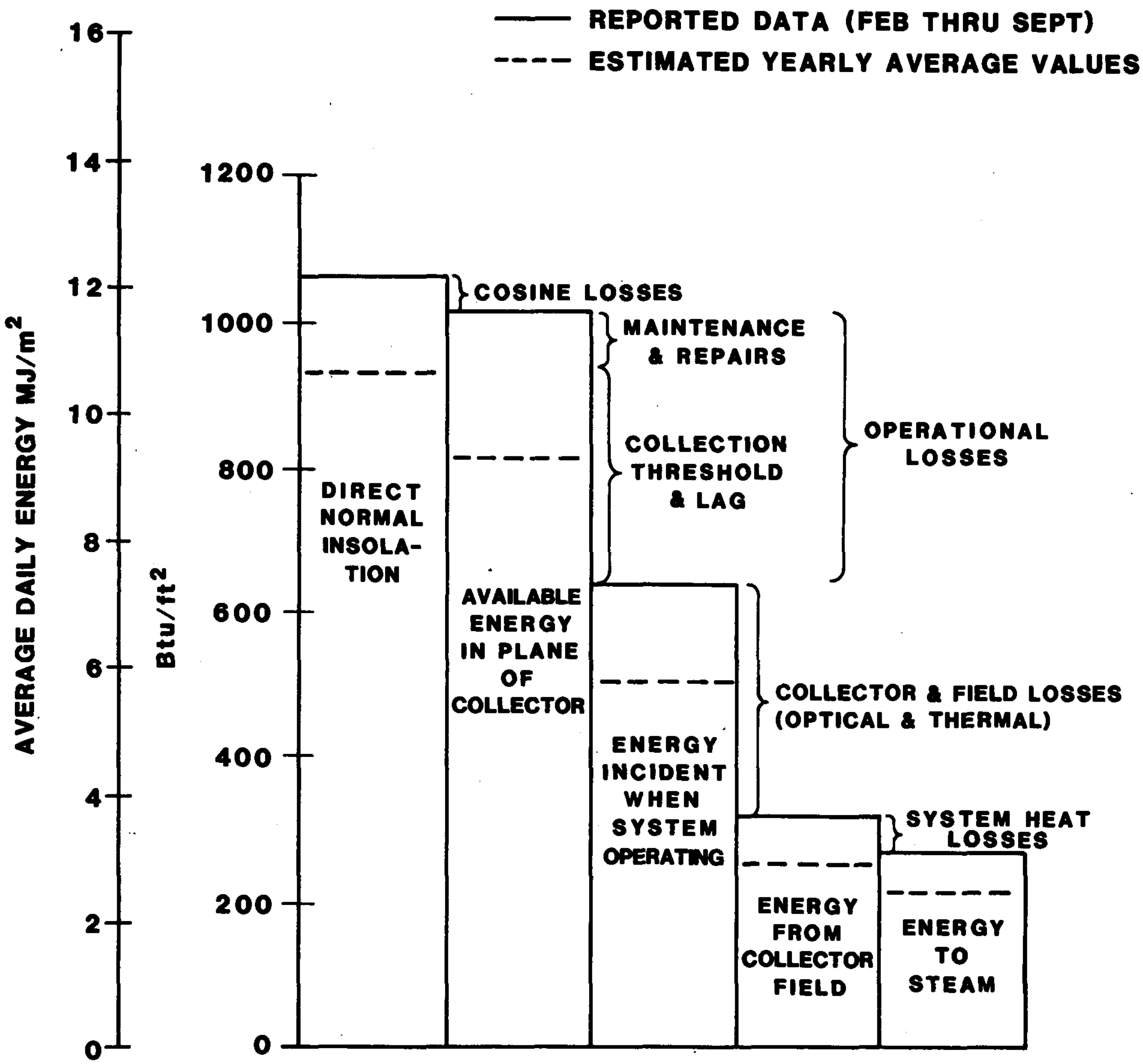

Figure 2-9. System Losses - USS Chemicals Co.

Table 2-5

System Tracking Axis Orientation

Caterpillar Tractor	22° east of north-south, horizontal
Dow Chemical	North-south, 10° tilt to south
Home Laundry	North-south, horizontal
Lone Star Brewery	North-south, horizontal
Ore-Ida Foods	11° east of north-south, horizontal
Southern Union Refining	East-west, horizontal
USS Chemicals	25° west of north-south, horizontal

TMY data recorded at the weather station closest to each site. The data for performing this reduction were taken from Reference 9. The loss varies from 5% for USS Chemicals, where only spring and summer data are reported, to 22% at Southern Union Refining Co., where the collectors have an east-west orientation. Cosine losses for the Lone Star Brewery are higher than for other north-south systems (22%) because the system operated only during the fall and winter when a north-south tracking orientation normally produces large cosine losses. The yearly estimate for this location shows a smaller percentage of cosine loss. The reduction in available energy because of the cosine effect is shown for each system in Figures 2-3 through 2-9.

Operational Losses

For most of the systems analyzed, the major energy loss was energy that was lost because the collector was not operational and pointing toward the sun. This category of losses includes both times when the system is operable, but there is no demand for the steam or hot water by the industrial process, and times when there is demand for energy, but the solar system is not operable.

Load Mismatch -- Many of the systems discussed here are connected to industrial loads that require energy 24 hours a day, 7 days a week. Often these industries require an energy rate much greater than could be supplied by the solar energy system operating at maximum efficiency. However some systems, such as Home Laundry, do not require energy once the plant has shut down for the afternoon or weekend and therefore experience significant loss of solar energy production during these periods. Other systems experienced an energy loss in this category because of plant shutdowns for holidays, maintenance, or modification.

A similar cause of system energy loss results from a reduction in plant energy requirements. In the case of the Caterpillar Tractor Co., the need for energy was less than the solar energy system could deliver on a clear day. As a result, the system would overheat and shut down, with restart occurring soon thereafter. The cycling problem was resolved by temporarily deactivating part of the system, thereby reducing the energy output.

Most systems automatically activate in the morning and automatically turn off at night. However one system, Southern Union Refining Co., required an operator to be present on days when the system was operating. On days when an operator was not available because of various supervisory reasons, the system could not be activated and so no energy was supplied.

System-Caused Losses -- System-related causes of energy loss are those that occur during normal operation. This category includes activation thresholds, control system lag, and intercollector shadowing.

The activation threshold losses occur because all collector-field control systems have an insolation threshold below which the system either will not "come up" or will "stow" if operating. Although this threshold represents a minor portion of clear-day insolation, it can represent a major portion of the available energy during partly cloudy or hazy days.

The second system-related cause of energy loss, control system lag, results from collector-field control systems that incorporate a time-lag function to prohibit rapid cycling during cloudy weather. This time lag, in addition to the slew rate of the tracking drives, causes loss of available energy, especially on cloudy days when the passage of clouds initiates a transient from which it takes the control system several minutes to recover.

Collector shadowing occurs in the early morning and late evening when the sun's altitude angle is small. The amount of energy lost is a function of the spacing between collector rows and the sun's altitude angle. This spacing is represented by the coverage fraction shown in Table 2-6. The estimated amount of energy lost over the year because of shadowing was found using results of computer system design studies.[13]

Table 2-6

Annual Percentage of Energy Lost from Shadowing

System	Coverage (%)	Yearly Shadowing Losses (%)
Capital Concrete	NA	NA
Caterpillar Tractor	52.5	8
Dow Chemical	44	5
Home Laundry	40.5	3
Lone Star Brewery	52.5	8
Ore-Ida Foods	60	15
Southern Union Refining	43.4	2 (E-W)
USS Chemicals	35	3

Energy is also lost when the system is shut down for maintenance and repair. In this study, the energy lost during long periods of system or DAS nonoperation are not considered as a loss since this condition is not representative of normal system performance. However, short periods of system failure or partial system shutdown do contribute to this category of loss. The periods of operation from which full-year performance extrapolations have been made are indicated in Figure 2-10.

The total operational losses are a combination of the energy lost because of a lack of demand and that lost because of nonoperation. A summary of the percentage of these losses relative to the energy in the plane of the collector is given in Table 2-7.

Measurement of Incident Energy -- In effect, operational losses are the difference between the energy that would have been available in the plane of the collectors if they had been operating and that which was actually measured in the plane of the collectors. This measured energy is labeled "energy incident when system operating." The measurement was made using two different techniques at the different sites.

One method, noted as Method #1 in the list below, is to measure the direct normal solar radiation only when the system is operating using a tracking NIP. The energy incident on the collector plane is then calculated by multiplying the direct normal insolation by the cosine of the angle of incidence.

The second method of measurement, noted as Method #2 below, is to attach two pyranometers to the aperture of one of the collector rows. One of the pyranometers has a shadow band over the sensor along the tracking axis, which occludes the direct normal component. Since pyranometers measure direct normal, diffuse, and reflected irradiation on the aperture, the

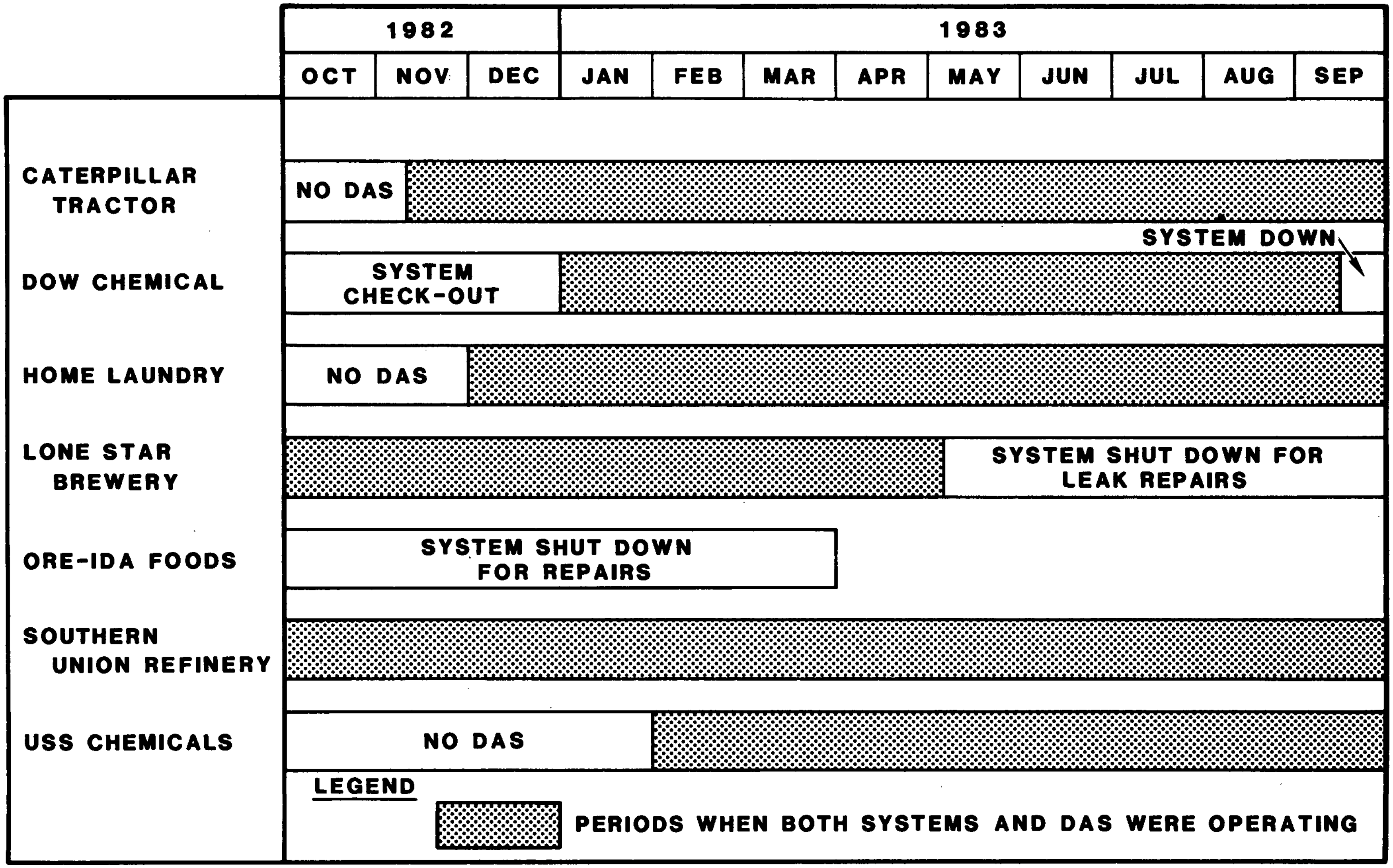

Figure 2-10. Major Periods of System Operation with Data Collection

difference between the output of the two instruments represents insolation in the plane of the collector. A summary of the measurement techniques used is given in Table 2-8.

Table 2-7

Percentage of Energy Lost from Lack of Demand or Solar Energy System Downtime

Caterpillar Tractor	82%
Southern Union Refining	69%
Home Laundry	68%
Lone Star Brewery	41%
USS Chemicals	38%
Dow Chemical	27%
Ore-Ida Foods	---
Capital Concrete	---

Table 2-8

Insolation Measurement Technique

System	Method
Capital Concrete	#1
Caterpillar Tractor	#2
Dow Chemical	#1
Home Laundry	#1
Lone Star Brewery	#2
Ore-Ida Foods	#1
Southern Union Refining	#2
USS Chemicals	#1

Collector Field Losses

Part of the energy that falls on the collector aperture is lost, resulting in reduced system performance. This loss of energy is composed of optical and thermal components. Optical losses result from less-than-perfect reflectance of the reflector and less-than-perfect transmittance of the receiver cover shield, both of which can be further reduced by dirt. When collector fields are washed either naturally with rain or artificially, a significant increase in collector performance is observed. Additional optical losses occur because of reflectance from the receiver tube and manufacturing inaccuracies in the reflector surface. In addition, when the sun is not normal to the aperture, some of the rays reflected from the concentrator will be reflected off the end of the receiver tube.

One final contributor to collector field optical losses is inaccurate tracking. If the tracking system does not align the collector precisely, some or all of the reflected energy will miss the receiver tube and not be absorbed.

Once the solar energy has been absorbed on the receiver tube, additional energy is lost by thermal means of reradiation, conduction, and convection. These losses are proportional to the operating temperature of the system and occur not only from the receiver tube but also at its supports and at interconnection points between collector banks. Also energy is lost in startup of the collector field.

The total of the optical and thermal losses from the collector field represent the energy incident in an operating aperture that is not collected and transferred to the heat-transfer fluid. The ratio of collected to incident energy in the plane of the collector is called the collector-field efficiency. A summary of the measured values of the annual average collector-field losses is given in Table 2-9.

Table 2-9

Annual Collector Field Losses

Dow Chemical	72%
Lone Star Brewery	67%
Southern Union Refining	67%
Caterpillar Tractor	65%
Home Laundry	60%
USS Chemicals	49%
Ore-Ida Foods	---
Capital Concrete	---

Balance-of-Plant Heat Losses

Some thermal energy is lost from the system between the solar collector field and the point of use. Two major sources of this loss are (1) the heat lost from the fluid piping between the collector field and the process and (2) that lost in the heat exchange process between the solar heat-transfer fluid and the process fluid (hot water or steam in these systems).

In general, these losses are small in magnitude since they come at the end of a long chain of major losses. However, their percentage is significant because, as other losses are reduced, the system heat losses will become a greater percentage of the total loss. Yearly average values of these losses in terms of percent of energy collected, based on the measured data, are given in Table 2-10.

The large variation in these figures represents a difference in system design, collector-field fluid temperature, and quality of insulation. Caterpillar Tractor is a singular example of low system heat losses (0%). In this design, no intermediate heat-transfer fluid is used, and the system is located just above the existing process heat system.

Table 2-10

Balance-of-Plant Heat Losses

Lone Star Brewery	48%
Southern Union Refining	41%
Dow Chemical	32%
Home Laundry	18%
USS Chemicals	15%
Caterpillar Tractor	0%
Ore-Ida Foods	---
Capital Concrete	---

Parasitic Energy Losses -- Parasitic losses include the electrical power required to operate circulating pumps, the collector drive, control systems, and heat tracing (if used). The measured parasitic losses for each system are indicated in Table 2-11. Data are presented for both operating and idle (nonoperating) conditions and the yearly average derived from the operating data. The yearly average power consumption is presented in terms of a constant (24 h/day) power consumption.

Since parasitic energy is usually consumed in the form of electricity, it is difficult to account for these losses in an overall energy balance. In some analyses, a comparison is made by multiplying electrical parasitics by a factor of from 3 to 10 to represent the heat-to-work conversion efficiency, and then subtracting this from the system output. However, in this analysis, the parasitic data are reported separately, and no attempt has been made to subtract them from the system energy outputs.

The last column in Table 2-11 is the ratio between parasitic losses and thermal output energy with no attempt to include a conversion efficiency. If a 25% to 30% conversion efficiency were applied, then the net energy production of some systems would be significantly reduced.

Table 2-11

Parasitic Energy Consumption

	Instantaneous				Yearly Averages		
	Operating		Idle				
	kW	W/m^2	kW	W/m^2	kW	W/m^2	% Output*
Capitol Concrete	---	---	---	---	---	---	---
Caterpillar Tractor Co.	13.4	2.86	0	0	1.6	0.34	3.0%
Dow Chemical	1.8	1.95	0.44	0.48	0.7	0.76	4.1%
Home Laundry	6.8	11.3	1.0	1.7	1.35	2.2	10.4%
Lone Star Brewery	1.31	1.5	0	0	0.282	0.3	2.5%
Ore-Ida Foods	---	---	---	---	---	---	---
Southern Union Refinery	16	17.0	1.2	1.3	2.3	2.5	19.1%
USS Chemicals	13	2.8	4	0.9	4.8	1.0	2.9%

*Parasitic energy in KW_e divided by the energy produced by the system in KW_{th}.

Overview

The experimental results discussed above are summarized in Figure 2-11. The figure is arranged in descending order of the amount of energy delivered by each system. The system located in the lowest average insolation region (USS Chemicals located in Haverhill, OH) outperformed all of the other sytems, some located in regions with more than twice the available direct normal insolation.

Further comparisons may be made by considering the percentage loss between each energy step from the direct normal insolation arriving at the site to the energy delivered to the system. Table 2-12 provides such a comparison.

The cosine losses of most systems are similar. The notable exception is Southern Union Refining Co. where the tracking axes of the collectors are oriented in the east-west direction rather than the north-south as are the other systems. The east-west orientation gives a more uniform output over the year but greater cosine losses.

Operational losses are high in three systems--Home Laundry, Southern Union Refining Co. and Caterpillar Tractor. High operational losses for Home Laundry occurred because of early afternoon plant shutdown and lack of weekend operation. Caterpillar Tractor has somewhat similar time restrictions on demand due to reductions in work schedules during FY 1983. Demand was also low during operational periods, which required a major portion of the system to be deactivated. High operational losses for Southern Union Refining Co. were caused largely by system failures and occasional unavailability of an operator to turn the system on and to monitor its operation.

Collector losses are similar for most systems, ranging between 50% and 70% of the energy incident while operating.

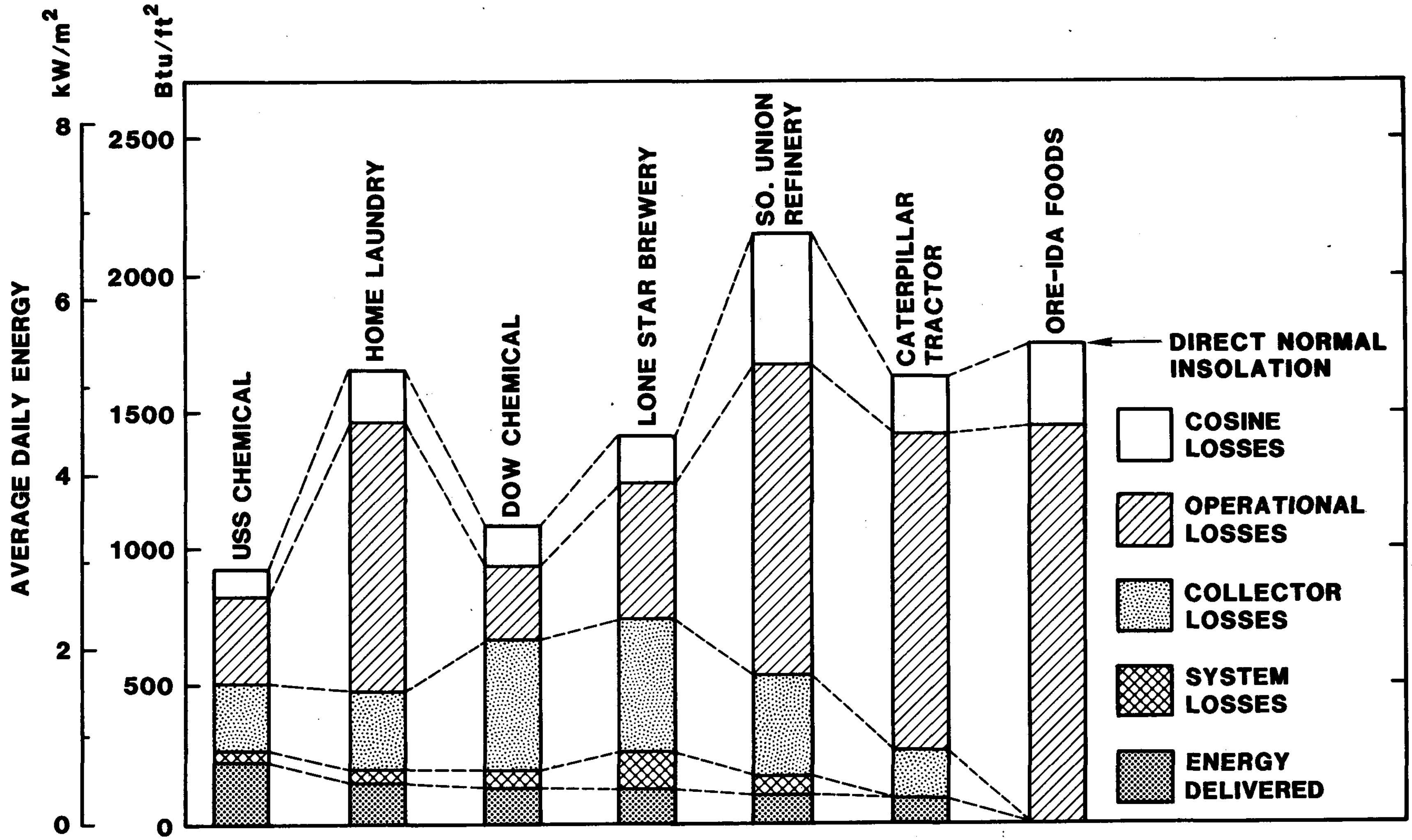

Figure 2-11. Summary Comparison of Measured System Performance

Table 2-12

Comparison of Individual Energy Losses

	Cosine Losses	Operational Losses	Collector Losses	System Losses
USS Chemicals	12%	38%	49%	15%
Home Laundry	11%	68%	60%	18%
Dow Chemical	15%	27%	72%	32%
Lone Star Brewery	13%	41%	67%	48%
Southern Union Refining Co.	22%	69%	67%	41%
Caterpillar Tractor	12%	82%	65%	0%
Ore-Ida Foods	17%	---	---	---

Note: Percentages are the portion of energy remaining after losses from the previous column have been deducted.

System losses are highest for the Lone Star Brewery system. An evaluation of the piping design and insulation did not indicate a reason for this system to have higher losses than the others. However, it operates at a higher temperature and uses an intermediate heat-transfer fluid. At the opposite extreme, the Caterpillar Tractor system has no system losses because there is no intermediate heat-transfer fluid and the system is closely coupled to the industrial load.

Clear-Day Performance

During each reporting period, a clear day was selected for detailed performance review. Data are plotted hourly and give a picture of the instantaneous performance of the system with relatively stable solar energy input. Clear-day performance data represent the maximum energy collection conditions and the conditions for which the system was designed.

Examples of clear-day performance data are presented in Figures 2-12 through 2-17 for the systems that reported data during FY 1983. A day near the equinox was selected to represent average insolation input. Energy collection and delivery are shown in addition to the temperature and flow of fluid through the collector field.

Since the direct normal insolation is not measured at most sites, clear-day insolation data for a similar day near the equinox from the TMY data set at a nearby location was used. Insolation in the collector plane is determined at each site. It is either calculated from a direct normal measurement and the cosine of the angle of incidence or is the difference between two pyrheliometers mounted in the plane of the collectors as described on p. 80.

Energy collected is measured at the collector-field exit and is the product of field flow, temperature difference, and fluid-specific heat. The energy delivered as steam or hot water is measured at the interface between the solar energy system and the industrial process. In the case of Caterpillar Tractor, process water is circulated through the collectors and immediately re-enters the industrial process heat system. Therefore, there is no difference between energy collected and energy delivered.

An asymmetry in the beam energy incident in the collector plane is evident for most of the systems. It probably is caused by a misalignment of the tracking system, which improves in either the morning or the afternoon, and by offsets of the tracking axes from true north-south for some systems. The dip at noontime for all the systems except Southern Union Refining

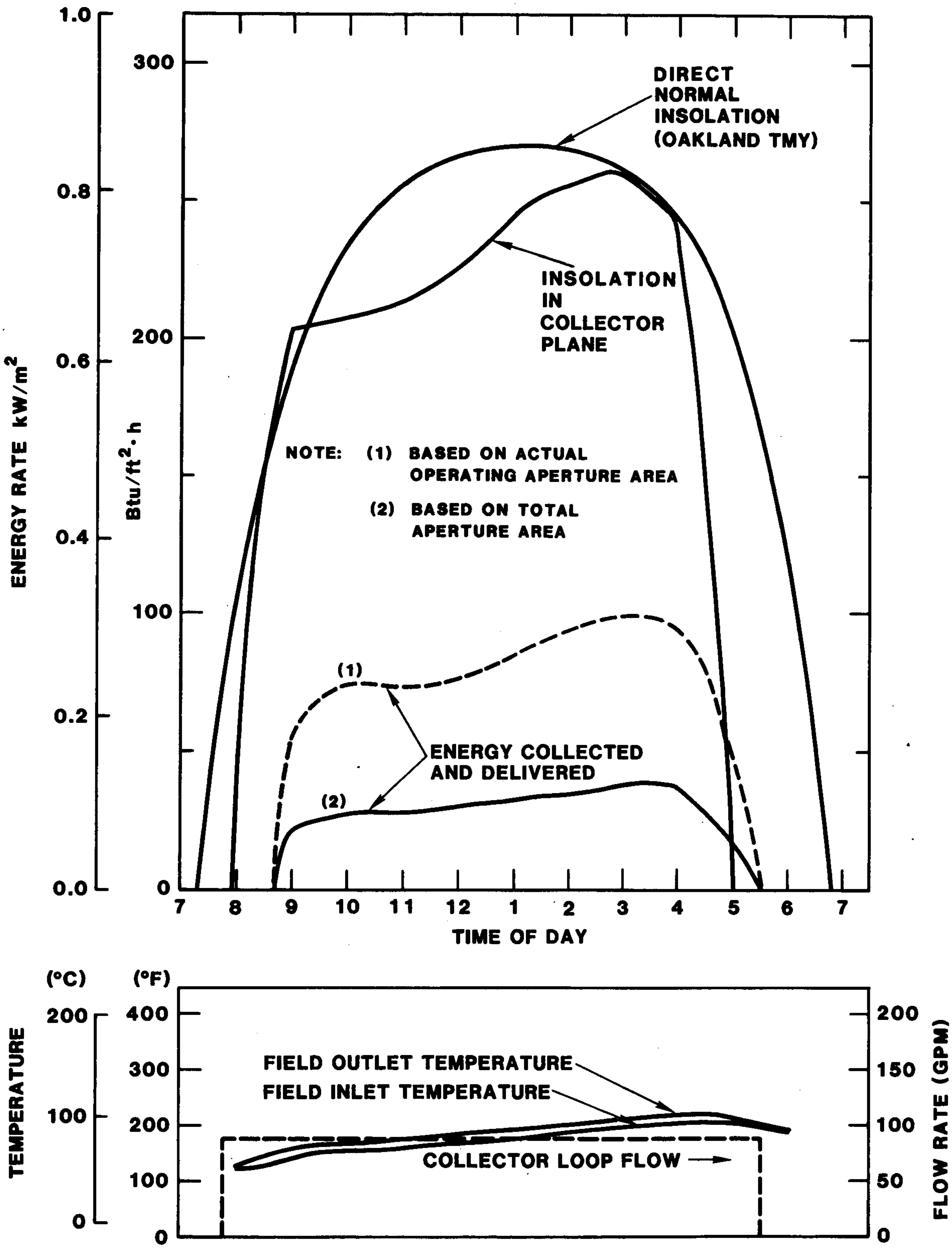

Figure 2-12. Clear-Day Performance - September 11, 1983 - Caterpillar Tractor Co.

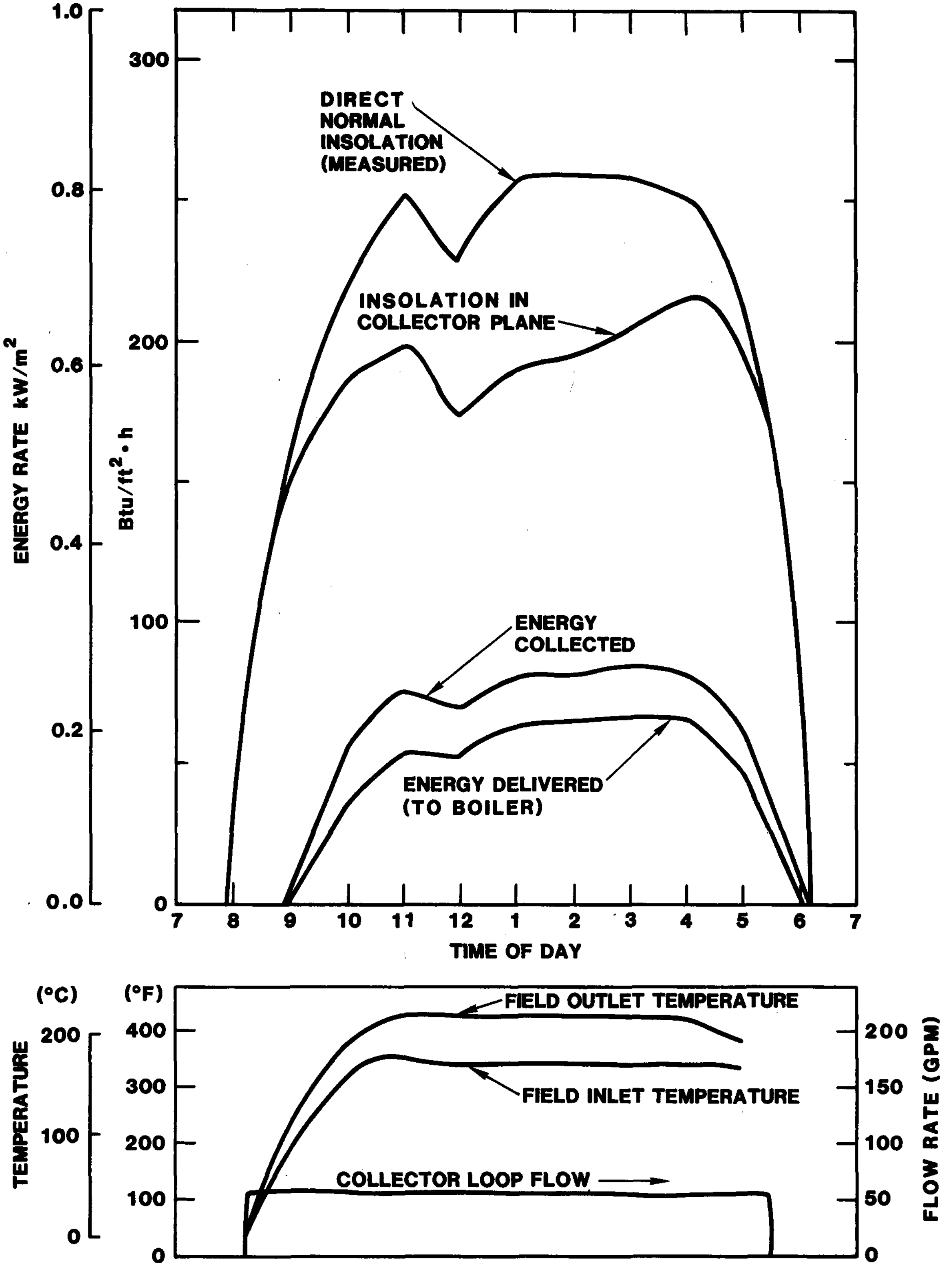

Figure 2-13. Clear-Day Performance - March 2, 1983 - Dow Chemical Co.

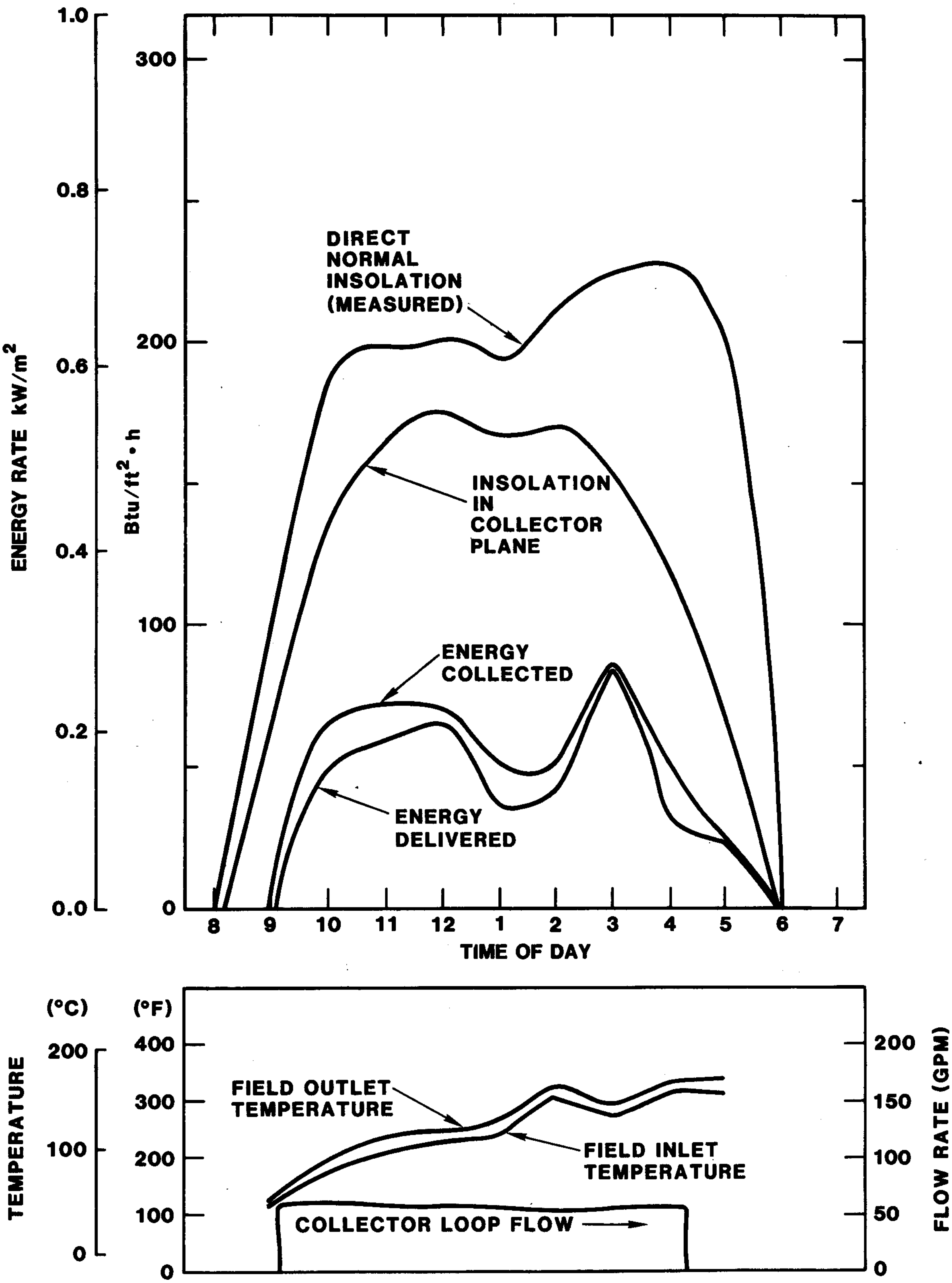

Figure 2-14. Clear-Day Performance - September 7, 1983 - Home Laundry

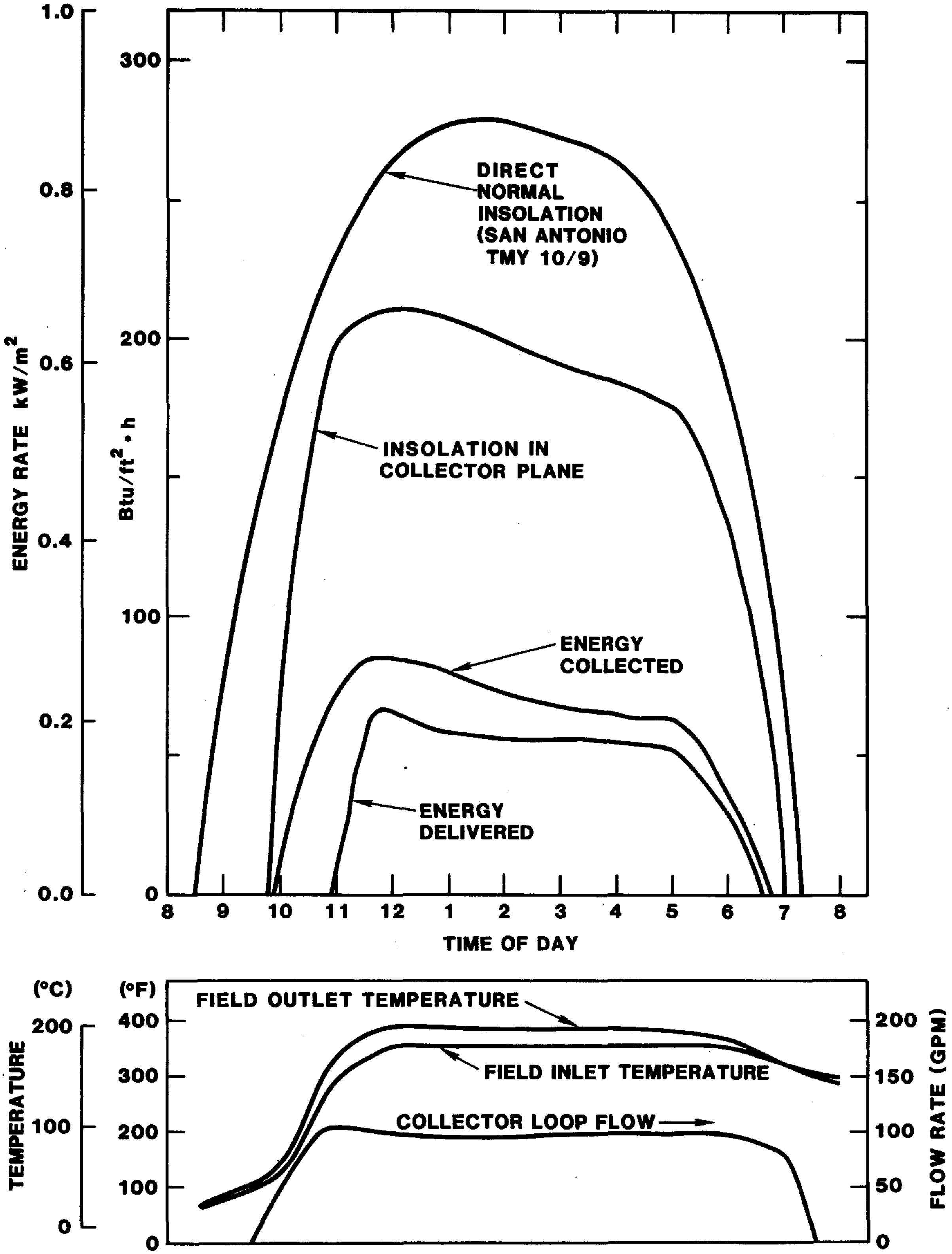

Figure 2-15. Clear-Day Performance - October 24, 1983 - Lone Star Brewery

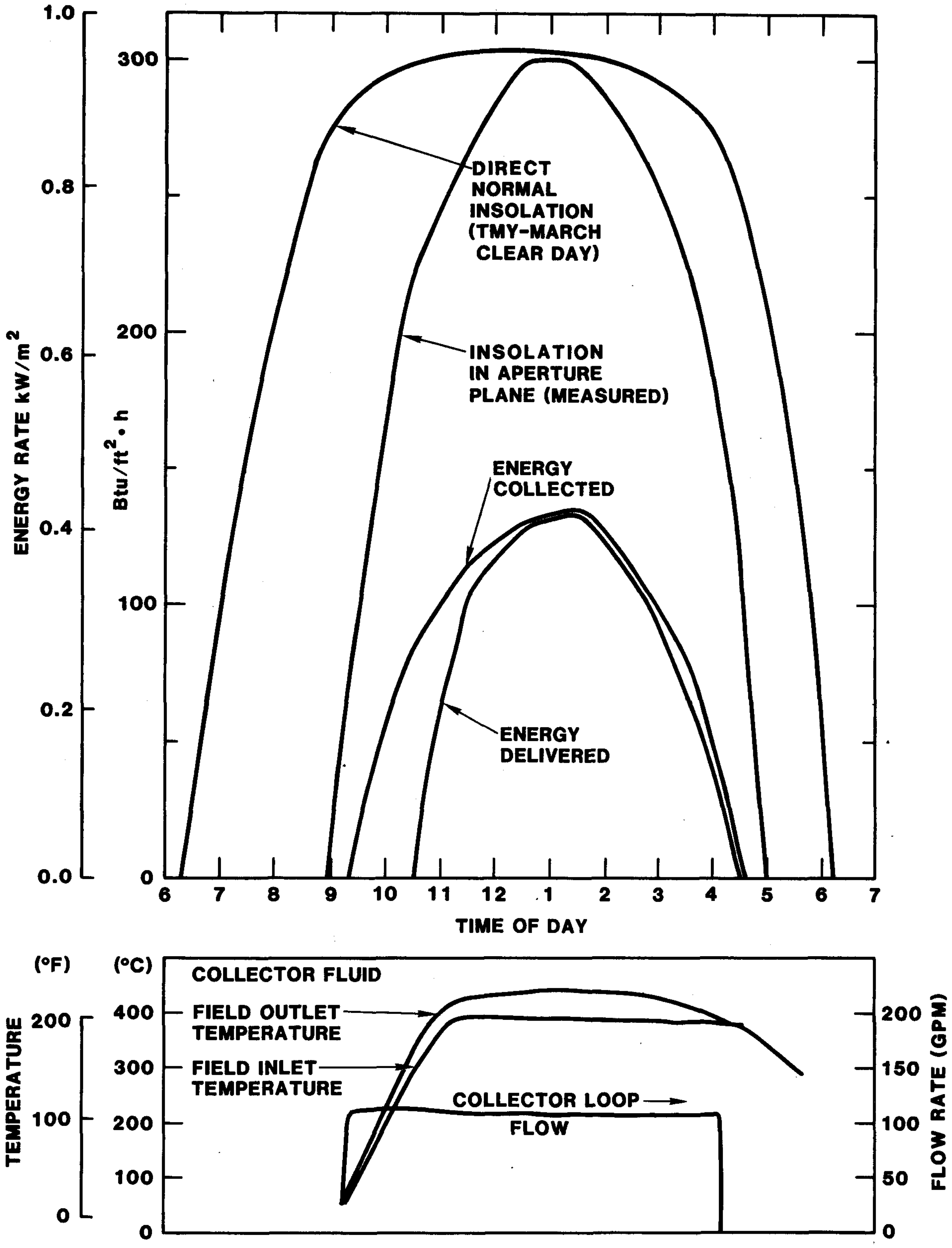

Figure 2-16. Clear-Day Performance - March 10, 1983 - Southern Union Refining Co.

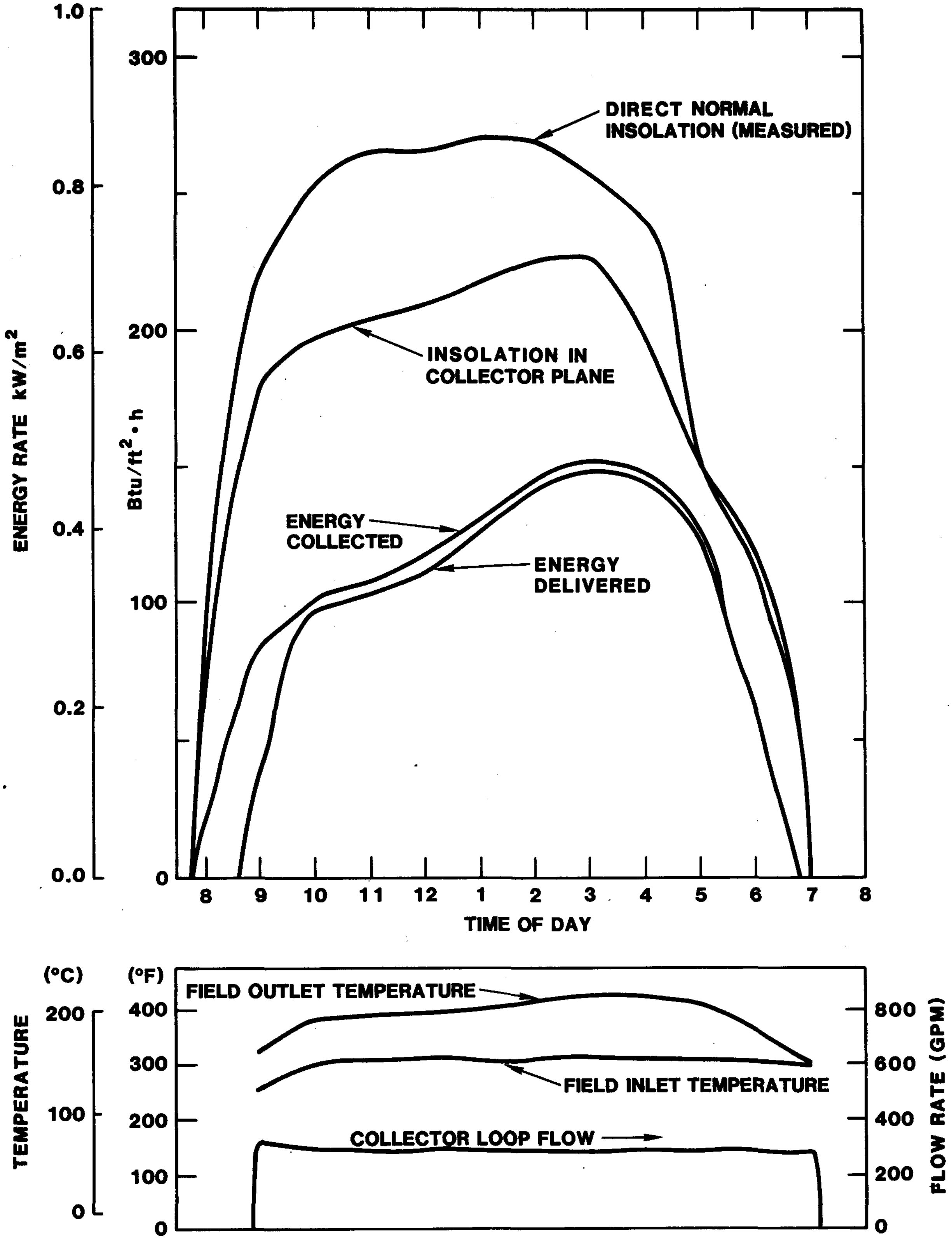

Figure 2-17. Clear-Day Performance - September 8, 1983 - USS Chemicals Co.

Co. is due to their north-south tracking axis orientation, which produces maximum cosine losses at noontime. The Southern Union collectors are oriented in the east-west direction and therefore have the lowest (zero) cosine loss at noon.

CHAPTER 3. COMPUTER SIMULATION STUDIES

SOLIPH Model

As part of the program to evaluate the performance of these systems, a computer simulation code called SOLIPH was developed by the Solar Energy Research Institute (SERI). This code uses an hour-by-hour simulation that calculates average system conditions during the hour, based on input data from weather tapes for appropriate site locations.

Typical weather data are available for 234 sites in the United States. These data sets include hourly values of insolation and ambient temperature. For most sites, the direct normal insolation data were fabricated from long-term recordings of percentage sunshine and cloud cover conditions. Data sites close to the IPH system sites were selected for input to the computer model.

Each system (except Capitol Concrete) was modeled in terms of collectors, system components, and connective piping. Performance and heat-loss models were developed for each. System operational characteristics including start-up conditions, set-points for various automatic control functions, and plant process schedules were included in the control portion of the model.

Data output includes total irradiation at the location, collector plane irradiation, energy collected, energy delivered to the process, and parasitic energy. These parameters are totaled for a day, a month, or a year. In addition, collector-field temperatures and flow are available on an hour-by-hour basis.

The results of these computer simulation studies are reported in SERI TR-253-2161.[12] Calculated performance for all systems except Capitol Concrete (which was not modeled) are presented and analyzed in Volume I of that report. Volume II contains program listings and complete model output for each site. Only the highlights of these results will be covered here.

Annual Performance Predictions

Annual predicted performance data for each system are summarized in Appendix A as Tables A-1 through A-8. Because the Home Laundry system can operate either in a steam generation or a domestic hot water heating mode, a table representing each mode is presented. A comparison plot of these data is given in Figure 3-1. The data have been normalized by collector-aperture area and divided by 365 days for comparison with Figure 2-11. The actual system output shown in Figure 2-11 is also shown in Figure 3-1.

The systems are ordered from left to right in terms of their predicted output. As was true with Figure 2-11, the systems located in higher insolation regions do not necessarily have the highest expected output. However, the order generally follows insolation level with the exception of Caterpillar Tractor where the collectors operate at a lower temperature and the solar energy system is directly coupled to the industrial process heat system.

Operational losses (losses by load mismatch) are present only for Caterpillar Tractor Co. and for Home Laundry. These

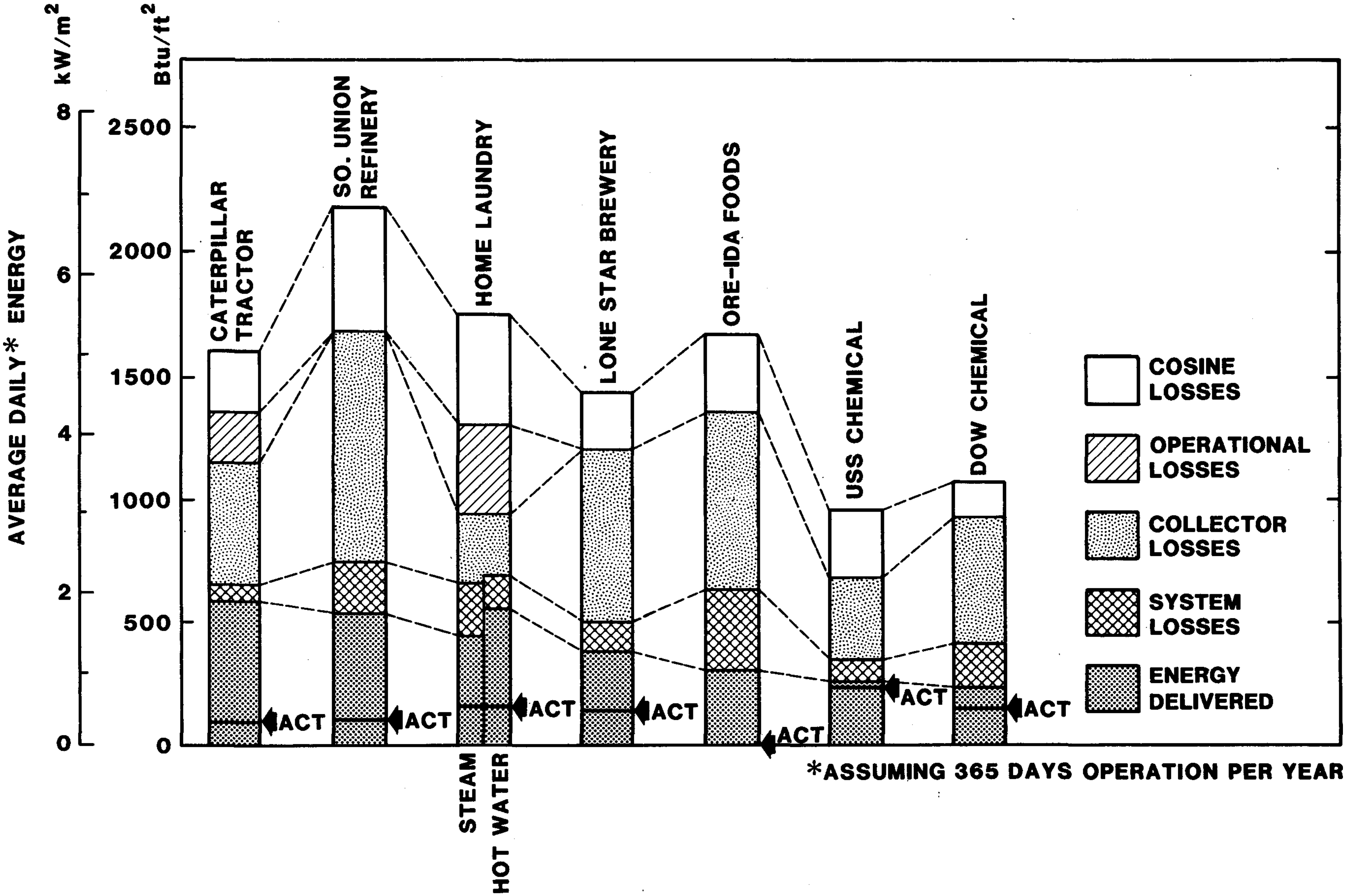

Figure 3-1. Annual Predicted Performance

losses occur because the Caterpillar Tractor system was modeled for a 6 day/wk operational period and Home Laundry for a 5 day/wk operational period from 7 a.m. to 3:30 p.m.

Three systems show low collection losses: Caterpillar Tractor, USS Chemicals, and Home Laundry. The first two systems use SKI T-700A collectors, which have improved performance, and the Home Laundry system uses Del collectors with silvered glass reflectors giving them a very high reflectance and therefore high performance.

Balance-of-plant losses (those caused by thermal loss between the collectors and the process heat system) are lowest at Caterpillar Tractor and USS Chemicals. The Caterpillar system is close-coupled to its load, and the USS Chemicals system is extremely well insulated. The Ore-Ida Foods system shows high system losses because of the long distance between the collector field and the industrial process load. This system, originally proposed as a roof-top installation, was relocated to a vacant land area at some distance from the process load.

The actual (measured) system output indicated on Figure 3-1 is taken from Figure 2-11. The difference between the actual (measured) output and the predicted output consists of two factors--inability to model the system precisely and inability of the system to operate as expected. The first factor is discussed in Reference 11, which concludes that modeling could be improved by including the effect of dust and dirt on collector surface optical properties, transient system performance caused by cloudcover, and by using actual solar irradiance and other weather data. The second is a measure of the operational and maintenance difficulties with the system. This difference represents a grey area that could be reduced by expanding the complexity of the model and ensuring that the system is operational every day.

Annual average subsystem and system efficiencies as defined in Chapter 2 are given in Table 3-1 for the SOLIPH model data. Parasitic energy consumption is given as a percentage of the energy delivered to the process.

Table 3-1

SOLIPH Predictions of Annual Average Efficiencies

Project	Collector Field Efficiency (%)	Delivery System Efficiency (%)	System Thermal Efficiency (%)	Parasitic Energy* (%)
Caterpillar Tractor Co.	56	92	52	1
Dow Chemical	45	52	23	2
Home Laundry (steam)	50	67	34	6
Home Laundry (DHW)	53	81	42	5
Lone Star Brewery	42	76	32	1
Ore-Ida Foods	46	48	22	6
Southern Union Refining Co.	43	73	32	9
USS Chemicals	48	76	36	3

*Parasitic energy in KW_e divided by energy production by system in KW_{th}.

Predicted annual system thermal efficiencies vary from a high of 52% (Caterpillar) to a low of 22% (Ore-Ida Foods). The high system efficiency of the Caterpillar Tractor system is attributable to its lower operating temperature and therefore lower losses. Also the collectors used are upgraded versions of the SKI T-700A. The low system thermal efficiency of the Ore-Ida system is caused by the high mass of the system piping and the long distance between the collector field and the load.

Clear-Day Performance Predictions

Hour-by-hour energies, temperatures, and flows for one clear day in each month are presented in SERI/TR-253-2161 to describe the instantaneous performance of each system. One of these clear-day performance printouts for each system has been reproduced in Appendix A as Tables A-9 through A-16. A September clear day was selected for each system except for Home Laundry. For Home Laundry, the March clear day was selected because the September day was not completely clear. Sun angles for the March day are similar to those for the September day.

The important performance parameters from these listings are plotted as Figures 3-2 through 3-8. These may be compared with the measured clear-day system performance shown in Figures 2-12 through 2-17.

The radiation in the collector plane for most of the systems shows the typical noontime dip of the single axis tracking collector with the tracking axis oriented in the north-south direction. With this orientation, the collector aperture is closer to normal to the sun's rays in the morning and afternoon than at noon. In fact, on the equinoxes in March and September, the collector aperture is normal to the sun at sunrise and sunset.

The opposite condition is exhibited by the east-west oriented Southern Union Refining Co. system. With this orientation, the collector apertures are normal to the sun at noon, which results in a "peaked" solar input rather than the more constant daily input of the north-south oriented collectors. However, as mentioned in the previous section, the average daily insolation does not vary as much over the year for the system oriented east-west.

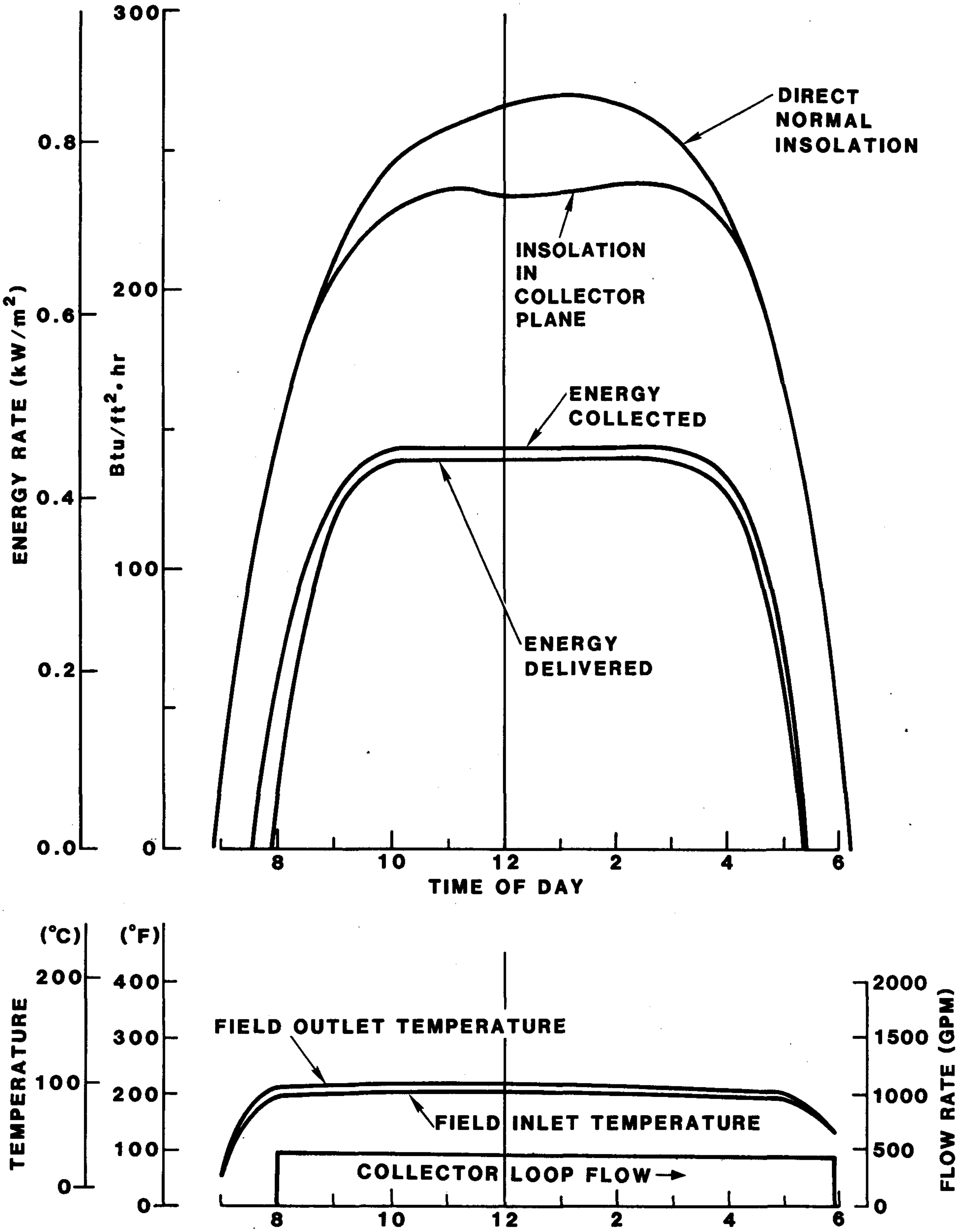

Figure 3-2. Clear-Day Simulation of Caterpillar Tractor for September 1

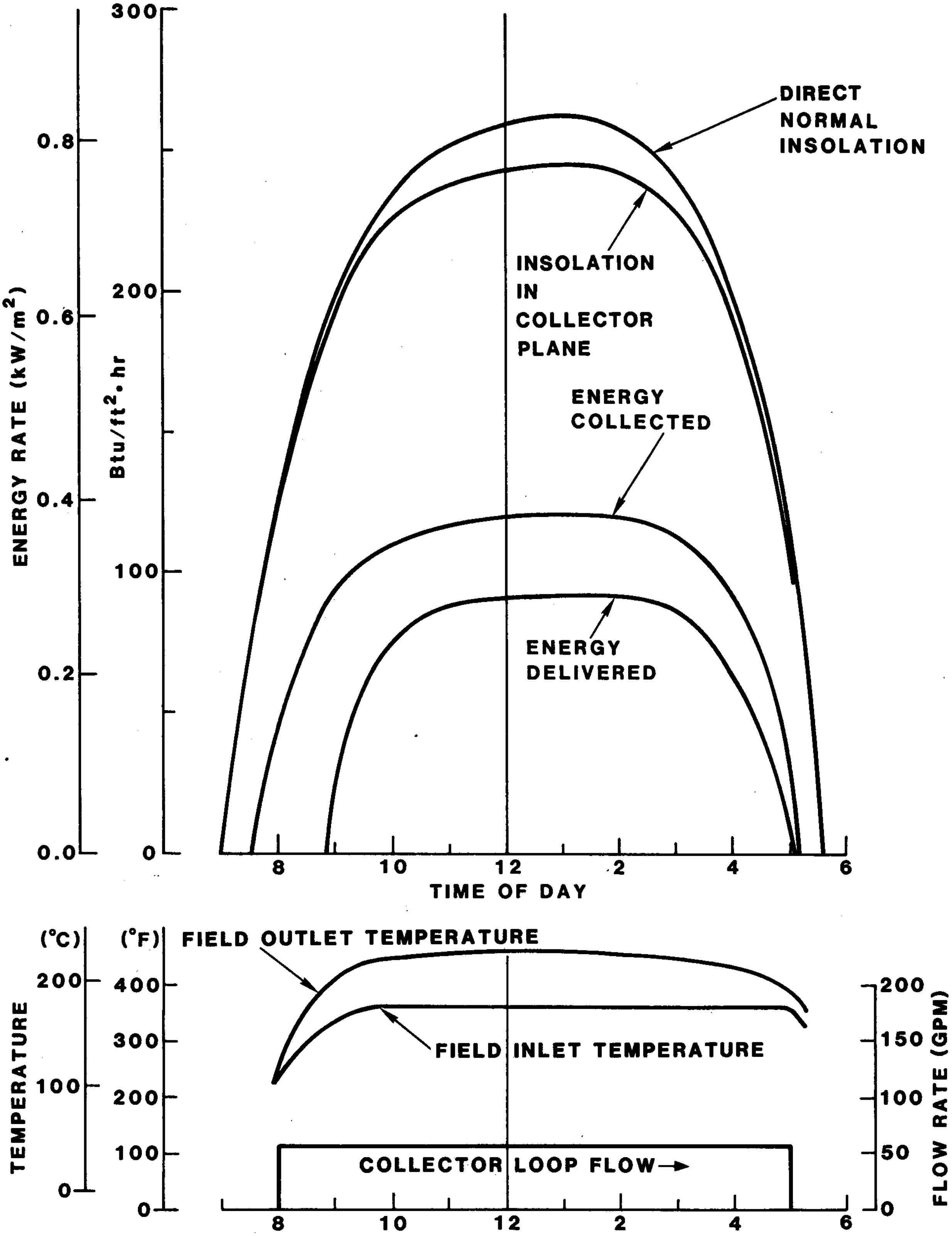

Figure 3-3. Clear-Day Simulation of Dow Chemical for September 13

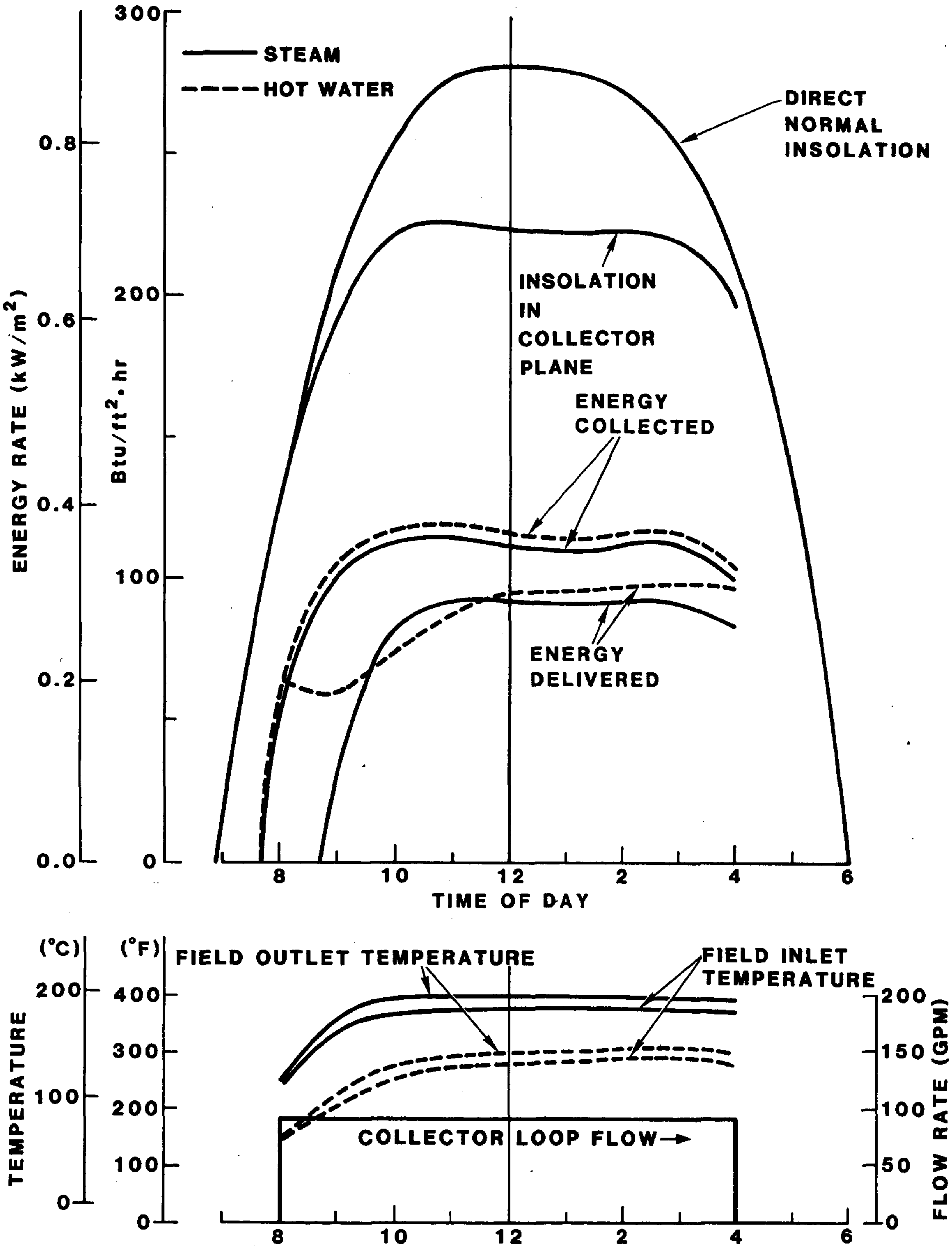

Figure 3-4. Clear-Day Simulation of Home Laundry Producing Steam or Hot Water for March 15

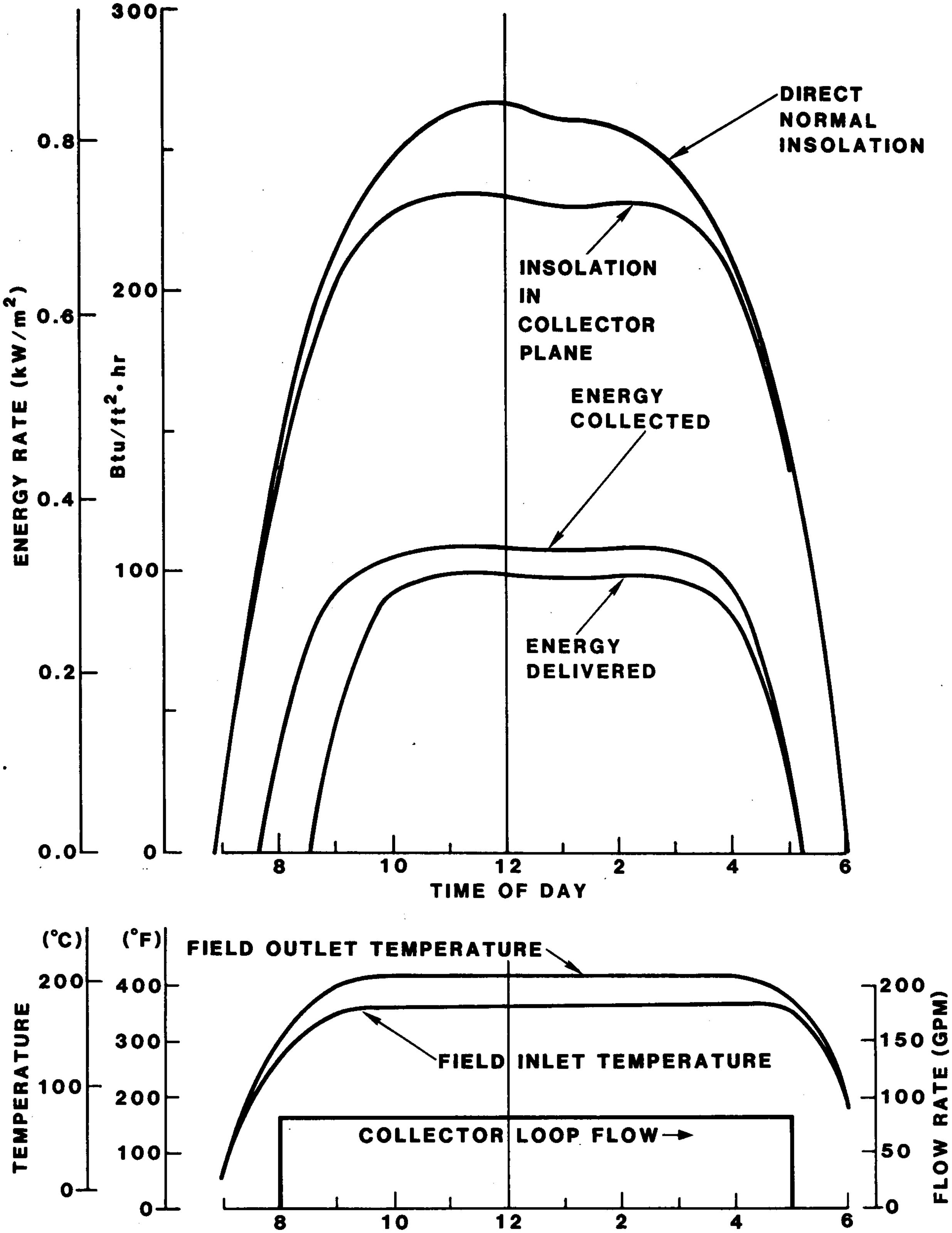

Figure 3-5. Clear-Day Simulation of Lone Star Brewery for September 18

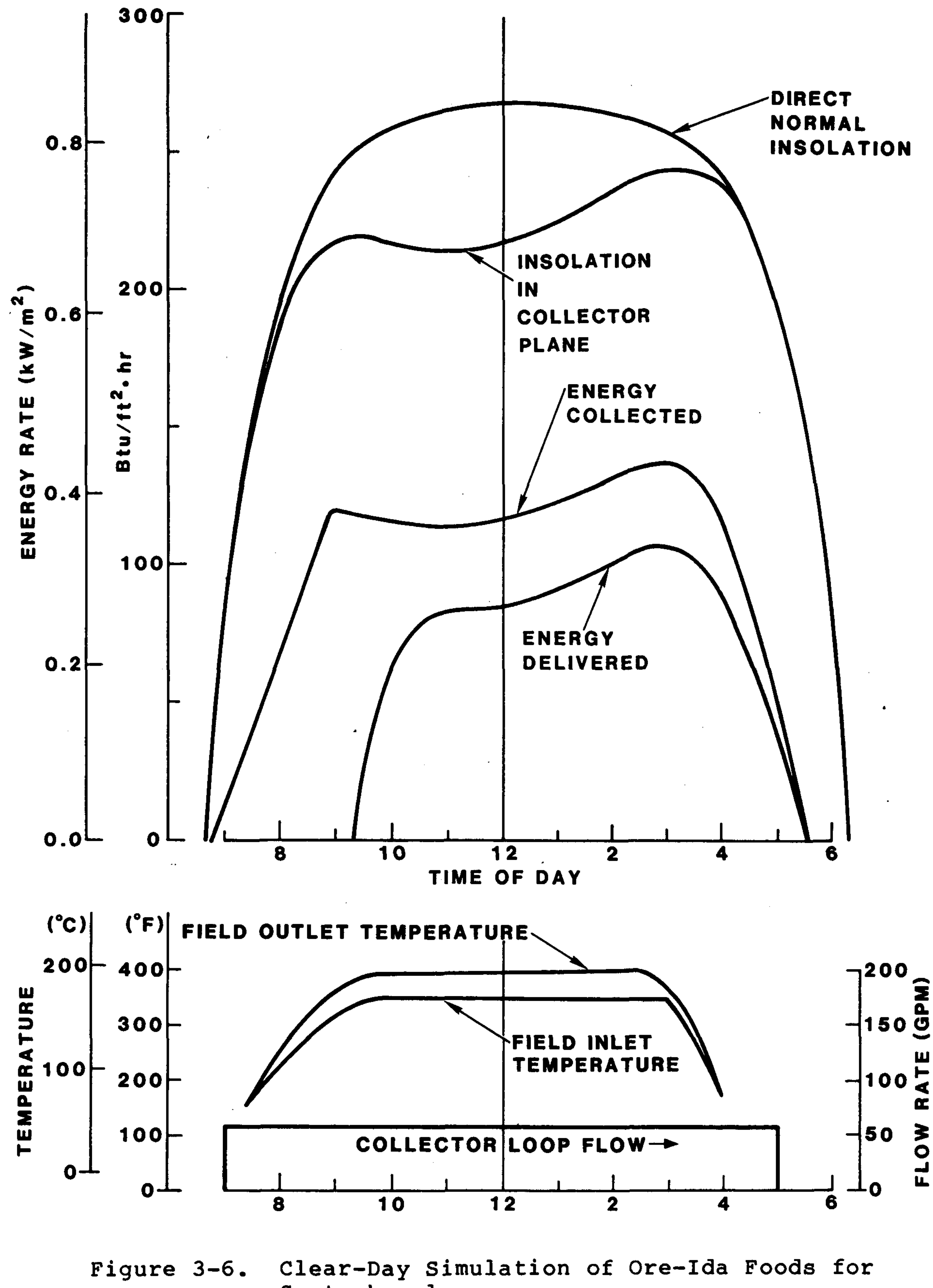

Figure 3-6. Clear-Day Simulation of Ore-Ida Foods for September 1

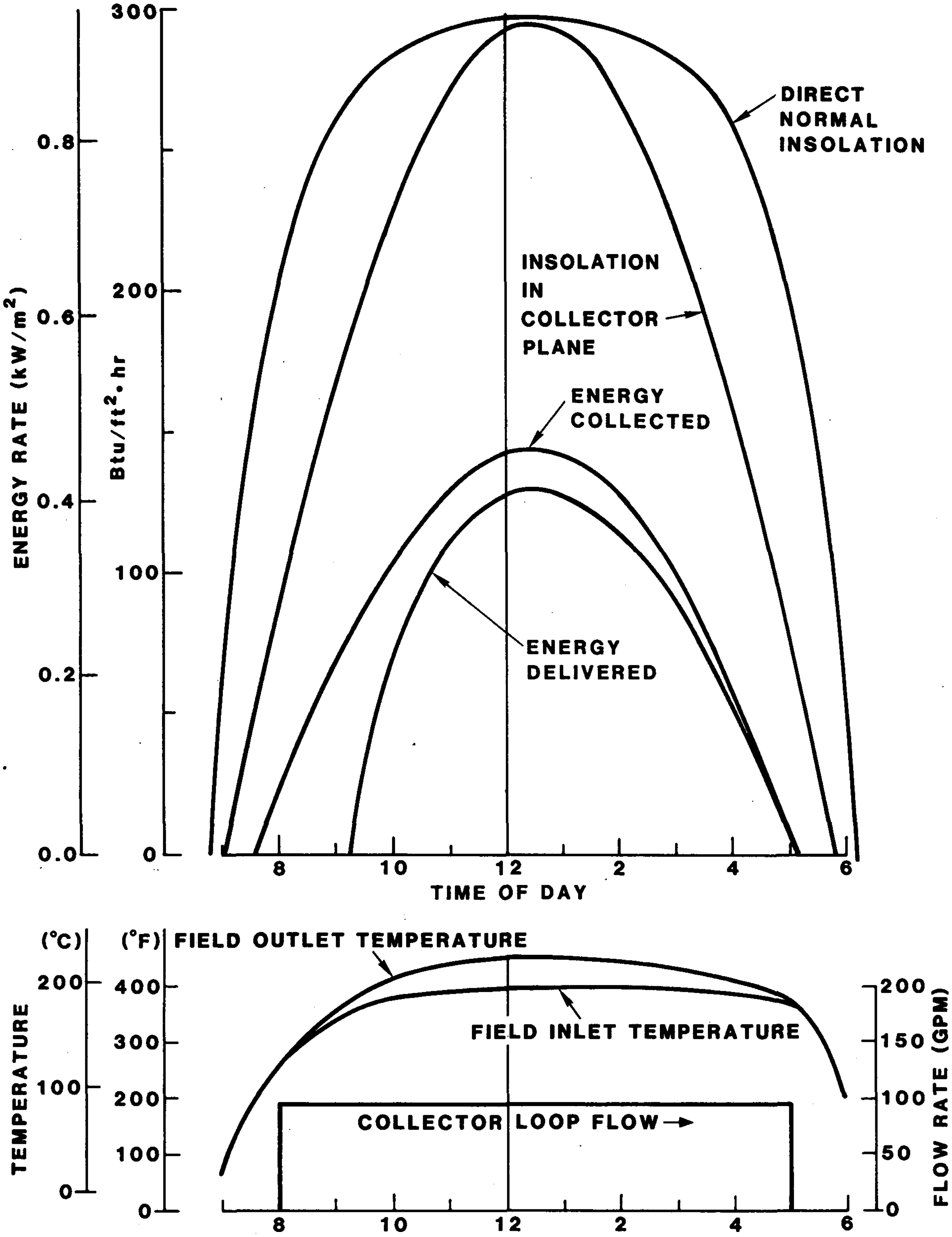

Figure 3-7. Clear-Day Simulation of Southern Union Refining Co. for September 2

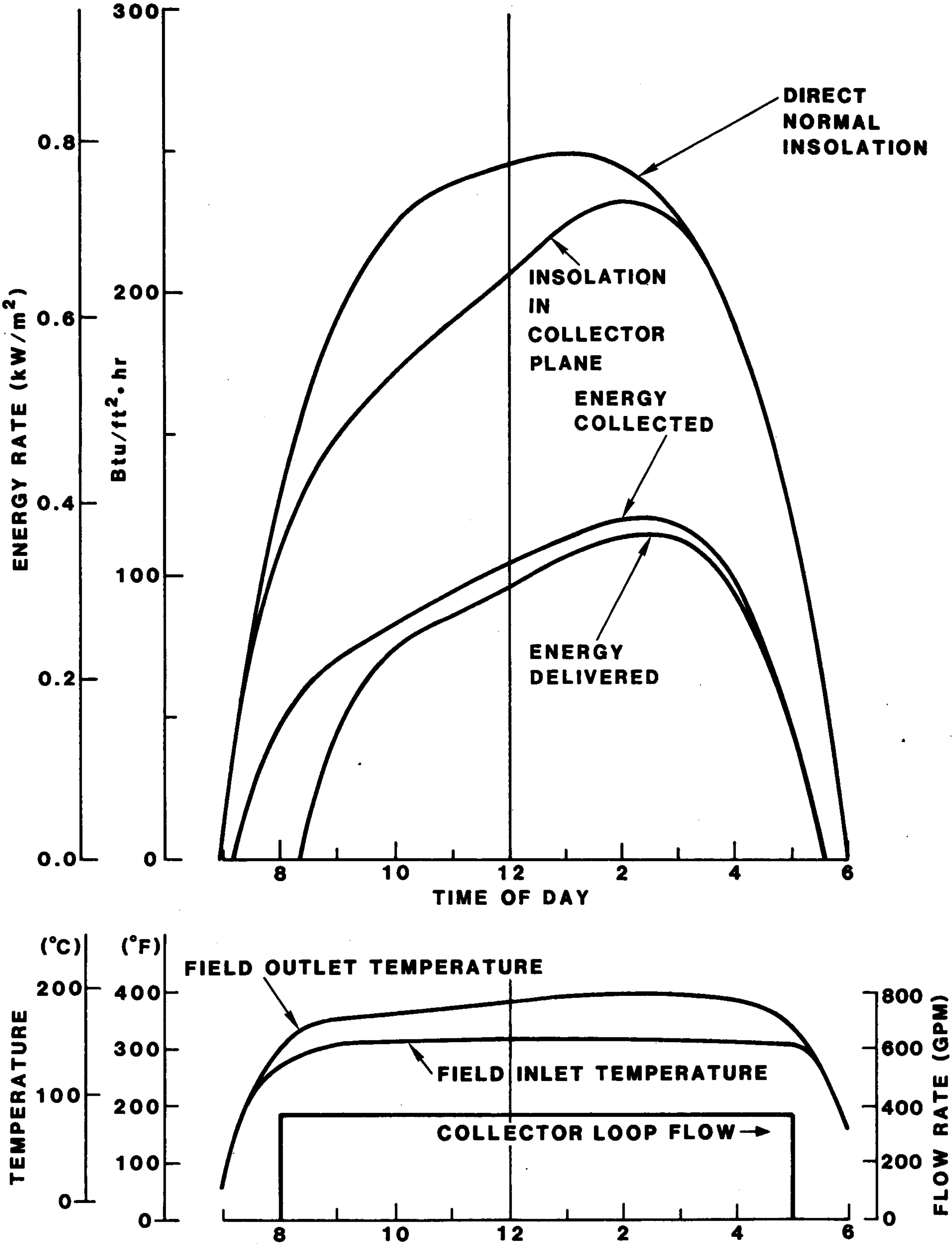

Figure 3-8. Clear-Day Simulation of USS Chemicals for September 8

There is an asymmetry between the morning and afternoon radiation in the plane of the collector at Ore-Ida Foods and at USS Chemicals. This asymmetry is caused by the orientation of the collectors, which is 11° from true north at Ore-Ida and 25° from true north at USS Chemicals.

All of the systems show a significant lag between energy collected and energy delivered in the morning. The lag represents the time required to heat the system piping and components to operating temperature. This lag is most noticeable for the Ore-Ida Foods system where there is a long length of field piping between the solar collector field and the plant interface and where the receiver tubes and piping are thick-walled high-pressure pipes. This large mass must be heated before operating temperature can be reached.

Both steam generation and hot water heating are shown for the Home Laundry system. Hot water heating occurs at a higher efficiency because the system is operating at a lower temperature. When in the hot water mode, the system starts delivering energy almost as soon as it is turned on. Steam delivery, on the other hand, requires that the system be heated to a higher temperature, and the water in the steam generator must also be heated. Therefore, in the steam mode, the warm-up time is similar to the other systems. In the model, the Home Laundry system shuts down at 4 p.m., before all of the available energy can be delivered. Actually this shutdown occurs at 3:30 p.m. but can not be modeled since the computer simulation model uses one hour increments.

The day-long performance for the clear days shown in Figures 3-3 through 3-8 is summarized in Table 3-2.

The parasitic energy loads for each system are presented as percentages of the energy delivered by the system. There is a wide variation between these. Both Dow Chemical and Lone

Star Brewery have a low parasitic energy requirement of approximately 1%, whereas Southern Union Refining Co. has a parasitic load of 8% of the system output. As discussed in the previous section, although the parasitic loads are electrical loads, no attempt has been made to incorporate a conversion efficiency into these values.

Table 3-2

SOLIPH Predictions of September* Clear-Day Average Component and System Efficiencies

Project	Collector Field Efficiency (%)	Delivery Efficiency (%)	System Thermal Efficiency (%)	Parasitic Energy** (%)
Caterpillar Tractor Co.	59	94	49	6
Dow Chemical	47	65	29	1
Home Laundry (steam)	50	71	28	5
Home Laundry (DHW)	50	81	33	4
Lone Star Brewery	44	82	33	1
Ore-Ida Foods	49	59	25	4
Southern Union Refining Co.	44	77	25	8
USS Chemicals	50	86	37	2

*For Home Laundry, a March clear day is shown since there were no full clear days in these TMY data for September.

**Parasitic energy in KW_e divided by energy production by system in KW_{th}.

CHAPTER 4. OPERATION AND MAINTENANCE

Operation and maintenance (O&M) activities were reported monthly by the contractors for the eight experiments operating under DOE funding in FY 1983. Contractors maintained a daily log of events describing problems with the solar energy system, including suspected causes of the problems and corrective action taken. They also reported O&M costs that were incurred and fossil fuel savings.

Maintenance activities consisted of routine maintenance and repair functions. Routine maintenance included activities such as collector cleaning, bearing lubrication, and operational checks. Repair functions, which consisted of component repair or replacement because of failure or malfunction, included such tasks as repair of drive mechanisms, adjustment of tracking devices, and replacement of motor seals. These activities are detailed in the following sections of this report.

O&M experience differed significantly at each of the experiments and was affected by local circumstances. Although systems were operated in the automatic mode, some contractors gave more attention to their operation than others. Where this was true, O&M costs were higher, but energy production was also higher. Other local factors also influenced O&M costs. At one experiment, Southern Union Refining Co., insurance costs were high. At Home Laundry, local property taxes were based on initial cost of equipment and ran $500/month. No other projects reported insurance or tax costs. Labor rates charged to O&M varied from $10/hr to $33/hr, and fossil fuel costs varied from

\$3.25/GJ (\$3.43/MBtu) to \$6.63 GJ (\$7/MBtu). Boiler efficiencies (for computing fossil fuel savings) ranged from 65% to 85%. These costs are summarized in Table 4-1. O&M costs ranged from $\$1.51/m^2$-yr to $\$13.67/m^2$-yr (Figure 4-1).

A summary of operation and maintenance activities at each of the experiments follows.

Capitol Concrete Products

The solar IPH system at Capitol Concrete Products was operated under DOE funding through November 1982 at which time operation was transferred to Capitol Concrete Products, the site owner. The system continued to operate into December when the feedwater line and the boiler (part of the receiver) were damaged by freezing. The system remained shutdown until May 1983 when Capitol Concrete was encouraged to resume operation by several sources of outside interest. Midwest Research of Kansas City, which was participating in a Saudi Arabian desalinization project, provided some funding. PKI, the collector manufacturer, assisted with repairs. Sandia provided both technical assistance and funding to support continued operation and reporting of data. The system operated through the rest of the fiscal year but experienced three more breakdowns detailed below. The system was available (operable) 154 days between October 1, 1982 and September 30, 1983. Forty of the 154 days were cloudy with no energy production, and the block plant was shut down for 10 more days. The system produced energy for 104 days during FY 1983. Thirty-two of these days were weekends during which the system was used to keep the plant boiler warm.

During the year, five malfunctions resulted in extended periods of downtime. They are summarized in Table 4-2.

Table 4-1

Summary -- Maintenance Costs and Fossil Fuel Savings

Project	Area (m^2)	Period of Operation	Labor Rate ($/hr)	Cost of O&M ($)	Fuel Cost ($/GJ)	Fuel Cost ($/MBtu)	Boiler Efficiencies (%)	Fossil Fuel Savings* ($)
1. Capitol Concrete	80	10/82-11/82	14-25	81	3.93	4.15	70	39
2. Caterpillar Tractor	4682	2/83-9/83	25	4945	6.63	7.00	--	21,250
3. Dow Chemical	923	1/83-9/83	14-32	2613	6.47	6.83	--	2361
4. Home Laundry	603	10/82-9/83	28	5591	6.63	7.00	70	3338
5. Lone Star Brewery	878	10/82-5/83	25	3131	4.74	5.00	65	1531
6. Ore-Ida Foods	884	--	--	--	--	--	--	--
7. Southern Union Refining Co.	937	10/82-9/83	10	1449	3.25	3.43	65	2151
8. USS Chemicals	4682	10/82-9/83	28-33	64,244	4.74	5.00	85	15,508

*Fossil fuel displaced[14] multiplied by cost of fuel at IPH site.

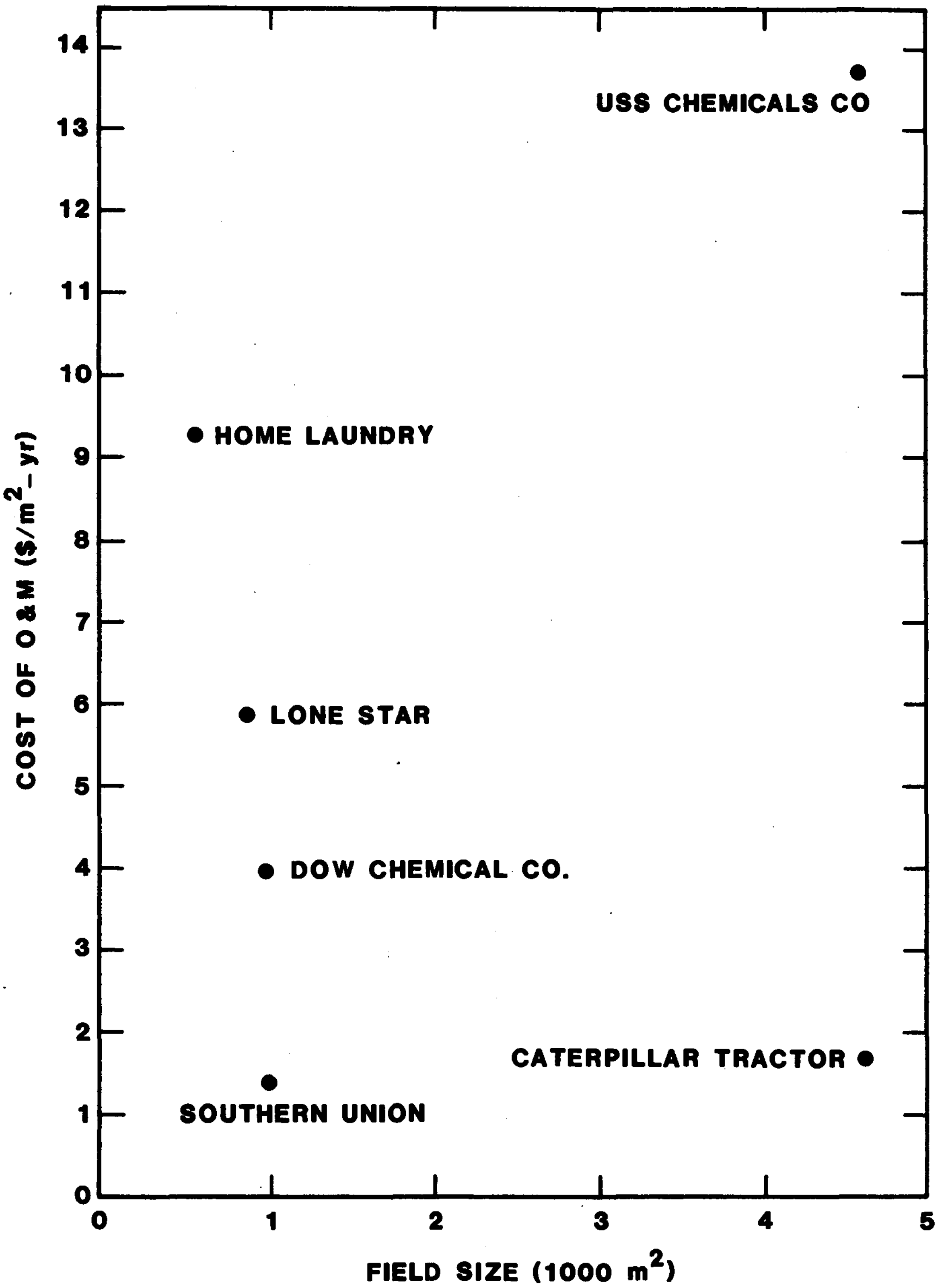

Figure 4-1. Unit Costs of O&M - IPH Experiments (Actual costs for periods of operation extrapolated to full-year cost.)

Table 4-2

Summary of Malfunctions and Downtime
for Capitol Concrete Products

October 1982 - August 1983

Month	Number of Days Down	Problem	Category
Oct	13	Elevation-control relay failure	Design
Nov	3	Feedwater flow meter gasket	Wear
Dec-Apr	143	Freeze damage to boiler	Design, Procedure
May	19	Control-relay failure	Design
Aug	14	Azimuth drive chain	Wear, Design

Detailed reliability for this system was not assessed, nor were accurate costs of maintenance and repairs maintained. Because the solar equipment was an early developmental model, the information, were it available, would not be applicable as an indication of solar IPH system performance. Knowledge gained from this experiment was used to improve the design of later model concentrators. Maintenance experience is tabulated in Table 4-3.

Maintenance costs were reported for October and November 1982, the period in FY 1983 when the system was operating under DOE funding. During this period, the system was down for 20 days for nonroutine repairs, 25 days were cloudy, and the block plant was shut down for 8 days. Energy was produced for only 8 days. The cost of routine maintenance reported was $80.50, and energy savings were $39.43.

Caterpillar Tractor Co.

The solar IPH system at Caterpillar Tractor Co. was operated under a cooperative agreement between Southwest Research

Table 4-3

Maintenance Experience for Capitol Concrete Products
October 1982 - September 1983

Date	Component	Comment	Category
Oct 1982	(1) Elevation-control relay	Poor contact on one elevation-control relay caused lower quadrant walkoff and two cables to be melted. Restored to operation in November.	Design
Nov 1982	(1) Condensate return flow meter	Changed DAS to compensate for faulty meter.	
	(2) Feedwater flow meter	Gasket failed, replaced.	Component Failure
	(3) Elevation stow limit switch	Caught on lead screw bellows, system repaired	Design
Dec 1982	(1) Boiler and feedwater line	Damaged by freezing feedwater line, repaired in March, boiler replaced in May 1983	Design
	(2) Azimuth drive	Replaced gears	Component Failure
	(3) Controller	Minor problems	Design
	(4) Mirrors	Forced out of alignment by wind	Design
Jan 1983		System Down	
Feb 1983		System Down	
Mar 1983	(1) Boiler high-temperature gasket	Unserviceable, replaced.	Component Failure
Apr 1983	(1) Flux trap	Replaced aluminum flux trap with stainless steel	Design
	(2) Overtemperature sensors	Relocated from trap to boom area.	Design
May 1983		Resumed operation after boiler installation	

Table 4-3 (Continued)

Maintenance Experience for Capitol Concrete Products
October 1982 - September 1983

Date	Component	Comment	Category
June 1983	(1) Focus problems	Balanced azimuth shadow band	
	(2) Elevation-drive control relays	Relays adjusted	
	(3) Control system	Lost track and burned aluminum jacket around piping insulation	Component Failure
July 1983		Control relays replaced, system restored to operation	
Aug 1983	(1) Azimuth drive	Chain jumped sprocket	Wear
	(2) Feedwater pump	Pump failed; changed piping to permit use of city water.	Component Failure
Sep 1983		Operated throughout month with no problems	

Institute and the DOE throughout FY 1983. At the beginning of the fiscal year (October 1982), the system was inoperative pending modification of the collectors to prevent interference between the reflectors and the pylons. The system was put into operation in mid-November, and transition from the construction phase to Phase III operation began. The acceptance test was performed in early February 1983, after which the system operated throughout the rest of the fiscal year. During the year, production at the Caterpillar plant was reduced, and the full thermal energy demand of the plant was satisfied with as little as one-third of the solar IPH system. The plant was shut down for employee vacations and for maintenance from July 5 through August 2, 1983.

Maintenance activities were minor and were primarily unscheduled for repair or adjustment of faulty components. Problems encountered were with collector tracking and with collector hydraulic drives. The central light switch was replaced, row control boards were repaired, and the collectors were manually refocused a number of times when they failed to come into focus at startup. Some fluid leakage occurred from the hydraulic drives. The fluid leakage caused concern because it causes deterioration of roofing materials. There was no systematic cleaning of collectors during FY 1983. Rain wash occurred upon occasion but was not documented. Because Caterpillar was operating on a reduced production schedule and because portions of the IPH system were defocused to avoid exceeding the energy demand from the plant, additional cleaning was not considered necessary. The system was operated and maintained by Caterpillar Tractor Co. personnel.

Total cost of operation and maintenance activities for the period February through September 1983 was $4945. Extrapolated for a full year, this amounts to $1.61/m^2-yr ($0.15/ft^2-yr). For the same period, conventional energy savings, computed at ($7.39/GJ) $7/MBtu including boiler efficiency, were $21,250.

Maintenance activities are detailed in Table 4-4.

Dow Chemical Co.

The solar IPH experiment at Dow Chemical Co., Dalton, GA was in the operational phase throughout FY 1983. During the first quarter the system was operated, however, repair and maintenance activities on both the IPH system and the data acquisition system were extensive. From January through the middle of September 1983, the system operated consistently with routine maintenance functions. In the middle of September, the system was shut down for upgrade. The upgrade consisted of replacing pipe supports and reinsulating system piping to reduce thermal loss.

During the period from January through mid-September system availability was 85% and utilization was 94%. The value of 85% for availability includes a reduction for inoperative rows when the rest of the collectors were functioning. Components requiring repair during this period included local row control circuit boards, the main circulating pump, and system valves. Collectors were washed only one time, when rain wash occurred.

The total cost of operation and maintenance, including parasitics from January through mid-September, was $2800. This amounts to $\$4.31/m^2$-yr ($\$0.40/ft^2$-yr). An additional $3840, which is not included in the O&M costs, was charged to the project for "monitoring and reporting," which was handled by co-op students working for Dow Chemical. Fossil fuel savings during the period January through mid-September were $2361.

A summary of maintenance activities is shown in Table 4-5.

Table 4-4

Maintenance Summary -- Caterpillar Tractor
February - Setpember 1983

	O & M Activity	Hours	Cost: Labor $	Cost: Materials $	Cost: Total $
February	• Repair Row BH-92 • Manually refocusing collectors periodically because of startup sequence failure	18.0	433.37	-0-	433.37
March	• Maintenance of Row BH-47 hydraulics • Maintenance of Row BH-81 controls • Adjustments to system operation due to overtemperature conditions	27.2	693.91	-0-	693.91
April	• Maintenance of Row BH-94 hydraulics • Adjustments to system operation due to overtemperature conditions	12.0	275.59	-0-	275.59
May	• Reinstall Row BH-81 controller • Reinstall BH-94 hydraulics • Maintenance of Row BH-67 hydraulics • Adjustments to system operation due to overtemperature conditions	34.8	793.24	260.00	1053.24
June	• Repair Row BH-47, -67 hydraulics • Manually refocus field because of startup sequence failure	35.0	837.10	200.00	1037.10
July	• Maintenance of Row BH-69 hydraulics • Adjustments to system operation to match output to load	10.0	246.31	-0-	246.31
August	• Manually refocus rows that miss sun • Routine inspection • Deactivate Row BH-47/-69 • Activate Row BH-48/-70 • Repair DAS printer	20.0	529.27	-0-	529.27
September	• Routine inspection and DAS disk changes • Remove hose from Row BH-49 • Checkout datalogger cassette recorder	20.0	498.52	178.00	676.52
	TOTAL	177.0	4307.31	638.00	4945.31

Table 4-5

Maintenance Summary -- Dow Chemical Co.
January - September 1983

Month	O & M Activity	Hours	Cost: Labor $	Cost: Materials $	Cost: Total $
January	• Instrument and controls calibration • Receiver glass cutting (subcontract) • Reinsulate steam valves	3.5	112	165	277
February	• Repair pump - replace seal • Replace gate valve in steam line	30	438	---	438
March	• Troubleshoot control boards	2	64	---	64
April	• Local control board repair	---	---	371	371
May	• Tighten packing on HTF valves • Repair pump seal line	4	53	---	53
June	• Spare local control board repaired • Collector field batteries recharged • Insulated boiler hi-level switch	4	128	151	279
July	• Troubleshoot local control boards • Replace valve in feedwater line • Adjusted feedwater flow cell	7	206	---	206
August	• Local control boards repaired • Replaced pressure relief valves	6	192	219	411
September	• Replace pump seal and gasket • Replace steam valves	26	364	150	514
	TOTAL	82.5	1557	1056	2613

[a]Parasitic Energy = $.04/kWh

[b]Fossil Fuel = $6.83/mBtu

Home Laundry

The solar IPH system at Home Laundry, Pasadena, CA, was operated by Jacobs Engineering Group, Inc. from October 1982 through September 1983. A full-time operator was assigned to the project to assure continuous system operation and optimum performance. Operation was discontinued at the end of the operating period when the laundry was moved to a new location. The new owners of the building did not have a need for the energy. Therefore, the solar energy system was dismantled by a salvage company.

The system, which can produce either hot water or steam and which has storage capability, was operated in the hot water mode from October 1982 through April 1983. For the rest of the operating period steam was produced when solar conditions permitted; otherwise hot water was produced. Because the system was oriented in a north-south direction, energy production near the winter solstice was insufficient to achieve steam pressures to meet the laundry's minimum requirement.

The laundry's work day ended at 3:30 p.m. each day. By March the length of the solar day had increased so that energy could be collected after the laundry shut down. Also in March, production of hot water exceeded the demand from the laundry. Excess energy was then used to generate steam or to charge first a domestic hot water tank and then a high-temperature storage tank. Energy from the high-temperature storage tank was used on the day following collection for startup or during cloudy conditions. Flow through the storage tanks was controlled manually.

Maintenance activities were divided by Jacobs Engineering into two categories: preventive and corrective. Preventive maintenance, which consisted of tasks such as inspection and adjustment of components and subsystems, totaled $3878 for one year. Corrective maintenance (excluding the data acquisition system and instrumentation) was $1713 for the same period. Total maintenance costs were $5591 or $9.26/m^2$-yr ($0.86/ft^2$-yr).

There was almost no need for repair of components from failure or wear except for the data acquisition system. Cost of replacement parts was less than $100 for the year. The most critical maintenance problem was leakage through the packing of the main circulating pump. A leak rate of 6 to 10 drops per minute was specified by the manufacturer to provide lubrication. However, the leak rate varied with temperature. When the leak rate was adjusted for the system operating temperature it became excessive during nonoperating periods. The leakage required that makeup water be added frequently. Otherwise the system would shut down automatically from low-level in the compression tank.

The collectors were washed once a month. Different methods were tried to determine the most cost effective. Conclusions were that collectors should not be washed on hot sunny days because the collectors tend to spot. Also, to get effective cleaning from rain, at least one-half hour of hard rain is required. The most cost-effective and efficient methods were ranked as follows: rain of storm intensity, light precipitation coupled with cold wash water, warm wash water, and deionized water.

For the first quarter of the fiscal year, accurate performance data were not obtained because of problems with the instrumentation software. As a result fossil-fuel savings were not measured. However good data was obtained from January through September of 1983.

A summary of maintenance activities at Home Laundry is shown in Table 4-6.

Table 4-6

Maintenance Summary -- Home Laundry
October 1982 - September 1983

			Cost[a b]		
	O & M Activity	Hours	Labor $	Materials $	Total $
Oct 1982	Preventive maintenance consisting of: • Tracker alignment adjustment • Add makeup water • Receiver glass inspection and adjustment • Collector cleaning • Lubricant inspection and topoff • Vent air traps • Pyrheliometer alignment • Lubricant level inspection • Compression-tank pressure and level adjustment • Feedwater treatment Corrective maintenance Changed control system to improve standalone operation • Troubleshoot increasing feedwater level • Inspect and adjust shadowband tracker • Monitored loop temperature differential	13.1	366.8	19.15	385.95
Nov 1982	Preventive maintenance as above Corrective maintenance • Tracker motor troubleshooting • Repair shadow-band tracker • Steam generator feedwater treatment • Receiver glass replacement	12.3	344.40	40.72	385.12
Dec 1982	Preventive maintenance as above Corrective maintenance • Tracker motor troubleshooting	6.6	184.80	41.00	225.80
Jan 1983	Preventive maintenance as above Corrective maintenance • Drive shaft repair	8.3	232.40	--	232.40
Feb 1983	Preventive maintenance as above Corrective maintenance • Tighten packing gland plate	5.6	156.80	--	156.80

Table 4-6 (Continued)

Maintenance Summary -- Home Laundry
October 1982 - September 1983

	O & M Activity	Hours	Cost[a b] Labor $	Materials $	Total $
Mar 1983	Preventive maintenance as above	8.5	238.00	10.00	248.00
Apr 1983	Preventive maintenance as above	8.4	235.20	10.00	245.20
May 1983	Preventive maintenance as above Corrective maintenance • Tighten flange bolts to correct leak	10.4	291.20	20.00	311.20
June 1983	Preventive maintenance as above Corrective maintenance • Add nitrogen	32.9	921.20	64.45	985.65
July 1983	Preventive maintenance as above Corrective maintenance • Repair panel wiring • Tighten packing gland plate	34.6	968.80	44.25	1013.05
Aug 1983	Preventive maintenance as above Corrective maintenance • Tracker troubleshooting • Tighten packing gland plate	25.3	708.40	44.25	752.65
Sept 1983	Preventive maintenance	21.6	604.80	44.25	649.05
	TOTALS	187.6	5252.80	338.07	5590.87

[a] Fossil-fuel savings not available Oct-Dec 1983.
[b] Instrumentation and data acquisition not included.

Parasitic energy costs at \$0.10/kWh totaled \$828, and fossil-fuel savings at \$7.39/GJ (\$7/MBtu) were \$3338.47. The cost of operation was affected significantly by property taxes of \$500/month assessed by local authorities.

Lone Star Brewery

The solar IPH system at Lone Star Brewery, San Antonio, TX, was operated by Southwest Research Institute from December 1981 until May 1983. During FY 1983, beginning in October 1982, the system was operated with only 13 of 15 rows; two rows were shut down because of oil leaks from progressive failure of flex hoses. The system was shut down in May 1983 when oil leaks on two more rows became excessive. At this time, it was decided to retrofit the receiver tubes with new receivers of a later design and to convert the system to use hot water at 100°C (210°F) for boiler preheat. Previously the system used an organic heat-transfer fluid and operated at 218°C (425°F).

In addition to the oil leaks, some energy production was lost when one or more collector rows stowed after losing their focus on the sun either at startup or during periods of cloud-cover. At such times, the collectors would automatically focus on the west horizon and would remain in that position until manually refocused. Because the collector field was not tended daily, the length of time that rows were left out of focus is not known.

Maintenance activities involved routine reflector cleaning, repair of hydraulic drive components, and replacement of miscellaneous system components. Flex hoses leaked persistently and became progressively worse until the leakage rate became so great that the system was shut down. Detailed maintenance activities are shown in Table 4-7.

Table 4-7

Maintenance Summary -- Lone Star Brewery
October 1982 - May 1983

	O & M Activity	Hours	Cost: Labor $	Cost: Materials $	Cost: Total $
Oct 1982	• Added hydraulic fluid to drives • Cleaned receiver-tube glass covers • Calibrated collector array flow meter • Boiler blowdown • Fixed Therminal leak at flow-meter flanges • Added Therminal • Repaired boiler steam leak	11	275	468	743
Nov 1982	• Realigned tracker head • Replaced temperature switch • Replaced pressure relief valve • Charged hydraulic-drive accumulators with nitrogen • Repaired hydraulic-drive fluid leaks • Adjusted expansion-tank fluid-level switch	8	200	141	341
Dec 1982	• Focused collectors manually • Replaced steam-pressure relief valve • Added Therminal • Boiler blowdown • Charged hydraulic-drive accumulators with nitrogen • Washed reflectors	14	350	294	644
Jan 1983	• Replaced steam-pressure relief valve piping	6	150	51	201
Feb 1983	• Tightened receiver tube standoffs • Adjusted receiver focus • Washed collectors • Cleaned receiver-tube glass covers • Boiler blowdown • Repaired boiler manhole-cover leak • Boiler sight gage blowdown • Plumbed boiler sight gage blowdown outlet to vent	19	475	104	579

Table 4-7 (Continued)

Maintenance Summary -- Lone Star Brewery
October 1982 - May 1983

			Cost		
	O & M Activity	Hours	Labor $	Materials $	Total $
Mar 1983	• Reinstalled boiler insulation jacket • Replaced steam bucket trip • Shut down row -- flex hose failure • Installed new central light switch • System failure -- low level in expansion tank • Added Therminal • Charged hydraulic-drive accumulators with nitrogen • Replaced boiler manhole-cover gasket • Removed hydraulic pump	14	356	58	414
Apr 1983	• Replaced hydraulic fluid pump • Restarted central controller after power failure	2	50	11	61
May 1983	• Total of 4 rows down because of flex hose failures, flex hoses leaking on 5 other rows. System shut down • Cleaned oil spill on roof • Reset pressure switch and installed on hydraulic drive	5	125	233	148
	TOTAL	79	1981	1150	3131

The cost of maintenance for the period from October 1982 to May 1983 (7.2 months) was $3131. Extrapolated for one full year this amounts to $5218/yr or $5.92/m^2-yr ($0.55/ft^2-yr). Actual energy savings for the operating period October 1982 to May 1983 were $1531 with an assumed boiler efficiency of 65% and the present natural gas cost of $5.28/GJ ($5/MBtu). Parasitics for the period were $149 at $0.10/kWh.

Ore-Ida Foods

The IPH system at Ore-Ida Foods, Ontario, OR, for which TRW Energy Development Group was responsible, was in the operational phase from August 1981 to April 1983. At the beginning of FY 1983 (October 1982) the system was not operating because of failure of the main circulating pump. The pump had been returned to Roth Pump Co., the manufacturer, for repair. The pump was returned to the site in November. However, at that time control and instrumentation problems prevented startup. Also, energy production from the system, which is oriented on a north-south axis, would have been too low to justify operation. As a result, the system was drained for the winter. The system was filled and started in March 1983, but control and instrumentation problems again prevented operation. The contract expired in April and operation was discontinued. No operation and maintenance costs were reported.

Southern Union Refining Co.

The solar IPH system at Southern Union Refining Co., Lovington, NM, has been operated by Energetics Corp. since October 1981, when Phase III, Operation and Evaluation, was begun. At the beginning of FY 1983 (October 1982) the system was in full operation. Operation continued throughout the year until September 1983 when the system was shut down to upgrade the collector-field piping. In April 1983, one row of collectors was damaged by high winds. The system continued to operate, with one row down, until August when the damaged collectors were replaced.

Routine maintenance consisted of cleaning the collectors and the receiver-tube glass jackets once a month and miscellaneous activities such as blowing down the steam generator, lubricating the collector bearings, and replacing and repairing valves and relays. The SKI hydraulic drives caused considerable problems and required frequent repair. These drives were an early design. Subsequently this design was superceded by an improved hydraulic drive, an electro-mechanical drive of SKI design, and finally by the Winsmith electromechanical design developed under DOE contract. In addition, there was extensive breakage of receiver-tube glass jackets caused by faulty design of the receiver-tube support structure. This problem was subsequently corrected in the upgrade that began in September 1983.

The maintenance record (Table 4-8) appears very good with an average of less than 8 hours per month expended for both scheduled and nonscheduled activities. However, an analysis performed by Sandia indicated a generally low reliability.[15] In this analysis, the reliability of the system was determined to be 0.07 for one month's operation, which means that there is a 0.07 probability of operating for one month without a failure that would cause the system to shut down (or a 93% probability of experiencing such a failure). For the collector field, the reliability is 0.27. Further the mean time-to-repair for the system is 145 hours (six 24-hour days) and for the collector system 283 hours (twelve 24-hour days). The following is quoted from the conclusions of the analysis:

Table 4-8

Maintenance Summary -- Southern Union Refining Co.
October 1982 - September 1983

	O & M Activity	Hours	Cost		
			Labor $	Materials $	Total $
Oct 1982	• Clean collectors and receiver-tube glass • Manual blowdown • Drive unit adjustment • Insulate piping • Replace bypass coil • Repair tracking board • Repair heat transfer leaks	10	100	5	117
Nov 1982	• Clean collectors and receiver-tube glass • Repair drive units • Repair steam leak • Insulate pipes	12	132	-	132
Dec 1982	• Clean collectors and receiver-tube glass • Lubricate bearings • Repair hydraulic-drive units • Repair central controller • Check freeze-protection system	14	152	-	152
Jan 1983	• Repair main circulating pump gear reducer • Repair microprocessor • Repair hydraulic drives • Clean collectors and receiver-tube glass	12	180	420	600
Feb 1983	• Replace circuit boards • Clean collectors and receiver-tube glass • Battery maintenance • Manual blowdown	6	60	-	60

Table 4-8 (Continued)

Maintenance Summary -- Southern Union Refining Co.
October 1982 - September 1983

			Cost		
	O & M Activity	Hours	Labor $	Materials $	Total $
Mar 1983	• Repair steam check valve • Clean collectors and receiver-tube glass • Manual blowdown • Repair tracker head • Repair overtemperature switch	6	60	-	60
Apr 1983	• Adjust microprocessor • Replace tracker head • Clean collectors and receiver-tube glass • Manual blowdown • Repair wind-damaged collectors	6	60	-	60
May 1983	• Clean glass receiver tube • Drained steam generator	4	40	-	40
June 1983	• Clean collectors and receiver-tube glass • Replace two solenoid valves, hydraulic drives • Replace fuse in row controls	12	120	-	120
July 1983	• Clean collectors and receiver-tube glass	4	40	-	40
Aug 1983	• Clean collectors and receiver-tube glass • Replaced collectors damaged by wind*	4	40	-	40
Sept 1983	• Clean collectors and receiver-tube glass	4	40	-	40
	TOTAL	94	1024	425	1449

*Cost not included under "maintenance."

"Such performance is not considered desirable for unattended automatic operation and for general industrial use.

"The values for mean time-to-repair in this report, although very real in this experiment, are misleading if one concludes that repairs are time consuming or parts are hard to get. The high values actually point to a major discrepancy in the planning and execution of the experiment. Two-thirds of the times-to-repair were caused by not having spare parts. By provisioning spare parts, a standard practice for all maintenance operations, the mean time-to-repair for the system could have been reduced to one-third of that experienced. Time-to-repair could have been further and substantially reduced by expediting repair activities."

Subsequent to the period covered by the reliability analysis, the solar IPH system at Southern Union was modified, spare parts were procured, the system was put into automatic operation, and energy production was increased. Although the reliability analysis was not solely responsible for the improvements in the system, it did provide valuable insights into the problems of design and operation. The use of reliability analyses, both a priori and as data are accumulated, should be a part of the design process for future solar energy projects.

The cost of maintenance activities for the IPH system at Southern Union Refining Co. for FY 1983 was $1449 or $1.55/m^2$-yr ($0.14/ft^2$-yr). The cost of parasitics (not included above) was $373 at $0.059/kWh. In addition, there was an insurance cost of $1859. Fossil-fuel savings, computed at $3.62/GJ ($3.43/MBtu) with an assumed burner efficiency of 65%, were $2151.

USS Chemicals Co.

The solar IPH system at USS Chemicals Co., Haverhill, OH was operated by Columbia Gas System Service Corp., under a cooperative agreement with DOE. The acceptance for the system occurred in May 1982 and operation began in June 1982. At the beginning of FY 1983, October 1982, the solar IPH system was operating well, but energy production data was not available because of problems with the Hewlett-Packard data acquisition system. The system was shut down for a period of 20 days in March while receiver-tube seals were replaced. Upon restart, the system continued to produce energy at design values through the end of the fiscal year.

Major maintenance activities consisted of repairing heat-transfer fluid leaks at receiver junctions and repairing hydraulic drive units. In addition it was necessary to replace broken receiver-tube glass jackets. Insufficient feedwater flow caused shutdowns from low level in the steam generator. The problem with heat-transfer fluid leaks was caused by failure of silicone rubber O-Rings that could not withstand the 219°C (425°F) operating temperature. It was corrected by SKI, the collector manufacturer, by replacing the O-Rings with grafoil seals. At the same time silicone seals between the receiver tubes and their glass jackets were changed to metal-backed teflon seals. Prior to the change, the heat-transfer fluid leaked into the receiver-tube jackets and onto the reflectors creating a major cleaning problem. The hydraulic drive units became a routine maintenance item with a small number of them requiring repair each month.

During the year corrosion was observed on the sheathing of flex hoses. Metallurgical examinations by USS Chemicals Process Engineering showed that the sheathing had experienced transgranular stress corrosion cracking initiated from the inside. The corrosion was attributed to chlorides in the fiberglass insulation between the hose and the sheathing. As a result of this problem a retrofit of hoses was initiated. In the new hoses, the fiberglass insulation will be replaced by a ceramic wool, and all mild steel parts will be changed to stainless steel.

The cost of maintenance activity at USS Chemicals Co. for FY 1983 was $64,244 or $13.67/m^2-yr ($1.27/ft^2-yr). An additional $15,531 was reported under operation costs to cover "solar system operation checks." The total is significantly higher than for other systems, probably because greater attention was given to keeping the system operating. Other factors may have included different accounting procedures (other projects may have separated test activities from hypothetical operating conditions) and charging time at $30 per hour (compared to $10 to $35 per hour for other projects). The number of maintenance hours required was 1502, more than 5 times that reported for Caterpillar Tractor Co. However, USS Chemicals operates at a higher temperature than Caterpillar, 218°C (425°) and 113°C (235°F) respectively, and Caterpillar also operated at a reduced capacity for much of the year. Finally, energy production at USS Chemicals was the highest of all the IPH projects relative to design conditions. A summary of maintenance costs is shown in Table 4-9.

Fossil-fuel savings for the period February through September 1983 were $13,508 computed at $5.28/GJ ($5/MBtu) and a boiler efficiency of 85%. Cost of parasitics for the same period was $2229 at $0.08/kWh.

Table 4-9

Maintenance Summary -- USS Chemicals Co.
October 1982 - September 1983

			Cost		
	O & M Activity	Hours	Labor $	Materials $	Total $
Oct 1982	• Repair air compressor • Install chain-operated valve • Remove Therminal from reflector surfaces • Repair hydraulic drives • Wash solar collector panels	200	5680	925	6605
Nov 1982	• Replace PI in overhead steam line • Clean and repaint steam generator building floor • Adjust solar control sensor • Repair hydraulic drives • Add high-range steam flow pressure transmitter • Install collars on collector support arms • Install new local controls on each drive pylon	176	5421	1395	6816
Dec 1982	• Repair hydraulic drives • Add heat-transfer fluid • Revise space heater piping • Assist SKI to replace receiver-tube seals*	167	4059	1385	17874
Jan 1983	• Repair drive pylons • Replace and adjust feedwater regulator • Inspect solar collectors	85	2263	75	2338
Feb 1983	• Repair leak • Preventive maintenance checks • Collector drive pylon repair	30	1013	26	1039
Mar 1983	• Receiver tube seal replacement** • Repair drive pylons • Preventive maintenance	114	3921	77	3998

Table 4-9 (Continued)

Maintenance Summary -- USS Chemicals Co.
October 1982 - September 1983

	O & M Activity	Hours	Cost: Labor $	Cost: Materials $	Cost: Total $
Apr 1983	• Preventive maintenance • Remove heat-transfer fluid from reflective film • Replace and calibrate sensors • Repair drive pylons	183	6520	263	6783
May 1983	• Preventive maintenance • Wash collectors • Replace broken receiver-glass tubes • Repair flux line trackers	229	7415	1068	8483
June 1983	• Repair feedwater supply line • Clean and paint 60 control boxes	62	2072	364	2436
July 1983	• Preventive maintenance • Cleaning and painting • Repair collector drive pylons	110	3059	44	3103
Aug 1983	• Preventive maintenance • Repair feedwater valve • Repair collector drive pylons • Wash solar collectors	116	3295	574	3869
Sept 1983	• Preventive maintenance • Repair low-level alarm • Repair controller linkage • Repair drive pylons	30	900	-	900
	TOTAL	1502	45,618	18,626	64,244

*SKI, the collector manufacturer, expended 252 man-hours to replace seals at no cost to project. Cost of SKI's labor is not included in this table.

**Does not include 540 man-hours expended by SKI at no cost to project.

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APPENDIX A

SOLIPH Computer Simulation Program Results

Table A-1

RUN ID: CT3
83/11/16.

CATERPILLAR TRACTOR

ANNUAL PERFORMANCE SUMMARY TABLE

MONTH	INCIDENT SOLAR ENERGY HORIZONTAL SURFACE GJ	INCIDENT SOLAR ENERGY DIRECT NORMAL GJ	INCIDENT SOLAR ENERGY COLLECTOR PLANE (*) GJ	ENERGY COLLECTED GJ	COLLECTOR EFFICIENCY BASED ON (*) %	ENERGY DELIVERED GJ	SYSTEM OPERATING LOSSES GJ	SYSTEM NON-OPERATING LOSSES GJ	SYSTEM EFFICIENCY BASED ON (*) %	PARASITIC ENERGY GJ
JANUARY	960.9	1278.8	748.1	348.7	46.6	289.9	24.9	33.7	38.8	7.2
FEBRUARY	1257.7	1460.8	1029.0	521.0	50.6	459.8	30.4	30.0	44.7	8.8
MARCH	1934.5	1848.2	1473.3	807.9	54.8	728.1	38.1	41.8	49.4	10.9
APRIL	2596.2	2488.9	2213.9	1273.7	57.5	1181.2	49.2	43.1	53.4	14.0
MAY	3236.4	3020.2	2878.7	1686.0	58.6	1585.4	59.1	41.5	55.1	16.9
JUNE	3188.1	2857.5	2717.1	1628.4	59.9	1534.5	53.3	40.6	56.5	15.2
JULY	3133.3	2915.9	2747.3	1640.4	59.7	1545.2	53.4	42.6	56.2	15.4
AUGUST	3003.5	3024.9	2824.4	1643.3	58.2	1540.6	58.0	43.9	54.5	16.9
SEPTEMBER	2290.8	2472.4	2124.6	1228.1	57.8	1141.1	45.6	42.2	53.7	13.5
OCTOBER	1732.6	2081.3	1526.9	822.3	53.9	738.5	40.0	43.2	48.4	11.9
NOVEMBER	1091.1	1539.0	942.1	454.4	48.2	383.7	30.1	40.7	40.7	8.9
DECEMBER	914.9	1464.6	842.2	368.6	43.8	298.4	32.1	38.1	35.4	9.4
TOTALS/AVERAGES	25340.2	26452.5	22067.5	12422.7	56.3	11426.4	514.1	481.4	51.8	149.1

Table A-2

RUN ID: DW2
83/09/02.

DOW CHEMICAL

ANNUAL PERFORMANCE SUMMARY TABLE

MONTH	INCIDENT SOLAR ENERGY HORIZONTAL SURFACE GJ	INCIDENT SOLAR ENERGY DIRECT NORMAL GJ	INCIDENT SOLAR ENERGY COLLECTOR PLANE (*) GJ	ENERGY COLLECTED GJ	COLLECTOR EFFICIENCY BASED ON (*) %	ENERGY DELIVERED GJ	SYSTEM OPERATING LOSSES GJ	SYSTEM NON-OPERATING LOSSES GJ	SYSTEM EFFICIENCY BASED ON (*) %	PARASITIC ENERGY GJ
JANUARY	213.5	252.1	175.8	68.0	38.7	22.5	28.6	16.6	12.8	.8
FEBRUARY	260.0	265.9	208.4	87.4	41.9	40.8	31.5	14.8	19.6	.8
MARCH	369.4	305.3	262.1	115.9	44.2	58.4	38.4	19.4	22.3	1.0
APRIL	504.5	387.6	348.3	161.1	46.3	89.5	49.6	21.7	25.7	1.3
MAY	546.6	384.6	363.7	169.9	46.7	99.5	52.1	18.1	27.4	1.4
JUNE	570.8	392.4	364.5	168.2	46.1	90.4	55.5	22.1	24.8	1.6
JULY	551.5	374.3	333.4	155.3	46.6	82.4	50.7	22.3	24.7	1.4
AUGUST	525.7	418.3	386.6	182.5	47.2	100.5	55.6	26.1	26.0	1.5
SEPTEMBER	415.9	350.3	319.4	147.2	46.1	83.6	44.3	19.3	26.2	1.2
OCTOBER	357.6	381.8	306.6	136.2	44.4	71.7	44.2	20.6	23.4	1.2
NOVEMBER	253.6	325.7	233.6	95.7	40.9	41.9	35.5	18.1	17.9	1.0
DECEMBER	186.1	223.1	144.0	53.7	37.3	13.1	25.6	14.9	9.1	.7
TOTALS/AVERAGES	4755.2	4061.3	3446.4	1541.0	44.7	794.4	511.6	233.9	23.0	14.0

Table A-3

RUN ID: HS2
83/09/02.

HOME LAUNDRY (STEAM)

ANNUAL PERFORMANCE SUMMARY TABLE

MONTH	INCIDENT SOLAR ENERGY: HORIZONTAL SURFACE GJ	INCIDENT SOLAR ENERGY: DIRECT NORMAL GJ	INCIDENT SOLAR ENERGY: COLLECTOR PLANE (*) GJ	ENERGY COLLECTED GJ	COLLECTOR EFFICIENCY BASED ON (*) %	ENERGY DELIVERED GJ	SYSTEM: OPERATING LOSSES GJ	SYSTEM: NON-OPERATING LOSSES GJ	SYSTEM EFFICIENCY BASED ON (*) %	PARASITIC ENERGY GJ
JANUARY	144.7	225.4	141.5	61.4	43.4	32.2	16.6	11.6	22.8	3.7
FEBRUARY	171.2	215.4	145.2	69.5	47.8	41.9	15.6	11.5	28.8	3.3
MARCH	248.0	258.0	194.4	96.6	49.7	63.4	18.6	14.1	32.6	3.9
APRIL	276.8	255.2	204.6	106.3	51.9	75.1	17.4	13.2	36.7	3.5
MAY	343.7	298.1	237.7	125.6	52.8	89.2	20.4	15.4	37.5	4.1
JUNE	308.4	252.3	192.9	103.0	53.4	72.2	16.3	14.1	37.4	3.3
JULY	362.6	354.4	295.2	157.6	53.4	118.6	24.0	14.1	40.2	4.7
AUGUST	343.3	345.1	285.1	150.0	52.6	110.2	23.5	15.5	38.7	4.7
SEPTEMBER	241.8	245.8	198.3	101.3	51.1	69.6	17.9	13.4	35.1	3.7
OCTOBER	205.5	235.1	164.7	80.9	49.1	49.5	16.6	13.9	30.1	3.6
NOVEMBER	151.5	216.4	135.8	60.9	44.8	33.3	15.8	11.2	24.5	3.5
DECEMBER	120.1	188.7	113.5	47.5	41.9	20.7	14.1	12.0	18.3	3.3
TOTALS/AVERAGES	2917.5	3089.8	2309.1	1160.5	50.3	776.2	216.9	160.2	33.6	45.2

RUN ID: HW2
83/09/02.

Table A-4

HOME LAUNDRY (DHW)

ANNUAL PERFORMANCE SUMMARY TABLE

	INCIDENT SOLAR ENERGY						SYSTEM			
MONTH	HORIZONTAL SURFACE GJ	DIRECT NORMAL GJ	COLLECTOR PLANE (*) GJ	ENERGY COLLECTED GJ	COLLECTOR EFFICIENCY BASED ON (*) %	ENERGY DELIVERED GJ	OPERATING LOSSES GJ	NON-OPERATING LOSSES GJ	SYSTEM EFFICIENCY BASED ON (*) %	PARASITIC ENERGY GJ
JANUARY	144.7	225.4	141.5	66.7	47.1	54.4	7.1	4.3	38.4	3.7
FEBRUARY	171.2	215.4	145.2	74.1	51.0	59.9	8.1	5.5	41.2	3.3
MARCH	248.0	258.0	194.4	101.6	52.2	81.3	11.2	8.3	41.8	3.9
APRIL	276.8	255.2	204.6	110.1	53.8	87.6	12.2	9.3	42.8	3.5
MAY	343.7	298.1	237.7	130.0	54.7	104.2	14.3	10.7	43.8	4.1
JUNE	308.4	252.3	192.9	106.4	55.1	84.3	11.5	10.0	43.7	3.3
JULY	362.6	354.4	295.2	162.1	54.9	132.1	18.1	11.1	44.7	4.7
AUGUST	343.3	345.1	285.1	154.9	54.3	125.7	16.9	11.5	44.1	4.7
SEPTEMBER	241.8	245.8	198.3	105.7	53.3	85.3	11.3	8.6	43.0	3.7
OCTOBER	205.5	235.1	164.7	85.6	52.0	68.6	9.0	7.3	41.7	3.6
NOVEMBER	151.5	216.4	135.8	65.8	48.4	54.0	6.9	4.3	39.8	3.5
DECEMBER	120.1	188.7	113.5	52.0	45.8	42.3	5.3	3.8	37.3	3.3
TOTALS/AVERAGES	2917.5	3089.8	2309.1	1215.0	52.6	979.7	131.9	94.6	42.4	45.2

Table A-5

RUN ID: LS2
83/09/02.

LONE STAR BREWERY

ANNUAL PERFORMANCE SUMMARY TABLE

MONTH	INCIDENT SOLAR ENERGY HORIZONTAL SURFACE GJ	INCIDENT SOLAR ENERGY DIRECT NORMAL GJ	INCIDENT SOLAR ENERGY COLLECTOR PLANE (*) GJ	ENERGY COLLECTED GJ	COLLECTOR EFFICIENCY BASED ON (*) %	ENERGY DELIVERED GJ	SYSTEM OPERATING LOSSES GJ	SYSTEM NON-OPERATING LOSSES GJ	SYSTEM EFFICIENCY BASED ON (*) %	PARASITIC ENERGY GJ
JANUARY	288.8	396.4	259.9	90.6	34.9	58.6	15.6	15.9	22.5	.9
FEBRUARY	315.5	342.5	262.1	98.4	37.5	68.5	15.6	14.0	26.1	.8
MARCH	453.4	410.4	345.9	144.7	41.8	111.3	18.4	14.8	32.2	1.0
APRIL	466.1	329.3	284.9	122.5	43.0	90.2	15.9	16.3	31.6	.9
MAY	573.3	440.4	417.3	182.5	43.7	142.8	23.1	16.4	34.2	1.2
JUNE	621.9	497.7	477.8	214.5	44.9	171.3	26.9	16.1	35.9	1.5
JULY	672.0	586.3	564.0	255.5	45.3	208.6	30.5	16.3	37.0	1.6
AUGUST	583.8	511.2	477.9	214.1	44.8	171.3	25.8	16.9	35.8	1.4
SEPTEMBER	497.5	457.2	409.0	176.8	43.2	137.2	23.5	16.1	33.5	1.3
OCTOBER	409.0	447.2	361.6	145.6	40.3	109.1	20.6	16.1	30.2	1.1
NOVEMBER	296.5	363.0	250.2	93.0	37.2	62.2	15.0	15.5	24.8	.8
DECEMBER	264.0	356.5	228.1	76.7	33.6	47.4	14.6	14.3	20.8	.8
TOTALS/AVERAGES	5441.9	5138.0	4338.7	1814.8	41.8	1378.5	245.4	188.9	31.8	13.3

RUN ID: OR2
83/09/02.

Table A-6

ORE IDA FOODS

ANNUAL PERFORMANCE SUMMARY TABLE

	INCIDENT SOLAR ENERGY						SYSTEM			
MONTH	HORIZONTAL SURFACE GJ	DIRECT NORMAL GJ	COLLECTOR PLANE (*) GJ	ENERGY COLLECTED GJ	COLLECTOR EFFICIENCY BASED ON (*) %	ENERGY DELIVERED GJ	OPERATING LOSSES GJ	NON-OPERATING LOSSES GJ	SYSTEM EFFICIENCY BASED ON (*) %	PARASITIC ENERGY GJ
JANUARY	149.4	222.2	108.0	37.6	34.8	-.2	15.6	21.6	-.2	2.3
FEBRUARY	239.5	352.4	214.0	80.1	37.4	9.3	40.5	33.9	4.4	3.9
MARCH	380.0	419.1	311.7	130.5	41.9	35.5	58.9	38.9	11.4	4.9
APRIL	541.1	555.3	480.8	220.5	45.9	100.6	79.2	44.2	20.9	6.4
MAY	675.9	686.2	621.3	303.3	48.8	162.5	94.6	49.4	26.2	7.8
JUNE	730.4	763.2	708.1	352.8	49.8	198.2	105.4	52.4	28.0	8.8
JULY	794.1	898.4	832.2	425.6	51.1	264.7	114.0	50.2	31.8	9.1
AUGUST	671.6	793.1	725.4	351.7	48.5	200.7	105.9	48.6	27.7	8.7
SEPTEMBER	499.9	623.0	507.4	236.5	46.6	114.9	80.3	45.4	22.6	6.7
OCTOBER	343.1	520.9	353.5	144.2	40.8	42.4	60.3	45.0	12.0	5.4
NOVEMBER	176.8	264.5	146.4	53.3	36.4	2.9	26.6	27.2	2.0	3.0
DECEMBER	131.5	209.9	95.3	31.8	33.3	-.2	16.6	18.9	-.2	2.5
TOTALS/AVERAGES	5333.2	6308.2	5104.1	2368.0	46.4	1131.3	798.0	475.7	22.2	69.3

Table A-7

RUN ID: SU2
83/09/02.

SOUTHERN UNION

ANNUAL PERFORMANCE SUMMARY TABLE

MONTH	INCIDENT SOLAR ENERGY HORIZONTAL SURFACE GJ	INCIDENT SOLAR ENERGY DIRECT NORMAL GJ	INCIDENT SOLAR ENERGY COLLECTOR PLANE (*) GJ	ENERGY COLLECTED GJ	COLLECTOR EFFICIENCY BASED ON (*) %	ENERGY DELIVERED GJ	SYSTEM OPERATING LOSSES GJ	SYSTEM NON-OPERATING LOSSES GJ	SYSTEM EFFICIENCY BASED ON (*) %	PARASITIC ENERGY GJ
JANUARY	349.1	604.5	495.7	217.8	44.0	156.8	31.8	28.2	31.6	12.3
FEBRUARY	411.6	597.9	470.8	204.5	43.4	148.2	31.3	24.8	31.5	12.6
MARCH	604.7	706.0	526.3	226.8	43.1	164.5	35.3	26.7	31.3	14.3
APRIL	708.1	765.4	536.4	229.7	42.8	166.3	35.8	27.4	31.0	14.6
MAY	807.4	814.3	585.5	249.0	42.5	181.1	41.1	26.3	30.9	17.6
JUNE	825.2	833.3	624.8	269.2	43.1	200.7	43.0	25.3	32.1	18.1
JULY	821.1	838.9	635.4	277.8	43.7	208.3	43.1	26.0	32.8	18.4
AUGUST	724.0	758.8	563.4	246.5	43.8	180.7	38.0	27.6	32.1	16.2
SEPTEMBER	613.0	690.9	526.1	227.5	43.2	165.9	35.8	25.6	31.5	15.0
OCTOBER	487.7	667.6	524.2	231.0	44.1	171.1	34.2	25.5	32.6	14.1
NOVEMBER	370.0	608.9	497.3	219.4	44.1	158.8	32.6	27.9	31.9	13.0
DECEMBER	312.4	558.2	469.8	203.3	43.3	143.5	30.7	29.0	30.5	11.8
TOTALS/AVERAGES	7034.2	8444.8	6455.7	2802.7	43.4	2046.0	432.7	320.4	31.7	178.0

RUN ID: US3
83/10/07.

Table A-8

USS CHEMICALS

ANNUAL PERFORMANCE SUMMARY TABLE

	INCIDENT SOLAR ENERGY						SYSTEM			
MONTH	HORIZONTAL SURFACE GJ	DIRECT NORMAL GJ	COLLECTOR PLANE (*) GJ	ENERGY COLLECTED GJ	COLLECTOR EFFICIENCY BASED ON (*) %	ENERGY DELIVERED GJ	OPERATING LOSSES GJ	NON-OPERATING LOSSES GJ	SYSTEM EFFICIENCY BASED ON (*) %	PARASITIC ENERGY GJ
JANUARY	789.0	845.5	473.8	187.7	39.6	93.7	22.4	69.7	19.8	5.4
FEBRUARY	1123.4	1054.0	604.6	250.6	41.4	152.8	28.0	67.2	25.3	6.3
MARCH	1672.9	1184.4	760.4	353.2	46.5	250.2	31.4	71.0	32.9	6.9
APRIL	2176.3	1504.4	1152.1	566.4	49.2	444.9	43.0	78.1	38.6	9.2
MAY	2888.4	2134.6	1748.2	870.9	49.8	707.6	65.1	100.1	40.5	14.5
JUNE	3029.7	2162.5	1740.3	883.0	50.7	725.8	61.3	92.6	41.7	14.0
JULY	2893.3	2034.2	1567.3	785.5	50.1	621.9	58.4	105.1	39.7	13.4
AUGUST	2662.3	2191.9	1784.1	890.6	49.9	725.2	67.1	97.8	40.7	15.4
SEPTEMBER	1911.0	1537.7	1132.8	555.5	49.0	428.7	43.4	84.9	37.8	10.0
OCTOBER	1576.6	1748.9	1174.2	541.8	46.1	404.0	47.0	88.8	34.4	10.8
NOVEMBER	896.7	975.8	530.8	213.7	40.3	120.5	25.3	68.9	22.7	6.4
DECEMBER	735.5	829.2	408.6	161.3	39.5	77.0	19.4	63.9	18.8	5.0
TOTALS/AVERAGES	22355.2	18203.1	13077.2	6260.1	47.9	4752.3	511.8	988.0	36.3	117.3

RUN ID: CT3
83/11/16.

Table A-9

CATERPILLAR TRACTOR

CLEAR DAY PERFORMANCE TABLE

1 SEPTEMBER (DAY 244)

HOUR	AMBIENT TEMP C	INCIDENT SOLAR ENERGY DIRECT NORMAL GJ	INCIDENT SOLAR ENERGY COLLECTOR PLANE (*) GJ	FLOW RATE KG/S	COLLECTOR TEMP INLET C	COLLECTOR TEMP OUTLET C	ENERGY COLLECTED GJ	COLLECTOR EFFICIENCY BASED ON (*) %	ENERGY DELIVERED GJ	SYSTEM LOSSES GJ	PARASITIC ENERGY GJ
1	15.0	0.00	0.00	0.00	17.3	17.3	0.00	0.0	0.00	.07	0.00
2	14.6	0.00	0.00	0.00	16.4	16.4	0.00	0.0	0.00	.06	0.00
3	14.2	0.00	0.00	0.00	15.7	15.7	0.00	0.0	0.00	.06	0.00
4	13.7	0.00	0.00	0.00	15.0	15.0	0.00	0.0	0.00	.05	0.00
5	13.3	0.00	0.00	0.00	14.5	14.5	0.00	0.0	0.00	.05	0.00
6	12.9	0.00	0.00	0.00	14.0	14.0	0.00	0.0	0.00	.05	0.00
7	15.6	1.65	0.00	0.00	14.5	14.5	0.00	0.0	0.00	.03	0.00
8	16.7	7.86	7.80	27.31	86.5	94.6	3.36	43.1	1.56	.20	.06
9	18.3	11.37	10.97	27.31	90.3	106.5	6.69	61.0	6.46	.22	.06
10	20.6	13.16	12.20	27.31	90.3	108.4	7.49	61.4	7.27	.22	.06
11	21.1	13.96	12.44	27.31	90.3	108.8	7.64	61.4	7.41	.22	.06
12	25.0	14.23	12.37	27.31	90.3	108.7	7.61	61.5	7.39	.22	.06
13	25.6	14.22	12.36	27.31	90.3	108.7	7.60	61.5	7.39	.22	.06
14	25.0	14.03	12.50	27.31	90.3	109.0	7.70	61.6	7.49	.22	.06
15	23.3	13.39	12.42	27.31	90.3	108.8	7.65	61.6	7.43	.22	.06
16	22.8	11.86	11.44	27.31	90.3	107.3	7.02	61.4	6.80	.22	.06
17	21.7	8.74	8.67	27.31	90.3	99.5	3.78	43.6	3.57	.21	.06
18	18.9	2.52	0.00	0.00	56.8	56.8	0.00	0.0	0.00	.44	0.00
19	17.2	0.00	0.00	0.00	40.1	40.1	0.00	0.0	0.00	.24	0.00
20	16.1	0.00	0.00	0.00	30.9	30.9	0.00	0.0	0.00	.17	0.00
21	15.6	0.00	0.00	0.00	25.3	25.3	0.00	0.0	0.00	.13	0.00
22	15.0	0.00	0.00	0.00	21.7	21.7	0.00	0.0	0.00	.10	0.00
23	15.0	0.00	0.00	0.00	19.5	19.5	0.00	0.0	0.00	.09	0.00
24	15.0	0.00	0.00	0.00	18.0	18.0	0.00	0.0	0.00	.08	0.00
TOTAL/AVE	---	126.99	113.18	---	---	---	66.53	58.8	62.76	3.79	.64

RUN ID: DW2
83/09/02.

Table A-10

DOW CHEMICAL

CLEAR DAY PERFORMANCE TABLE

13 SEPTEMBER (DAY 256)

HOUR	AMBIENT TEMP C	INCIDENT SOLAR ENERGY DIRECT NORMAL GJ	INCIDENT SOLAR ENERGY COLLECTOR PLANE (*) GJ	FLOW RATE KG/S	COLLECTOR TEMP INLET C	COLLECTOR TEMP OUTLET C	ENERGY COLLECTED GJ	COLLECTOR EFFICIENCY BASED ON (*) %	ENERGY DELIVERED GJ	SYSTEM LOSSES GJ	PARASITIC ENERGY GJ
1	16.1	0.00	0.00	0.00	16.5	16.5	0.00	0.0	0.00	.02	0.00
2	15.6	0.00	0.00	0.00	15.9	15.9	0.00	0.0	0.00	.02	0.00
3	15.0	0.00	0.00	0.00	15.2	15.2	0.00	0.0	0.00	.02	0.00
4	13.9	0.00	0.00	0.00	14.3	14.3	0.00	0.0	0.00	.02	0.00
5	13.9	0.00	0.00	0.00	14.0	14.0	0.00	0.0	0.00	.01	0.00
6	13.9	0.00	0.00	0.00	13.9	13.9	0.00	0.0	0.00	.01	0.00
7	13.9	.08	0.00	0.00	13.9	13.9	0.00	0.0	0.00	.01	0.00
8	16.1	1.28	1.27	3.13	109.6	127.7	.45	35.6	0.00	.16	.01
9	19.4	2.09	2.04	3.13	173.8	212.9	.98	47.9	.12	.27	.01
10	20.6	2.46	2.36	3.13	183.2	229.2	1.15	48.9	.78	.29	.01
11	21.1	2.63	2.48	3.13	183.6	232.5	1.22	49.4	.91	.30	.01
12	22.2	2.69	2.51	3.13	183.7	233.4	1.24	49.6	.94	.30	.01
13	22.8	2.73	2.54	3.13	183.7	234.2	1.26	49.7	.96	.30	.01
14	23.3	2.67	2.52	3.13	183.8	233.8	1.25	49.7	.96	.30	.01
15	24.4	2.50	2.40	3.13	183.7	231.0	1.18	49.3	.90	.29	.01
16	25.0	2.12	2.07	3.13	183.2	222.8	.99	47.7	.74	.29	.01
17	25.0	1.26	1.25	3.13	181.7	195.2	.34	27.0	.19	.27	.01
18	23.9	.08	0.00	0.00	69.7	69.7	0.00	0.0	0.00	.33	0.00
19	21.7	0.00	0.00	0.00	35.0	35.0	0.00	0.0	0.00	.15	0.00
20	19.4	0.00	0.00	0.00	23.8	23.8	0.00	0.0	0.00	.08	0.00
21	17.2	0.00	0.00	0.00	19.0	19.0	0.00	0.0	0.00	.05	0.00
22	16.1	0.00	0.00	0.00	16.9	16.9	0.00	0.0	0.00	.04	0.00
23	15.0	0.00	0.00	0.00	15.5	15.5	0.00	0.0	0.00	.03	0.00
24	13.9	0.00	0.00	0.00	14.4	14.4	0.00	0.0	0.00	.03	0.00
TOTAL/AVE	---	22.59	21.43	---	---	---	10.07	47.0	6.51	3.57	.07

Table A-11

RUN ID: HS2
83/09/02.

HOME LAUNDRY (STEAM)

CLEAR DAY PERFORMANCE TABLE

15 MARCH (DAY 74)

HOUR	AMBIENT TEMP C	INCIDENT SOLAR ENERGY: DIRECT NORMAL GJ	INCIDENT SOLAR ENERGY: COLLECTOR PLANE (*) GJ	FLOW RATE KG/S	COLLECTOR TEMP: INLET C	COLLECTOR TEMP: OUTLET C	ENERGY COLLECTED GJ	COLLECTOR EFFICIENCY BASED ON (*) %	ENERGY DELIVERED GJ	SYSTEM LOSSES GJ	PARASITIC ENERGY GJ
1	10.6	0.00	0.00	0.00	56.3	56.3	0.00	0.0	0.00	.02	0.00
2	10.2	0.00	0.00	0.00	54.5	54.5	0.00	0.0	0.00	.02	0.00
3	9.8	0.00	0.00	0.00	52.9	52.9	0.00	0.0	0.00	.01	0.00
4	9.4	0.00	0.00	0.00	51.6	51.6	0.00	0.0	0.00	.01	0.00
5	9.0	0.00	0.00	0.00	50.4	50.4	0.00	0.0	0.00	.01	0.00
6	8.7	0.00	0.00	0.00	49.4	49.4	0.00	0.0	0.00	.01	0.00
7	8.3	.12	0.00	0.00	48.5	48.5	0.00	0.0	0.00	.01	0.00
8	10.9	.89	.86	4.40	113.9	118.9	.34	39.2	0.00	.08	.03
9	13.5	1.44	1.33	4.40	172.8	183.1	.69	51.6	.22	.12	.03
10	16.1	1.74	1.52	4.40	186.6	198.2	.77	50.9	.57	.13	.03
11	16.7	1.88	1.56	4.40	188.8	200.5	.78	50.2	.63	.14	.03
12	17.2	1.92	1.54	4.40	188.9	200.4	.77	49.7	.63	.14	.03
13	17.8	1.89	1.51	4.40	188.8	200.1	.75	49.6	.62	.14	.03
14	17.6	1.85	1.53	4.40	188.7	200.2	.77	50.2	.63	.14	.03
15	17.4	1.73	1.51	4.40	188.8	200.3	.77	50.8	.63	.14	.03
16	17.2	1.46	1.35	4.40	187.0	197.3	.69	51.1	.57	.13	.03
17	15.9	.93	0.00	0.00	124.1	124.1	0.00	0.0	0.00	.15	0.00
18	14.6	.11	0.00	0.00	99.2	99.2	0.00	0.0	0.00	.10	0.00
19	13.3	0.00	0.00	0.00	85.3	85.3	0.00	0.0	0.00	.08	0.00
20	13.3	0.00	0.00	0.00	76.6	76.6	0.00	0.0	0.00	.06	0.00
21	13.3	0.00	0.00	0.00	70.6	70.6	0.00	0.0	0.00	.05	0.00
22	13.3	0.00	0.00	0.00	66.3	66.3	0.00	0.0	0.00	.04	0.00
23	13.3	0.00	0.00	0.00	63.0	63.0	0.00	0.0	0.00	.03	0.00
24	13.3	0.00	0.00	0.00	60.5	60.5	0.00	0.0	0.00	.03	0.00
TOTAL/AVE	---	15.96	12.72	---	---	---	6.32	49.7	4.50	1.79	.23

Table A-12

RUN ID: HW2
83/09/02.

HOME LAUNDRY (DHW)

CLEAR DAY PERFORMANCE TABLE

15 MARCH (DAY 74)

HOUR	AMBIENT TEMP C	INCIDENT SOLAR ENERGY: DIRECT NORMAL GJ	INCIDENT SOLAR ENERGY: COLLECTOR PLANE (*) GJ	FLOW RATE KG/S	COLLECTOR TEMP INLET C	COLLECTOR TEMP OUTLET C	ENERGY COLLECTED GJ	COLLECTOR EFFICIENCY BASED ON (*) %	ENERGY DELIVERED GJ	SYSTEM LOSSES GJ	PARASITIC ENERGY GJ
1	10.6	0.00	0.00	0.00	55.1	55.1	0.00	0.0	0.00	.01	0.00
2	10.2	0.00	0.00	0.00	53.5	53.5	0.00	0.0	0.00	.01	0.00
3	9.8	0.00	0.00	0.00	52.2	52.2	0.00	0.0	0.00	.01	0.00
4	9.4	0.00	0.00	0.00	51.0	51.0	0.00	0.0	0.00	.01	0.00
5	9.0	0.00	0.00	0.00	49.9	49.9	0.00	0.0	0.00	.01	0.00
6	8.7	0.00	0.00	0.00	49.0	49.0	0.00	0.0	0.00	.01	0.00
7	8.3	.12	0.00	0.00	48.1	48.1	0.00	0.0	0.00	.00	0.00
8	10.9	.89	.86	4.40	58.7	64.0	.35	41.0	.44	.04	.03
9	13.5	1.44	1.33	4.40	96.4	107.3	.73	54.5	.41	.06	.03
10	16.1	1.74	1.52	4.40	120.8	132.9	.81	53.4	.51	.08	.03
11	16.7	1.88	1.56	4.40	132.3	144.6	.82	52.4	.60	.09	.03
12	17.2	1.92	1.54	4.40	136.2	148.2	.80	51.8	.65	.09	.03
13	17.8	1.89	1.51	4.40	136.8	148.6	.78	51.7	.67	.09	.03
14	17.6	1.85	1.53	4.40	138.6	150.6	.80	52.2	.68	.10	.03
15	17.4	1.73	1.51	4.40	139.4	151.3	.80	52.8	.69	.10	.03
16	17.2	1.46	1.35	4.40	134.6	145.4	.72	53.5	.68	.09	.03
17	15.9	.93	0.00	0.00	107.1	107.1	0.00	0.0	0.00	.10	0.00
18	14.6	.11	0.00	0.00	90.4	90.4	0.00	0.0	0.00	.07	0.00
19	13.3	0.00	0.00	0.00	79.9	79.9	0.00	0.0	0.00	.06	0.00
20	13.3	0.00	0.00	0.00	72.9	72.9	0.00	0.0	0.00	.04	0.00
21	13.3	0.00	0.00	0.00	68.0	68.0	0.00	0.0	0.00	.03	0.00
22	13.3	0.00	0.00	0.00	64.3	64.3	0.00	0.0	0.00	.03	0.00
23	13.3	0.00	0.00	0.00	61.5	61.5	0.00	0.0	0.00	.02	0.00
24	13.3	0.00	0.00	0.00	59.3	59.3	0.00	0.0	0.00	.02	0.00
TOTAL/AVE	---	15.96	12.72	---	---	---	6.61	51.9	5.33	1.17	.23

Table A-13

RUN ID: LS2
83/09/02.

LONE STAR BREWERY

CLEAR DAY PERFORMANCE TABLE

18 SEPTEMBER (DAY 261)

HOUR	AMBIENT TEMP C	INCIDENT SOLAR ENERGY DIRECT NORMAL GJ	INCIDENT SOLAR ENERGY COLLECTOR PLANE (*) GJ	FLOW RATE KG/S	COLLECTOR TEMP INLET C	COLLECTOR TEMP OUTLET C	ENERGY COLLECTED GJ	COLLECTOR EFFICIENCY BASED ON (*) %	ENERGY DELIVERED GJ	SYSTEM LOSSES GJ	PARASITIC ENERGY GJ
1	17.2	0.00	0.00	0.00	18.7	18.7	0.00	0.0	0.00	.01	0.00
2	16.7	0.00	0.00	0.00	17.9	17.9	0.00	0.0	0.00	.01	0.00
3	16.1	0.00	0.00	0.00	17.1	17.1	0.00	0.0	0.00	.01	0.00
4	15.6	0.00	0.00	0.00	16.5	16.5	0.00	0.0	0.00	.01	0.00
5	13.9	0.00	0.00	0.00	15.4	15.4	0.00	0.0	0.00	.01	0.00
6	13.9	0.00	0.00	0.00	14.8	14.8	0.00	0.0	0.00	.01	0.00
7	15.0	.15	0.00	0.00	14.9	14.9	0.00	0.0	0.00	.01	0.00
8	18.9	1.37	1.35	3.67	128.8	140.4	.38	27.9	0.00	.07	.01
9	21.7	2.11	2.03	3.67	173.0	201.7	.93	46.0	.46	.10	.01
10	23.9	2.46	2.28	3.67	178.4	211.2	1.06	46.7	.93	.11	.01
11	25.0	2.62	2.35	3.67	178.6	212.6	1.10	47.0	.99	.11	.01
12	25.6	2.67	2.35	3.67	178.6	212.6	1.10	46.9	1.00	.11	.01
13	26.1	2.61	2.30	3.67	178.6	211.8	1.08	46.8	.97	.11	.01
14	27.2	2.58	2.32	3.67	178.6	212.2	1.09	47.0	.98	.11	.01
15	28.3	2.47	2.29	3.67	178.6	211.9	1.08	47.1	.97	.11	.01
16	27.8	2.16	2.07	3.67	178.3	207.9	.96	46.3	.87	.11	.01
17	27.8	1.44	1.42	3.67	176.5	186.7	.33	23.3	.30	.10	.01
18	27.2	.12	0.00	0.00	84.7	84.7	0.00	0.0	0.00	.21	0.00
19	25.0	0.00	0.00	0.00	54.5	54.5	0.00	0.0	0.00	.10	0.00
20	23.3	0.00	0.00	0.00	40.1	40.1	0.00	0.0	0.00	.06	0.00
21	22.2	0.00	0.00	0.00	32.2	32.2	0.00	0.0	0.00	.04	0.00
22	21.7	0.00	0.00	0.00	27.7	27.7	0.00	0.0	0.00	.03	0.00
23	20.6	0.00	0.00	0.00	24.7	24.7	0.00	0.0	0.00	.02	0.00
24	20.0	0.00	0.00	0.00	22.8	22.8	0.00	0.0	0.00	.02	0.00
TOTAL/AVE	---	22.75	20.75	---	---	---	9.12	43.9	7.47	1.57	.05

RUN ID: OR2
83/09/02.

Table A-14

ORE IDA FOODS

CLEAR DAY PERFORMANCE TABLE

1 SEPTEMBER (DAY 244)

HOUR	AMBIENT TEMP C	INCIDENT SOLAR ENERGY DIRECT NORMAL GJ	INCIDENT SOLAR ENERGY COLLECTOR PLANE (*) GJ	FLOW RATE KG/S	COLLECTOR TEMP INLET C	COLLECTOR TEMP OUTLET C	ENERGY COLLECTED GJ	COLLECTOR EFFICIENCY BASED ON (*) %	ENERGY DELIVERED GJ	SYSTEM LOSSES GJ	PARASITIC ENERGY GJ
1	15.7	0.00	0.00	0.00	16.4	16.4	0.00	0.0	0.00	.07	0.00
2	15.0	0.00	0.00	0.00	15.4	15.4	0.00	0.0	0.00	.06	0.00
3	14.6	0.00	0.00	0.00	14.9	14.9	0.00	0.0	0.00	.05	0.00
4	14.7	0.00	0.00	0.00	14.8	14.8	0.00	0.0	0.00	.04	0.00
5	15.2	0.00	0.00	0.00	15.1	15.1	0.00	0.0	0.00	.03	0.00
6	16.0	0.00	0.00	0.00	15.7	15.7	0.00	0.0	0.00	.03	0.00
7	16.9	.94	.92	2.92	66.1	68.5	.11	12.1	0.00	.10	.03
8	17.8	2.06	1.94	2.92	94.4	109.0	.70	36.0	0.00	.17	.03
9	20.9	2.56	2.27	2.92	156.5	182.7	1.25	55.0	0.00	.30	.03
10	24.1	2.72	2.27	2.92	173.9	199.6	1.22	53.9	.66	.34	.03
11	27.2	2.80	2.24	2.92	173.8	198.9	1.20	53.5	.87	.34	.03
12	28.9	2.82	2.27	2.92	173.8	199.4	1.22	53.8	.88	.34	.03
13	30.5	2.82	2.36	2.92	173.8	200.9	1.29	54.8	.95	.34	.03
14	32.2	2.79	2.49	2.92	173.7	202.9	1.39	55.8	1.04	.34	.03
15	32.4	2.71	2.57	2.92	173.6	204.0	1.45	56.3	1.11	.34	.03
16	32.6	2.54	2.51	2.92	173.8	199.8	1.24	49.5	.96	.33	.03
17	32.8	2.03	2.03	2.92	174.5	187.1	.60	29.6	.41	.32	.03
18	30.9	.92	0.00	0.00	76.7	76.7	0.00	0.0	0.00	.41	0.00
19	29.1	0.00	0.00	0.00	44.3	44.3	0.00	0.0	0.00	.27	0.00
20	27.2	0.00	0.00	0.00	32.7	32.7	0.00	0.0	0.00	.20	0.00
21	25.2	0.00	0.00	0.00	27.6	27.6	0.00	0.0	0.00	.15	0.00
22	23.1	0.00	0.00	0.00	24.5	24.5	0.00	0.0	0.00	.13	0.00
23	21.1	0.00	0.00	0.00	22.2	22.2	0.00	0.0	0.00	.10	0.00
24	20.9	0.00	0.00	0.00	21.3	21.3	0.00	0.0	0.00	.08	0.00
TOTAL/AVE	---	27.71	23.87	---	---	---	11.67	48.9	6.87	4.89	.28

RUN ID: SU2
83/09/02.

Table A-15

SOUTHERN UNION

CLEAR DAY PERFORMANCE TABLE

2 SEPTEMBER (DAY 245)

HOUR	AMBIENT TEMP C	INCIDENT SOLAR ENERGY: DIRECT NORMAL GJ	INCIDENT SOLAR ENERGY: COLLECTOR PLANE (*) GJ	FLOW RATE KG/S	COLLECTOR TEMP INLET C	COLLECTOR TEMP OUTLET C	ENERGY COLLECTED GJ	COLLECTOR EFFICIENCY BASED ON (*) %	ENERGY DELIVERED GJ	SYSTEM LOSSES GJ	PARASITIC ENERGY GJ
1	21.3	0.00	0.00	0.00	23.9	23.9	0.00	0.0	0.00	.03	0.00
2	20.9	0.00	0.00	0.00	22.7	22.7	0.00	0.0	0.00	.03	0.00
3	20.6	0.00	0.00	0.00	21.8	21.8	0.00	0.0	0.00	.02	0.00
4	20.2	0.00	0.00	0.00	21.1	21.1	0.00	0.0	0.00	.02	0.00
5	19.8	0.00	0.00	0.00	20.6	20.6	0.00	0.0	0.00	.02	0.00
6	19.4	0.00	0.00	0.00	20.1	20.1	0.00	0.0	0.00	.02	0.00
7	19.4	.65	0.00	0.00	19.8	19.8	0.00	0.0	0.00	.01	0.00
8	20.0	2.14	.86	4.98	121.2	125.9	.22	25.3	0.00	.08	.06
9	24.4	2.81	1.73	4.98	166.9	182.0	.69	39.5	0.00	.11	.06
10	26.7	3.01	2.40	4.98	191.2	215.2	1.09	45.4	.71	.15	.06
11	29.4	3.10	2.87	4.98	194.0	224.1	1.37	48.0	1.17	.16	.06
12	30.6	3.13	3.10	4.98	194.8	228.2	1.52	49.0	1.34	.16	.06
13	32.2	3.14	3.11	4.98	194.9	228.5	1.53	49.2	1.36	.16	.06
14	33.9	3.10	2.87	4.98	194.5	224.9	1.39	48.3	1.25	.16	.06
15	34.4	3.01	2.40	4.98	193.2	217.4	1.10	45.9	.99	.15	.06
16	35.0	2.79	1.72	4.98	191.1	205.4	.65	37.8	.57	.14	.06
17	35.0	2.10	.84	4.98	188.6	191.1	.11	13.1	.06	.12	.06
18	33.9	.52	0.00	0.00	91.7	91.7	0.00	0.0	0.00	.25	0.00
19	32.2	0.00	0.00	0.00	61.6	61.6	0.00	0.0	0.00	.13	0.00
20	30.3	0.00	0.00	0.00	47.1	47.1	0.00	0.0	0.00	.09	0.00
21	28.4	0.00	0.00	0.00	38.9	38.9	0.00	0.0	0.00	.07	0.00
22	26.6	0.00	0.00	0.00	33.6	33.6	0.00	0.0	0.00	.05	0.00
23	24.7	0.00	0.00	0.00	29.8	29.8	0.00	0.0	0.00	.05	0.00
24	22.8	0.00	0.00	0.00	26.9	26.9	0.00	0.0	0.00	.04	0.00
TOTAL/AVE	---	29.50	21.90	---	---	---	9.67	44.1	7.44	2.22	.57

RUN ID: US3
83/10/07.

Table A-16

USS CHEMICALS

CLEAR DAY PERFORMANCE TABLE

8 SEPTEMBER (DAY 251)

HOUR	AMBIENT TEMP C	INCIDENT SOLAR ENERGY: DIRECT NORMAL GJ	INCIDENT SOLAR ENERGY: COLLECTOR PLANE (*) GJ	FLOW RATE KG/S	COLLECTOR TEMP INLET C	COLLECTOR TEMP OUTLET C	ENERGY COLLECTED GJ	COLLECTOR EFFICIENCY BASED ON (*) %	ENERGY DELIVERED GJ	SYSTEM LOSSES GJ	PARASITIC ENERGY GJ
1	15.0	0.00	0.00	0.00	17.5	17.5	0.00	0.0	0.00	.17	0.00
2	14.6	0.00	0.00	0.00	16.4	16.4	0.00	0.0	0.00	.15	0.00
3	14.3	0.00	0.00	0.00	15.7	15.7	0.00	0.0	0.00	.14	0.00
4	13.9	0.00	0.00	0.00	15.0	15.0	0.00	0.0	0.00	.13	0.00
5	13.5	0.00	0.00	0.00	14.5	14.5	0.00	0.0	0.00	.12	0.00
6	13.2	0.00	0.00	0.00	14.0	14.0	0.00	0.0	0.00	.11	0.00
7	12.8	1.09	0.00	0.00	13.6	13.6	0.00	0.0	0.00	.10	0.00
8	15.6	6.80	5.71	20.13	132.1	149.7	2.66	46.7	0.00	.27	.07
9	18.3	10.27	8.10	20.13	154.0	179.3	3.82	47.1	2.25	.33	.07
10	21.1	11.97	9.18	20.13	156.2	185.6	4.42	48.1	3.89	.34	.07
11	22.8	12.76	10.01	20.13	156.6	189.4	4.95	49.4	4.49	.34	.07
12	24.4	13.07	10.90	20.13	157.0	193.8	5.55	51.0	5.08	.34	.07
13	26.1	13.18	11.83	20.13	157.4	198.3	6.17	52.1	5.69	.34	.07
14	26.3	12.91	12.33	20.13	157.6	200.6	6.47	52.5	6.06	.34	.07
15	26.5	12.10	12.00	20.13	157.6	199.6	6.33	52.7	6.02	.34	.07
16	26.7	10.29	10.27	20.13	157.1	192.7	5.36	52.2	5.23	.34	.07
17	25.4	6.44	6.26	20.13	155.9	175.0	2.88	45.9	3.09	.32	.07
18	24.1	.65	0.00	0.00	71.2	71.2	0.00	0.0	0.00	.92	0.00
19	22.8	0.00	0.00	0.00	47.7	47.7	0.00	0.0	0.00	.43	0.00
20	21.1	0.00	0.00	0.00	36.2	36.2	0.00	0.0	0.00	.33	0.00
21	19.5	0.00	0.00	0.00	29.5	29.5	0.00	0.0	0.00	.28	0.00
22	17.8	0.00	0.00	0.00	24.9	24.9	0.00	0.0	0.00	.25	0.00
23	17.1	0.00	0.00	0.00	22.0	22.0	0.00	0.0	0.00	.22	0.00
24	16.3	0.00	0.00	0.00	19.8	19.8	0.00	0.0	0.00	.19	0.00
TOTAL/AVE	---	111.52	96.59	---	---	---	48.61	50.3	41.79	6.83	.73

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