375
3-14-80

DR. 980

ORO-5122-T1

FINAL REPORT FOR APPLICATION OF SOLAR ENERGY TO INDUSTRIAL DRYING OF SOYBEANS—PHASE III, PERFORMANCE EVALUATION

Final Report

MASTER

October 31, 1979

Work Performed Under Contract No. EY-76-C-05-5122

Systems Division
Teledyne Brown Engineering
Huntsville, Alabama

U.S. Department of Energy

Solar Energy

DISCLAIMER

DISCLAIMER

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy $16.00
Microfiche $3.50

ORO-5122-T1
Distribution Category UC-59b

FINAL REPORT FOR APPLICATION OF SOLAR ENERGY TO INDUSTRIAL DRYING OF SOYBEANS PHASE III, PERFORMANCE EVALUATION

FINAL REPORT

October 31, 1979

Prepared For

U.S. DEPARTMENT OF ENERGY
WASHINGTON, D.C.

Contract No. DE-AC05-76CS35122

Prepared By

SYSTEMS DIVISION
TELEDYNE BROWN ENGINEERING
HUNTSVILLE, ALABAMA

ABSTRACT

A 15-month performance evaluation was conducted on a solar system designed and constructed to augment the industrial drying of soybeans at the Gold Kist, Inc., extraction plant in Decatur, Alabama. The plant employs three oil-fired, continuous-flow dryers of 3,000 bu/hr each.

The solar system consists of 672 Solaron air collectors that temper the airflow into the existing dryers. Since the requirement for energy exceeds the peak solar system capacity, no storage is provided. The interface with the existing facility is simply accomplished by three ducts that release the solar heated air directly adjacent to the dryer air intakes, and no mechanical coupling is needed.

The solar system was operated for 1,752 hr on 290 days during the 15-month period without a single failure sufficient to cause shutdown. No interference with normal plant operations was experienced. Maintenance of the solar system, consisting of service to the air handling unit, cleaning of collector glazing, and minor duct repair, totaled $1,564.

System utilization for the 15-month period was only 46.3%. This was primarily due to daytime routine maintenance performed on the conventional drying and processing equipment. The solar fraction was not large enough to justify maintenance shift changes.

The 1,215 m^2 (13,104 ft^2) of collection area supplied 1.04×10^{12} J (986.54×10^6 Btu). At a more realistic utilization of 95%, the system would have delivered 2.13×10^{12} J ($2,024 \times 10^6$ Btu), representing 13,600 gal of No. 5 fuel oil.

An average collector efficiency of 26.2% was experienced. Contamination caused by the local plant environment reduced the average collector efficiency by 9.3 percentage points. A prototype of an automatic cleaning system was constructed, tested, and proved to be an effective method for removing the contaminant on a daily basis. An emission control evaluation revealed that all plant emissions were within the limits prescribed by the permits issued by local and stated authorities. Various emission control devices specific to this industry were investigated.

An economic analysis was conducted under ground rules provided by DOE. Using a modified system cost of $405,615 and the actual ownership, operation, and maintenance cost, the life-cycle cost per million Btu of solar-derived energy was $48.10.

Prepared By:

B. R. Hall
Program Manager

Approved By:

K. H. McKechnie
Manager
Systems Engineering Department

TABLE OF CONTENTS

TABLE OF CONTENTS - Concluded

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS - Concluded

LIST OF TABLES

1. INTRODUCTION

1.1 GENERAL

About 40% of the total energy used in the United States is consumed by industry. A considerable amount of this is used in drying or dehydrating processes ranging from mining to the manufacturing industries. The use of solar energy to supplement some of the fuels now being used for these processes is being increasingly recognized, because of its widespread and continuous availability and its clean, nonpolluting form. To demonstrate the applicability of solar energy to industrial uses, the U.S. Department of Energy (DOE) initiated a three-phase program to design, test, and evaluate a solar system to collect energy for an industrial drying process and to provide an assessment of the economic and resource benefits of such a system. Phase I was a 9-month program to design and analyze a solar drying process; in Phase II, lasting 1 yr, the system was fabricated and installed; and during Phase III, operational data was acquired over a 15-month period to permit a comparison with a conventional fuel-operated facility.

To contribute to DOE's overall objective of demonstrating and evaluating the capability of solar energy for supplying industrial process heat, the drying of soybeans at an industrial site was proposed as an example that would be representative of other drying or dehydration processes. The Gold Kist, Inc., extraction plant at Decatur, Alabama, was chosen as the demonstration site. This plant employs three large continuous-flow dryers to dry soybeans for storage and for processing. The solar energy system consists of 672 Solaron air collectors to temper the airflow into the existing dryers. The 1,215 m^2 (13,104 ft^2) of collection area provided 1.04×10^{12} J (986.5×10^6 Btu), representing 6,666 gal of No. 5 fuel oil. With 95% utilization, the system was capable of displacing 13,600 gal of oil with the solar incidence that was available.

This report presents the final results of Phase III, "Performance Evaluation", conducted by Teledyne Brown Engineering (TBE). The effort was conducted under DOE Contract No. DE-AC05-76CS35122. In addition to performance evaluation, Phase III included a task to conduct a conceptual design of a glazing cleaning system and a task to evaluate the emission control of the Gold Kist Facility.

1.2 CONTRIBUTORS

The success of this program is attributable in part to the cooperation of the Marshall Space Flight Center (MSFC) for calibration equipment and to The University of Alabama in Huntsville (UAH) for providing solar radiation data for the area as well as assistance in pyrometer calibration. The program is also indebted to Gold Kist, Inc., for its excellent cooperation during system operation and for its inputs concerning emission controls.

1.3 TELEDYNE BROWN ENGINEERING

TBE is one of a large number of advanced-technology companies that are wholly owned by Teledyne, Inc. The family of Teledyne companies provides goods and services to the aerospace, military, industrial, and consumer markets. The products offered cover the spectrum from complete systems to the equipment and components that make up such systems. These products are supported by the technical services required to create and operate them.

Since its inception in 1953, TBE has maintained major capabilities in electronic, mechanical, and structural development and design; prototype fabrication; and testing. Since 1960, these capabilities have been greatly expanded to include areas such as systems engineering and applied research in space and military related sciences; design, fabrication, and test of electronic and mechanical hardware; and the development of information systems software. Today, TBE provides engineering support services to NASA; it is contributing to a number of U.S. Army, Navy, Air Force, Department of Transportation, Corps of Engineers, U.S. Department of Energy, and Post Office Department programs; and it serves a number of industrial firms with its specialized capabilities.

1.4 GOLD KIST, INC.

Gold Kist, Inc., a farmers' cooperative, was originally organized in 1933 to market cotton for a local group of farmers near Carrollton, Georgia. Today the company ranks among the top 500 industrial corporations in America with a 1975-76 fiscal year volume of nearly $1 billion. Operations now extend throughout 11 states from Arizona to Virginia. Gold Kist is the world's largest processor of peanuts and one of the nation's largest producers of poultry. Other products include peanut and soybean oil and meal, pork, pecans, eggs, cereal grains, animal feeds, seeds, plant food, agricultural chemicals, and animal health products. Many of these items are sold in the export trade. Products marketed at retail include fire logs, garden mulch, pecans, cat litter, and processed pork products. In four states, the company operates over 125 local Farmers Mutual Exchanges. These centers are the source of products and services for the farmer necessary to grow crops and livestock. Savings made in the operation of the business are returned to the members in proportion to participation. The continuing Gold Kist mission, then, is to improve the economic well-being of its members of supplying products and services for farm production and by marketing selected products.

The Gold Kist Soy Facility at Decatur, Alabama, after the solar system installation, is shown in Figure 1-1.

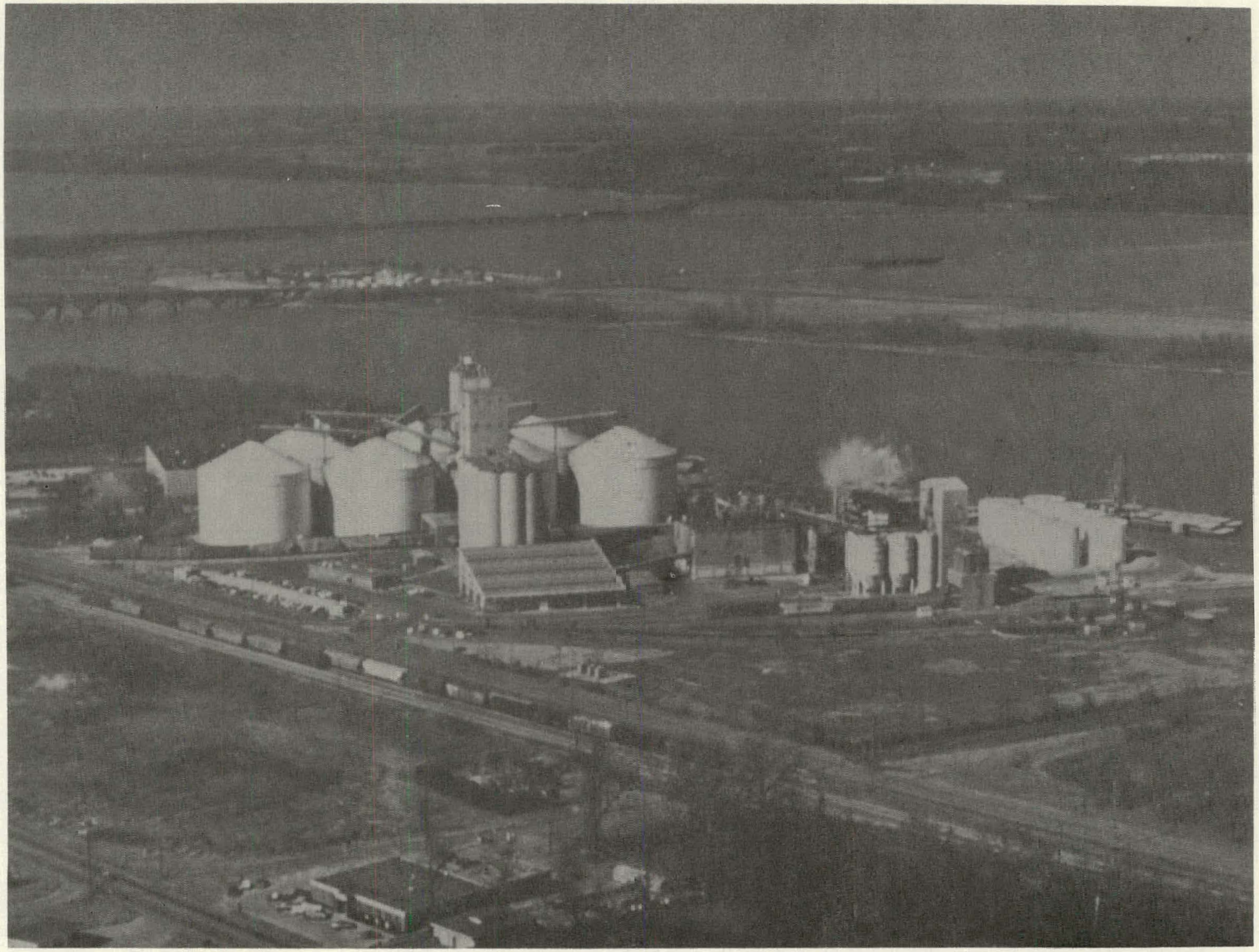


FIGURE 1-1. GOLD KIST, INC., DECATUR PLANT WITH SOLAR SYSTEM INSTALLED

2. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

2.1 SUMMARY

A brief summary of the application of solar energy to industrial drying of soybeans is shown in Table 2-1.

2.1.1 The Site

The selection of the Gold Kist Soy Facility as an experimental site for a solar energy program was made after a survey of various energy-intense industrial activities. In addition to consuming large amounts of fossil fuel, the Gold Kist facility served as an ideal test site to satisfy the objectives of the DOE program.

As a demonstration project, it had good market visibility. The Gold Kist facility is one of the largest, if not the largest, soy extraction plants in the world. Because of the nature of the process and the size of the plant, the solar system for the drying of soybeans had wide industrial exposure. Its visibility to the farm market, both nationally and internationally, served well to spread the "word" on the applicability of solar energy to industrial processes.

The geographical location of the Gold Kist facility enhanced the visibility of a solar demonstration program. It is located on the Tennessee River, a major national waterway, and Interstate I-65 passes just east of the site, a main road artery from the grain area of the midwest to the Gulf Coast and Florida resort areas.

2.1.2 The Solar System

The solar system consists of the following major subsystems: the collector, structural, energy transport, and controls subsystems. It also includes a data acquisition system to support the experimental nature of the program. Since the soybean dryers are capable of instantaneously using the entire solar system capacity, no thermal energy storage system was provided.

TABLE 2-1. SUMMARY OF APPLICATION OF SOLAR ENERGY TO INDUSTRIAL DRYING OF SOYBEANS

SITE	
Process:	Soybean drying in an oil extraction plant
Location:	Decatur, Alabama
Latitude:	34°40'
Annual Insolation:	380 Langleys (1,420 Btu/ft^2/day) horizontal surface
Altitude:	575 ft
Plant Capacity:	2,480,000 bu/mo
SOLAR ENERGY SYSTEM	
Fluid:	Air
Collector Mfg.:	Solaron
Array Size:	13,104 ft^2
Tilt Angle:	15 deg
Orientation:	24 deg east of south
Storage:	None
Transport System:	Positive pressure
Ducting:	Medium pressure, sheetmetal using pocket lock joints
Duct Insulation:	Owens-Corning Type ASJ #25, 2-in. thick
Blower:	30 HP Trane, 27,000 ft^3/min at 3-in. wg
Number of Collectors:	672
Flow Rate:	27,000 ft^3/min
Air Filter:	Continuous roll, automatic advance
EXISTING DRYER PROCESS	
Manufacturer:	Ferrell-Ross
Type:	Continuous flow
Fuel:	No. 5 fuel oil
Capacity:	Three dryers at 3,000 bu/hr each

SYSTEM INTERFACES	
With Dryer:	None (the solar heated air is entrained into the dryer airflow)
With Building:	(1) Penetration of the dryer house sidewall by ducts (2) Attachment of ducts to outside of dryer house sidewall
With Site:	Collectors are mounted on a 115- by 144-ft steel structure over a parking lot
PERFORMANCE	
Collector Efficiency:	Annual efficiency = 25.1%
Energy Collected:	823.6×10^6 Btu/yr
Temperature Lift:	40 to 60°F
System Impact:	The solar energy system provided 1.18% of the energy requirements for one dryer (during an 8-month period)
SYSTEM UTILIZATION	
Daylight Drying:	Drying occurred during 40% of daylight hours
Thermal Utilization:	$\frac{\text{Btu Utilized}}{\text{Btu Utilizable}}$ = 54.6% (annual)
Total Solar System Operation Time:	1,534 hr/yr
Conventional Dryer Operation Time:	Daytime - 1,794 hr/yr; nighttime - 2,768 hr/yr; Total - 4,562 hr/yr
SAFETY CONSIDERATIONS:	
Transport System:	Positive pressure to minimize dust ingestion
Fire Dampers:	Located between solar energy system and plant (smoke activated)
Maximum Temperature Limit:	Alarm sounds when collector temperature exceeds 250°F; operator turns blower on and energy is dumped
Collector Array:	Access ladder, handrails, and walkways to meet OSHA requirements
Lighting:	Twenty-four 400-W mercury vapor (vapor- and duct-protected)

TABLE 2-1 - Concluded

INSTRUMENTATION AND MONITORING

Instrumentation:	Eleven parameters; sensors selected according to ERDA preferred list
Data Acquisition:	Fluke Model 2240A data logger; one sample/ 5 min
Data Display:	LED display at site; printed paper at site
Data Processing:	Varian Model V-73 computer at TBE
Noninstrumented Data:	Logs and recorded operational data

OPERATION

Turn-On:	When temperature differential between collector and ambient air exceeds a threshold
Airflow:	Solar heated air can be directed to any desired combination of three dryers by manual positioning of dampers on dryer house manifold

CONSTRUCTION COST

Site Work:	$ 43,660
Collectors:	168,500
Supporting Structure:	173,642
Ducting:	94,275
Instrumentation:	6,649
Controls:	6,000
Miscellaneous:	93,380
Total:	586,106

ECONOMICS

Energy Cost for Process Heat

(1)	Using Heat from Fuel Oil	- $3.15/MBtu
(2)	Using Combined Solar/Fuel Oil	- 4.96/MBtu
(3)	Solar Alone	- 48.10/MBtu

MANAGEMENT APPROACH

Phase III

(1) Gold Kist operated the facility

(2) TBE conducted data analysis and reporting

The collector subsystem consists of 672 Solaron single-glazed air collectors (13,104 ft^2) arranged in 84 sets of 8-collector modules encompassing 4 two-in-series pairs of collectors. A cost/performance tradeoff study conducted in Phase I resulted in a 15-deg tilt for the array. To align the array with a row of large silos nearby, it was oriented 24 deg east of south.

Because of space availability constraints at the Gold Kist facility, the solar array had to be elevated above an existing parking lot. This required a structural subsystem to support the solar array in such a manner not to interfere with plant operations.

The energy transport subsystem delivers 27,000 ft^3/min of ambient air to the collectors and carries the solar-heated air from the collectors to the dryers. This subsystem consists of conventional air handling equipment that encompasses an automatic roll-type filter, commercial ducting (insulated on the hot air portion), and the necessary fire dampers. The blower is located on the upstream side of the collectors to ensure a positive pressure in the collectors, which prevents ingestion of contaminants at leakage points.

The solar heated air from the collectors is delivered from the array to the dryer house through a 4- by 4-ft galvanized metal duct. All hot air ducting has 2 in. of fiberglass insulation coated with a weatherproof mastic. The transport ducting conforms to SMACNA and ASHRAE criteria for industrial ducting.

The energy transport subsystem supply duct terminates with three inlets (with dampers) to the dryer house. Each inlet is located directly in front of a dryer air inlet. This type of interface provides minimal impact on the conventional operation of the dryers.

A standard Penn Control Delta-T type controller is used to control the system. One sensor is located behind and adjacent to the collecting surface of one collector, while the other sensor senses ambient temperature. When the collector temperature exceeds ambient by 15°F, the system trips on. Trip-off occurs when the collector temperature is within 7°F of ambient. The solar system also has an electrical interlock with the main conveyor, which delivers beans from all three dryers. This interlock makes the control system completely independent of operational personnel.

2.1.3 Data Acquisition System

The data acquisition system consists of eight RTD-type temperature sensors, a pyrometer, a hot-wire anemometer, a watt transducer, a relative humidity sensor, and a Fluke Model 2240A data logger. The printed data was keypunched and fed to the performance evaluation computer program for processing on TBE's Varian V-73 computer.

2.1.4 System Operation

Because of the working shift arrangement at the Gold Kist facility, a large portion of the routine plant maintenance occurs during the day. Many times, this affects dryer operation, either directly or indirectly. As a result of scheduled and unscheduled maintenance, the dryers operated only 40% of the available daylight hours. Total (day and night) dryer operation was sufficient to have consumed 100% of the daylight hours.

2.1.5 Maintenance and Reliability

The solar system operated for 1,752 hr on 290 days during the 15-month period without a single malfunction sufficient for shutdown. The only maintenance actions required were routine cleaning of the glazings, fan belt replacement, filter change, lubrication, and one minor duct repair. There is no reason to believe that the system would not last as long as the drying facility itself with only minimal maintenance.

2.1.6 Economics

The Lawrence Livermore Laboratories format for life-cycle cost analysis has been followed in deriving the cost comparisons. The results of the Plan A and Plan B calculations for the solar drying system are summarized below:

LOCATION	SOLAR ALONE	PLAN A*	PLAN B*
Albuquerque	$42.19/MBtu	$3.91/MBtu	$5.05/MBtu
Omaha	$52.03/MBtu	$3.90/MBtu	$4.97/MBtu
Decatur (TRUE)	$48.10/MBtu	$3.15/MBtu	$4.96/MBtu

2.1.7 Performance

During the 15-month period, the solar system displaced 6,630 gal of No. 5 fuel oil. Assuming a system utilization factor of 95%, the system was capable of displacing 13,600 gal during the same period.

Collector efficiency ranged from 28.3% in September to 23.2% in June, with an annual efficiency of 25.1%. Contamination on the collectors accounted for reduction of approximately 9.3% in efficiency, as evidenced by the data before and after cleaning the glazings.

2.2 CONCLUSIONS

The principal conclusions resulting from Phase II, "Performance Evaluation", are as follows:

- Large-scale, air-based solar drying systems for industrial applications are feasible, including retrofit systems.
- Conventional air transport equipment can be used reliably in air-based industrial solar systems.
- Industrial process heat solar systems must be sufficiently large to justify changing plant maintenance schedules to nondaylight hours, if required.
- The concept of solar industrial process heat systems are readily acceptable by the industrial consumer.
- A direct impingement, oscillating water jet type cleaning system is effective for cleaning collector glazings at sites with a particulate/chemical-laden environment.

*Plan A - Represents conventional process heat using fuel oil

**Plan B - Represents a combined solar/fuel oil facility

2.3 RECOMMENDATIONS

The recommendations resulting from this performance evaluation are:

- Long-range, limited performance evaluation is needed to determine:
  - Performance degradation
  - Extended performance maintenance requirements
  - Economic trends
  - Overall system refurbishment cycle
- A full-scale cleaning system based on the prototype installed should be designed, installed, and evaluated during the long-range system performance evalution program.
- Larger systems that produce 8 to 12% of the industrial process heat requirement should be used in future demonstrations. This is needed to justify, in many cases, operational shift changes to take maximum advantage of the available solar energy.
- Continuing cost-saving innovations relative to system installation, collector mountings, and ducting methods.

3. PROGRAM BACKGROUND

3.1 PHASES I AND II

Phase I was initiated on June 25, 1976. Program objectives were to identify and synthesize the most cost-effective solar drying system and to prepare detailed design and performance specifications. This effort resulted in the current system configuration.

Phase II, initiated on July 12, 1977, consisted of component procurement, fabrication, and system construction and checkout. This phase was completed on May 31, 1978.

3.2 PHASE III

The performance evaluation effort, Phase III, contractually began on September 11, 1978; however, data acquisition and reduction activities actually began on June 1, 1978. Phase III consisted of the following tasks:

- Task I - System Operation: Under this task, a System Verification Plan was established (see Appendix A). This plan detailed system operation procedures to minimize plant operation impact, maintenance requirements and schedules, data reduction methods, and the operational logs, forms, and reporting formats. The performance evaluation computer program was developed under this task.

- Task II - Data Acquisition: The preliminary measurements list was finalized to determine specific parameters to be monitored. All data acquisition system verification, calibration, and repair was accomplished under this task.

- Task III - Operational Analysis: This task included the use of a computer program developed to integrate various pertinent performance parameters and provide various summaries on a periodic basis. These summaries were analyzed to detect system anomalies and performance trends.

- Task IV - Cleaning System Concept Design: Several concepts for automated solar panel cleaning systems were investigated. These concepts were based on the cleaning requirements known to exist at the beginning of Phase III. A preliminary design and prototype fabrication and test program was accomplished in the most promising design. Performance and economic data were derived for the system chosen.

- Task V - Emission Control Evaluation: Using Gold Kist engineering personnel as consultants, TBE conducted a study of the emission control devices currently in use or potentially applicable to the processes at Gold Kist. Economics and efficiencies versus cost per cfm were investigated for several types of filtration equipment.

4. SYSTEM DESCRIPTION

A detailed description of the solar system is contained in the ERDA report entitled, "Final Design Report for Application of Solar Energy to Industrial Drying of Soybeans", dated February 28, 1977. For convenience, a summarized system description is presented in this section.

4.1 THE SOLAR DRYING SYSTEM

The solar drying system is an air-based concept designed to safety and efficiently collect and transfer solar energy for use in a conventional soybean drying process with minimum impact on existing facilities and operations. Functionally, the solar drying system consists of the following practical subsystems:

- Collector
- Energy Transport
- Structural
- Controls.

Additionally, the solar drying system includes an instrumentation subsystem in support of the experimental nature of the program. Although solar energy systems typically employ storage to supply energy at night or during cloudless days, none was required in the selected solar drying system because all the energy potentially collectable could be used immediately in the existing drying operations. These subsystem and system operations are discussed below.

The solar drying system is shown schematically (to the level of principal components) in Figure 4-1. During operations, approximately 12.74 m^3/sec (27,000 ft^3/min) of outside air is drawn through the collectors and dumped in a preheating mode into the airstream entering the dryer house where the mixed flow is subsequently heated by the conventional dryer equipment.

The 12.74 m^3/sec air flow corresponds to 0.010 m^3/sec-m^2 (2 ft^3/min/ft^2) for the gross area of the 336 pairs of Solaron collectors arrayed in a basic two-in-series pattern.

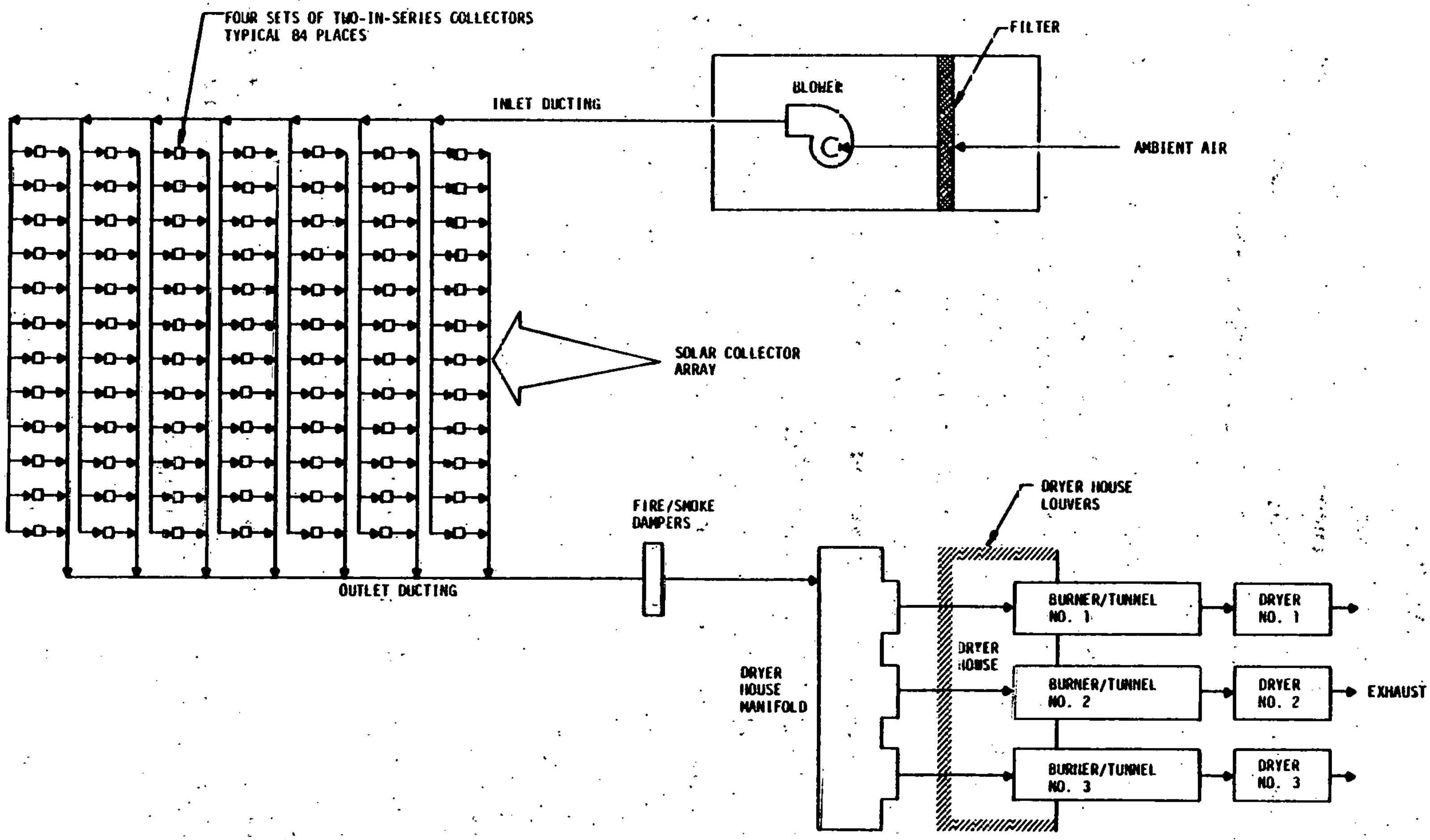


FIGURE 4-1. SCHEMATIC OF SOLAR DRYING SYSTEM

4.1.1 Collector Subsystem

The collector subsystem consists of 672 Solaron collectors arrayed in 84 sets of 8 modules encompassing 4 two-in-series pairs of collectors. The layout of the 4 paired collectors is shown in Figure 4-2. The collector array is tilted at 15 deg and pointed some 24 deg east of south.

The collectors are about 0.914 m (3.0 ft) wide by 1.98 m (6.5 ft) long by 0.183 m (7 in.) deep. The design employs one glass cover (3.175×10^{-3} m thick) and a nonselective absorber surface ($\alpha/\varepsilon \approx 1$). The insulation of the collector is shown in Figure 4-3.

The 4 two-in-series pattern or module used in the collector array requires some 16 collector-to-collector joints (in pairs), as illustrated in Figure 4-2. These joints are sealed with butyl tape.

4.1.2 Energy Transport Subsystem

The energy transport subsystem distributes the air to be heated to the solar collectors and transfers the solar heated air to the conventional drying process. The principal components of the subsystem are:

- Air filter
- Blower
- Inlet ducting
- Outlet ducting
- Dryer house manifold
- Fire dampers.

The relative locations of these components correspond to the schematic of Figure 4-1.

An air filter is used in the system for two reasons. First, the immediate environment of grain elevators and feed mills tends to be dusty and the ingestion of dust into the system could cause maintenance and operation problems that can be minimized by using a filter at the inlet. However, the filters also serve an important safety function by limiting the amount of dust that will enter the system and present the potential for supporting combustion in the event of a fire in or near the system.

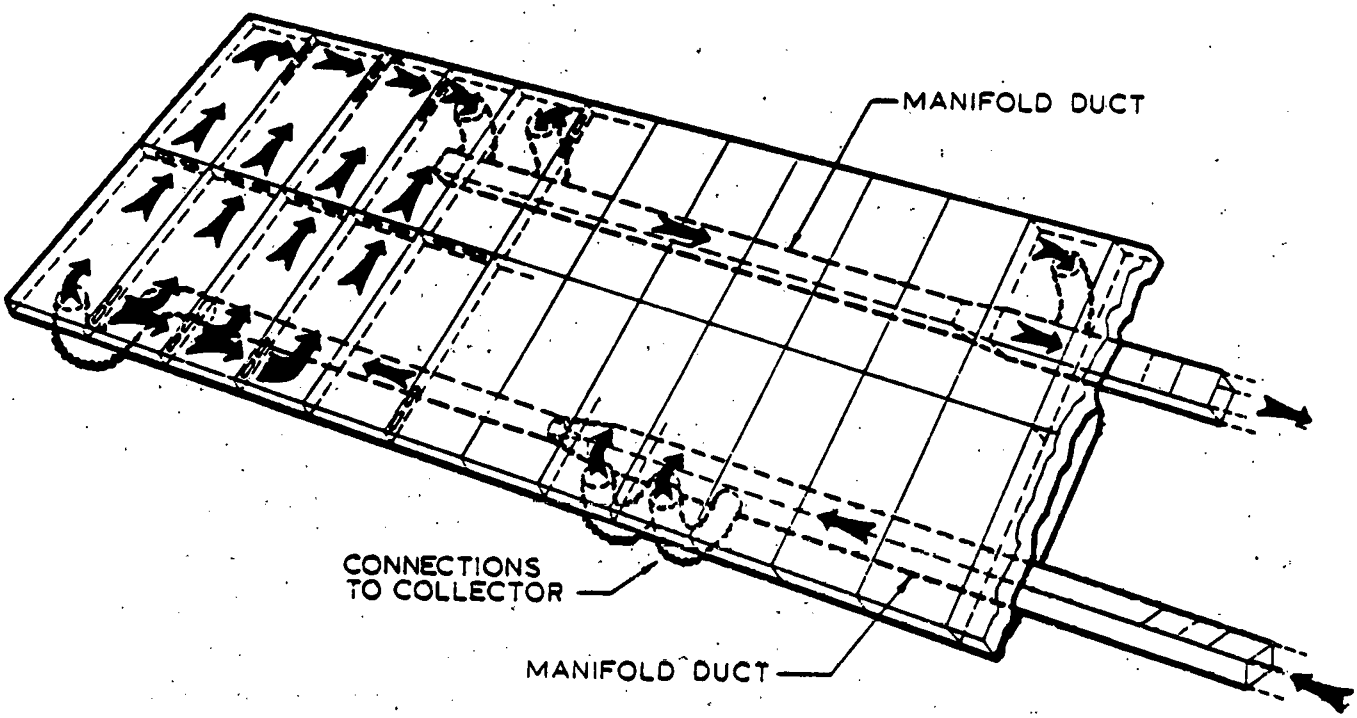
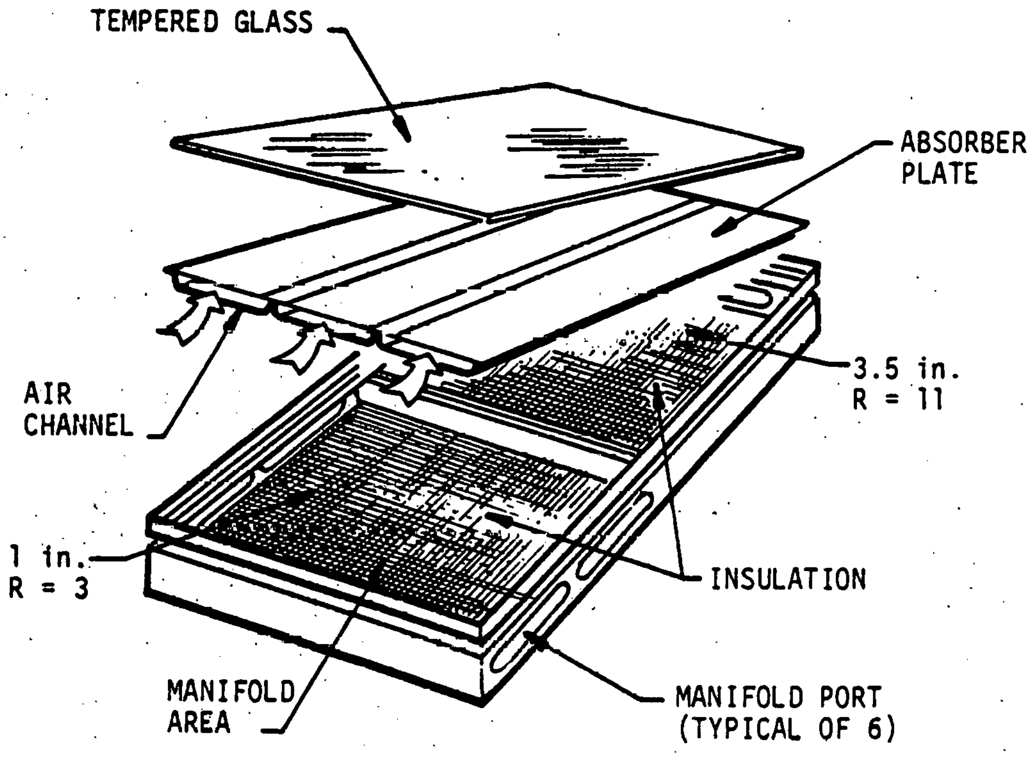


FIGURE 4-2. COLLECTOR INSTALLATION PATTERN



PANEL DIMENSIONS: 3 ft WIDE BY 6 ft 6 in. LONG by 7.25 in. HIGH

NOTE: AIR FLOWS THROUGH THE CHANNELS BENEATH THE ABSORBER PLATE.

FIGURE 4-3. COLLECTOR INSULATION

The filter and blower are housed together as a prepackaged unit. This type of assembly was selected on the basis of cost since it is less expensive than an on-site assembly of the filter/blower/housing and is easier to seal against air leaks. The assembly is a Trane Company Model PCC No. 50 "Penthouse Climate Changer" unit with no coils. This unit has a roll-type automatic filter with a rated overall efficiency of 85% at a face velocity of 2.54 m/sec (500 ft/min) and a rated dust loading of 4.31 kg/m^2 (400 g/ft^2). The blower in the assembly is a forward-curved type with a rating of 13 m^3/sec (27,000 ft^3/min) at 746.4 Pa (3 in. H_2O).

The blower is positioned between the filter and the remaining components, as shown schematically in Figure 4-1. Positioning the blower upstream of the collector subsystem results in a positive pressure system that provides several advantages. First, it ensures system safety in the event of accidental or gradual failure of any of the air transport system seals. Any such leaks will result in the loss of "clean" air as opposed to the ingestion of dirty air into the system, which could eventually create an explosive mixture within the collectors and ducting.

The inlet ducting (Figure 4-1) provides for the delivery of filtered air to the solar collector. This ducting was designed for a pressure loss of 0.571 Pa/m of duct length (0.07 in. H_2O/100 ft) and maximum air velocities on the order of 10.16 m/sec (2,000 ft/min). Technically, these values are somewhat lower than would occur if a rigorous tradeoff between duct costs and blower power were considered.

Rectangular ducts are employed for trunks and branch lines to simplify the duct inspection and maintenance tasks since the bottoms of the runs are in the same plane despite area changes. Also, sealing of the "takeoffs" from the branch lines to the collectors was easier for flat ducts relative to round ducts, and the takeoffs are more nearly uniform in length, thus reducing erection complexity. The takeoffs are 0.254 m (10 in.) round, semirigid aluminum ducts with galvanized "spin-in" type connections. Each of these inlet takeoffs has an integral (vane-type) damper for flow balancing.

The inlet ducting is not insulated since the air temperature in the ducts will be only slightly above the ambient temperature. The outlet ducting, in effect, recombines the individual collector flows and provides for the transfer of the collected energy to the manifold that feeds the conventional dryers. The same design criteria used for the inlet ducting have been employed for the outlet ducting, and the systems are basically physically similar. The major exceptions are that the outlet ducting is insulated and there are no dampers in the collector-to-duct takeoffs.

The dryer house manifold provides the interface between the solar drying system and the conventional drying processes and is a critical component of the system. Figure 4-4 depicts the dryer house manifold, the design of which involved a number of important considerations. First and foremost of these considerations is that the interface with the existing Gold Kist dryer system has minimal impact on facilities and operations during the construction, checkout, and operational phases. The design goal has been to achieve these minimum impacts and to design a system that for all practical purposes operates in a fashion similar to the conventional system.

The dryer house manifold is a 1.22- by 1.22-m duct that has six 0.61- by 1.22-m openings on the lower side with short extensions extending through the face of the louvers. The six openings are placed such that there are two at each dryer position. These openings contain baffle-type outlet dampers such that any one dryer or combination of dryers can receive the solar heated air.

Basically, the solar drying system-to-dryer interface utilizes the induced draft of the dryer blowers (some 70 m^3/sec or 150,000 ft^3/min per dryer) to entrain the incoming solar heated air. The physical principle involved is that the greater momentum of the induced draft from the dryer blower will entrain the smaller solar heated flow with no significant influence.

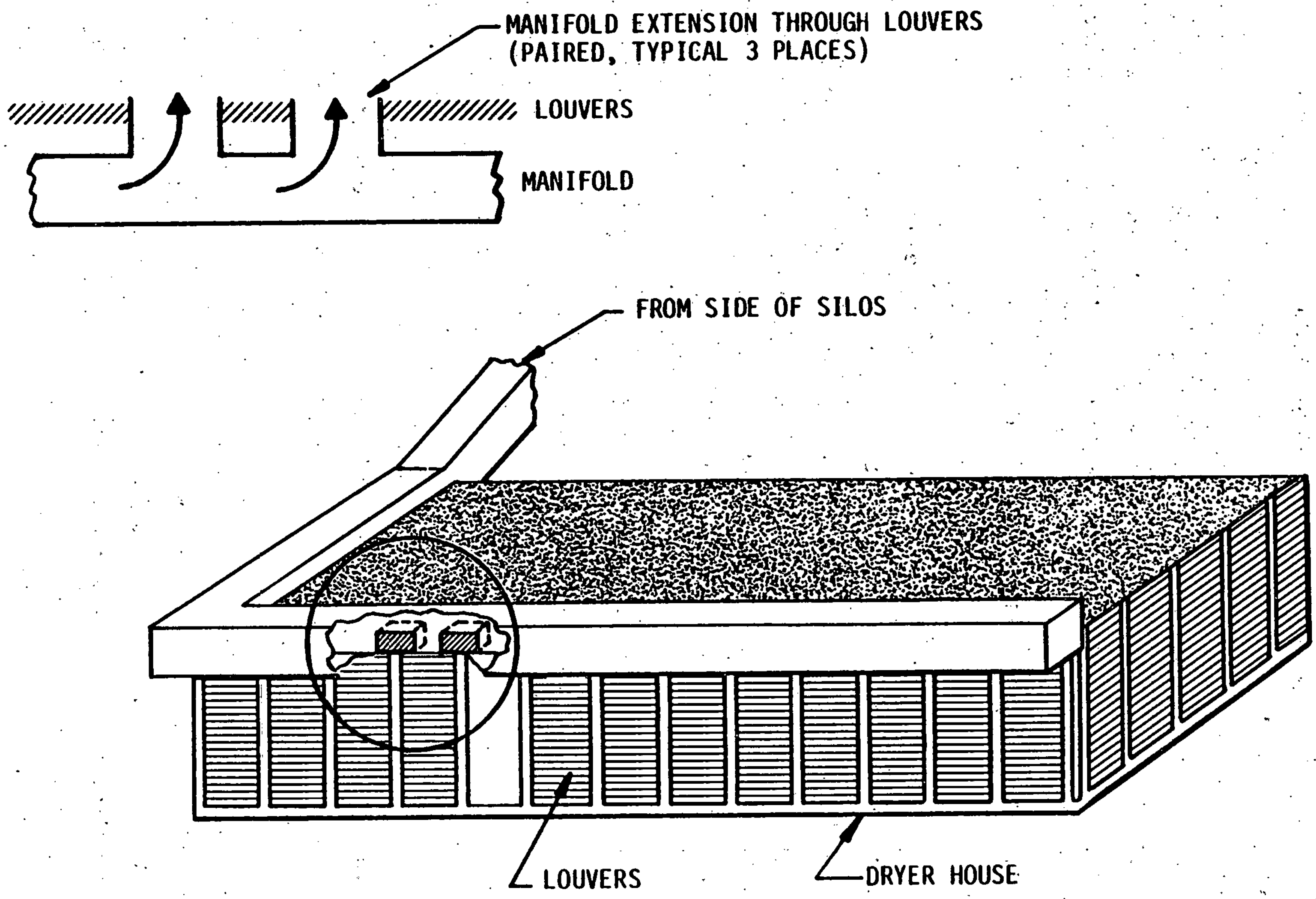


FIGURE 4-4. SKETCH OF DRYER HOUSE MANIFOLD

Normally, fire dampers are installed in ducts only when a fire-rated wall is penetrated in order to maintain the rating of the wall. In the current case, no such physical wall exists (either at the solar drying system or at the dryer house). However, it was desirable to maintain the physical isolation of the two structures, which is compromised by the outlet ducting and the dryer house manifold. Therefore, a fire damper was installed in the outlet ducting to achieve physical separation in the event of a fire at either location.

Physically, this damper is located in the duct run at the south face of the silos, which is a relatively shielded location with respect to either the collectors or the dryer house.

4.1.3 Structural Subsystem

The structural subsystem serves primarily to support the collector array above the parking lot at the Gold Kist plant. This was done in such a way as to not interfere with the Gold Kist operations since the parking lot was the only available space for the solar drying system. In general, the noninterference requirement was that the low point of any structure has a grade clearance of 5.03 m (16.5 ft). However, the parking lot has a rise of about 1.0 m (3 ft) in the south-to-north direction, and the clearance requirement was relaxed at the north end of the assembly to some 4.11 m (13.5 ft). The 5.03-m requirement provides clearance for tractor-trailer type vehicles.

The structure supports 672 Solaron collector panels, which represents 13,104 ft^2 of surface area and approximately 103,000 lb of dead load. Level walkways that are 3 ft wide are provided around the perimeter of the solar array and between seven rows of panel modules to provide access for cleaning and other maintenance. A permanent access ladder is located at the east end to gain access to the 16-ft level, and walkways are protected with 42 high-level rails in accordance with OSHA. Gutters are installed at the bottom of each row of panel modules for the entire row length to route water to downspouts and ultimately to underground drain lines. This drainage system is necessary to protect the parking area and the support foundations.

The total structural area, including all walkways, is 150 ft long by 120 ft wide, which is 18,000 ft^2.

4.1.4 Controls Subsystem (and System Operation)

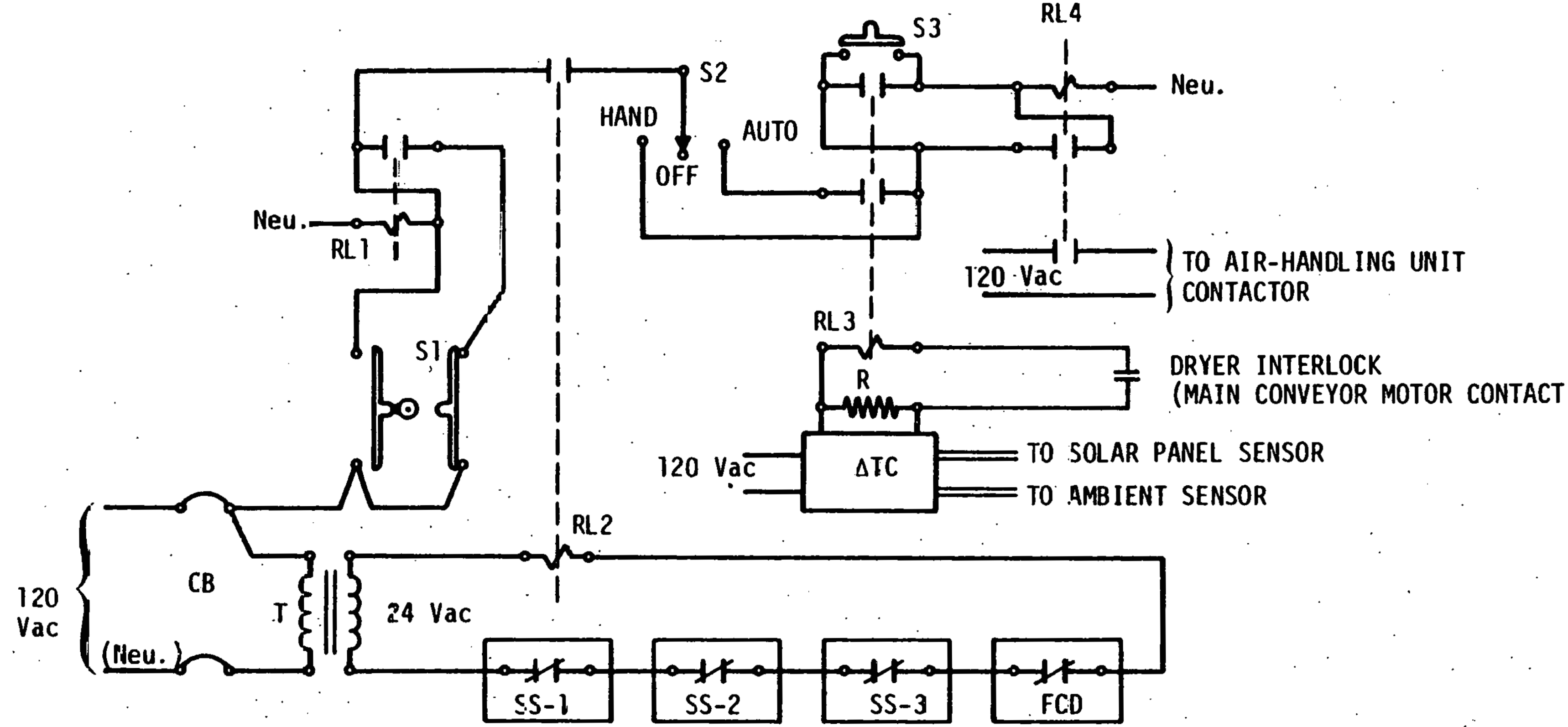
The solar drying system controls are shown schematically in Figure 4-5. These controls provide the following functions:

- Manual on/off control of the solar drying system blower (pushbutton)
- Smoke/fire sensing in the inlet ducting of the blower discharge, in the outlet ducting at the north edge of the collector assembly, and at the smoke/fire damper location
- Turn-on of the blower when either the temperature in a specified collector or the air temperature at the manifold exceeds some threshold differential with respect to the ambient temperature. Turn-off of the blower when both of the collector temperatures and the manifold temperature fall below the threshold value. Both on and off functions will have a 60-sec delay or hold. (Turn-on is dependent on having the solar drying system in the on position.)
- Interlock with dryer operations is provided through a spare set of contacts on the main dryer conveyor.

The principal function of the smoke/fire damper is to provide isolation of the solar drying system and the dryer house, particularly in the direction of the airflow. Three smoke sensors, as shown in Figure 4-6, are employed. The sensors at the blower, collector outlet, and damper provide protection to the collectors (upstream events), dryer house (upstream events), and collectors/blowers/filter/ducting (downstream events), respectively.

4.2 DATA ACQUISITION

The data acquisition system, fabricated from off-the-shelf components, is illustrated schematically in Figure 4-7. Detailed information concerning this system is contained in Appendix A. A summary description follows.



CB L/C PANEL, CIR. NO. 1
S1 KEY SWITCH, MOMENTARY, 120 Vac, 10 A
S2 SELECTOR SWITCH, 3 POSITION, 120 Vac, 10 A
S3 PUSH-BUTTON SWITCH, MOM., SPST, N.O., 120 Vac, 10 A
R RESISTOR, 250 ohms, 150 W
RL1, RL2 RELAY, 120 Vac, SPST, N.O., 10 A
RL3, RL4 RELAY, 120 Vac, SPDT, N.O., 10 A

FCD FIRE/SMOKE DAMPER, AIRSTREAM NO. PEB-802/SST ACTUATOR/225-deg LINK
SS SMOKE SENSOR, HONEYWELL TC-100
T TRANSFORMER, 120/24 Vac
ΔTC DIFFERENTIAL THERMOSTAT CONTROLLER, SOLARON HW0070, WITH SENSORS

FIGURE 4-5. SOLAR DRYING SYSTEM CONTROL SCHEMATIC

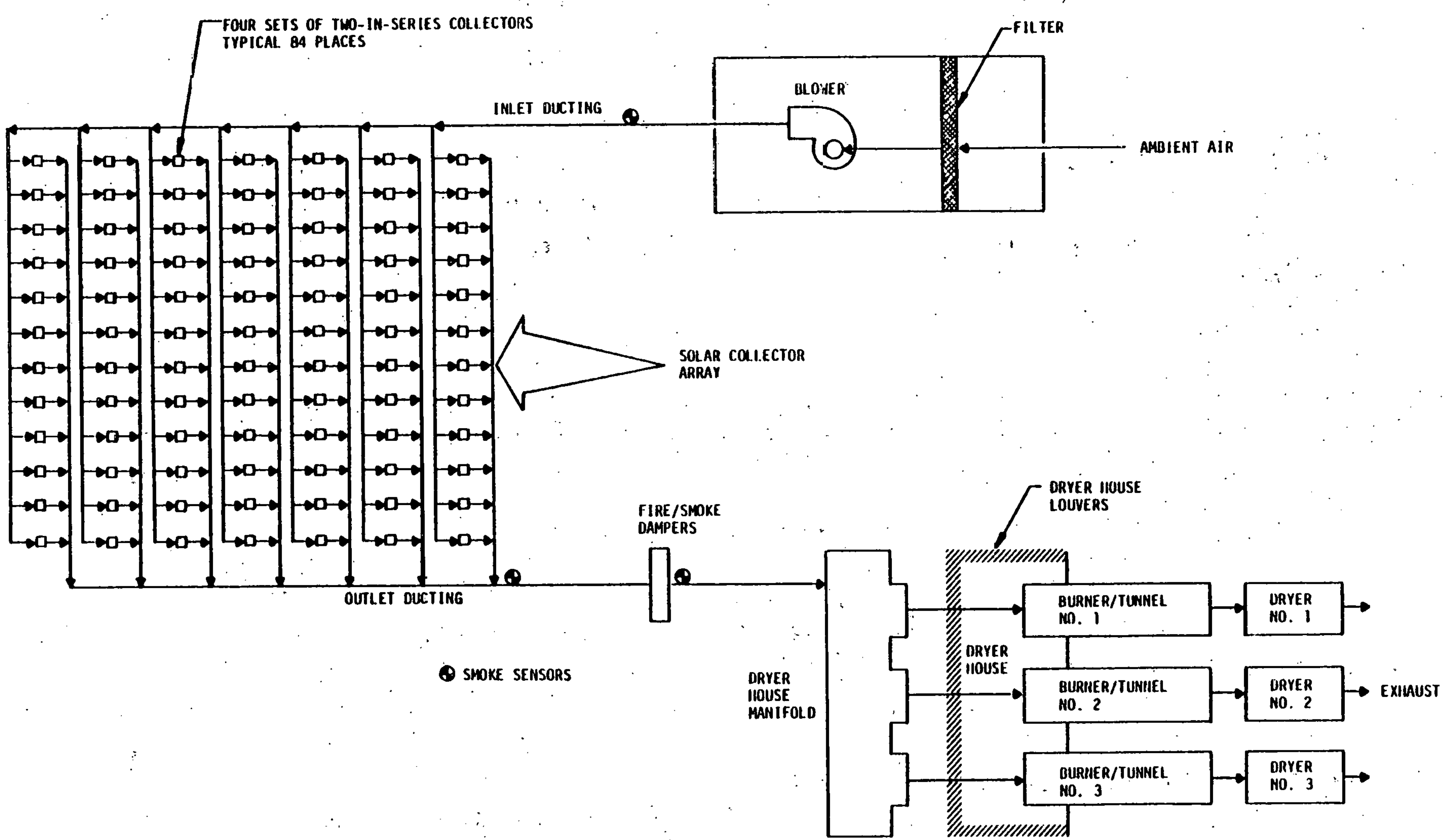


FIGURE 4-6. SMOKE SENSOR LOCATIONS

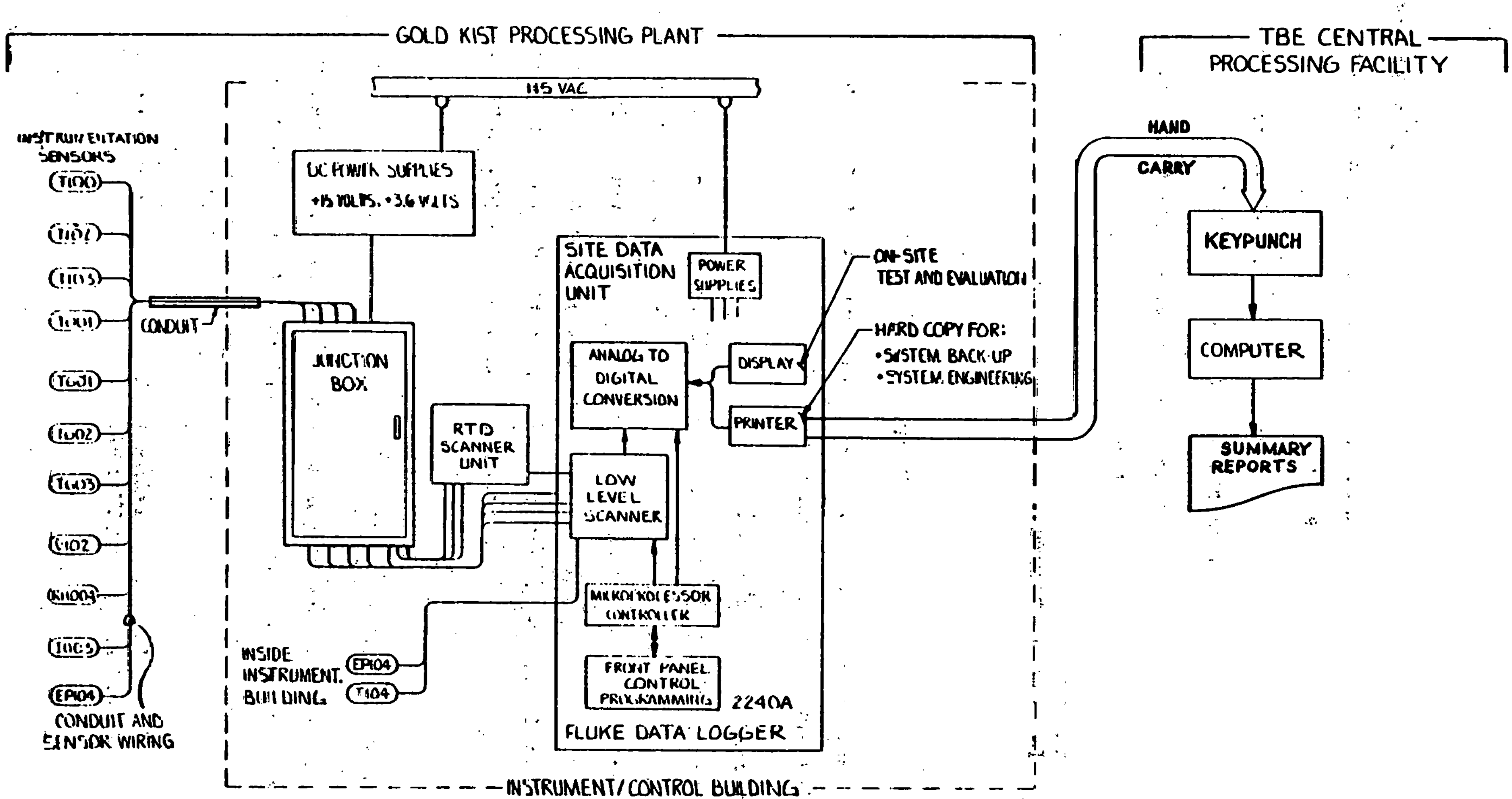


FIGURE 4-7. INSTRUMENTATION MONITORING AND PROCESSING SYSTEM

4.2.1 Sensors

Twelve sensors, selected from the ERDA preferred list of sensors*, are interconnected to the data acquisition unit through a function box. Sensor locations are shown in Figure 4-8.

Twelve parameters are used to evaluate system performance. These parameters and pertinent sensor data are listed in Table 4-1.

Outputs from the following sensors were used as inputs to the Varian V-73 performance evaluation program:

- T001 Ambient Temperature
- T100 Inlet Temperature
- T102 Outlet Temperature
- T103 Temperature in Duct
- T003 Solar Insolation
- V102 Air Velocity
- EP104 Solar System Blower Power.

The other parameters were measured to assist in determining the source of any data anomalies and equipment failures.

4.2.2 Data Acquisition Unit

A Fluke Model No. 2240A Data Logger performs all the data acquisition unit tasks required in this system. Figure 4-9 illustrates the instrumentation rack containing the data logger and its associated equipment. The function of the data logger is to automatically scan many analog input signals, digitize these signals, and output the data on printed tape. The data logger system is represented in block diagram form in Figure 4-10.

4.3 DATA PROCESSING AND ANALYSIS

A detailed description of the analytical tools and processes is contained in Appendix A. A summary of the analytical techniques is presented for convenience.

*"Instrumentation Installation Guidelines for National Solar Heating and Cooling Demonstration Program", SCH 1006

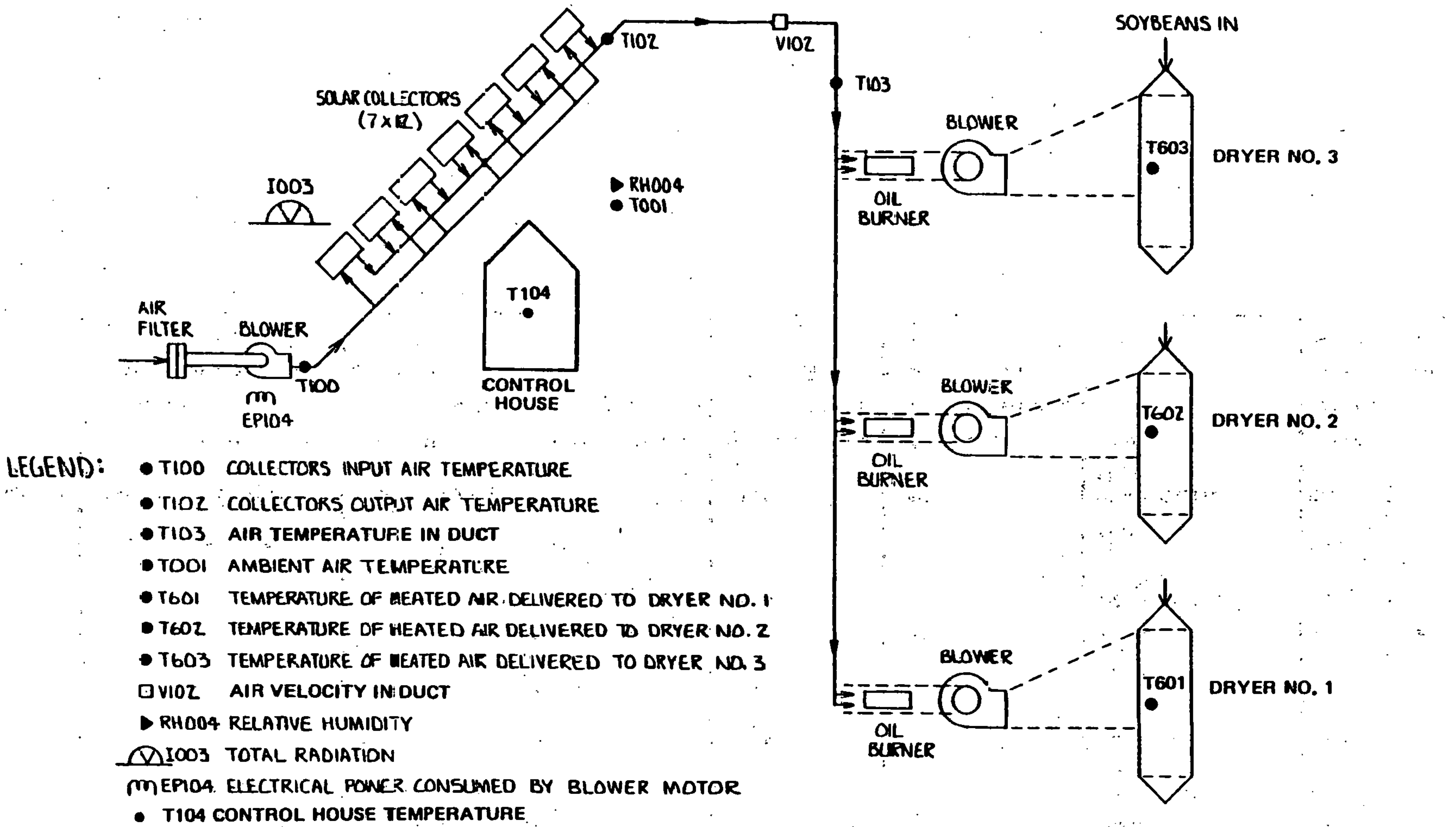


FIGURE 4-8. SENSOR LOCATION

TABLE 4-1. SOLAR DRYING SYSTEM SENSOR DATA

MEASUREMENT SYMBOL	PARAMETER	RANGE	SENSOR ACCURACY	SENSOR TYPE	PART NO.	MANUFACTURER
T001	Ambient Temperature	-17.4 to 44°C (0 to 110°F)	±0.11°C (0.2°F)	RTD	S1078B	Minco
T100	Inlet Temperature	-17.4 to 44°C (0 to 110°F)	±0.5%	RTD	S53-CP Platinum 100-24	Minco
T102	Outlet Temperature	-17.4 to 44°C (0 to 110°F)	±0.5%	RTD	S53-CP Platinum 100-24	Minco
T103	Temperature in Duct	-17.4 to 121°C (0 to 250°F)	±0.5%	RTD	S53-CP Platinum 100-24	Minco
T104	Control Room Temperature	-17.4 to 44°C (0 to 110°F)	±0.11°C (0.2°F)	RTD	TRSP-RM1-2 3/4	Weather-Measure
T601	Temperature at Blower 1	-17.4 to 93.7°C (0 to 200°F)	±0.5%	RTD	S53-CP Platinum 100-24	Minco
T602	Temperature at Blower 2	-17.4 to 93.7°C (0 to 200°F)	±0.5%	RTD	S53-CP Platinum 100-24	Minco
T603	Temperature at Blower 3	-17.4 to 93.7°C (0 to 200°F)	±0.5%	RTD	S53-CP Platinum 100-24	Minco
I003	Solar Insolation	0 to 1,103 W/m² (0 to 350 Btu/hr-ft²)	±0.5 %/in.	Pyronometer	PSP/WG7	Eppley
V102	Air Velocity	7.6 to 15.2 m/sec (1,800 to 3,000 ft/min)	±2% (±2.5% F.S.)	Hot Wire Anemometer	430/435	Kurz Instruments
EP104	Solar System Blower Power	0 to 25 kW	±2% (F.S.)	Watt Transducer	PC 5-54, with Option C	Ohio-Semitronics
RH004	Relative Humidity	0 to 100%	±3%	R.H. Probe	HM111-P	Weather-Measure

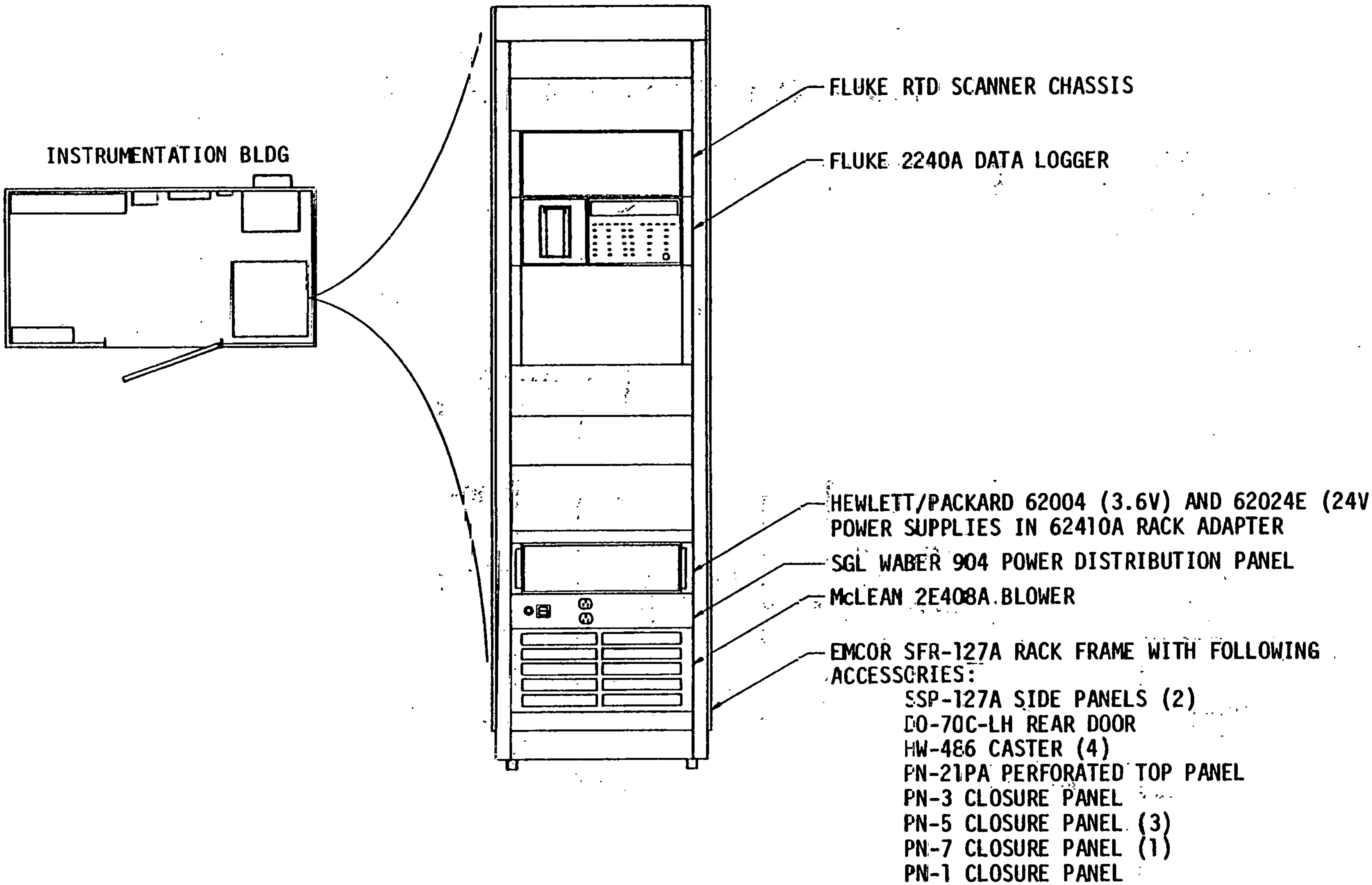


FIGURE 4-9. INSTRUMENTATION RACK CONTAINING THE SITE DATA ACQUISITION UNIT

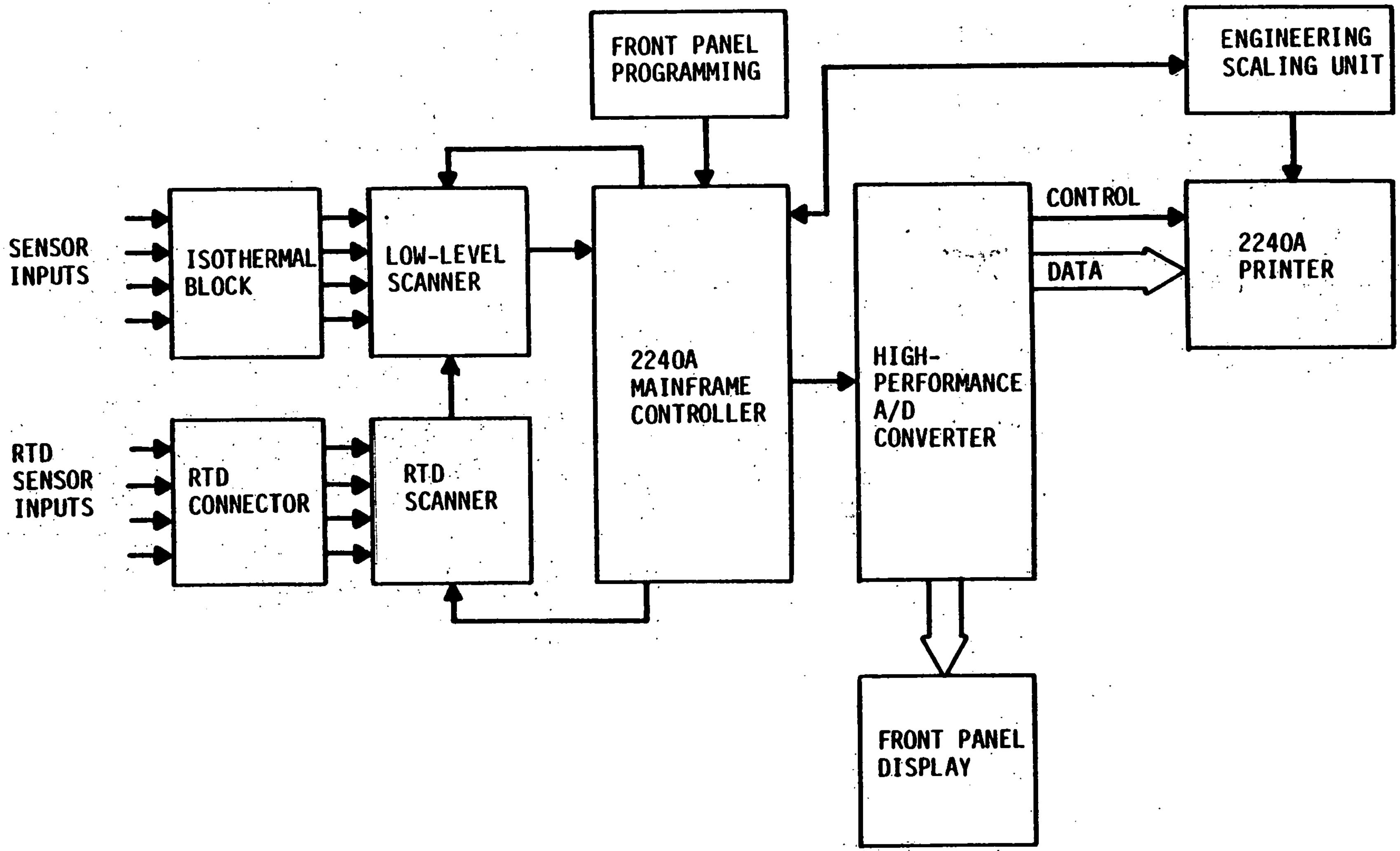


FIGURE 4-10. **DATA LOGGER MODEL 2240A SYSTEM**

Two types of performance evaluation factors are used: 1) a thermal energy quantity defined by the letter "Q" and 2) a performance index defined by the letter "N".

The measured parameters are sampled at 5-min intervals if the system is in operation. To determine hourly summaries of performance factors, the measurements acquired over the hour are averaged and the appropriate conversion factors are applied. Daily summaries are similarly determined by averaging the hourly summaries over the day.

Table 4-2 describes the measured variables, their units as recorded on the output tape of the data logger, and the data channel number. In addition to the measured variable, the date and time are entered with each sample. Figure 4-11 is a sample of a tape obtained from the data logger.

Tables 4-3 and 4-4 present the thermal energy parameters and performance indexes used to evaluate system and subsystem performance for hourly and daily summaries. The defining equations used to compute the performance parameters and a description of the computer program used are presented in Appendix A.

TABLE 4-2. INPUT VARIABLES

DESCRIPTION	UNITS	VARIABLE	RANGE	CHANNEL NUMBER
Total Solar Incident	mV	I003	0 to 11	1
Collector Input Air Temperature	°F	T100	-10 to +110	11
Collector Output Air Temperature	°F	T102	-10 to +300	12
Blower Power	V	EP101	0 to 4	2
Temperature in Duct	°F	T103	-10 to +200	13
Ambient Air Temperature	°F	T001	-10 to +110	14
Temperature in Dryer No. 1	°F	T601	-10 to +200	17
Temperature in Dryer No. 2	°F	T602	-10 to +200	16
Temperature in Dryer No. 3	°F	T603	-10 to +200	15
Relative Humidity	%	RH004	0 to 100	4
Air Flow Velocity	V	V102	0 to 6	3
Fuel Flow to Dryer No. 1*				
Fuel Flow to Dryer No. 2*				
Fuel Flow to Dryer No. 3*				

*Not currently measured. Will be added at future time.

```
 18        93.3   F
 17       193.6   F
 16       114.4   F
 15       164.3   F
 14        40.5   F
 13       146.0   F
 12       149.6   F
 11        90.3   F
  4      144.68  mV
  3       3.519   V
  2       2.398   V
  1       6.621  mV

     999999
150:13:15:36

 18        93.2   F
 17       192.7   F
 16       115.5   F
 15       164.4   F
 14        65.9   F
 13       147.2   F
 12       145.0   F
 11        69.9   F
  4      145.36  mV
  3       3.527   V
  2       2.560   V
  1       6.674  mV

     999999
150:13:10:36


 18        93.1   F
 17       193.0   F
 16       115.7   F
 15       165.1   F
 14        65.1   F
 13       146.4   F
 12       146.2   F
 11        65.9   F
  4      146.62  mV
  3       3.560   V
  2       2.647   V
  1       6.846  mV

     999999
150:13:05:36
```

FIGURE 4-11. SAMPLE OF TAPE OUTPUT FROM DATA LOGGER

TABLE 4-3. DAILY SUMMARY OF THERMAL ENERGY PARAMETERS

DESCRIPTION	VARIABLE	UNITS	
		SI	BRITISH ENGINEERING
Total Solar Incident	Q081	J	Btu
Total Solar Incident	Q031	J/m^2	Btu/ft^2
Solar Energy Collected	Q180	J	Btu
Solar Energy Collected	Q130	J/m^2	Btu/ft^2
ECDS Operating Energy	Q132	J	Btu
Collector Efficiency	N131	%	%
Average Ambient D.B. Temperature	N143	°C	°F
Collector Panel Efficiency Factor	N132	$\frac{°C\ m^2}{J}$	$\frac{°F\ ft^2}{Btu}$

TABLE 4-4. HOURLY SUMMARY OF THERMAL ENERGY PARAMETERS

DESCRIPTION	VARIABLE	UNITS	
		SI	BRITISH ENGINEERING
Total Solar Incident	Q001	W/m^2	$Btu/hr\text{-}ft^2$
Solar Energy Collected	Q100	W/m^2	$Btu/hr\text{-}ft^2$
ECDS Operating Energy	Q102	W	Btu/hr
Collector Efficiency	N101	%	%
Collector Panel Efficiency Factor	N102	$\frac{°C\ m^2}{J}$	$\frac{°F\ ft^2}{Btu}$
Average Ambient D.B. Temperature	N113	°C	°F

5. SYSTEM OPERATIONS

5.1 GENERAL

Performance evaluation operations began on June 1, 1978, and continued through August 31, 1979. During this period, the solar system operated for 1,752 hours on 290 days without a single failure sufficient to cause system shutdown. There was virtually no interference with conventional system operation during the evaluation period. A summary chart of significant maintenance, system modification, and instrumentation events is presented in Figure 5-1.

5.2 MAINTENANCE REQUIREMENTS

There was no system downtime attributable to solar system maintenance. During the five quarters of operation, maintenance consisted of routine glazing, cleaning, air handler service, and the repair of one 10-in. collector supply duct. Maintenance cost totalled $1,564. The quarterly distribution of maintenance costs is shown in Table 5-1.

TABLE 5-1. QUARTERLY MAINTENANCE COST SUMMARY

	QUARTER					
MAINTENANCE ACTION	1	2	3	4	5	
Clean Glazing	$340	$445	$ 0	$170	$170	
Grease Blower and Motor	0	17	0	0	0	
Replace Blower Belts	0	85	0	0	0	
Replace Filter/Clean Inlet	0	0	330	0	0	
Repair Ducting	0	0	7	0	0	
TOTAL	$340	$547	$337	$170	$170	$1,564

1 - June, July, August (1978)
2 - September, October, November (1978)
3 - December, January, February (1978-79)
4 - March, April, May (1979)
5 - June, July, August (1979)

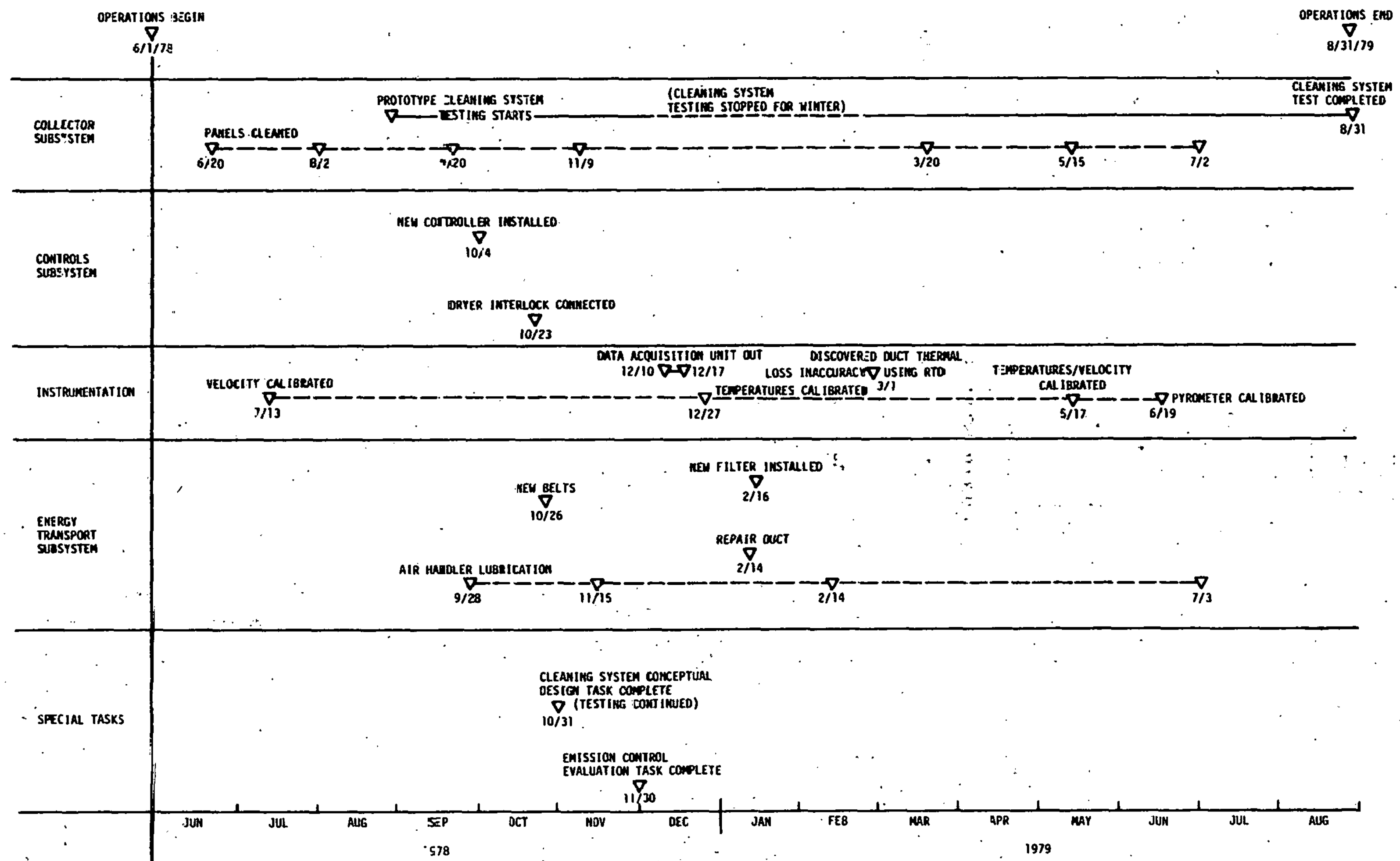


FIGURE 5-1. EVENT SUMMARY CHART

5.2.1 Collector Glazing Cleaning

At the close of Phase II, "Construction", it became apparent that the contamination problem was more severe than had been anticipated. With the assistance of the Chemistry Department of The University of Alabama in Huntsville (UAH), a detailed investigation was conducted to identify the nature of the contaminant. Results indicated the presence of chaff and dirt particulates and soybean oil. The oil polymerizes under exposure to ultraviolet and serves as an adhesive for the very fine particulates. It was determined that the polymerized oil can be chemically altered by the application of methylene chloride or chlorinated nophtenates. This replaces the oxygen bond in the chain with a chlorine bond, resulting in a more fluid compound that is readily removed by flushing. Because of constraints of safety, cost, and environmental compatibility, a simple detergent along with mechanical scrubbing was elected for the duration of Phase III.

From operation of a prototype cleaning system (Section 8), it was determined that a direct impingement spray, with detergent, applied briefly each day easily removes the contaminant.

The cleaning process used for the entire array during Phase III involved three men performing the following operations:

- Using a built-in high-pressure/detergent injection spray system, one man sprayed the panels to loosen the contaminant.
- The second man followed the spray with mechanical action, using a long-handle brush.
- The third man followed with rinse water, using a hose and tap water.

This process required approximately 6 hr (18 man-hours) to complete and cleaned the panels very effectively. It was accomplished every 30 to 60 days (except during the winter).

This contamination clearly affected collector efficiency. This efficiency is discussed in Section 7.5.

5.2.2 Air Handling Unit Service

The use of the commercial-grade air handling unit proved very practical and posed no maintenance or operational problems. Only routine greasings, one filter change/intake cleaning, and one belt replacement were required.

5.2.3 Air Transport Duct Maintenance

Prior to the start of Phase III, some problems were encountered concerning the 10-in. metal flex ducts connecting the cold air manifold ducts to the collector modules. These lightweight, uninsulated, aluminum flex ducts were fatigued by wind-induced vibration, particularly in the higher locations near the grain silos. Several affected ducts were replaced with heavier gauge rigid ducts prior to the start of Phase III. Repair of one additional duct was required during Phase III.

Water leakage was experienced in the mastic coating over the insulation on the main 4- by 4-ft supply duct between the collectors and the dryer house. Investigation revealed the collection of soybean chaff on top of this duct. When wet by rain, this damp chaff caused permanent impressions in the upper surface of the insulation. These impressions held significant quantities of rain water each time if rained, allowing it to seep through the mastic and wet the insulation. The design of this duct should have specified a metal cap on top of the upper surface to prevent leakage.

Analysis of duct losses caused by this portion of wet duct revealed a loss of approximately 2.5% of the energy collected, independent of ambient temperature (see Section 7.6.2). Placing a metal cap on the duct was not economically feasible, considering bids received versus increased energy saved.

5.2.4 Maintenance Forms and Logs

Forms were established for recording scheduled and unscheduled maintenance. Figure 5-2 is the scheduled maintenance log depicting the schedule and dates of accomplishment of all scheduled maintenance. The

	1978							1979							
ITEM	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
Clean Collector Glazing	● 6/20	●	● 8/2	● 9/20	●	● 11/9	●	●	●	● 3/20	●	● 5/15	●	● 7/2	●
Lubricate Blower Bearings	●	●	●	● 9/28	●	● 11/15	●	●	● 2/14	●	●	●	●	● 7/3	●
Check Blower Belt Tension			● 8/5		10/26	●	12/20		● 2/14			● 6/17			●
Lubricate Blower Motor			●	9/28		● 11/15			● 2/14			●		7/3	●
Change Oil in Cleaning System Pressure Pump						●						●			●

● = Month due

FIGURE 5-2. SCHEDULED MAINTENANCE LOG

frequency of equipment maintenance was lessened to correspond to the lower-than-expected system utilization. Collector cleaning performed by Gold Kist personnel was not kept on schedule either because of lack of personnel or inclement weather during the winter months.

Figure 5-3 presents the maintenance data forms used to record all solar drying system maintenance. These forms were also intended for recording dryer maintenance; however, this was impractical because of the various shifts during which dryer maintenance occurred and the frequency of occurrence.

1. DATE	2. PREPARED BY	3. MAINTENANCE PERFORMED BY
6/20/78		Max Madison

4. AREA OF MAINTENANCE - SUBSYSTEM

COLLECTOR ☐ ENERGY TRANSPORT ☐ CLEANING ☒

CONTROL ☐ STRUCTURAL

COMPONENT/PART	TYPE OF ACTION (SEE CODES BELOW)	TIME REQUIRED hr	TIME REQUIRED min
A. Soap	N/A	18	—
B.			
C.			

TYPE OF ACTION CODES: ADJUSTMENT ADJ; REPAIR R; REPLACEMENT RPL

5. DESCRIPTION OF MAINTENANCE

TYPE: SCHEDULED ☒ UNSCHEDULED ☐

A. PROBLEM:

B. CAUSE:

C. CORRECTIVE ACTION: Routine Cleaning

6. SOLAR DOWN TIME (ESTIMATED SOLAR RADIATION TIME LOST DUE TO):

SOLAR SYSTEM MAINTENANCE 0 hr; DRYER MAINTENANCE ____ hr

7. COST OF MAINTENANCE

PERFORMED BY: IN-HOUSE GOLD KIST ☒

IN-HOUSE TBE ☐

CONTRACTED (INVOICE ATTACHED) ☐

LABOR CATEGORY	hr		RATE ($/hr)		LABOR COST
A- Operator	6	×	8.51	=	51.06
C- operator	12	×	6.17	=	74.04
		×		=	

TOTAL LABOR COST	125.10
PARTS COST	
MATERIAL COST	45.00
TOTAL MAINTENANCE COST	$170.10

FIGURE 5-3. MAINTENANCE DATA FORM

1. DATE	2. PREPARED BY	3. MAINTENANCE PERFORMED BY
8/2/78		MAX Madison

4. AREA OF MAINTENANCE - SUBSYSTEM

COLLECTOR ☐ ENERGY TRANSPORT ☐ CLEANING ☒

CONTROL ☐ STRUCTURAL

COMPONENT/PART	TYPE OF ACTION (SEE CODES BELOW)	TIME REQUIRED hr	TIME REQUIRED min
A. SOAP	N/A	18	—
B.			
C.			

TYPE OF ACTION CODES: ADJUSTMENT ADJ; REPAIR R; REPLACEMENT RPL

5. DESCRIPTION OF MAINTENANCE

TYPE: SCHEDULED ☒ UNSCHEDULED ☐

A. PROBLEM:

B. CAUSE:

C. CORRECTIVE ACTION: Routine Cleaning

6. SOLAR DOWN TIME (ESTIMATED SOLAR RADIATION TIME LOST DUE TO):

SOLAR SYSTEM MAINTENANCE ______ hr; DRYER MAINTENANCE ______ hr

7. COST OF MAINTENANCE PERFORMED BY: IN-HOUSE GOLD KIST ☐

IN-HOUSE TBE ☐

CONTRACTED (INVOICE ATTACHED) ☐

LABOR CATEGORY	hr		RATE ($/hr)		LABOR COST
A-Operator	6	×	8.51	=	51.06
C-Operator	12	×	6.17	=	74.04
		×		=	

TOTAL LABOR COST	125.10
PARTS COST	
MATERIAL COST	45.00
TOTAL MAINTENANCE COST	$170.10

FIGURE 5-3 - Continued

1. DATE	2. PREPARED BY	3. MAINTENANCE PERFORMED BY
9/20/78		Max Madison

4. AREA OF MAINTENANCE - SUBSYSTEM

COLLECTOR ☐ ENERGY TRANSPORT ☐ CLEANING ☒

CONTROL ☐ STRUCTURAL

COMPONENT/PART	TYPE OF ACTION (SEE CODES BELOW)	TIME REQUIRED hr	TIME REQUIRED min
A. soap	N/A	21	
B.			
C.			

TYPE OF ACTION CODES: ADJUSTMENT ADJ; REPAIR R; REPLACEMENT RPL

5. DESCRIPTION OF MAINTENANCE

TYPE: SCHEDULED ☒ UNSCHEDULED ☐

A. PROBLEM:

B. CAUSE:

C. CORRECTIVE ACTION: routine cleaning

6. SOLAR DOWN TIME (ESTIMATED SOLAR RADIATION TIME LOST DUE TO):

SOLAR SYSTEM MAINTENANCE 0 hr; DRYER MAINTENANCE ____ hr

7. COST OF MAINTENANCE

PERFORMED BY: IN-HOUSE GOLD KIST ☐

IN-HOUSE TBE ☐

CONTRACTED (INVOICE ATTACHED) ☐

LABOR CATEGORY	hr		RATE ($/hr)		LABOR COST
A-Operator	7	×	8.51	=	59.57
C-Operator	14	×	6.17	=	86.38
		×		=	

TOTAL LABOR COST	145.95
PARTS COST	
MATERIAL COST	45.00
TOTAL MAINTENANCE COST	$190.95

FIGURE 5-3 - Continued

1. DATE	2. PREPARED BY	3. MAINTENANCE PERFORMED BY
9/28/78		Max Madison

4. AREA OF MAINTENANCE - SUBSYSTEM

COLLECTOR ☐ ENERGY TRANSPORT ☐ CLEANING ☐

CONTROL ☐ STRUCTURAL

COMPONENT/PART	TYPE OF ACTION (SEE CODES BELOW)	TIME REQUIRED hr	TIME REQUIRED min
A. grease	N/A	1/2	
B.			
C.			

TYPE OF ACTION CODES: ADJUSTMENT ADJ; REPAIR R; REPLACEMENT RPL

5. DESCRIPTION OF MAINTENANCE

TYPE: SCHEDULED ☒ UNSCHEDULED ☐

A. PROBLEM:

B. CAUSE:

C. CORRECTIVE ACTION: scheduled greasing of blower & motor

6. SOLAR DOWN TIME (ESTIMATED SOLAR RADIATION TIME LOST DUE TO):

SOLAR SYSTEM MAINTENANCE 0 hr; DRYER MAINTENANCE ____ hr

7. COST OF MAINTENANCE PERFORMED BY: IN-HOUSE GOLD KIST ☐

IN-HOUSE TBE ☐

CONTRACTED (INVOICE ATTACHED) ☐

LABOR CATEGORY	hr		RATE ($/hr)		LABOR COST
A Operator	1/2	×	8.51	=	4.26
		×		=	
		×		=	

TOTAL LABOR COST	4.26
PARTS COST	—
MATERIAL COST	—
TOTAL MAINTENANCE COST	4.26

FIGURE 5-3 - Continued

1. DATE	2. PREPARED BY	3. MAINTENANCE PERFORMED BY
26 Oct 78	B.L. Hall	Harper

4. AREA OF MAINTENANCE - SUBSYSTEM

COLLECTOR ☐ ENERGY TRANSPORT ☑ CLEANING ☐

CONTROL ☐ STRUCTURAL

COMPONENT/PART	TYPE OF ACTION (SEE CODES BELOW)	TIME REQUIRED hr	TIME REQUIRED min
A. Blower Belts	RPL	1	0
B.			
C.			

TYPE OF ACTION CODES: ADJUSTMENT ADJ; REPAIR R; REPLACEMENT RPL

5. DESCRIPTION OF MAINTENANCE

TYPE: SCHEDULED ☐ UNSCHEDULED ☑

A. PROBLEM: Worn Belts

B. CAUSE: Normal Wear

C. CORRECTIVE ACTION: Replace & check tension

6. SOLAR DOWN TIME (ESTIMATED SOLAR RADIATION TIME LOST DUE TO):

SOLAR SYSTEM MAINTENANCE 1 hr; DRYER MAINTENANCE ____ hr

7. COST OF MAINTENANCE

PERFORMED BY: IN-HOUSE GOLD KIST ☐
IN-HOUSE TBE ☑
CONTRACTED (INVOICE ATTACHED) ☐

LABOR CATEGORY	hr		RATE ($/hr)		LABOR COST
Mech. Tech.	1	×	14.32	=	14.32
		×		=	
		×		=	

TOTAL LABOR COST 14.32
PARTS COST 70.44
MATERIAL COST —
TOTAL MAINTENANCE COST 84.76

FIGURE 5-3 - Continued

1. DATE	2. PREPARED BY	3. MAINTENANCE PERFORMED BY
11/9/78		M. MADISON

4. AREA OF MAINTENANCE - SUBSYSTEM

COLLECTOR ☐ ENERGY TRANSPORT ☐ CLEANING ☑

CONTROL ☐ STRUCTURAL

COMPONENT/PART	TYPE OF ACTION (SEE CODES BELOW)	TIME REQUIRED hr	TIME REQUIRED min
A. Soap	N/A	30	0
B.			
C.			

TYPE OF ACTION CODES: ADJUSTMENT ADJ; REPAIR R; REPLACEMENT RPL

5. DESCRIPTION OF MAINTENANCE

TYPE: SCHEDULED ☒ UNSCHEDULED ☐

A. PROBLEM:

B. CAUSE:

C. CORRECTIVE ACTION: routine cleaning

6. SOLAR DOWN TIME (ESTIMATED SOLAR RADIATION TIME LOST DUE TO):

SOLAR SYSTEM MAINTENANCE 0 hr; DRYER MAINTENANCE ____ hr

7. COST OF MAINTENANCE

PERFORMED BY: IN-HOUSE GOLD KIST ☒
IN-HOUSE TBE ☐
CONTRACTED (INVOICE ATTACHED) ☐

LABOR CATEGORY	hr		RATE ($/hr)		LABOR COST
A-Operator	10	×	8.51	=	85.10
C-Operator	20	×	6.17	=	123.40
		×		=	

TOTAL LABOR COST 208.50
PARTS COST ____
MATERIAL COST 45.00
TOTAL MAINTENANCE COST 253.50

FIGURE 5-3 - Continued

1. DATE	2. PREPARED BY	3. MAINTENANCE PERFORMED BY
11/15/78	Hall	Hall

4. AREA OF MAINTENANCE - SUBSYSTEM

COLLECTOR ☐ ENERGY TRANSPORT ☑ CLEANING ☐

CONTROL ☐ STRUCTURAL

COMPONENT/PART	TYPE OF ACTION (SEE CODES BELOW)	TIME REQUIRED hr	TIME REQUIRED min
A. grease	N/A	1/2	
B.			
C.			

TYPE OF ACTION CODES: ADJUSTMENT ADJ; REPAIR R; REPLACEMENT RPL

5. DESCRIPTION OF MAINTENANCE

TYPE: SCHEDULED ☑ UNSCHEDULED ☐

A. PROBLEM:

B. CAUSE:

C. CORRECTIVE ACTION: routine greasing of Blower & Motor

6. SOLAR DOWN TIME (ESTIMATED SOLAR RADIATION TIME LOST DUE TO):

SOLAR SYSTEM MAINTENANCE 0 hr; DRYER MAINTENANCE ____ hr

7. COST OF MAINTENANCE

PERFORMED BY: IN-HOUSE GOLD KIST ☐
IN-HOUSE TBE ☑
CONTRACTED (INVOICE ATTACHED) ☐

LABOR CATEGORY	hr		RATE ($/hr)		LABOR COST
Engr	1/2	×	25	=	12.50
		×		=	
		×		=	

TOTAL LABOR COST	12.50
PARTS COST	—
MATERIAL COST	—
TOTAL MAINTENANCE COST	12.50

FIGURE 5-3 - Continued

1. DATE	2. PREPARED BY	3. MAINTENANCE PERFORMED BY
2/14/79	B. R. HALL	GOLD KIST

4. AREA OF MAINTENANCE - SUBSYSTEM

COLLECTOR ☐ ENERGY TRANSPORT ☑ CLEANING ☐

CONTROL ☐ STRUCTURAL

COMPONENT/PART	TYPE OF ACTION (SEE CODES BELOW)	TIME REQUIRED hr	TIME REQUIRED min
A. COLD AIR FLEX. SUPPLY DUCT	R	0	30
B.			
C.			

TYPE OF ACTION CODES: ADJUSTMENT ADJ; REPAIR R; REPLACEMENT RPL

5. DESCRIPTION OF MAINTENANCE

TYPE: SCHEDULED ☐ UNSCHEDULED ☑

A. PROBLEM: FLEX DUCT BROKE AWAY FROM MAIN SUPPLY DUCT

B. CAUSE: WIND.

C. CORRECTIVE ACTION: RE-CLAMPED DUCT TO MAIN DUCT

6. SOLAR DOWN TIME (ESTIMATED SOLAR RADIATION TIME LOST DUE TO):

SOLAR SYSTEM MAINTENANCE 0 hr; DRYER MAINTENANCE ____ hr

7. COST OF MAINTENANCE

PERFORMED BY: IN-HOUSE GOLD KIST ☑
IN-HOUSE TBE ☐
CONTRACTED (INVOICE ATTACHED) ☐

LABOR CATEGORY	hr		RATE ($/hr)		LABOR COST
A-OPERATOR	1/2	×	8.51	=	4.26
C-OPERATOR	1/2	×	6.17	=	3.09
		×		=	

TOTAL LABOR COST	7.35
PARTS COST	—
MATERIAL COST	—
TOTAL MAINTENANCE COST	7.35

FIGURE 5-3 - Continued

1. DATE	2. PREPARED BY	3. MAINTENANCE PERFORMED BY
2/23/79	B.R. HALL	METRO AIR CONDITIONING DECATUR, AL

4. AREA OF MAINTENANCE - SUBSYSTEM

COLLECTOR ☐ ENERGY TRANSPORT ☑ CLEANING ☐

CONTROL ☐ STRUCTURAL

COMPONENT/PART	TYPE OF ACTION (SEE CODES BELOW)	TIME REQUIRED hr	TIME REQUIRED min
A. Roll-o-Matic FILTER MEDIA	RPL	1	30
B. CLEAN INTAKE LOUVERS	—	1	00
C.			

TYPE OF ACTION CODES: ADJUSTMENT ADJ; REPAIR R; REPLACEMENT RPL

5. DESCRIPTION OF MAINTENANCE

TYPE: SCHEDULED ☐ UNSCHEDULED ☒

A. PROBLEM: DIRTY FILTER & INTAKE LOUVERS

B. CAUSE: DUST

C. CORRECTIVE ACTION: REPLACE FILTER; CLEAN INTAKE

6. SOLAR DOWN TIME (ESTIMATED SOLAR RADIATION TIME LOST DUE TO):

SOLAR SYSTEM MAINTENANCE 2.5 hr; DRYER MAINTENANCE _____ hr

7. COST OF MAINTENANCE

PERFORMED BY: IN-HOUSE GOLD KIST ☐

IN-HOUSE TBE ☐

CONTRACTED ☒

LABOR CATEGORY	hr		RATE ($/hr)		LABOR COST
_____	_____	×	_____	=	_____
_____	_____	×	_____	=	_____
_____	_____	×	_____	=	_____

TOTAL LABOR COST _____
PARTS COST
MATERIAL COST (CONTR) 330.00
TOTAL MAINTENANCE COST 330.00

FIGURE 5-3 - Continued

1. DATE	2. PREPARED BY	3. MAINTENANCE PERFORMED BY
3/20/79	Madison	Gold Kist

4. AREA OF MAINTENANCE - SUBSYSTEM

COLLECTOR ☐ ENERGY TRANSPORT ☐ CLEANING ☒

CONTROL ☐ STRUCTURAL

COMPONENT/PART	TYPE OF ACTION (SEE CODES BELOW)	TIME REQUIRED hr	TIME REQUIRED min
A. SOAP	N/A	18	—
B.			
C.			

TYPE OF ACTION CODES: ADJUSTMENT ADJ; REPAIR R; REPLACEMENT RPL

5. DESCRIPTION OF MAINTENANCE

TYPE: SCHEDULED ☒ UNSCHEDULED ☐

A. PROBLEM:

B. CAUSE:

C. CORRECTIVE ACTION: Routine Cleaning

6. SOLAR DOWN TIME (ESTIMATED SOLAR RADIATION TIME LOST DUE TO):

SOLAR SYSTEM MAINTENANCE ______ hr; DRYER MAINTENANCE _____ hr

7. COST OF MAINTENANCE

PERFORMED BY: IN-HOUSE GOLD KIST ☑
IN-HOUSE TBE ☐
CONTRACTED (INVOICE ATTACHED) ☐

LABOR CATEGORY	hr		RATE ($/hr)		LABOR COST
A-operator	6	×	8.51	=	51.06
C-operator	12	×	6.17	=	74.04
		×		=	

TOTAL LABOR COST 125.10
PARTS COST
MATERIAL COST 45.00
TOTAL MAINTENANCE COST $ 170.10

FIGURE 5-3 - Continued

1. DATE	2. PREPARED BY	3. MAINTENANCE PERFORMED BY
5/15/79	HALL	M. MADISON

4. AREA OF MAINTENANCE - SUBSYSTEM

COLLECTOR ☐ ENERGY TRANSPORT ☐ CLEANING ☒

CONTROL ☐ STRUCTURAL

COMPONENT/PART	TYPE OF ACTION (SEE CODES BELOW)	TIME REQUIRED hr	TIME REQUIRED min
A. SOAP	N/A		
B.			
C.			

TYPE OF ACTION CODES: ADJUSTMENT ADJ; REPAIR R; REPLACEMENT RPL

5. DESCRIPTION OF MAINTENANCE

TYPE: SCHEDULED ☒ UNSCHEDULED ☐

A. PROBLEM:

B. CAUSE:

C. CORRECTIVE ACTION: ROUTINE CLEANING

6. SOLAR DOWN TIME (ESTIMATED SOLAR RADIATION TIME LOST DUE TO):

SOLAR SYSTEM MAINTENANCE ______ hr; DRYER MAINTENANCE _____ hr

7. COST OF MAINTENANCE

PERFORMED BY: IN-HOUSE GOLD KIST ☑

IN-HOUSE TBE ☐

CONTRACTED (INVOICE ATTACHED) ☐

LABOR CATEGORY	hr		RATE ($/hr)		LABOR COST
A-Operator	6	×	8.51	=	51.06
C-Operator	12	×	6.17	=	74.04
		×		=	

TOTAL LABOR COST	125.10
PARTS COST	
MATERIAL COST	45.00
TOTAL MAINTENANCE COST	170.10

FIGURE 5-3 - Continued

1. DATE	2. PREPARED BY	3. MAINTENANCE PERFORMED BY
7/2/79	HALL	M. MADISON

4. AREA OF MAINTENANCE - SUBSYSTEM

COLLECTOR ☐ ENERGY TRANSPORT ☐ CLEANING ☒

CONTROL ☐ STRUCTURAL

COMPONENT/PART	TYPE OF ACTION (SEE CODES BELOW)	TIME REQUIRED hr	TIME REQUIRED min
A. SOAP	N/A		
B.			
C.			

TYPE OF ACTION CODES: ADJUSTMENT ADJ; REPAIR R; REPLACEMENT RPL

5. DESCRIPTION OF MAINTENANCE

TYPE: SCHEDULED ☒ UNSCHEDULED ☐

A. PROBLEM: CONTAMINATED GLAZING

B. CAUSE:

C. CORRECTIVE ACTION: WASH

6. SOLAR DOWN TIME (ESTIMATED SOLAR RADIATION TIME LOST DUE TO):

SOLAR SYSTEM MAINTENANCE ______ hr; DRYER MAINTENANCE _____ hr

7. COST OF MAINTENANCE

PERFORMED BY: IN-HOUSE GOLD KIST ☒

IN-HOUSE TBE ☐

CONTRACTED (INVOICE ATTACHED) ☐

LABOR CATEGORY	hr		RATE ($/hr)		LABOR COST
A-OPERATOR	6	×	8.51	=	51.06
C-OPERATOR	12	×	6.17	=	74.04
		×		=	

TOTAL LABOR COST	125.10
PARTS COST	
MATERIAL COST	45.00
TOTAL MAINTENANCE COST $	170.10

FIGURE 5-3 - Concluded

6. DATA ACQUISITION OPERATIONS

6.1 INSTRUMENTED DATA

6.1.1 General

The performance-critical channels of the data acquisition unit operated with good reliability, and it is estimated that less than 2% of the data available was missed because of data acquisition unit or operations problems. The data acquisition unit was activated each morning at approximately 6 a.m. and deactivated after sunset each day regardless of the weather or dryer operation. This was placed on the routine of the morning and night shifts of Gold Kist personnel and was accomplished daily. Gold Kist supervisors were trained to replenish the data logger tape and to set the clock, when necessary, after a power failure. Data anomalies were reported to TBE by Gold Kist personnel.

The data was picked up twice weekly by TBE during routine system checks and delivered to the Data Processing Department.

6.1.2 Instrumentation Calibration

6.1.2.1 Velocity Probe - The velocity probe was calibrated twice during the program, with the following results:

Date:	July 13, 1978
Calibration Equipment:	Portable KURZ hot-wire anemometer and and a pitot tube/manometer
Results:	Velocity channel output adjusted from 2.75 V (1,375 ft/min) to 2.49 V (1,245 ft/min)
Date:	May 17, 1979
Calibration Equipment:	Portable TSI hot-wire anemometer
Results:	Velocity channel output adjusted from 2.82 V (1,410 ft/min) to 2.55 V (1,275 ft/min).

6.1.2.2 Temperature - The performance-critical temperature channels were calibrated twice during the program, with the following results:

Date: December 27, 1978

Calibration Equipment: Ice bath

Results:

CHANNEL	WAS	NEW SETTING
11 - Collector Input Air Temperature	31.9°F	Not Required
12 - Collector Output Air Temperature	33.3°F	32.0°F
13 - Duct Temperature	31.3°F	32.0°F
14 - Ambient Air Temperature	32.1°F	Not Required

Date: May 17, 1979

Calibration Equipment: Fluke Model No. 2180A Digital Thermometer and an ice bath and heated water

Results:

CHANNEL	WAS	NEW SETTING
11 - Collector Input Air Temperature	131.0°F	129°F
12 - Collector Output Air Temperature	127.9°F	Not Required
14 - Ambient Air Temperature	75.7°F	Not Required

Linearity was good on channels 12 and 14. Minor nonlinearity exists on channel 11, as shown in Figure 6-1. (Channel 13, duct temperature, is no longer used; see Section 7.6.2.)

6.1.2.3 Pyrometer - One June 19, 1979, the pyrometer output was compared with the output of an identical unit at UAH, approximately 25 min northeast of Gold Kist. Results were as follows:

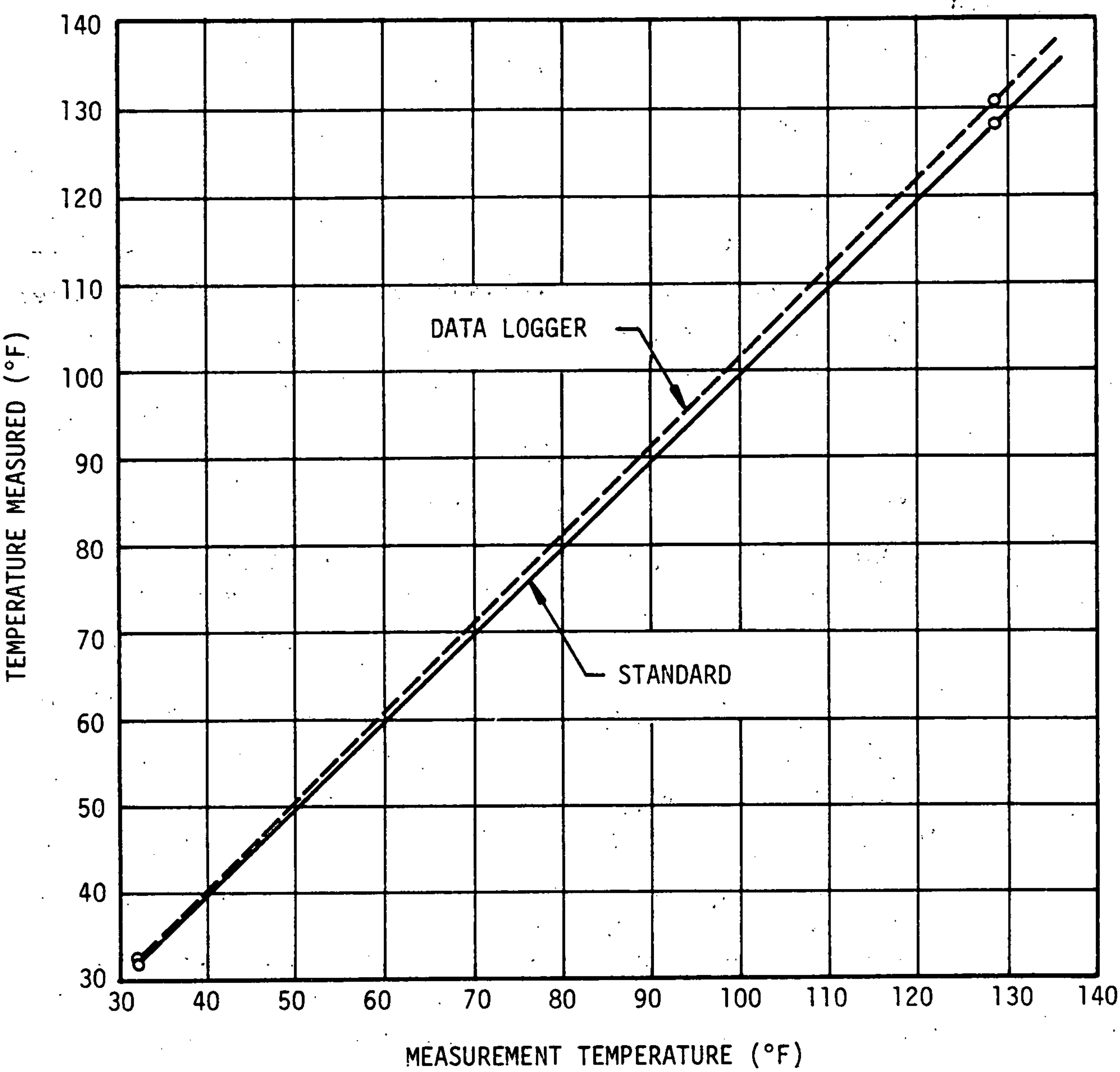


FIGURE 6-1. TEMPERATURE CALIBRATION CURVE - CHANNEL 11

TIME	SKY CONDITION	GOLD KIST INSTRUMENT READING (W/m^2)	UAH INSTRUMENT READING (W/m^2)	DIFFERENCE (%)
10:12:28	Clear	815.2	806.4	1.0
11:12:28	Clear	942.0	951.7	1.0
12:12:28	Clear	1011.4	1004.5	0.7
13:12:28	Scattered Clouds	442.0	953.4	53.6
14:12:28	Scattered Clouds	902.5	940.8	4.1
15:12:28	Scattered Clouds	770.1	782.8	1.6
16:12:28	Scattered Clouds	524.9	580.1	9.5
17:12:28	Scattered Clouds	372.9	360.7	3.4
18:12:28	Scattered Clouds	174.4	171.1	1.9

As a result of the extremely close comparison, it was decided not to remove the instrument from the Gold Kist facility for calibration.

6.2 NONINSTRUMENTED DATA

The following noninstrumented data was provided by Gold Kist personnel on a monthly basis:

- Fuel costs ($/gal)
- Electricity cost ($/kWh)
- Fuel consumed by each dryer (gal)
- Dryer operations log
- Maintenance man-hours, by type
- Maintenance labor cost, by type ($/man-hour)
- Data Logger operations log.

Hourly solar radiation data was provided by UAH on a monthly basis. Portions of this data came from the Marshall Space Flight Center (MSFC) when the UAH equipment was not operating.

7. OPERATIONAL ANALYSIS

7.1 GENERAL

The solar system operated for a 15-month period. The data contained in this section are presented in two ways: 1) for the total period and 2) for a 12-month period from September 1978 through August 1979. This method presents the data for the entire operational phase and also allows comparison with other systems on an annual basis.

Basic performance data for the entire 15-month period are summarized in Table 7-1.

7.2 SOLAR INSOLATION

Table 7-2 presents the statistical and the actual solar flux experienced in the operational phase. Note the significant reduction (11.3%) in solar flux for the annual period.

7.3 SOLAR SYSTEM UTILIZATION

System utilization is defined as the fraction that the utilized energy is of the utilizable energy. The values of monthly energy utilized are taken directly from system performance data printouts. Monthly energy utilizable is derived as follows:

- A clear day with full system run time is selected for each month. The energy utilized that day is selected as typical "clear day" usable energy.
- Monthly system utilization (S.U.) for the month is then calculated as follows:

$$\text{S.U.} = \frac{\text{monthly energy actually utilized}}{\text{"Clear-day" usable energy} \times \text{cloud cover attenuation} \times \text{no. days in month}} \times 100$$

EXAMPLE: October 1978
Julian Day No. 275, had full run time, was clear, and 6.605×10^6 Btu were utilized.

$$\text{S.U.} = \frac{103.58 \times 10^6 \text{ Btu}}{6.605 \times 10^6 \times 0.809 \times 31} \times 100 = 62.5\%$$

TABLE 7-1. PERFORMANCE DATA SUMMARY

		JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
Q031 - Total Solar Incident (Btu/ft² × 10³)	Monthly	13.5	10.1	15.0	8.9	34.8	11.0	4.3	15.2	8.4	28.4	31.5	24.7	39.0	23.4	26.4
	Cumulative		23.6	38.6	47.5	82.3	93.3	97.6	112.8	121.2	149.6	181.1	205.8	244.8	268.2	294.6
Q180 - Solar Energy Collected (Btu × 10⁶)	Monthly	68.6	44.1	55.5	33.2	106	36.4	13.4	54.8	25.8	98.3	111.8	82.9	118.9	76.9	84.9
	Cumulative		112.7	168.2	201.4	307.4	343.8	357.2	412	437.8	536.1	647.9	730.8	849.7	926.6	1012
Q233 - Total Solar Utilized (Btu × 10⁶)	Monthly	66.9	43.0	54.1	32.4	103.6	35.5	13.1	53.5	25.2	95.8	109.0	80.9	115.9	75.0	82.8
	Cumulative		109.0	164.0	196.4	300.0	335.5	348.6	402.1	427.3	523.1	632.1	713	828.9	903.9	986.7
N131 - Collector Efficiency	Monthly	38.7	33.3	28.2	28.5	23.2	25.3	23.8	27.5	23.4	26.4	27.1	25.6	23.3	25.1	24.5
	Average		36.4	33.3	32.4	28.5	28.1	27.9	27.9	27.6	27.3	27.3	27.1	26.5	26.4	26.2
N143 - Average Ambient Dry Bulb Temperature (°F)	Monthly	83.8	86.7	86.1	79.2	67.1	60.8	56.6	33.1	42.7	58.8	65.9	74.8	80.4	82.1	83.9
	Average		85.0	85.4	83.8	80.5	77.2	74.3	69.1	66.2	65.4	65.5	66.2	67.3	68.4	69.4

TABLE 7-2. SOLAR FLUX FOR DECATUR-HUNTSVILLE AREA

Tilt = 15 deg
Azimuth = 24° East of South

STATISTICAL*				ACTUAL 1978-1979	
MONTH	CLEAR SKY FLUX (Btu/ft^2-day)	CLOUD COVER (ATTENUATION FACTOR)	NET FLUX (Btu/ft^2-day)	NET FLUX (Btu/ft^2-day)	CLOUD COVER (ATTENUATION FACTOR)
Jun.	2,580	0.770	1,987	2,035	0.790
Jul.	2,550	0.779	1,986	1,962	0.769
Aug.	2,445	0.779	1,905	1,620	0.662
Sep.	2,250	0.775	1,744	1,404	0.624
Oct.	1,965	0.740	1,454	1,590	0.809
Nov.	1,665	0.658	1,096	1,038	0.623
Dec.	1,465	0.527	772	864	0.590
Jan.	1,590	0.545	867	674	0.424
Feb.	1,905	0.589	1,120	842	0.442
Mar.	2,235	0.641	1,430	1,339	0.560
Apr.	2,445	0.699	1,710	1,450	0.593
May	2,550	0.732	1,870	1,575	0.618
Jun.	2,580	0.770	1,987	1,890	0.732
Jul.	2,550	0.779	1,986	1,455	0.570
Aug.	2,445	0.779	1,905	1,792	0.733
Average (15 mo.)	2,215	0.717	1,588	1,435	0.648
Average (Sep.-Aug.)	2,137	0.700	1,495	1,325	0.620

*P. N. Fisher, "Final Design Report for Application of Solar Energy to Industrial Drying of Soybeans," TBE Report SD77-ERDA-2078, February 28, 1977.

System utilization for each month during operation is shown in Table 7-3. The low overall and annual system utilization is attributable primarily to daytime routine maintenance on the dryers. Daytime dryer down-time has the following estimated distribution:

- Routine dryer maintenance 94.5%
- Unscheduled dryer or plant maintenance 5%
- Lack of raw product and miscellaneous 0.5%

The more experienced personnel at Gold Kist work the day shift. It is desirable to have these people perform the maintenance activities. The solar fraction involved in this program was too small to justify any major shift or operational changes.

Table 7-4 compares the daytime and nighttime drying operations at Gold Kist. Note the close monthly correlation between daylight utilization in Table 7-4 and system utilization i.. Table 7-3. The relative density of day and night operation can be seen in Figure 7-1. These data were extracted from Gold Kist dryer operation logs.

7.4 ENERGY DISPLACED

The solar system displaced 986.54×10^6 Btu equivalent of fossil fuel during the 15 months of operation. During the annual period (September through August), it displaced 822.54×10^6 Btu equivalent. The annual savings assuming 95% system utilization would be $1,430 \times 10^6$ Btu. Monthly distribution of these savings is shown in Figure 7-2.

The dryers operated on fuel oil from June 1, 1978, through May 31, 1979. During June 1979, one dryer was operated on natural gas and the other two on fuel oil. During the last 2 months of operation, July and August, the dryers operated exclusively on natural gas.

Table 7-5 presents the solar fraction for one dryer (assuming all solar energy was dedicated to the same dryer). Figure 7-3 presents the daily fuel saved by the solar system from September 1978 through August 1979.

TABLE 7-3. SOLAR SYSTEM UTILIZATION*

YEAR	MONTH	ENERGY UTILIZABLE (Btu × 10^6)	ENERGY UTILIZED (Btu × 10^6)	SOLAR SYSTEM UTILIZATION (%)
1978	Jun.	272.2	66.88	24.6
1978	Jul.	180.8	43.02	23.8
1978	Aug.	160.1	54.10	33.8
1978	Sep.	129.8	32.35	24.9
1978	Oct.	165.9	103.58	62.5
1978	Nov.	90.3	35.53	39.3
1978	Dec.	45.2	13.08	28.9
1979	Jan.	65.6	53.46	81.5
1979	Feb.	57.5	25.19	43.8
1979	Mar.	157.0	95.81	61.0
1979	Apr.	161.1	109.03	67.7
1979	May	171.1	80.85	47.3
1979	Jun.	161.6	115.90	71.7
1979	Jul.	122.9	75.01	61.0
1979	Aug.	177.6	82.75	46.6
Total (15 mo.)		2,118.7	989.54	46.6
Total (Sep.-Aug.)		1,505.6	822.54	54.6

*All data normalized for
1) collector tilt, 15 deg
2) collector orientation, 24° East of South
3) collector area, 13,104 ft²

TABLE 7-4. DRYER OPERATIONS

YEAR	MONTH	USABLE* DAYLIGHT (hr)	NIGHT DRYING (hr)	DAY DRYING (hr)	TOTAL DRYING (hr)	DAYLIGHT** HOUR UTILIZATION (%)
1978	Jun.	372.5	337	96	433	25.8
1978	Jul.	375.2	190	56	246	14.9
1978	Aug.	355.2	261	81	342	22.8
1978	Sep.	311.3	187	73	260	23.5
1978	Oct.	289.3	340	173	513	59.8
1978	Nov.	250.0	238	78	316	31.2
1978	Dec.	246.7	229	69	298	28.0
1979	Jan.	253.1	199	198	347	78.2
1979	Feb.	250.8	220	128	348	51.0
1979	Mar.	307.4	237	187	424	60.8
1979	Apr.	331.2	199	189	388	57.1
1979	May	369.4	187	170	357	46.0
1979	Jun.	372.5	191	204	395	54.8
1979	Jul.	375.2	282	174	456	46.4
1979	Aug.	355.2	259	151	410	42.5
Total (15 mo.)		4,815.0	3,556	2,027	5,583	42.1
Total (Sep.-Aug.)		3,712.1	2,768	1,794	4,562	48.3

* Assumes 1 hour after sunrise through 1 hour before sunset.

**Includes time that at least one of the three dryers is operated over 2 consective hours.

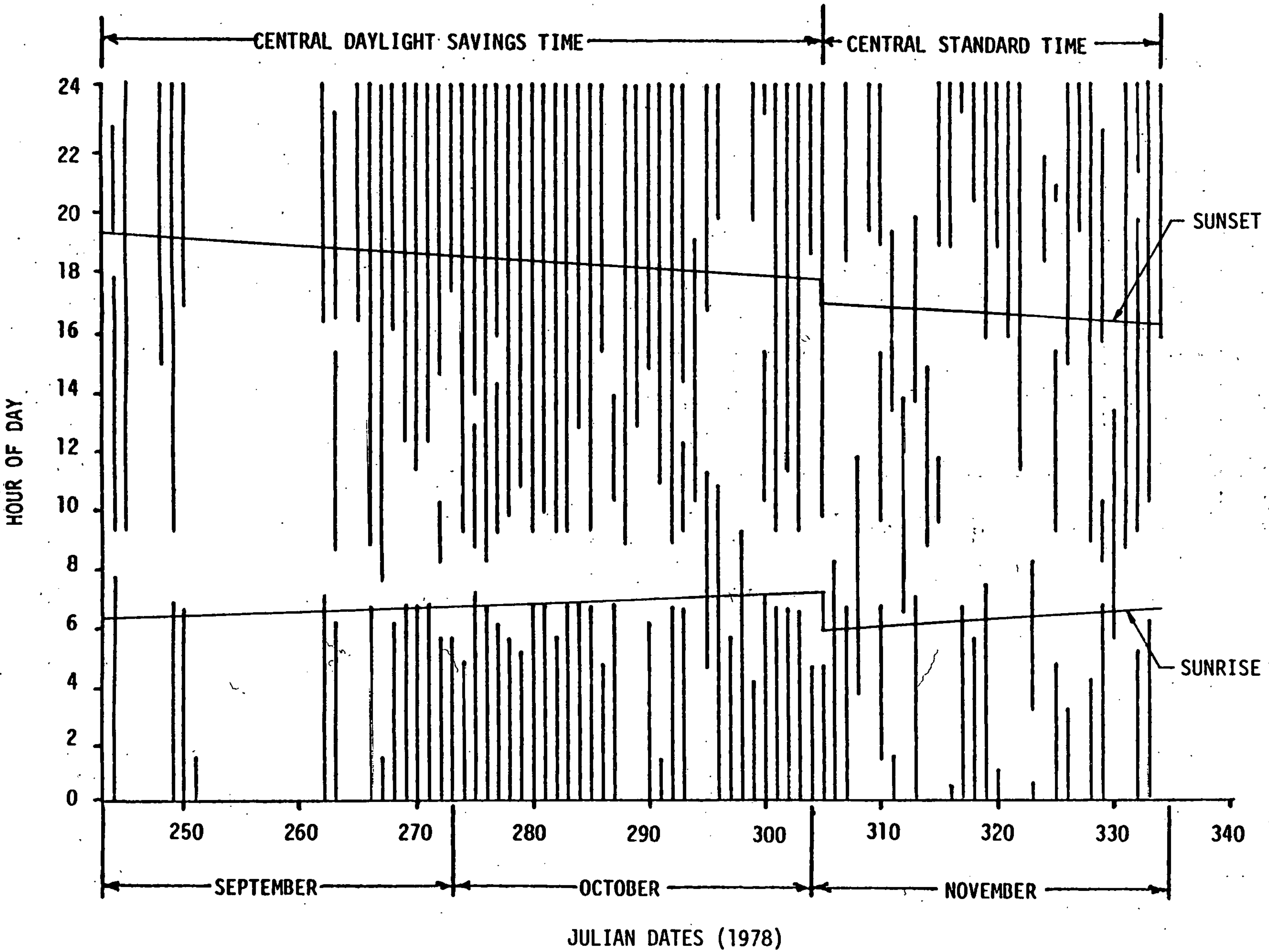


FIGURE 7-1. DRYER "ON" TIME

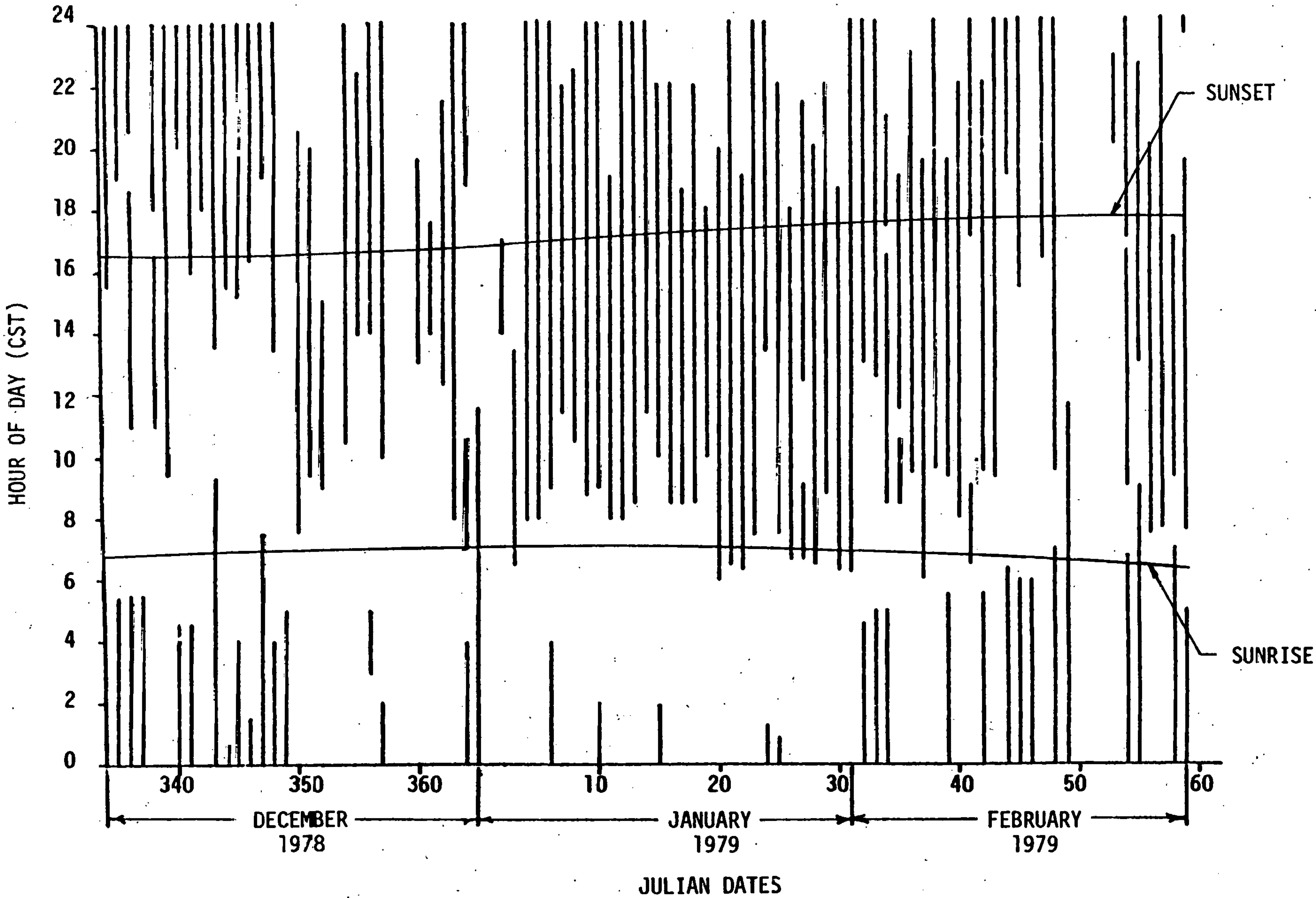


FIGURE 7-1 - Continued

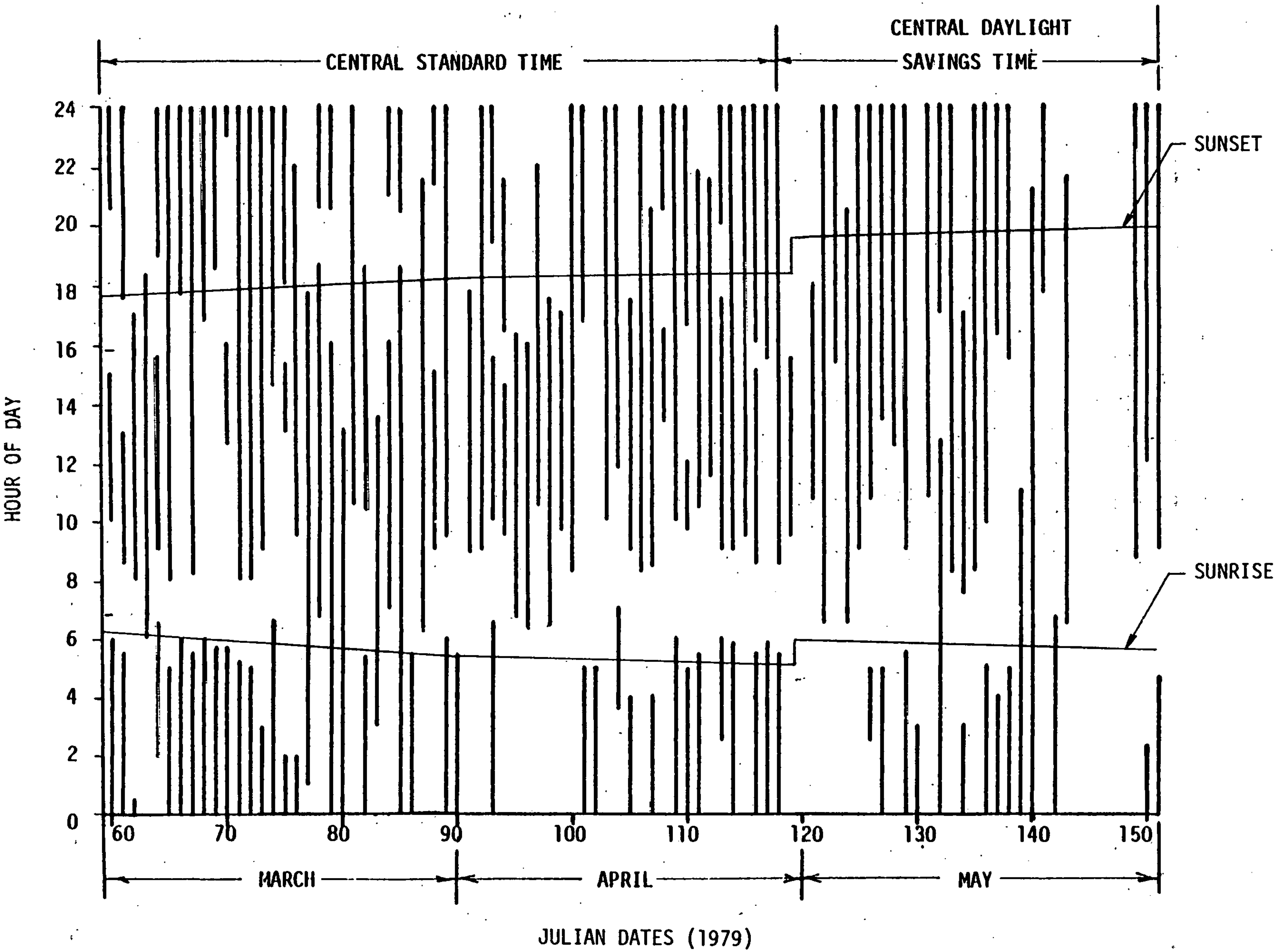


FIGURE 7-1 - Continued

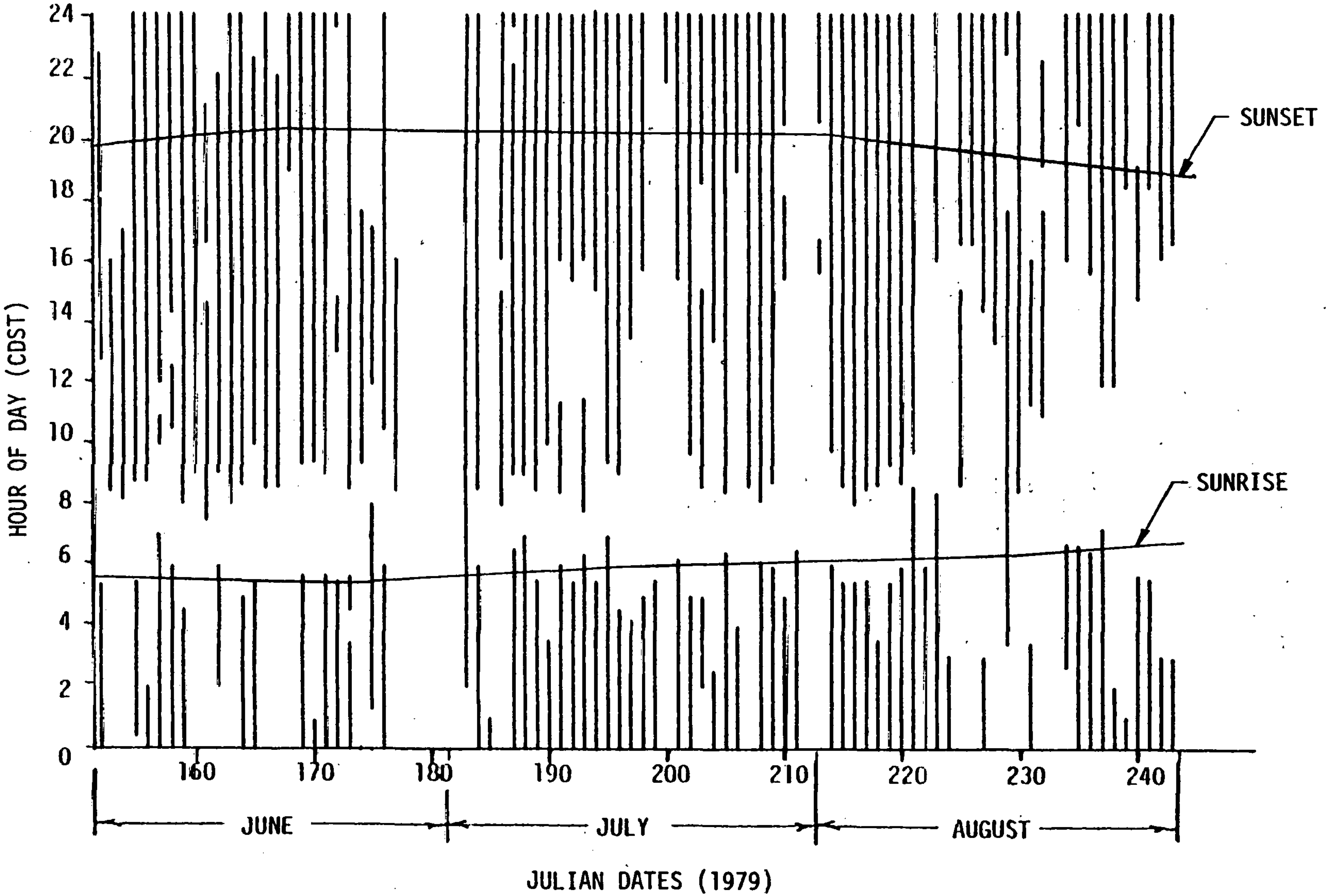


FIGURE 7-1 - Concluded

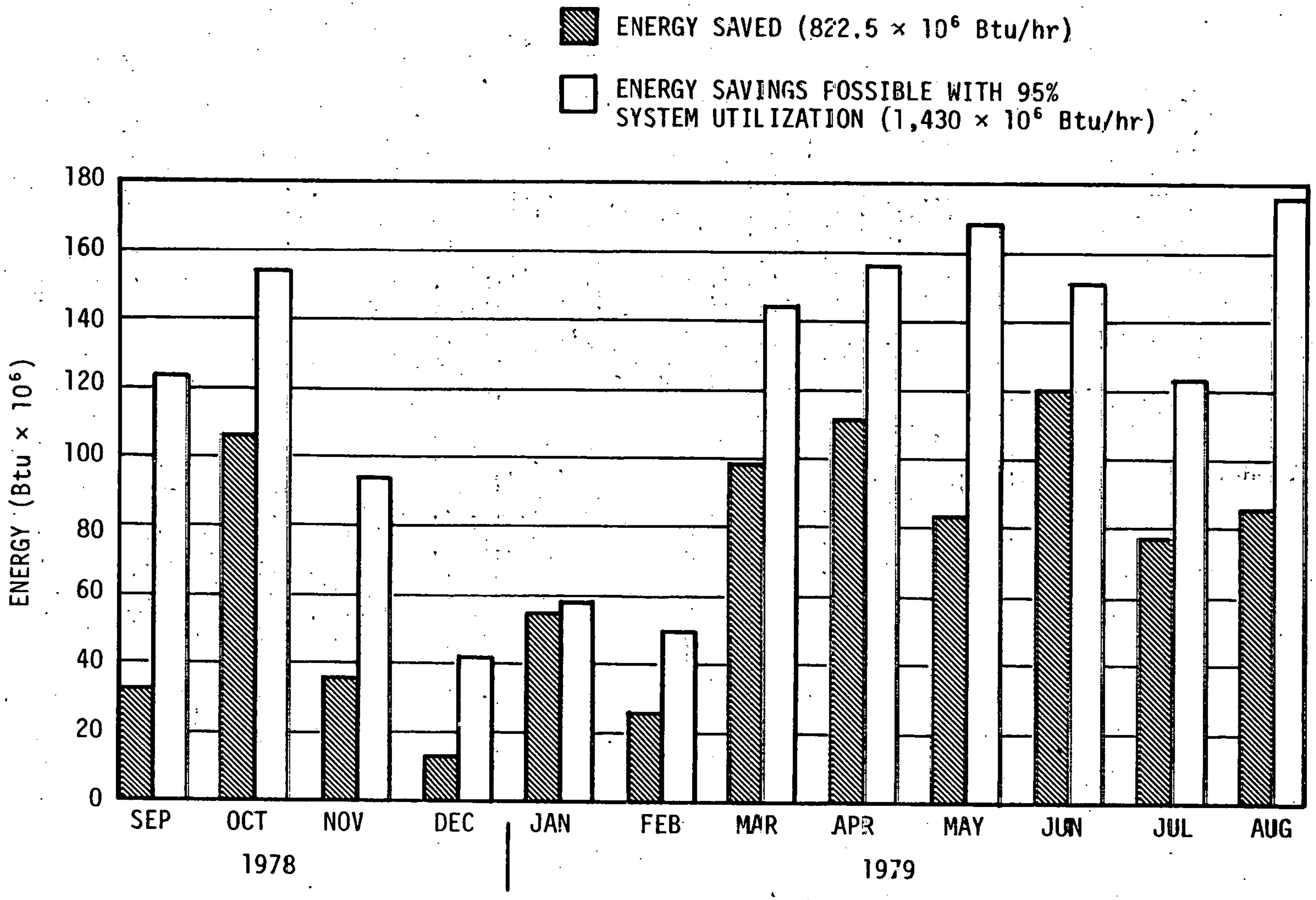


FIGURE 7-2. MONTHLY ENERGY SAVINGS

TABLE 7-5. SOLAR FRACTION, ONE DRYER

YEAR	MONTH	FUEL OIL USED PER DRYER (gal × 10^3)	SOLAR ENERGY OIL EQUIVALENT (gal × 10^3)	TOTAL ENERGY OIL EQUIVALENT PER DRYER (gal × 10^3)	SOLAR FRACTION FOR ONE DRYER (%)
1978	Jun.	*	0.449	*	*
1978	Jul.	*	0.289	*	*
1978	Aug.	*	0.364	*	*
1978	Sep.	*	0.217	*	*
1978	Oct.	57.7	0.696	58.396	1.19
1978	Nov.	44.2	0.239	44.439	0.54
1978	Dec.	43.8	0.088	43.888	0.20
1979	Jan.	41.2	0.359	41.559	0.86
1979	Feb.	31.2	0.169	31.369	0.54
1979	Mar.	30.7	0.644	31.344	2.05
1979	Apr.	21.3	0.733	22.033	3.33
1979	May	20.7	0.543	21.243	2.56
1979	Jun.	**	0.779	**	**
1979	Jul.	**	0.504	**	**
1979	Aug.	**	0.556	**	**
Totals (Oct.-May)		290.8	3.471	294.271	1.18

* No dedicated fuel meter

**Natural gas used; no dedicated gas meters

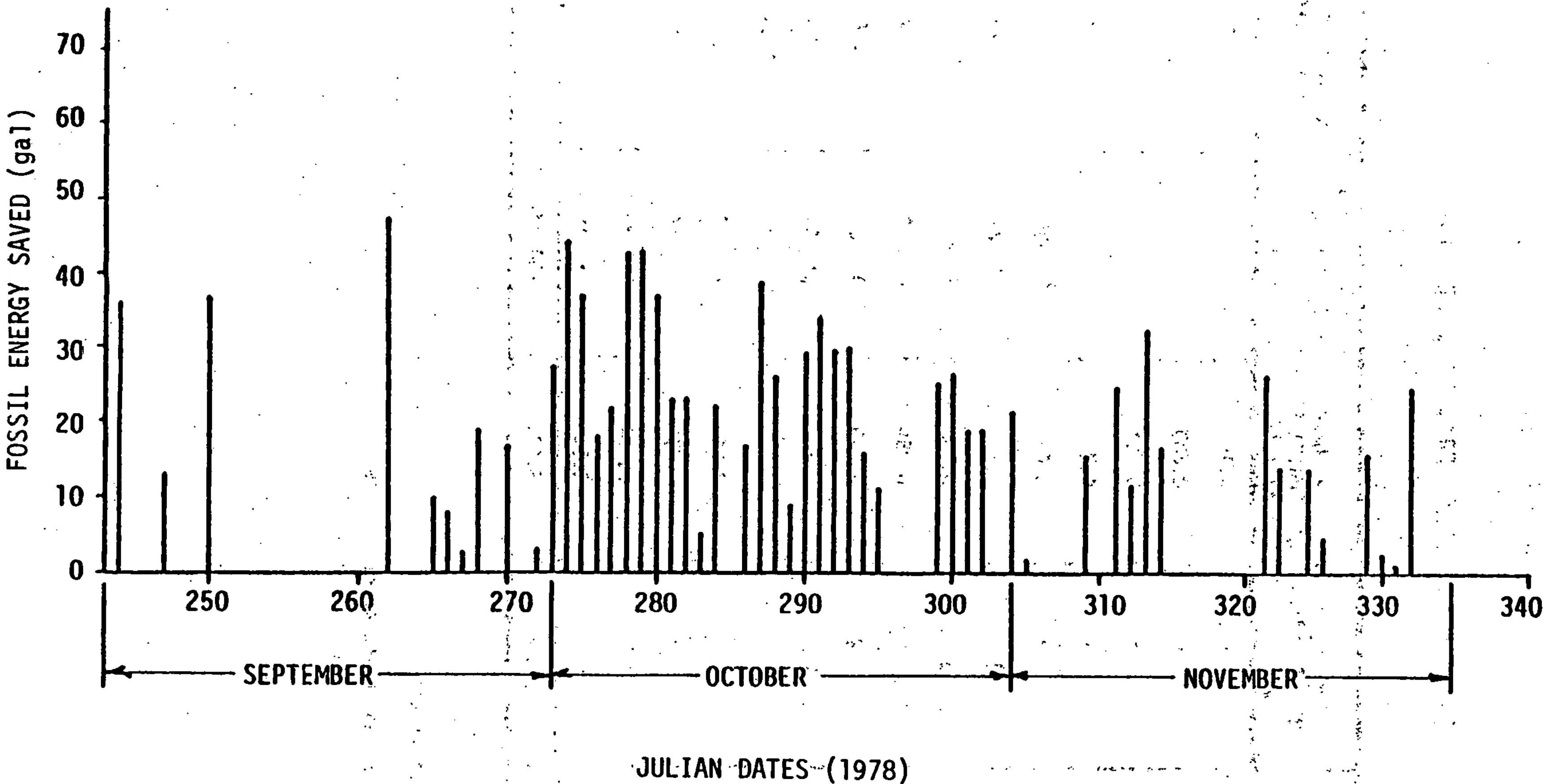


FIGURE 7-3. DAILY FUEL SAVINGS

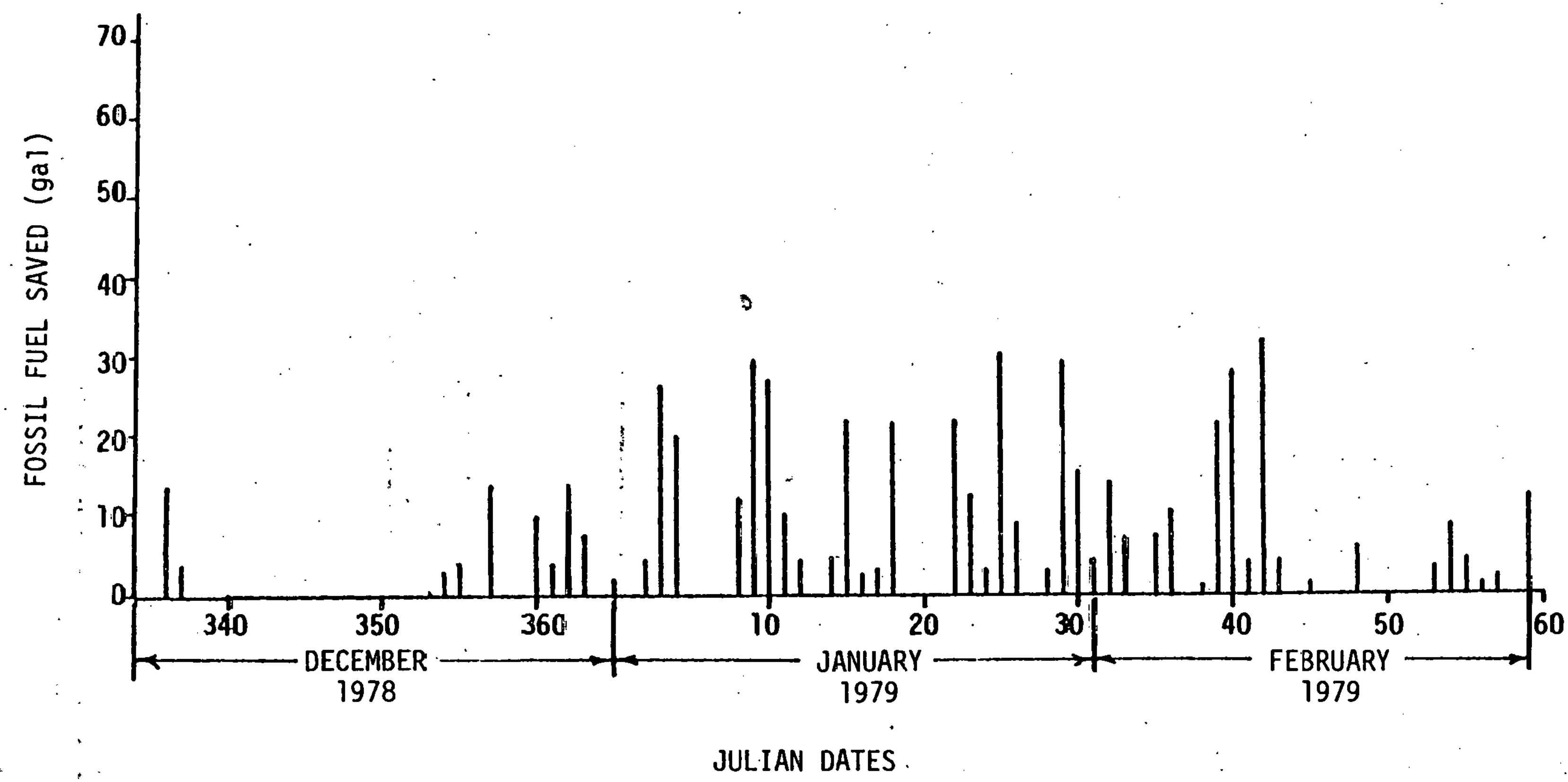


FIGURE 7-3 - Continued

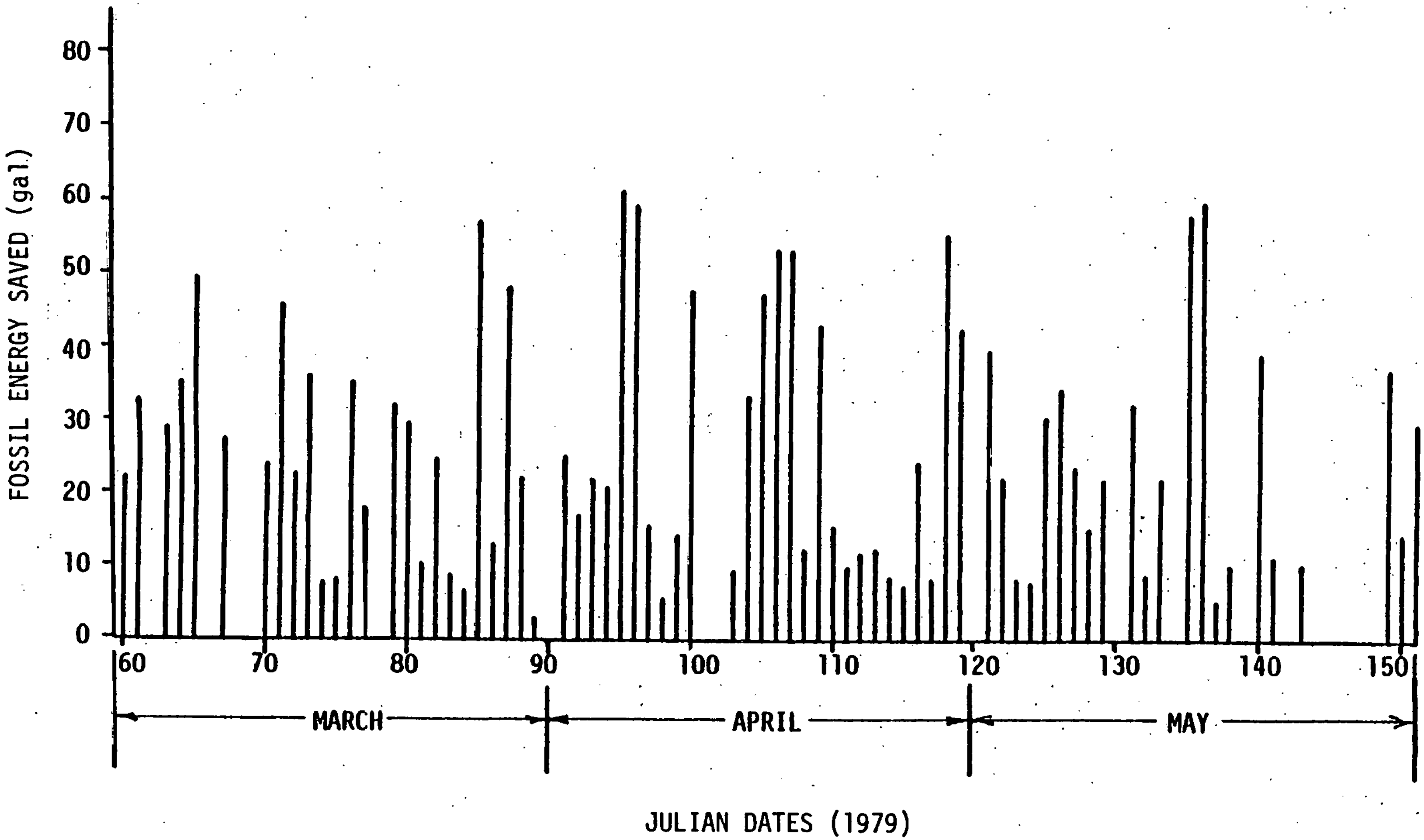


FIGURE 7-3 - Continued

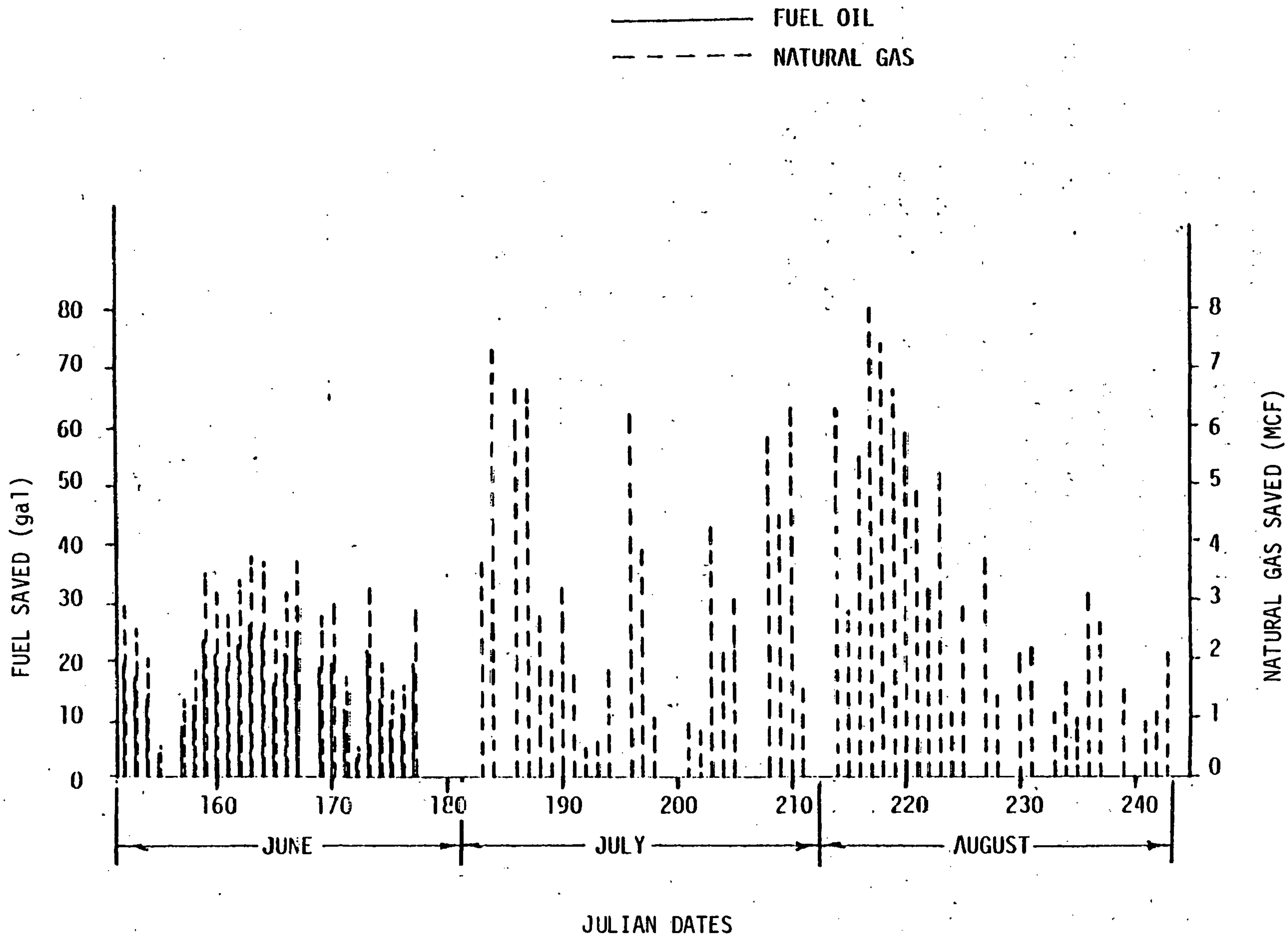


FIGURE 7-3 - Concluded

7.5 COLLECTOR PERFORMANCE

Collector efficiency was less than the 52% predicted by the performance evaluation model constructed during Phase I. During the performance year (September 1978 through August 1979), collector monthly efficiency ranged from 28.3% to 23.2% and averaged 26.2%, as shown in Figure 7-4. Analysis of a full day's operation immediately before and after each cleaning reveals a collector efficiency increase of approximately 9.3% after cleaning. Figure 7-5 presents the daily collector efficiencies.

Not discernible in Figure 7-4 or 7-5 is the correlation of efficiency with the time of day. Figure 7-6 shows the diurnal variation of efficiency for two August days. The profile of efficiencies indicates some thermal capacitance effects that cause artifically low steady-state efficiency in the early hours and a higher value during the last hour of operation as energy is removed from the collector mass and the support structure.

Typical peak temperature lifts for winter and summer are 40°F and 60°F, respectively. This parameter is shown in Figure 7-7.

The relationship of the steady-state efficiency of a flat plate collector to the environmental conditions can be approximated by a linear function of $(T_{outlet} - T_{ambient})/I$, $\Delta T/I$. Figure 7-8 shows hourly efficiencies as a function of $\Delta T/I$ for a typical August day. It also presents theoretical predictions of the performance of a double-glazed collector.

7.6 ENERGY TRANSPORT SYSTEM

7.6.1 Air Flow

Some concern still exists over the inconsistency of the velocity data. They ranged from 1,245 ft/min to a high of 1,705 ft/min. Both calibrations required 9.5% reduction in voltage output. The blower speed was verified to be 585 rpm, the specification speed. No significant flow change occurred after filter change.

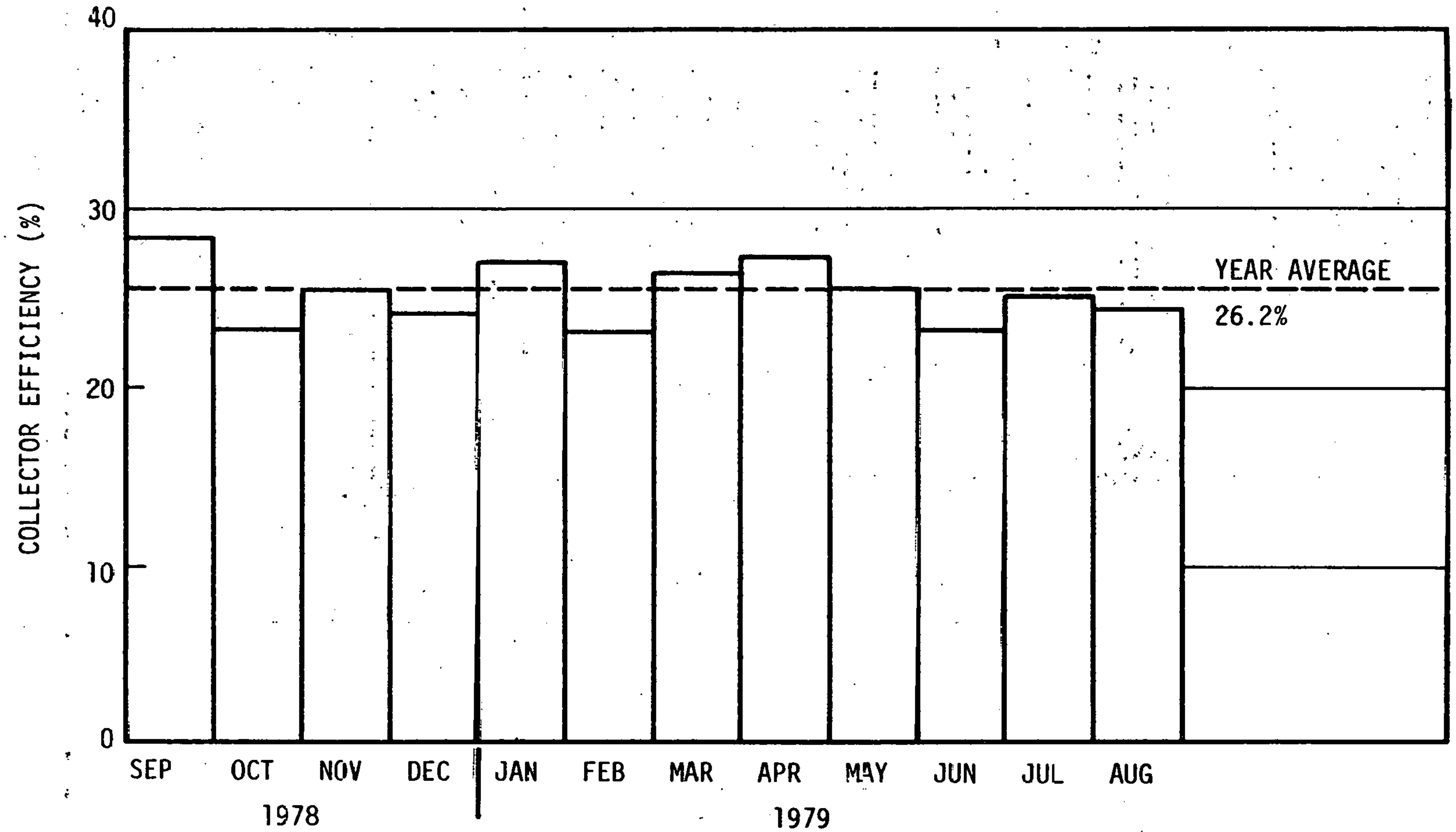


FIGURE 7-4. MONTHLY COLLECTOR EFFICIENCY

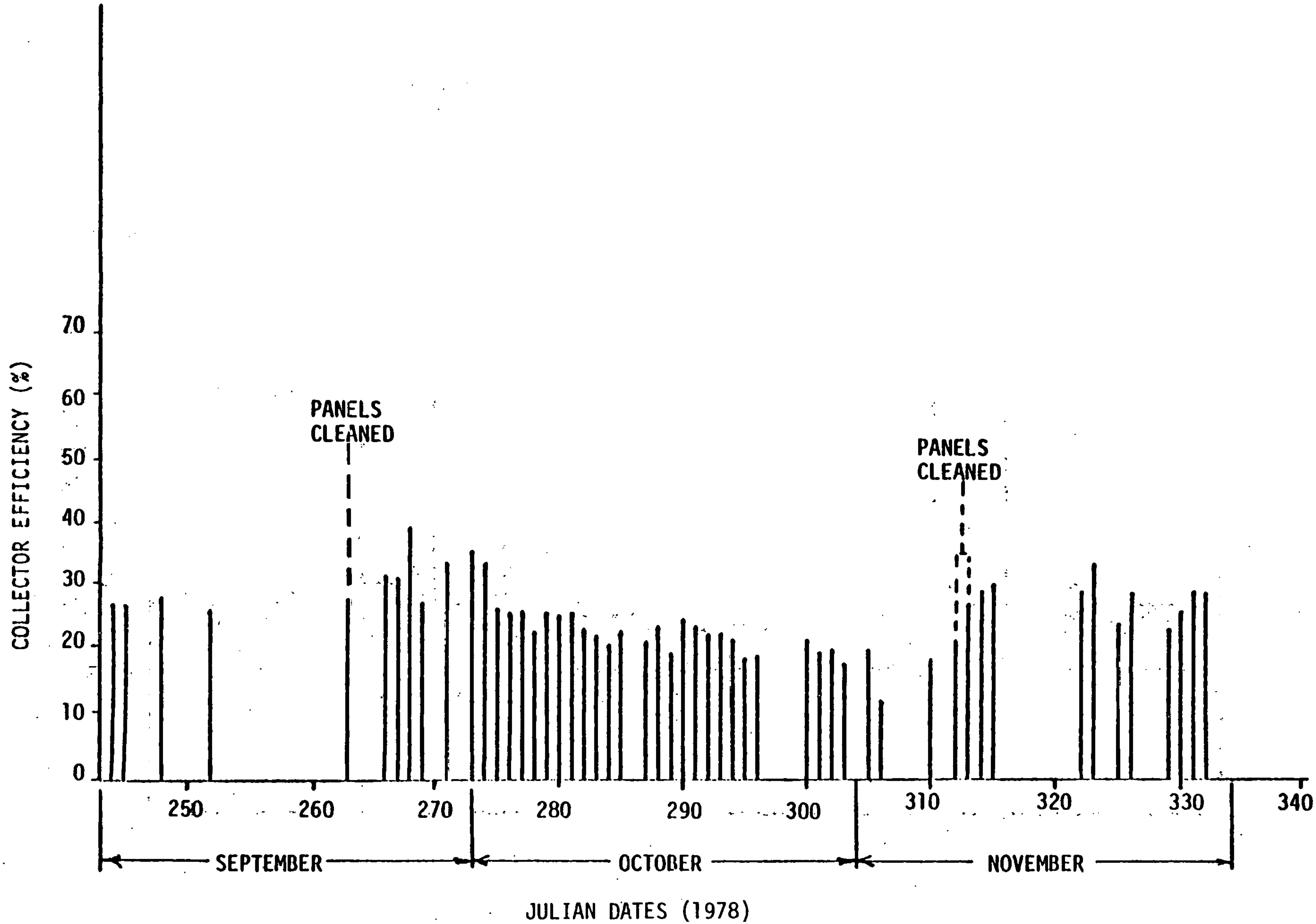


FIGURE 7-5. DAILY COLLECTOR EFFICIENCY

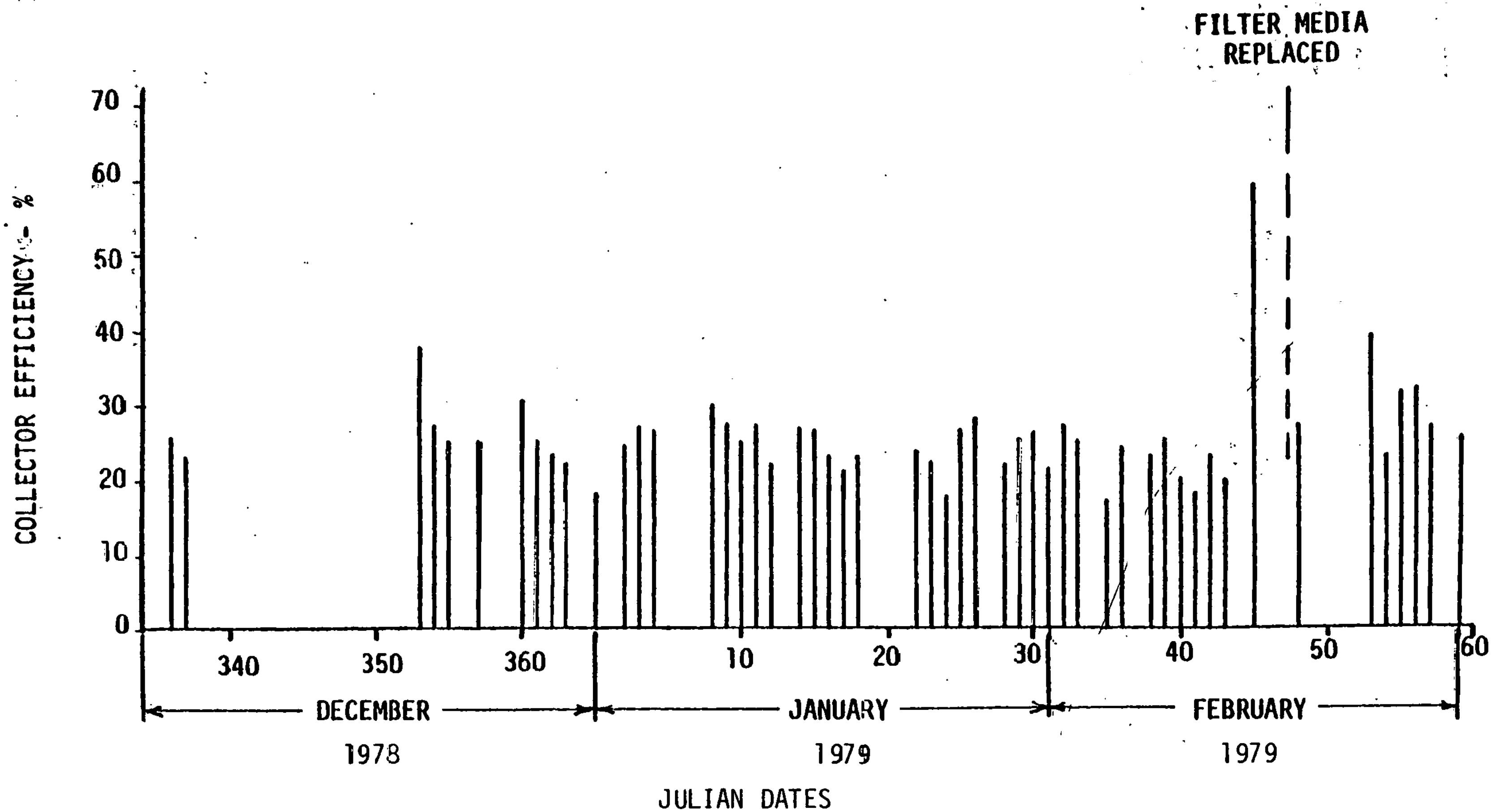
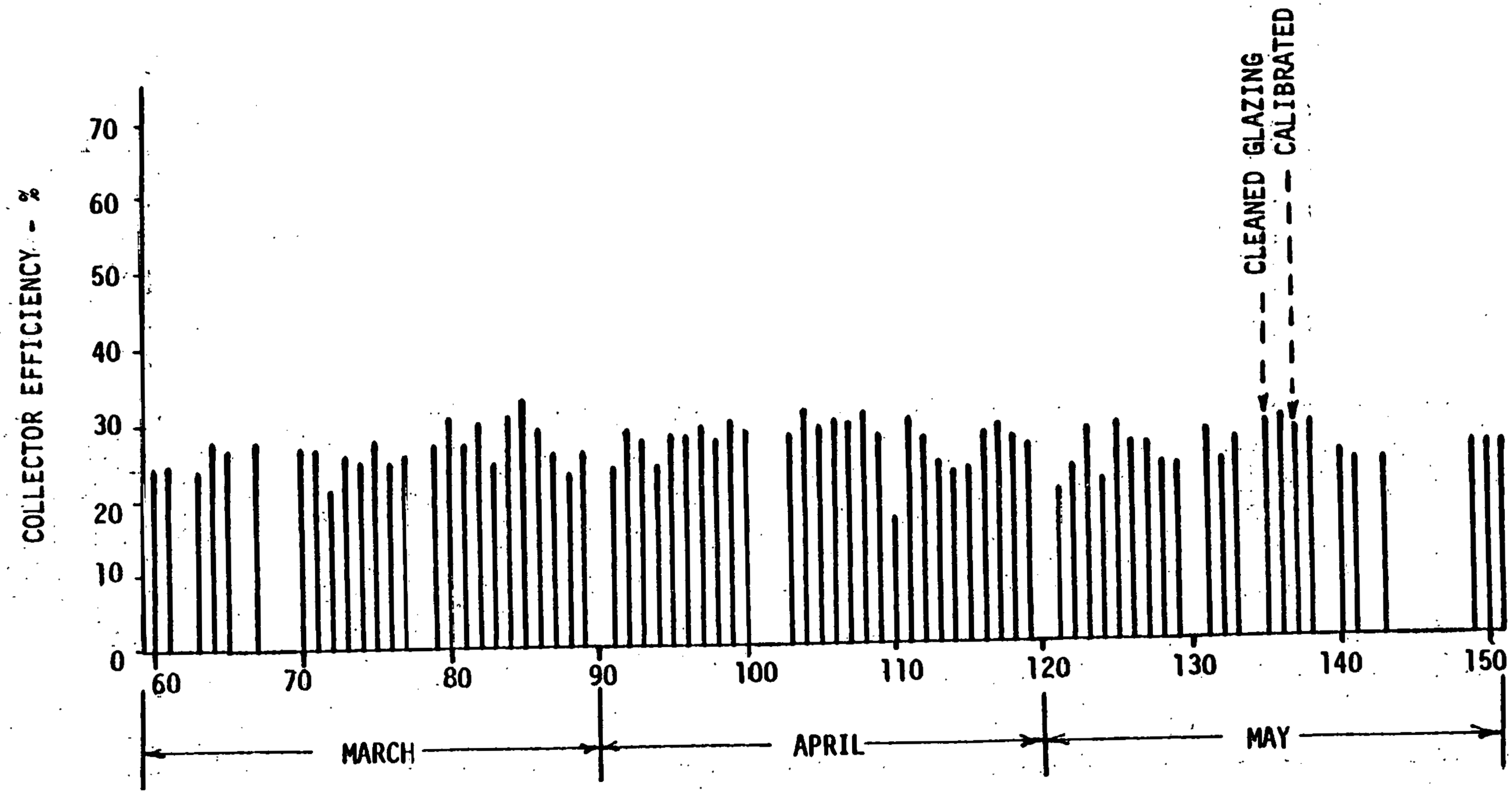


FIGURE 7-5 - Continued



JULIAN DATES, 1979

FIGURE 7-5 - Continued

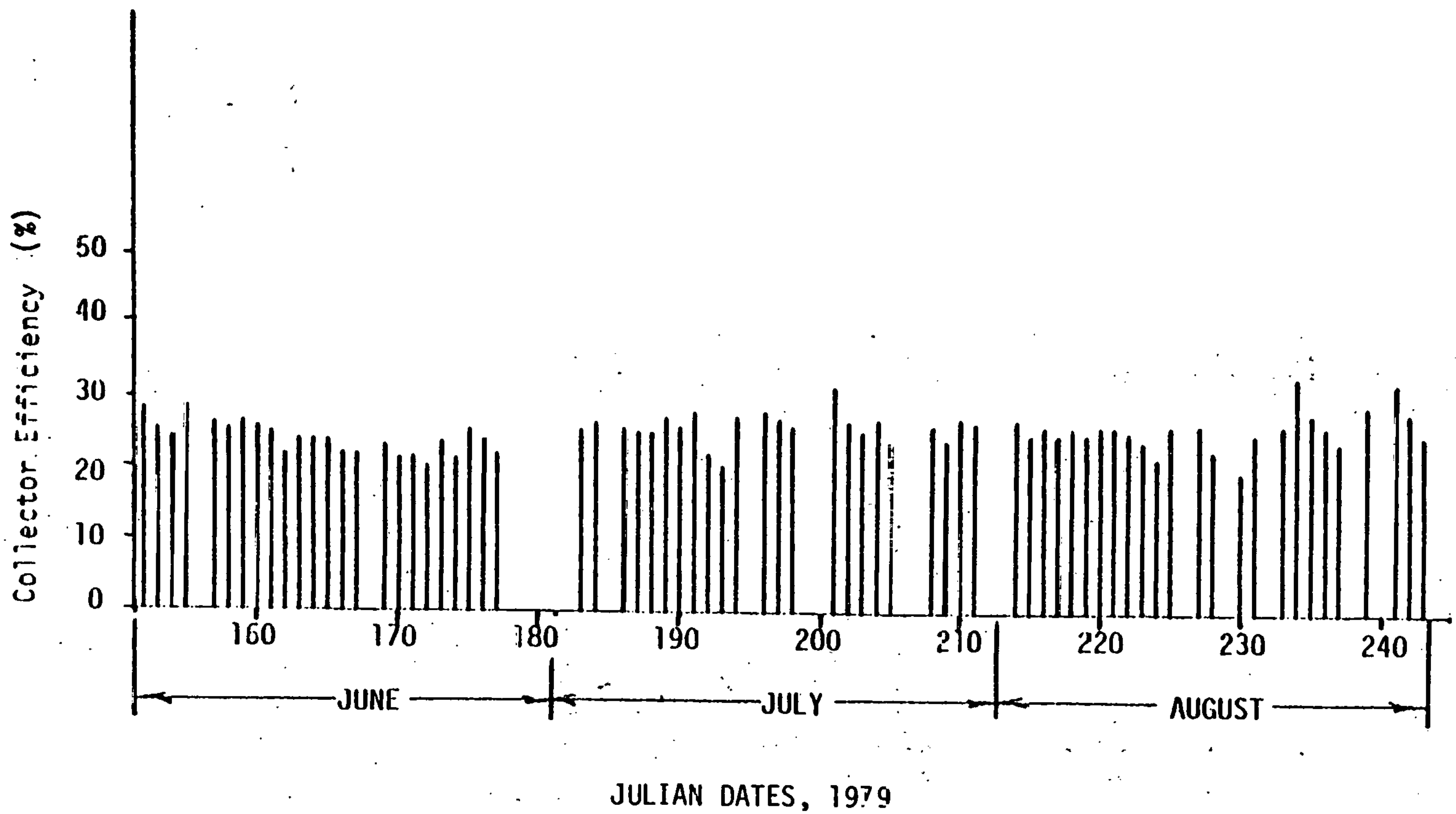


FIGURE 7-5 - Concluded

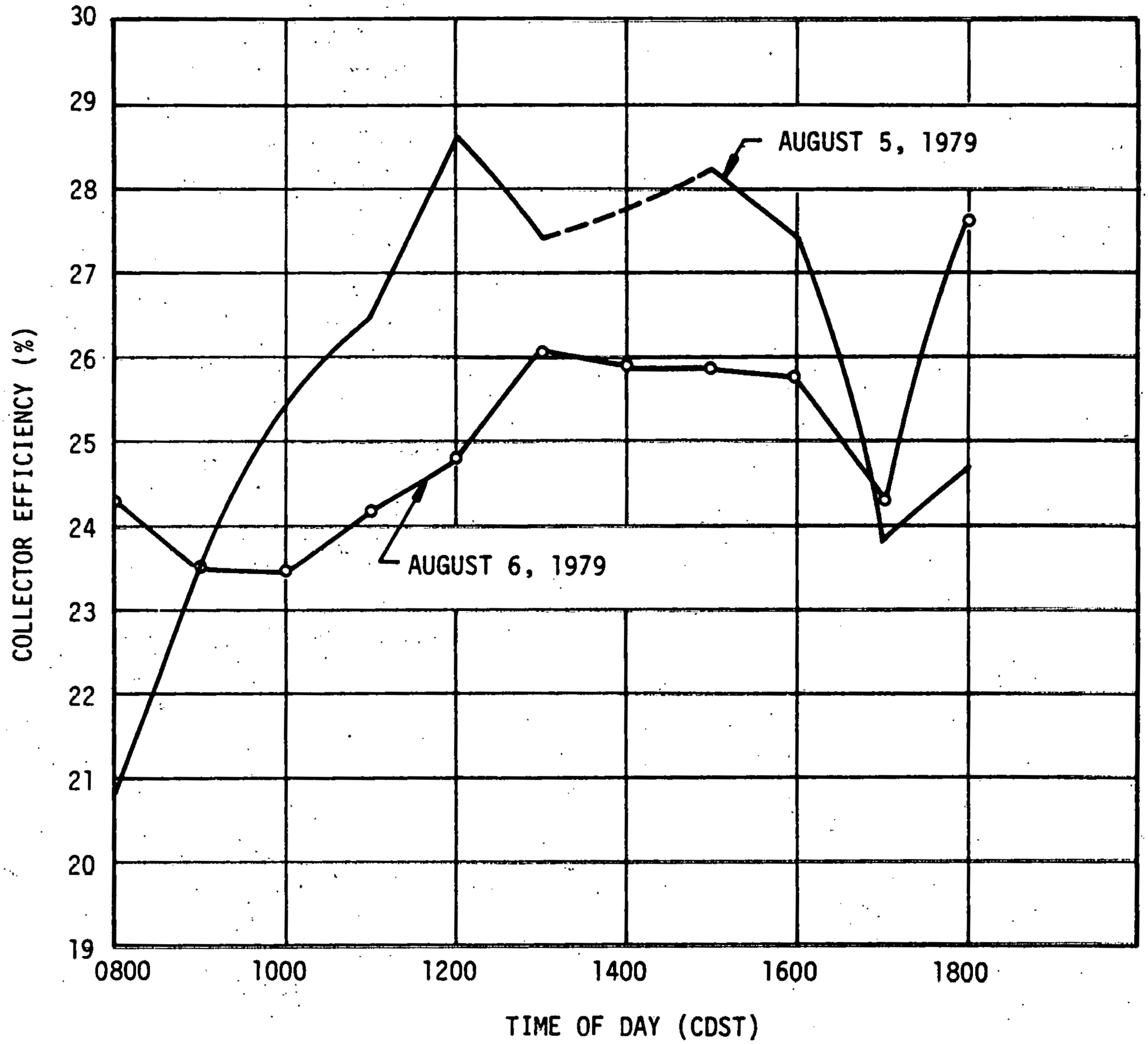


FIGURE 7-6. COLLECTOR EFFICIENCY PROFILE

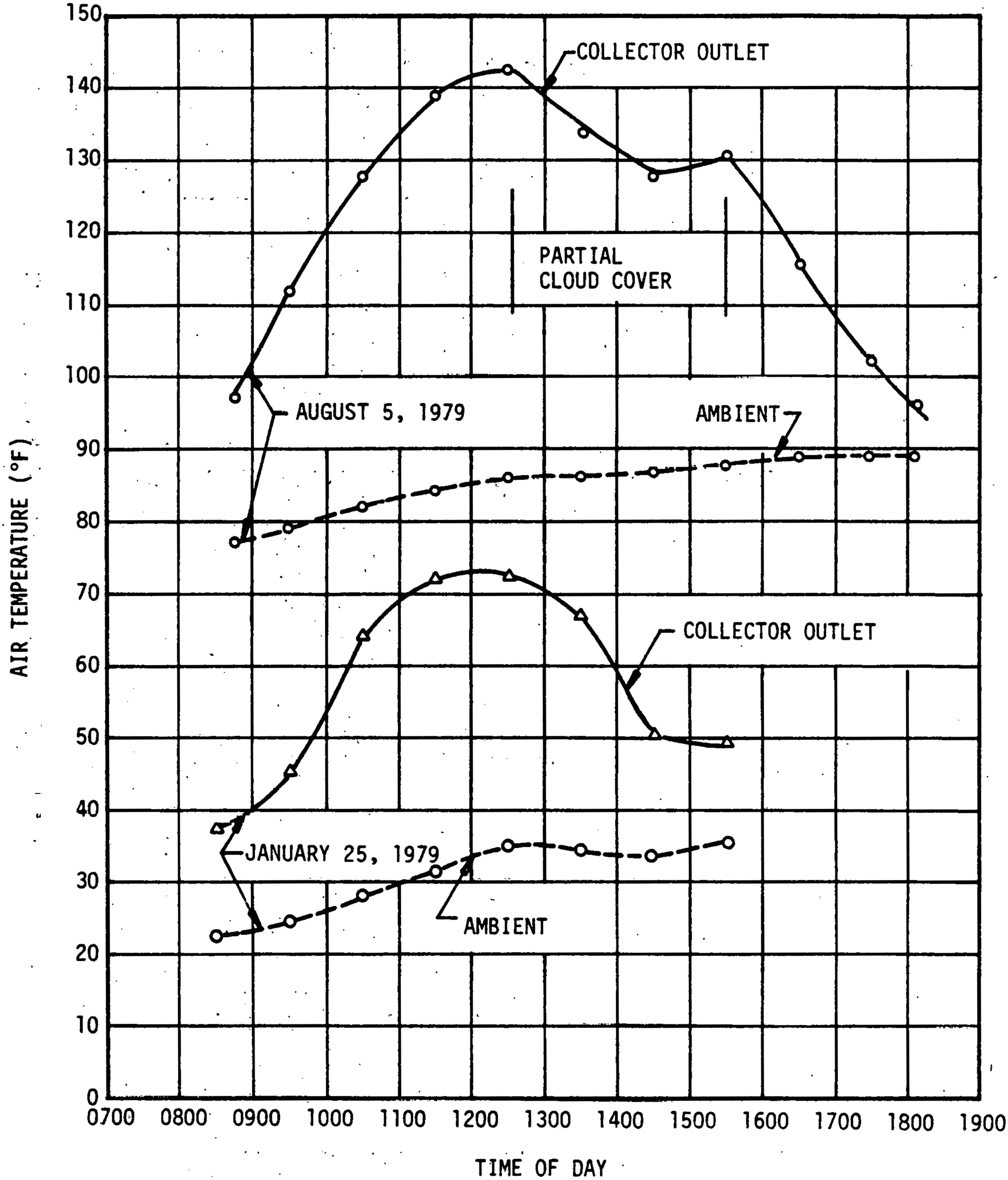


FIGURE 7-7. TYPICAL TEMPERATURE LIFT

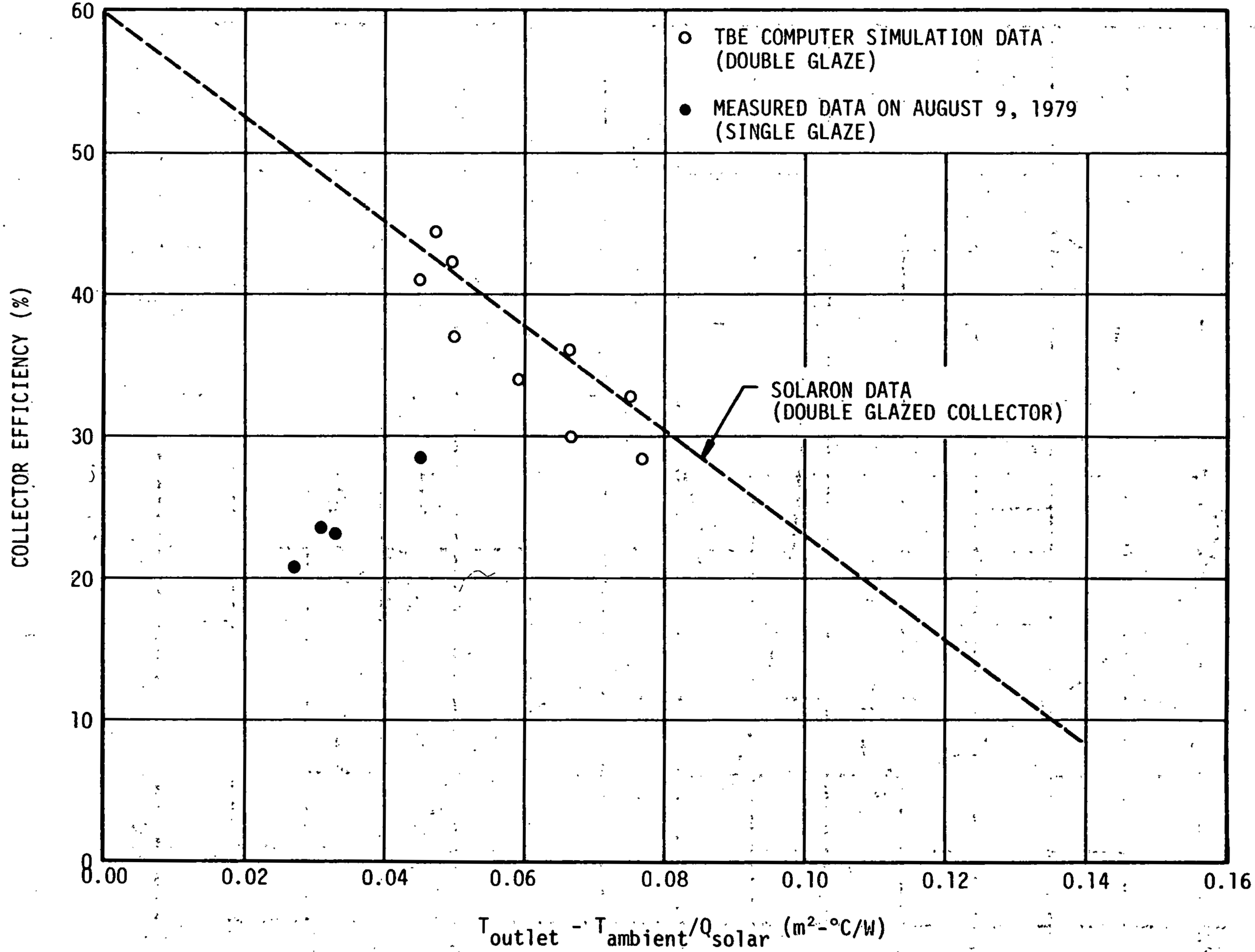


FIGURE 7-8. ARRAY EFFICIENCY AS A FUNCTION OF COLLECTOR PANEL EFFICIENCY FACTOR

Since no concrete reason could be found for an actual drift in flow, it is assumed that the drift occurred in the velocity instrumentation. This probe should be pulled and factory calibrated across the entire operating temperature range.

Since the operational phase ended (August 31, 1979), it was discovered that one of the three phase power leads from the Gold Kist power distribution station was partially grounded. The resistance to ground on the "bad" leg drifted and was 50% of the value on the two "good" legs. This problem is being corrected at the time of this writing. Further tests should be run on the air flow in the system after this electrical problem is solved.

7.6.2 Duct Thermal Losses

The December 1978 data revealed a negative duct loss (gain). This prompted a detailed study of the duct temperature-sensing techniques. Using calibrated thermocouples and read-out devices from UAH, it was determined that the temperature across the cross section of the duct varied ±1.5°F in a somewhat random manner. This condition existed near the collector array output and near the dryer house. It was concluded that the single RTD probe did not represent average duct temperatures sufficiently close to determine duct thermal losses. An array of thermocouples would be needed at each end of the duct.

As a result, a detailed analysis of the duct loss was conducted. This analysis concluded the following:

- Energy loss will approximate a constant percent of energy transported.
- Energy percent losses computed were:
  - ▲ Dry insulation - 1.2%
  - ▲ 50 ft of wet insulation - 4.4%
  - ▲ Entire supply duct with wet insulation (172 ft) - 12%
  - ▲ Expected temperature drops in the duct for various operating conditions are as shown in Figure 7-9.

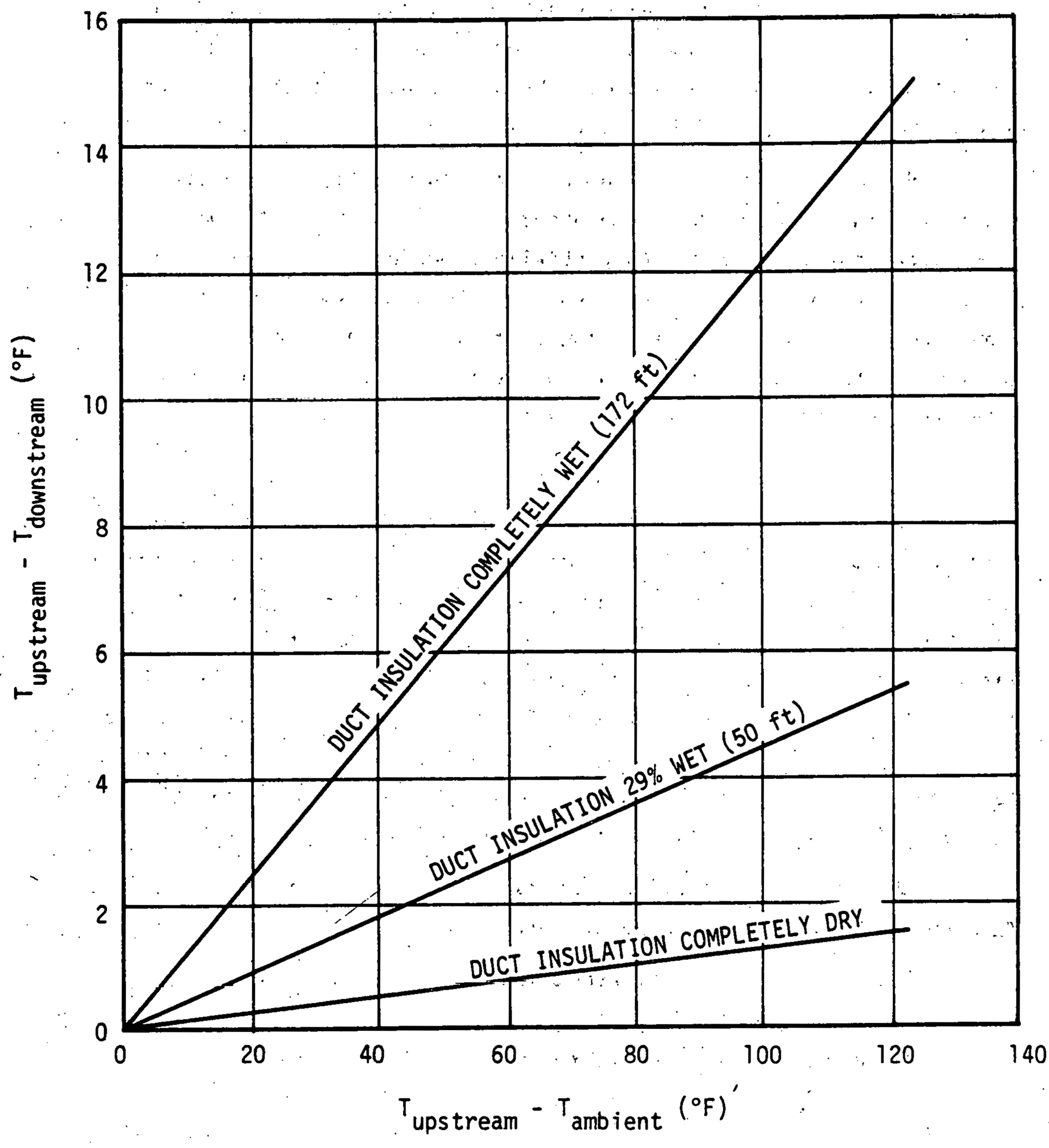


FIGURE 7-9. TEMPERATURE DROP IN SUPPLY DUCT

Since only about 50 ft of the duct is subject to leakage and only stays wet an assumed 50% of the time, a duct loss of 2.5% × energy collected was assumed and is reflected in all the thermal data in this report.

7.7 PARASITIC ENERGY

The system blower was the only parasitic energy required. It consumed 21,638 kWh (73.8×10^6 Btu) of energy or 8.97% of the energy utilized during the 12-month performance period.

8. CLEANING SYSTEM CONCEPTUAL DESIGN

8.1 GENERAL

As a result of the contamination problem prior to the start of Phase III, a task was included in the Phase III contract to examine cleaning systems and conduct a conceptual design. The objective of the task was to conceive a system that would minimize recurring panel cleaning cost while meeting an acceptable compromise between capital cost, reliability, degraded performance, and maintainability.

After several concepts were studied, a conceptual design was conducted on the most promising, and a prototype system was constructed and tested. A complete report on this activity is contained in Appendix II. Following is a summary of the activity.

8.2 DESIGN CRITERIA

To meet the objectives stated above, the following design criteria were established:

- Minimum shading by the mechanism
- Automatic operation
- Freeze protection
- Minimum moving parts and adjustments or alignment
- Minimum consumption of water, detergent, and electricity.

8.3 DESIGN CONCEPTS CONSIDERED

Figure 8-1 presents a summary and comparison of the concepts considered. The oscillating spray appeared to be the most promising of all concepts studied. Therefore, a pilot and a prototype system were constructed and tested.

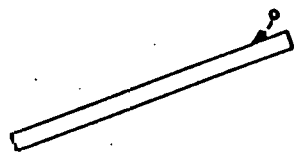
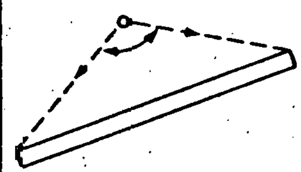
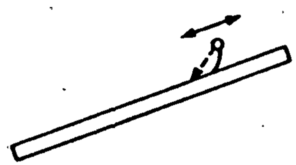
CONCEPT	PROBABLE CLEANING EFFECTIVENESS	RELATIVE COST	MAINTENANCE REQUIREMENTS
 FIXED SPRAY (FLOOD)	POOR - DIRECT IMPINGEMENT AT UPPER EDGE ONLY. FLOODING STREAMS SPLIT AS WATER PROGRESSES OVER GLAZING, LEAVING DRY AREAS.	VERY LOW - SIMPLE FIXED PIPING SYSTEM	VERY LOW - NO MOVING PARTS
 OSCILLATING SPRAY	GOOD - DIRECT IMPINGEMENT AND FLOODING ALONG FULL LENGTH OF GLAZING	LOW - MINIMAL MOVING PARTS	LOW - FEW SLOW MOVING PARTS. NO CRITICAL ALIGNMENT REQUIRED
 MOVING SQUEEGY WITH SPRAY	GOOD - DIRECT IMPINGEMENT AND SQUEEGY ACTION ALONG FULL LENGTH OF GLAZING	HIGH - COMPLEX ROLLERS, GUIDE RAILS AND DRIVE MECHANISM	HIGH - NUMEROUS MOVING PARTS; CRITICAL ALIGNMENT; SENSITIVE TO FREEZING CONDITIONS ON RAILS. SQUEEGY REPLACEMENT DUE TO WEAR AND BRITTLENESS.

FIGURE 8-1. CLEANING CONCEPT COMPARISON

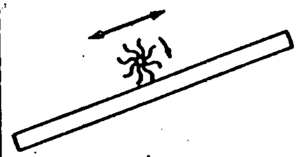
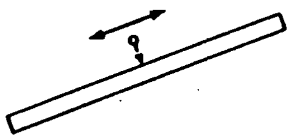
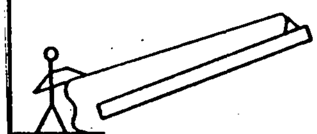
CONCEPT	PROBABLE CLEANING EFFECTIVENESS	RELATIVE COST	MAINTENANCE REQUIREMENTS
 ROTATING/MOVING BRUSH WITH SPRAY	EXCELLENT - BRUSHING ACTION OVER ENTIRE GLAZING	VERY HIGH - COMPLEX TRANSLATION AND ROTATION MECHANISM. DYNAMIC WATER SEALS REQUIRED	VERY HIGH - MOTION LIMIT ADJUSTMENTS CRITICAL; FREEZING OF BRUSH ELEMENTS; BRUSH WEAR AND REPLACEMENT; BRUSH PRESSURE ADJUSTMENTS
 MOVING SPRAY	GOOD - DIRECT WATER IMPINGEMENT OVER ENTIRE GLAZING SURFACE	HIGH - COMPLEX TRANSLATION MECHANISM. LONG, FLEXIBLE FEEDER TUBES	HIGH - MOTION LIMIT ADJUSTMENTS; CRITICAL ALIGNMENT: FREEZING OF WATER ON RAILS AND MECHANISM
 IMPROVED MANUAL (LONG SPRAY/BRUSH)	GOOD - BRUSH/SPRAY ACTION OVER ENTIRE GLAZING SURFACE	LOW INITIAL COST - SIMPLE FIXED PIPING SYSTEM HIGH LABOR COST - REQUIRES APPROXIMATELY 12 TO 14 MAN-HOURS EACH CLEANING	LOW - OCCASIONAL BRUSH REPLACEMENT

FIGURE 8-1 - Concluded

8.4 PROTOTYPE CLEANING SYSTEMS

To obtain a preliminary verification, a simple pilot model was constructed and tested. This consisted of an inverted lawn sprinkler, as shown in Figure 8-2. This pilot model covered four panels and consumed approximately 5 gpm (0.063 gpm/ft^2). After 2 weeks of operation, the cleaning effectiveness appeared excellent. As a result, it was decided to prepare a more elaborate system incorporating controlled soap injection and various jet sizes and spacings to determine the best combinations.

The following prototype detailed design criteria were established for the prototype system:

- Several test sections to evaluate different jet sizes and spacings
- An actuator with an adjustable stroke
- A variable soap injection system
- Sufficient line sizing to provide at least 65 psi pressure at a delivery rate of 25 gpm
- Manual control, without freeze protection
- Expandable to a full-scale system
- Minimum system cost.

The resulting system consisted of a 48-ft oscillating spray bar covering 32 collectors (16 pairs). The system was designed to be constructed from off-the-shelf hardware, requiring no special tooling. The system is shown in Figures 8-3 and 8-4.

8.5 TESTING AND RESULTS

The prototype system was tested under the following conditions:

- One-minute wash, one-minute rinse, twice daily (early morning and late afternoon)

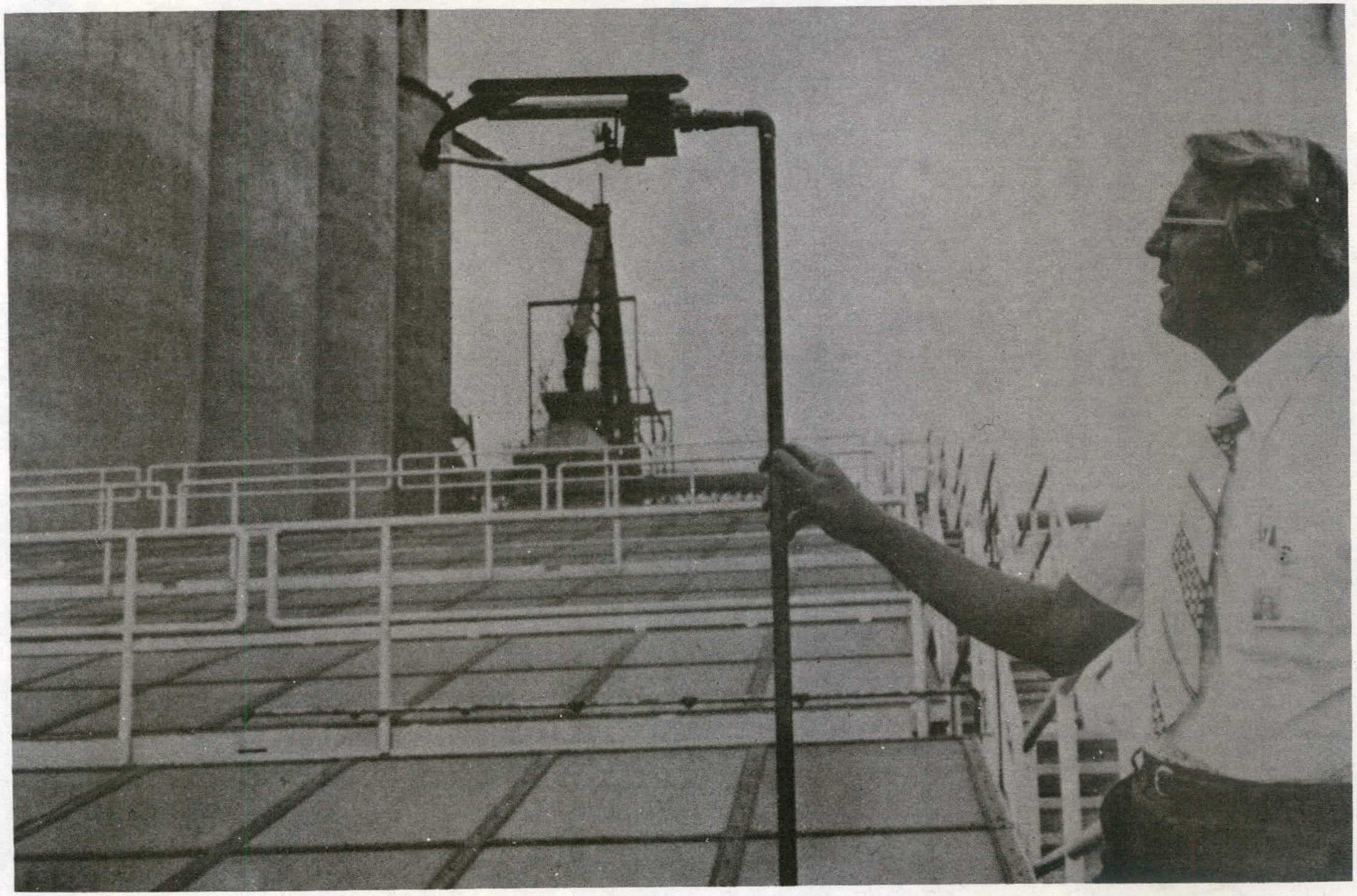


FIGURE 8-2. OSCILLATING SPRAY TEST SETUP

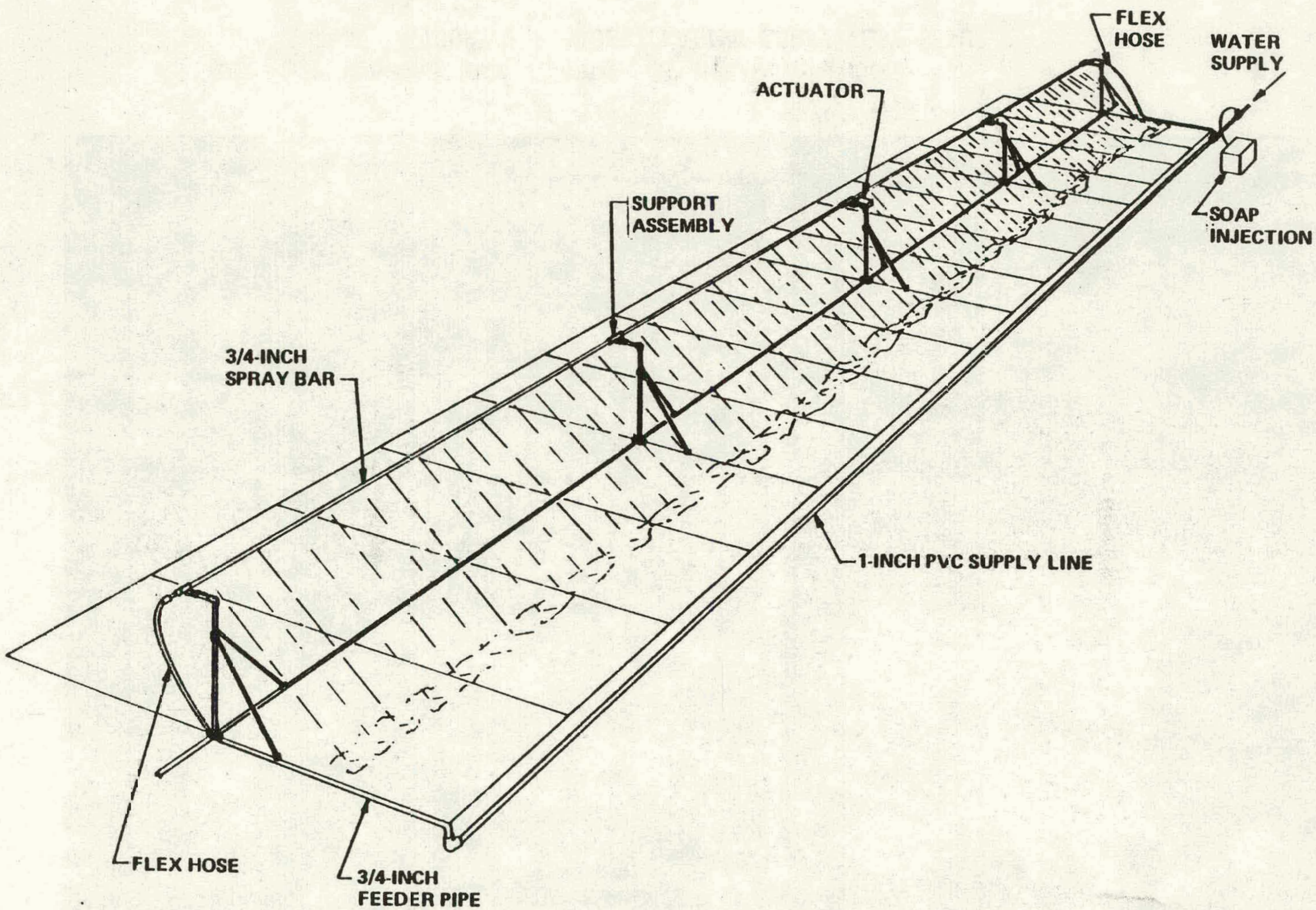


FIGURE 8-3. PROTOTYPE CLEANING SYSTEM

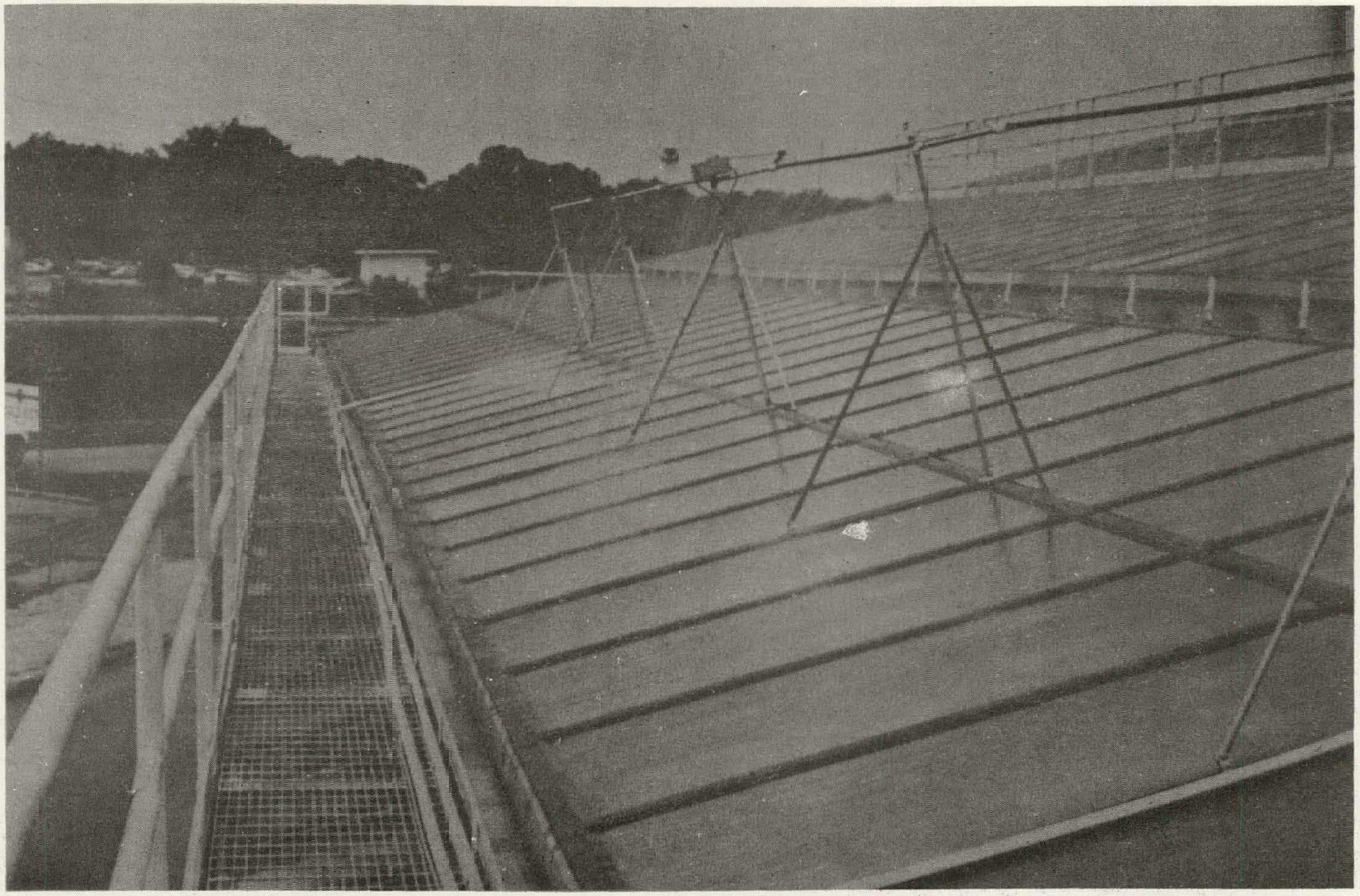


FIGURE 8-4. PROTOTYPE CLEANING SYSTEM TESTING

- Two-minute rinse only (no soap), twice daily
- One-minute rinse only, once daily (early morning).

Several types and quantities of detergent were tested, and no discernible difference was detected.

The most effective/economical cycle appeared to be the 1-minute rinse only, in the early morning. This procedure removed the contaminate prior to extended exposure to ultraviolet.

The most effective jet sizing and spacing was the 0.037-in. jet spaced at 4-in. intervals. The flow in this section was 0.055 gpm/ft^2.

8.6 SYSTEM BUDGETARY COST

A budgetary cost estimate resulted in the following completely automated system cost:

- Including engineering - \$2.36/ft^2
- Excluding engineering - \$1.59/ft^2.

It should be noted that considerable savings could be realized if the mechanical fabrication and installation were conducted by Gold Kist personnel.

Based on a 10% overall performance improvement, the system would increase current annual fuel savings by \$317. The experienced manual cleaning costs were \$785/year. The combination of these two is an estimated \$1,102 annual economic improvement assuming approximately equal amounts of water are consumed by either method of cleaning.

9. EMISSION CONTROL EVALUATION

9.1 BACKGROUND

Even before construction of the solar array was complete, it was apparent that contamination of the collector glazings by particulate emissions from the plant would degrade performance. As a result, DOE authorized a study to identify emission sources and potentially suitable suppression techniques. The complete report on this activity, conducted jointly by TBE and Gold Kist, Inc., is contained in Appendix III. A summary of the findings and results is presented here.

9.2 EMISSION SOURCES

The three sources of air pollution in a soybean processing plant are:

- Soybean receiving, handling, and drying operations
- Soybean processing operations
- Soybean meal loadout operations.

Table 9-1 presents the more significant potential sources in each category.

9.3 EMISSION SURVEY AND IDENTIFICATION

On July 24, 1978, the information contained in the air quality permit applications for each emission source was verified by inspection. Each source has been issued an air quality permit by the Tri-Counties Health Department. Each emission source and its type of control device are listed in Table 9-2. It was also observed that the bean dryers may emit some particulate matter in the area of the solar power.

Certain other fugitive sources may also be influencing the collector contamination. These are:

- Conveyers under the bean dryers (when covers are loose)
- Overhead conveyer No. D-27
- Bean conveyer from storage to preparation.

TABLE 9-1. POTENTIAL SOURCES OF AIR POLLUTANTS IN SOYBEAN PROCESSING PLANTS

• Grain Receiving, Cleaning, Drying, and Storage	
Grain Unloading	Trippers, Conveyor Transfer Points
Elevator Leg Vents	Grain Cleaner
Corner and Side Vents	Grain Dryer
• Soybean Processing	
Cracking Rolls	Desolventizer-Toaster
Dehulling System	Meal Dryer
Hull Toaster	Meal Cooler
Hull Grinding	Meal Grinder
Bean Conditioner	Solvent Vapor Recovery System
Flaking Mills	
• Product Shipping	
Meal Loadout	

TABLE 9-2. PRIMARY EMISSION SOURCES,
DECATUR OIL PRODUCTS FACILITY
DECATUR, ALABAMA

SOURCE PERMIT NUMBER	DESCRIPTION	TYPE OF CONTROL DEVICE
Z001	Bean Receiving, Storage, Conveying; Truck, Rail, Barge Loadout	Fabric Filter
Z002	Bean Scalper, Screener, Hammer Mill	Fabric Filter
Z003	Preparation Screener 52EC	High Efficiency Cyclone
Z004	Cracking Operation	High Efficiency Cyclone
Z005	Dehulling Operation, Separator, Cleaners, Aspirators	Fabric Filter High Efficiency Cyclones
Z006	Flaking Operation	High Efficiency Cyclones
Z007	Meal Drying/Meal Cooling	Fabric Filter
Z008	Meal Sifters/Grinders	Fabric Filter
Z009	Meal Handling/Transfer	Fabric Filter
Z010	Bean Drying	Perforated Column Plates
Z011	Toasted Hull/Grinders	High Efficiency Cyclone

Evidence of oily material on the panels was observed. The sources of this material were not clearly apparent; however, they probably are generated at process points where physical or chemical changes to the soybean occur.

All emission abatement devices were performing within the limits required by local and state authorities.

10. ECONOMIC ANALYSIS

The economic assessment of the solar system involves comparing conventional life-cycle fuel cost with the additional first cost of the solar drying systems and its impact on operating costs. The actual installed cost of the solar system was $575,384. Because of the limited space available at Gold Kist, the array had to be supported on a massive steel structure erected over an existing parking lot. Since the solar system has potential for industrial sites that do not have this limitation, 80% of the cost of this structure is removed for this analysis. The cost assumed for this study is $405,615.

Since system utilization was only 54.6%, the annual energy savings used in the study was increased to a value corresponding to 95% system utilization or $1,430 \times 10^6$ Btu. Likewise, the actual maintenance and operating cost was increased to an estimated value of $3,257.

The system performance at Decatur lies between that for Albuquerque and Omaha. The net results is a life-cycle cost estimate of $48.10 per million Btu of solar energy.

This section presents detailed cost data, calculations, and comparisons. The technique used follows the prescribed guidelines contained in the Lawrence Livermore Laboratory document "Method of Economic Analysis for Comparison of Solar Process Heat Systems", revised August 1, 1976.

INPUT PARAMETERS AND ASSUMPTIONS

1. Total Annual Energy Requirements:

Albuquerque	55,050 MBtu
Omaha	59,680 MBtu
Decatur	58,140 MBtu

2. Energy Delivered by Solar Facility and Percentage of Total:

Albuquerque	1,629 MBtu	3.0%
Omaha	1,321 MBtu	2.2%
Decatur	1,430 MBtu	2.5%

3. Installed Cost of Solar Facility (see page 10-3): $405,615
4. Useful Life of Solar Facility and Dryers: 20 years
5. Depreciation Method: Straight Line
6. Estimate Cost for Operation, Maintenance, Replacement Parts, and Insurance (OMRI) of Solar Facility (see page 10-4): $3,257
7. Combined Income Tax Rate: 50% (actual: $0)
8. Investment Tax Credit: 10% (actual: $0)
9. Inflation Rate: Zero
10. After-Tax Rate of Return on Investment: 10%
11. Delivered Cost of Fuel Oil: $15/bbl
12. Fuel Heating Value: 5.8 MBtu/bbl
13. Dryer OMRI (see page 16-5): $12,000
14. Fuel Oil Conversion Efficiency: 70%
15. Salvage Value of Solar Facility and Dryers: Zero
16. System Utilization: 95% (actual: 54.6%)
17. Reduced Actual Structure, Foundation, and Site-Work Cost by 80%.
18. Electricity Cost: $0.03/kWh
19. Assume no Property Tax (actual anticipated: $3,176)
20. Assume Labor Cost is $15/hr (actual: $6.95)
21. Assume no Insurance Cost (actual anticipated: $324)

DETAILED INVESTMENT COST BREAKDOWN (WITH REDUCED STRUCTURE)

Collector Array		$190,500
Panels (672)	$168,500	
Installation and Assembly	22,000	
Supporting Structure		34,728
Site Preparation		3,892
Foundations		4,840
Ducting		94,275
Major Mechanical/Electrical Material		14,840
Miscellaneous Mechanical Components		20,959
Electrical System		22,581
Instrumentation and Controls Modifications		6,000
Startup and Checkout		13,000
TOTAL		$405,615

ANNUAL COSTS OF OWNERSHIP, OPERATION, MAINTENANCE, AND REPLACEMENTS (OMRI) (ASSUMING 95% SYSTEM UTILIZATION)

Solar Facility

Labor: 105 man-hours @ $15/mhr	$1,575
Electricity: 37,580 kWh @ .030/kWh	$1,127
Replacement Parts:	555
	$3,257

Ferrell-Ross Dryer

Assumed Costs: $0.20/MBtu × 60,000 MBtu = $12,000

Actual Costs:

Capital Recovery (0.11746 × $125,000)	$14,684
Property Taxes (0.783/100 × $125,000)	978
Replacement Parts	610
Labor (416 man-hours × $6.92/hr)	2,878
Electricity (2,160,000 kWh × $0.018/kWh)	38,880
Insurance ($0.08/100 × $125,000)	100
	$58,130

PLAN A - ANNUAL ENERGY COST

CONVENTIONAL FUEL ONLY

	ALBUQUERQUE		OMAHA	
Cost of Fuel Oil Energy		$203,388		$220,494
Dryer Operation and Maintenance		12,000		12,000
Deductible Expenses:				
Fuel Cost	$203,388		$220,494	
Dryer	12,000		12,000	
	$215,388		$232,494	
Income Tax Deduction		($107,694)		($116,247)
After-Tax Cost		$107,694		$116,247
Before-Tax Cost		$215,388		$232,494
UNIT COST PER MBtu	$\frac{\$215,388}{55,050}$	= $3.91	$\frac{\$232,494}{59,680}$	= $3.90

PLAN B - ANNUAL ENERGY COST
CONVENTIONAL FUEL + SOLAR

	ALBUQUERQUE		OMAHA	
Repayment to Equity for Solar Facility		$ 47,643		$ 47,643
Investment Tax Credit		(4,764)		(4,764)
Cost of Fuel Oil Energy		197,368		215,612
Dryer OMRI		12,000		12,000
Solar Facility OMRI		3,257		3,257
Deductible Expenses:				
Fuel Cost	$138,158		$150,928	
Dryer OMRI	12,000		12,000	
Solar OMRI	3,257		3,257	
Depreciation	20,281		20,281	
	$232,906		$251,150	
Income Tax Deduction		(116,453)		(125,575)
After-Tax Cost		139,051		148,173
Before-Tax Cost		278,102		296,346
UNIT COST PER MBtu	$\frac{\$278,102}{55,050}$ =	$5.05	$\frac{\$296,346}{59,680}$ =	$4.97

ANNUAL COST OF SOLAR ENERGY ALONE

Repayment to Equity		$47,643
Investment Tax Credit		(4,764)
OMRI		3,257
Deductible Expenses:		
OMRI	$ 3,257	
Depreciation	20,281	
	$23,538	
Income Tax Deduction		($11,769)
After-Tax Cost		34,367
Before-Tax Cost		68,734

	ALBUQUERQUE	OMAHA
UNIT COST PER MBtu	$\frac{\$68,734}{1,629} = \$42.19$	$\frac{\$68,734}{1,321} = \$52.03$

PAYBACK PERIOD FOR PLAN B

	ALBUQUERQUE	OMAHA
Percentage of Energy Supplied by Solar Facility	3.0	2.2
Plan A Fuel Cost	$203,388	$220,494
Value of Fuel Saved	6,020	4,882
Solar OMRI	3,257	3,257
Annual Cash Savings	2,763	1,625
Added Income Before Tax	(17,518)	(18,656)
Added Income Tax	(8,759)	(9,328)
Net Incremental Cash Flow	11,522	10,953
Payback Period	35.2 yr	37.0 yr

ANNUAL COSTS AT DECATUR

Conventional Fuel + Solar

Repayment to Equity	$ 47,643
Investment Tax Credit	(4,764)
Cost of Fuel Oil Energy	207,479
Dryer OMRI	12,000
Solar Facility OMRI	3,257

Deductible Expenses:

Fuel Cost	$207,478
Dryer OMRI	12,000
Solar OMRI	3,257
Depreciation	20,281
	$243,016

Income Tax Deduction:	($121,508)
After Tax Cost	144,107
Before Tax Cost	288,214

UNIT COST PER MBtu $\frac{\$288,214}{58,140} = \underline{\underline{\$4.96}}$

Solar Alone

Before Tax Cost (from page 16-8): $68,734

Energy Delivered: 1,429 MBtu

UNIT COST PER MBtu $\frac{\$\ 68,734}{1,429} = \underline{\underline{\$48.10}}$

APPENDIX A. TBE TECHNICAL REPORT SYSTEM VERIFICATION PLAN

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

TECHNICAL REPORT
SD78-DOE-2225

SOLAR DRYING OF SOYBEANS
SYSTEM VERIFICATION PLAN

By

G. R. Guinn, Ph.D.

June 1978

Prepared For

DEPARTMENT OF ENERGY
WASHINGTON, D.C.

Contract No. DOE EY-76-C-05-5122

Prepared By

SYSTEMS DIVISION
TELEDYNE BROWN ENGINEERING
HUNTSVILLE, ALABAMA

ABSTRACT

This report presents the verification plan for a solar energy system used to augment the conventional dryers of a soybean processing plant. The project is funded under the Department of Energy's Solar Demonstration Program for Agricultural and Industrial Process Heat. The 1,215 m^2 (13,104 ft^2) of collection area are expected to supply about 3.9 TJ/yr (3.7×10^9 Btu/hr), representing about 25,000 gal of No. 5 fuel oil currently used in the drying operations. The system is to be operated for 1 year by Gold Kist, Inc., of Decatur, Alabama, as a part of the drying operations required for storing or processing soybeans for oil extraction. Instrumented and noninstrumented data will be acquired, processed, and analyzed to verify and evaluate system operational and technical features. Results will be issued in monthly reports.

Prepared By:

G. R. Guinn

G. R. Guinn, Ph.D.
Program Manager

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS - Concluded

LIST OF TABLES

1. INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

A major objective of the Department of Energy's (DOE's) Industrial Process Heat Program is to verify and evaluate the technical and operational performance of solar thermal energy systems for process drying. For this purpose, a demonstration system using air collectors has been constructed at the Gold Kist Soy plant in Decatur, Alabama. The system is designed to temper the combustion air of conventional dryers used to dry soybeans prior to storage and as a first step in the extraction process.

Construction of the solar facility and data acquisition has been completed and operational status has been achieved. The system will be operated and maintained for 1 year by Gold Kist as a part of their drying operations. Operational and technical data will be acquired, analyzed, evaluated, and reported by Teledyne Brown Engineering (TBE). In this System Verification Plan, the procedures for achieving these objectives are described in detail. This report is prepared under sponsorship of the Department of Energy under Contract No. DOE-E-(40-1)-5122.

1.2 SUMMARY

This System Verification Plan encompasses a complete description of the hardware systems, software systems, and methods of analyses to be used in evaluating operational and technical performance. Operation and maintenance responsibilities for the solar energy system are assigned to Gold Kist and the data acquisition system to Teledyne Brown Engineering.

The data base to be developed consists of noninstrumented data and instrumented data. The noninstrumented data consist of operator logs and carefully prepared forms to report operational and maintenance events and corrective procedures undertaken. Instrumented data consist of measurements designed to evaluate technical performance. The requirements for the instrumented data are based as closely as possible to those that have been defined for the National Solar Heating and Cooling Demonstration Program.

The instrumented data will be analyzed to provide parameters that indicate system performance and operational condition. The data will be presented in monthly reports that provide daily, monthly, and monthly cumulative total and average values.

2. SYSTEM DESCRIPTION

The Solar Drying System (SDS) is an air-based concept designed to collect and transfer solar energy to augment a conventional soybean drying process. The system consists of the following principal subsystems:

- Collectors
- Energy transport
- Structure
- Controls subsystem
- Cleaning subsystem.

Additionally, an instrumentation, monitoring, and processing subsystem is included in support of the experimental nature of the program.

2.1 SOLAR DRYING SYSTEM

The Solar Drying System is shown schematically in Figure 2-1. Although solar energy systems typically employ storage to supply energy at night or during cloudy days, none was incorporated in the selected system approach because all the energy potentially collectable could be used immediately in the existing drying operations.

2.1.1 Collector Subsystem

The collector subsystem consists of 672 Solaron collectors arranged in 84 sets of 8 modules encompassing 4 two-in-series pairs of collectors. The layout of the four paired collectors is shown in Figure 2-2. The collector array is tilted at 15 deg and pointed 24 deg east of south.

The collectors are 0.914 m (3.0 ft) wide by 1.98 m (6.5 ft) long by 0.18 m (7 in.) deep. The design employs one glass cover 3.175×10^{-3} m thick and a nonselective absorber surface ($\alpha/\varepsilon \approx 1$). Figure 2-3 illustrates the collector.

The design flow rate is 0.0102 m/sec (2 $ft^3/min/ft^2$) based on gross collector area. Since each of the collectors has a gross area of 1.81 m^2 (19.5 ft^2), the design flow rate for the SDS is about 12.4 m^3/sec

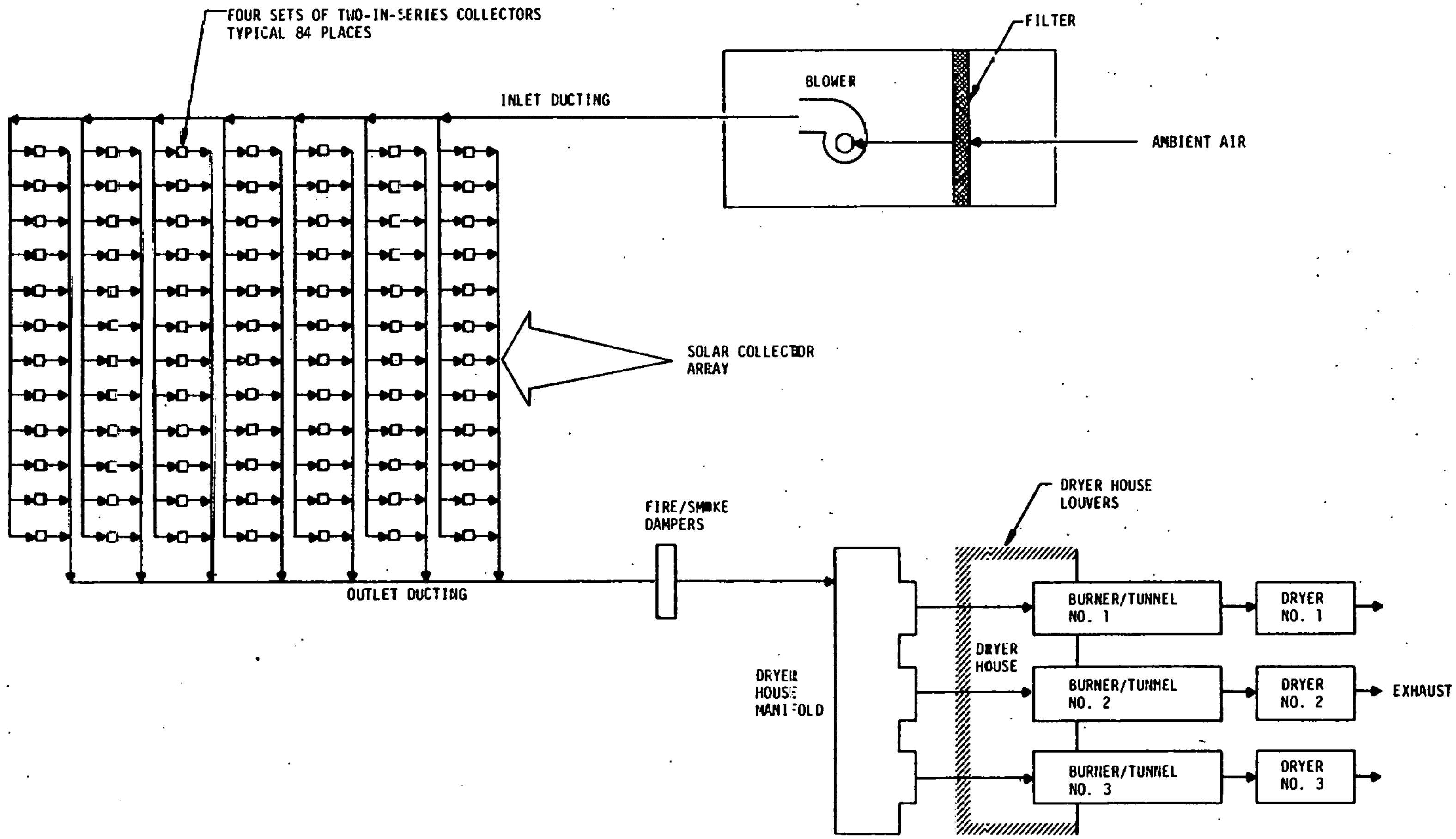


FIGURE 2-1. SCHEMATIC OF SOLAR DRYING SYSTEM

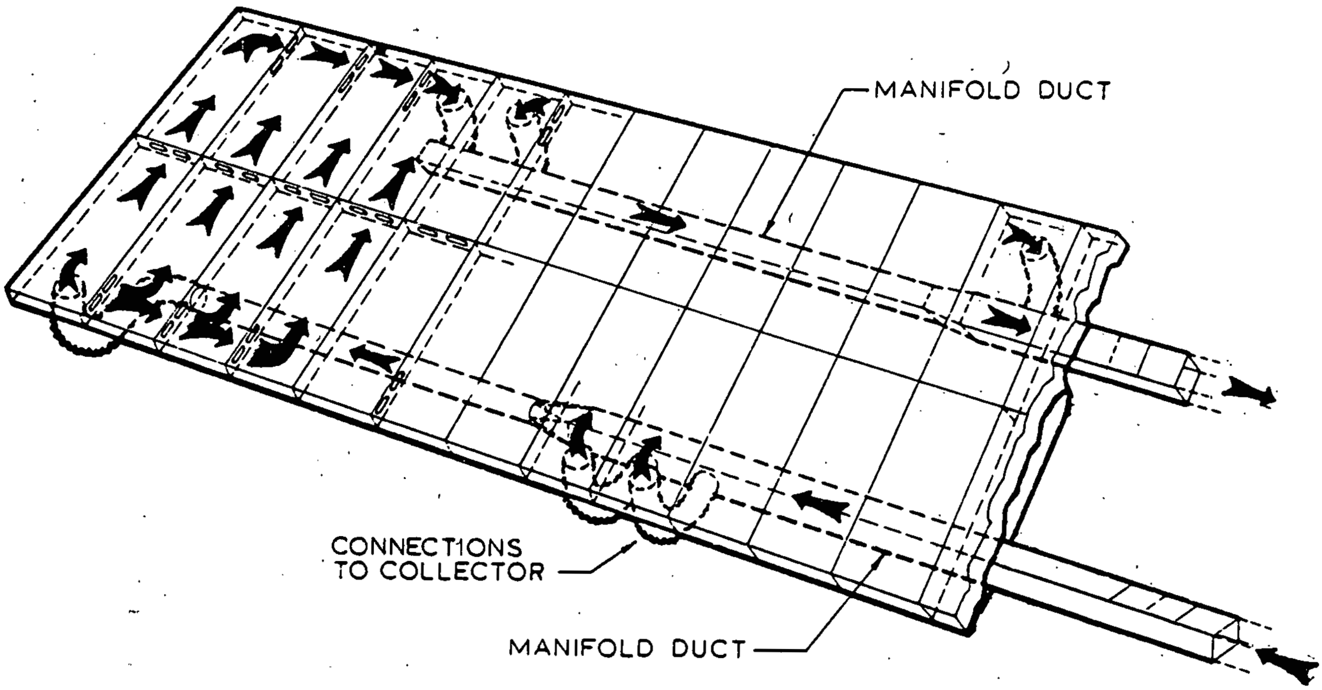
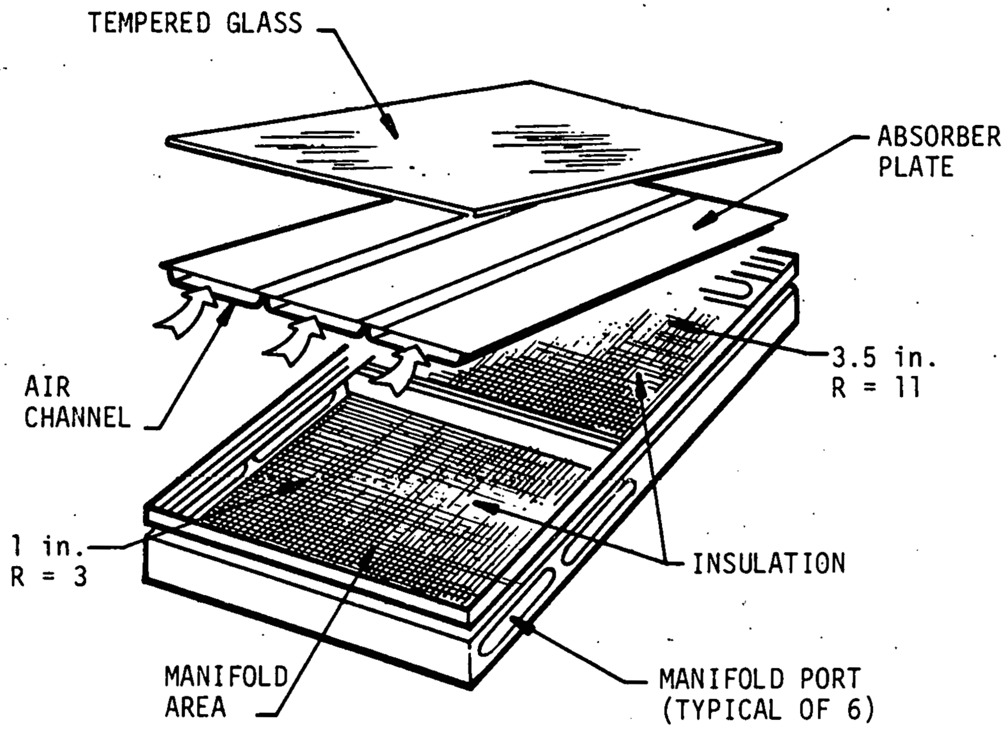


FIGURE 2-2. COLLECTOR INSTALLATION PATTERN



PANEL DIMENSIONS: 3 ft WIDE BY 6 ft 6 in. LONG by 7.25 in. HIGH

NOTE: AIR FLOWS THROUGH THE CHANNELS BENEATH THE ABSORBER PLATE.

FIGURE 2-3. COLLECTOR

(26,300 ft^3/min). The 4 two-in-series pattern or module used in the collector array requires 16 collector-to-collector joints (in pairs). The collector porting arrangement is illustrated in Figure 2-3. These joints are sealed with butyl tape.

The modules consisting of eight collectors each have a pressure loss of about 57.2 Pa (0.23 in. H_2O) at the 0.0102-m/sec (2-ft^3/min/ft^2) volumetric flow rate.

2.1.2 <u>Energy Transport System</u>

The energy transport system distributes the ambient air to the solar collectors and transfers the solar-heated air to the conventional drying process. The principal components of the subsystem are:

- Air filter
- Blower
- Inlet ducting
- Outlet ducting
- Dryer house manifold
- Fire dampers.

The relative locations of these components correspond to the schematic of Figure 2-1.

An air filter is used in the system for two reasons. First, the immediate environment of grain elevators and feed mills tends to be dusty and the ingestion of dust into the system could cause maintenance and operation problems that can be minimized by using a filter at the inlet. However, the filters also serve an important safety function by limiting the amount of dust that will enter the system and present the potential for supporting combustion in the event of a fire in or near the system.

The filter and blower are housed together as a prepackaged unit, which is a Trane Company Model PCC No. 50 "Penthouse Climate Charger" unit without coils. This unit has a roll-type automatic filter with a rated overall efficiency of 85% at a face velocity of 2.54 m/sec (500 ft/min) and a rated dust loading of 4.31 kg/m^2 (400 g/ft^2). The blower in the assembly is a forward-curved type with a rating of 13 m^3/sec (27,000 ft^3/min) at 746.4 Pa (3 in. H_2O). All equipment in the assembly meets the requirements for a Class II, Division II, Group G location. The technical rating of the air handler is summarized in Table 2-1.

TABLE 2-1. SUMMARY OF AIR HANDLER RATINGS

RATING

- 13 m/sec (27,000 ft^3/min) at 746.4 Pa (3.0 in. WG external)
- Fan: 586 rpm
- Motor: 30 hp/480 V/3 phase

INTERNAL LOSSES AT RATING

- Inlet hood/moisture/eliminator: 50 Pa (0.2 in. WG)
- Filter: 75 Pa (0.3 in. WG)
- Allowance (dirt load): 50 Pa (0.3 in. WG)

The inlet ducting (Figure 2-1) provides for the delivery of filtered air to the solar collector. This ducting was designed for a pressure loss of 0.571 Pa/m of duct length (0.07 in. H_2O/100 ft) and maximum air velocities on the order of 10.16 m/sec (2,000 ft/min).

Rectangular ducts are employed for trunks and branch lines to simplify the duct inspection and maintenance tasks since the bottoms of the runs can be in the same planes despite area changes. The takeoffs are 0.254-m (10-in.) round, semirigid aluminum ducts with galvanized "spin-in" type connections. Each of these inlet takeoffs has an integral (vane-type) damper for flow balancing.

The inlet ducting is not insulated since the air temperature in the ducts will be only slightly above the ambient temperature.

The outlet ducting, in effect, recombines the individual collector flows and provides for the transfer of the collected energy to the manifold that feeds the conventional dryers. The same design criteria used for the inlet ducting have been employed for the outlet ducting and the systems are physically similar. The major exceptions are that the outlet ducting is insulated (Table 2-2) and there are no dampers in the collector-to-duct takeoffs.

TABLE 2-2. SUMMARY OF DUCT CONSTRUCTION

SIZE	TYPE	MATERIAL	STRUCTURAL: TRANSVERSE SUPPORT	STRUCTURAL: DUCT SUPPORT	CONNECTION	INSULATION HOT DUCTS ONLY	JOINT SEAL
10 in.	Round/Flex	Aluminum	Support only 4 ft or longer horizontal runs		Manufactured "Spin In"	All hot ducts: 2-in. Owens-Corning	All joints: Hard cast tape sealed
12 by 24 in.		24G galvanized	48 in. 1 by 1 by 0.125 Angle	$\leq$12 ft 0.5-in. rod	1-in. Pocket Lock	Rectangular: Type #705/board back, 6 1/4 # density	
24 by 24 in.		24G galvanized	48 in. 1 by 1 by 0.125 Angle	$\leq$12 ft 0.5-in. rod	1-in. Pocket Lock	10-in. round: Owens-Corning type ASJ #25	
40 by 24 in.	Rectangular	22G galvanized	36 in. 1 by 1 by 0.125 Angle	$\leq$6 ft 0.5-in. rod	1.5-in. Pocket Lock		
48 by 24 in. 48 by 31 in. 48 by 48 in.		20G galvanized	24 in. 2 by 2 by 0.125 Angle	$\leq$6 ft 0.5-in. rod	1.5-in. Pocket Lock with 1.5 by 1.5 by 0.125 Angle Reinforcement		

The dryer house manifold, as shown in Figure 2-4, provides the interface between the SDS and the conventional drying processes. It is a 1.22- by 1.22-m duct that has six 0.61- by 1.22-m openings on the lower side with short extensions extending through the face of the louvers. The six openings are placed such that there are two at each dryer position. These openings contain baffle-type outlet dampers such that any one dryer or combination of dryers can receive the solar-heated air.

Induced draft of the dryer blowers (70 m^3/sec or 150,000 ft^3/min per dryer) is used to entrain the incoming solar-heated air. The physical principle involved is that the greater momentum of the induced draft from the dryer blower will entrain the smaller solar-heated flow with no significant influence on the net dryer flow.

2.1.3 Structural Subsystem

The structural subsystem for the SDS serves primarily to support the collector array above the parking lot at the Gold Kist plant. This must be done in such a way as to not interfere with the Gold Kist operations. In general, the noninterference requirement is that the low point of any structure has a grade clearance of 5.03 m (16.5 ft). However, the parking lot has a rise of about 1.0 m (3 ft) in the south-to-north direction and the clearance requirement is relaxed at the north end of the assembly to 4.11 m (13.5 ft). The 5.03-m requirement provides clearance for tractor-trailer type vehicles. The total structural area is 45.7 m (150 ft) by 36.6 m (120 ft) or 1,672.3 m^2 (18,000 ft^2).

2.1.4 Control Subsystem

The control subsystem, shown schematically in Figure 2-5, provides the following functions:

- Key-operated master switch
- Push-button manual blower control
- Smoke sensing at the blower discharge, outlet ducting at the north edge of the collector assembly and at the fire damper location; automatic blower shutdown if smoke is sensed at any location

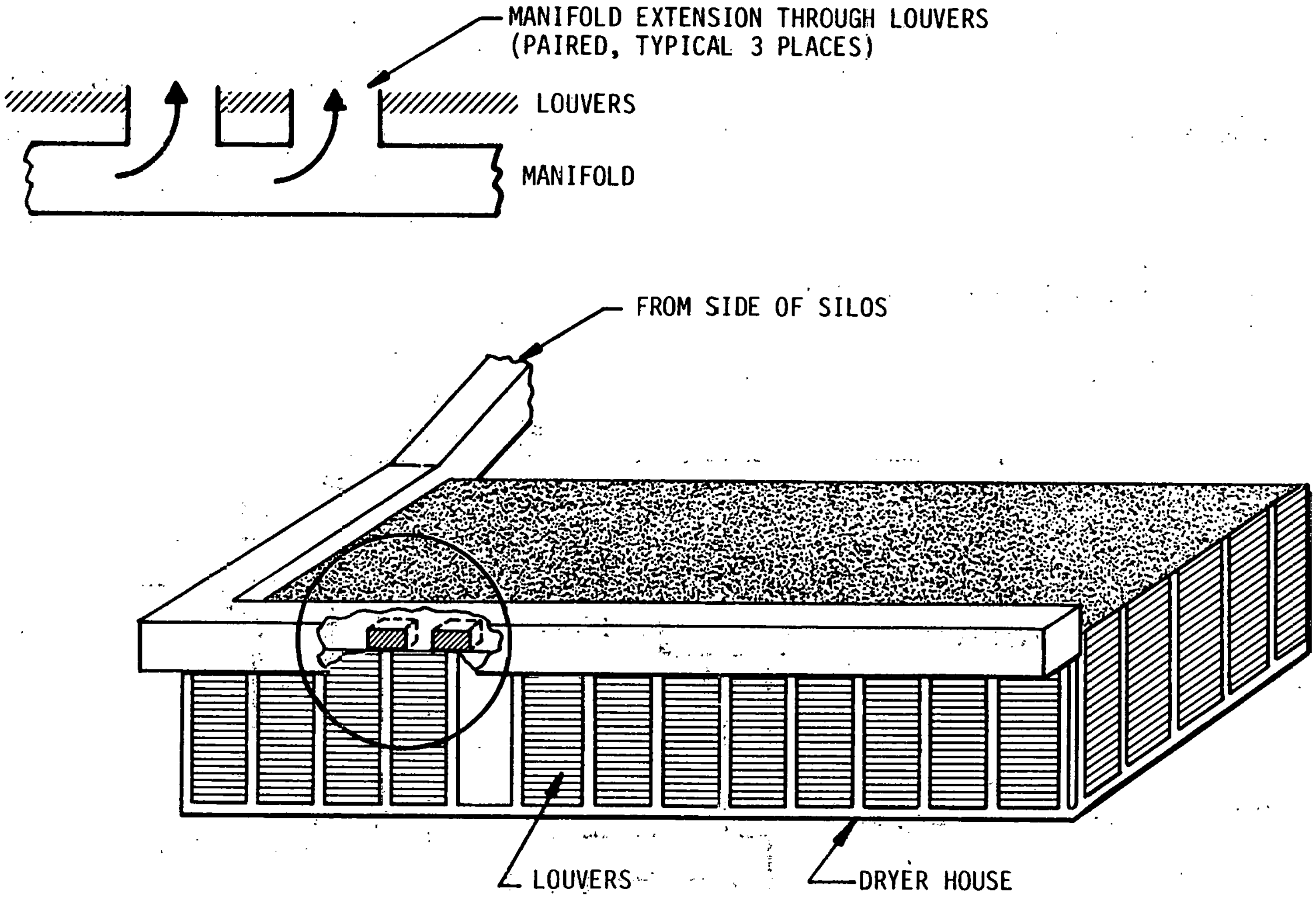
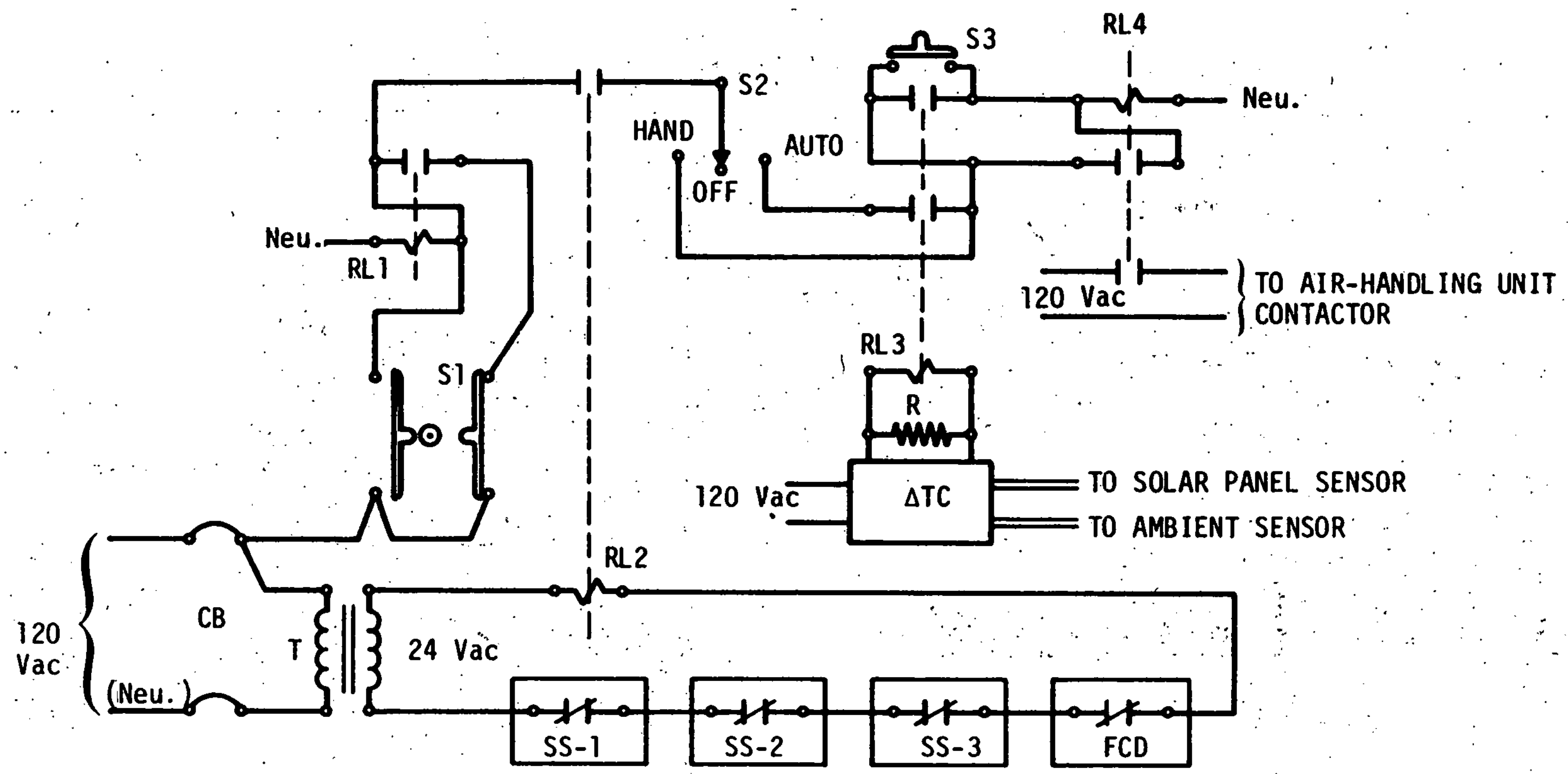


FIGURE 2-4. DRYER HOUSE MANIFOLD



CB L/C PANEL, CIR. NO. 1

S1 KEY SWITCH, MOMENTARY, 120 Vac, 10 A

S2 SELECTOR SWITCH, 3 POSITION, 120 Vac, 10 A

S3 PUSH-BUTTON SWITCH, MOM., SPST, N.O., 120 Vac, 10 A

R RESISTOR, 250 ohms, 150 W

RL1, RL2 RELAY, 120 Vac, SPST, N.O., 10 A

RL3, RL4 RELAY, 120 Vac, SPDT, N.O., 10 A

FCD FIRE/SMOKE DAMPER, AIRSTREAM NO. PEB-802/SST ACTUATOR/225-deg LINK

SS SMOKE SENSOR, HONEYWELL TC-100

T TRANSFORMER, 120/24 Vac

ΔTC DIFFERENTIAL THERMOSTAT CONTROLLER, SOLARON HW0070, WITH SENSORS

FIGURE 2-5. SOLAR DRYING SYSTEM CONTROL SCHEMATIC

- Automatic operation whereby the blower turns on when the collector temperature exceeds ambient by 22.2°C (40°F) and turns off when this threshold falls below 11.11°C (20°F).

The principal function of the smoke/fire damper is to provide isolation of the SDS and the dryer house, particularly in the direction of the airflow. Three smoke sensors (Figure 2-6) are employed. The sensors at the blower, collector outlet, and damper provide protection to the collectors (upstream events), dryer house (upstream events), and collectors/blowers/filter/ducting (downstream events), respectively.

A layout of the control room is shown in Figure 2-7.

2.1.5 Cleaning Subsystem

The dispensing and cleaning system consists of a 3-hp pump located in the Gold Kist break house, a mixer attached to the pump, piping from the pump to the top of the solar array, a manifold along the east handrail which contains four quick disconnects, a 42.4-m (139-ft) hose with a disconnect attached to one end, and a 3.048-m (10-ft) dispensing wand attached to the other end. In one pass across the array, the operator sprays detergent onto the glazing that penetrates, softens, and lifts deposits. On the return pass, water is used to flush away the detergent and the soil. Selection of water or detergent is accomplished by rotating into place nozzles located on a rollover valve at the end of the wand. A pressure-sensitive switch at the mixer senses the change in flow resistance and provides, accordingly, pure water or detergent at the proper dilution ratio. Manual brushing is used to enhance mechanical removal of deposits.

Two different cleaning chemicals may be selected. These are manufactured by Cerfact Laboratories of Tucker, Georgia, and have the trade names CERFOX and POLI-CERF. They are nontoxic, biodegradable, nonstreaking, and contain no harsh alkalines.

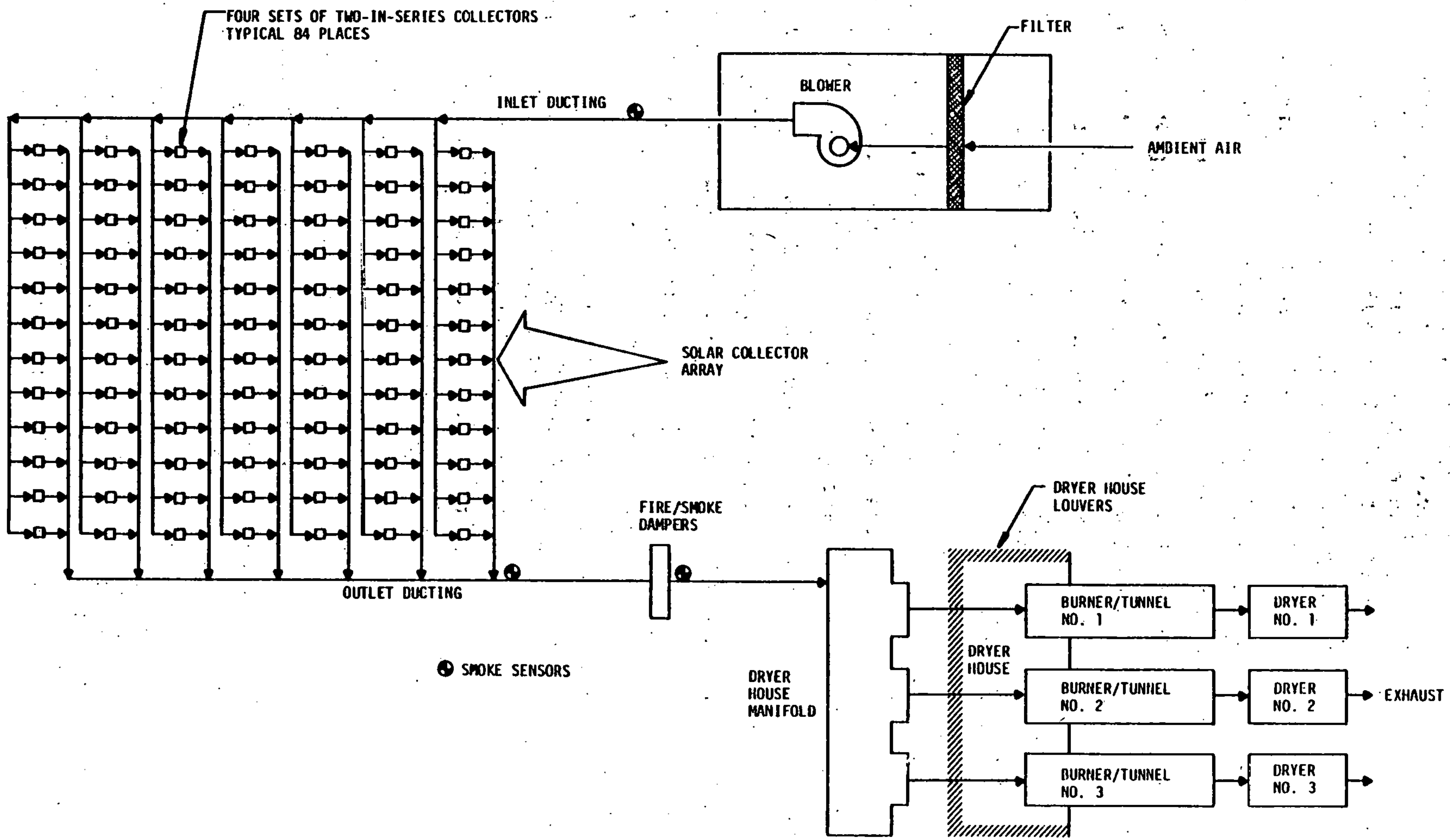


FIGURE 2-6. SMOKE SENSOR LOCATIONS

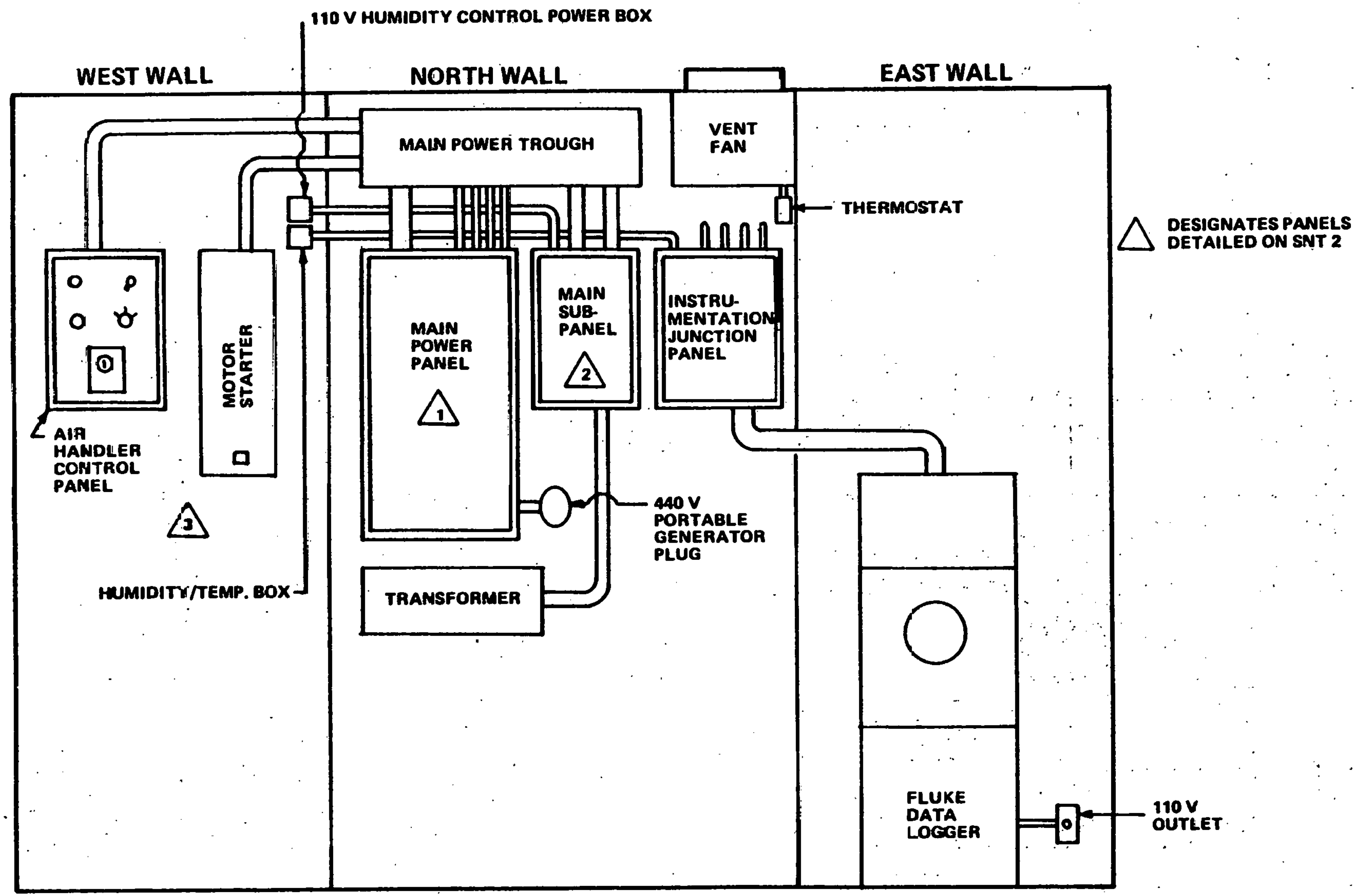


FIGURE 2-7. SOLAR SYSTEM CONTROL ROOM

POLI-CERF is a mild detergent that contains a surface-active ingredient that deposits a mono-molecular film that acts as a polish and soil barrier. POLI-CERF is used for routine washing of the collectors, and each application removes the previous film. CERFOX is an acidic detergent. It is used only when excessive soil buildup occurs.

2.2 INSTRUMENTATION MONITORING AND PROCESSING SYSTEM

The Instrumentation Monitoring and Processing System is illustrated schematically in Figure 2-8. It is composed of four major functional elements:

- Data Acquisition Unit (DAU)
- Sensors
- Sensor interconnection cables, grounding, and installation hardware
- Central Data Processing System (CDPS).

The sensors are interfaced to the DAU through the instrumentation junction box. The DAU is a commercial 2240A Fluke data logger with supporting peripheral equipment. The sensor data are processed, printed, and displayed. The printed and displayed data are used for on-site test and evaluation of the SDS. The recorded paper tape is hand-carried to TBE's central data processing facility for computation of performance and efficiency parameters and for further analysis. The various subsystems are discussed in greater detail in subsequent paragraphs.

2.2.1 Data Acquisition Unit

A Fluke Model 2240A data logger performs all of the DAU tasks required in this system. It can easily be expanded to handle more channel capacity and different sensor types. Figure 2-9 illustrates the DAU and its location in the control house. The data logging system embodies the following features:

- Complete interactive keyboard programming of range, function, skip, and limits
- Resolution of 1 μV and 1 deg

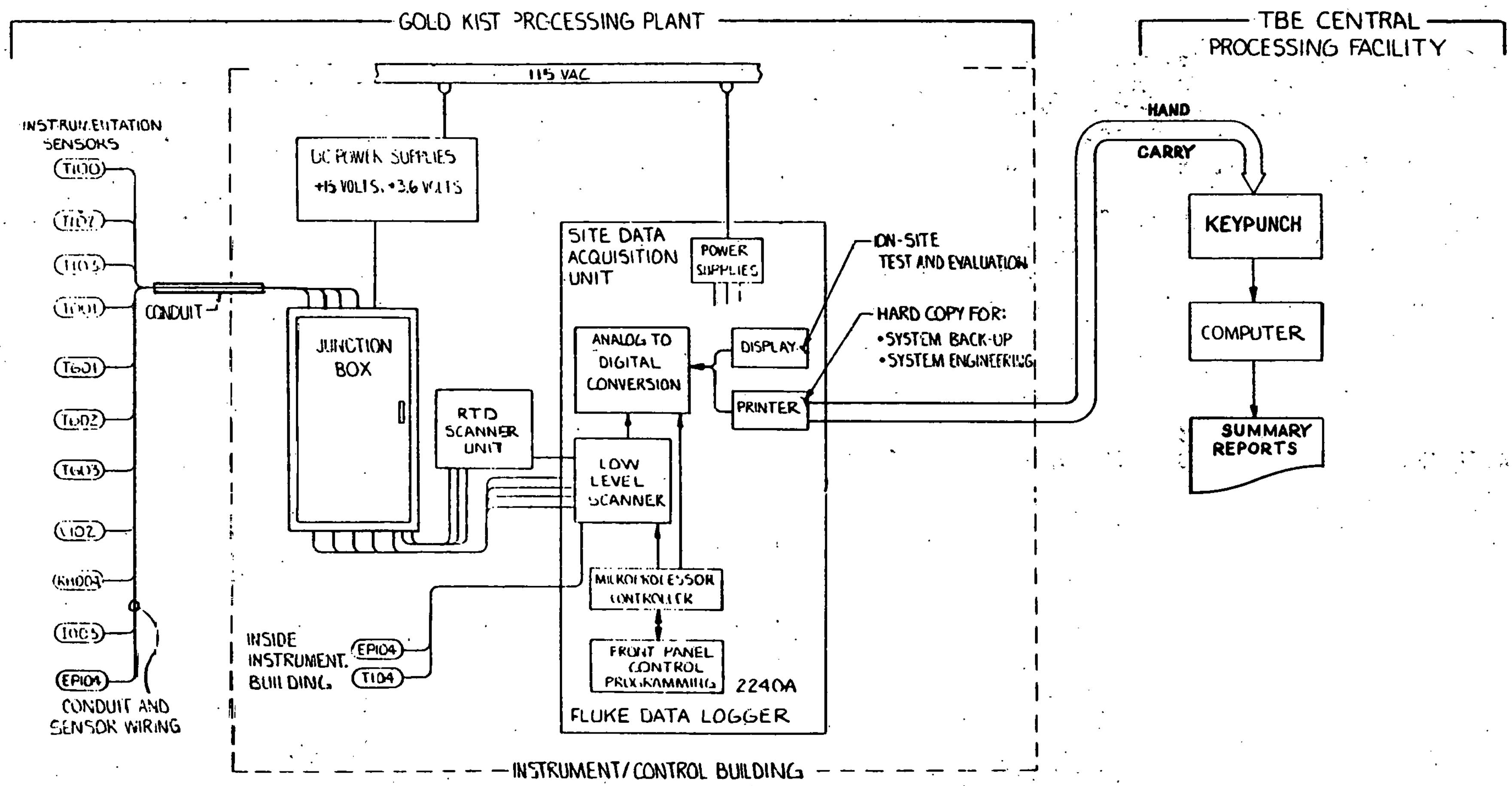


FIGURE 2-8. INSTRUMENTATION MONITORING AND PROCESSING SYSTEM

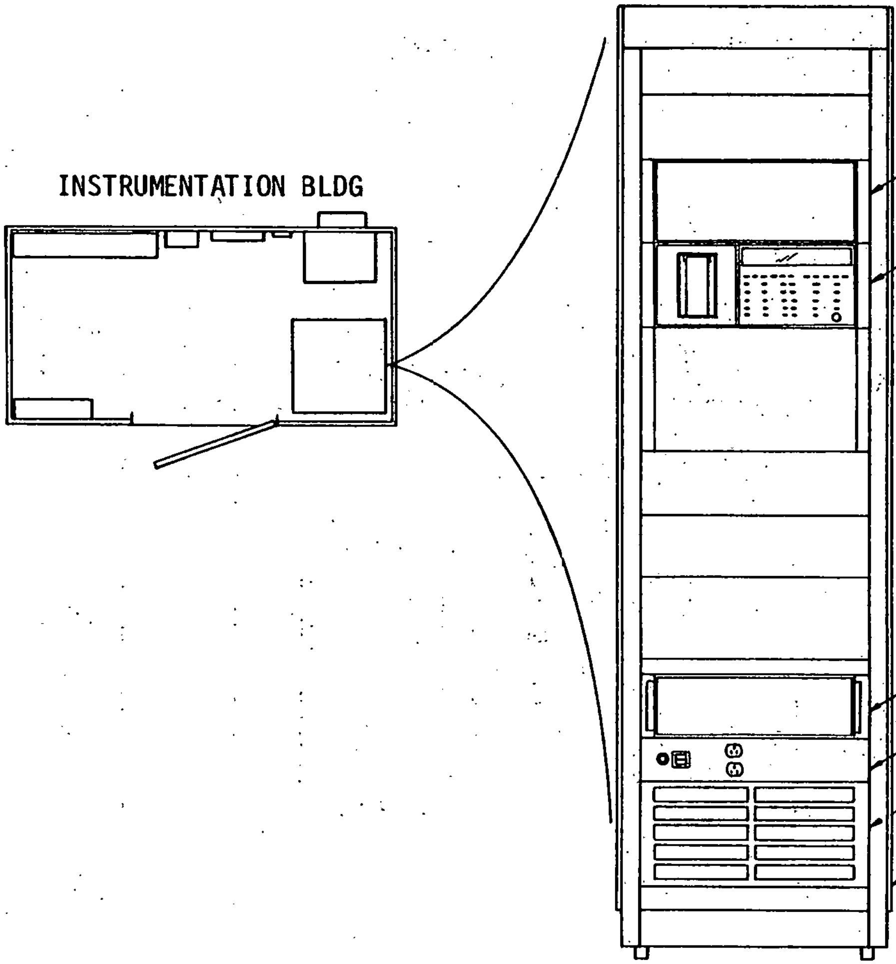


FIGURE 2-9. INSTRUMENTATION RACK CONTAINING THE SITE DATA ACQUISITION UNIT

- Scans 1 to 1,000 points, up to 60 in the mainframe (selected system has the 60-channel capability)

- Mixes voltages, thermocouples, and thermocouple types of adjacent channels

- Multiple scan modes -- continuous limits monitoring intervals scan, delayed interval scan, and monitor channels

- Keyboard-selectable scan interval (1 sec to 24 hr)

- Displays date, time, data, channel identification, function, and polarity

- Displays monitor channel without interrupting scan

- Internally selectable scanning rates (3 to 15 channels/sec)

- Thermocouple conditioning

- Complete program list printout

- Six-digit fixed data

- Field-expandable

- Reference voltages for self-check

- Switch selectable output formats

- Clock: days, hours, minutes, seconds.

The function of the data logger is to automatically scan many analog input signals, digitize these signals, and output the data on printed tape. The 2240A data logger system is represented by the block diagram in Figure 2-10. The 2240A data logger is divided into three categories: input, control, and output. These categories are described below.

2.2.1.1 Input - The basic system is required to accept the following signal types:

- 0 to 100 mVac
- 0 to 25.2 mVdc
- 0 to 10 Vdc
- 0.5 to 5.5 Vdc
- Resistance Temperature Detector (RTD) probes.

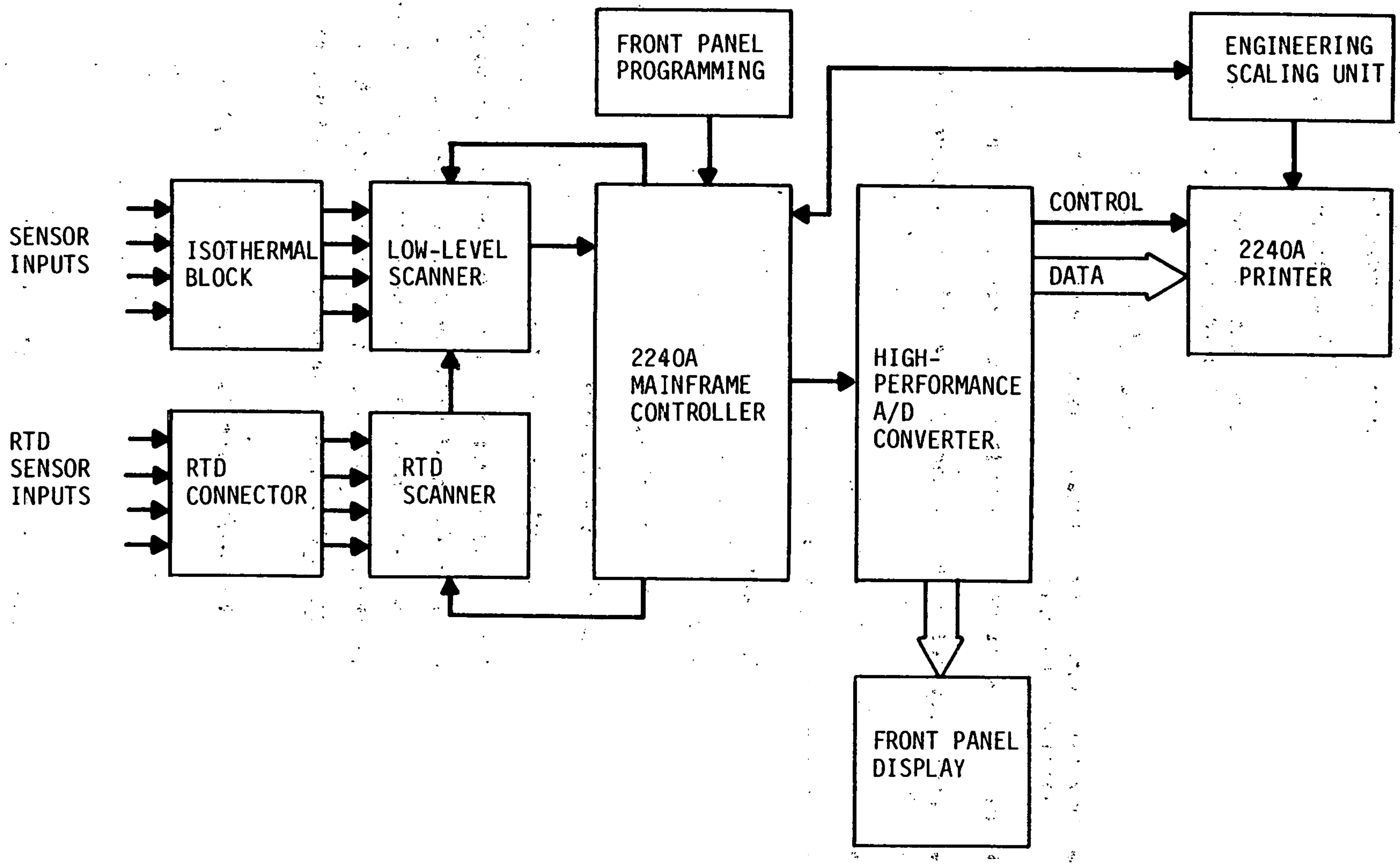


FIGURE 2-10. DATA LOGGER MODEL 2240A SYSTEM

Inputs 1 through 4 are introduced to the DAU system through an isothermal block connector. These 10-channel connectors plug into a low-level scanner via card-edge connectors. Input 5, the RTD probes, interfaces with the DAU through special RTD connectors. These connectors plug into the RTD scanner via card-edge connectors.

The low-level scanner also plugs into the system motherboard via card-edge connectors. However, the RTD scanner is a separate chassis whose interface with the system is through one of the low-level scanner inputs. The scanner samples each channel and transmits the data to the system's high-performance A/D converter. The A/D converter plugs into the system motherboard via a card-edge connector.

2.2.1.2 Control - The 2240A can be programmed to scan sequentially between the first and last channel. Scan will automatically stop on the last channel selected when the unit is in the single-scan mode. In the interval-scan mode, the scan will repeat between the first and last channel at a programmed interval.

The local data display on the face of the unit can be programmed to monitor a single channel continuously or to monitor all channels sequentially between the first and the last channel. The display can be dedicated to only monitoring the date and time.

The printer can be programmed to record all data readings, to record data only when a limit has been exceeded, or to record one scan periodically at preselected intervals.

Each channel is programmed for a function and a range. The function will be millivolts, volts, temperature, or a skip. The range will be ±40 mV, ±4 V, or ±40 V.

2.2.1.3 Output - The DAU data output can be displayed on the front panel or printed on the digital printer.

The front panel display is made up of large, 0.56-in., seven-segment LEDs; three are dedicated to channel identification or days and six to data, polarity, or time. There are also four annotation LEDs for indication of display function, millivolts, volts, temperature, or date/time.

All scan data for each channel are automatically displayed when the All-Channels display format is employed. Only the Monitor Channel is displayed when this display format is employed. Date/time is displayed between scans, except in the single-scan mode where the Last Channel is displayed at the end of the scan, and when the Date and Time format is employed.

The internal printer is a 16-column digital printer that has a print rate of 2.65 lines/sec (channels/sec).

Every time a scan or series of readings is initiated, the following data are printed in the sequence indicated:

- Time of day/date
- Fixed data or header data entered from the keyboard, scan counter data
- Digital input data.

These data are followed by scan data from the First Channel to the Last Channel. The channel number, polarity, data, and function annotation appear on one line.

2.2.2 Sensors

The sensors were selected from the ERDA* preferred list of sensors where accuracies and environmental requirements allowed their use.

The sensors are interconnected into the DAU through a junction box. The internal wiring of this junction box is as outlined in the instrumentation installation guidelines.

It was determined that, as a minimum, 12 parameters are required to accurately evaluate the system's performance. These parameters and pertinent sensor data are listed in Table 2-3.

The characteristics of each of the selected sensors are described below.

*"Instrumentation Installation Guidelines for National Solar Heating and Cooling Demonstration Program", SHC 1006.

TABLE 2-3. SDS SENSOR DATA

MEASUREMENT SYMBOL	PARAMETER	RANGE	SENSOR ACCURACY	SENSOR TYPE	PART NO.	MANUFACTURER
T001	Ambient Temperature	-17.4 to 44°C (0 to 110°F)	±0.11°C (0.2°F)	RTD	S1078B	Minco
T100	Inlet Temperature	-17.4 to 44°C (0 to 110°F)	±0.5%	RTD	S53-CP Platinum 100-24	Minco
T102	Outlet Temperature	-17.4 to 44°C (0 to 110°F)	±0.5%	RTD	S53-CP Platinum 100-24	Minco
T103	Temperature in Duct	-17.4 to 121°C (0 to 250°F)	±0.5%	RTD	S53-CP Platinum 100-24	Minco
T104	Control Room Temperature	-17.4 to 44°C (0 to 110°F)	±0.11°C (0.2°F)	RTD	TRSP-RM1-2 3/4	Weather-Measure
T601	Temperature at Blower 1	-17.4 to 93.7°C (0 to 200°F)	±0.5%	RTD	S53-CP Platinum 100-24	Minco
T602	Temperature at Blower 2	-17.4 to 93.7°C (0 to 200°F)	±0.5%	RTD	S53-CP Platinum 100-24	Minco
T603	Temperature at Blower 3	-17.4 to 93.7°C (0 to 200°F)	±0.5%	RTD	S53-CP Platinum 100-24	Minco
I003	Solar Insolation	0 to 1,103 W/m² (0 to 350 Btu/hr-ft²)	±0.5 %/in.	Pyronometer	PSP/HG7	Eppley
V102	Air Velocity	7.6 to 15.2 m/sec (1,800 to 3,000 ft/min)	±2% (±2.5% F.S.)	Hot Wire Anemometer	430/435	Kurz Instruments
EP104	Solar System Blower Power	0 to 25 kW	±2% (F.S.)	Watt Transducer	PC 5-54, with Option C	Ohio-Semitronics
RH004	Relative Humidity	0 to 100%	±3%	R.H. Probe	HM111-P	Weather-Measure

2.2.2.1 Resistance Temperature Detector (Type S53) - The S53 RTDs are tip-sensitive, accurate probe-type resistance temperature detectors designed for industrial uses. They are used for temperature measurements within the 1.22-m (48-in.) square ducts. In particular, these sensors will be used for the following system parameters:

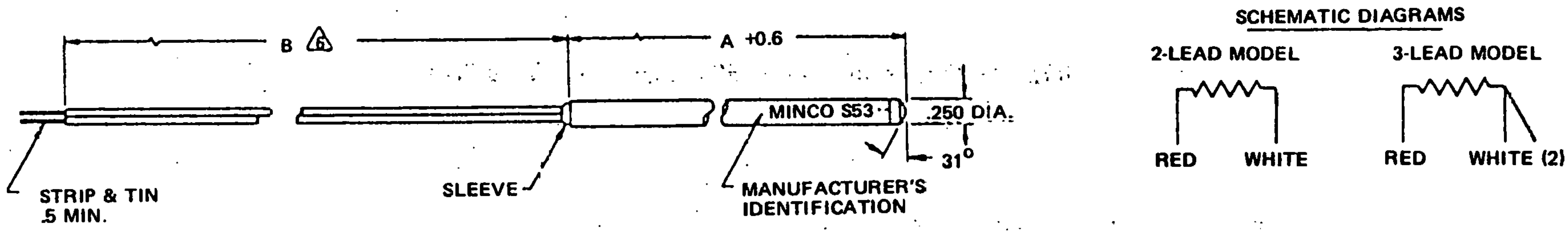
- T100 Air temperature
- T102 Air temperature
- T103 Duct temperature
- T601 Dryer hot air plenum
- T602 Dryer hot air plenum
- T603 Dryer hot air plenum.

Each of these measurements requires an S53 type RTD with a case length of 24 in. and a case diameter of 0.25 in. The three lead elements are used to acquire the desired accuracies. These sensors are also housed in thermowells and have weatherproof connection heads. They penetrate the duct wall through a metal plate.

The RTD resistance element is of CP platinum material with a 100-ohm resistance at 0°C (32°F) and a calibration accuracy of ±0.5%.

Dimension drawings and schematic diagrams of the S53 resistance thermometer are shown in Figures 2-11 through 2-13. The accuracy of these RTDs over the -17.4 to 44°C (0 to 110°F) range is approximately ±0.3°C (±0.54°F). The accuracy over the 0 to 150°C (0 to 300°F) range is ±0.7°C (±1.26°F).

2.2.2.2 Relative Humidity Probe (HM111-P) - The HM111-P is a solid-state relative humidity probe. The sensor operates on the capacitance change of a polymer thin-film capacitor. A 1-µm-thick dielectric polymer layer absorbs water molecules through a thin metal electrode and causes capacitance change proportional to the relative humidity. The thin polymer layer reacts very fast and therefore the response time is very short. The HM111-P relative humidity probe specifications are given in Table 2-4.



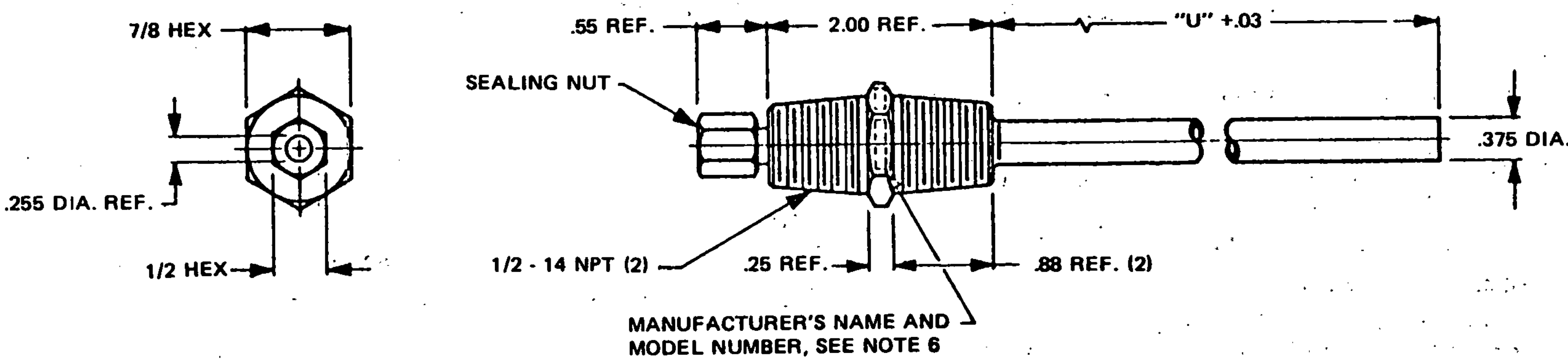
SPECIFY LEADWIRE LENGTH, NUMBER OF LEADS, CASE LENGTH AND MISSING ELEMENT WHEN ORDERING. BELOW IS AN EXAMPLE OF MODEL NUMBER MAKEUP.

F5 C 124 Y 24

- LEADWIRE LENGTH B IN INCHES
- NUMBER OF LEADS: Y - 2-LEAD MODEL; Z - 3-LEAD MODEL
- CASE LENGTH A IN 0.1" INCREMENTS. 124 = 12.4" MINIMUM A IS 28 (2.8") MAXIMUM A IS 480 (48.0")
- SENSING ELEMENT. C FOR COPPER; F FOR NICKEL-IRON; P FOR PLATINUM; OR N FOR NICKEL
- SPECIFICATIONS DRAWING NUMBER

9. IF CUSTOMER LISTED ON JOB ORDER IS TABULATED ON SHEET 2 OF THIS DRAWING, SPECIAL HANDLING AND/OR OTHER REQUIREMENTS OF SHEET 2 ARE APPLICABLE.
8. CASE MAY BE CUT TO SHORTER LENGTH. USE CARE NOT TO DAMAGE LEADWIRE INSULATION. LOCATE THE SLIP-FIT TEFLON SLEEVE IN END OF CUT-OFF CASE TO PROTECT LEADWIRE INSULATION AT POINT OF EMERGENCE. MINIMUM A FOR CUT-OFF IS 28 (2.8")
7. CASE: STAINLESS STEEL, COPPER ALLOY TIP.
6. TOLERANCE ON LEAD LENGTH: 28" AND UNDER: +1/-0"; 24" TO 71"; +2/-0"; 72" TO 119"; +4/-0"; 120" AND OVER; +6/-0"
5. LEADS: A.W.G. NO. 22, STRANDED, TEFLON INSULATED, LEADS RESISTANCE OF APPROXIMATELY .016 OHM/FOOT IS INCLUDED IN ELEMENT RESISTANCE OF 2-LEAD MODELS FOR ANY COMBINED LENGTH OF CASE AND LEADS TO 48" (A + B 48"). THE CALIBRATION TOLERANCE IS INCREASED BY 0.03 OHM FOR EACH 12" INCREASE BEYOND 48". LEADS RESISTANCE IS NOT INCLUDED IN ELEMENT RESISTANCE OF 3-LEAD MODELS.
4. INSULATION RESISTANCE: 1,000 MEGOHMS MINIMUM AT 500 VOLTS D.C., LEADS TO CASE.
3. TEMPERATURE RANGE: -73°C TO 260°C (-100°F TO 500°F), EXCEPT NICKEL-IRON ELEMENT TO 232°C (450°F)
2. RESISTANCE: COPPER - 10.00 OHMS +.2% (10.02/9.98) AT 28°C, R/T TABLE NO. 16-9; NICKEL-IRON - 676.0 OHMS +.5% (670.3/672.7) AT 25°C, R/T TABLE NO. 14-604; PLATINUM - 100.0 OHMS +.5% (100.5/99.5) AT 0°C, R/T TABLE NO. 1-100; NICKEL - 120.0 OHMS +.5% (120.6/119.4) AT 0°C, R/T TABLE NO. 7-120
1. ELEMENT: WIRE WOUND COPPER, NICKEL-IRON, PLATINUM OR NICKEL.

FIGURE 2-11. RESISTANCE THERMOMETER PROBE TYPE



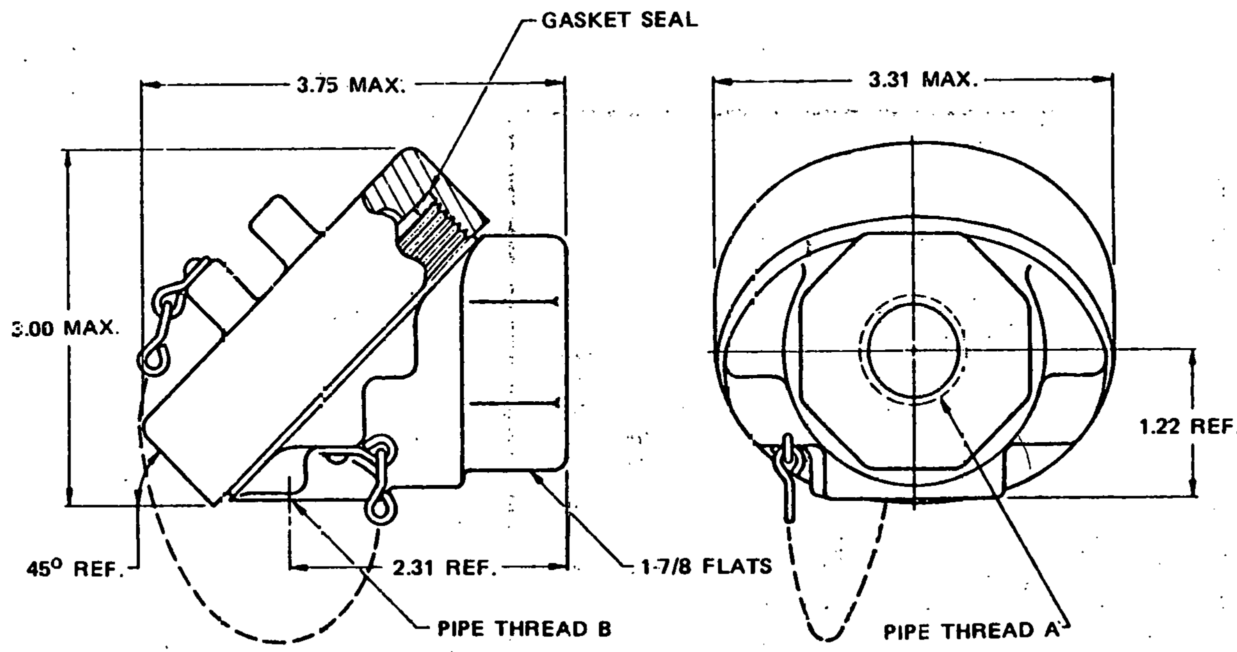
SPECIFY DIMENSION U WHEN ORDERING. BELOW IS AN EXAMPLE OF MODEL NUMBER MAKEUP:

E203U124
- U124 — DIMENSION U IN .1" INCREMENTS. 124 = 12.4" MINIMUM U IS 5 (.5"), MAXIMUM IS 480 (48.0").
- E203 — SPECIFICATIONS DRAWING NUMBER.

NOTES:

1. WELL IS EQUIPPED WITH A BRASS COMPRESSION RING TO SEAL AROUND A .250 DIAMETER PROBE.
2. TO INSTALL PROBE, REMOVE THE SEALING NUT AND SLIDE THE SEALING NUT AND COMPRESSION RING ONTO THE PROBE. INSERT THE PROBE INTO THE WELL TO FULL DEPTH MAKING CERTAIN PROBE IS SEATED AT TIP. APPLY A THIN COAT OF THREAD SEALANT TO THE SEALING NUT THREAD. TIGHTEN SEALING NUT SUFFICIENTLY TO COMPRESS RING AND LOCK PROBE IN POSITION. DO NOT OVER TIGHTEN. PROBE MAY BE REMOVED BY FIRST REMOVING THE SEALING NUT.
3. SHEATH MATERIAL: STAINLESS STEEL. FITTING AND SEALING NUT MATERIAL: BRASS. ASSEMBLY NICKEL PLATED.
4. TEMPERATURE LIMIT: +500°F. MAXIMUM.
5. PRESSURE: WELL IS CAPABLE OF WITHSTANDING 1,000 PSI PRESSURE AT THE MAXIMUM TEMPERATURE LIMIT.
6. IF CUSTOMER LISTED ON JOB ORDER IS TABULATED ON SHEET 2 OF THIS DRAWING, SPECIAL MARKING AND/OR OTHER REQUIREMENTS OF SHEET 2 ARE APPLICABLE.

FIGURE 2-12. WELL FOR RESISTANCE THERMOMETER



6. WHEN INSTALLING: THE MOUNTING FITTING FOR THE PROBE TYPE RESISTANCE THERMOMETER OR THERMOCOUPLE NORMALLY ATTACHES TO PIPE THREAD A. CONDUIT ADAPTER OR PIPE FOR EXTENSION WIRES NORMALLY ATTACHES TO PIPE THREAD B.
5. TEMPERATURE LIMIT: 750°F. (399°C.) MAXIMUM FOR CONNECTION HEAD WITH WIRE NUTS; 500°F. (260°C.) MAXIMUM FOR CONNECTION HEAD WITH TERMINAL BOARD.
4. TERMINAL BOARD: CONNECTIONS CAN BE EITHER SCREW-TYPE OR SOLDERED. SUITABLE FOR CONNECTING PROBE LEADWIRES TO EXTENSION WIRES RANGING IN SIZE UP TO A.W.G. NO. 12.
3. WIRE NUTS: PORCELAIN, SUITABLE FOR CONNECTING PROBE LEADWIRES TO EXTENSION WIRES RANGING IN SIZE FROM A.W.G. NO. 14 TO A.W.G. NO. 22.
(2) CONNECTION HEAD IS SUPPLIED EITHER WITH 4 WIRE NUTS OR WITH A 4-CONNECTOR TERMINAL BOARD (MODEL NUMBER WITH "T" SUFFIX) FOR MAKING CONNECTIONS BETWEEN PROBE LEADWIRES AND EXTENSION WIRES.
1. CONNECTION HEAD PROVIDES A WEATHERPROOF ENCLOSURE IN WHICH LEADWIRES FROM A PROBE TYPE RESISTANCE THERMOMETER OR THERMOCOUPLE CAN BE CONNECTED TO EXTENSION WIRES LEADING TO REMOTELY LOCATED READOUT OR CONTROL INSTRUMENTATION.

MODEL NUMBER	PIPE THREAD A	PIPE THREAD B	REMARKS (2)
F102-1	3/4 – 14 NPT	1/2 – 14 NPT	
F102-1T	3/4 – 14 NPT	1/2 – 14 NPT	TERMINAL BOARD
F102-2	3/4 – 14 NPT	3/4 – 14 NPT	
F102-2T	3/4 – 14 NPT	3/4 – 14 NPT	TERMINAL BOARD
F102-3	1/2 – 14 NPT	1/2 – 14 NPT	
F102-3T	1/2 – 14 NPT	1/2 – 14 NPT	TERMINAL BOARD
F102-4	1/2 – 14 NPT	3/4 – 14 NPT	
F102-4T	1/2 – 14 NPT	3/4 – 14 NPT	TERMINAL BOARD

FIGURE 2-13. WEATHERPROOF CONNECTION HEAD

TABLE 2-4. MODEL HM111-P RELATIVE HUMIDITY PROBE SPECIFICATIONS*

Sensing Element	Thin-film capacitor
Range	0 to 100% relative humidity
Operating Temperature	-40°F to 175°F
Response Time	10 to 20 sec
Probe Accuracy	±3%
Sensitivity	±0.5%
Hysteresis	≤ ±1%
Temperature Coefficient	0.07%/°C
Weight	1 lb
Power Consumption	10 mA
Output	0 to 100 mV
Input Power	Regulated 3.6 Vdc

*Manufacturer's Data

2.2.2.3 Flow Rate Measurement - An anemometer probe, manufactured by Kurz Instruments, Inc., is used to provide a measurement of velocity at a point location in the duct. With a predetermined knowledge of average velocity across the duct, the air flow rate can be monitored continuously.

The probe consists of two integral sensors: a velocity sensor and a temperature sensor. The velocity sensor is a constant-temperature thermal anemometer which measures "standard" velocity referenced to 70°F and 760 mm Hg. Velocity is related to the cooling effect of the moving airstream as it passes over the heated sensor. The sensor is heated electrically by control circuitry in the electronics package. The temperature sensor accurately compensates for temperature variations over a wide range.

The sensor system is linear between 0 and 2,500 ft/min, with a full range output of 5 Vdc. Accuracy is ±2% of reading plus 0.5% of full-scale over a range of -20 to +60°C.

To extract flow rate from a measurement of velocity at a single point, the average velocity across the duct must be known. The basic equation for air flow in a duct is:

$$Q = A\overline{V} \quad ft^3/min$$

where

Q - air flow rate in standard cubic feet per minute

A - duct cross-section area in square feet

$\overline{V}$ - average velocity in standard feet per minute.

With the selected system, the standard velocity is measured at only one point in the duct. If the velocity distribution across the duct is assumed to be constant with time, then the measured standard flow rate is:

$$Q = V_1 \; A\left(\frac{\overline{V}}{V_1}\right) ft^3/min$$

where

$\overline{V}/V_1$ - normalized average velocity across the duct

V_1 - velocity at the point of measurement.

To obtain the weight flow rate we have:

$$\dot{W} = 60 \cdot \rho_{std} \cdot Q \text{ lb/hr}$$

$$= 60 \cdot \rho_{std} \cdot V_1 \cdot A \cdot (\overline{V}/V_1)$$

where ρ_{std} is the density of air at standard temperature and pressure (= 0.075 lb/ft^3).

The area of the duct at the velocity measurement station is:

$$A = (4 \text{ ft} - 7/8 \text{ in.}) \times (4 - 1\ 1/16 \text{ in.})$$

$$= 16.65 \text{ ft}^2.$$

The procedure for determining the average velocity in the duct involves the division of the flow area into several equal areas. Velocity readings are taken at the center of each area and averaged arithmetically to obtain the average velocity. Figure 2-14 illustrates the horizontal and vertical probe traverses for equal area readings. Figure 2-15 presents the measured results of the traverses. Since there is considerable scatter of the data, a line was faired through the data and the points used in the averaging process were obtained from that curve. The average velocity was determined to be:

$$\frac{\overline{V}}{V_1} = 1.011$$

when V_1 is referenced to the center of the duct (point 1). Thus the flow rate can be computed as follows:

$$\dot{W} = (60)(0.075)(1.011)(16.65)\ V_1 \quad \text{lb/hr}$$

$$= 75.75\ V_1.$$

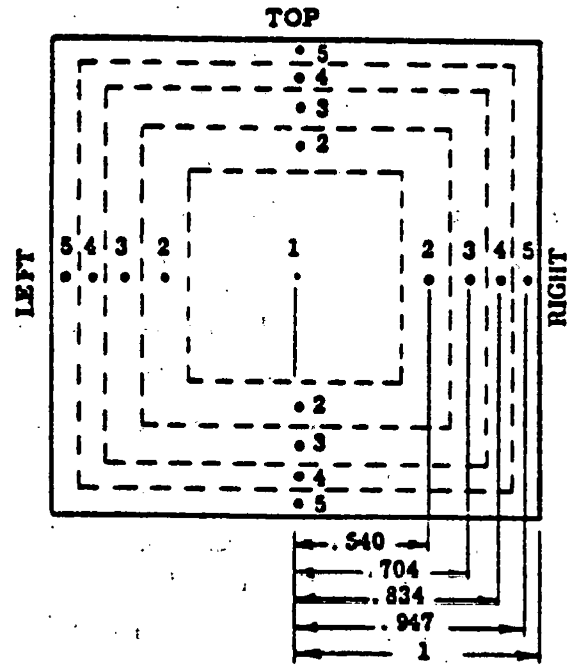


FIGURE 2-14. EQUAL-AREA TRAVERSES FOR OBTAINING AVERAGE VELOCITY

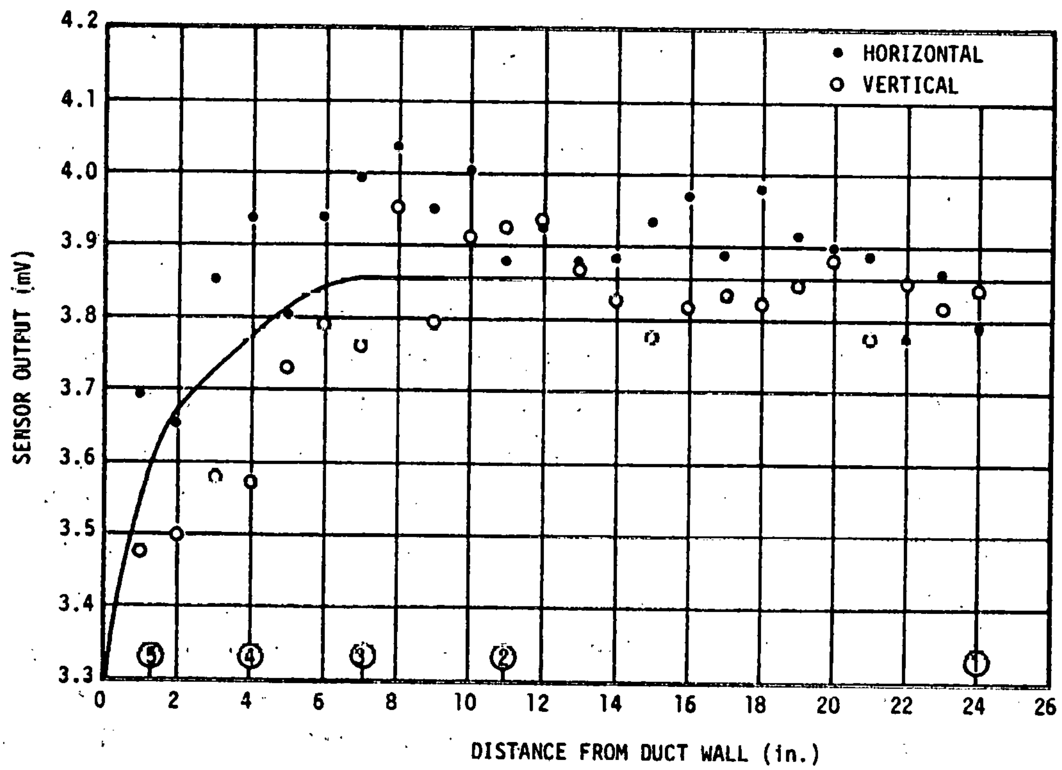


FIGURE 2-15. MEASURED VELOCITY PROFILE IN DUCT

2.2.2.4 Watt Transducer PC5-54 - The watt transducer utilizes Hall effect multipliers to provide an output that is proportional to the electrical power delivered to single-phase or three-phase loads. The multipliers provide instantaneous multiplication of the voltage times the current on a continuous basis. Output of the unit is 0.25 kW per volt.

The PC5-54 is a three-phase, three-wire 42-kW transducer. Option C provides an output of 0 to 10 Vdc through the use of an internal signal conditioning amplifier. The performance specification and dimensional drawing are shown in Figure 2-16.

2.2.2.5 Resistance Temperature Detector (TRSP-RM1) - The RTD is located in the instrumentation/control building to monitor the room ambient temperature in the data logger environment. The TRSP-RM1 is a shielded platinum bulb with a 100-ohm resistance at 0°C (32°F). It has a response time of approximately 40 sec in still air and is accurate to ±0.11°C (0.2°F) over the range of -30 to +130°C (-22 to +266°F). Figure 2-17 shows the TRSP-RM1 specifications and assembly drawing.

2.2.2.6 Resistance Temperature Detector (S1078B) - The S1078B is a precision platinum resistance thermometer. Accuracies greater than 0.11°C (0.2°F) are obtainable. The sensor provides a three-wire termination for more accurate measurements. It is protected from shock and vibration and is hermetically sealed. Sensor specifications are given in Figure 2-18.

2.2.2.7 Pyronometer (Type PSP) - The Model PSP is an improved model of an earlier Eppley instrument. It comprises a circular multijunction Eppley thermopile of the wire-wound type. The thermopile has the added advantage of withstanding severe mechanical vibration and shock. Its receiver is coated with Parsons' black lacquer (nonwavelength-selective absorption). This instrument is supplied with a pair of removable precision ground and polished hemispheres of Schott optical glass (the inner of clear WG7 glass, the outer of WG7 glass). Also supplied is a spirit level and a desiccator that can be inspected readily. The instrument has a cast bronze body with a white enameled guard disk.

SPECIFICATIONS

INPUT

Overload (Continuous):
- Voltage, 1.25 X Rating
- Current, 2 X Rating (5, 10 and 15A Models)
  - 10 X Rating (50A thru 2000A Models)

Burden (At Max. Rated Input):
- Voltage, 1.25 VA
- Current, 1.25 VA
- Amplifier, 2VA

Power Factor Range: 0.5 lead to 0.5 lag
Frequency Range: 50 to 70 Hz
Dielectric Test (Input/Output/Case):
1500V RMS
Models PC5-28 through PC5-48 are complete with O.S.I. Current Transducers.
Models PC5-49 through PC5-102 are supplied with current transformers.

OUTPUT

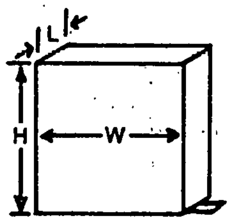
Output Load: 100 ohms
Adjustment Range: ±10%
Response Time (Base Unit): 5 Milliseconds
(With Options): 400MS
Temperature Effect (−10°C to +60°C):
±1% FS from the Calibrated Value.

ACCURACY AT 25°C

Including Power Factor Error, Linearity, Repeatability, and Initial Calibration Set Point Error:

PC5-54 ±2% FS

PC5-54 EXTERNAL TRANSDUCER SIZES



L	W	H
3⅝	4¼	4½

WATT TRANSDUCER CASE SIZE

FIGURE 2-16. WATT TRANSDUCER SPECIFICATIONS AND OUTLINE DRAWING

MODEL NO.	PROTECTIVE TUBE		LEAD LENGTH (ft)	USABLE TEMPERATURE RANGE (°C)
	LENGTH (in.)	DIAMETER (in.)		
TRSP-RM-1	2-3/4, 6-3/4, 8-3/4, 10-1/2	9/64	0	-30 to 130
TRSP-RS-1	2-3/4, 6-3/4, 8-3/4, 10-1/2	1/4	0	-200 to 500

SENSORS: RM-1: 0.1 in. O.D. BY 0.8 in. LONG, SILICONE RUBBER COVER, 3 COPPER LEADS
RS-1: 0.18 in. O.D. BY 1.06 in. LONG, HARD GLASS COVER, 3 SILVER LEADS
RB-1: 0.12 in. O.D. BY 1.22 in. LONG, HARD GLASS COVER, 2 SILVER LEADS

CONFIGURATION

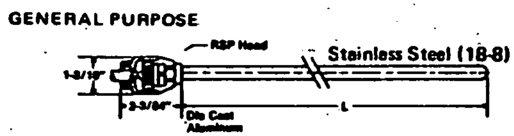


FIGURE 2-17. RESISTANCE TEMPERATURE DETECTOR (TRSP-RM-1)

SPECIFICATIONS

Temperature Range: —100°C. to +204°C. (—148°F. to +400°F.).

Calibration Accuracy: Available in ±.10%, .25%, .50% calibration based on nominal resistance at the ice point (0°C.).

Time Constant: Typically 1.3 to 1.6 seconds in agitated water or comparable heat sink.

Linearity: Deviation from absolute linearity less than 1% of full range. Nominal resistance versus temperature curve and measured Ro (ice point resistance) are included with each thermometer.

Calibration Data: Additional measured points or individual coefficients to 5-place accuracy to customer specification are available at extra charge.

Dielectric Test: 500 volts rms minimum, leads to case.

Insulation Resistance: 1000 megohms minimum at 100 volts D.C., leads to case.

Sensing Element: Strain-free assembly of chemically-pure reference-grade platinum. Vibration - shock protected.

Case: Gold-plated metal

Leads: 3-terminal lead resistance-cancelling configuration is standard. Available with 2 leads on special request.

Mounting: Normal mechanical mounting, clamping, cementing, potting, or lead suspension may be used.

Self heating of models with either the "B" or "C" suffix is less than 0.1°C. at 0°C. if current is less than 3 ma in still air or 5 ma in liquid. Current of 1 ma or less will produce negligible heating effect in either still air or liquid.

Immersion: Gold-plated metal case, epoxy lead anchoring, and glass-to-metal hermetic seal permits models with insulated leads (S31-6, S31-10, S31-20 and S31-21) to be immersed in most electrically conductive or non-conductive liquids. The Model S31 having uninsulated leads, can be immersed in most non-conductive liquids only.

Custom Variations: Special resistance, different lead lengths, special mounting or case configurations can be supplied to your specifications. Please contact the factory or engineering representative.

ELEMENT RESISTANCE — 100 ohms AT 0°C
OHMS PER °C CHANGE — 0.392/°C
OHMS PER °F CHANGE — 0.217 ohms/°F

RESISTANCE TEMPERATURE RATIO

To obtain the resistance at any given temperature shown on the bottom margin, multiply the resistance at 0°C. by the factor indicated in the left margin.

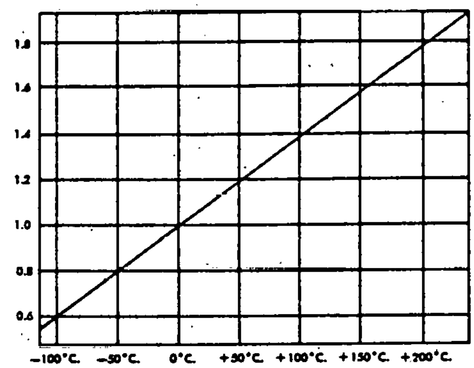


FIGURE 2-18. TEMPERATURE DETECTOR (S1078B) SPECIFICATIONS

The WG7 clear glass is transparent from a wavelength of about 285 to 2,800 μm.

A specification sheet for the Model PSP pyronometer is given in Table 2-5.

TABLE 2-5. MODEL PSP PYRONOMETER SPECIFICATIONS

Sensitivity	9 μV/W-m^{-2} (approximately)
Impedance	650 ohms (approximately)
Receiver	Circular 1 cm^{-2}, coated with Parsons' black optical lacquer
Temperature Dependence	±1% over ambient temperature range -20 to +40°C
Linearity	±0.5% from 0 to 2,800 W-m^{-2}
Response Time	1 sec (i/e signal)
Cosine	±1% from normalization 0 to 70 deg zenith angle ±3% 70 to 80 deg zenith angle
Orientation	No effect on instrument performance
Mechanical Vibration	Tested up to 20 g without damage
Calibration	Integrating hemisphere (approximately 1 cal cm^{-2}min^{-1}, ambient temperature +25°C): calibration reference Eppley primary standard group of Angstrom pyrheliometers reproducing the International Pyrheliometric Scale
Readout	Potentiometric in preference to microammeter devices
Range	0 to 2,800 W-m^{-2} 0 to 887.6 Btu/hr-ft^2*
Output	0 to 25.2 mV

*1 W-m^2 = 0.317 Btu/hr-ft^2

Shortwave solar radiation comprises the direct component of sunlight and the diffuse component of skylight. When measured together as the total shortwave flux on a horizontal surface, this integral is referred to as the global radiation. The other shortwave component of the radiation budget is that reflected from natural surfaces. The wavelength range of these components is usually taken to be 0.3 to 5 μm but is about 0.3 to 3 μm in practice.

Longwave terrestrial radiation comprises the incoming atmospheric component (i.e., downward emission by the gases of the atmosphere, especially water vapor and carbon dioxide) and the outgoing terrestrial component (i.e., upward emission and reflection by natural surfaces and atmospheric gases). The wavelength range of these components is usually taken to be 3 to 100 μm ideally but is about 4 to 50 μm in practice.

There are two main operating requirements for the PSP pyronometer: 1) periodic verification of pyronometer calibration and 2) application of corrections, where judged necessary, to take account of instrument obstruction to a free horizon. Calibration of the instrument against the Eppley group of reference standards indicates 9.69×10^{-3} W/m^2 per mW output.

The pyronometer is mounted on a bracket attached to the handrail on the southwest section of the solar panel support structure. The mounting surface of the bracket and the pyronometer is in the same plane as the upper surface of the solar panels so that the solar panels do not cast a shadow on the pyronometer. The pyronometer is oriented so that the electrical connector is located north of the receiving surface.

2.2.3 Sensor Interconnection Cabling, Grounding, and Installation

All sensors used in the SDS are located to provide easy access for checkout, maintenance, and replacement. A flow diagram (Figure 2-19) indicates the points at which the various types of measurements are taken. A sensor location and mounting drawing (Figure 2-20) shows the installation of sensors used for measuring air temperature and local environment, including incoming insolation.

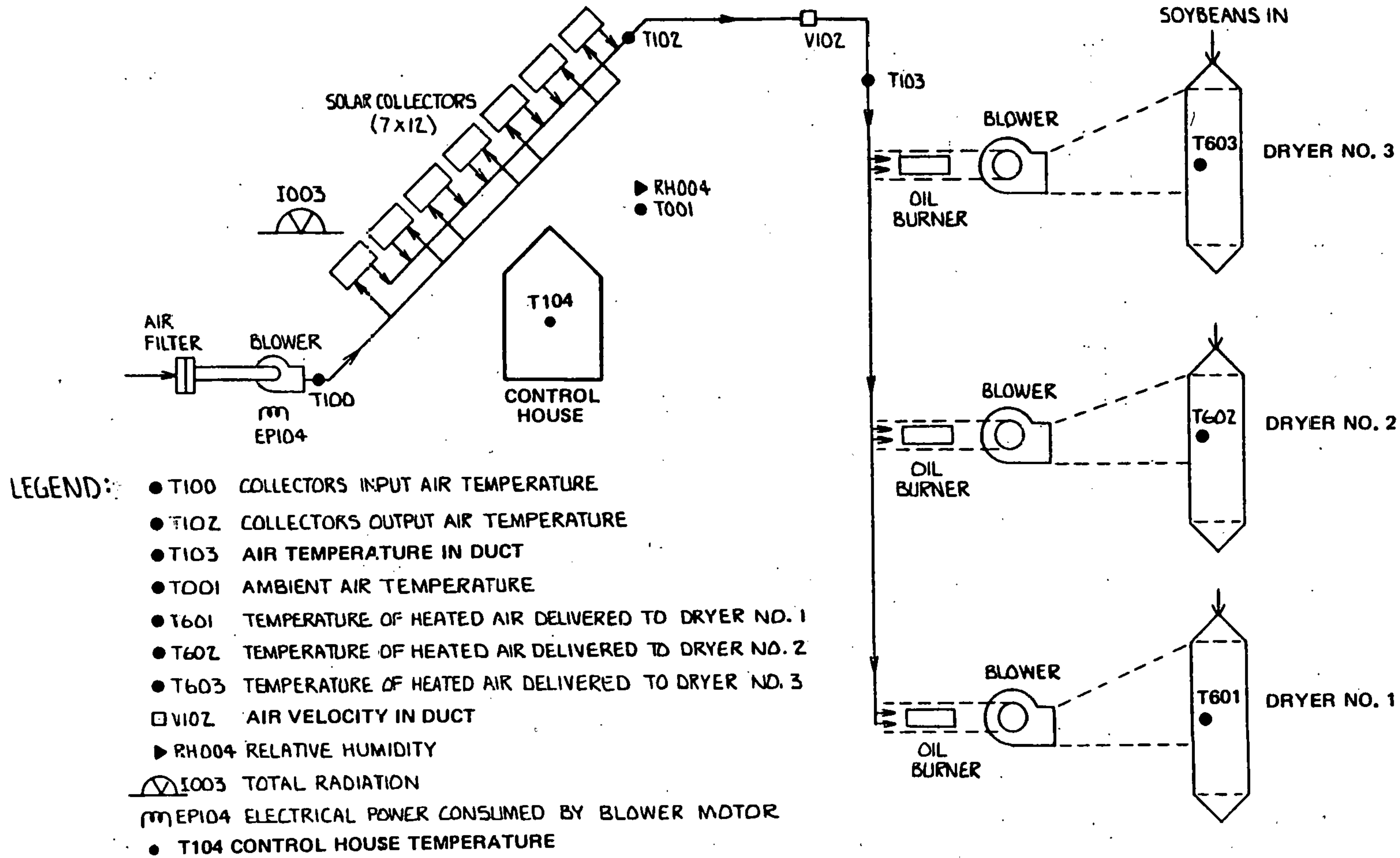
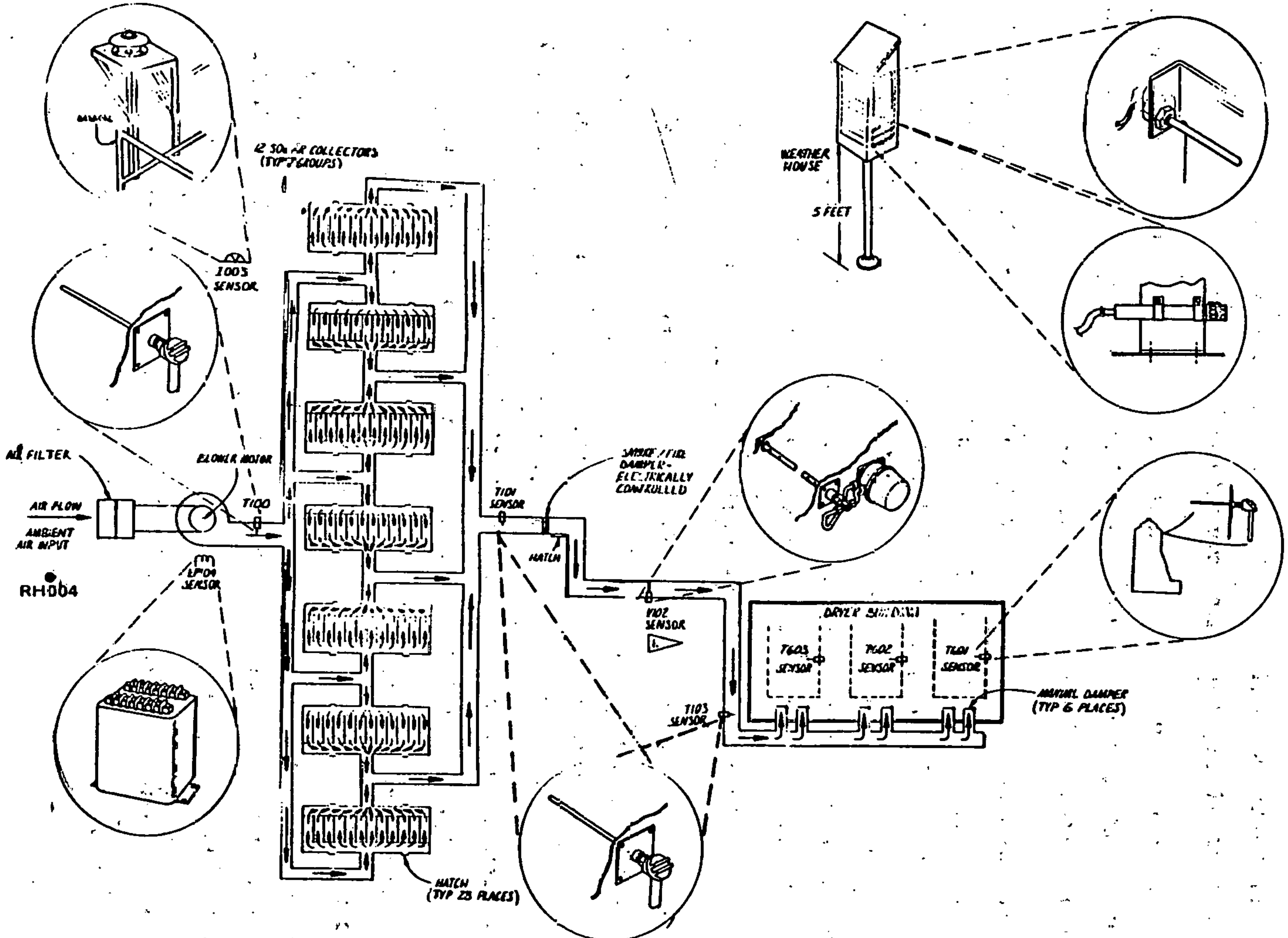


FIGURE 2-19. SENSOR LOCATION



NOTES:

1. AIR FLOW METER SHALL BE LOCATED IN A STRAIGHT SECTION OF DUCT NO SHORTER THAN 48 FEET. POSITION FLOW METER SO THAT THE RATIO OF DISTANCES FROM ELBOW DOWNSTREAM TO ELBOW UPSTREAM SHALL BE 3:1
2. TEMPERATURE SENSOR T104 IS LOCATED WITHIN INSTRUMENTATION BUILDING
3. LOCATE 15 FEET FROM SOLAR BLOWER FILTER

SENSOR TABLE

	SYMBOL	MEASUREMENT
1.	T001	AMBIENT TEMPERATURE (note 3)
2.	RH004	RELATIVE HUMIDITY (note 3)
3.	I003	TOTAL RADIATION
4.	T100	SOLAR COLLECTOR INLET TEMPERATURE
5.	T101	SOLAR COLLECTOR OUTLET TEMPERATURE
6.	T103	TEMPERATURE AT FLOW METER
7.	V102	AIR FLOW METER - VELOCITY (note 1)
8.	EP104	ELECTRICAL POWER CONSUMED BY BLOWER MOTOR
9.	T601	TEMPERATURE OF AIR DELIVERED TO DRYER NO. 1
10.	T602	TEMPERATURE OF AIR DELIVERED TO DRYER NO. 2
11.	T603	TEMPERATURE OF AIR DELIVERED TO DRYER NO. 3
12.	T104	TEMPERATURE INSIDE INSTRUMENTATION BLDG (note 2)

FIGURE 2-20. SENSOR LOCATION AND MOUNTING

Cables selected to interconnect sensors and instrumentation recording equipment are audio and instrumentation grade, UL-approved, foil-shielded, plastic-jacketed, multiconductor cables having 18 AWG stranded tinned copper conductors. Temperature rating is -20 to +60°C, and the maximum operating voltage rating is 400 V. The number of conductors and the color coding of each conductor are shown in the wire run list (Table 2-6).

All instrumentation wiring is run inside a rigid steel conduit installed exclusively for instrumentation use.

Wire nuts are used to connect sensors with cables except in the blower motor and soybean dryer area. Because of vibration in the sensor installation area, a butt splice was made.

The sensors used in the air system have weatherproof heads and are installed in thermowells. The weatherproof heads are arranged to minimize accidental damage. Dow Corning DC-340 heat transfer grease is applied to the bottom of the RTD probe prior to insertion into the thermowell. Pipe thread sealing compound is used to connect the conduit to the weatherproof heads in accordance with local codes.

2.2.4 Description of Central Data Processing System

The solar soybean dryer evaluation program is a computer code used to calculate performance and efficiency factors of the solar dryer utilizing data acquired from sensors located within the system (see Section 5). These factors are conveniently summarized in reports that can be reviewed on an hourly, daily, monthly, and yearly basis to evaluate the system performance and operational characteristics.

The program is executed on Teledyne Brown Engineering's Varian 73, a minicomputer. The Varian operating system and the Varian FORTRAN compiler are the only software used other than the program itself. The Vortex II operating system is described in the Vortex II Reference Manual (98 A 9952 245, July 1977).

The FORTRAN compiler used by the program is described in the Vortex FORTRAN IV Reference Manual (98 A 9952 041, December 1976).

TABLE 2-6. SENSOR WIRE RUN LIST

NAME	SENSORS: MEASUREMENT NUMBER	SENSORS: WIRE COLOR	JUNCTION BOX: TERMINAL STRIP	JUNCTION BOX: WIRE COLOR	JUNCTION BOX: CONNECTOR PIN	JUNCTION BOX: LEVEL
Pyranometer (Total Sun and Sky Radiation)	I003	Black	TB1-1	Black	J1/A	LO
			TB1-2	Red	J1/B	
		Shield	TB1-3	Shield	J1/C	
		White	TB1-4	White	J1/D	HI
			TB1-5	Green	J1/E	
Flowmeter (Air Velocity)	V102	Black	TB1-6	Black	J1/F	LO/-10V
		Red	TB1-7	Red	J1/G	
		Shield	TB1-8	Shield	J1/H	
		White	TB1-9	White	J1/J	HI/+10V
			TB1-10	Green	J1/K	
Relative Humidity	RH004	Black	TB1-11	Black	J1/L	-3.6 Vdc
		Red	TB1-12	Red	J1/M	+3.6 Vdc
		Shield	TB1-13	Shield	J1/N	
		White	TB1-14	White	J1/P	HI
		Green	TB1-15	Green	J1/R	LO
Blower Motor Electrical Power	EP104	Black	TB2-1	Black	J1/S	LO
		Red	TB2-2	Red	J1/T	HI
			TB2-3	Shield	J1/U	
			TB2-4	White	J1/V	
			TB2-5	Green	J1/W	
Dryer No. 3 Air Temperature	T603	Black	TB2-6	Black	J1/X	LO
		Red	TB2-7	Red	J1/Y	HI
		Shield	TB2-8	Shield	J1/Z	
		White	TB2-9	White	J1/a	LO
			TB2-10	Green	J1/b	
Dryer No. 2 Air Temperature	T602	Black	TB2-11	Black	J1/c	LO
		Red	TB2-12	Red	J1/d	HI
		Shield	TB2-13	Shield	J1/e	
		White	TB2-14	White	J1/f	LO
			TB2-15	Green	J1/g	
Dryer No. 3 Air Temperature	T601	Black	TB3-1	Black	J1/h	LO
		Red	TB3-2	Red	J1/i	HI
		Shield	TB3-3	Shield	J1/j	
		White	TB3-4	White	J1/k	LO
			TB3-5	Green	J1/m	
Temperature in Duct	T103	Black	TB3-6	Black	J1/N	LO
		Red	TB3-7	Red	J1/P	HI
		Shield	TB3-8	Shield	J1/Q	
		White	TB3-9	White	J1/R	LO
			TB3-10	Green	J1/S	
Collector Output Temperature	T102	Black	TB3-11	Black	J2/A	LO
		Red	TB3-12	Red	J2/B	HI
		Shield	TB3-13	Shield	J2/C	
		White	TB3-14	White	J2/D	LO
			TB3-15	Green	J2/E	
Collector Input Temperature	T100	Black	TB4-1	Black	J2/F	LO
		Red	TB4-2	Red	J2/G	HI
		Shield	TB4-3	Shield	J2/H	
		White	TB4-4	White	J2/J	LO
			TB4-5	Green	J2/K	
Ambient Temperature	T001	Black	TB4-6	Black	J2/L	LO
		Red	TB4-7	Red	J2/M	HI
		Shield	TB4-8	Shield	J2/N	
		White	TB4-9	White	J2/P	LO
			TB4-10	Green	J2/R	
Instrument/Control Building Temperature	T004	Black	TB4-11	Black	J2/S	LO
		Red	TB4-12	Red	J2/T	HI
		Shield	TB4-13	Shield	J2/U	
		White	TB4-14	White	J2/V	LO
			TB4-15	Green	J2/W	

The software architecture that coordinates the data flow of Figure 2-21 includes 12 FORTRAN subroutines, 5 external files, and 9 internal common blocks. The FORTRAN subroutines are independently compilable modules. Each module is listed in Table 2-7 with a brief statement of its purpose. The external files identified in Table 2-8 include one user input file and four mass storage recordkeeping files. The definition of common blocks is given via Internal Parameter Tables (IPTs) in Table 2-9.

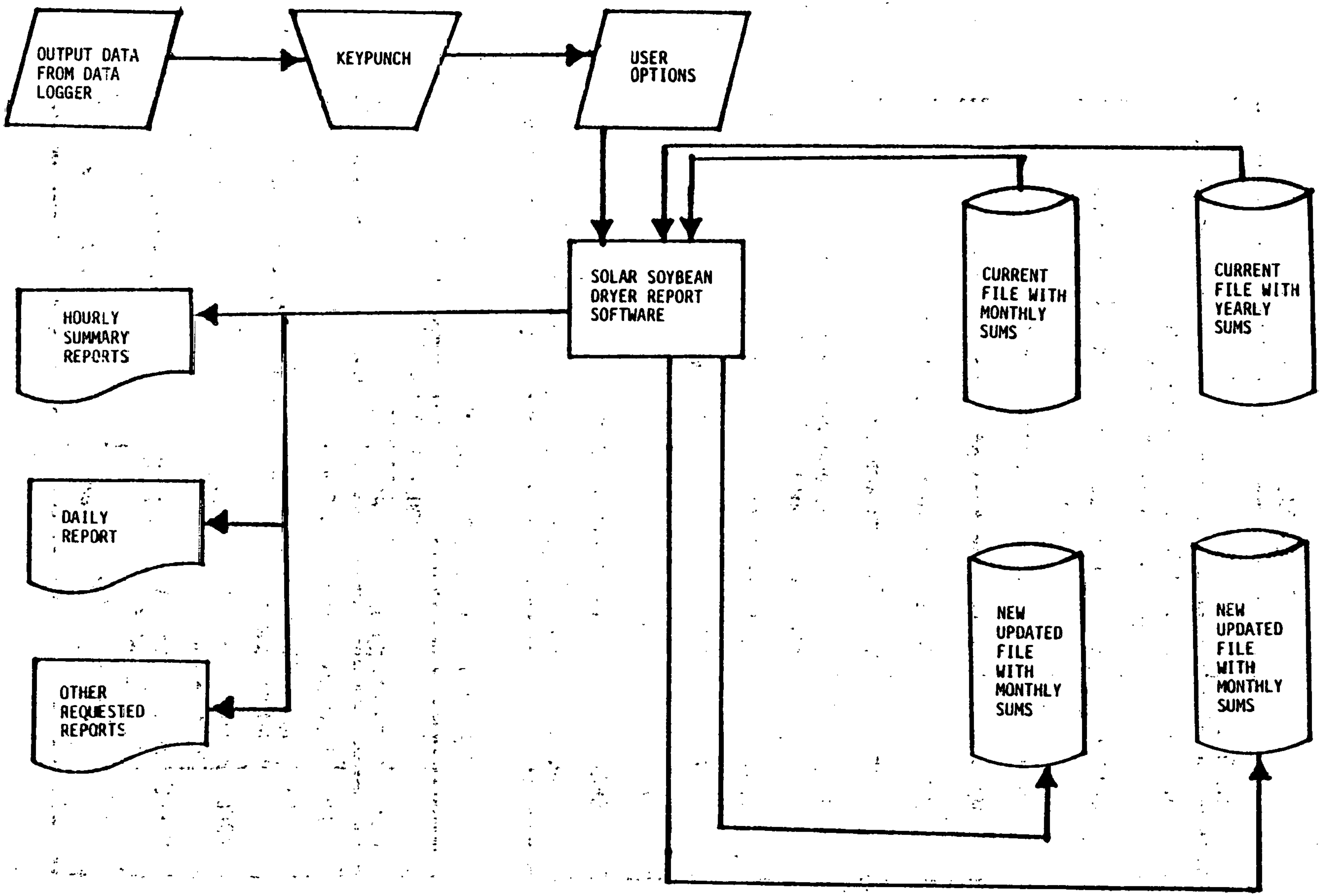


FIGURE 2-21. OVERVIEW OF PERFORMANCE AND EFFICIENCIES FOR EVALUATING SYSTEM

TABLE 2-7. MODULE IDENTIFICATION

MODULE	PURPOSE
AVERAGE	Calculate, sum, and average data for hourly and daily reports.
DATCHK	Read input data and choose appropriate processing method.
JULDAY	Check for new month or year.
MAIN	Driver for type of reports desired.
MNTHLY	Calculate monthly averages.
PARM	Calculate parameters.
PRINT	Print reports and create data buffers and create data files.
TEST	Test input data for validity.
YEARLY	Calculate yearly averages.
HEAD	Hourly report heading.
DHEAD	Daily report heading.
NAMNTH	Data statement with names of months.

TABLE 2-8. IDENTIFICATION OF EXTERNAL FILES

NAME	DEFINITION	MODULE INTERFACE		FILE TYPE
		READ	WRITE	
BUFF	User Card Input	DATCHK		Card deck
MNFL1	Input File for Monthly Sums	DATCHK	Print	Mass storage
YRFL3	Input File for Yearly Sums	Yearly	Print	Mass storage
MBFL2	Output File for Monthly Sums	DATCHK	Print	Mass storage
YRFL4	Output File for Yearly Sums	Yearly	Print	Mass storage

TABLE 2-9. INPUT PARAMETER TABLE

GRP NO.	PARAMETER NAME	MNEMONIC	VALUES	UNITS/VALUE MEANING
	PARAMETERS USED IN EQUATIONS	PARAM		
	INPUT VARIABLES	INPUT		
	INTERNATION VARIABLES USED WITHIN PROGRAM	INTERN		
	OUTPUT VARIABLES	OUTPUT		
	BUFFER USED TO STORE HOURLY AND DAILY OUTPUTS	BUFFER		
	INFORMATION REGARDING TIME	DAY		
	CARD READER AND LINE PRINTER	TST		
	COUNTERS FOR BUFFERS	COUNT		
	INFORMATION REGARDING DAY	DATE		
	FILE NAMES	FILE		
	NAMES OF MONTHS	MONTH		
	NEW OUTPUT FOR REPORTS	NEW		
	NEW MONTHLY OUTPUTS FOR REPORTS	NEW MONT.		

ISSUE COMMON BLOCK DATE 6/12/78 ID SEC PAGE

3. SYSTEM OPERATION AND MAINTENANCE

3.1 RESPONSIBILITIES

The solar energy system and its ancillary systems are conveniently delineated for purposes of operation and maintenance. Teledyne Brown Engineering will be responsible for maintaining the control subsystem and the instrumentation monitoring and processing system. Gold Kist will be responsible for maintaining and operating the solar system (with the exception noted above) and for minor operation and maintenance requirements of the Data Acquisition Unit. These latter functions primarily consist of refilling the printer tape and control of the DAU when the dryers are not operating during repair and maintenance periods.

It is the responsibility of TBE and Gold Kist to properly log and fill out the appropriate operation and maintenance log and forms. The following sections describe the significant operation and maintenance requirements.

3.2 SYSTEM OPERATION

3.2.1 Solar Energy System

System operation is performed by Gold Kist dryer operators. Control of the system is extremely simple; there are only two operations that must be considered: controlling the blower and positioning the louvers in the dryer house.

Prior to operation of any electrical subsystem, the proper switches must be activated to provide power. Figure 3-1 illustrates the main power panel, main subpanel, and air handler control panel. The location of these panels in the control room can be identified in Figure 2-7. Table 3-1 presents the power-on sequence and the normal position of all switches.

The air handler blower can be controlled in either of two modes: manual or automatic. Table 3-2 presents the manual start-up sequence.

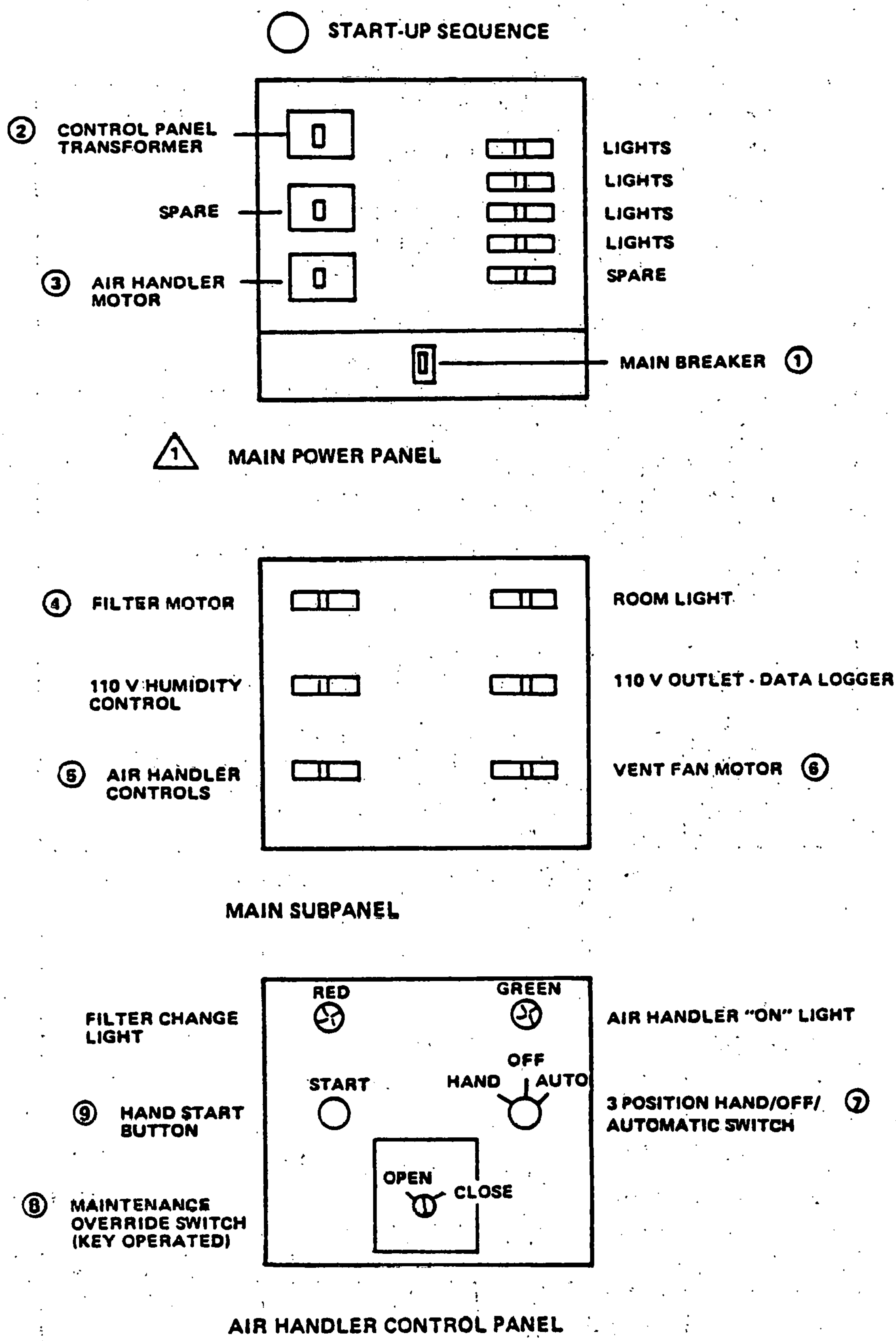


FIGURE 3-1. CONTROL PANELS

TABLE 3-1. POWER-ON SOLAR SYSTEM SEQUENCE

1*	Main Breaker - On
2	Control Panel Transformer - On
3	Air Handler Motor - On
4	Filter Motor - On
5	Air Handler Controls - On
6	Vent Fan Motor - On

*Operation number is keyed to switches in Figure 3-1.

TABLE 3-2. MANUAL START-UP SEQUENCE

7*	3-Position Switch - to "Hand"
8	Maintenance Override Switch - Key to "Close"
9	Hand Start Button - Push to Start

*Operation number is keyed to switches in Figure 3-1.

An automatic system is provided as the primary mode of operation. This system turns the blower on when the temperature in the solar panel reaches about 40° above ambient and shuts it down when the temperature drops to 20°F above ambient. Table 3-3 illustrates the sequence for automatic start-up. This mode would be interrupted for two reasons: 1) shutdown for maintenance of the conventional grain drying system and 2) shutdown for maintenance of the solar facility.

The solar facility is checked at least twice daily, morning and night, by a Gold Kist dryer operator. If the system is being operated manually, the blower is turned on. Regardless of the mode of operation, he checks the filter light to determine whether filter roll refill is required.

TABLE 3-3. AUTOMATIC START-UP SEQUENCE

7*	3-Position Switch - to "Auto"
8	Maintenance Override Switch - Key to "Close"

*Operation number is keyed to switches in Figure 3-1

The operator is also responsible for positioning the three louvers that control the flow of solar-heated air to the dryer house. The louvers are simply positioned open at the dryers that are in operation and closed at the dryers that are not in operation. Louver position is checked each time dryer operations are changed.

3.2.2 Data Acquisition System

During normal operation, the Data Acquisition Unit presents minimal operational requirements. These are: 1) halt printing when either the conventional grain dryers or the solar facility are not operational and 2) reset the clock if power is interrupted. The former is accomplished by pressing the SINGLE button under SCAN CONTROL. To restart data recording, the MONITOR button is pressed.

All the data are keyed to the clock provided in the logger. Table 3-4 presents the clock reset operations after power interruption.

3.3 SOLAR ENERGY SYSTEM MAINTENANCE

Maintenance of the solar facility is conducted by Gold Kist maintenance personnel. There are two areas of maintenance that require regular attention: 1) panel cleaning and cleaning system and 2) the air handler.

Scheduled maintenance should be accomplished according to the appropriate equipment manufacturers' instructions as follows:

Maintenance Item	Frequency
Clean Collector Glazing	Monthly
Lubricate Blower Bearings	Monthly
Check Blower Belt Tension	Quarterly
Lubricate Blower Motor	Quarterly
Change Oil in Cleaning Subsystem Pressure Pump	Semiannually

TABLE 3-4. CLOCK RESET PROCEDURE

PRESS BUTTON	DISPLAY
	Light (POWER FAILURE REENTER TIME)
DAYS (under TIME ENTRY)	
0 } This is the day of	0
7 } the year; for example,	7
5 } the 75th day is March 11.	5
ENTER/STEP (under DATA ENTRY)	
HR MIN SEC	
1 } Put in the hour of the day from midnight; for	1
5 } example, the 15th hour is 3 p.m. (12:00 + 3:00).	15
0 } Put in the minute of the hour; for example, the	150
5 } time is 3:05 p.m.	1505
5 } Put in the second of the minute; for example, the	10555
2 } time is 3:05:52.	105552
ENTER/STEP (under DATA ENTRY)	

All scheduled maintenance interrupting system operation should be performed during night shift operation to minimize the interruption of solar energy collection.

3.3.1 Panel Cleaning and Cleaning System

Limited experience has shown that cleaning the collector panels at monthly intervals will maintain a qualitatively acceptable level of contamination. Performance tests will be conducted on individual panels to quantitatively determine whether performance loss is acceptable with this cleaning frequency. During Phase III, cleaning frequency will be adjusted to provide a balance between cleaning costs and performance degradation.

Operation of the high-pressure cleaning system is described in Section 2.1.5. Three men are required to effectively accomplish the cleaning exercise. One man applies the soap from the high-pressure dispensing system and one man follows with a brush, scrubbing up accumulated deposits. The third man follows with a water hose to flush off soap and deposits. Approximately 6 hours are required for a cleaning, although with experience this time may be reduced somewhat.

The washing system requires little maintenance. The procedures are detailed in the instruction and operation manual provided with the system. The major item requiring attention is semiannual oil change of the pump.

3.3.2 Air Handler

Detailed maintenance instructions are contained in the installation manual provided with the unit. The primary item that must be considered is replacement of the roll filter medium when the need for a new filter is indicated by a red warning light that appears on the air handler control panel (Figure 2-7).

3.4 DATA ACQUISITION SYSTEM MAINTENANCE

The data acquisition system requires little scheduled maintenance. It primarily involves refilling the printer with paper tape as required and periodic calibration of critical sensors. Each morning as the dryer operator makes his scheduled round to the control house, he will check the paper level in the printer and refill as necessary. He also cleans the outer hemisphere of the pyronometer at least once a day. This is accomplished with a lint-free soft cloth to avoid scratching the surface and consequently altering the optical properties. The dessicant installed in the pyronometer case will be inspected quarterly and dried out if required.

Measurement of the solar energy system performance is critically dependent on the measurement of temperature and air flow rate. Thus instruments providing these measurements will be calibrated quarterly against standard references. Calibration of temperature probes in an ice bath is an effective means of providing a 0°C (32°F) temperature reference.

The flowmeter will be field calibrated against a pitot tube and inclined manometer reference. The range of the manometer is 0.05 to 0.25 in. of water with a minor scale division of 0.005 in. of water (283 ft/sec at standard temperature and pressure). This scale provides a reading accuracy of about 3%, enough to assess any large drift in flowmeter accuracy.

It is recommended that the pyronometer be checked at least once a year, which is beyond the term of Phase III. However, to assure quality of data being collected, it will be removed and transported to The University of Alabama in Huntsville where it will be checked against carefully maintained units.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

4. NONINSTRUMENTED DATA ACQUISITION

A complete system evaluation program must contain a thorough and systematic acquisition and analysis procedure for noninstrumented data. These data consist of manually recorded information associated with system maintenance, operation, and owning costs.

The nature, cost, and system down time associated with scheduled and unscheduled maintenance will be recorded on prepared forms. Figure 4-1 is a sample of the Maintenance Data Form to be filled out at the completion of each maintenance action, scheduled or unscheduled. Each completed form should indicate the subsystem on which maintenance was conducted. For recording purposes, the following subsystem categories will be used:

- Collector Subsystem
  - ▲ Collectors
- Control Subsystem
  - ▲ Sensors
  - ▲ Sensor interconnections
- Energy Transport Subsystem
  - ▲ Air handling unit
  - ▲ Duct and dampers
- Structural Subsystem
  - ▲ Steel members and fasteners
  - ▲ Foundations
  - ▲ Walkways, handrails, and gutters
  - ▲ Lightning protection
- Cleaning Subsystem
  - ▲ Pump
  - ▲ Piping
  - ▲ Hose/nozzle
  - ▲ Chemical injection equipment

MAINTENANCE DATA FORM

1. DATE	2. PREPARED BY	3. MAINTENANCE PERFORMED BY
7/19/78	John Doe	Jim Smith

4. AREA OF MAINTENANCE - SUBSYSTEM

COLLECTOR ☐ ENERGY TRANSPORT ☒ CLEANING ☐

CONTROL ☐ STRUCTURAL

COMPONENT/PART	TYPE IF ACTION (SEE CODES BELOW)	TIME REQUIRED hr	TIME REQUIRED min
A. Air Handling Unit (Belts)	REPL	1	20
B.			
C.			

TYPE OF ACTION CODES: ADJUSTMENT ADJ; REPAIR R; REPLACEMENT RPL

5. DESCRIPTION OF MAINTENANCE

TYPE: SCHEDULED ☐ UNSCHEDULED ☒

A. PROBLEM: Frayed Belts

B. CAUSE: Normal Wear

C. CORRECTIVE ACTION: Replaced all 4 belts

6. SOLAR DOWN TIME (ESTIMATED SOLAR RADIATION TIME LOST DUE TO):

SOLAR SYSTEM MAINTENANCE 1 hr; DRYER MAINTENANCE ____ hr

7. COST OF MAINTENANCE PERFORMED BY: IN-HOUSE GOLD KIST ☐

IN-HOUSE TBE ☐

CONTRACTED (INVOICE ATTACHED) ☐

LABOR CATEGORY	hr		RATE ($/hr)		LABOR COST
1243	1/3	×	6.86	=	2.29
5678	1	×	5.49	=	5.49
		×		=	

TOTAL LABOR COST 7.78

PARTS COST 26.13

MATERIAL COST

TOTAL MAINTENANCE COST 33.91

FIGURE 4-1. SAMPLE MAINTENANCE DATA FORM

IMPORTANT: Item 6 on the Maintenance Data Form is for recording solar collection hours lost due to maintenance. A Maintenance Data Form should also be filled out when the solar system is operational and the conventional dryer system is down for maintenance.

The labor rate used on the Maintenance Data Form will include all benefits, overhead, and Social Security costs.

Figure 4-2 is an example of the Scheduled Maintenance Log. This form will be kept in a secure location in the instrument building. When the items of scheduled maintenance are accomplished, the appropriate block will be initialed and dated. Scheduled maintenance will also be recorded on the Maintenance Data Form.

The cost of energy and insurance is recorded monthly on the Energy and Insurance Data form shown in Figure 4-3. These data will be obtained by TBE from the Gold Kist accounting department. The electricity and insurance data are associated with owning and operating the solar system and must reflect a value for cash flow analysis every month. Therefore, the insurance premium must be shown as a monthly distribution of cost.

SCHEDULED MAINTENANCE LOG

ITEM	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Clean Collector Glazing	●	●	●	●	●	●	●	●	●	●	●	●
Lubricate Blower Bearings	●	●	●	●	●	●	●	●	●	●	●	●
Check Blower Belt Tension			●			●			●			●
Lubricate Blower Motor			●			●			●			●
Change Oil in Cleaning System Pressure Pump						●						●

● = Month due

FIGURE 4-2. SAMPLE SCHEDULED MAINTENANCE LOG

		INITIAL SUPPLY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
FUEL OIL	Date of Last Purchase													
	Gallons Purchased													
	Rate ($/gal)													
ELECTRICITY	kWh Used													
	Rate ($/kWh)													
	Value ($)													
INSURANCE	Date Paid													
	Premium ($)													
	Monthly Distribution ($)													

FIGURE 4-3. ENERGY AND INSURANCE DATA SUMMARY

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

5. INSTRUMENTED DATA ANALYSIS

5.1 DESCRIPTION OF ANALYTICAL PROCEDURES

This section describes the analytical procedures used to determine thermal effectiveness for hourly, daily, and annual operating periods. Performance evaluation factors and nomenclature have been selected to conform as closely as possible to the requirements imposed on the National Solar Heating and Cooling Demonstration Program*.

The performance evaluation factors are of two types: 1) a thermal energy quantity defined by the letter "Q" and 2) a performance index defined by the letter "N". Figure 5-1 illustrates the location and type of measurements used in determining performance evaluation factors.

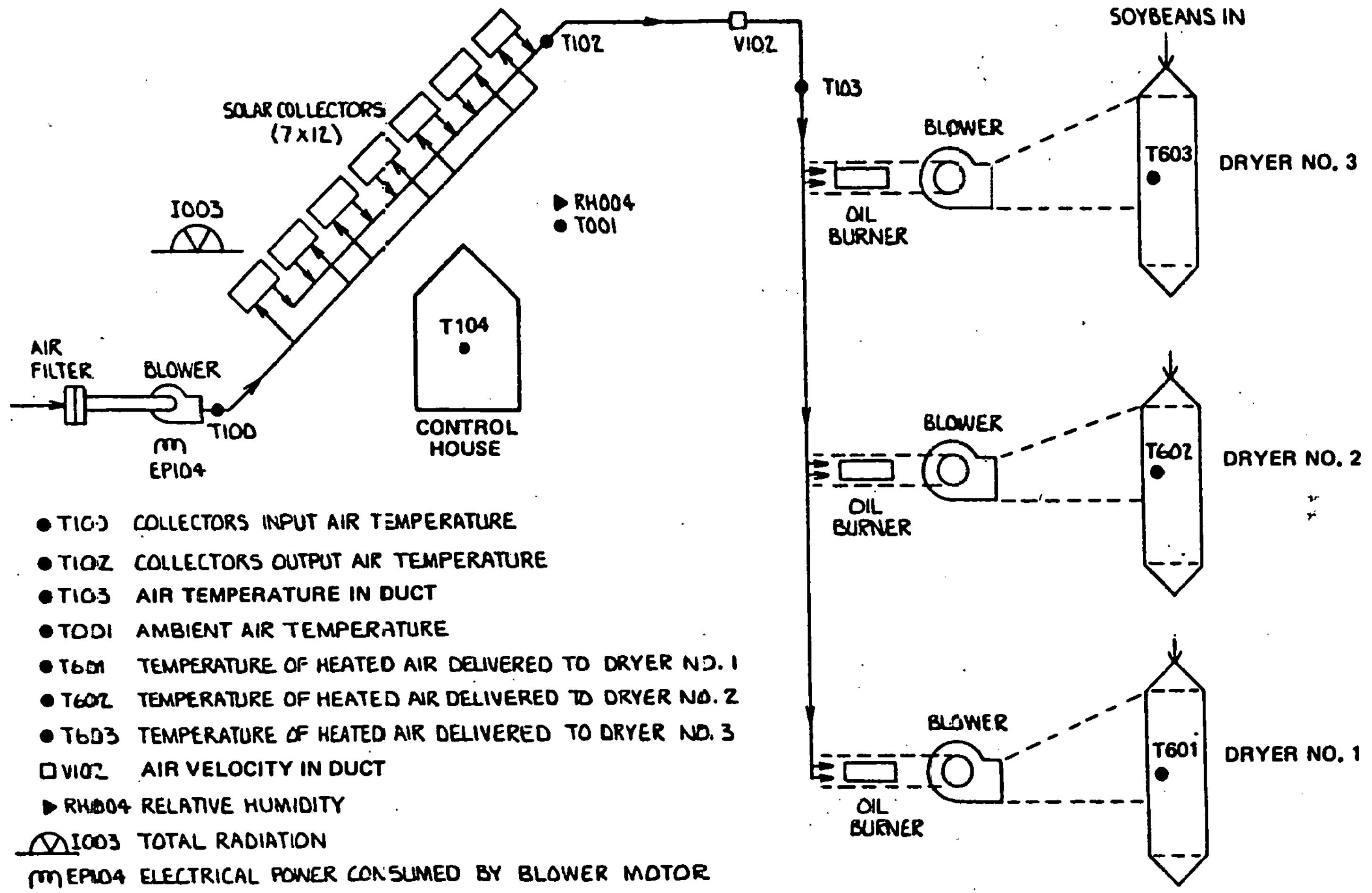
The measured parameters are sampled at 5-min intervals if the grain drying system is in operation. Whenever grain drying operations are not in progress, then the Data Acquisition Unit is inactivated. To determine hourly summaries of performance factors, the measurements acquired over the hour are averaged and the appropriate conversion factors are applied. Daily summaries are similarly determined by averaging the hourly summaries over the day. Figures 5-2 and 5-3 illustrate the index notation used in describing the hourly and daily summaries.

Table 5-1 describes the measured variables, their units as recorded on the output tape of the data logger, and the data channel number. In addition to the measured variables, the date and time are entered with each measurement sample. The units are:

- Date - Julian days
- Hours - military hours
- Minutes
- Seconds.

Figure 5-4 is a sample of a tape obtained from the data logger.

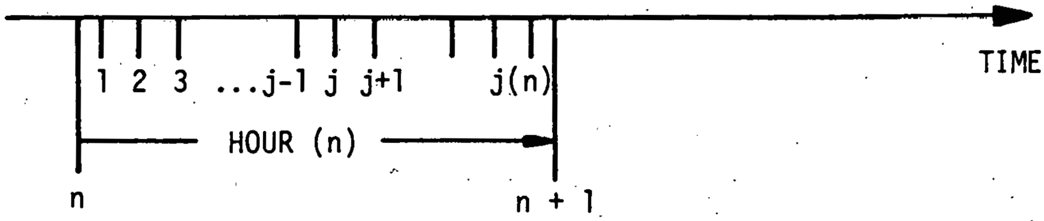
*"Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program", National Bureau of Standards, BNSIR 76-1137



LEGEND:

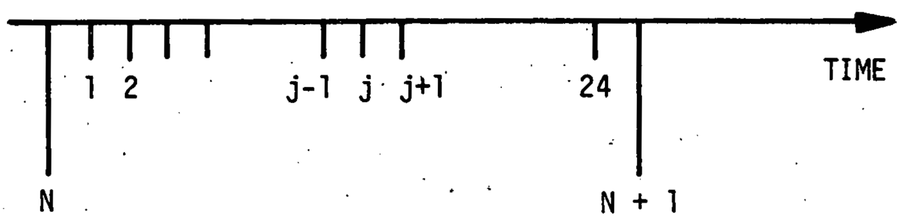
- ● T100 COLLECTORS INPUT AIR TEMPERATURE
- ● T102 COLLECTORS OUTPUT AIR TEMPERATURE
- ● T103 AIR TEMPERATURE IN DUCT
- ● T001 AMBIENT AIR TEMPERATURE
- ● T601 TEMPERATURE OF HEATED AIR DELIVERED TO DRYER NO. 1
- ● T602 TEMPERATURE OF HEATED AIR DELIVERED TO DRYER NO. 2
- ● T603 TEMPERATURE OF HEATED AIR DELIVERED TO DRYER NO. 3
- □ V102 AIR VELOCITY IN DUCT
- ▶ RH004 RELATIVE HUMIDITY
- I003 TOTAL RADIATION
- EP104 ELECTRICAL POWER CONSUMED BY BLOWER MOTOR
- ● T104 CONTROL HOUSE TEMPERATURE

FIGURE 5-1. SENSOR LOCATION



j - jth SAMPLE IN THE nth HOUR INTERVAL
n - nth HOUR IN THE DAY
j(n) - NUMBER OF DATA SAMPLES IN THE nth HOUR

FIGURE 5-2. INDEX NOTATION FOR HOURLY PERFORMANCE FACTOR SUMMARIES



j - jth HOUR IN THE DAY
N - Nth DAY OF THE YEAR

FIGURE 5-3. INDEX NOTATION OF DAILY PERFORMANCE FACTOR SUMMARY

TABLE 5-1. INPUT VARIABLES

DESCRIPTION	UNITS	VARIABLE	RANGE	CHANNEL NUMBER
Total Solar Incident	mV	I003	0 to 11	1
Collector Input Air Temperature	°F	T100	-10 to +110	11
Collector Output Air Temperature	°F	T102	-10 to +300	12
Blower Power	V	EP101	0 to 4	2
Temperature in Duct	°F	T103	-10 to +200	13
Ambient Air Temperature	°F	T001	-10 to +110	14
Temperature in Dryer No. 1	°F	T601	-10 to +200	17
Temperature in Dryer No. 2	°F	T602	-10 to +200	16
Temperature in Dryer No. 3	°F	T603	-10 to +200	15
Relative Humidity	%	RH004	0 to 100	4
Air Flow Velocity	V	V102	0 to 6	3
Fuel Flow to Dryer No. 1*				
Fuel Flow to Dryer No. 2*				
Fuel Flow to Dryer No. 3*				

*Not currently measured. Will be added at future time.

18	93.3	°F
17	193.8	°F
16	114.4	°F
15	184.3	°F
14	90.5	°F
13	146.0	°F
12	149.8	°F
11	90.3	°F
4	144.66	mV
3	3.919	V
2	2.398	V
1	6.621	mV

999999
150:13:15:38

18	93.2	°F
17	192.7	°F
16	115.5	°F
15	184.4	°F
14	89.9	°F
13	147.2	°F
12	145.0	°F
11	89.9	°F
4	145.36	mV
3	3.927	V
2	2.560	V
1	6.674	mV

999999
150:13:10:38

18	93.1	°F
17	193.0	°F
16	115.7	°F
15	185.1	°F
14	89.1	°F
13	146.4	°F
12	146.2	°F
11	89.9	°F
4	148.62	mV
3	3.960	V
2	2.647	V
1	6.846	mV

999999
150:13:05:38

FIGURE 5-4. SAMPLE OF TAPE OUTPUT FROM DATA LOGGER

Tables 5-2 and 5-3 present the thermal energy parameters and performance indices used to evaluate system and subsystem performance for hourly and daily summaries.

The following sections present the defining equations used to compute the performance parameters.

5.1.1 Climatic Performance Factors

5.1.1.1 Total Solar Incident - Direct and diffuse incident solar radiation is measured by a sensor mounted in the plane of the collector array. The instantaneous total radiation samples are used to determine the hourly value by the following equation:

$$Q001 = \frac{1}{9.69(10^{-3}) \times 3.153 \times J(n)} \sum_{j=1}^{J(n)} I003(j) \quad \text{Btu/hr-ft}^2$$

where the constants are as follows:

Conversion of sensor output to engineering units

$$1 \text{ mV} = \frac{1}{9.69(10^{-3})} \quad \text{W/m}^2$$

Conversion from SI units to British engineering units

$$1 \text{ W/m}^2 = \frac{1}{3.153} \quad \text{Btu/hr-ft}^2 \quad .$$

The daily summaries are computed as follows:

$$Q031 = \frac{H}{J(N)} \sum_{j=1}^{J(N)} I003(j) \text{ Btu/ft}^2$$

$$Q081 = Q031 \; A_C \quad \text{Btu}$$

where H is the integer number of hours in which data samples occur.

TABLE 5-2. HOURLY SUMMARY OF THERMAL ENERGY PARAMETERS

DESCRIPTION	VARIABLE	UNITS	
		SI	BRITISH ENGINEERING
Total Solar Incident	Q001	W/m^2	$Btu/hr\text{-}ft^2$
Solar Energy Collected	Q100	W/m^2	$Btu/hr\text{-}ft^2$
ECDS Operating Energy	Q102	W	Btu/hr
Transport Heat Loss	Q103	W	Btu/hr
Total Solar Energy Utilized	Q203	W	Btu/hr
Collector Efficiency	N101	%	%
Collector Panel Efficiency Factor	N102	$\frac{°C\ m^2}{J}$	$\frac{°F\ ft^2}{Btu}$
ECDS Coefficient of Performance	N110	%	%
ECDS Conversion Efficiency	N111	%	%
ECDS Utilization Efficiency	N112	%	%
Dryer Load	Q402	W	Btu/hr
Fossil Energy for Auxiliary	Q410	W	Btu/hr
Average Ambient D.B. Temperature	N113	°C	°F
Solar Fraction of Energy Consumed	N410	%	%

TABLE 5-3. DAILY SUMMARY OF THERMAL ENERGY PARAMETERS

DESCRIPTION	VARIABLE	UNITS	
		SI	BRITISH ENGINEERING
Total Solar Incident	Q081	J	Btu
Total Solar Incident	Q031	J/m^2	Btu/ft^2
Solar Energy Collected	Q180	J	Btu
Solar Energy Collected	Q130	J/m^2	Btu/ft^2
ECDS Operating Energy	Q132	J	Btu
Transport Heat Loss	Q133	J	Btu
Total Solar Energy Utilized	Q233	J	Btu
Fossil Energy Saved	Q243	liters	gal
Collector Efficiency	N131	%	%
Dryer Load	Q432	J	Btu
Fossil Energy for Auxiliary	Q450	J	Btu
Average Ambient D.B. Temperature	N143	°C	°F
Solar Fraction of Energy Consumed	N441	%	%
Collector Panel Efficiency Factor	N132	$\frac{°C\ m^2}{J}$	$\frac{°F\ ft^2}{Btu}$

5.1.1.2 Average Ambient Dry Bulb Temperature - Average ambient dry bulb temperature is a significant parameter in determination of system performance and comparison of alternative solar energy systems in different climatic regions. The hourly averaged dry bulb temperature is:

$$N113 = \frac{1}{J(n)} \sum_{j=1}^{J(n)} T001(j) \quad {}^{\circ}F \quad .$$

The daily average ambient dry bulb temperature is:

$$N143 = \frac{H}{J(N)} \sum_{j=1}^{J(n)} T001(j) \; {}^{\circ}F$$

5.1.2 Energy Collection and Distribution Subsystem (ECDS)

5.1.2.1 Solar Energy Collected - The amount of energy collected in the hourly interval is:

$$Q100 = \frac{1}{A_c\, J(n)} \sum_{j=1}^{J(n)} W100(j) \times C100(j) \times TD100(j) \quad Btu/hr\text{-}ft^2$$

where

A_c - total collector area defined by the collector aperture, ft^2

W100(j) - air flow rate, lb/hr

C100(j) - specific heat of air at temperature TA100(j), Btu/lb-°F

TA100(j) = [(T100 + T102)/2 + 460] 5/9 °K

TD100(j) = T102 - T100 °F .

The daily summary of solar energy collected is

$$Q130 = \frac{H}{J(N)} \sum_{j=1}^{J(N)} W100(j) \times C100(j) \times TD100(j) \quad Btu/ft^2$$

$$Q180 = Q130\, A_c \quad Btu/day \quad .$$

5.1.2.2 Collector Efficiency - The ratio of the solar energy collected by the array to the total solar energy incident on the array is termed the collector efficiency. It is a measure of the ability of the solar collector to convert incident radiation into thermal energy, which is subsequently transported to the dryer. The efficiency is calculated by:

$$\text{N101} = \frac{100 \times \text{Q100}}{\text{Q001}} \quad \% \; .$$

The daily summary of collector efficiency is:

$$\text{N131} = \frac{100 \times \text{Q130}}{\text{Q031}} \quad \% \; .$$

5.1.2.3 Collector Panel Efficiency Factor - The efficiency of a flat-plate collector operating under steady-state conditions can be approximated by a linear equation with the following independent variable:

$$\frac{\text{fluid temperature leaving collector - ambient temperature}}{\text{total incident radiation}} \; .$$

This variable is calculated by:

$$\text{N102} = \frac{1}{\text{J(n)}} \sum_{j=1}^{\text{J(N)}} \frac{\text{T102}(j) - \text{T001}(j)}{\text{I001}(j)} \quad \frac{°\text{F hr}}{\text{Btu}} \; .$$

The daily averaged efficiency factor is

$$\text{N132} = \frac{1}{\text{J(N)}} \sum_{j=1}^{\text{J(N)}} \frac{\text{T102}(j) - \text{T001}(j)}{\text{I001}(j)} \quad \frac{°\text{F hr}}{\text{Btu}} \; .$$

5.1.2.4 ECDS Operating Energy - The blower electrical energy consumption is measured by a wattmeter with an output of 0.25 kW/V. Hence the equation for thermal energy introduced into the system by the blower is:

$$Q102 = \frac{3413 \times 4}{J(n)} \sum_{j=1}^{J(n)} EP101(j) \quad \text{Btu/hr} \quad .$$

The daily summary of ECDS operating energy is:

$$Q123 = \frac{3413 \times 4 \times H}{J(N)} \sum_{j=1}^{J(N)} EP101(j) \quad \text{Btu.}$$

The constant, 4, converts the linear output of the wattmeter from volts to kilowatts.

5.1.2.5 Total Solar Energy Utilized - The solar energy used is that which is injected into the dryer house and measured relative to the air conditions entering the collector. Since there is not a temperature measurement of the solar-heated air at the dryer house, the temperature at the exit of the SCDS must be estimated based on extrapolations from measurements of air temperature at upstream locations in the duct.

The duct, which is immersed in ambient air, behaves as a heat exchanger in which one medium is at constant temperature. Thus the air temperature varies according to the exponential relationship. The equations for this extrapolation are:

$$K = \frac{1}{X103} \ln \frac{T102 - T001}{T103 - T001}$$

and the temperature at the dryer house is extrapolated to be:

$$T104 = T001 + (T102 - T001) \exp(-X104 \cdot K) \quad .$$

The solar heat injected into the dryer house is therefore:

$$Q203 = \frac{1}{J(n)} \sum_{j=1}^{\infty} W100(j) \times C104(j) \times TD104(j) \quad \text{Btu/hr} .$$

where

W100(j) - air flow rate, lb/hr

C104(j) - specific heat of air at temperature TA104(j), Btu/lb-°F

$$TA104(j) = \left[\frac{T104(j) + T102(j)}{2} + 460\right] \frac{5}{9} \quad K$$

$$TD104(j) = T104(j) - T100(j) \quad °F$$

X103 = 152 ft

X104 = 222 ft.

The daily summary of total solar energy utilized is:

$$Q233 = \frac{H}{J(N)} \sum_{j=1}^{J(N)} W100(j) \times C104(j) \times TD104(j) \quad \text{Btu} .$$

5.1.2.6 Fossil Energy Saved - The fossil energy saved is computed for the daily summary only. It is the fuel oil equivalent of the solar energy utilized. Hence:

$$Q243 = \frac{Q233}{(HVF) \times (NHTF)} \quad \text{gal}$$

where

HVF - heating value of No. 5 fuel oil (=148,800), Btu/gal

NHTF - thermal efficiency of fossil combustors (= 0.99).

5.1.2.7 Transport Subsystem Heat Loss - The transport subsystem heat loss is the difference between the energy collected and the energy at the dryer house. Hence:

$$Q103 = Q100\ A_c - Q203 \text{ Btu/hr} .$$

The daily summary of transport subsystem heat loss is:

$$Q133 = Q180 - Q233 \text{ Btu.}$$

5.1.2.8 ECDS Coefficient of Performance - Energy conversion equipment uses electrical energy or thermal energy to raise heat from a low-temperature source to a higher-temperature sink. It is rated by the ratio of useful heat transferred to the energy input. Thus the coefficient of performance is:

$$N110 = \frac{Q203}{Q102} .$$

5.1.2.9 ECDS Conversion Efficiency - The ratio of total solar energy actually used to the total solar energy incident on the collector array is termed the solar subsystem conversion efficiency and is a measure of the ability of the system to convert incident radiation into useful thermal energy. The ECDS conversion efficiency is calculated by:

$$N111 = \frac{100 \times Q203}{A_c \times Q001} .$$

5.1.2.10 ECDS Utilization Efficiency - The ratio of total solar energy actually used to the solar energy collected is termed the utilization efficiency and is a measure of the ability of the system to utilize collected energy. The ECDS utilization efficiency is calculated by:

$$N112 = \frac{100 \times Q203}{A_c \times Q100} .$$

5.1.2.11 Solar Fraction of Energy Consumed - The fraction of solar energy consumed by the drying process is:

$$N410 = \frac{100 \times Q203}{Q402} .$$

5.1.3 Conventional Grain Drying System

5.1.3.1 Fossil Energy for Auxiliary - The fossil energy used for drying will be accurately measured by flowmeters to be installed at a later date. The relationship for computing the energy added is

$$Q410 = \frac{60 \times HVF}{J(n)} \sum_{j=1}^{J(n)} F401(j) + F402(j) + F403(j) \quad Btu/hr .$$

Since the flowmeters are not yet installed, fossil energy used must be approximated from the energy in the air flow. This estimate is an approximation only because measurements and accurate data are lacking on combustion efficiency, heat loss in dryer hot air plenum, blower electrical energy*, and most importantly, air flow rate. Hence, for the time being:

$$Q410 = Q402 - Q203 - Q102 \quad Btu/hr \quad .$$

5.1.3.2 Dryer Load - The dryer load is determined indirectly from the temperature in the dryer hot air plenum and an estimate of the dryer standard air flow rate. Thus:

$$Q41 = \frac{1}{J(n)} \sum_{j=1}^{J(n)} 1.08 \times 150{,}000 \times TD601(j)$$

$$Q42 = \frac{1}{J(n)} \sum_{j=1}^{J(n)} 1.08 \times 150{,}000 \times TD602(j)$$

$$Q43 = \frac{1}{J(n)} \sum_{j=1}^{J(n)} 1.08 \times 150{,}000 \times TD603(j)$$

$$Q402 = Q41 + Q42 + Q43 \quad Btu/hr$$

*Blowers in the grain dryer house.

where

$$TD601(j) = T601(j) - T001(j) \quad °F$$

and so on for 602 and 603.

The daily summary of dryer load is

$$Q41D = \frac{H}{J(N)} \sum_{j=1}^{J(N)} 1.08 \times 150{,}000 \times TD601(j)$$

$$Q42D = \frac{H}{J(N)} \sum_{j=1}^{J(N)} 1.08 \times 150{,}000 \times TD601(j)$$

$$Q43D = \frac{H}{J(N)} \sum_{j=1}^{J(N)} 1.08 \times 150{,}000 \times TD602(j)$$

$$Q432 = Q41D + Q42D + Q43D \quad \text{Btu} \quad .$$

5.1.4 Special Parameters

5.1.4.1 Air Mass Flow Rate - The equation used to compute air mass flow rate is

$$W100(j) = 73.65 \; V102(j) \quad .$$

This equation was derived in Section 2.2.2.

5.1.4.2 Specific Heat of Air - The specific heat of air is based on a polynomial relationship provided by Obert and Gaggioli*. For example:

$$C100 = \frac{6.713 + 0.4697(10^{-3})(TA100) + 1.147(10^{-6})(TA100)^2 - 0.4696(10^{-9})(TA100)^3}{28.967}$$

where

$$TA100 = \left[\frac{(T100 + T102)}{2} + 460\right]\frac{5}{9} \quad K \quad .$$

*E. F. Obert and R. A. Gaggioli, "Thermodynamics", Second Edition, McGraw Hill Book Company, New York, 1963

The equation is valid within a range of 273 to 1,800 K with a maximum error of 0.72%.

5.2 DESCRIPTION OF COMPUTER PROGRAMS

In the computer program used to evaluate the equations described in the previous section (5.1), the user inputs the data that were collected and punched on cards, as described in Section 2.2. The program allows the user to choose the type of output report he desires, or the program automatically chooses the necessary type of report using the date or time. Within the program, data analyses are performed and averages or percentages are calculated as described in Section 5.1. The following subsections describe in greater detail the inputs, processing, and outputs.

5.2.1 Inputs

The inputs necessary for the program to be executed are numbers to identify the input and output files, a number to describe the type or types of reports desired, and the data cards that contain the instrumented data from the data logger. Numbers must be input to specify the FORTRAN units from which input data files will be read and the FORTRAN units onto which output data files will be written. These four external input and output files are described in Table 2-8 and the FORTRAN unit numbers that are input are described in Table 5-4, GRP1. Defining the number that signifies the type of report is the input variable IBUF. Three numbers describe the type of report. A "1" signifies that hourly and daily reports are to be printed if the date of any data sample is the first day of the month of the first day of the year. A "2" read into IBUG signifies that a monthly report is to be printed, and a "3" read into IBUF signifies that a yearly report is to be printed. IBUF is described in Table 5-4, GRP2. Up to 10 values for IBUF may be input at one time so that multiple executions of the program may be made. There are three data cards for each data sample for the test equipment. These inputs are described in Table 5-4, GRP3.

TABLE 5-4. SOLAR SOYBEAN DRYER EVALUATION PROGRAM, FORTRAN INPUTS

GRP NO.	PARAMETER NAME	MNEMONIC	VALUES	UNITS/VALUE MEANING
1	MONTHLY INPUT FILE	IFILE	8 or 9*	INTEGER FOR FORTRAN DISC UNIT
1	MONTHLY OUTPUT FILE	OFILE	8 or 9*	INTEGER FOR FORTRAN DISC UNIT
1	YEARLY INPUT FILE	IYFILE	10 or 11*	INTEGER FOR FORTRAN DISC UNIT
1	YEARLY OUTPUT FILE	OYFILE	10 or 11*	INTEGER FOR FORTRAN DISC UNIT
2	REPORT NUMBER	IBUF	1 to 3	1 - MONTHLY AND YEARLY REPORTS WILL BE PRINTED IF A SAMPLE'S DATE SIGNIFIES BEGINNING OF MONTH OR YEAR. OTHERWISE, HOURLY AND DAILY REPORTS WILL BE PRINTED. 2 - MONTHLY REPORT WILL BE PRINTED. 3 - YEARLY REPORT WILL BE PRINTED.
3	TOTAL SOLAR INCIDENT	I003	0 to 11	MV
3	COLLECTOR INPUT AIR TEMPERATURE	T100	-10 to 110	°F
3	COLLECTOR OUTPUT AIR TEMPERATURE	T102	-10 to 300	°F
3	BLOWER POWER	EP101		VOLTS
3	TEMPERATURE IN DUCT	T103	-10 to 200	°F

* These file numbers are switched from run to run so that the output from one run becomes the input for the next run.

ISSUE INPUTS DATE 6/12/78 ID SEC PAGE

TABLE 5-4 - Concluded

GRP NO.	PARAMETER NAME	MNEMONIC	VALUES	UNITS/VALUE MEANING
3	AMBIENT AIR TEMPERATURE	T001	0 to 110	°F
3	TEMPERATURE IN DRYER NO. 1	T601		°F
3	TEMPERATURE IN DRYER NO. 2	T602	0 to 200	°F
3	TEMPERATURE IN DRYER NO. 3	T603	-10 to 200	F
3	FUEL FLOW TO DRYER NO. 4	F401		
3	FUEL FLOW TO DRYER NO. 4	F402		
3	FUEL FLOW TO DRYER NO. 4	F402		
3	TEMPERATURE DIFFERENCE ACROSS ARRAY	TD104		
3	RELATIVE HUMIDITY	RH004	0 to 100	%
3	AIR FLOW VELOCITY	V102	900 to 2500	VOLTS

ISSUE Inputs DATE 6/12/78 ID SEC PAGE

5.2.2 Processing

Program variables are calculated using program constants and input data. These program variables are then used to calculate the outputs as described in Section 5.1. Outputs are then summed and averaged if necessary. The calculations, summing, and averaging are done in three separate steps. In some cases where the output data are a percentage, no summing or averaging occurs.

For example, the mathematical equation used to express Q100 (solar energy collected) is:

$$Q100 = \frac{1}{\text{collector area}} \frac{1}{\text{No. samples}} \sum_{j=1}^{j(n)} Q_{coll}(j)$$

where j(n) is number of samples.

This equation in the computer is accomplished in the following steps:

1. Q100 = $Q_{coll}(j)$ = W100(j) × C100(j) × TD100(j)
2. Sum of Q100 = sum of Q100 + Q100
3. Q100 = (1/collector area)(1/No. samples) (sum of Q100).

The sum of Q100 is initialized to zero. For each sample in a given timeframe (daily or hourly), the first and second steps are repeated. At the end of the specified time, the third step is performed to calculate Q100 for that period. The hourly and daily calculations are summed and averaged separately so that the daily calculations are not based on the hourly calculations but on individual data samples.

Monthly averages are based on daily averages. The sums of the days' averages are stored on a disk file. This file is input to the program each time it is run. When a daily average is made, the daily average is added to the respective average on the monthly file. When the first day of a new month is input, the program averages the sum of the daily averages and produces a monthly average.

Monthly averages are stored on a disk file. When a new month's average is calculated, the new month's average is then added to the monthly average file. When the first day of a new year is input, this file is read and the yearly average is calculated based on the previous monthly averages.

5.2.3 Output

There are four groups of outputs. These groups consist of hourly, defined in Table 5-5, GRP1; daily, defined in Table 5-5, GPR2; monthly, defined in Table 5-5, GRP3; and yearly, defined in Table 5-5, GRP4.

Five types of reports are provided as required: hourly, daily, daily summary, monthly, and yearly. The hourly report gives a table of all the outputs for each hour. Outputs are given in both SI units and British engineering units if applicable. At the end of each 24-hour period, a daily report is printed that summarizes the daily outputs for that period. The daily summary report includes outputs for each day in tabular form. At the end of each month a monthly report is written, and at the end of each year a yearly report is written.

There are four pages in each hourly report. An example of the hourly report is shown in Figure 5-5. The daily report provides the parameters calculated for a 24-hour period from 0100 to 2400 hours. The example daily report is shown in Figure 5-6. The monthly reports and the yearly reports will contain the same information as the daily report (Figure 5-6).

TABLE 5-5. SOLAR SOYBEAN DRYER EVALUATION PROGRAM, OUTPUTS

GRP NO.	PARAMETER NAME	MNEMONIC	VALUES	UNITS/VALUE MEANING
1	TOTAL SOLAR INCIDENT	Q001HA		WATTS/m^2 (Btu/hr/ft^2)
1	SOLAR ENERGY COLLECTED	Q100HA		WATTS/m^2 (Btu/hr/ft)
1	ECDS OPERATING ENERGY	Q102HA		WATTS (Btu/hr)
1	COLLECTOR TRANSPORT HEAT LOSS	Q103HA		WATTS (Btu/hr)
1	TOTAL SOLAR ENERGY UTILIZED	Q203HA		WATTS (Btu/hr)
1	INSTANTANEOUS COLLECTOR EFFICIENCY	N101HA		% (%)
1	COLLECTOR PANEL EFFICIENCY FACTOR	N102HA		% (%)
1	ECDS COEFFICIENT OF PERFORMANCE	N110HA		% (%)
1	ECDS CONVERSION EFFICIENCY	N111HA		% (%)
1	ECDS UTILIZATION EFFICIENCY	N112HA		% (%)
1	DRYER LOAD	Q402HA		WATTS (Btu/hr)
1	FOSSIL ENERGY FOR AUXILIARY	Q410HA		WATTS (Btu/hr)
1	AVERAGE AMBIENT D.B. TEMPERATURE	N113HA		°C (°F)
1	ECDS COEFFICIENT OF PERFORMANCE	N410HA		% (%)

ISSUE DATE ID SEC PAGE

TABLE 5-5 - Continued

GRP NO.	PARAMETER NAME	FORMAT	MNEMONIC	VALUES	UNITS/VALUE MEANING
2	TOTAL SOLAR INCIDENT	E12.5	Q031DA		JOULES/m^2 BRITISH ENGINEERING
2	TOTAL SOLAR INCIDENT	E12.5	Q081DA		JOULES (BTU)
2	SOLAR ENERGY COLLECTED	E12.5	Q180DA		JOULES (BTU)
2	SOLAR ENERGY COLLECTED	E12.5	Q130DA		JOULES/m^2(BTU/FT^2)
2	ECDS OPERATING ENERGY	E12.5	Q132DA		JOULES (BTU)
2	COLLECTOR TRANSPORT HEAT LOSS	E12.5	Q132DA		JOULES (BTU)
2	TOTAL SOLAR ENERGY UTILIZED	E12.5	Q233DA		JOULES (BTU)
2	FOSSIL ENERGY SAVED	E12.5	Q243DA		JOULES (BTU)
2	COLLECTOR EFFICIENCY	E12.5			JOULES (BTU)
2	DRYER LOAD	E12.5	Q432DA		JOULES (BTU)
2	FOSSIL ENERGY FOR AUXILIARY	E12.5	Q450DA		JOULES (BTU)
2	SOLAR FRACTION OF ENERGY CONSUMED	E12.5	N441DA		% (%)
2	AVERAGE AMBIENT D.B. TEMPERATURE	E12.5	N113DA		°C (°F)
2	COLLECTOR PANEL EFFICIENCY FACTOR	E12.5	N132DA		°Cm^2/WATTS (°F FT^2 HR/BTU)

Table 5-5 - Continued

GRP NO.	PARAMETER NAME	MNEMONIC	VALUES	UNITS/VALUE MEANING	
3	TOTAL SOLAR INCIDENT	Q081MA		JOULES	(Btu)
3	TOTAL SOLAR INCIDENT	Q031MA		JOULES/m^2	(Btu/ft^2)
3	SOLAR ENERGY COLLECTED	Q180MA		JOULES	(Btu)
3	SOLAR ENERGY COLLECTED	Q130MA		JOULES	(Btu)
3	ECDS OPERATING ENERGY	Q132MA		JOULES	(Btu)
3	COLLECTOR TRANSPORT HEAT LOSS	Q133MA		JOULES	(Btu)
3	TOTAL SOLAR ENERGY UTILIZED	Q233MA		JOULES	(Btu)
3	FOSSIL ENERGY SAVED	Q243MA		LITERS	(gal)
3	COLLECTOR EFFICIENCY	N131MA		%	(%)
3	DRYER LOAD	Q432MA		JOULES	(Btu)
3	FOSSIL ENERGY FOR AUXILIARY	Q450MA		JOULES	(Btu)
3	AVERAGE AMBIENT D.B. TEMPERATURE	N113MA		°C	°F
3	SOLAR FRACTION OF ENERGY CONSUMED	N441MA		%	(%)
3	COLLECTOR PANEL EFFICIENCY FACTOR	N132MA		°C m^2/WATTS	(°F FT^2 HR/BTU)

ISSUE DATE ID SEC PAGE

TABLE 5-5 - Concluded

GRP NO.	PARAMETER NAME	MNEMONIC	VALUES	UNITS/VALUE MEANING	
4	TOTAL SOLAR INCIDENT	Q081YA		(JOULES)	(Btu)
4	TOTAL SOLAR INCIDENT	Q031YA		(JOULES/m^2)	(Btu/ft^2)
4	SOLAR ENERGY COLLECTED	Q180YA		(JOULES/m^2)	(Btu/ft^2)
4	SOLAR ENERGY COLLECTED	Q130YA		(JOULES)	(Btu)
4	ECDS OPERATING ENERGY	Q132YA		(JOULES)	(Btu)
4	COLLECTOR TRANSPORT HEAT LOSS	Q133YA		(JOULES)	(Btu)
4	TOTAL SOLAR ENERGY UTILIZED	Q233YA		(JOULES)	(Btu)
4	FOSSIL ENERGY SAVED	Q243YA		(LITERS)	(GAL)
4	COLLECTOR EFFICIENCY	N131YA		(%)	(%)
4	DRYER LOAD	Q432YA		(JOULES)	(Btu)
4	FOSSIL ENERGY FOR AUXILIARY	Q450YA		(JOULES)	(Btu)
4	AVERAGE AMBIENT D.B. TEMPERATURE	N113YA		°C	°F
4	SOLAR FRACTION OF ENERGY CONSUMED	N441YA		(%)	(%)
4	COLLECTOR PANEL EFFICIENCY FACTOR	N132YA		(°C m^2/WATTS)	(°F FT^2 HR/Btu)

ISSUE DATE ID SEC PAGE

HOURLY SUMMARIES
JULIAN DAY 13151

TIME	TOTAL SOLAR INCIDENT (Q001) WATTS/M**2	(BTU/HR FT**2)	ECOS CONVERSION EFFICIENCY (N111) %	SOLAR ENERGY COLLECTED (Q100) WATTS/M**2	(BTU/HR FT**2)	INSTANEOUS COLLECTOR EFFICIENCY (N101) %
8	.57014E 03	(.18082E 03)	.16648E 02	.12010E 03	(.38090E 02)	.21065E 02
9	.69168E 03	(.21937E 03)	.48786E 02	.35769E 03	(.11345E 03)	.51713E 02
10	.82916E 03	(.26298E 03)	.50594E 02	.43255E 03	(.13719E 03)	.52167E 02
11	.93155E 03	(.29545E 03)	.51243E 02	.48893E 03	(.15507E 03)	.52485E 02
12	.95445E 03	(.30271E 03)	.53418E 02	.51842E 03	(.16442E 03)	.54315E 02
13	.89857E 03	(.28499E 03)	.54694E 02	.49614E 03	(.15735E 03)	.55214E 02
14	.79905E 03	(.25342E 03)	.53902E 02	.43560E 03	(.13816E 03)	.54515E 02
15	.63756E 03	(.20221E 03)	.56139E 02	.36341E 03	(.11526E 03)	.57000E 02
16	.43794E 03	(.13890E 03)	.52455E 02	.23575E 03	(.74770E 02)	.53831E 02
17	.27624E 03	(.87611E 02)	.46027E 02	.13666E 03	(.43342E 02)	.49471E 02

* DATA WITH .99999 VALUE EXCEEDS BOUNDS

FIGURE 5-5. HOURLY SUMMARIES

HOURLY SUMMARIES
JULIAN DAY 1S151

TIME	ECDS OPERATING ENERGY (0102) WATTS	(BTU/HR)	TRANSPORT HEAT LOSS (0103) WATTS	(BTU/HR)	TOTAL SOLAR ENERGY UTILIZED (0203) WATTS	(BTU/HR)
8	.38400E 04	(.13106E 05)	.30656E 05	(.10467E 06)	.11554E 06	(.39447E 06)
9	.10897E 05	(.37190E 05)	.24651E 05	(.84162E 05)	.41077E 06	(.14024E 07)
10	.10382E 05	(.35434E 05)	.15875E 05	(.54199E 05)	.51067E 06	(.17435E 07)
11	.10535E 05	(.35955E 05)	.14086E 05	(.48092E 05)	.58109E 06	(.19839E 07)
12	.10267E 05	(.35041E 05)	.10428E 05	(.35601E 05)	.62064E 06	(.21190E 07)
13	.10135E 05	(.34590E 05)	.56826E 04	(.19401E 05)	.59827E 06	(.20426E 07)
14	.10101E 05	(.34474E 05)	.59656E 04	(.20367E 05)	.52430E 06	(.17900E 07)
15	.10497E 05	(.35825E 05)	.66821E 04	(.22813E 05)	.43570E 06	(.14875E 07)
16	.10686E 05	(.36472E 05)	.73363E 04	(.25047E 05)	.27964E 06	(.95474E 06)
17	.10896E 05	(.37189E 05)	.11581E 05	(.39537E 05)	.15477E 06	(.52842E 06)

* DATA WITH .99999 VALUE EXCEEDS BOUNDS

FIGURE 5-5 - Continued

HOURLY SUMMARIES
JULIAN DAY IS151

TIME	COLLECTOR PANEL EFFICIENCY FACTOR (N102) C M2/WATT (F FT2 HR/BTU)		SOLAR FRACTION OF ENERGY CONSUMED (N410) %	ECDS COEFFICIENT OF PERFORMANCE (N110)
8	.23042E-01	(.13077E 00)	.28840E 01	.30098E 02
9	.37203E-01	(.21114E 00)	.76488E 02	.37709E 02
10	.37083E-01	(.21046E 00)	.10614E 02	.49204E 02
11	.37331E-01	(.21187E 00)	.67833E 01	.55178E 02
12	.39136E-01	(.22211E 00)	.69059E 01	.60470E 02
13	.40148E-01	(.22785E 00)	.66273E 01	.59051E 02
14	.40664E-01	(.23078E 00)	.62547E 01	.51924E 02
15	.42269E-01	(.23989E 00)	.56826E 01	.41522E 02
16	.39505E-01	(.22421E 00)	.36809E 01	.26177E 02
17	.37374E-01	(.21211E 00)	.20157E 01	.14209E 02

* DATA WITH .99999 VALUE EXCEEDS BOUNDS

FIGURE 5-5 - Continued

HOURLY SUMMARIES
JULIAN DAY IS151

TIME	ECDS UTILIZTION EFFICIENCY (N112) %	DRYER LOAD (Q402) WATTS	(BTU/HR)	FOSSIL ENERGY FOR AUXILIARY (Q410) WATTS	(BTU/HR)	AVG. AMBIENT D.B. TEMPERATURE (N113) C	(F)
8	.79031E 02	.41218E 07	(.14072E 08)	.40063E 07	(.13678E 08)	.23889E 02	(.75000E 02)
9	.94339E 02	.94781E 06	(.32359E 07)	.53704E 06	(.18335E 07)	.24907E 02	(.76833E 02)
10	.96985E 02	.53219E 07	(.18170E 08)	.48112E 07	(.16426E 08)	.26759E 02	(.80167E 02)
11	.97633E 02	.91475E 07	(.31231E 08)	.85664E 07	(.29247E 08)	.28102E 02	(.82583E 02)
12	.98348E 02	.96078E 07	(.32802E 08)	.89872E 07	(.30683E 08)	.29769E 02	(.85583E 02)
13	.99059E 02	.96256E 07	(.32863E 08)	.90273E 07	(.30820E 08)	.30231E 02	(.86417E 02)
14	.98875E 02	.89067E 07	(.30409E 08)	.83824E 07	(.28619E 08)	.31157E 02	(.88083E 02)
15	.98490E 02	.81028E 07	(.27664E 08)	.76672E 07	(.26177E 08)	.31435E 02	(.88583E 02)
16	.97444E 02	.78767E 07	(.26892E 08)	.75970E 07	(.25937E 08)	.31574E 02	(.88833E 02)
17	.93039E 02	.78331E 07	(.26743E 08)	.76783E 07	(.26215E 08)	.31212E 02	(.88182E 02)

* DATA WITH .99999 VALUE EXCEEDS BOUNDS

FIGURE 5-5 - Concluded

D A I L Y   R E P O R T

JDAY 151

DAILY	VARIABLE	SI	BRITISH ENGINEERING
TOTAL SOLAR INCIDENT	Q081	.31453E 11 JOULES	.29813E 08 (BTU)
TOTAL SOLAR INCIDENT	Q031	.25837E 08 JOULES/M**2	.22751E 04 (BTU/FT**2)
SOLAR ENERGY COLLECTED	Q180	.16662E 11 JOULES	.15793E 08 (BTU)
SOLAR ENERGY COLLECTED	Q130	.13687E 08 JOULES/M**2	.12052E 04 (BTU/FT**2)
ECDS OPERATING ENERGY	Q132	.37099E 09 JOULES	.35165E 06(BTU)
TRANSPORT HEAT LOSS	Q133	.42825E 09 JOULES	.40592E 06 (BTU)
TOTAL SOLAR ENERGY UTILIZED	Q233	.16234E 11 JOULES	.15387E 08 (BTU)
FOSSIL ENERGY SAVED	Q243	.38749E 03 LITERS	.10237E 03 (GAL)
COLLECTOR EFFICIENCY	N131	.52973E 02 %	.52973E 02 (%)
DRYER LOAD	Q432	.26620E 12 JOULES	.25233E 09 (BTU)
FOSSIL ENERGY FOR AUXILIARY	Q450	.24954E 12 JOULES	.23653E 09 (BTU)
AVG. AMBIENT D.B. TEMPERATURE	N113	.29293E 02 C	.84727E 02 (F)
SOLAR FRACTION OF ENERGY CONSUMED	N441	.62590E 01 %	
COLLECTOR PANEL EFFICIENCY FACTOR	N132	.38548E-01 C M**2/WATTS	.21878E 00(F FT**2 HR/BTU)

```
I      2
IBUF( 2)     0
 10:46:55  /ENDJOB
 10:46:56  /FINI
```

FIGURE 5-6. DAILY REPORT

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

6. REPORTING

Reporting of technical, economic, and operational data will be provided at monthly intervals. Some analysis and evaluation will be performed for the monthly reports, and a complete evaluation, including life-cycle cost, will be provided in the annual report.

6.1 TECHNICAL REPORT

The technical report will consist of computer-prepared performance summaries, some manually prepared analyses, and a month-by-month log of important performance parameters.

The computer-prepared reports will consist of:

- Hourly summaries
- Daily summaries
- Monthly summaries

for the reporting month. The format for these summaries and a sample copy are presented in Section 5.2.3.

The manually prepared report will deal primarily with the presentation of collector performance in familiar formats and with data that are not readily extracted by computerized techniques. One of these is discussed in the following paragraphs.

The performance of flat-plate collectors operating under steady-state conditions can be described by the following equation:

$$\frac{Q_u}{A_c} = F_R' \left[I_T (\tau\alpha)_e - U_L (\overline{T}_f - T_a)\right]$$

where

Q_u - rate of useful energy extracted by the collector

A_c - collector aperture area

F_R - ratio of useful energy collected to useful energy collected if the entire collector surface were at the average fluid temperature $\overline{T}_f$

$\overline{T_f} = \frac{T_{f,i} + T_{f,o}}{2} - T_a$

I_T - total incident solar radiation

$(\tau\alpha)_e$ - effective transmission absorptance product of collector

U_L - heat transfer loss coefficient for the collector

$T_{f,i}$ - fluid temperature entering collector

$T_{f,o}$ - fluid temperature leaving collector

T_a - ambient temperature.

Thus the instantaneous (hourly) efficiency is:

$$N101 = \frac{Q_u}{A_c\ I_T} = F_R'\ (\tau\alpha)_e - F_R'\ U_L\ \frac{(\overline{T_f} - T_a)}{I_T} .$$

The solar grain drying system uses 100% ambient air; therefore, to a close approximation, $T_{f,i} \simeq T_a$. Now the average temperature becomes:

$$T_f \simeq \frac{T_{f,a} + T_{f,o}}{2}$$

and the relationship for instantaneous efficiency is

$$N101 = F_R'\ (\tau\alpha)_e - \frac{F_R'\ U_L}{2}\ \frac{(T_{f,o} - T_a)}{I_T} .$$

The term $F_R'(\tau\alpha)_e$ is related to the optical properties of the glazing and hence to surface contamination originating from plant processes. Each month the plots presented in Figure 6-1 will be manually prepared for both hourly summaries and daily summaries. Linear curve fits to the data will be developed by the method of least squares. The Y intercept point of the linear relationship is the term $F'(\tau\alpha)_e$, which will be determined from the plots and tabulated monthly.

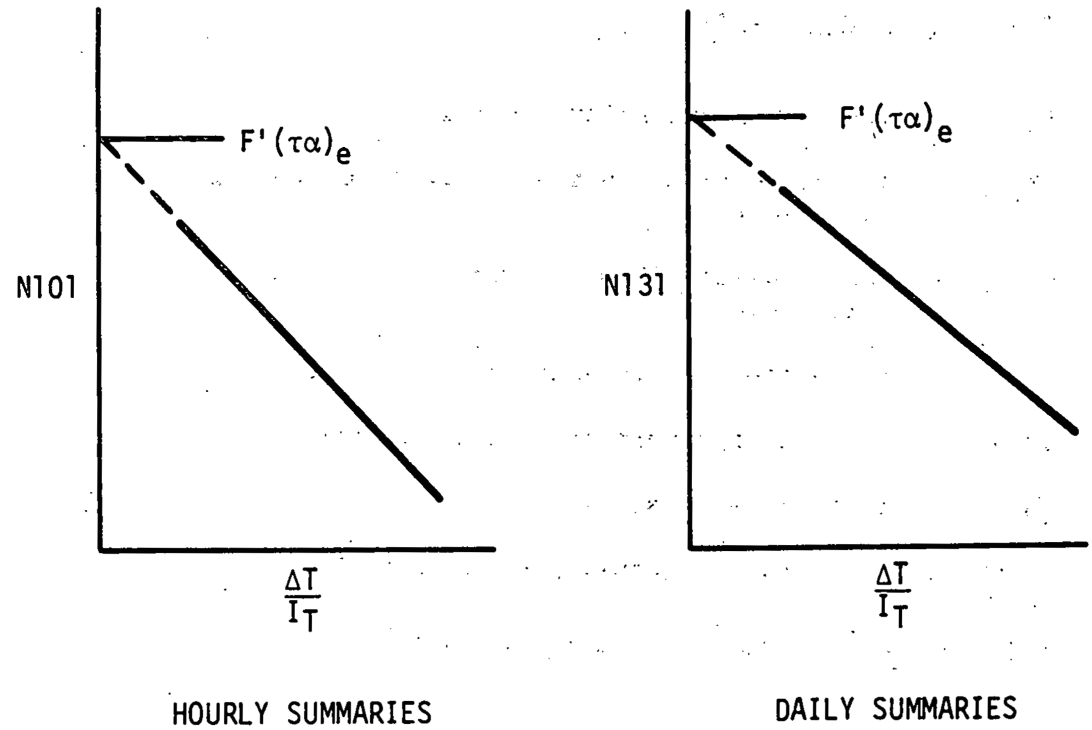


FIGURE 6-1. EFFICIENCY VALUES FOR COLLECTOR ARRAY

To provide a convenient historical record of performance during the entire evaluation phase, a monthly Performance Data Summary table will be provided of important performance parameters. Figure 6-2 illustrates the proposed format.

System behavior and trends are sometimes more readily discerned visually from plots than from tabulation. Hence several important parameters will be plotted on a month-by-month basis and updated in each report period. Some of these are:

- Q031 - Total Solar Incident
- Q130 - Solar Energy Collected
- Q233 - Total Solar Utilized
- Q243 - Fossil Energy Saved
- N131 - Efficiency.

Others will be presented if it is considered desirable.

PERFORMANCE DATA SUMMARY

		JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Q031 - Total Solar Incident (Btu/ft^2)	Monthly												
	Cumulative												
Q180 - Solar Energy Collected (Btu)	Monthly												
	Cumulative												
Q233 - Total Solar Utilized (Btu)	Monthly												
	Cumulative												
N131 - Collector Efficiency	Monthly												
	Average												
N143 - Average Ambient Dry Bulb Temperature (°F)	Monthly												
	Average												
Y Intercept Point	Monthly												
	Average												

FIGURE 6-2. PERFORMANCE DATA SUMMARY FORMAT

6.2 FINANCIAL REPORTING

Monthly reporting of the financial aspects of system operation will consist of data summarized from the instrumented and noninstrumented data. The quantity and value of fuel saved and the cost of owning, maintaining, and operating the system will be reflected on the Financial Data Summary, shown in Figure 6-3. These data are further summarized into a monthly Cash Flow Impact Summary, shown in Figure 6-4.

At the conclusion on one year's operation, a life-cycle cost analysis will be conducted in accordance with the specific guidelines provided in the Lawrence Livermore Laboratory report, "Method of Economic Analysis for Comparison of Solar Process Heat Systems", prepared by W. C. Dickinson and J. N. Shearer.

FINANCIAL DATA SUMMARY

				JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
FOSSIL FUEL SAVED			gal												
			$/gal												
			$												
COSTS	MAINTENANCE	CLEANING	hr												
			Avg $/hr												
			Labor Cost												
			Material												
			Total												
		OTHER	hr												
			Avg $/hr												
			Labor Cost												
			Material												
			Parts												
			Total												
		TOTAL MAINTENANCE													
	PROPERTY TAXES														
	INSURANCE														
	ENERGY		kWh Used												
			$/kWh												
			Cost												
	TOTAL COST														

FIGURE 6-3. FINANCIAL DATA SUMMARY

CASH FLOW IMPACT SUMMARY

		JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
VALUE OF FUEL SAVED	Monthly												
	Cumulative												
OWNING AND OPERATING COSTS	Monthly												
	Cumulative												
NET	Monthly												
	Cumulative												

FIGURE 6-4. CASH FLOW IMPACT SUMMARY

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

APPENDIX B. TBE SPECIAL TASK REPORT
CLEANING SYSTEM FOR SOLAR PANEL GLAZING

SPECIAL TASK REPORT
SD78-DOE-2276

SPECIAL TASK REPORT FOR CONCEPTUAL DESIGN OF AUTOMATIC CLEANING SYSTEM FOR SOLAR PANEL GLAZING-SOLAR DRYING OF SOYBEANS

October 31, 1978

Prepared For

U.S. DEPARTMENT OF ENERGY

Contract No. EY-76-C-05-5122
(Mod. A003), Task No. 4

Prepared By

SYSTEMS DIVISION
TELEDYNE BROWN ENGINEERING
HUNTSVILLE, ALABAMA

ABSTRACT

During the installation and checkout portion of the Department of Energy's program on the Application of Solar Energy to Industrial Drying of Soybeans, it became evident that a significant solar panel cleaning problem existed. The problem stems from soybean oil droplets and particles in the environment of the plant site. A conceptual design has been prepared for an automatic cleaning system for the solar panels.

Investigations into the nature of the contaminant revealed that the soybean oil polymerizes with extended exposure to ultraviolet rays. This polymerization is accelerated by the presence of ozone. It was concluded that the most practical method of panel cleaning would involve daily removal of deposits before significant polymerization could occur.

Several cleaning system concepts were studied. An oscillating spray bar promised the optimum cleaning action/initial investment ratio. A 48-ft-long prototype of this type was constructed and a test program initiated. This test program will continue throughout Phase III. To date, the prototype has operated daily without incident and has performed a credible cleaning job.

A preliminary design of a control system is presented. This system is completely automatic and incorporates freeze protection.

Excluding final design cost, the cleaning system cost will be between \$1.00 and \$1.59/ft^2, depending on whether Gold Kist labor is used. The economic improvement in system operation is anticipated to be \$2,790 annually. This includes the reduction in labor now used for manual cleaning and a 15% estimated performance improvement.

Recommendations include continuation of testing on the prototype and a final design-and-build program with emphasis on using Gold Kist labor to a maximum extent.

APPROVED:

B. R. Hall
Program Manager

R. A. Rieth
Vice President
Systems Division

TABLE OF CONTENTS

TABLE OF CONTENTS - Concluded

LIST OF ILLUSTRATIONS

1. INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

A major objective of the Department of Energy's (DOE's) Industrial Processing Heat Program is to verify and evaluate the technical and operational performance of solar thermal energy systems for process drying. For this purpose, a demonstration system using air collectors has been constructed at the Gold Kist Soy plant in Decatur, Alabama. The system is designed to temper the combustion air of conventional dryers used to dry soybeans prior to storage and as a first step in the extraction process.

Construction of the solar facility and data acquisition have been completed and operational status has been achieved. The system will be operated and maintained for 1 year by Gold Kist as a part of its drying operations. Operational and technical data will be acquired, analyzed, evaluated, and reported by Teledyne Brown Engineering (TBE).

The environmental conditions at Gold Kist have presented a significant problem in maintaining clean glazings on the collectors. As a result, DOE has authorized a task to perform a conceptual design of a cleaning system for the solar array. This report, prepared under Contract No. EY-76-C-05-5122, presents the results of this conceptual design effort.

1.2 SUMMARY

This report encompasses a definition of the cleaning problem, conceptual approaches to automated cleaning systems, results of a prototype cleaning system test, and recommendations for the design of a full-scale automatic cleaning system.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

2. PROBLEM DEFINITION

2.1 SOLAR ARRAY DESCRIPTION

The solar array in the Gold Kist project consists of 672 single, glazed Solaron collectors. The arrangement of the 114.5-by-144-ft array is shown in Figure 2-1. The entire array is tilted 15 deg from horizontal and is supported on a steel structure. The low end of the array is 16.5 ft from ground elevation.

There are seven double rows of collectors, with each double row containing 96 collectors. A walkway and handrail are provided at the bottom and between every other double row.

2.2 NATURE OF CONTAMINATION

Samples of the contaminated glazings have been examined by personnel in the Chemistry Department at the University of Alabama in Huntsville (UAH) to determine their nature and to obtain recommendations for cleaning solutions. UAH has determined that the contamination begins as a coating of soybean oil settling on the glazing. This oil polymerizes when exposed to ultraviolet and ozone and hardens very much like a varnish. During the process, soybean husks and flakes are deposited on and then bonded to the surface by the partially polymerized soybean oil.

2.3 CURRENT CLEANING TECHNIQUES

The current cleaning technique requires three men working 6 hours to clean the entire array. The first man uses a hand wand to apply a detergent solution (concentrated carwash solution) under 600-psi pressure. This is followed immediately with scrubbing using a long handled brush. The third man uses a hose to apply rinse water.

This cleaning process is accomplished on approximately a 40-day schedule. From the performance data obtained through August 1978, the efficiency improvement following cleaning is approximately 10 to 15%

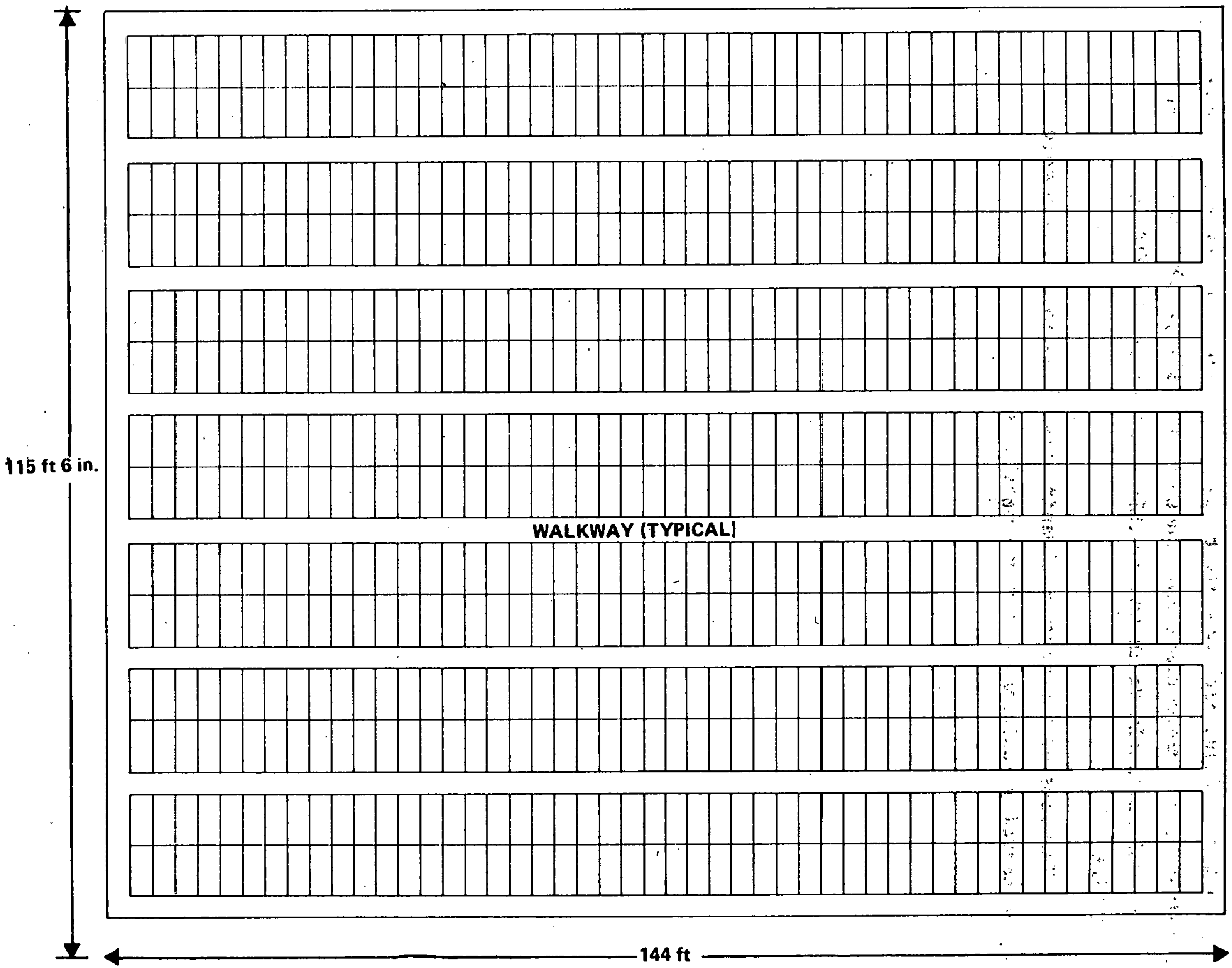


FIGURE 2-1. SOLAR ARRAY ARRANGEMENT

(Figure 2-2). Plans are underway to perform comparison testing of contaminated versus clean glazings. These tests will be performed by UAH. Results will be included in the monthly progress report following test completion.

The cost of the current cleaning technique is approximately $1,800 annually including labor and materials.

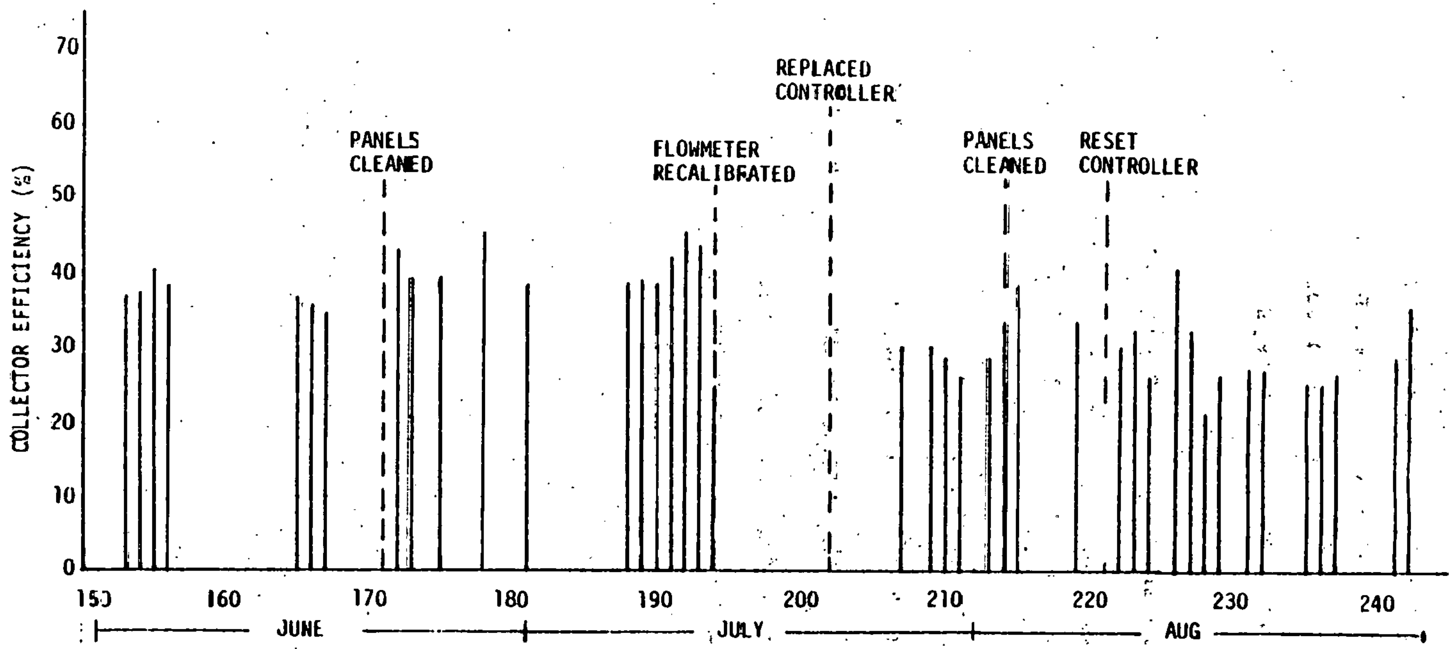


FIGURE 2-2. EFFECTS OF CLEANING GLAZING

3. CLEANING SYSTEM CRITERIA

The objective of the cleaning system design is to minimize recurring panel cleaning costs while meeting an acceptable compromise between capital cost, reliability, degraded performance, and maintainability. To meet this objective, the cleaning system must incorporate the following features:

- Minimum shading by the cleaning mechanism
- Automatic control system to cycle the cleaning action with a frequency sufficient to prevent excessive polymerization and deposit
- Freeze protection
- Minimum moving parts and adjustment or alignment
- Minimum consumption of water, detergent, and electricity.

Since the optimum cleaning frequency and detergent concentration requirements must be determined over a long period of operation, these functions should have a wide latitude for experimentation.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

4. DESIGN CONCEPTS CONSIDERED

Using the criteria presented in Section 3, TBE studied several cleaning system concepts. During these studies, cleaning equipment vendors and specialists were contacted in an effort to establish a data base to use in evaluating various concepts. Because of the unique nature of the contaminant and the physical layout and size of the solar array, no significant data base was established. As a result, the evaluation of each concept had to be subjected and on a relative basis rather than absolute.

Figure 4-1 presents a sketch and comparison of the major cleaning concepts considered. A brief discussion of each follows.

4.1 FIXED SPRAY (FLOOD)

This system is simply a fixed piping system that directs a spray at the upper edge of each collector row. Because of its attractive low cost and simplicity, a simple prototype was constructed. The performance was poor because of splitting of the flooding into small streams, resulting in dry areas.

4.2 OSCILLATING SPRAY

This system incorporates a pipe (with a row of small orifices) supported a few feet over the collector and an actuator to provide rotation. This system appeared to be the most promising of all concepts studied. Therefore, two prototypes were constructed and tested. A detailed description of this system and the test results are presented in Sections 5 and 6.

4.3 MOVING SQUEEGY WITH SPRAY

This system consists of a flexible squeegy and spray bar that translate the length of a collector. The effectiveness of this type of system was considered good because of the mechanical action of the squeegy. However, it was considered impractical because of the complexity and consequent poor reliability.

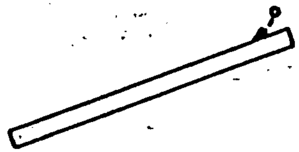
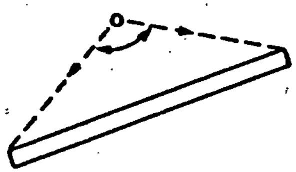
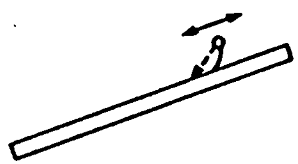
CONCEPT	PROBABLE CLEANING EFFECTIVENESS	RELATIVE COST	MAINTENANCE REQUIREMENTS
 FIXED SPRAY (FLOOD)	POOR - DIRECT IMPINGEMENT AT UPPER EDGE ONLY. FLOODING STREAMS SPLIT AS WATER PROGRESSES OVER GLAZING, LEAVING DRY AREAS.	VERY LOW - SIMPLE FIXED PIPING SYSTEM	VERY LOW - NO MOVING PARTS
 OSCILLATING SPRAY	GOOD - DIRECT IMPINGEMENT AND FLOODING ALONG FULL LENGTH OF GLAZING	LOW - MINIMAL MOVING PARTS	LOW - FEW SLOW MOVING PARTS. NO CRITICAL ALIGNMENT REQUIRED
 MOVING SQUEEGY WITH SPRAY	GOOD - DIRECT IMPINGEMENT AND SQUEEGY ACTION ALONG FULL LENGTH OF GLAZING	HIGH - COMPLEX ROLLERS, GUIDE RAILS AND DRIVE MECHANISM	HIGH - NUMEROUS MOVING PARTS; CRITICAL ALIGNMENT; SENSITIVE TO FREEZING CONDITIONS ON RAILS. SQUEEGY REPLACEMENT DUE TO WEAR AND BRITTLENESS.

FIGURE 4-1. CLEANING CONCEPT COMPARISON

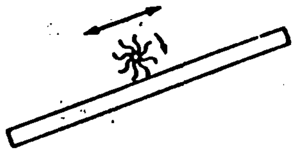
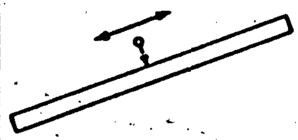
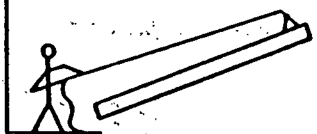
CONCEPT	PROBABLE CLEANING EFFECTIVENESS	RELATIVE COST	MAINTENANCE REQUIREMENTS
 ROTATING/MOVING BRUSH WITH SPRAY	EXCELLENT - BRUSHING ACTION OVER ENTIRE GLAZING	VERY HIGH - COMPLEX TRANSLATION AND ROTATION MECHANISM. DYNAMIC WATER SEALS REQUIRED	VERY HIGH - MOTION LIMIT ADJUSTMENTS CRITICAL; FREEZING OF BRUSH ELEMENTS; BRUSH WEAR AND REPLACEMENT; BRUSH PRESSURE ADJUSTMENTS
 MOVING SPRAY	GOOD - DIRECT WATER IMPINGEMENT OVER ENTIRE GLAZING SURFACE	HIGH - COMPLEX TRANSLATION MECHANISM. LONG, FLEXIBLE FEEDER TUBES	HIGH - MOTION LIMIT ADJUSTMENTS; CRITICAL ALIGNMENT: FREEZING OF WATER ON RAILS AND MECHANISM
 IMPROVED MANUAL (LONG SPRAY/BRUSH)	GOOD - BRUSH/SPRAY ACTION OVER ENTIRE GLAZING SURFACE	LOW INITIAL COST - SIMPLE FIXED PIPING SYSTEM HIGH LABOR COST - REQUIRES APPROXIMATELY 12 TO 14 MAN-HOURS EACH CLEANING	LOW - OCCASIONAL BRUSH REPLACEMENT

FIGURE 4-1 - Concluded

4.4 ROTATING/MOVING BRUSH WITH SPRAY

This system bears a resemblance to equipment used in the carwash industry. It would certainly offer a better cleaning effectiveness than all methods considered. However, the initial cost and maintenance penalties were too severe for further serious consideration.

4.5 MOVING SPRAY

This system consists of a spray bar that translates the length of the collector. It offers very little performance improvement over the oscillating spray and has the same disadvantage of the other systems incorporating translation.

4.6 IMPROVED MANUAL METHOD

The current manual cleaning technique involves a separate spray and brushing operation. A high-flow, long-handled, spray/brush was found in the market survey. This method offers the same cleaning effectiveness as the method now employed and the initial cost is low. However, it is estimated that it would take 12 to 14 man-hours per cleaning as compared to the 18 man-hours now required. As a result, the concept was not given further consideration.

5. PROTOTYPE SYSTEMS

Before final selection of a concept, two test setups were made and a prototype cleaning system was constructed and tested. One test setup was used to examine the effectiveness of the fixed spaybar concept. The other test setup and prototype were used to determine the effectiveness of the oscillating spray concept.

5.1 FIXED SPRAY TEST SETUP

The low initial cost and reliability of this concept prompted the construction of the test setup shown in Figure 5-1. The testing of this system revealed good cleaning effectiveness only in the area of direct water impingement. Below this area, the water formed a random pattern and offered no cleaning effectiveness.

5.2 OSCILLATING SPRAY TEST SETUP

A simple test setup using an inverted standard lawn sprinkler was installed to verify the cleaning effectiveness of the oscillating spray concept. This setup is shown in Figures 5-2 and 5-3. This system was installed on August 4 and tested until August 31. The system was operated once in the morning and once in the late afternoon. Each cycle consisted of 1 min of cleaning with detergent injection and 1 min of rinse. This system incorporated an inexpensive syphon-type soap injector with no accurate method of determining concentration. The system covered four panels and had a flow rate of approximately 5 gpm (0.063 gpm/ft^2).

Although no specific performance testing was performed, the cleaning effectiveness appeared excellent. As a result, it was decided to prepare a more elaborate system incorporating controlled soap injection and various hole spacings and sizes to determine the best combinations of each of these variables.

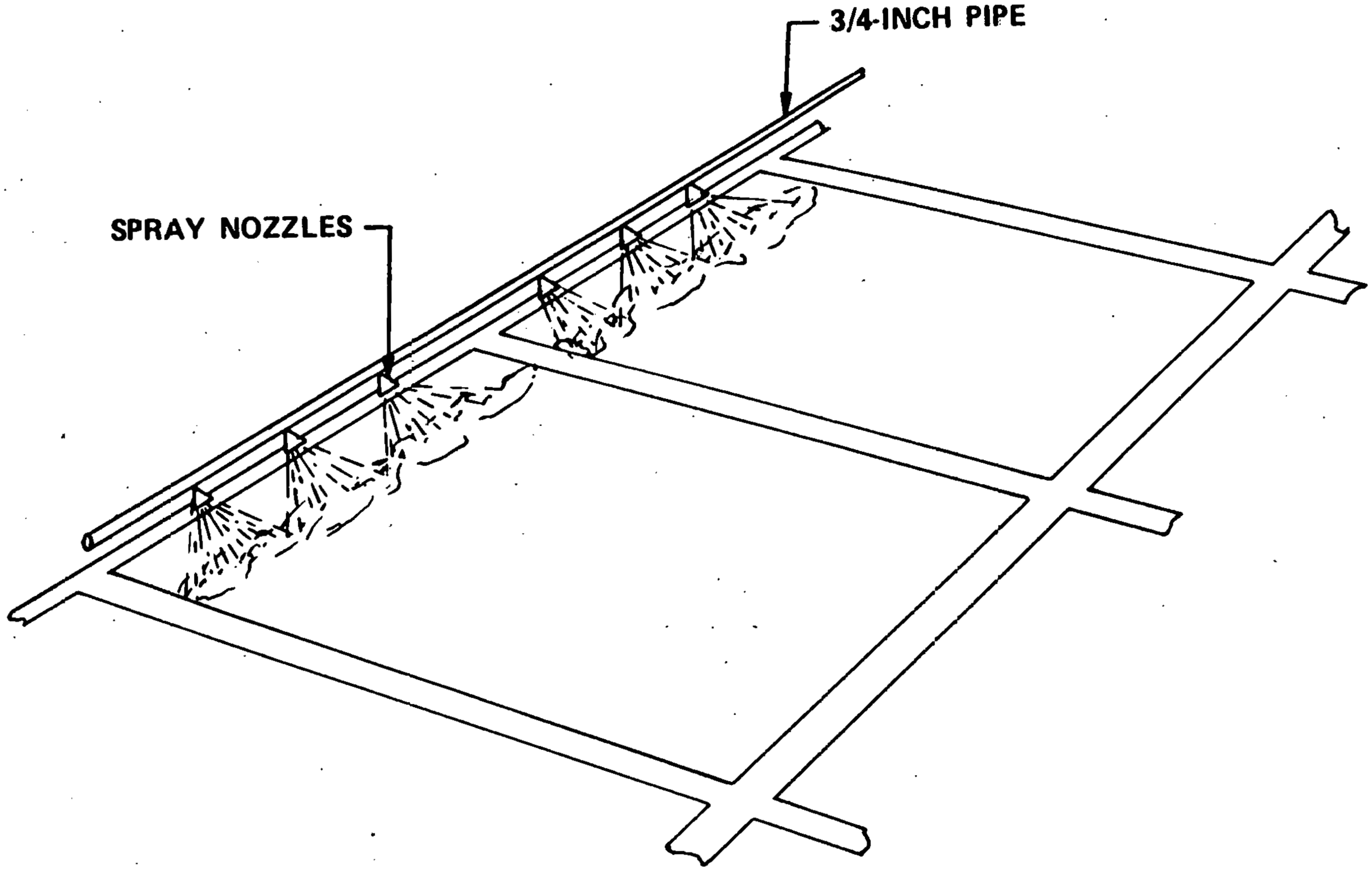


FIGURE 5-1. FIXED SPRAY TEST SETUP

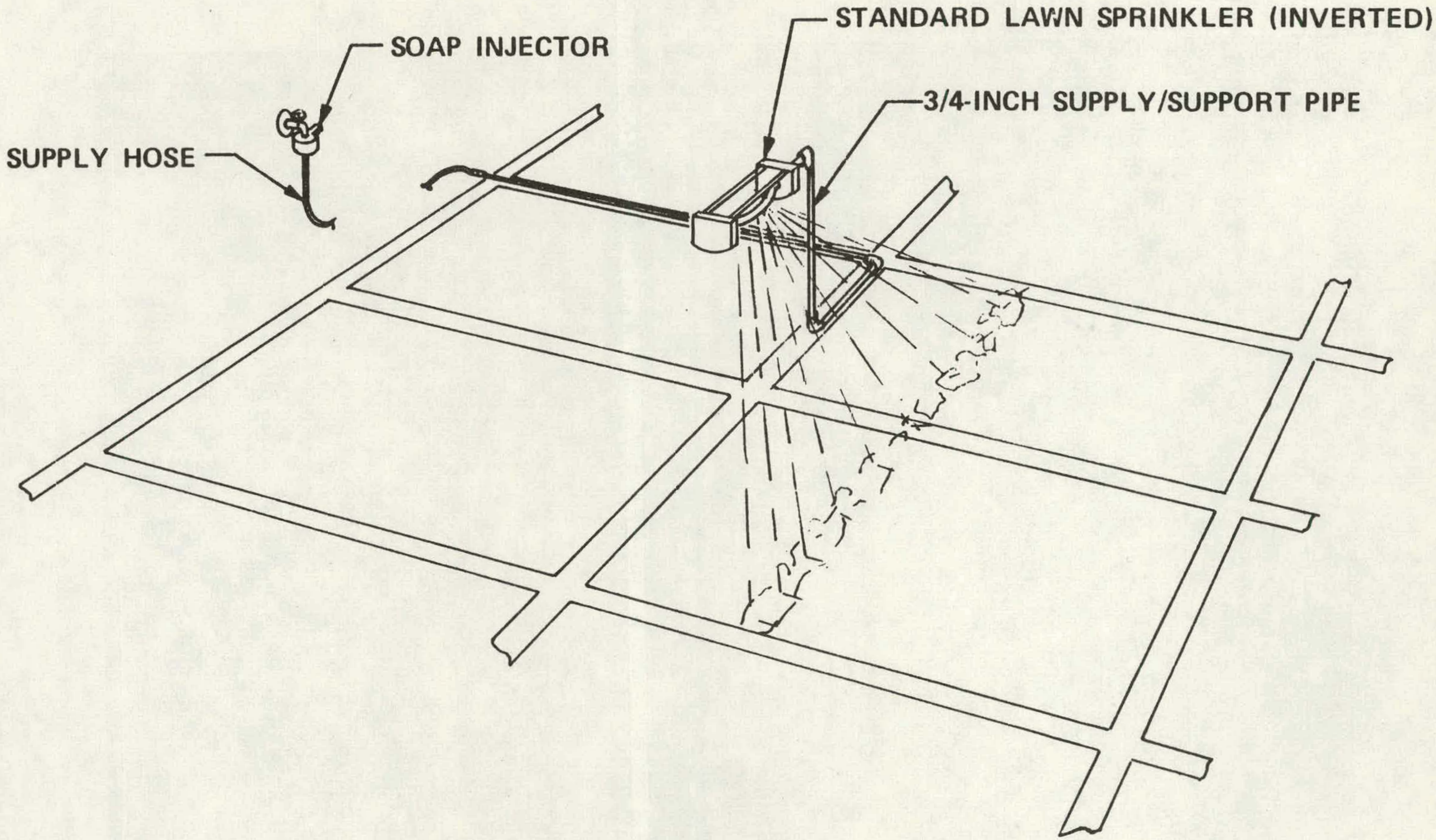


FIGURE 5-2. OSCILLATING SPRAY TEST SETUP

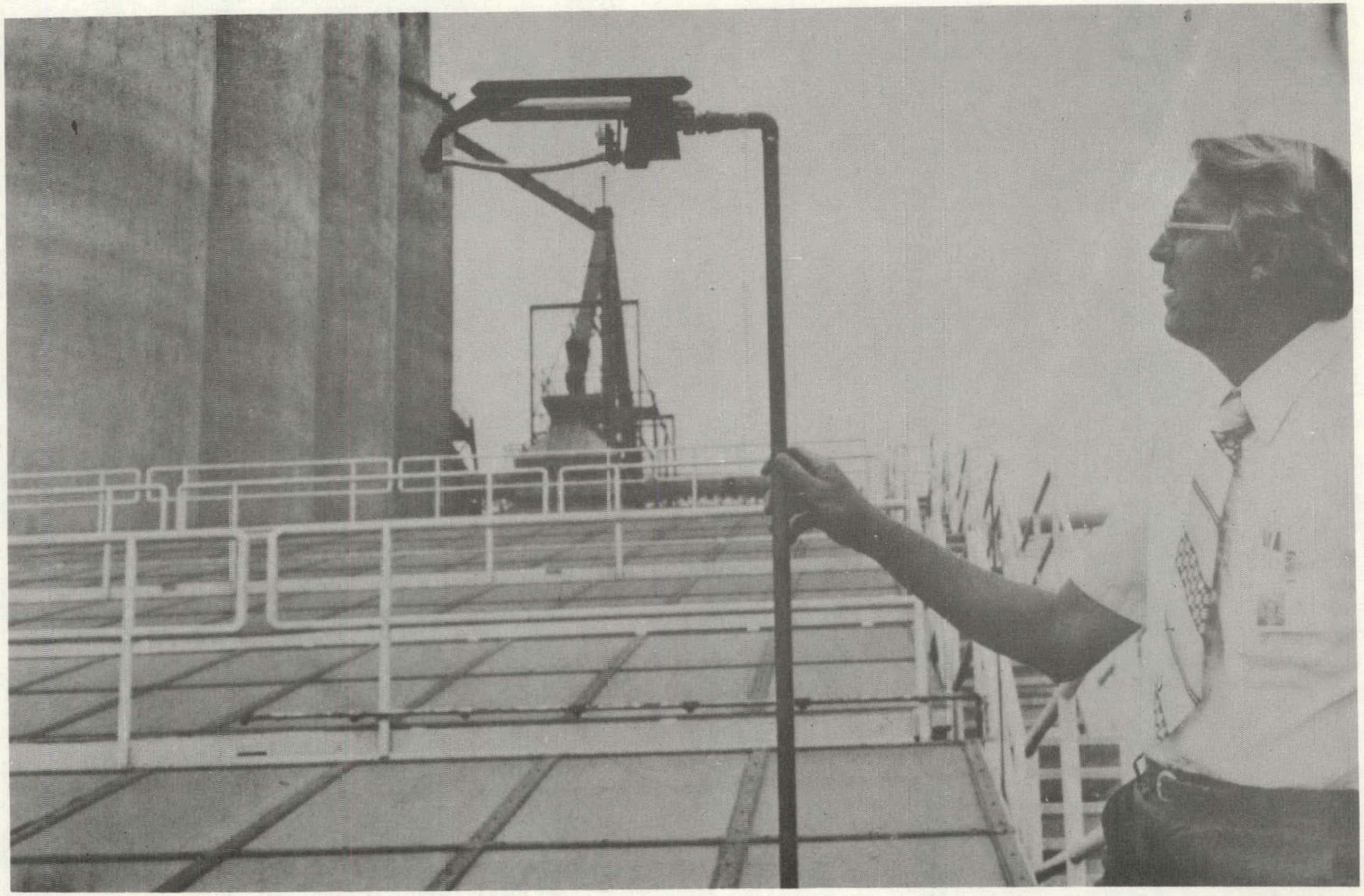


FIGURE 5-3. OSCILLATING SPRAY TEST SETUP

5.3 OSCILLATING SPRAY PROTOTYPE

A 48-ft-long oscillating spray prototype has been installed and partially tested. The testing of this system in continuing. Figures 5-4 and 5-5 present an overall view and photograph of the system.

5.3.1 Prototype System Design

The basic design criteria used in this system were as follows:

- Several test sections to evaluate different hole spacings and diameters
- An actuator with an adjustable stroke
- An accurate, variable soap feed system
- Sufficient line sizing to provide at least 65-psi pressure at a delivery rate of 25 gpm
- Manual control system without freeze protection
- Expandable to a full-scale system
- Minimum system cost.

The prototype system that was designed is a 48-ft oscillating spray bar. The system covers 32 collectors (16 pairs). A discussion of the design follows.

To ensure adequate delivery and to incorporate sufficient structural rigidity, a 0.75-in, type K, rigid copper pipe was chosen as the spray bar. Through experimentation, it was determined that this pipe required support at least every 12 ft. This led to the four-section, 48-ft spray bar shown in Figure 5-6. The spray bar is fed from both ends. The various hole sizing and spacing will allow evaluation of these parameters through testing. These are critical parameters since they are directly associated with the total water consumption required for each cleaning.

Each spray bar support is made up of inexpensive, off-the-shelf hardware. Figure 5-7 shows details of the supports.

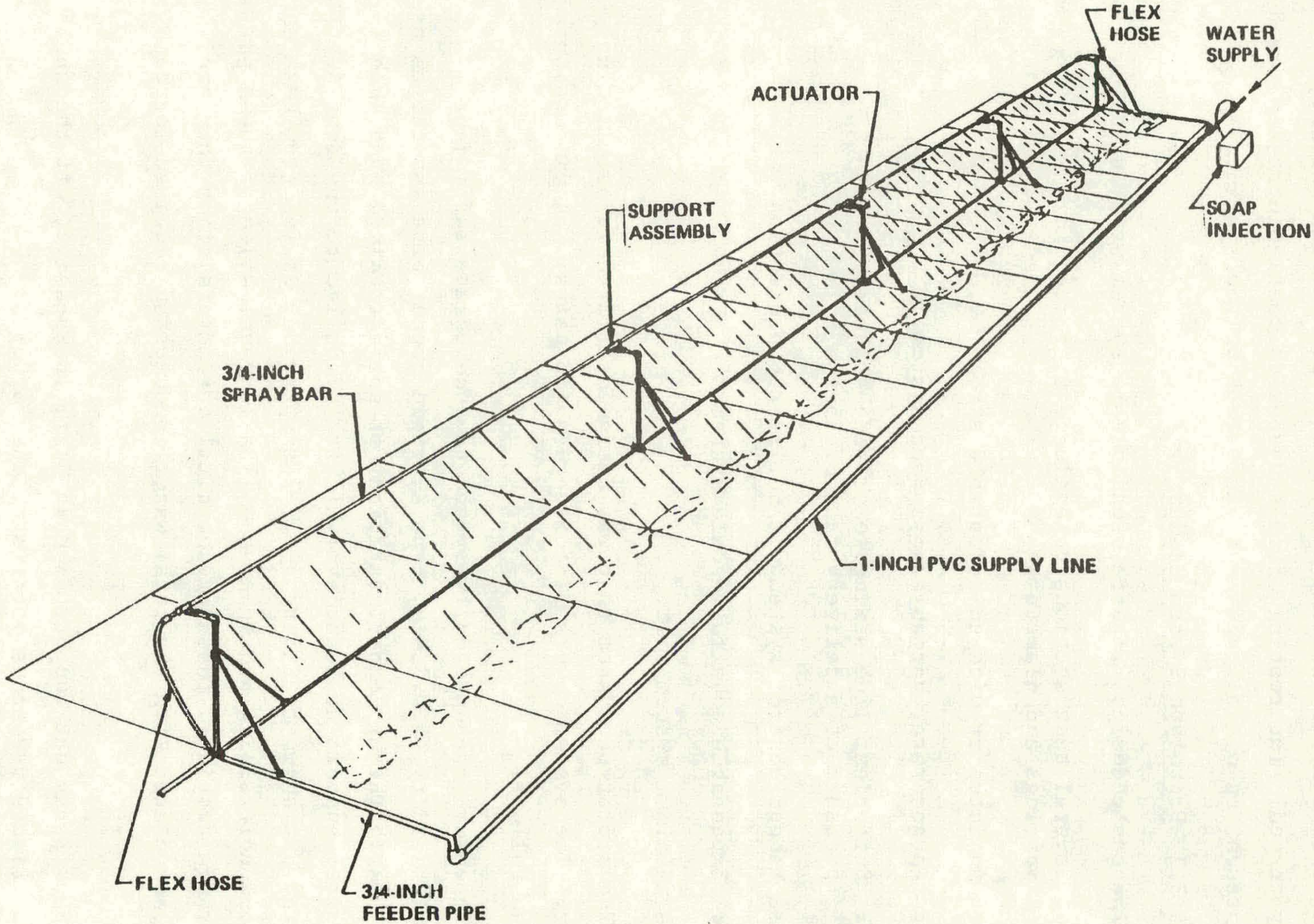


FIGURE 5-4. PROTOTYPE CLEANING SYSTEM

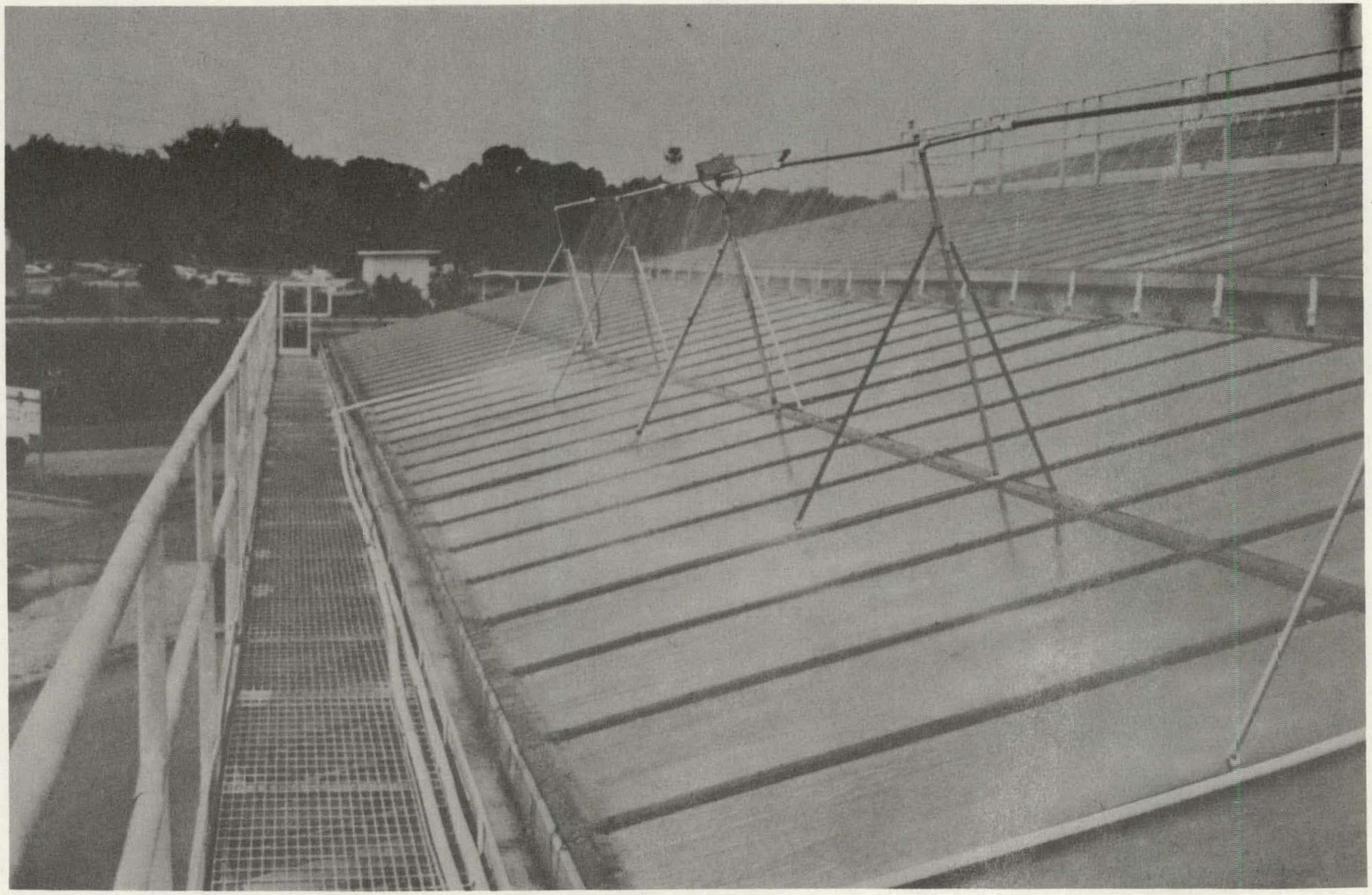


FIGURE 5-5. 48-ft PROTOTYPE CLEANING SYSTEM

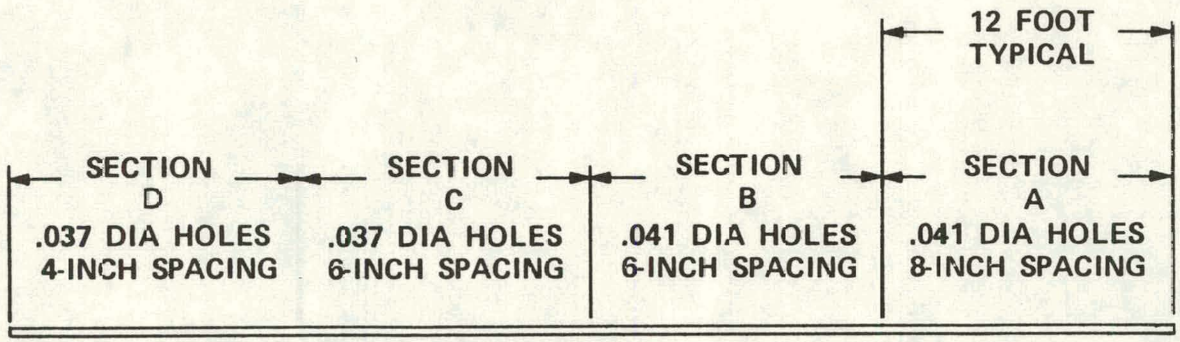


FIGURE 5-6. SPRAY TUBE HOLE PATTERN

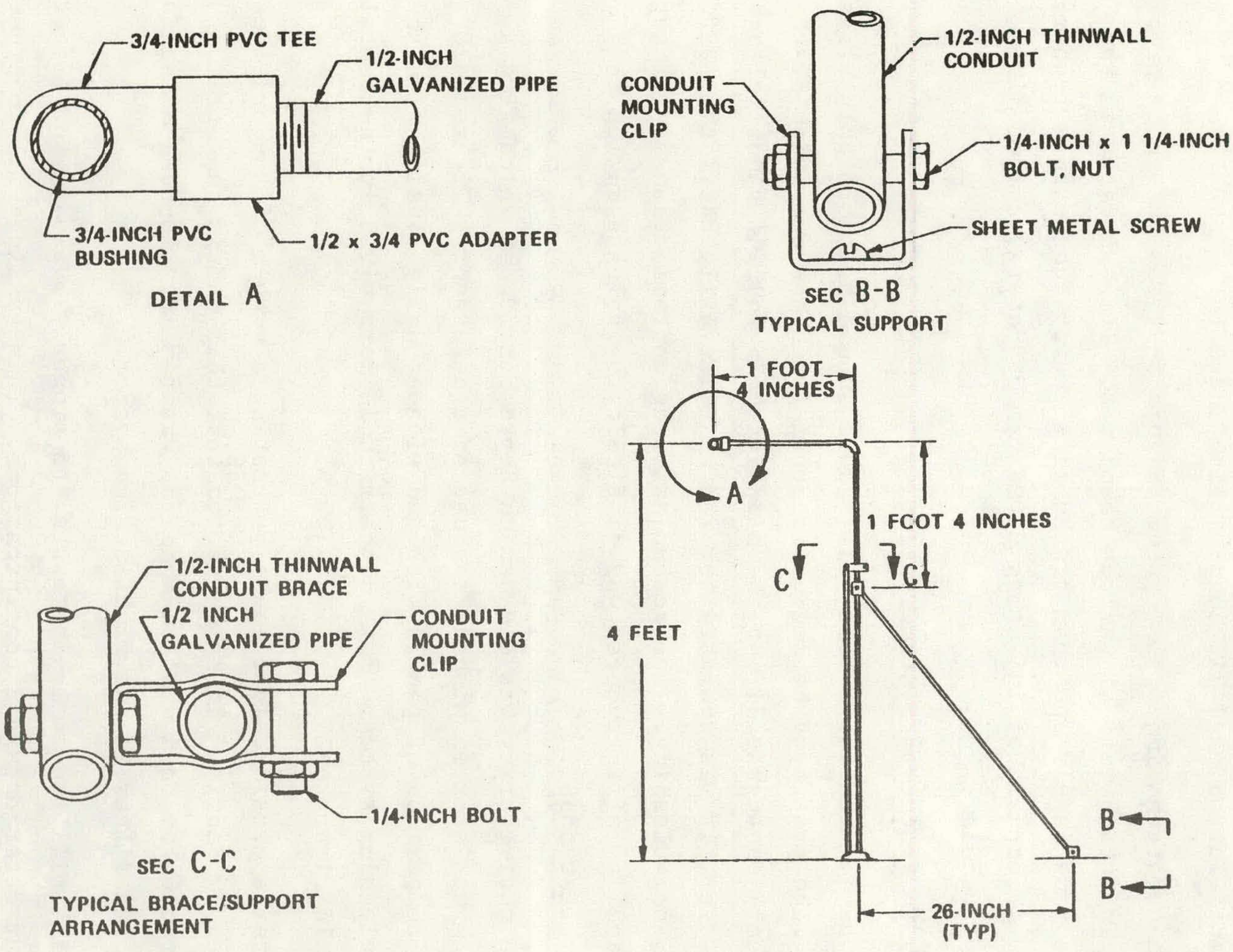


FIGURE 5-7. SPRAY TUBE SUPPORT ASSEMBLY

The actuator assembly is shown in the drawing and photograph of Figure 5-8. The motor is a standard 2-rpm, 25-in.-lb gearmotor. For rigidity, a cast aluminum box was chosen to house the motor. The linkage system consists of crank arms and a push rod that are standard in the heating, ventillation, and air conditioning industry.

The detergent injection system (Figure 5-9) was chosen to provide a variable injection rate of various chemicals. It is located in the supply line immediately upstream of the first spray tube supply feeder. This system is capable of injecting 0.008 gpm of detergent at a line pressure of 70 psig.

5.3.2 Prototype System Testing

To have a realistic test, all panels should be thoroughly cleaned initially. The prototype became operational (with the exception of the soap injector) on August 31, at the midpoint of a routine manual cleaning cycle. However, it was operated for 2 min. twice daily until the next scheduled panel cleaning. The accumulation of contamination at startup was heavy and its effectiveness was difficult to evaluate during this preliminary test phase.

The entire array was cleaned on September 20, at which time a test program was started without the use of a detergent. Figure 5-10 presents a comparison of panels with and without daily rinsing with the prototype cleaning system. This comparison is more vivid in the overall view shown in Figure 5-11.

After approximately 2 weeks of testing a number of the orifices were plugged by debris. It is suspected that this debris came from a repair operation by Gold Kist on a nearby water main. It does establish the need for a filter in the final design system.

It is still too early in testing to properly evaluate the effects of different detergents and concentrations. This testing will continue beyond this writing until freezing conditions dictate draining. Results of this further testing will be contained in monthly and quarterly contract status reports.

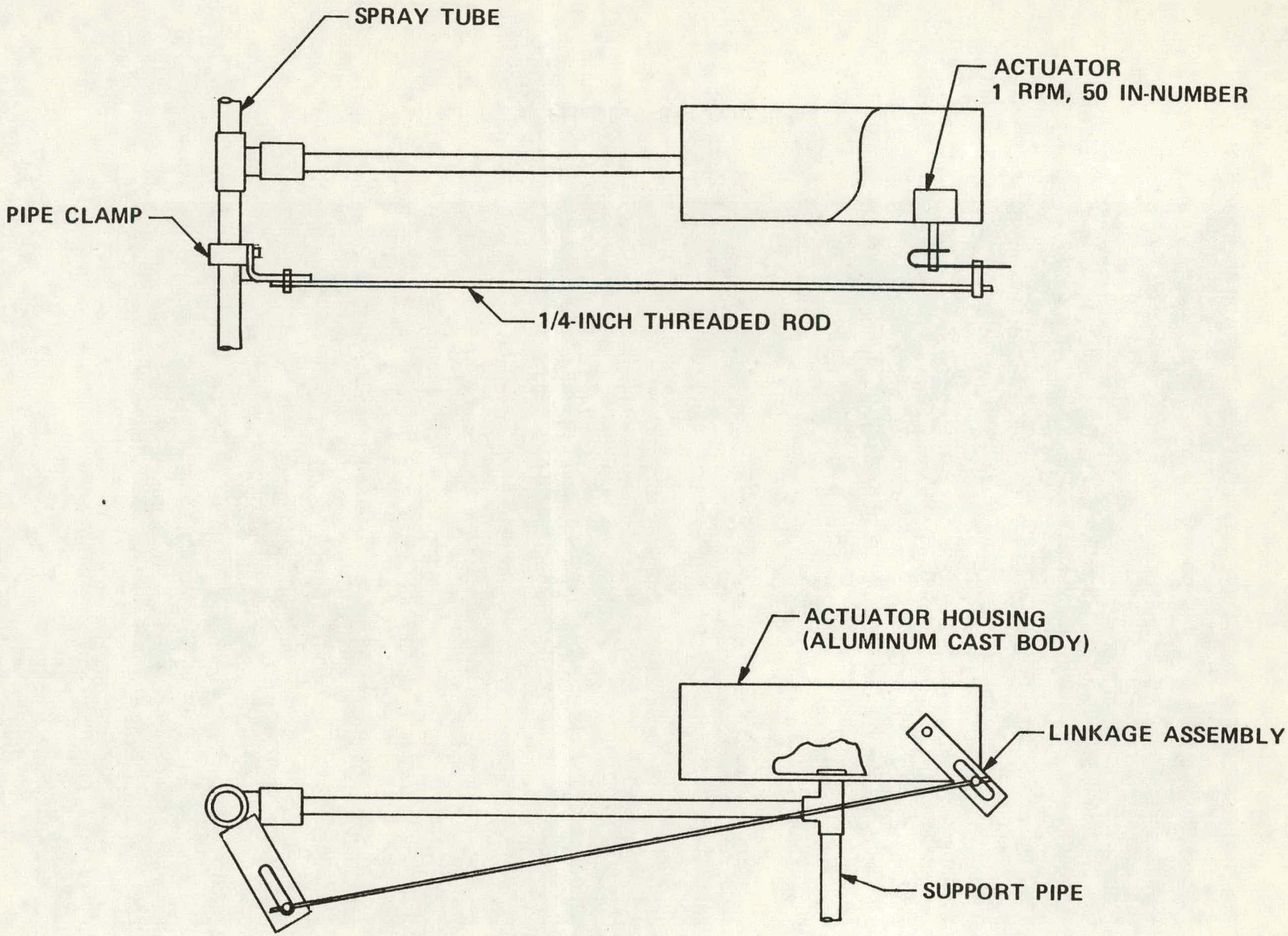


FIGURE 5-8. ACTUATOR ARRANGEMENT

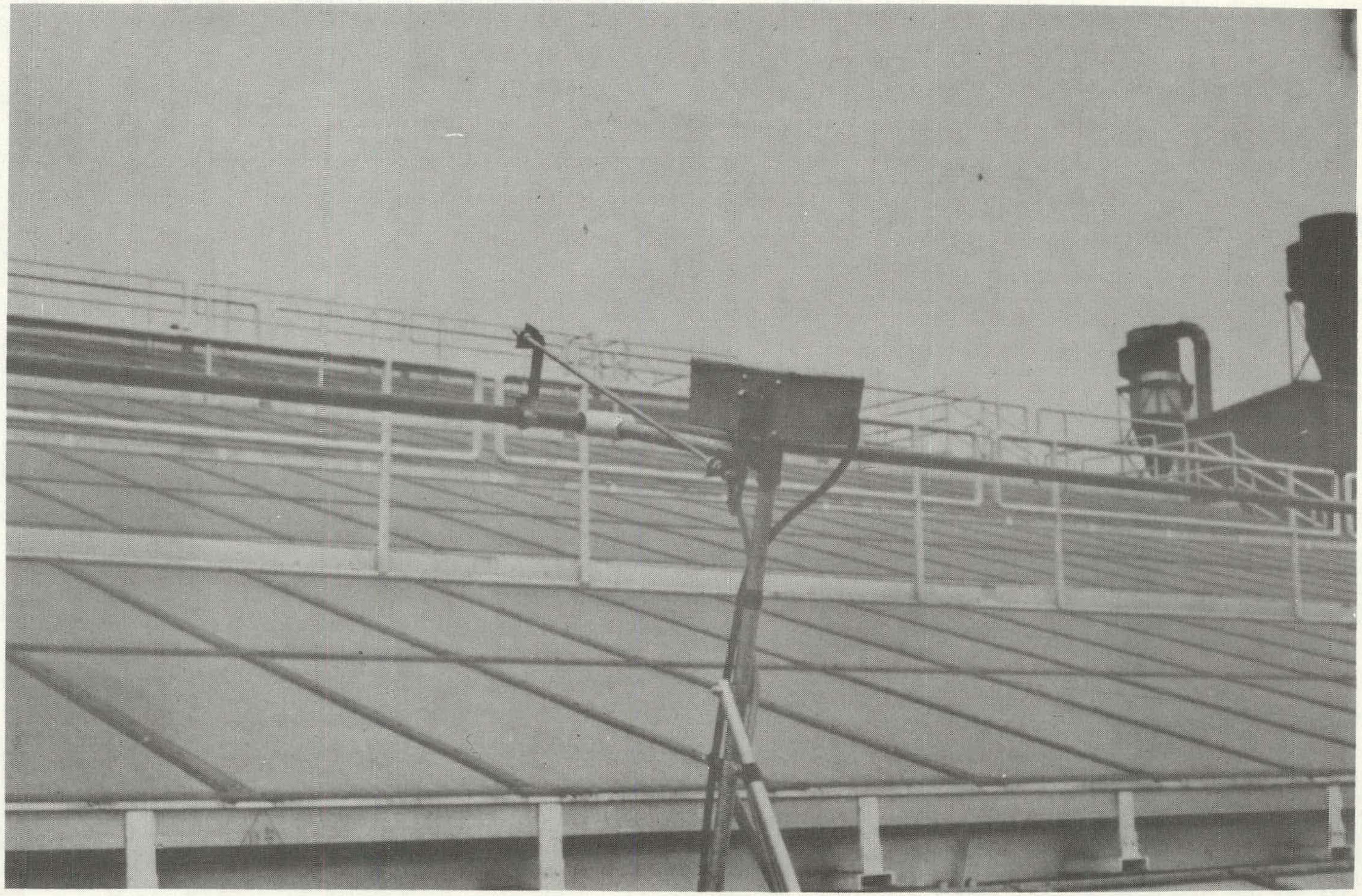


FIGURE 5-8 - Concluded

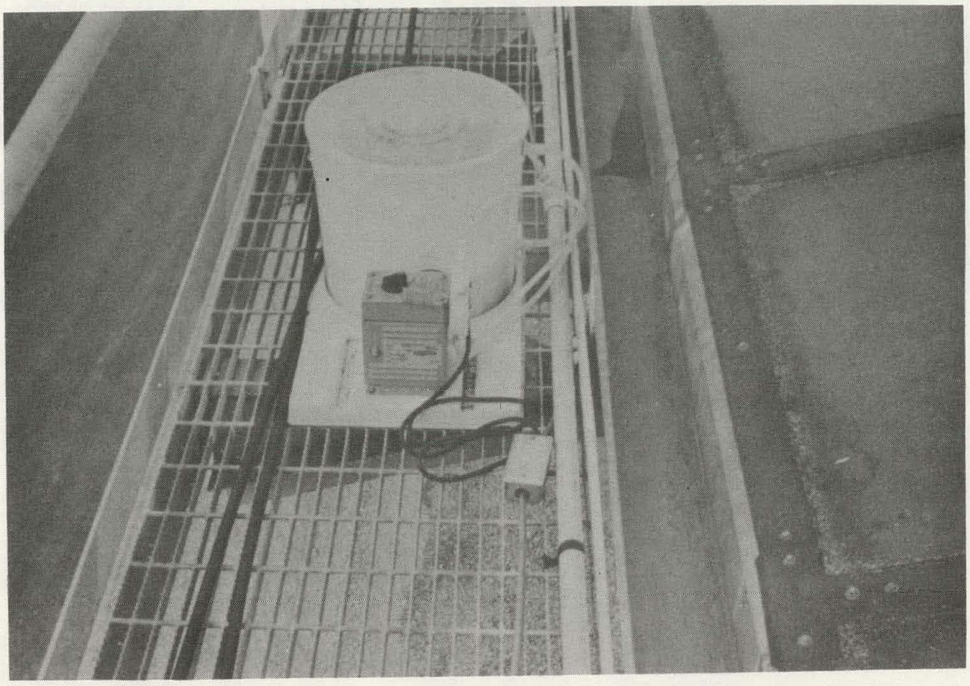
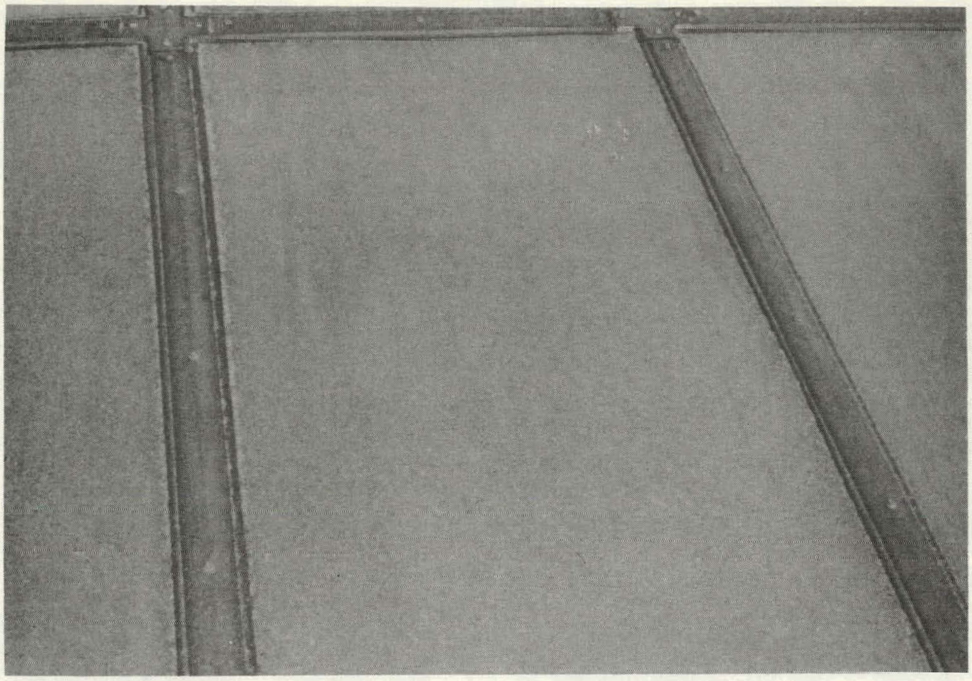
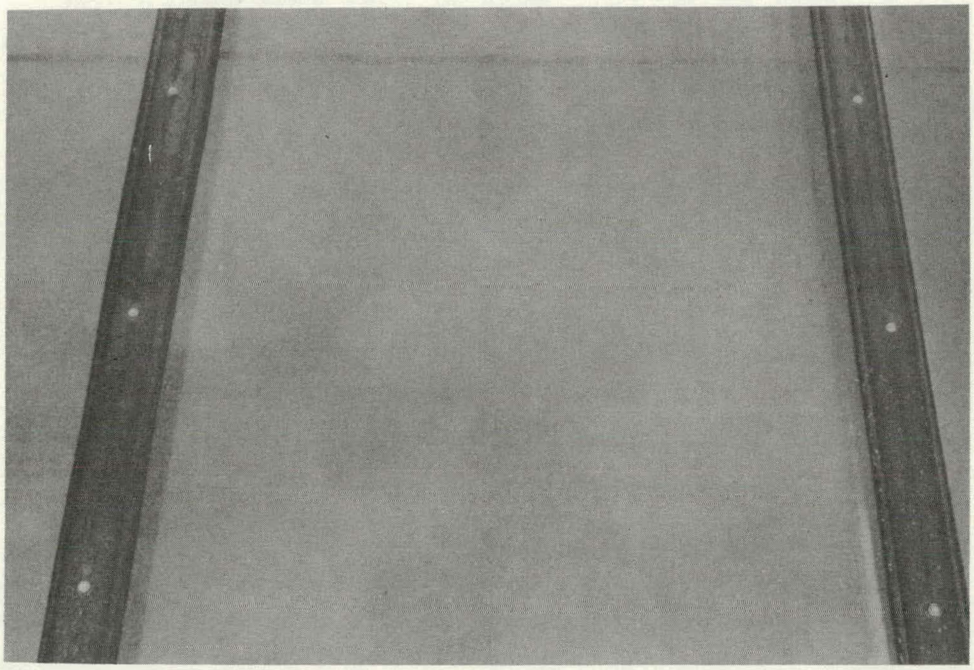


FIGURE 5-9. DETERGENT INJECTION SYSTEM



a. PANELS WITHOUT PROTOTYPE CLEANING SYSTEM



b. PANELS WITH PROTOTYPE CLEANING SYSTEM

FIGURE 5-10. COMPARISON OF PANELS

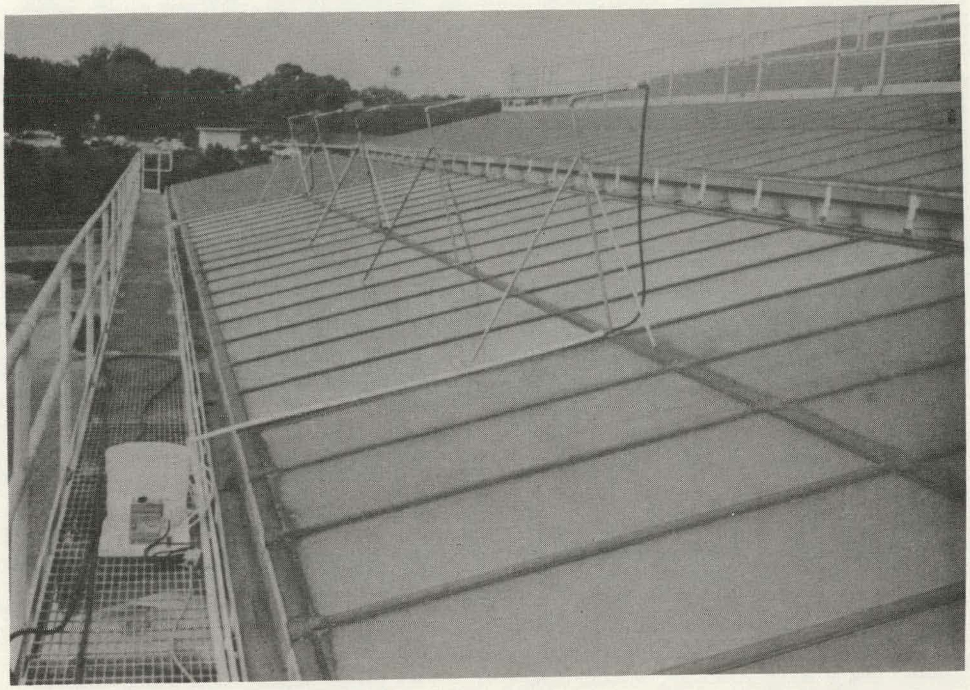


FIGURE 5-11. CLEANING SYSTEM EFFECTIVENESS

6. SYSTEM DESIGN CONCEPT

6.1 SPRAY BAR ARRANGEMENT

The spray bar syetem is conceived as being 21 modules, 48 ft long. Each module would be similar to the prototype described in Section 5. The support system will require some modification to accommodate the intersection of each module. A design concept of this modification is shown in Figure 6-1.

As in the prototype, standard materials may be used throughout the spray bar system. The actuator assemblies are conceived as being identical to the prototype, requiring one per module.

Each module is fed from both ends. This ensures maximum delivery pressure for good water impingement cleaning action.

Although not yet conclusive, testing to date indicates optimum hole sizing to be 0.037 in., spaced at 4-in. intervals. This provides a flow of 0.055 gpm/ft^2. Therefore, flow of 34 gpm is anticipated.

6.2 PLUMBING

A study of optimum pipe size has resulted in the choice of 1-in. PVC main runs and 0.75-in. feeder runs. To minimize total flow, each module is isolated with a solenoid valve and will be operated in series by an automatic control system.

Figure 6-2 presents a layout of the typical plumbing proposed. Careful design and installation will be necessary to ensure proper gravity draining for freeze protection.

6.3 DETERGENT INJECTION

The detergent injection system used in the prototype is sufficient for use in the full-scale system since only one module will be operated at any one time.

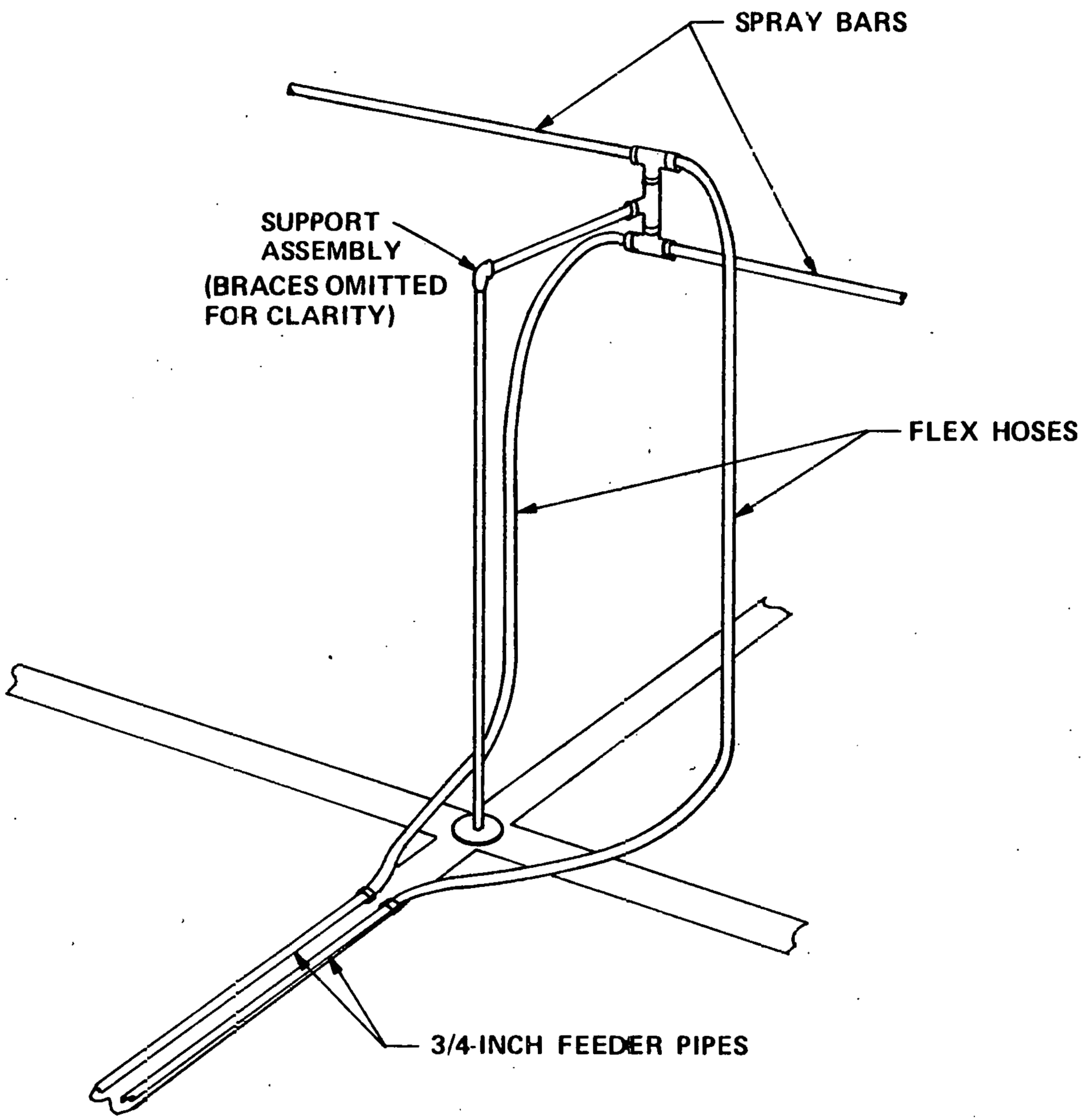


FIGURE 6-1. SUPPORT SYSTEM AT MODULE INTERFACES

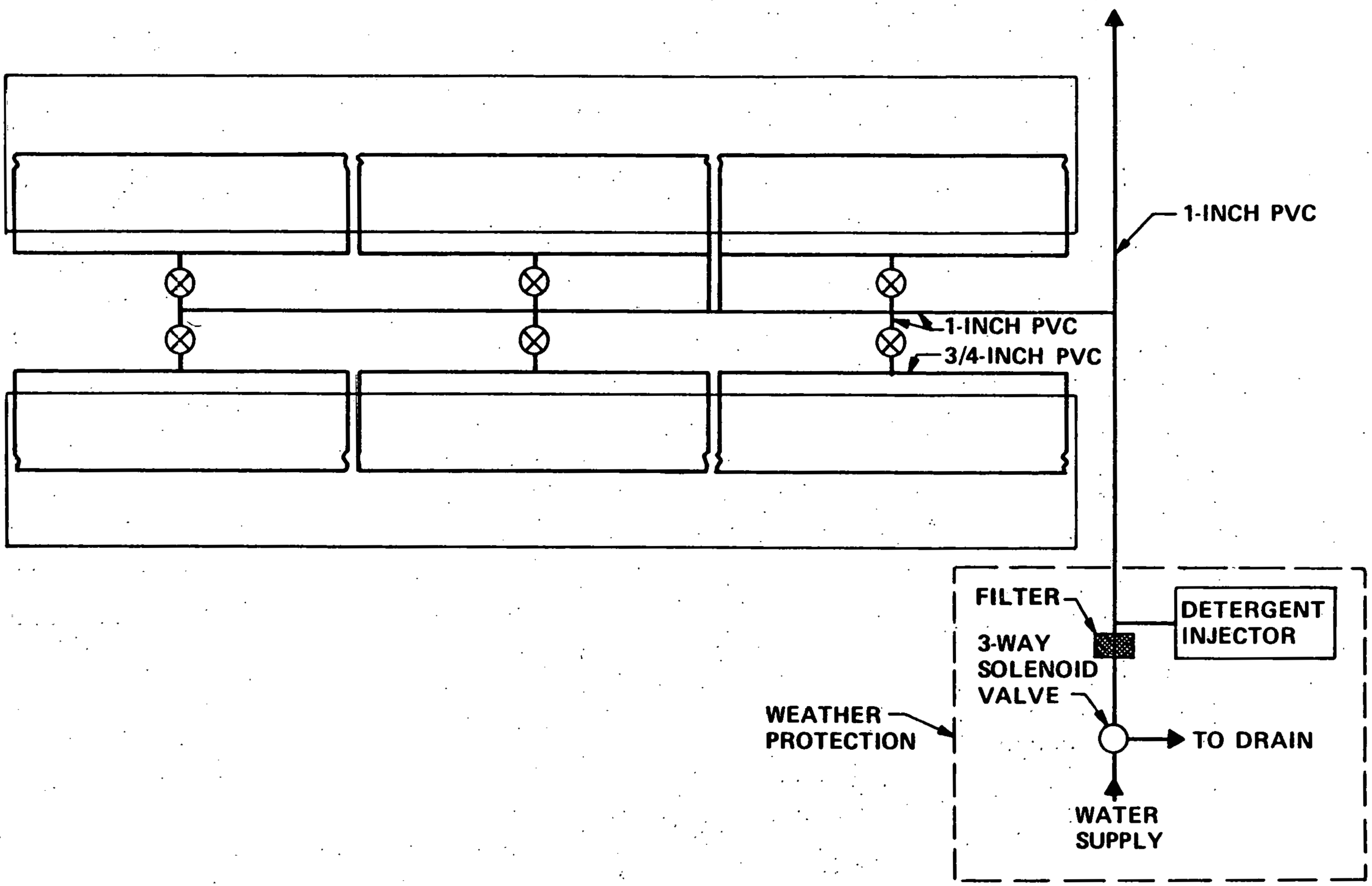


FIGURE 6-2. TYPICAL WATER DISTRIBUTION LAYOUT

6.4 CONTROL SYSTEM

The control system will manipulate the system to apply a detergent solution to each module for a duration of 1 min. each. With 21 modules, this will allow a 20-min. "soak" with the detergent solution. The soap injector would then be turned off and a 1 min. rinse applied to each module.

The control logic, shown in Figure 6-3, also provides for freeze protection. If, at the end of each rinse cycle, the temperature is below 33°F, the main water supply valve is positioned to "drain" and all control valves are positioned to "on" to allow the system to drain.

The system will be designed to use relay logic, a time clock, and a thermostat. System packaging will consist of a power panel and a control panel housing the relays and the time clock. A block diagram of the control system is presented in Figure 6-4.

6.5 SYSTEM LAYOUT

For weather protection, the control system, main water valve, and soap injector will be located in the building adjacent to the solar array. This location has the necessary water and power requirements and offers full-time freeze protection for this part of the system.

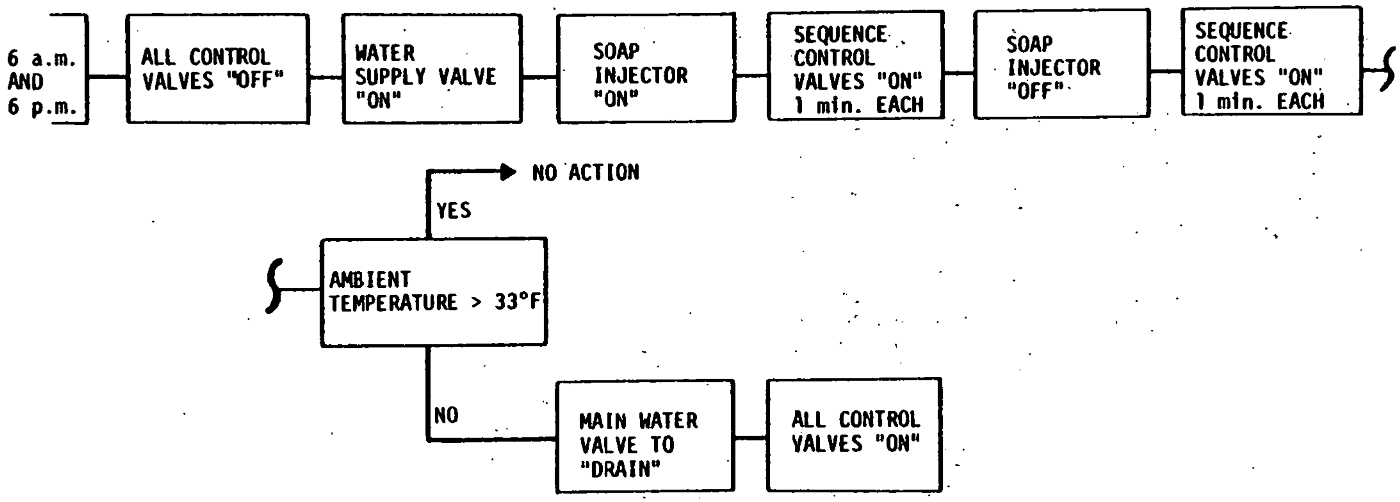


FIGURE 6-3. CONTROL LOGIC

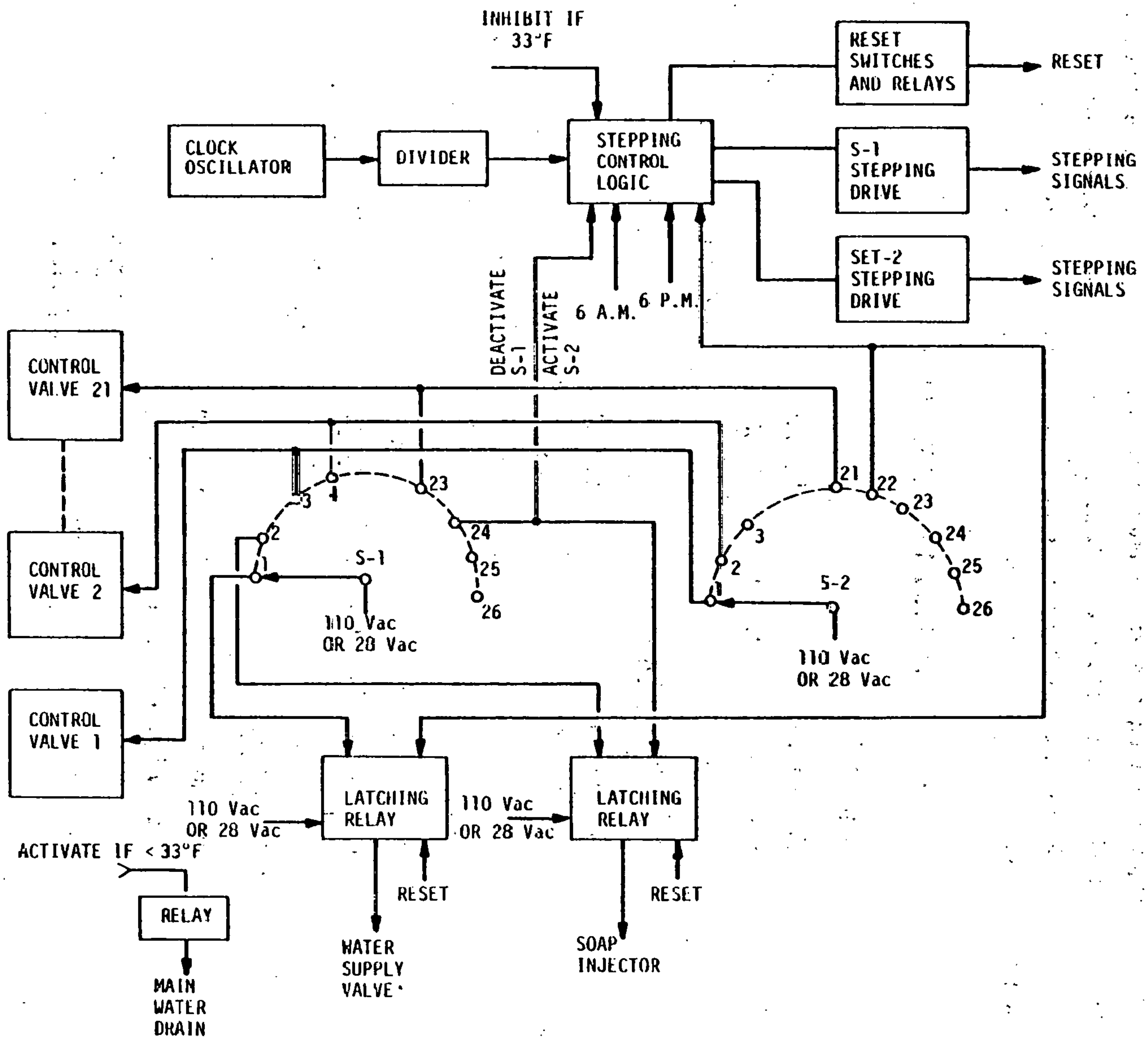


FIGURE 6-4. CONTROL SYSTEM BLOCK DIAGRAM

7. SYSTEM BUDGETARY COST

Based on experience gained during the fabrication and installation of the prototype cleaning system, a budgetary estimate has been prepared for the full-scale cleaning system. The results of this estimate are in Table 7-1. Engineering estimates shown are based on minimum engineering documentation.

TABLE 7-1. BUDGETARY COST ESTIMATE

ENGINEERING		
Mechanical	$5,000	
Electrical/Electronic	5,000	
		$10,000
FABRICATION LABOR		
Mechanical	$3,700	
Electronic	2,600	
		$ 6,300
MATERIAL		
Mechanical	$5,400	
Electrical/Electronic	1,500	
		$ 6,900
INSTALLATION		
Mechanical	$5,500	
Electrical/Electronic	2,200	
		$ 7,700
	TOTAL	$30,900

It should be noted that the mechanical fabrication and installation could be accomplished by Gold Kist personnel at significant savings.

Based on a 15% overall performance improvement, the cleaning system would increase annual fuel savings by $992 (based on June - August 1978 data). The manual cleaning cost, based on the first three months of operation, is projected to be $1,800 per year. The combination of these two is an estimated $2,792 annual economic improvement, assuming approximately equal quantities of water and detergent are consumed by either method of cleaning.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

The following conclusions are drawn from this conceptual design study:

- For this application, no translation or direct mechanical cleaning action is practical.
- Good cleaning action results from a direct water/detergent impingement on the face of collector glazings.
- The mechanical portions of such a system can be constructed using standard off-the-shelf hardware.
- An accurate economic assessment of an automatic cleaning system can be made only after specific performance testing on identical collectors in the contaminated condition and then in the cleaned condition.

8.2 RECOMMENDATIONS

The following recommendations are offered as a result of this study:

- Testing of the prototype system should continue (except during freezing weather) to determine the optimum cleaning agent and concentration and the best nozzle size and spacing.
- Tests should be performed to accurately determine the performance degradation as a result of the contamination.
- Based on results of the above, it is recommended that the system be designed and constructed in the following manner:
  - ▲ Design - TBE
  - ▲ Fabrication
    - - Control System - TBE
    - - Mechanical - Gold Kist

▲ Installation

- Control System - TBE
- Mechanical - Gold Kist
- Electrical - Gold Kist.

APPENDIX C. TBE SPECIAL TASK REPORT EMISSION SOURCES AND CONTROL DEVICES

TECHNICAL REPORT
SD78-DOE-2288

SPECIAL TASK REPORT FOR EVALUATION OF EMISSION SOURCES AND CONTROL DEVICES FOR GOLD KIST SOY FACILITY

Gerald R. Guinn, Ph.D.
Teledyne Brown Engineering

Gerald L. Forester
Gold Kist Technical Services

November 30, 1978

Prepared For

U.S. DEPARTMENT OF ENERGY
WASHINGTON, D.C.

Contract No. EY-76-C-05-5122
(Mod. A003, Task No. 5)

Prepared By

SYSTEMS DIVISION
TELEDYNE BROWN ENGINEERING
HUNTSVILLE, ALABAMA

ABSTRACT

As part of DOE's Industrial Process Heat Program, a demonstration solar collection system has been constructed at the Gold Kist soybean plant in Decatur, Alabama, to augment the fuel used in the soybean drying process. Even before construction was complete, it was apparent that contamination of the collector by plant emissions would severely degrade performance. As a result, DOE authorized this study to identify emission sources and potentially suitable suppression techniques. This study was conducted jointly by Teledyne Brown Engineering and Gold Kist, Inc.

A survey identified 11 sources of emissions. Permits exist for all identified sources. Also, all suppression devices were found to be operating within permit specifications. The source(s) of the oily material was not identified and needs a more detailed investigation.

Basic types of emission abatement equipment are compared. Specificially, bag filters and high and low-efficiency cyclone type equipment are presented. The bag filtration systems were found to range up to 99% collection efficiencies at a cost of approximately $5/cfm, compared with cyclone equipment, which ranges up to 95% efficient at an approximate cost of $4.25/cfm.

Data on specific operations within the grain and soybean processing industry and their associated flow ranges are presented. Installed cost ranges of equipment peculiar to each type of emission are also included.

PREPARED BY:

G. R. Guinn
Energy Program

APPROVED BY:

K. H. McKechnie
Manager
Systems Engineering Department

TABLE OF CONTENTS

1. INTRODUCTION

1.1 OBJECTIVES

A major objective of the Department of Energy's (DOE's) Industrial Process Heat Program is to verify and evaluate the technical and operational performance of solar thermal energy systems for drying and dehydration. For this purpose, a demonstration solar collection system using air collectors has been constructed at the Gold Kist soy plant in Decatur, Alabama. The system is designed to temper the combustion air of conventional dryers used to dry soybeans prior to storage and as a first step in the oil extraction process.

Even before construction of the solar array was complete, it was apparent that contamination of the collectors by particulate emissions from the plant would severely degrade performance. Much of the early contamination experienced during construction was subsequently eliminated by the installation of a baghouse to the seed cleaner located on top of the grain elevators. Although contamination had been significantly reduced, it was still severe enough to warrant a study to identify emission sources and potentially suitable suppression techniques. To accomplish these objectives, DOE authorized the study reported herein and prepared under Contract No. EY-76-C-05-5122.

1.2 BACKGROUND

Dust presents an important environmental consideration that must be addressed for any process heat application of solar energy. It enters into the design from two standpoints: 1) safety and 2) performance degradation due to deposits on the glazing surface. The safety hazard posed by fine organic particulates suspended in air has been dramatically illustrated by the recent explosions and fires at grain elevators. The concern for safety was a key consideration in the design of the Gold Kist solar drying system and eventually led to the selection of a positive-pressure air distribution system. Although leakage of air potentially reduces the collection efficiency of such a system over a negative-pressure system, it minimizes the possibility of dust ingestion into the collector and transport system. It also facilitates the filtering of the incoming air, which can be accomplished at a single location.

The effect of dust deposits on the flat plate collector glazing enters into the design from three standpoints: 1) reduction in performance and hence reduced fossil fuel savings, 2) increased operating costs resulting from panel cleaning labor and materials, and 3) increased investment cost attributed to panel cleaning or emission control equipment. The potential for collector contamination exists in any application of solar energy to industrial processes because 1) either the plant will produce emissions that will contaminate the collocated solar collector, as in the case at Gold Kist or 2) the plant will be located in an area of industrial activity producing condensables and particulates capable of contaminating collectors located at great distances from the point of discharge. The effects of contamination cited above provide a clue to potential solution approaches:

- Allow the collector to contaminate and thereby live with the reduced capability.
- Periodically clean the panels, thereby improving performance but with increased maintenance costs.
- Install automated techniques for panel cleaning or suppression devices at the point of emission (both techniques increase capital costs and add some operating and maintenance costs).

In a previously reported task (Ref. 1), the feasibility of automated cleaning systems has been examined. In this task, issues related to emission control will be examined.

2. PROCESSES AND EMISSIONS

The sources of air pollution in a soybean processing plant can be grouped into three board categories: 1) soybean receiving, handling, and drying operations; 2) soybean processing operations; and 3) soybean meal loadout operations. Table 2-1 presents some of the more significant potential sources in each category.

Emission sources associated with grain receiving and handling operations are similar to those involved in all grain handling storage operations. The grain cleaning and grain drying operations are the most significant emission sources in this part of the soybean processing facility. The particulate matter may contain 60 to 90% organic material. Of the inorganic matter, 3 to 20% may be free silicon (sand from entrained dirt). Specific materials in the particulate matter include particles of grain kernels, spores of smut and molds, insect debris, and pollen and dirt from the fields. Soybeans contain more dirt than corn, wheat, and milo since they grow close to the ground and the harvester may scrape up the earth as it cuts the plant off. As evidenced by the red color of the deposit, it was dirt emitted from the seed cleaner that contributed to the heavy accumulation experienced before installation of the baghouse.

In addition to the emissions typical of the grain elevator, the Gold Kist plant is potentially capable of producing emissions from the crushing and extraction processes. The major sources of emissions in the soybean processing section of the plant are the product recovery systems used on the dehulling equipment and the hull grinders and meal dryers and coolers. These emissions add to the severity of the problem because they may contain condensables or aerosols that act as a binder and provide adhesion of particulates to collector surfaces. Thus particulates that would normally be removed by wind or rain may be difficult to remove by strong mechanical action in such a case.

TABLE 2-1. POTENTIAL SOURCES OF AIR POLLUTANTS IN SOYBEAN PROCESSING PLANTS

- Grain Receiving, Cleaning, Drying, and Storage

Grain Unloading	Trippers, Conveyor Transfer Points
Elevator Leg Vents	Grain Cleaner
Corner and Side Vents	Grain Dryer

- Soybean Processing

Cracking Rolls	Desolventizer-Toaster
Dehulling System	Meal Dryer
Hull Toaster	Meal Cooler
Hull Grinding	Meal Grinder
Bean Conditioner	Solvent Vapor Recovery System
Flaking Mills	

- Product Shipping

Meal Loadout

3. EMISSION SURVEY AND IDENTIFICATION

On July 24, 1978, the information contained in the air quality permit applications for each emission source was verified by inspection. Each source has been issued an air quality permit by the Tri-Counties Health Department. Each emission source and its type of control device are listed in Table 3-1. During the inspection, evidence of satisfactory operation of each control device was apparent. Also, it was observed that the bean dryers may emit some particulate matter in the area of the solar panels.

In addition to the sources listed in Table 3-1, certain other fugitive sources may be influencing the accumulation of dust on the solar panels. The conveyors under the bean dryers may occasionally emit fugitive dust when conveyor covers are loose. The bean conveyor from storage to the preparation building formerly emitted fugitive particulate matter. However, this conveyor has been replaced with a covered conveyor to eliminate the fugitive dust. Light chaff and dust have been observed falling from overhead conveyor D-27. The head of this conveyor is equipped with aspiration dust control, and the discharge end of this conveyor is equipped with a scraper on the underneath side of the belt. Dust emissions from this conveyor should be negligible or eliminated with proper operation of the aspiration dust control system for this source.

Evidence of adhesion of proteinaceous or oily material to the solar panel surfaces was observed. The source or sources of this material are not clearly apparent. This material may be generated at process points where physical or chemical changes to the soybeans occur. Thus one or more emission sources in the bean preparation or oil extraction areas may be contributing small amounts of adhesive material.

As a result of the emissions source inspection, the following conclusions were obtained:

- Sources of particulate emission have been accurately identified by the air quality permit applications. Also, a visual inspection indicates that the particular collection devices are performing within or better than limits required by local and state authorities.

- Further reductions of particulate emissions may not be achievable without significant modifications. The following section describes techniques used in emission control.

- Sources of fugitive particulate emission are being controlled by the installation of improved conveying equipment and by proper use of existing aspiration systems.

- Sources of proteinaceous or oily material, if any, are not clearly established. The adhesion nature of this material may be causing the severe cleaning problem currently experienced on the solar panel surfaces.

The following actions are recommended:

- Ensure proper operation and maintenance of the dust control system on overhead conveyor D-27, including the belt loader hood and the belt scraper hood.

- Ensure that all conveyors under the bean dryers are tightly covered.

- Ensure the proper operation and maintenance of all dust control systems on top of the preparation building.

- Perform a detailed stack survey to establish the source(s), if any, of proteinaceous or oily material emissions that may contribute to the adhesion of particulate material to the solar panels.

TABLE 3-1. PRIMARY EMISSION SOURCES,
DECATUR OIL PRODUCTS FACILITY
DECATUR, ALABAMA

SOURCE PERMIT NUMBER	DESCRIPTION	TYPE OF CONTROL DEVICE
Z001	Bean Receiving, Storage, Conveying; Truck, Rail, Barge Loadout	Fabric Filter
Z002	Bean Scalper, Screener, Hammer Mill	Fabric Filter
Z003	Preparation Screener 52EC	High Efficiency Cyclone
Z004	Cracking Operation	High Efficiency Cyclone
Z005	Dehulling Operation, Separator, Cleaners, Aspirators	Fabric Filter, High Efficiency Cyclones
Z006	Flaking Operation	High Efficiency Cyclones
Z007	Meal Drying/Meal Cooling	Fabric Filter
Z008	Meal Sifters/Grinders	Fabric Filter
Z009	Meal Handling/Transfer	Fabric Filter
Z010	Bean Drying	Perforated Column Plates
Z011	Toasted Hull/Grinders	High Efficiency Cyclone

4. ABATEMENT EQUIPMENT

4.1 INTRODUCTION

Emissions can be controlled at two different points in the process. The emissions can be eliminated at the source, or a hooding and aspiration system leading to a dust collector can be employed to capture emissions. Techniques that eliminate the sources of dust emission or that retain it are the most effective. The grain and feed industry typically employs collection devices such as cyclones or fabric filters. Since elimination of sources involves techniques that apply only to the specific process involved, such as enclosures or covers on bins, tanks, and hoppers, discussion of abatement equipment is limited to collection devices that have general applications.

The physical and chemical characteristics and properties of particulates, including size, play an important role in the design and selection of dust capture equipment. Also of significant importance are the particulate concentrations in the gas, along with gas temperature and humidity.

Design and performance are also influenced by other parameters of the process such as total flow volume, temperature, and pressure of the carrier gas and its entrained particulates. Other factors to be considered include pressure drops in the system, site limitations affecting the accommodation of removal equipment, utility requirements, availability, and cost. Finally, the comparative maintenance and economics form the overriding consideration in material selection. It is especially important that this system be designed as an integrated unit with adequate capacity for current and planned production.

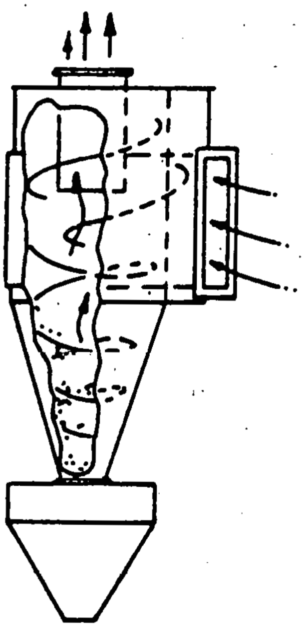
Standards of performance are designed to reflect the "best available technology". Generally, control of particulates in efficient gas streams is accomplished in the grain industry using cyclone separators and fabric filters.

4.2 CYCLONE

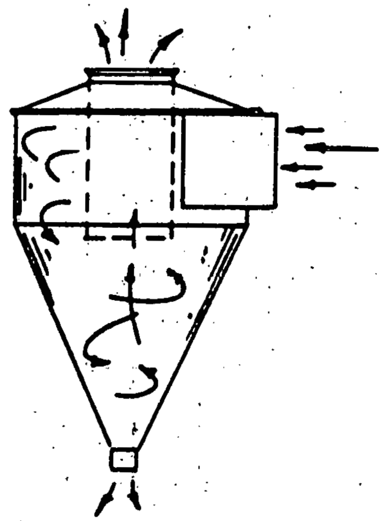
Cyclones are classified according to efficiency. High-efficiency cyclones are characterized by a narrow inlet opening, long body length relative to body diameter, and small outlet diameter (see Figure 4-1). The higher gas velocity results in a collection efficiency of about 25 to 95% and a pressure drop of 3 to 5 in. of water. This is the most common control device used at elevators. Low-efficiency cyclones have large inlet openings, large-diameter bodies, and large outlet diameters. The slower gas velocity results in collection efficiencies between 60 and 85% and pressure drops of only 0.5 to 2.0 in. of water.

The principal advantage of the cyclone is that it offers mechanical simplicity and high reliability along with low capital cost and energy consumption. Because of these features, they have been used extensively to control grain receiving and shipping operations, as well as a variety of grain processing emission sources. For units that are not properly maintained (e.g., dust accumulations on the walls, air infiltration through the dust discharge), the efficiency will decrease dramatically. Visible emissions can be quite noticeable even for the best operating units.

SOURCE: REF. 2



HIGH-EFFICIENCY DESIGN



HIGH-THROUGHPUT DESIGN

FIGURE 4-1. CYCLONE DUST COLLECTORS

Figure 4-2 shows the typical collection efficiency for both the high-throughput and high-efficiency cyclones for various particle diameters. Since both types of devices are inefficient for collecting small particles, and it is the smaller particles that scatter light most effectively, it is apparent that even the most efficient cyclone will operate with some visible emission if the incoming grain has a significant amount of fine dust or the emission is from a process that has emission of particulates with small mean diameters.

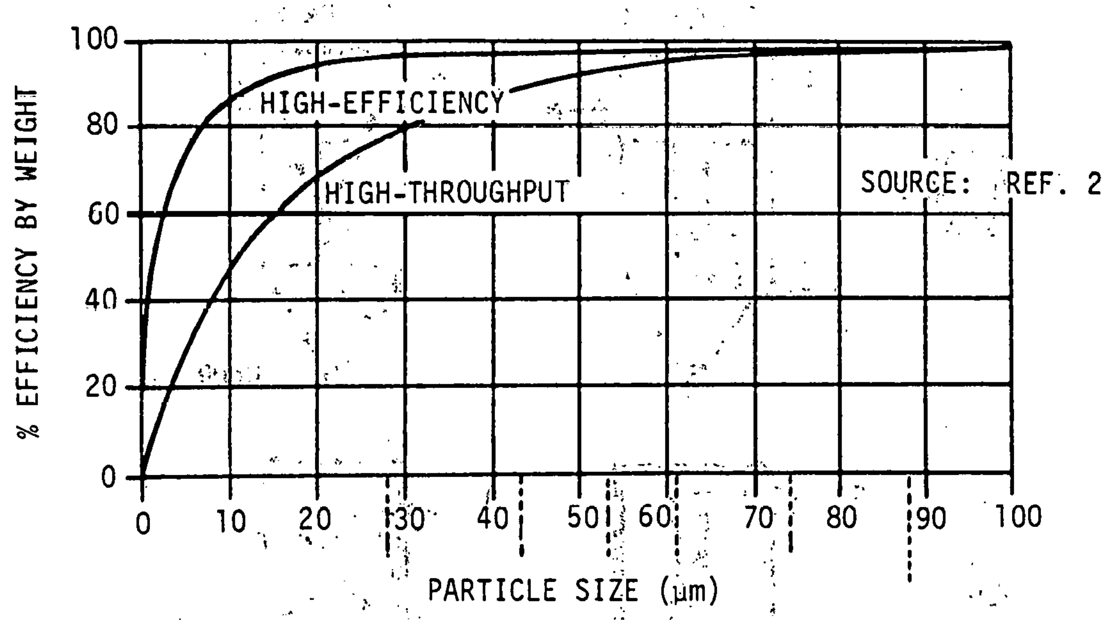


FIGURE 4-2. TYPICAL COLLECTION EFFICIENCY CURVES FOR HIGH-THROUGHPUT AND HIGH-EFFICIENCY CYCLONES

4.3 FABRIC FILTERS

Fabric filter systems typically consist of cloth bags or envelopes suspended in such a way that the collected particles will fall into a hopper when dislodged from the fabric. The particle-laden air usually flows from inside the bag out; envelopes from the outside in. The accumulated material can be dislodged by such devices as bag shakers, the reverse jet from a ring-slit-jet (which moves along the bag), and a pulse-jet reverse gas flow. The dislodged material drops into a bin for disposal. Fabric filters can be used to remove smaller particles than cyclone systems, but their costs for installation, operation, and maintenance are somewhat higher. Bag rupture can result in discharge of particulates until repairs are made. Fabric filters are capable of over 99% collection efficiency of fine particulates. Figure 4-3 presents some basic baghouse capture systems.

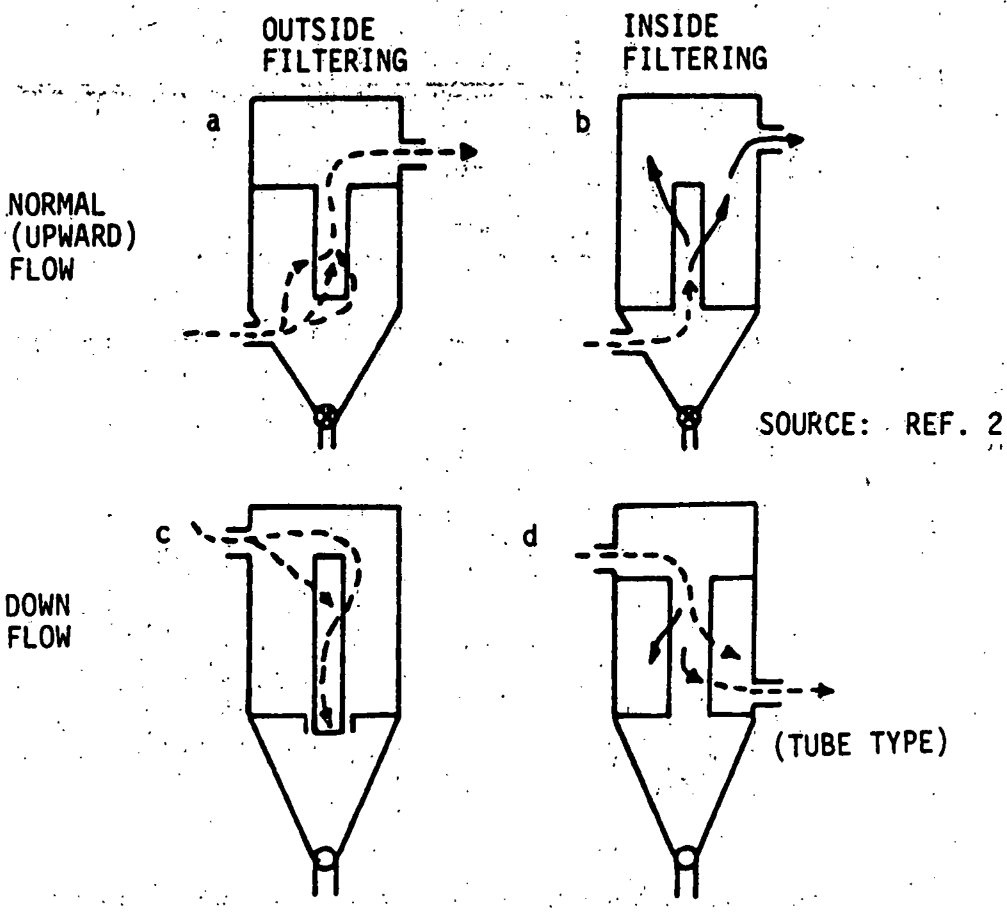


FIGURE 4-3. FABRIC FILTER CONFIGURATION

4.4 CONTROL DEVICE COSTS

The total installed cost for a given installation is highly variable depending on such factors as:

- Type of installation, new or existing plant
- Type of labor used, plant or contract
- Type of process controlled, amount of ductwork required, and geographical location.

Figures 4-4 and 4-5 present capital cost as a function of capacity for various types of control devices used on grain processing emission sources (Ref. 2). These figures represent the cost of the control and those appurtenances usually considered a part of the control device but not such items as ductwork, fans, starters, and motors whose costs vary considerably from one installation to another; nor do they include the installation costs.

Gold Kist has recently conducted a study of the installed costs of collection systems and has found that the following values generally apply:

Cyclone System - $4.25/cfm

Baghouse System - $5/cfm.

Table 4-1 (Ref. 2) lists the approximate cost range for controlling specific types of emission sources. These figures represent only the normal cost range that would be applicable to perhaps 90% of the various source types. The lower cost figures are for cyclone systems. Because of the large variability in costs, the cost to control an individual facility must be determined by careful evaluation of the particular requirements of that facility.

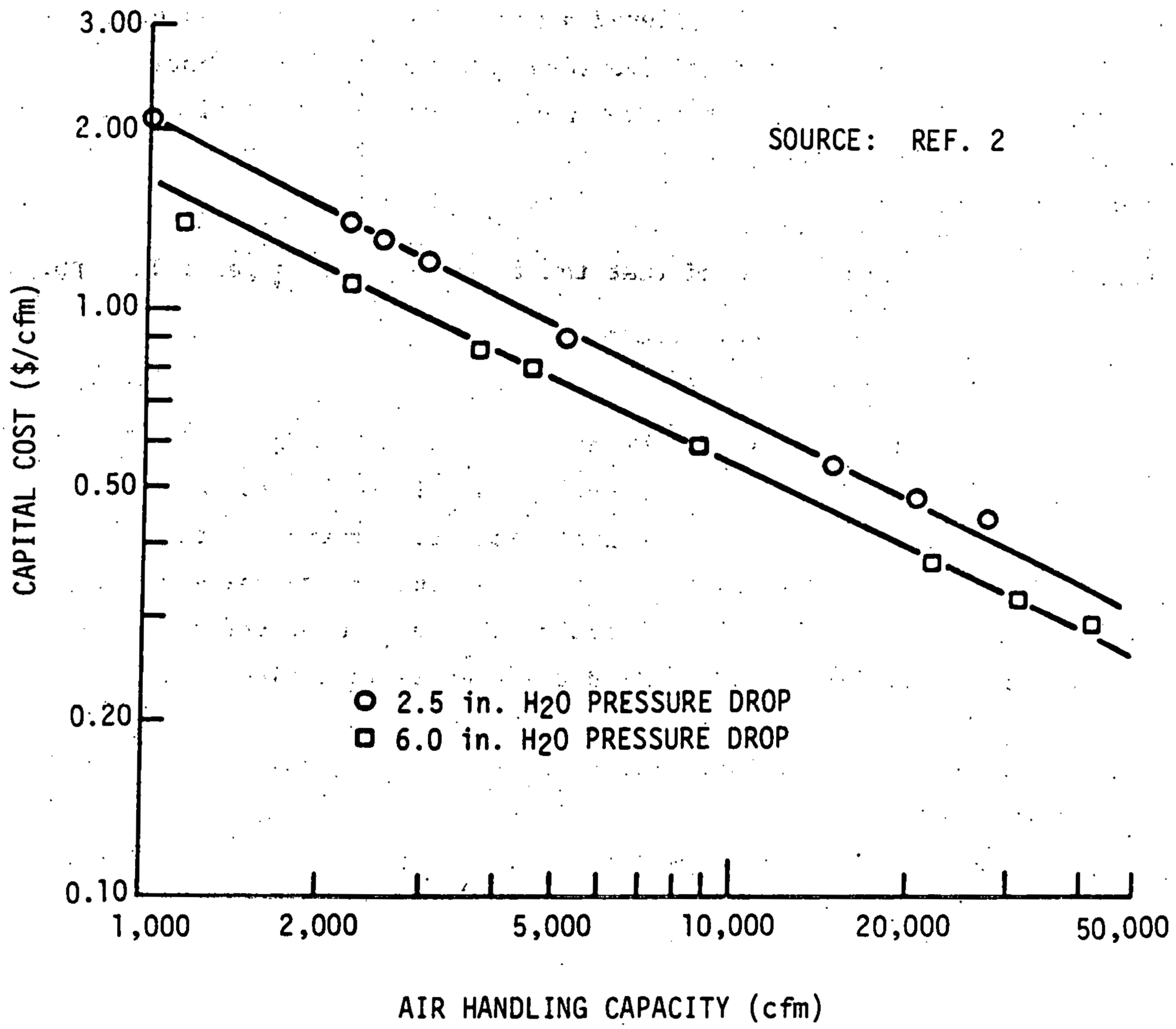


FIGURE 4-4. CYCLONE COLLECTOR (EQUIPMENT COST INCLUDES BASIC UNIT, DUST HOPPER, SCROLL OUTLET, WEATHER CAP, AND SUPPORT STAND)

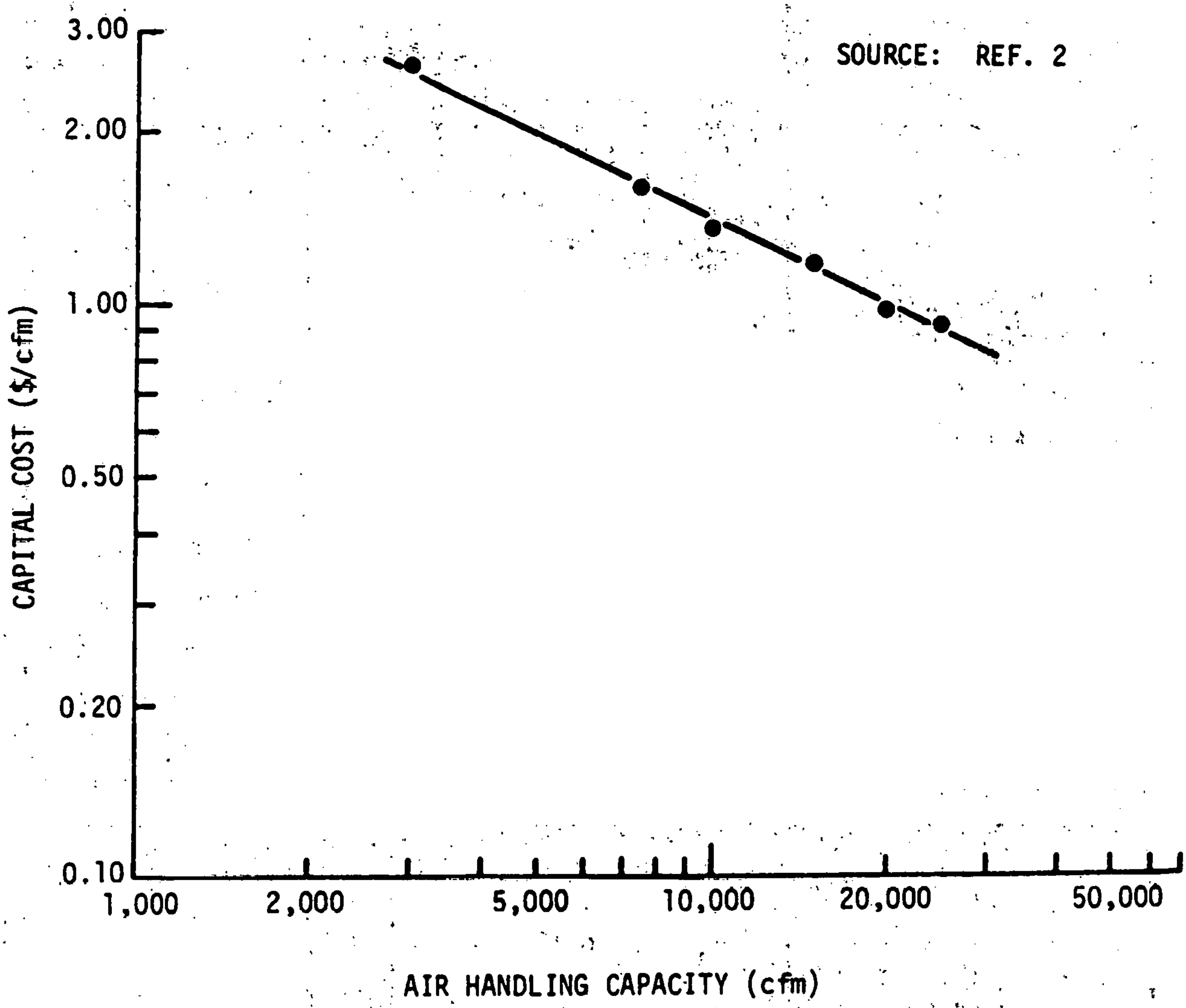


FIGURE 4-5. FABRIC FILTER (EQUIPMENT COST INCLUDES BASIC UNIT, COMPLETE WITH AIR PUMP AND ROTARY VALVES, MOTOR, STARTER)

TABLE 4-1. APPROXIMATE RANGE OF CONTROL COST
(TOTAL INSTALLED COST)

OPERATION	TYPICAL RANGE (cfm)	INSTALLED COST ($/cfm)
GRAIN HANDLING		
Receiving		
Truck Dump	10,000 to 20,000	1.75 to 4.00
Boxcar Receiving	10,000 t0 20,000	1.75 to 4.00
Hopper Car Receiving	10,000 to 20,000	1.75 to 4.00
Barge Receiving	10,000 to 20,000	1.75 to 4.00
Drying	30 to 100 cfm/bu/hr	0.25 to 0.75
Cleaning	5,000 to 15,000 (each)	2.00 to 3.00
Transfer Operations		
Scale and Garner	1,000 to 10,000	1.50 to 3.00
Transfer	Depends on plant configuration	--
Loadout (Truck, Boxcar, Hopper Car, Ship, Barge)	5,000 to 20,000 (each)	2.00 to 4.50
SOYBEAN PROCESSING		
Receiving and Transfer	(see Grain Handling above)	
Cracking Mills, Flaking, Conditioning, Dehulling, and Screening	5,000 to 15,000 (each)	2.50 to 4.50
Meal Drying	8,000 to 12,000	2.00 to 6.00
Meal Cooling	10,000 to 20,000	2.00 to 3.00
Hull Toaster and Grinder	5,000 to 20,000 (each)	2.00 to 3.50

REFERENCES

1. B. R. Hall, "Special Task Report for Conceptual Design of Automatic Cleaning System for Solar Panel Glazing - Solar Drying of Soybeans", Teledyne Brown Engineering, SD78-DOE-2276, October 31, 1978

2. Dr. Larry J. Shannon, et al., "Emission Control in the Grain and Feed Industry, Volume 1 - Engineering and Cost Study", Midwest Research Institute, PB-229 996, December 1973

☆U.S. GOVERNMENT PRINTING OFFICE: 1980-640-258 2004