DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-150544

SIMS PROTOTYPE SYSTEM 2 TEST RESULTS - ENGINEERING ANALYSIS

Prepared by

IBM Federal Systems Division
150 Sparkman Drive
Huntsville, Alabama 35805

under Contract NAS8-32036 with

National Aeronautics and Space Administration
George C. Marshall Space Flight Center, Alabama 35812

for the U. S. Department of Energy

(NASA-CR-150544) SIMS PROTOTYPE SYSTEM 2 TEST RESULTS: ENGINEERING ANALYSIS (IBM Federal Systems Div.) 46 p HC A03/MF A01 CSCL 10A

N78-19604

Unclas

G3/44 07293

U.S. Department of Energy

Solar Energy

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. DOE/NASA CR-150544	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE Sims Prototype System 2 Test Results - Engineering Analysis		5. REPORT DATE January 1978
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT # IBM 78W-0003
9. PERFORMING ORGANIZATION NAME AND ADDRESS IBM Federal Systems Division 150 Sparkman Drive Huntsville, Alabama 35805		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO. NAS8-32036
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D. C. 20546		13. TYPE OF REPORT & PERIOD COVERED Contractor Report
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This work was done under the technical management of Mr. Earle G. Harris, Marshall Space Flight Center.

16. ABSTRACT

This report describes the testing, the problems encountered, and the results and conclusions obtained from tests performed on the IBM Prototype System 2, solar hot water system, at the Marshall Space Flight Center Solar Test Facility.

System 2 is a liquid, non-draining solar energy system for supplying domestic hot water to single residences. The system consists of collectors, storage tank, heat exchanger, pumps and associated plumbing and controls.

17. KEY WORDS	18. DISTRIBUTION STATEMENT Unclassified-Unlimited WILLIAM A. BROOKSBANK, JR. Mgr, Solar Heating & Cooling Project Office

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	45	NTIS

MSFC - Form 3292 (May 1969)

For sale by National Technical Information Service, Springfield, Virginia 22151

TABLE OF CONTENTS

INTRODUCTION

System 2 is a liquid, non-draining solar energy system for supplying domestic hot water to single family residences. As shown in Figure 1, it consists of collectors, storage tank, heat exchanger, pumps and associated plumbing and controls. A silicone fluid circulated through the collectors absorbs heat energy which is transferred by way of the double wall heat exchanger to potable water in the preheat tank. The solar heated water is stored in the preheat tank until needed to service a standard domestic hot water heater. The standard hot water heater serves as a backup for the system by adding any necessary energy to bring the domestic hot water to approximately 140^{o}F.

Prototype System 2 was tested at the MSFC Solar Test Facility during September and early October 1977. The major objectives of the test are:

- To verify the system installation techniques, operation and performance
- To verify the adequate performance of the individual marketable subsystems
- To provide a general test data base for comparison with field data from the Togus, Maine site

This report discusses in general the testing which was done, the problems encountered, and the results and conclusions obtained. For additional detail on test equipment, procedures and photographs, see the details in Appendix A.

All testing, including writing of the test procedure, installing the test system and analyzing the data, was performed by Wyle Laboratories personnel at the MSFC Solar Test Facility.

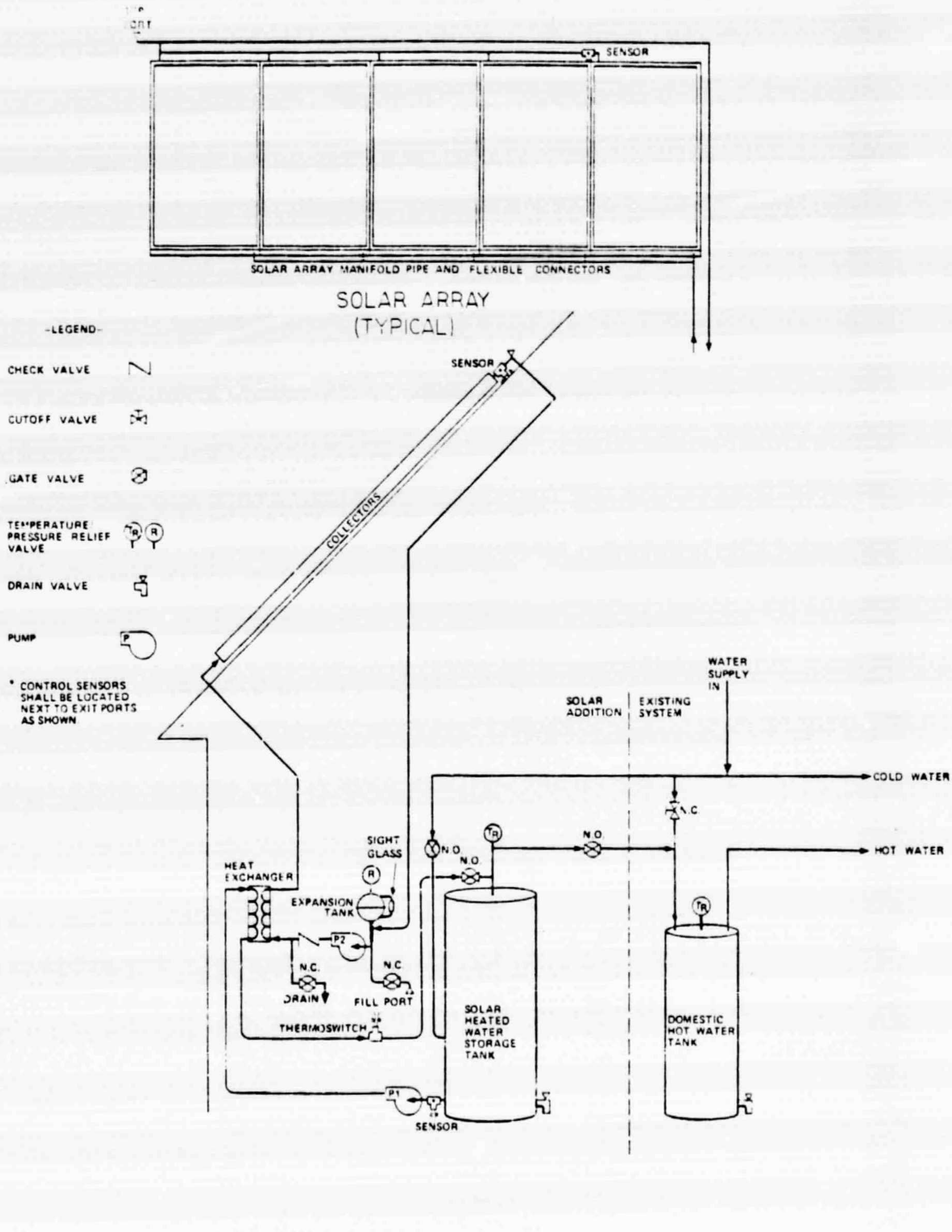


Figure 1. System 2 Functional Diagram

SUMMARY

Most System 2 hardware was installed in the MSFC Solar Test Facility in July and August 1977. Testing on the system was conducted in September and early October 1977. Only a few minor problems were encountered during installation.

The system was turned on for the first time in late August. There were no operational problems. The differential thermostat controller reliably turned the system on and off at near optimum set points.

Overall system performance was very close to the initial predictions. The system should perform satisfactorily in most areas of the United States without any problems of freezing, boiling, corrosion and collector fluid breakdown.

The system annual solar contribution should be approximately 60% based on the updated F-chart run. This is slightly better than the 56% originally predicted during system design.

DESCRIPTION OF TEST

Sketches and photographs of System 2 are included in Appendix A. The hardware was installed per the System 2 drawing with the exception of a sight glass on the expansion tank and a short section of 1 1/4 inch copper pipe under the expansion tank to aid in removing air bubbles from the collector fluid.

Most System 2 hardware was installed in the MSFC Solar Test Facility in July and August with testing conducted in September and early October. The five L.O.F. collectors were mounted in May and allowed to stagnate for four months prior to filling and testing of the system.

Installation of the plumbing and sensors was completed in August. The system was pressurized, checked for leaks, and two slow leaks repaired. The collector loop was filled on August 23.

Facility instrumentation problems delayed initial testing approximately two weeks.

System testing was conducted with two different heat exchangers, a Solar Shop HE1 and a Halstead and Mitchell HX1 (see Section 5.2), in order to assess heat exchanger affects on system performance. Approximately two weeks of testing was performed with each heat exchanger. A plumbing change was made to put the water coming from the heat exchanger into the top of the pre-heat tank (to eliminate "short circuiting") and two additional days of testing was made on each exchanger. Testing was completed on October 12, 1977.

The performance of the system was monitored with temperature probes and flow measurements. Heated water was taken from the system to simulate daily domestic hot water usage. The system controller was powered up each morning and allowed to control the daily system operation.

The test data was computer processed resulting in daily plots of the parameters monitored. These plots were used to evaluate system and subsystem performance.

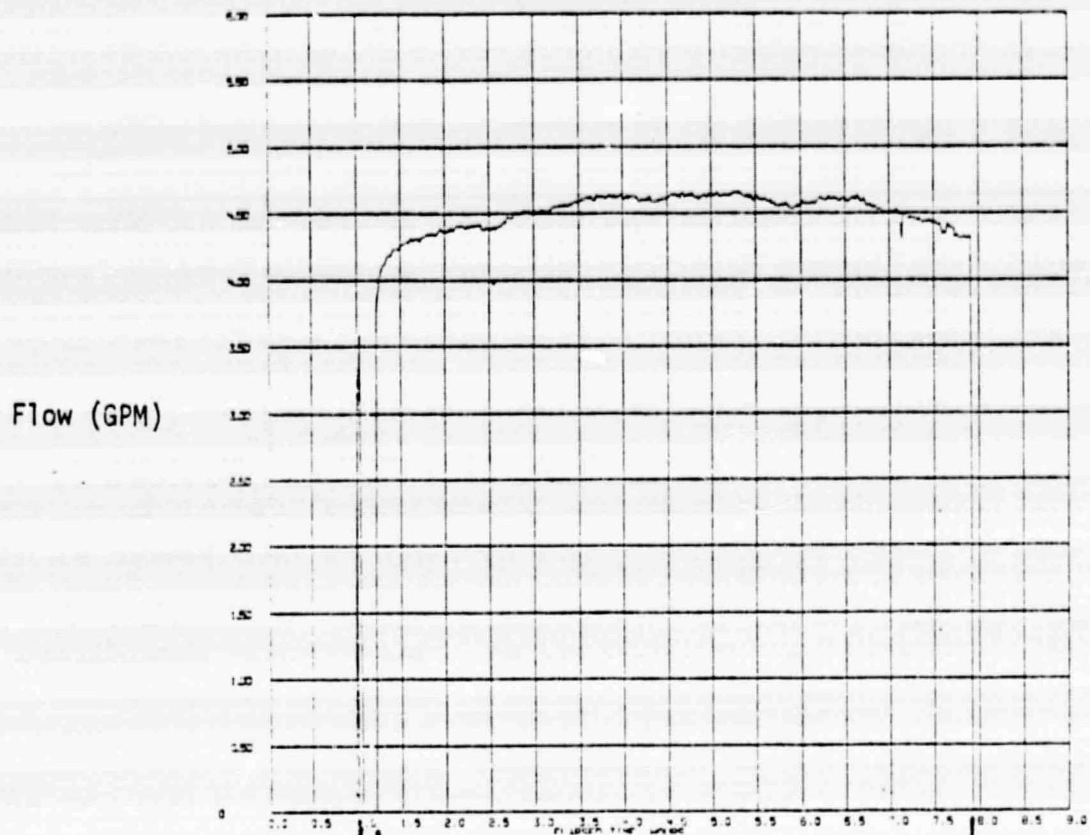
SYSTEM PERFORMANCE RESULTS

The System 2 controller was set to turn the system on when the collector fluid in the upper manifold was 20 degrees hotter than the water in the bottom of the preheat tank, and turn the system off when the collector fluid temperature come within 3 degrees of the water temperature. During testing, these set points resulted in the system operating from about 8:30 to 4:00 on clear days.

Figures 2, 3 and 4 are examples of the data from typical days of operation. Figure 2 shows the collector fluid flow rate and delta T across the collectors, while Figure 3 shows the water flow rate and delta T across the heat exchanger for the same day. The system turned on approximately one hour after the instrumentation was powered up. The pumps cycled on and off once, then stayed on for the rest of the day. The pumps continued to run for 15 minutes after the delta T across the collector had reached zero. The delta T on the water side of the heat exchanger remained between +3 and +16 degrees all day. The controller turned the system on and off at points which resulted in operation from early morning to late afternoon. Energy was therefore collected for a maximum amount of time each day.

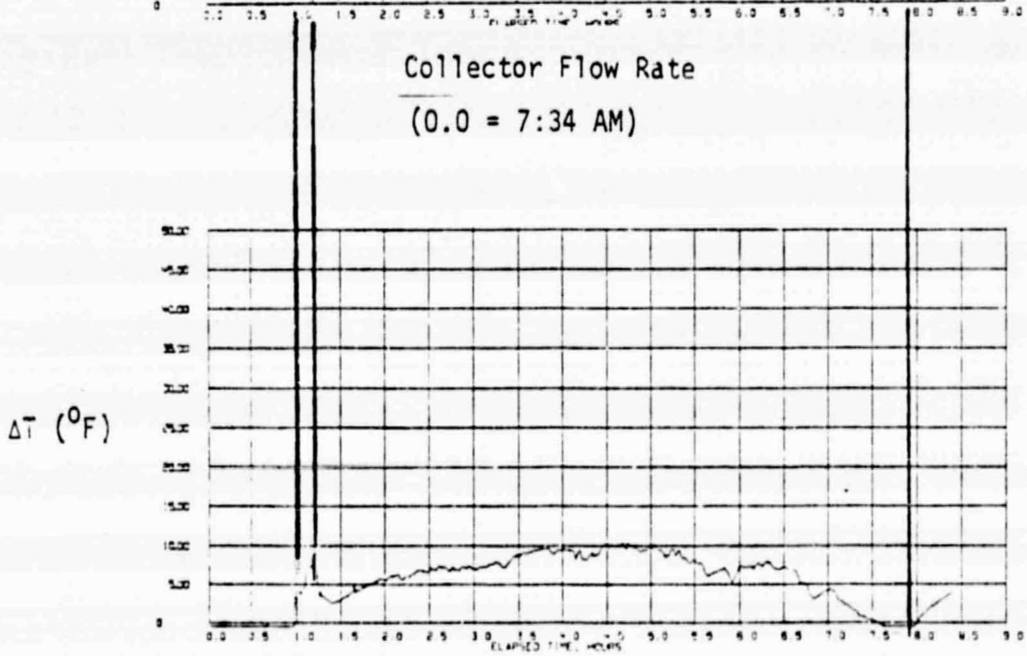
Figure 5 shows the temperature of water coming from the bottom of the preheat tank on a very good day. The dip in the plot at about 3.0 hours is the result of drawing 30 gallons of hot water from the system from 11:00 to 11:15 with cold water entering the preheat tank. At the end of the collecting day, the water in bottom of the preheat tank is at 130^{o}F. Figure 6 shows the locations of the sensors and direction of the flows.

Overall system efficiency for the final system configuration was calculated to be about 28% with Solar Shop's heat exchanger and about 26% with Halstead and Mitchell's heat exchanger. This means that between 25 and 30% of the solar energy hitting the collectors during the day was used to raise the temperature of the preheat tank water. Based on test data from other systems, these efficiencies are both acceptable and realistic.



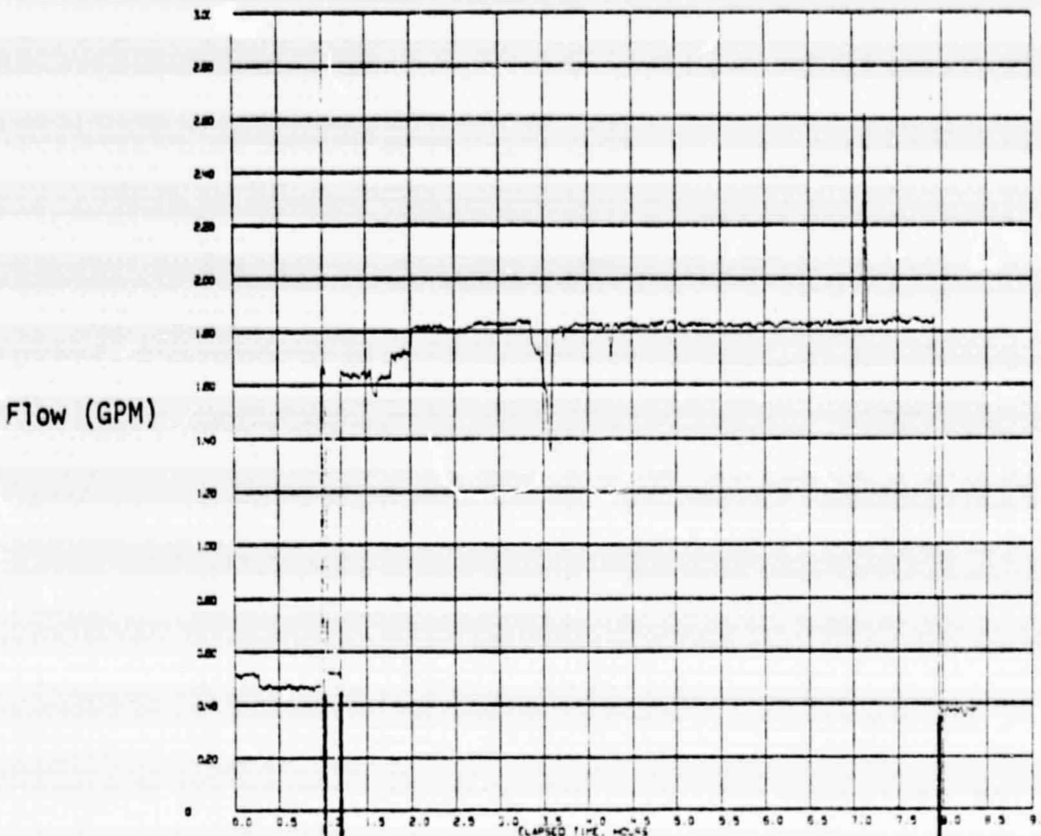
Collector Flow Rate

(0.0 = 7:34 AM)



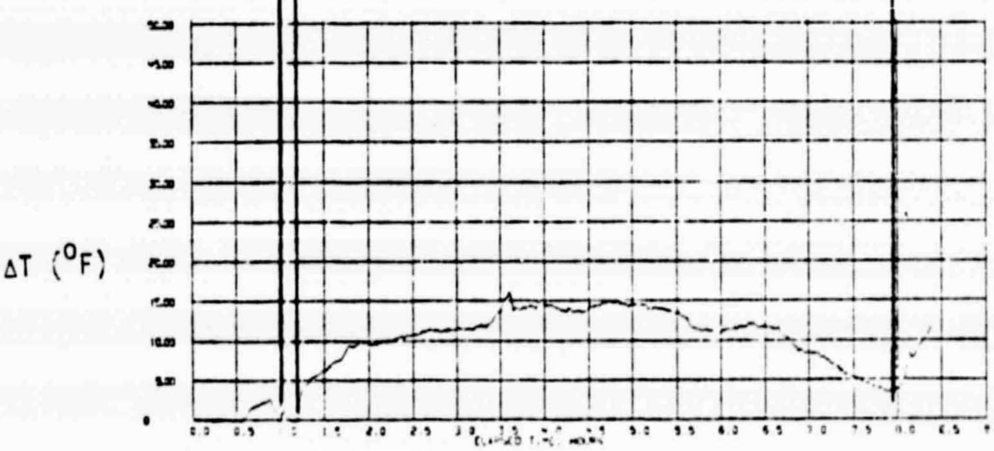
Collector ΔT

Figure 2. Typical Collector Fluid Flow & Collector ΔT
For October 7, 1977



Heat Exchanger Flow Rate (Water Side)

(0.0 = 7:34 AM)



Heat Exchanger ΔT (Water Side)

Figure 3. Typical Water Loop Flow and Heat Exchanger ΔT For October 7, 1977

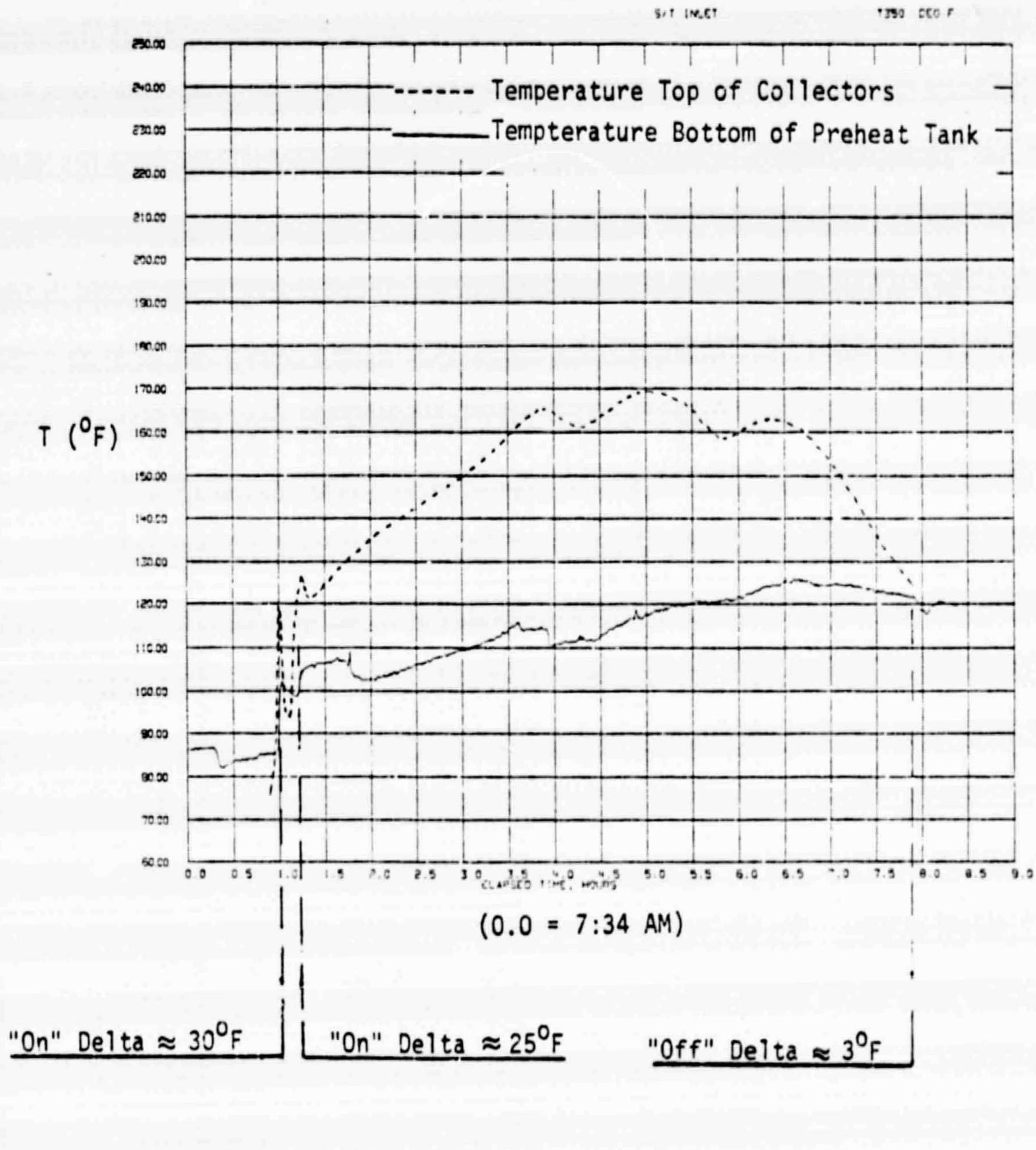
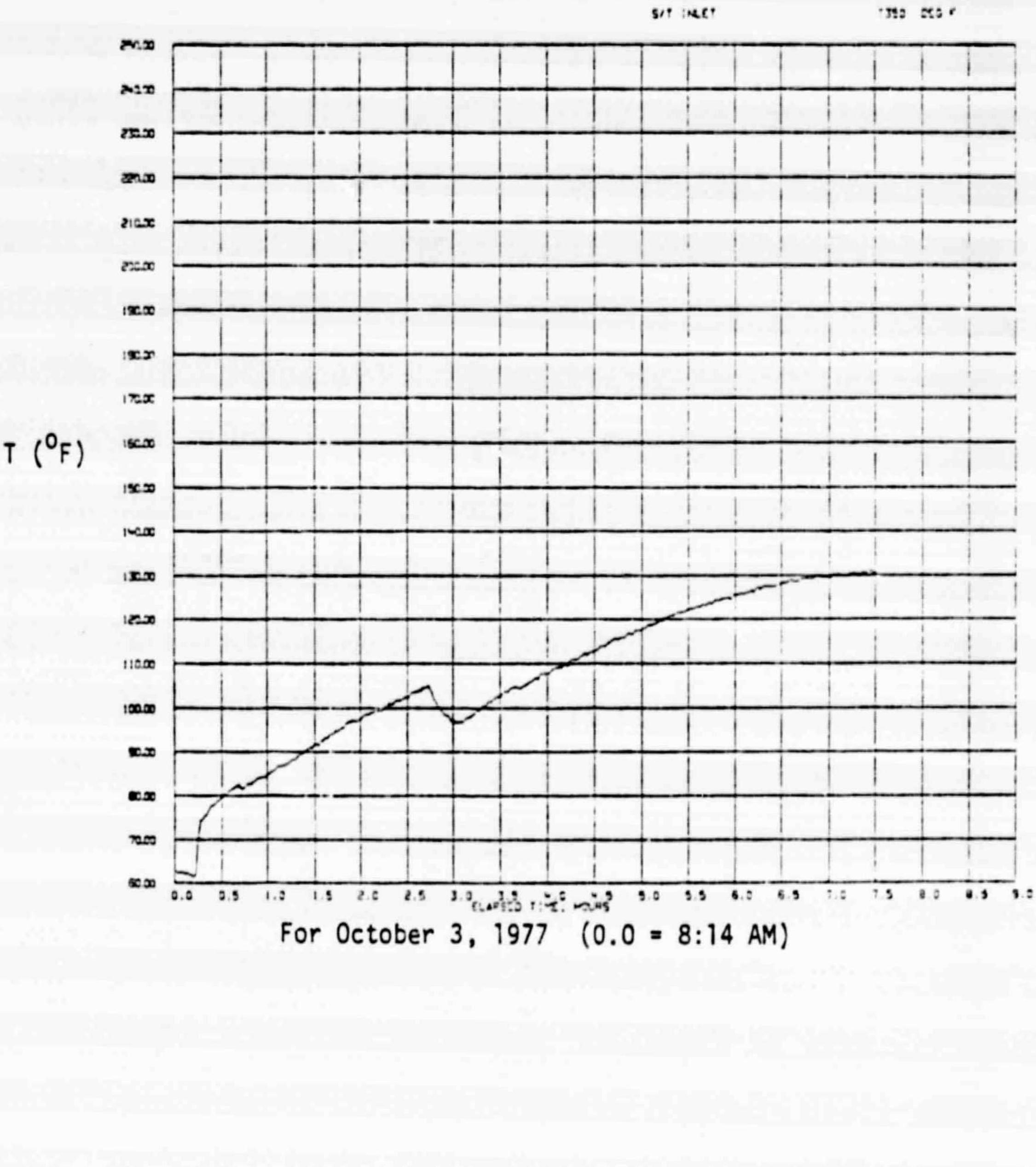


Figure 4. Typical System Start and Stop

For October 7, 1977



For October 3, 1977 (0.0 = 8:14 AM)

Figure 5. Temperature Bottom of Preheat Tank (Good Day)

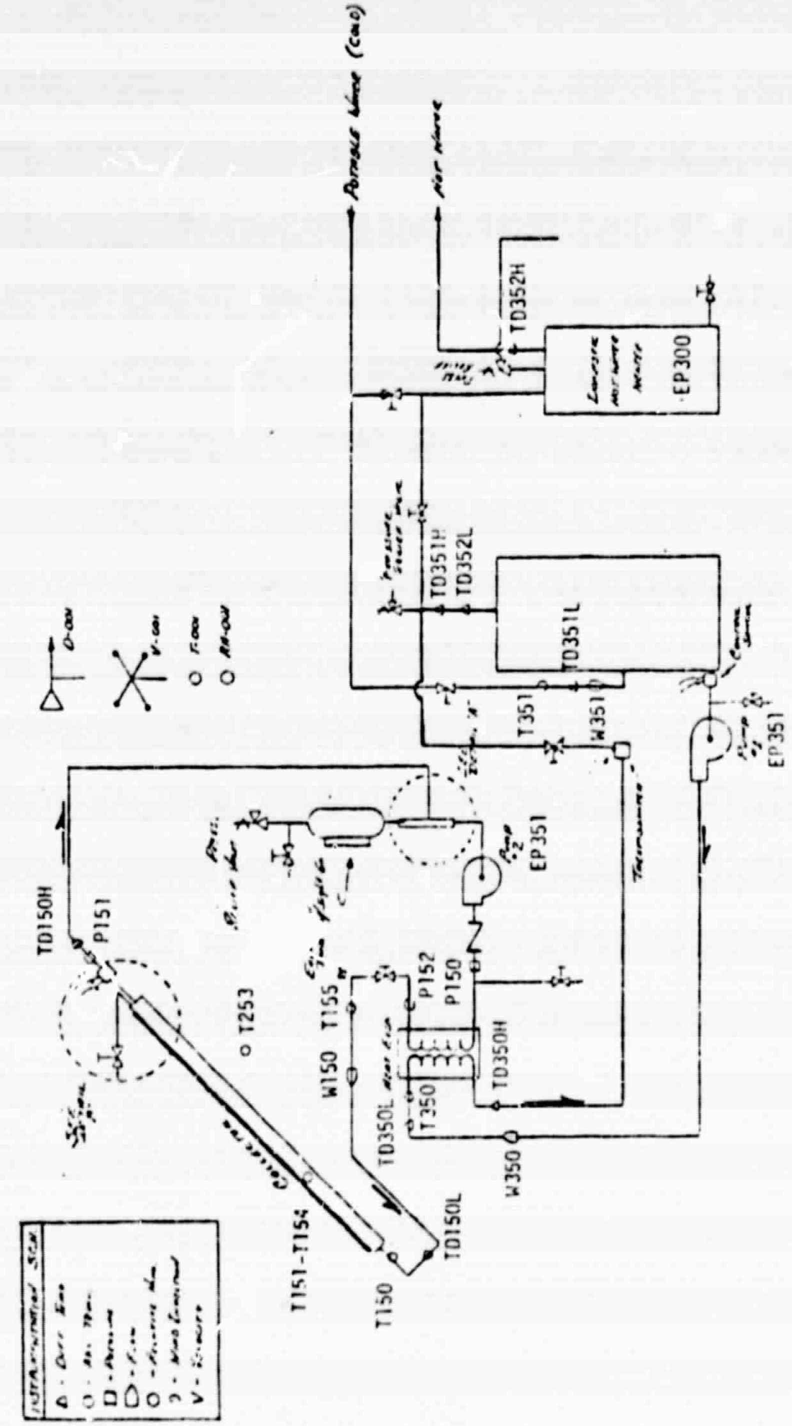


Figure 6. Location of Sensors and Flow Directions

By defining Coefficient of Performance (COP) as the ratio of energy added to the water over the energy used to run the system, calculated average daily COP values range from 5 to 8 for full day operation. The maximum hourly COP value for operation near solar noon was about 21. This means that near solar noon, the system is capable of providing energy equal to 21 times the electrical power required to run the pumps and controller. Raising the controller set points to approximately +30 (on) and +5 (off) would result in more efficient operation and higher daily COP values at the expense of a few Btu/day and a few percentage points of annual solar contribution.

Using test values for collector efficiency and heat exchanger effectiveness, an updated F-chart run was made. Figure 7 is a summary of the updated inputs and results. The original prediction of annual percent solar for System 2 in Togus, Maine was 56%. The updated run predicts approximately 60% annual solar contribution.

On very good days (average I>300 Btu/Hr Ft^2) the system should raise all the preheat tank water to approximately 140°F. With the 120 gallon preheat tank and domestic hot water heater full charged, the system should provide approximately two days supply of hot water for an average family. On average days, the system will still raise the preheat tank to 110 to 120°F and supply approximately 75% of the water heating requirements or better. On cloudy days, the system will provide very little if any water preheating, which pulls the annual solar contribution down to approximately 60%.

CODE	VARIABLE DESCRIPTION	VALUE	UNITS
1	AIR SYSTEM=1, LIQUID SYSTEM=2..................	2.00	
2	COLLECTOR AREA..................................	98.50	FT2
3	FRPRIME-TAU-ALPHA PRODUCT(NORMAL INCIDENCE)..	0.50	
4	FRPRIME-UL PRODUCT..............................	0.69	BTU/H-F-F2
5	NUMBER OF TRANSPARENT COVERS...................	2.00	
6	COLLECTOR SLOPE.................................	45.00	DEGREES
7	AZIMUTH ANGLE (E.G. SOUTH=0, WEST=90).........	0.00	DEGREES
8	STORAGE CAPACITY................................	10.00	BTU/F-FT2
9	EFFECTIVE BUILDING UA...........................	0.0	BTU/HR-F
10	CONSTANT DAILY BLDG HEAT GENERATION...........	0.0	BTU/DAY
11	(EPSILON)(CMIN)/(EFFECTIVE BUILDING UA)......	2.00	
12	HOT WATER USAGE.................................	75.00	GAL/DAY
13	WATER SET TEMPERATURE...........................	140.00	F
14	WATER MAIN TEMPERATURE..........................	55.00	F
15	CITY CALL NUMBER................................	117.00	
16	THERMAL PRINT OUT BY MONTH=1, BY YEAR=2......	1.00	
17	ECONOMIC ANALYSIS YES=1, NO=2..................	2.00	

TYPE IN CODE NUMBER AND NEW VALUE

r

PORTLAND ME 43.39

****THERMAL ANALYSIS****

TIME	PERCENT SOLAR	INCIDENT SOLAR (MMBTU)	HEATING LOAD (MMBTU)	WATER LOAD (MMBTU)	DEGREE DAYS (F-DAY)	AMBIENT TEMP (F)
JAN	37.7	3.53	0.0	1.65	1339.	23.
FEB	51.4	3.93	0.0	1.49	1182.	25.
MAR	66.3	5.30	0.0	1.65	1042.	32.
APR	69.5	4.56	0.0	1.60	675.	43.
MAY	68.8	5.16	0.0	1.65	378.	52.
JUN	71.3	4.94	0.0	1.60	111.	63.
JUL	77.8	5.44	0.0	1.65	12.	68.
AUG	75.9	5.28	0.0	1.65	53.	66.
SEP	72.0	4.94	0.0	1.60	195.	59.
OCT	62.9	4.66	0.0	1.65	508.	48.
NOV	36.5	3.11	0.0	1.60	807.	39.
DEC	34.8	3.31	0.0	1.65	1018.	27.
YR	59.7	54.16	0.0	19.44	7311.	

TYPE IN CODE NUMBER AND NEW VALUE

Figure 7. Updated FCHART Results For Togus, Maine

SUBSYSTEM PERFORMANCE RESULTS

5.1 COLLECTOR SUBSYSTEM

The collector loop was made up of 5 L.O.F. collectors arrayed in parallel, a heat exchanger and a pump, all linked together with one inch copper pipe. The fluid used in the collector loop was Dow Corning Q2-1132 silicone.

The collector loop was pressure tested to find all leaks prior to filling. Filling and draining were done from the low point in the loop. There were no leaks in the collector loop during testing. Slight residue was noted on the inside of the glass covers on two of the collectors.

Performance of the collectors with silicone fluid was about as predicted. Figure 7 shows the collector efficiency curve with silicone fluid derived from test data with the vendor data for 50/50 Ethylene Glycol/Water.

The collector efficiency points were calculated only for very stable one hour periods of insolation. For the data point for 11:00 to 12:00 October 12, 1977, the following values apply.

I_{av} = 312 Btu/hr/ft^2

A = 98.5 ft^2

Fluid flow = 5.15 gpm

C_p = 0.37

ΔT = 11.5^{o}F

Tin = 140^{o}F

Tamb = 50^{o}F

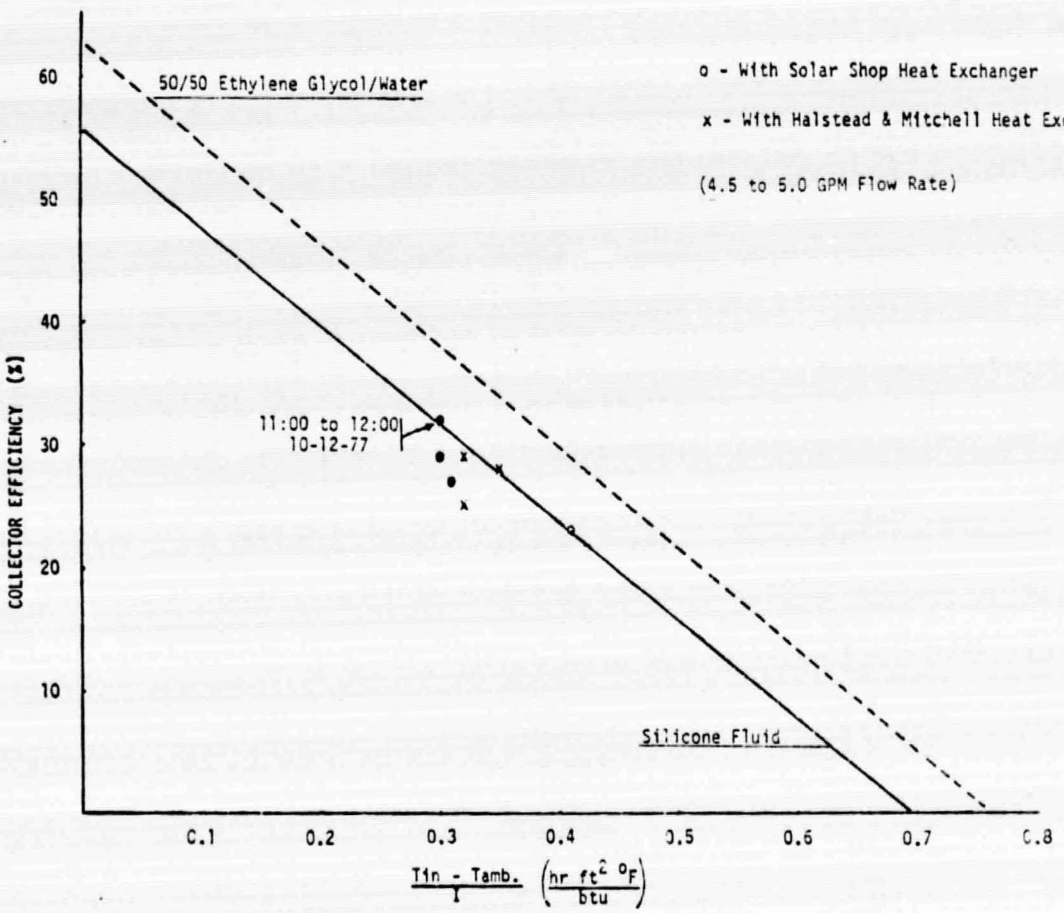


Figure 8. Collector Efficiency Data

$$\therefore \quad E = \frac{\dot{m}\, C_p\, \Delta T}{I\, A}$$

$$= \frac{60\,[5.15 \times 8.35 \times 0.9]\, 0.37 \times 11.5}{312 \times 98.5}$$

$$= 0.32 \quad = \underline{\underline{32\%}}$$

$$\frac{T_{in.} - T_{amb.}}{I} = \frac{140-50}{312} = \underline{\underline{0.29}}$$

The system flow rate was slightly low for optimum collector performance. No previous data was available on collector efficiency using silicone fluid. The System 2 collector efficiency was less than it would have been with water or water/ethylene glycol. (See Figure 8.) The lifetime efficiency of System 2 should compare well with other systems. Freezing, boiling, corrosion and collector fluid breakdown should not be a problem with this system. The silicone fluid (Dow Q2-1132) freezes below -100^{o}F and boils above +600^{o}F, is noncorrosive and has a good reputation for fluid stability.

5.2 DOUBLE WALL HEAT EXCHANGERS

A double wall heat exchanger was required to meet the IPC. Only two double wall heat exchangers were available. The system was tested with a Solar Shop HE1 and Halstead and Mitchell HX1. Either of these heat exchangers was capable of providing satisfactory performance. As predicted, the double wall heat exchangers with water on the cold side and silicone fluid on the hot side had relatively low effectiveness numbers. For the original analysis, an effectiveness of 0.3 was assumed. The test data yielded effectiveness numbers of 0.25 to 0.37 for each heat exchanger depending on test conditions. F-chart runs assuming 0.5 effectiveness yielded less than 5% improvement in system performance. Even though two heat exchangers could be used in series for better effectiveness in System 2, the improvement in performance probably could not justify the increase in cost and system pressure drop.

The Solar Shop heat exchanger had slightly less pressure drop on the silicone fluid side and therefore allowed about 20% higher flow rate in the collector loop than the Halstead and Mitchell heat exchanger. This higher flow in the collectors resulted in about 2 percent better system performance using the Solar Shop heat exchanger; therefore, the Solar Shop unit was chosen for site installation in Togus, Maine.

5.3 PUMPS

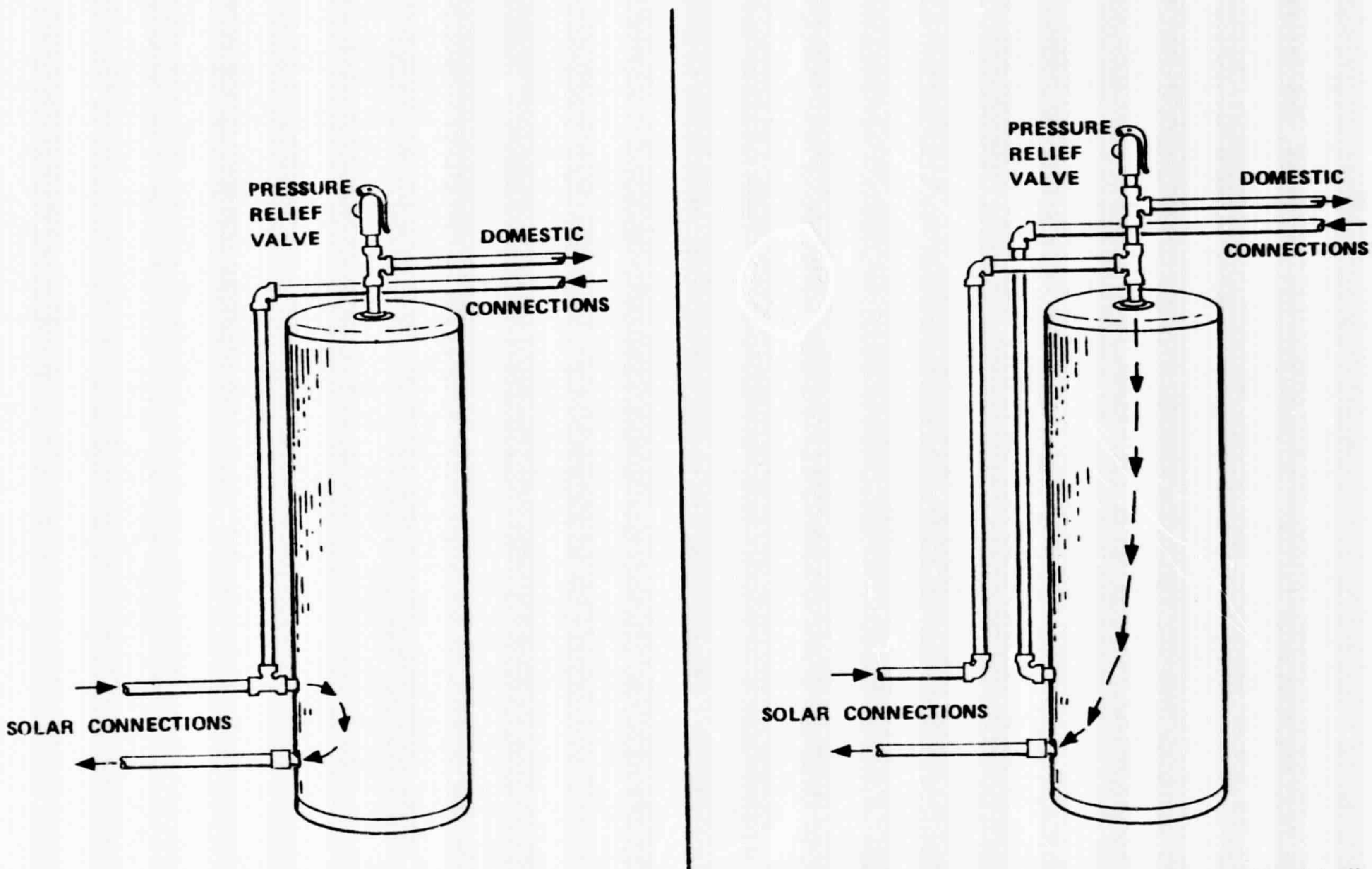
The two small Grundfos pumps performed as expected during test with no problems. The stainless circulator pump (UP25-42SF) in the water loop provided more than adequate flow through either heat exchanger.

The 1/12 HP variable head pump (UP26-64) was able to meet the required minimum flow rate (4 GPM) in the collector loop with either heat exchanger. This pump was set for maximum flow for all tests and typically provided 5 GPM with the Solar Shop heat exchanger. Systems with higher pressure drop in the collector loop will require two pumps in series or one larger pump.

Both pumps were extremely quiet and smooth in operation. Together the two pumps used between 280 and 300 watt of power (as expected), and therefore provided very efficient system operation.

5.4 PREHEAT TANK

The solar connections on the Ford Products preheat tank were too close together resulting in "short circuiting" from one connection to the other. The rapid increase in temperature of the water going to the heat exchanger during the first few minutes of operation indicate that "short circuiting" is taking place. There was insufficient instrumentation in the preheat tank to analyze this problem in depth. As a result of "short circuiting" the collector loop ran hotter (and therefore less efficient) than expected.



Intial Installation with "Short Circuiting"

Plumbing Change to Minimize "Short Circuiting"

Figure 9. Preheat Tank Plumbing

For the last week of testing, the plumbing was changed to pump the cooler water from the bottom of the tank through the heat exchanger, and return it to the top of the tank. This change resulted in better daily system performance. One hardware need illustrated by these tests is a preheat tank which has a minimum of "short circuiting" and a maximum of stratification. The system design was updated to include this plumbing change. (See Figure 9.)

The 120 gal. stone lined Ford Products tank should be a durable preheat tank for the system. The tank does not require an anode rod and is warranted for 10 years for water up to 180^{o}F.

5.5 PIPING AND EXPANSION TANK

One inch copper tubing with soldered fittings in the collector fluid loop provided a minimum of pressure drop and leak problems. Teflon tape and teflon pipe dope provided adequate seal on the few threaded connections in the loop. Prior to filling the collector loop, dry nitrogen was used to pressurize the loop and check for leaks. All leaks were found and repaired. No silicone fluid was lost from leaks during the two months of testing.

Locating the expansion tank just before the pump worked well. Air in the silicone fluid loop eventually settled in the expansion tank. The lowering of the fluid level in the sight glass during the first few minutes of operation after collector loop filling indicated that some air in the loop had been replaced with silicone fluid.

5.6 CONTROLLER

The Rho Sigma 106 differential thermostat provided adequate system control during testing. Typically, the system started as soon as the collector fluid was 20 to 30 degrees hotter than the water in the bottom of the preheat tank.

The Rho Sigma was set for +20°F (on) and +3°F (off). The Rho Sigma collector sensor was located down stream of the instrumentation sensor and therefore generally lagged the instrumentation sensor a few degrees at startup resulting in approximately +25°F "on" and +3°F "off". (See Figure 4.) This lag was beneficial in preventing excessive cycling. Increasing the Rho Sigma set points to perhaps +30°F and +5°F would result in still less cycling and better system efficiency and COP values. These higher set points would also result in the loss of a few percentage points of annual solar contribution; and for this reason, the design set points were not changed.

With the standard controller set points, the system starts relatively early in the mornings and runs until late in the afternoons. This assures a near maximum of collected energy each day (over 50,000 Btu on a good day). On a average sunny day (Figures 2, 3 & 4), the system cycled on and off once then run continuously for the rest of the day.

6.0 CONCLUSIONS

- With reasonable care, the silicone fluid loop can be assembled with acceptable pressure drop and be leak free.
- Small efficient circulator pumps work well with this size and type of system.
- Double wall heat exchangers are available and do provide acceptable performance.
- Overall system efficiency was less with silicone collector fluid than it would have been with water/ethylene glycol.
- Freezing, boiling and corrosion should never be a problem with this system.
- Very little maintenance is anticipated and the collector fluid should never require changing.
- System 2 should provide satisfactory performance for many years of operation.

APPENDIX A

TEST DETAILS

TABLE OF CONTENTS

1.0 SUMMARY

Performance tests and evaluations have been performed on System 2, a solar hot water system, under natural outdoor environmental conditions. These tests were performed in the Solar Test Facility located at Marshall Space Flight Center, Alabama.

Two fluid loops were associated with the system as tested. The collector fluid circuit utilized a silicone heat transfer for liquid as the working fluid which was thermally coupled to the water side via a double-walled heat exchanger. Independent tests were conducted to evaluate relative system's performance characteristics for heat exchangers as supplied by Solar Unlimited and Halstead-Mitchell. The first series of tests were performed during the interval from September 13 to September 20, 1977, using the Solar Unlimited heat exchanger. The Halstead-Mitchell heat exchanger was installed for the second series of tests from September 28 to October 7, 1977. A third series of tests were conducted on October 11 and 12, 1977, with the Solar Unlimited heat exchanger being installed.

Results of functional tests indicate that the system's manual and automatic control modes operated as designed. No significant problems occurred during system operation such as leaks, pump cavitation, or over-pressure conditions. However, it was found that the transducer provided with the system and utilized to measure fluid flow rates through the collector loop was improperly calibrated. This finding was determined subsequent to completion of operational testing and during the course of post-test evaluations. A similar transducer was utilized for flow rate measurements in the water heat transfer loop and the manufacturer's calibration was not verified on either of the instruments.

2.0 PURPOSE

The purpose of this document is to present the test results of an evaluation test program. The test program was conducted to determine the performance of System 2 to the evaluation requirements specified in Reference 3.1 in accordance with Reference 3.2, with the exception that paragraph 5.2.2.1 of Reference 3.2 has been modified to provide only 8 hours of testing per day.

3.0 REFERENCES

3.1	NBSIR 76-1137	Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program
3.2	IBM-7933448	Verification Plan/Procedure for Prototype Solar Energy Hot Water System Model No. 2
3.3	ASHRAE 93-77	Method of Testing To Determine The Thermal Performance of Solar Collectors
3.4	NBS TN 899	Proposed Standards for Testing Solar Collectors and Thermal Storage Devices
3.5	MSFC MMI 5300.4C	Metrology and Calibration
3.6	NAS8-32036	NASA/IBM Contract

4.0 MANUFACTURER

Equipment	Manufacturer	Model No.
Collectors	Libbey-Owens-Ford	1112
Silicone Fluid Pump	Grundfos Pump Corp. Clovis, CA 93612	UP-26-64
Water Pump	Grundfos Pump Corp. Clovis, CA 93612	UP-25-42SF
Solar Storage Tank	Ford Products Valley College, N.Y.	AB-120 Gal.
Hot Water Tank	Jackson Mfg. Co. Chattanooga, Tenn.	L-J052-2.05-52 Gal.
System Controller	RHO Sigma 15150 Raymer Street Van Nuys, CA 91405	106

4.0 MANUFACTURER (Continued)

Equipment	Manufacturer	Model No.
Heat Transfer Fluid	Dow Corning Midland, Michigan	Q2-1132
Expansion Tank	Ace Tank & Heater Co. 10847 S. Printer Ave. Sante Fe Springs, CA	X-8-00
Pressure Relief Valve	Bell & Grossett Morton Grove, Illinois	480-75 Lb/Hr
Check Valve	Nibco 500 Simpson Ave. Elkhart, Indiana 46514	T-413-Y 1"
Thermoswitch	Elmwood Sensors Van Nuys, CA	3000-53
Check Valve	Nibco 500 Simpson Ave. Elmhart, Indiana	S-113 1"
Check Valve	Nibco 500 Simpson Ave. Elmhart, Indiana	S-113 3/4"
Check Valve	Nibco 500 Simpson Avenue Elmhart, Indiana	S-413 1"
Heat Exchanger #1	Solar Unlimited Huntsville, AL	Translator 1
Heat Exchanger #2	Halstead-Mitchell Scottsboro, AL	HX-1

5.0 DESCRIPTION OF SYSTEM

Presented in Figure 1 is a schematic of Prototype Solar Energy Hot Water System No. 2 which was thermally evaluated. Although the domestic water heater was installed as shown, electrical heaters for auxiliary heat were not activated and hot water loads were taken across the solar storage tank. This system was installed and tested at the Solar Test Facility on Test Bed #1. An array of Libbey-Owens-Ford liquid collectors with an accumulative collector area of 105 ft^2 provided the primary heating for the system. The collector absorber plate was fabricated of #110 copper and is coated with 3M Black Velvet, series 101-C10 paint. The collector cover uses double glass glazing. Silicone oil was the heat transfer medium which was circulated by pump #2 through the collectors, piping system and an oil-to-water heat exchanger. The oil-to-water heat exchanger couples the heat transfer between the collector and the preheat tank where the city water supply/preheater water may be circulated by pump #1. On demand, hot water was supplied from the conventional domestic hot water heater via the preheat tank. A system controller was provided to automatically control pump operation. Sensors as located on the collector outlet and the preheat tank outlet provided the signal for differential temperature control.

System performance evaluations were made using the Solar Unlimited heat exchanger in tests conducted during intervals of time from September 13 to September 30, 1977, and October 11 through October 12, 1977. The Halstead-Mitchell heat exchanger was installed during tests performed from September 28 to October 7, 1977.

A change was made to the piping system on October 6, 1977, to redirect the water return from the heat exchanger to the solar storage tank top. This piping change is indicated in Figure 2.

6.0 TEST CONDITIONS AND TEST EQUIPMENT

6.1 Ambient Conditions

Unless otherwise specified herein, all tests shall be performed in the existing natural environment.

6.2 Instrumentation and Equipment

All test equipment and instrumentation used in the performance of this test program comply with the requirements of MSFC MMI 5300.4C. The outputs of all sensors are monitored and all data is recorded and processed by the data acquisition system located in Building 4646. A listing of the equipment used in each test follows:

Systems Operational Functional Test

Apparatus	Manufacturer/Model	Range/Accuracy
Digital Thermometer	Fluke/2175A	-99 to 999°F/± 1%
Volt Ammeter/Ohmmeter	Amprobe/RS3	0-300A,0-300v/± 5%
Digital Multimeter	Hewlett-Packard/3465A	4-1/2 digits/0.05% ± 1 count
Oscilloscope	Tektronix/335	Full Scale/± 2%
Volt/Ohm/Milliammeter	Simpson/260	Full Scale/ ± 2%
Pressure Gauge	Weksler Instruments	0-300 psi/± 1% FS
Pressure Gauge	Weksler Instruments	0-300 psi/± 1% FS
Flowmeter	Ramapo, Inc./MKV-1-J707	0-6 gpm/± 1% FS

System Test

Apparatus	Manufacturer/Model	Range/Accuracy
Pyranometer	Eppley/PSP	0-400 BTU/Hr·Ft^2 ± 3%
Platinum Resistance Thermometer	Minco, Hy-Cal	T: -50 - 500°F; 40 - 100°F ± .9°F; 60 - 250°
	Hy-Cal	ΔT 0 - 50°F ± .2°F

6.0 TEST CONDITIONS AND TEST EQUIPMENT (Continued)

6.2 Instrumentation and Equipment (Continued)

Apparatus	Manufacturer/Model	Range/Accuracy
Pressure Transducers	M.B. Electronics/151-HAC-118	0 - 100 psi/± 1% FS
Flowmeter - oil	Ramapo, Inc./MKV-1-J707	0 - 6 gpm/± 1% FS
Flowmeter - water	Ramapo, Inc./MKV-3/4-J707	0 - 3 gpm/± 1% FS
Flowmeter - water	Ramapo, Inc./MKV-3/4-J707	0 - 5 gpm/± 1% FS
Watt Transducer	Ohio Semitronics/PC5-106	0 - 300w/± .75% FS
Watt Transducer	Ohio Semitronics/PC5-29	0 - 12 kw/± .5% FS
Wind Velocity Sensor	Teledyne Geotech/M1567	0.75-60 mph/± .5%
Wind Direction Sensor	Teledyne Geotech/M1567	0-360°/± 1%

6.2.1 The instrumentation designations and locations are shown in Figure 1 for prototype system 2. A detailed description of the instrumentation is contained in the Instrumentation Program and Component List (IP&CL Rev. A-13). Instrumentation block diagrams depicting the primary data acquisition setup utilized during these tests are shown in Figure 3.

7.0 TEST REQUIREMENTS AND PROCEDURES

7.1 System Operational Functional Test

Tested By B. Henderson
Started 9/1/77
Completed 9/13/77

7.1.1 Performance Criteria Requirements

A systems operational functional test shall be conducted on prototype system 2. The test shall be conducted to insure that the major components of the system are operating properly after installation on Test Bed No. 1. The operational functional test shall consist of the following individual tests:

- A system pressure/leakage test.
- An operational test of the system pumps.
- An operational test of the system controller.
- The measurement of the system flow rate and pressure drop across the collector array.
- The measurement of the solar system pump pressure drop and the dead head pressure.
- The measurement of the pressure drop across the heat exchanger for both the oil side and the water side.

7.1.2 Test Procedure

1. Install the prototype system 2 on Test Bed No.1. The system should be installed as prescribed by IBM in order to duplicate the actual side installation as closely as possible. Wyle drawing No. SE-771047 shows the required system installation layout on Test Bed No. 1. A portion of this drawing, depicting a side and front elevation of the installation, is shown in Figure 3.

2. Connect the water side of the domestic hot water system to the city water supply and fill the system's preheat tank, the domestic hot water tank, the heat exchanger, the pump and all water lines. Shut valves to isolate the system from the city water supply. Pressurize the water side of the domestic hot water system to 150 ± 5 psig and maintain this pressure for one (1) hour. Check all system joints for leaks. If any leaks are found, drain the system, repair the leaks and retest as above for an additional hour.

7.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

7.1.2 Test Procedure (Continued)

3. Connect the solar portion (collectors, oil side of heat exchanger, expansion tank, oil pump and the transport lines) of the system to a pneumatic supply. Pressurize the system to 70 ± 5 psig and maintain the pressure for a minimum of two (2) hours. Leak test the system's soldered and mechanical joints with soap solution, disconnect the pneumatic source, seal the system and measure the pressure decay to verify that there is no system leakage. If leaks are found, repair them and retest.

4. After determining that there are no leaks in the solar collector fluid loop, fill the solar collector loop as follows:

   COLLECTOR LOOP CHARGING: Prior to charging with the silicone fluid, the collector loop piping must be free of moisture and free of leaks. Dry air or dry nitrogen shall be used to purge the loop.

   The silicone fluid can be pumped into the collector loop from the drain at the low point in the loop or poured into the collector return piping at the high point in the loop. The pump should be run briefly after the loop is filled to remove any trapped air and more fluid added if necessary. The plug at the top of the loop must then be closed tightly.

5. Turn on the system pumps and verify that they operate properly.

6. Turn on the system controller and verify that it operates properly.

7. Activate the system pumps and adjust the flow in the solar portion of the system (oil side) to 4.5 gpm ± .4 gpm.

8. Measure the pressure drop across the collector array, the oil pump and the oil side of the heat exchanger.

9. Measure the flow rate through the water side of the heat exchanger; the nominal flow rate should be 1.6 gpm ± 0.16 gpm.

10. Measure the pressure drop across the water side of the heat exchanger.

11. Conduct a dead head pressure test on the oil pump. This is a momentary test and the pump should not be operated in this mode for extended intervals.

7.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

7.1.3 Results of Functional Tests

Results of Systems Operational Functional Tests are summarized below:

- Pressure/Leakage Test - Several piping system leaks were detected and sealed prior to initiation of operational tests.

- Pump Operation - The pumps were determined to function satisfactorily.

- System Controller Operation - The system controller was determined to have operated as designed.

- System Flow Rate Measurements - Fluid flowrates for the silicone heat transfer liquid and the water flow circuits were set at 4.5 gpm and 1.6 gpm, respectively. These flowrates were set using the indicated flowrate levels of sensor W150 for the silicone heat transfer liquid circuit and sensor W350 for the water circuit.

- Measured Pressure Differentials* - A summary of measured pressure differentials on the silicone heat transfer circuit and corresponding flowrates are presented below:

Heat Exchanger	Flowrate, GPM	Pressure Differential, PSI	
		Across Collector	Across Heat Exchanger
#1	4.8	9.5	2.7
#2	4.2	9.0	2.2

* Silicon heat transfer fluid flow rates were subject to change during system operation, since the flow rate generally increased as a function of the fluid temperature. The flow rates and corresponding pressure drops shown were determined from operational test data on Julian days 280 and 285 at time intervals where the fluid temperatures were approximately equal.

7.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

7.2 System Test

Tested by B Henderson
Started 9/13/77
Completed 10/13/77

7.2.1 Performance Criteria Requirements

Prototype system 2 shall be tested to evaluate the system's capacity for control, energy collection, storage and distribution to load at outside ambient weather conditions.

The primary objective of this test is to obtain as much actual operating data as possible from prototype system 2 prior to its installation at a demonstration site.

During the system test, complete weather records will be kept. These will include total solar radiation, ambient temperature, wind speed and direction, relative humidity, barometric pressure and cloud cover. In addition, the prototype system 2 will be monitored to provide the following data:

- The total energy collected by the solar system per day.
- The total energy supplied to the hot water load per day.
- The power required to operate the system per day.
- The system control functions (manual observations).

7.2.2 Test Procedure

1. Apply power to prototype system 2 and allow the system to operate in accordance with the system controller's normal mode of operation. Allow the system to operate under a no load demand for a minimum of 24 hours.

2. The system shall be turned on daily, Monday through Friday, by 8:00 a.m., and operated continuously until 4:00 p.m. when the system shall be shut down. The system will be allowed to operate in its normal control mode.

7.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

7.2.2 Test Procedure (Continued)

3. Daily hot water will be drained from the system according to the following schedule:

Time	Quantity	Rate
0800 Hrs ± 30 min.	4 gal. ± 0.4 gal.	2 GPM ± 0.2 GPM
0900 Hrs ± 30 min.	8 gal. ± 0.8 gal.	2 GPM ± 0.2 GPM
1100 Hrs ± 30 min.	30 gal. ± 3.0 gal.	2 GPM ± 0.2 GPM
1200 Hrs ± 30 min.	5 gal. ± 0.5 gal.	2 GPM ± 0.2 GPM
1600 Hrs ± 30 min.	8 gal. ± 0.8 gal.	2 GPM ± 0.2 GPM

A container will be used to collect and measure the volume of hot water removed from the system. The container will be clearly marked to indicate the volumes of 4 gallons, 5 gallons, 8 gallons and 30 gallons.

4. Monitor system operation and check for malfunctions or leaks throughout the test duration. This operation will be performed at the intervals specified in procedure 3, above.

5. Throughout the system's operation, data will be collected on the data system located in Building 4646.

7.2.3 Results of Operational Tests

Systems operational test data was collected on magnetic tape with the data system located in Building 4646. Parameters which were measured and recorded during this evaluation are shown in Table I. Computer plots and integrated test parameters were prepared from data contained on the magnetic tapes by post-test processing on the UNIVAC 1108 computer. Data obtained from daily operational system tests are presented in Appendix II.

Analyses were performed to evaluate the system operational performance parameters on a daily basis. A summary of the calculated performance parameters is shown in Table II.

8.0 **ANALYSIS**

Analyses were performed of data obtained from System 2 tests to evaluate the required performance parameters. Equations used to evaluate the test data are indicated in the following paragraphs.

Solar Energy Collected - Daily solar energy collected was calculated based upon the measured flow and temperatures in the collector loop.

$$Q_c = \int_{\tau_1}^{\tau_2} W150\, \rho C_p TD150 \, d\tau$$

where,

Q_c = Quantity of solar energy collected during the daily test interval

W150 = Fluid volumetric flow rate

ρ = Silicone heat transfer fluid density

C_p = Silicone heat transfer fluid specific heat

TD150 = Temperature differential across the collector array

τ = time

Total Daily Hot Water Load - The total hot water loads were calculated by the equation,

$$Q_H = C_p \sum_{n=0}^{n} Mn \; TD351$$

where,

Q_H = Total daily hot water load

C_p = Specific heat of water

M = Mass of water removed to load

TD351 = Temperature differential across solar storage tank.

Total Daily Electrical Energy - Total electrical energy required to operate pump #1 and pump #2 was measured with watt transducer EP-351. The integrated total electrical energy utilized in each test was calculated by, 8.0 **ANALYSIS** (Continued)

$$Q_E = \int_{\tau_1}^{\tau_2} EP\text{-}351 \, d\tau$$

where,

Q_E = Total electrical energy

EP-351 = Electrical power measurement of pump #1 and pump #2

τ = Time

Total Solar Energy Available - The total solar energy available was calculated for the interval of time that the system was activated on a daily basis. The interval of time during the daily tests corresponds to the time during which data was being collected and, simultaneously, the System 2 controller was active.

$$Q_s = \int_{\tau_1}^{\tau_2} AI001 d\tau$$

where,

Q_s = Total daily solar energy available

A = Accumulative gross collector area

I001 = Measured solar insolation

τ = Time

TABLE I

Physical Quantities Measured in System 2 Tests

Measurement	Parameter
Solar radiation	BTU/Hr/Ft^2 vs time of day
Ambient temperature	°F vs time of day
Wind speed/direction	MPH/direction vs time of day
Relative humidity	% vs time of day
Collector inlet temperature	°F vs time of day in hours
Collector absorber temperature	°F vs time of day in hours
Collector delta temperature	°F vs time of day in hours
Heat exchanger inlet temp. (water)	°F vs time of day in hours
Heat exchanger delta temp. (water)	°F vs time of day in hours
City water supply temperature	°F vs time of day in hours
Hot water system differential temp.	°F vs time of day in hours
System temporary shelter temp.	°F vs time of day in hours
Oil flow through collectors	GPM vs time of day in hours
Heat exchanger flow (water)	GPM vs time of day in hours
Hot water flow to load	GPM vs time of day in hours
Collector pump power and preheat tank pump power	Watts vs time of day in hours
Domestic hot water heating element power	Watts vs time of day in hours
Solar pump outlet pressure	PSI vs time of day in hours
Collector outlet pressure	PSI vs time of day in hours
Heat exchanger outlet pressure (oil side)	PSI vs time of day in hours

TABLE II

SYSTEM 2 CALCULATED PERFORMANCE PARAMETERS

Test Date -1977-	Solar Energy Collected, BTU	Hot Water Load, BTU	Total Electrical Energy Consumed, BTU	Solar Energy Available, BTU
Sept. 13	29500	23448	6522	89794
Sept. 14	32160	23107	9273	111426
Sept. 15	36750	23697	7171	111897
Sept. 19	19350	11894	4881	75092
Sept. 20	36600	14093	5563	115195
Sept. 21	37120	23282	4915	137733
Sept. 23	39600	17455	6348	161476
Sept. 28	43300	22128	7304	190361
Oct. 3	50840	16749	6587	190298
Oct. 4	48130	29399	6416	197972
Oct. 6	17270	0	6041	72462
Oct. 7	36509	20144	6963	156426
Oct. 12	51138	19804	6758	183030

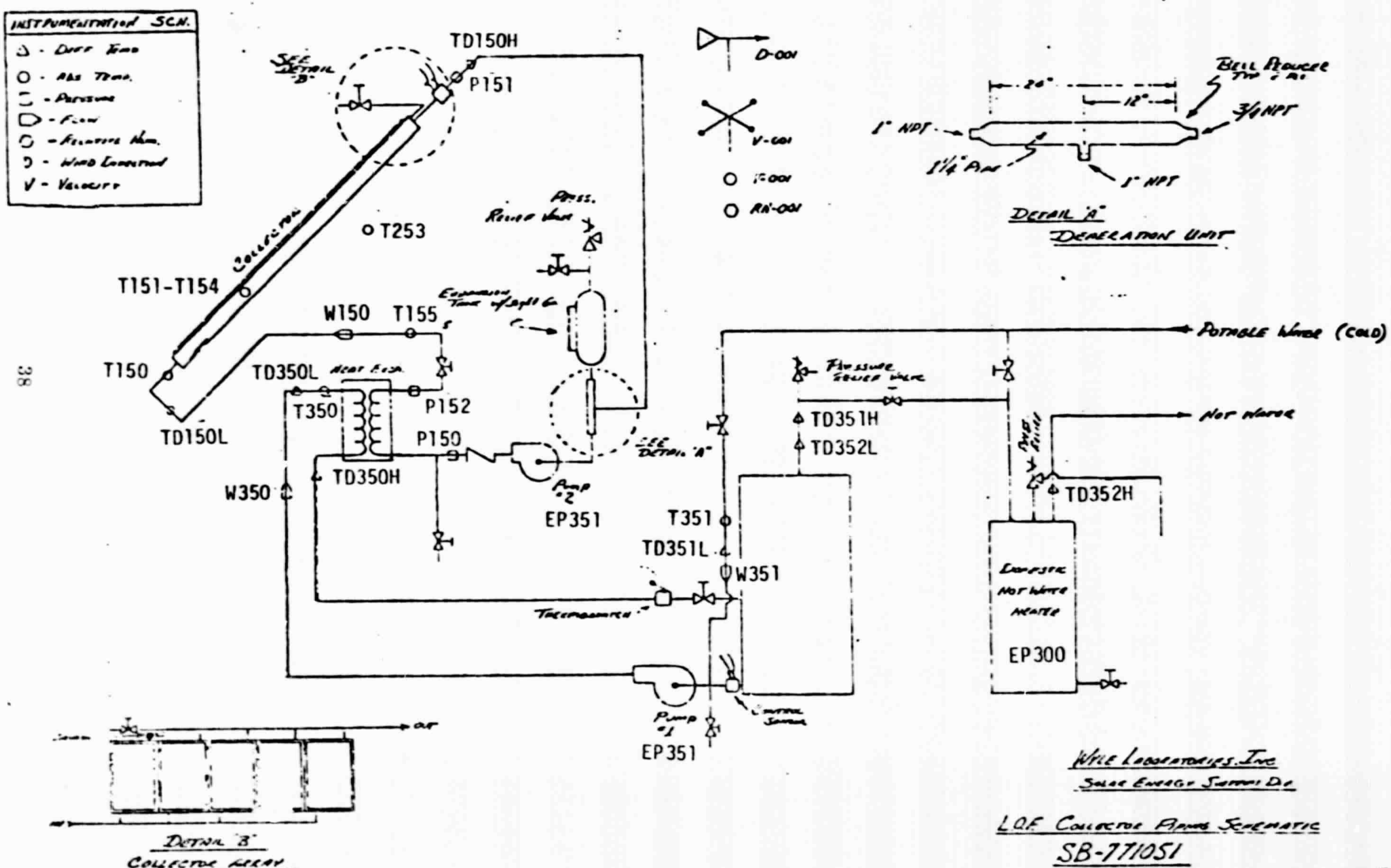


Figure 1. Illustration of System 2 Piping Schematic and Instrumentation Locations

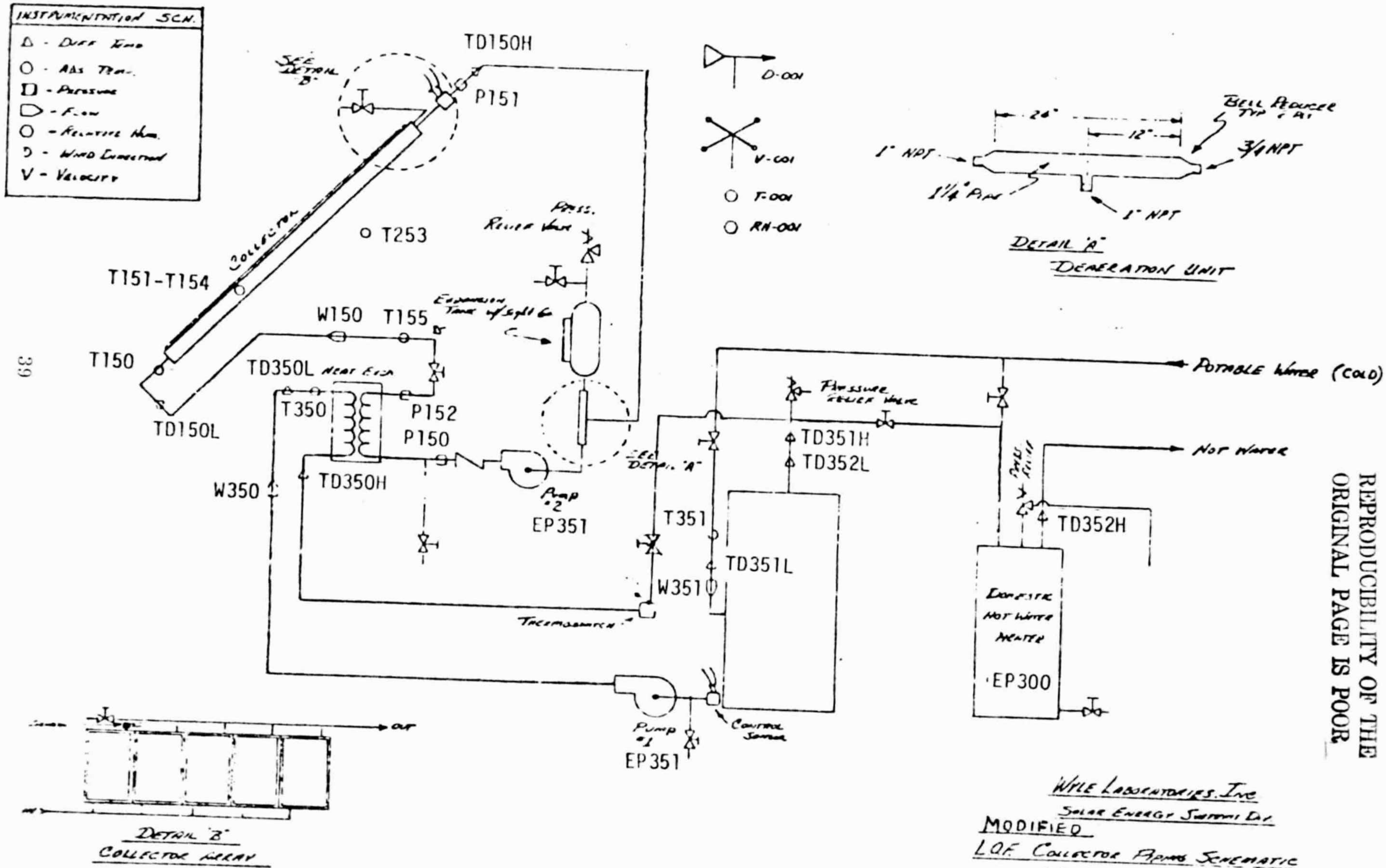


Figure 2. Illustration of System 2 Modified Piping Schematic and Instrumentation Locations

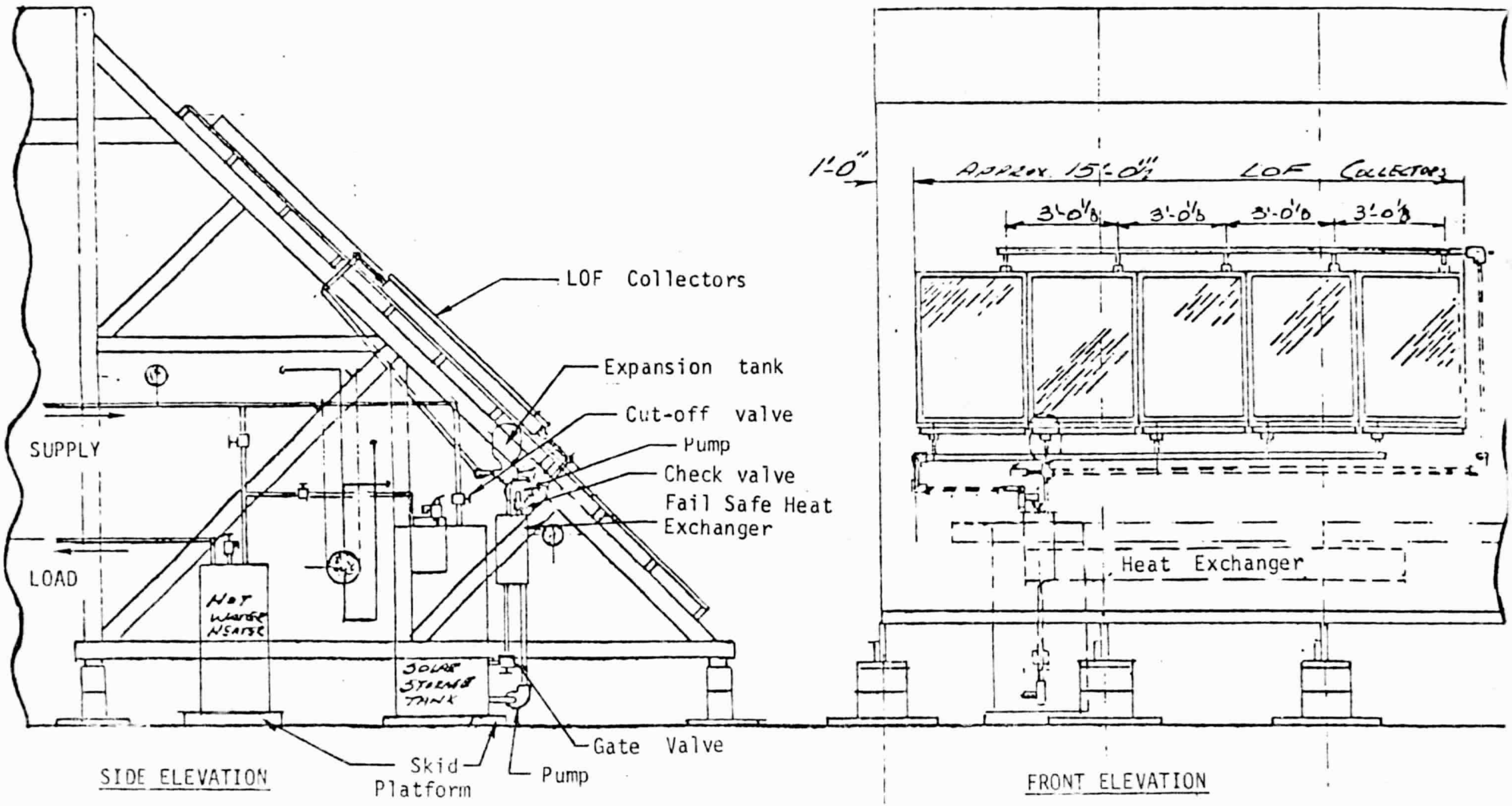
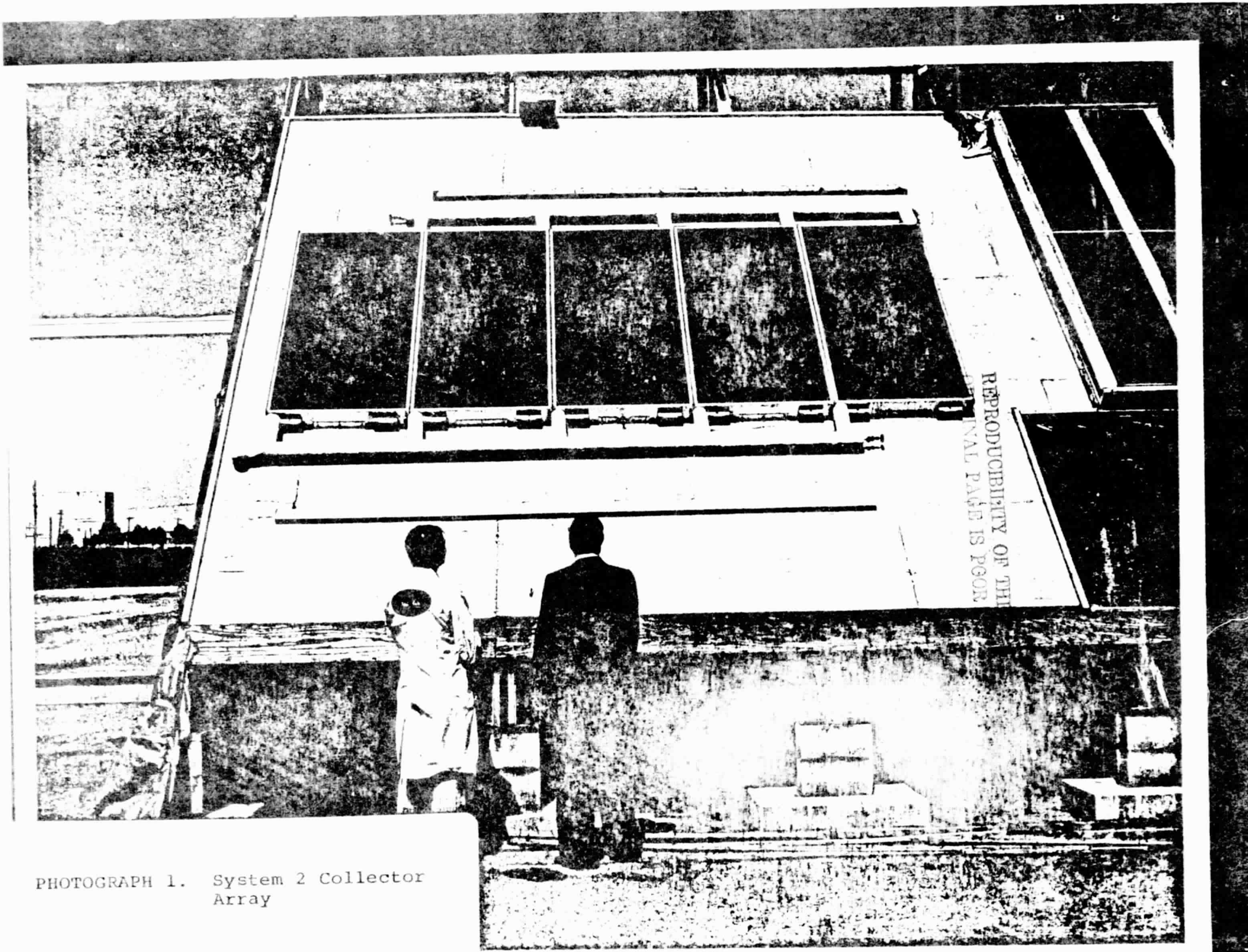
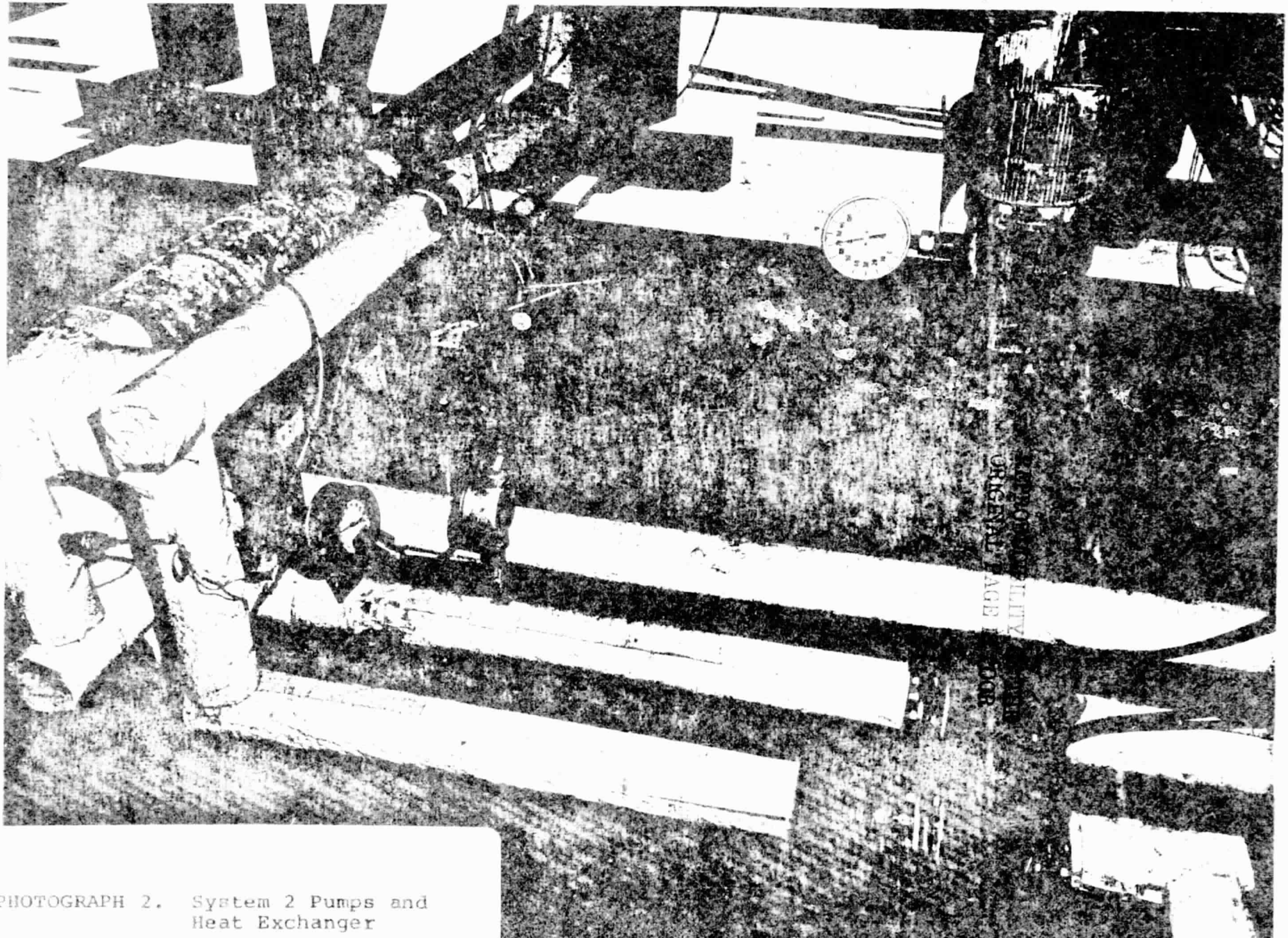


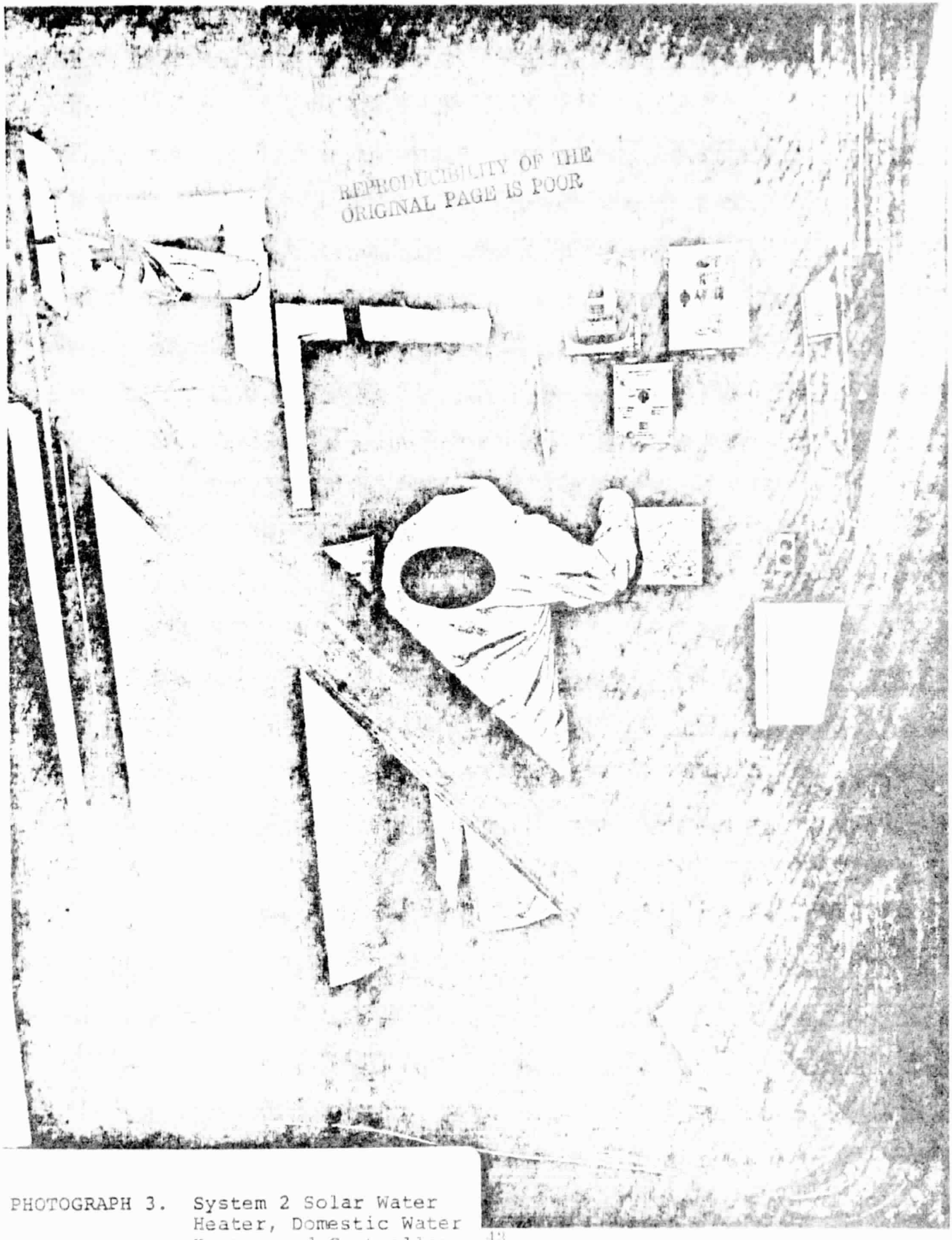
Figure 3. Sketch of System 2 Installation on Facility Test Bed #1.



PHOTOGRAPH 1. System 2 Collector Array



PHOTOGRAPH 2. System 2 Pumps and Heat Exchanger



PHOTOGRAPH 3. System 2 Solar Water Heater, Domestic Water Heater and Controller

☆ U. S. GOVERNMENT PRINTING OFFICE 1978–740-193/267 REGION NO. 4