DOE/NASA CONTRACTOR REPORT

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SIMS PROTOTYPE SYSTEM 1 TEST RESULTS - ENGINEERING ANALYSIS

Prepared by

IBM Corporation
Federal Systems Division
Huntsville, Alabama 35805

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Solar Energy

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16. ABSTRACT

The space and domestic water solar heating system designated SIMS Prototype System 1 has been evaluated at the MSFC Solar Heating and Cooling Test Facility. The test system used 720 ft^2 (gross) of Solar Energy Products Air Collectors, a Solar Control Corporation SAM 20 Air Handler with Model 75-175 control unit, a Jackson Solar Storage tank with Rho Sigma Mod 106 controller, and 20 tons of rock storage. The test data analysis performed by IBM evaluates the system performance and documents the suitability of SIMS Prototype System 1 hardware for field installation.

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I. INTRODUCTION

The space and domestic water solar heating system designated SIMS Prototype System 1 has been evaluated at the MSFC Solar Heating and Cooling Test Facility. The test system utilized 720 FT^2 (gross) of Solar Energy Products Air Collectors, a Solar Control Corporation SAM 20 Air Handler with Model 75-175 control unit, a Jackson Solar Storage tank with Rho Sigma Mod 106 controller, and 20 tons of rock storage in the configuration shown in figure 1-1. An illustration of the system 1 test configuration is shown in figure 1-2. All testing and data collection to support this evaluation were performed by the Solar Energy Systems Division of Wyle Laboratories.

A solar operating sequence is initialed, when solar insolation striking the absorber plates raises the collector control sensor above the rock storage temperature by 45^{O}F. Collector flow begins. The solar control will maintain collector flow only so long as 28^{O}F minimum temperature difference between the collector exit and storage is maintained.

The heat delivery subsystem is activated by a room thermostat first stage heat request if the rock storage temperature is above the minimum set point (90^{O}F). (If the minimum storage temperature test fails, the heat request is routed to the auxiliary heat equipment.) Room thermostat second stage heat requests always initiate electric heat strips. Solar heat and auxiliary heat may not operate concurrently.

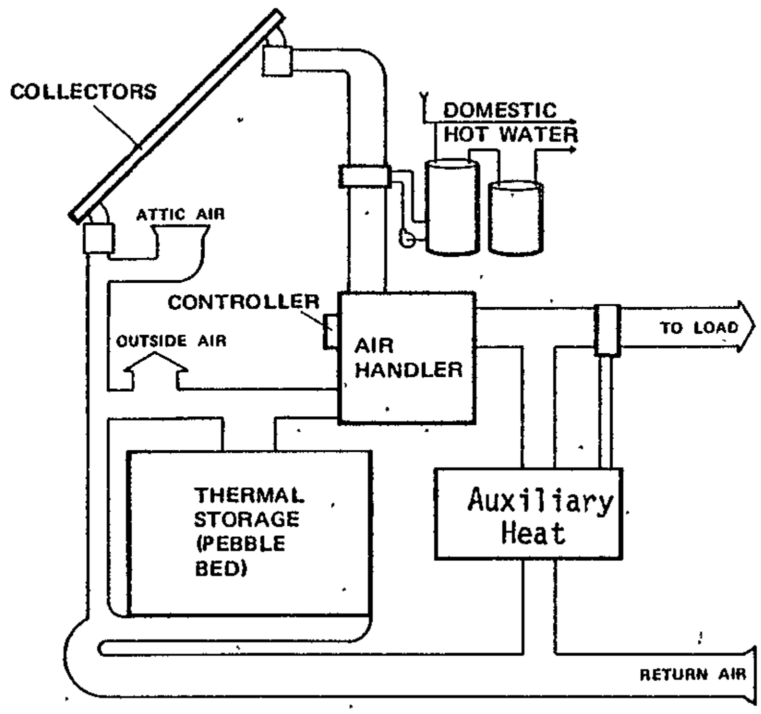
The heating of domestic water is restricted to collector operating periods. Heat will be transferred from the collector air stream to the DHW tank anytime collection temperature satisfies the 20^{O}F/3^{O}F differential thermostat parameters.

The major test objectives were:

- To verify that individual marketable subsystems performed to design requirements within a solar environment.
- To verify design concepts and to insure that the system performed to specification.
- To provide a performance data base for comparison with the performance reported by the National Solar Data Network from two Prototype System 1 field installations.

Test data analysis performed by IBM evaluates the system performance and document the suitability of SIMS Prototype System 1 Hardware for field installation.

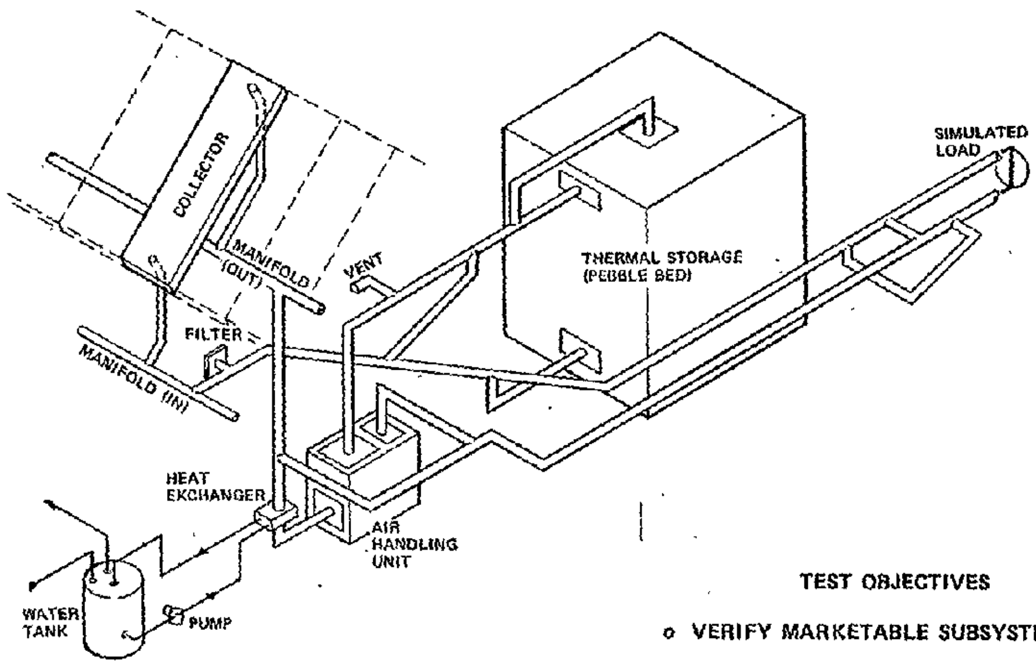
SIMS PROTOTYPE SYSTEM I



- AIR
  - 720 ft^2 SEPCO COLLECTORS
  - 20 TON ROCK STORAGE
  - 1400 CFM
- SPACE HEAT
  - 58% OF 65 X 10^6 BTU/YR
- DOMESTIC HOT WATER
  - 57% OF .9 X 10^6 BTU/MO.
- DESIGN SITE
  - 3300 HEATING DEGREE DAYS/YR
  - 770 BTU/FT^2 INSOLATION
- YEAR COP 7

Figure 1-1. SIMS Prototype System 1

SYSTEM I MSFC SOLAR TEST INSTALLATION



TEST OBJECTIVES

- o VERIFY MARKETABLE SUBSYSTEM FUNCTIONS
- o OPERATE SUBSYSTEMS WITHIN SOLAR ENVIRONMENT
- o DOCUMENT SYSTEM PERFORMANCE

Figure 1-2. Test Configuration

II. SIGNIFICANT RESULTS

The performance testing of SIMS Prototype System 1 as tested in the MSFC Solar Heating and Cooling Test Facility resulted in the following significant findings:

1. SIMS Prototype System 1, based on test data projected to Nashville, Tennessee weather data, will provide 46% of the 65 x 10^6 BTU design heating load.

2. The normal electrical energy required to drive the solar portion of the system was 1.3 KW with short-term operation near 1.4 KW.

3. Collector flow of 1.7 CFM/collector Ft^2 was less than the 2.5 CFM/Ft^2 design value. The 3/4 HP Air Handler Unit motor was inadequate for 720 Ft^2 collectors in the test configuration. This motor would be suitable, however, for a system with a smaller collector array.

4. Control relay failures resulted in vendor modification of the solar controller to reduce relay stress.

5. SIMS Prototype System 1 was judged suitable for field installation.

III. TEST DESCRIPTION

Testing was conducted in three principle phases: (1) simulated energy function (2) winter normal operation, and (3) summer normal operation. The simulated energy phase consisted of controlled temperature inputs and loads on the pebble bed storage and domestic hot water subsystem. Operation during phases (2) and (3) duplicate "as installed" operation for the winter and summer season. Detailed test procedures and test data may be found in Appendix A through D. The contents of the respective appendices are:

Appendix A - Operational Function Test
Appendix B - Simulated Energy Function
Appendix C - Winter Operation
Appendix D - Summer Operation

IV. SUBSYSTEM TEST

The collector, air handler unit, control, and domestic hot water subsystems were each tested at the subsystem level. The following paragraphs describe the test experience and performance measurements.

A. Collector Subsystem

Collector performance indicators calculated from short-term test data are not designed to supplant equivalent data derived from long-term testing. However, short-term testing can provide data that is useful in establishing a base to which engineering judgement can be applied and comments directed. To establish this base, test data from the MSFC solar test facility was used to calculate a collector array efficiency curve. Collector array efficiency data points are plotted relative to the vendor supplied collector efficiency curve in figure 4-1.

Collector array data point distribution was limited due to the small number of test days and to the high ambient temperatures which existed throughout the test schedule. The secondary grouping of three data points resulted from the higher temperatures associated with by-pass operation.

Two major factors contributed to array test performance being less than predicted.

- o The collector array flow rate during testing was only 1.7 CFM per Ft^2 of collector area. Vendor collector efficiency data converted to 1.7 CFM/Ft^2 is shown in figure 4-1.
- o No correction was applied to the test data for incidence angle modifier, collector thermal dynamics, and wind velocity.

SOLAR CONVERSION EFFICIENCY

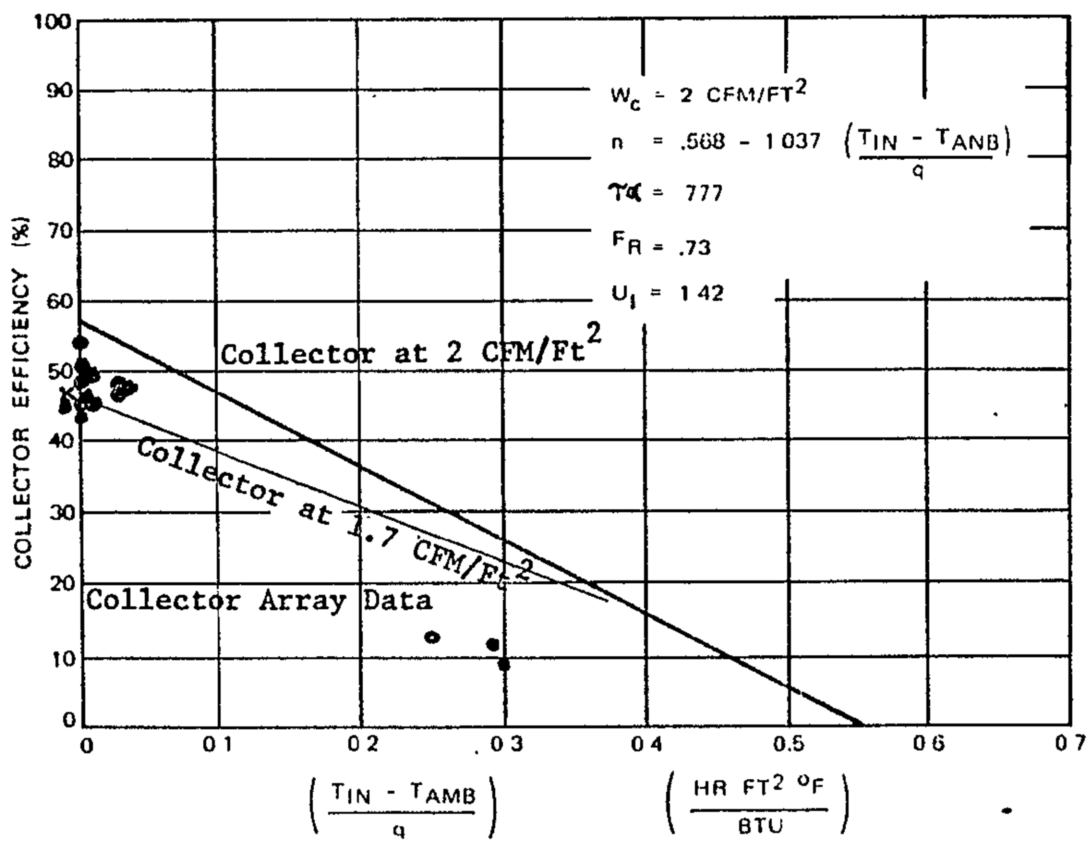


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Figure 4-1. Solar Conversion Efficiency

B. Air Handler Subsystem

Of the marketable subsystems, only the Air Handler Unit (AHU) and its integral controller caused significant test concerns. The AHU functioned properly during component testing in the IBM High Bay; however, leakage across the air control dampers was estimated to be near 5%. During testing in the MSFC Solar Test Facility, two control relays burned out and frequent blower motor thermal cutouts occurred. These problems occurred after the test system had been operating for several days in Alabama summer sunshine with the winter control mode selected. With high summer insolation and without a heating load to maintain storage stratification, the winter control mode allowed the collector inlet temperature to become abnormally high thus producing high temperatures throughout the system. When made the subject of close attention, these problems did not occur under normal operating conditions.

Another problem related to the AHU control dampers. Dampers were reported to have stuck in a closed position until freed by a prying force between damper and sealing strip.

Recent operating experience, without recurrence of these anomalies, suggest that all were caused by excessive temperatures resulting from abnormal system operation coupled with a marginal thermal rating of the relays. The AHU did have excessive air leakage across the air control dampers throughout the test program. Figure 4-2 shows 200 CFM leakage flow through the collectors when in the storage to load configuration. Inspection of the AHU at the completion of testing revealed a missing sealing strip from one end of the collector inlet control damper. System 1 AHU's used in the field have had the sealing strips replaced by an improved application.

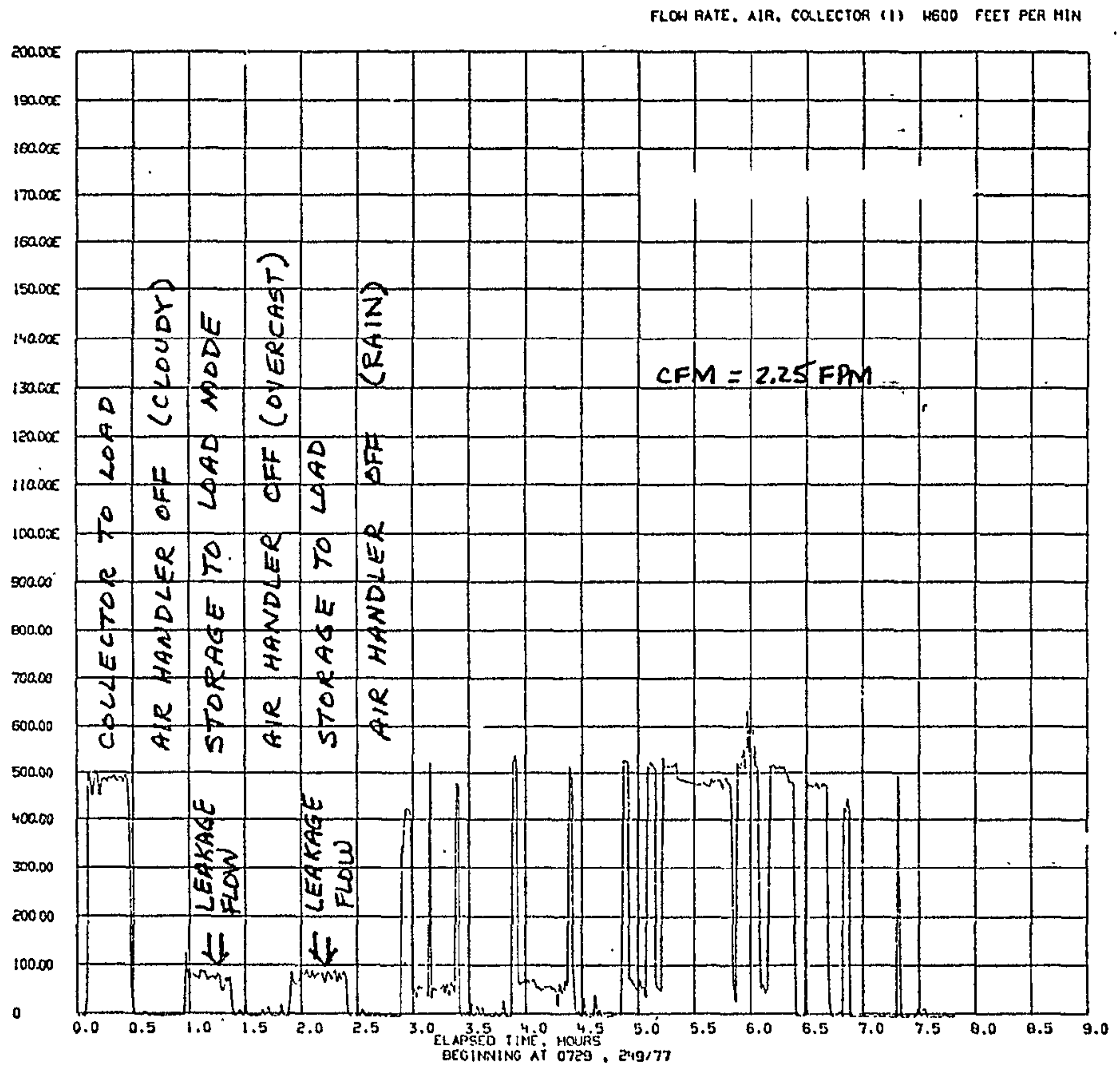


Figure 4-2 Air Control Damper Leakage

C. Control Subsystem

The control subsystem was tested in both the solar (winter) and heat pump (summer) operating mode. The control system design included specification of the control sensor location, sensor mounting detail, and also provided for the dual season operation of a heat pump auxiliary. A control subsystem pictoral drawing is shown in Figure 4-3.

During initial checkout of the test configuration two control relays mounted within the AHU controller compartment burned out. The replacement relays were instrumented and a series of special tests run; however, the problem did not recur. The probable failure cause was the abnormal temperatures, reported under the Air Handler Subsystem, coupled with excessive drive current on the relay coils. Controllers used in the System 1 field sites have had circuit modifications by the controller vendor to prevent relay recurrent problems.

All control system performance reported in the following paragraphs were recorded after the relays were replaced.

SOLAR (WINTER) CONTROL MODE

Control signals were not recorded; however, Figure 4-4 shows independent measurements of the control variables during a day's initial operation. Of special design interest is the sensor mounting bracket, which is mounted on the absorber plate in such a manner that the sensor protrude into the air flow path. The design theory predicted a turn-on temperature based primarily on absorber plate temperature with the sensor then becoming influenced primarily by air temperature with the sensor then becoming influenced primarily by air temperature once flow was established. Control event sequencing supports the collector sensor mounting design theory (Figure 4-3) and is consistent with the specified controller switching parameters (45^{o}F/ON; 28^{o}F/OFF).

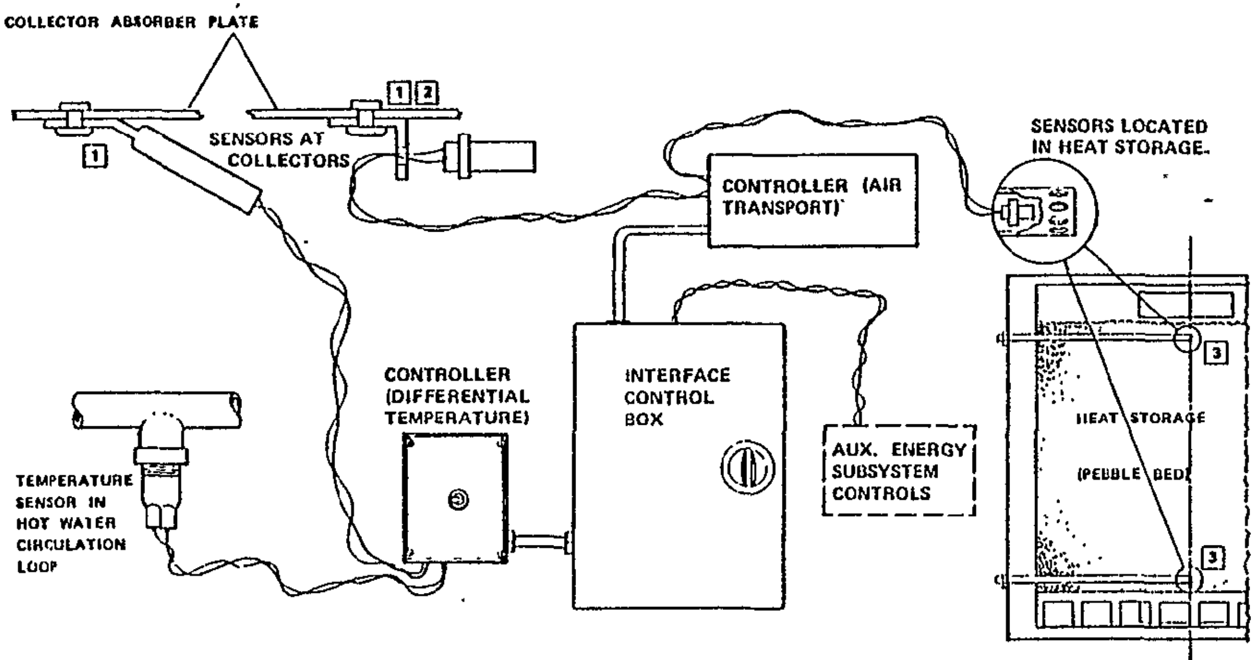
RELEASED FOR ASM	QTY	TECHNICAL APPROVAL			SYM	DATE	CHANGE NO	SYM	DATE	CHANGE NO	7933613
7933608	1	ELEC									DEVELOPMENT NO
		METAL									
		PLASTIC									

THE CONTROL SUBSYSTEM IS COMPRISED OF THREE FUNCTIONAL UNITS WHICH ARE INTERCONNECTED WITH EACH OTHER AND THE AUX. ENERGY SUBSYSTEM.

THE FUNCTIONAL UNITS ARE:

CONTROLLER (AIR TRANSPORT)	SOLAR CONTROL CORP. ZIA MODEL 75-176
CONTROLLER (DIFFERENTIAL TEMPERATURE)	RHO SIGMA MODEL 106
INTERFACE CONTROL BOX	IBM 7933619

11



NOTES:

1. COLLECTOR SENSORS MOUNTED FOR GOOD THERMAL CONTACT AND MAXIMUM EXPOSURE TO AIR FLOW AT EXIT DUCT
2. SENSOR MOUNTING BRACKET NOT TO EXCEED $1/16$" THICK X 1" LEGS
3. TYPICAL ACCESS TO CENTER LINE OF STORAGE IS AT A LEVEL 6" FROM TOP OF ROCK AND 6" FROM BOTTOM WITH CONDUIT OF ½" I.D MINIMUM

IBM MATERIAL	NO
IBM MATL ALTERNATE	NO
CASE DEPTH	
HARDNESS	
SURFACE TREATMENT	
7933613	B

SCALE: NONE — THIRD ANGLE PROJECTION — INCH / mm (0 – 1; 0 – 25.4)

MUST CONFORM TO ENG SPEC: 890350

TOLERANCES UNLESS OTHERWISE NOTED	INCH	mm
LINEAR ±		
ANGLES ±		
RADII UNLESS OTHERWISE NOTED		
EDGE/CORNER BREAKS — OUTSIDE MAX		
EDGE/CORNER BREAKS — INSIDE MAX		

IBM

NAME	CONTROL SUBSYSTEM	
DESIGNER	[signature]	11/23/76
DETAILER	[signature]	11/20/76
DWG CHK	[signature]	11/23/76
DSGN APPRO	[signature]	11-23-76
CLASSIFICATION		

Figure 4-3 Control Subsystem

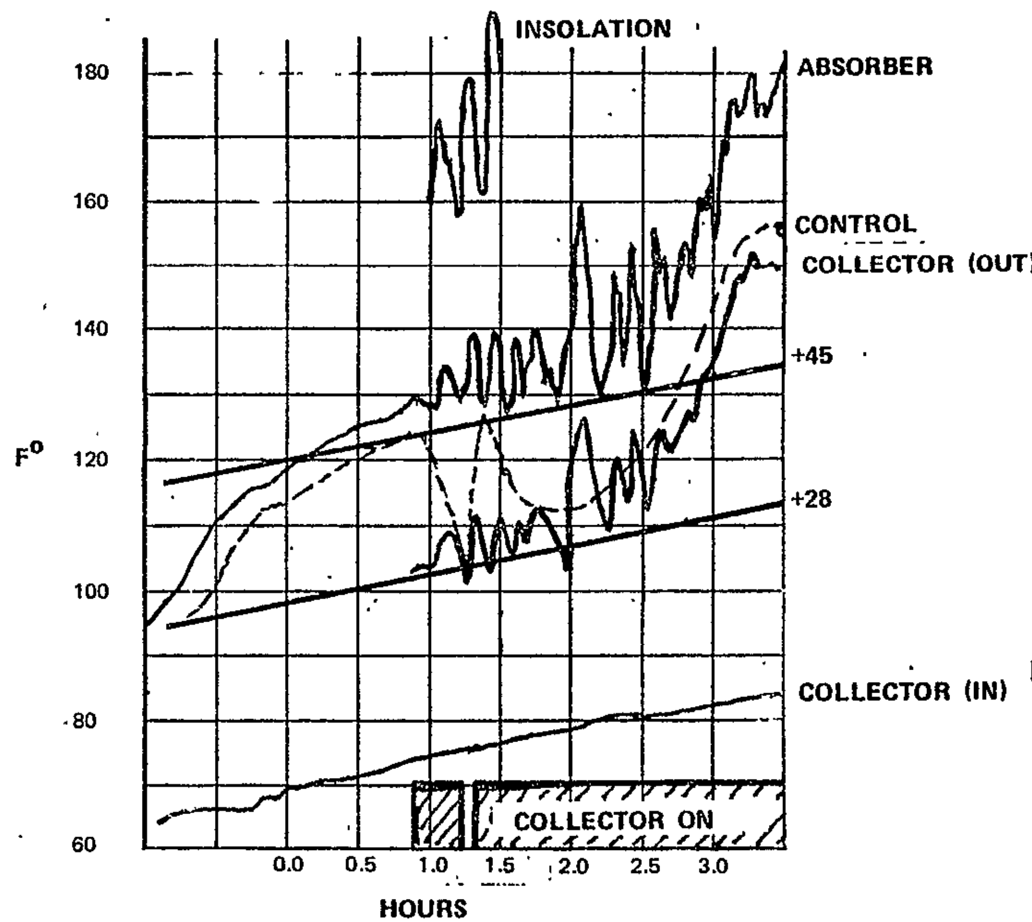


Figure 4-4. Initiate Solar

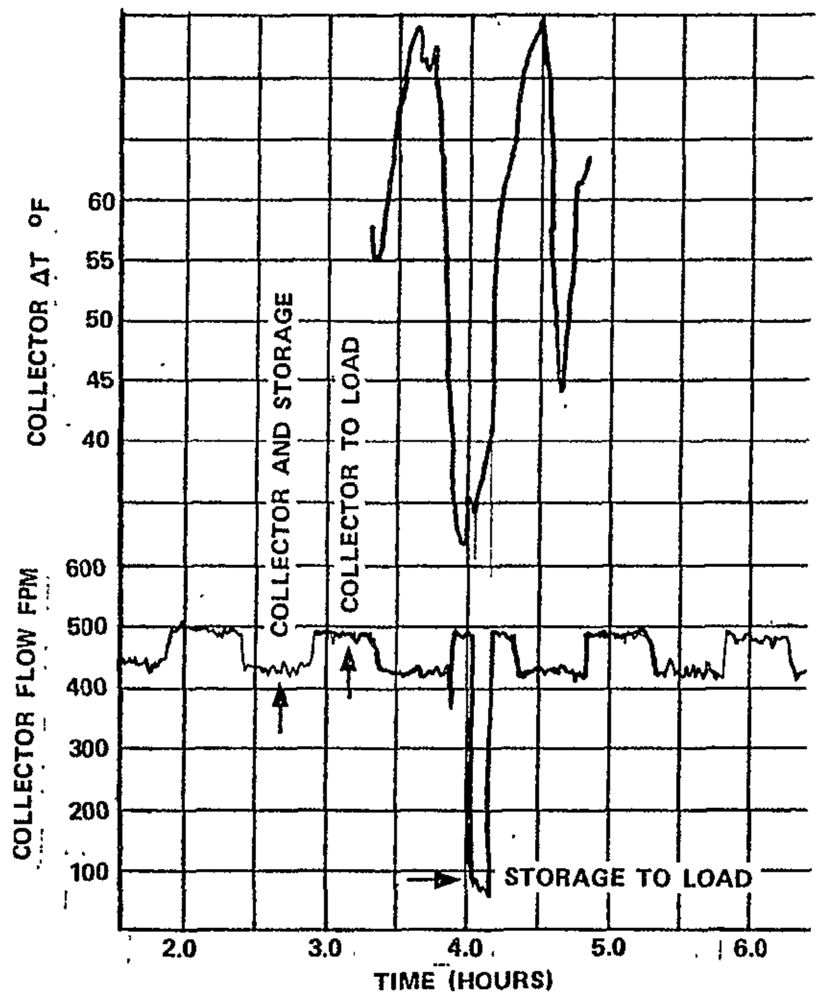


Figure 4-5. Control Operation

The control sequence may be summarized:

- 0.8 Hours - The control sensor mounted on the absorber plate detected a temperature at least 45 degrees hotter than storage (TS+45) and turned the AHU "ON". The exit air temperature sensed under zero flow condition (approximately 30°F cooler than the absorber temperature) is still below the control "ON" differential.

- 1.2 Hours - The cooler air flowing over the exposed sensor (TS+45°F) cools the sensor below the 28°F OFF differential. The AHU stops.

- 1.3 Hours - Absorber heat conduction and the warmer collector air, now stagnant, around the sensor again reach the TS+45 switch point. AHU turns ON.

- 2.0 Hours - Collector air temperature (TS+26°F) cannot overcome the TS+47°F absorber conductive path to the control sensor; therefore, operation continues.

Additional controller operation is shown in Figure 4-5. Near TIME = 4(HOURS), while operating collector to load, solar insolation became insufficient to maintain 18°F gain across the collectors. Solar control correctly changed to and maintained a storage to load until the 45°F initiate collection temperature was again met.

SUMMER MODE OPERATION

The Rho Sigma Controller associated with the Domestic Hot Water Subsystem initiates system operationin the Summer Mode. Sensor location and mounting detail are shown in Figure 4-3 presented earlier in this report.

SUMMER MODE WITH OUT STORAGE

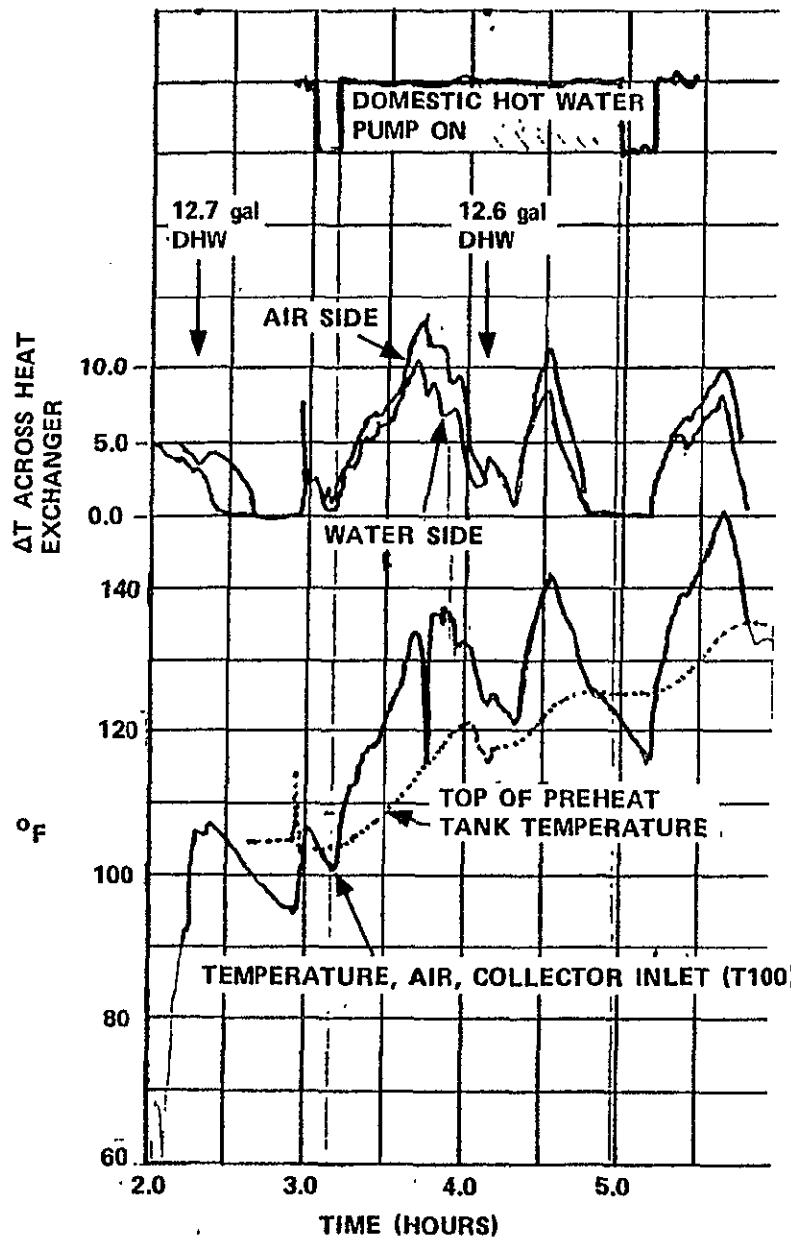


Figure 4-6. Summer Control Mode

The collector sensor for DHW control was mounted on the absorber plate with the active section protruding into the air flow path. The design theory predicted a turn-on temperature based primarily on absorber plate temperature with the sensor then becoming influenced primarily by air temperature after flow was established.

Figure 4-6 shows test results for a Summer Mode OFF/ON control event beginning near elapse time 3.2 hours and terminating near 4.9 hours. Since storage is by-passed in the summer mode, initiation of collector flow increases the collector inlet temperature. As a result, control start-up stability (ON/OFF cycling) is not a problem during summer mode operation.

Recorded temperature gain across the heat exchanger at initiation and termination of the DHW heating cycle shown in Figure 4-6 indicates that the 20^{O}F ON and 3^{O}F OFF controller parameters could be increased for summer operation.

During testing, the temperature control limit on the DHW preheat tank was not adjusted from the 157^{O}F factory set value to the 140^{O}F MPS specified limit. All performance projections are based on the 140^{O}F value. Screw driver adjustment is available for setting the required 140^{O} value limit before field installation.

D. <u>Domestic Hot Water Subsystem</u>

Summer operation uses all of the collected solar energy to heat domestic water. During winter operation, however, the DHW subsystem received only 6.5 to 11.5 percent of the collected energy. The salient component which determines this percentage is the air-to-liquid heat exchanger. Figure 4-7 shows the test data plot used to calculate a heat exchanger UA value of 580 BTU/Hr^{O}F and a 0.3 effectiveness factor. This is in close agreement with the 590 BTU/Hr^{O}F vendor supplied UA value. During the test, the 600 FPM air velocity and 3 GPM liquid flow through the heat exchanger were within design limits.

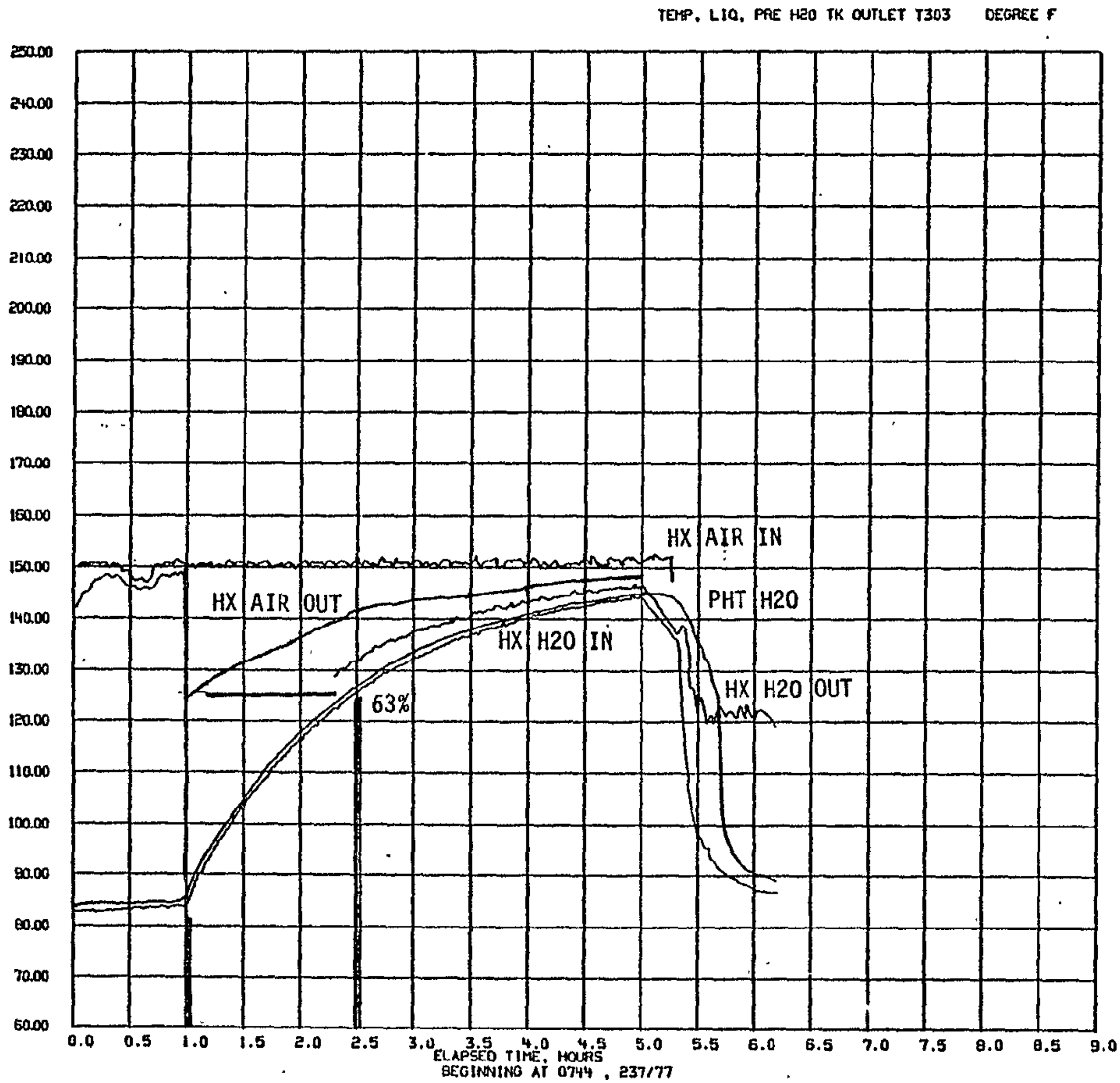


Figure 4-7. Domestic Hot Water Subsystem

DHW PREHEAT TANK DYNAMICS

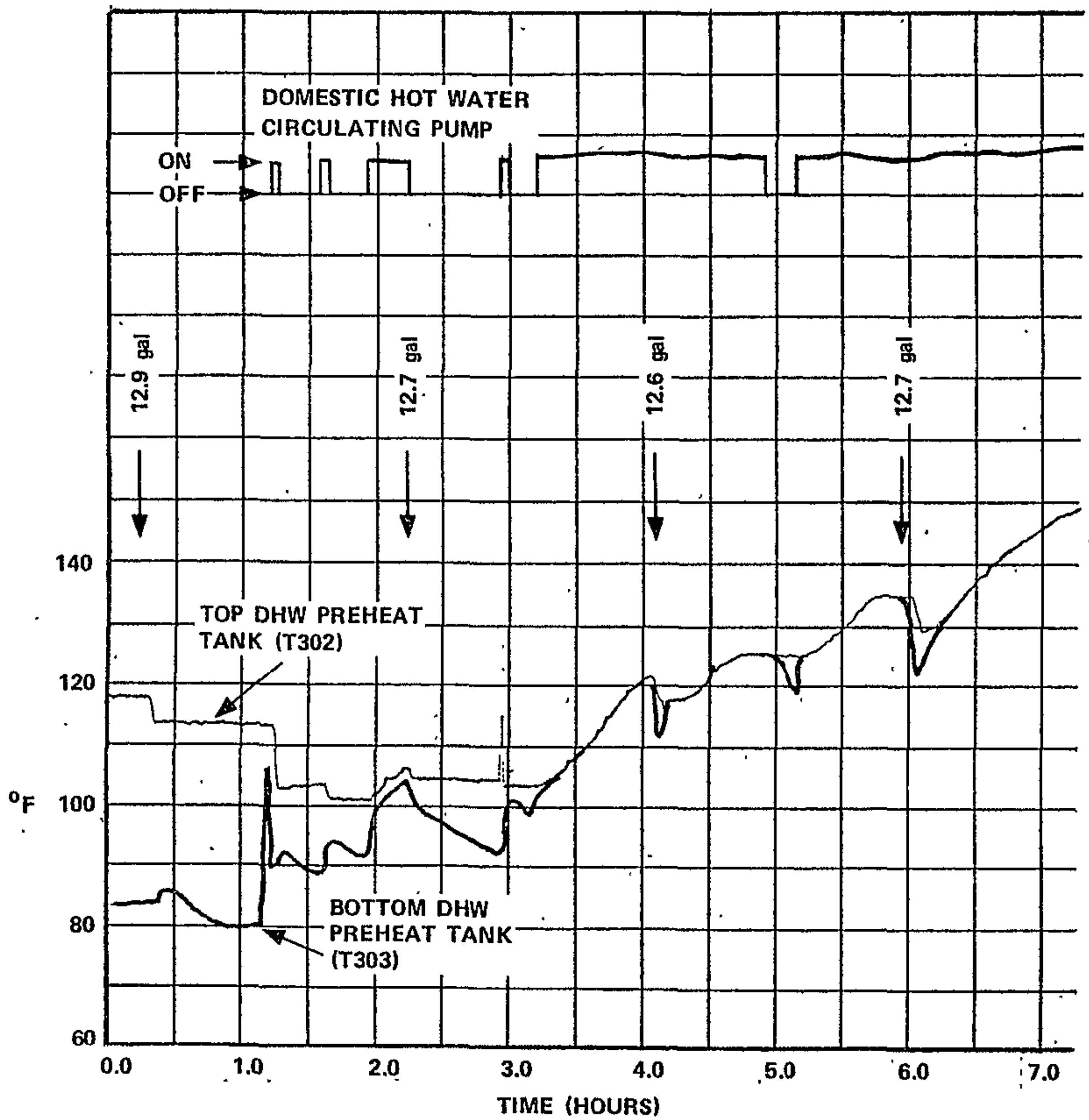


Figure 4-8. DHW Tank Dynamics

IBM

The prediction, measurement, and performance impact of thermal stratification (induced as hot water leaving the top of a storage tank is replaced by cold water entering near the tank bottom) is of great importance in liquid solar systems. DHW tank stratification in air solar systems will have very little impact on performance parameters; however, test data is being presented to aid future liquid solar system designs. The test data presented shows that DHW utilization induces stratification within the preheat tank and that DHW circulating pump operation reduces stratification. Figure 4-8 shows pump operating periods, DHW demand flows, preheat tank top section temperature (T302) and preheat tank bottom temperature (T303). Note that T303 is driven to T302 during DHW pump operation.

Short circuiting between the DHW circulating loop preheat tank inlet and outlet is evident near elapse time 1.2 hours and again at 5.0 hours. The short ON/OFF pump cycle near 1.2 hours and again at 5.0 hours. The short ON/OFF pump cycle near 1.2 hours is especially clear in showing over 30°F stratification delta, indicated as 8°F during "short circuiting", and rebounding to approximately 12°F stratification after pump shut down. Figure 4-8 should be used only to show dynamic trends since the test instrumentation was limited to that required to calculate system overall performance factors.

E. Storage Subsystem

The pebble bed storage subsystem fabricated at the test stand performed to design.

The storage temperature/time response to a inlet air temperature step is shown in Figure 4-9. Similar data for a discharge cycle with constant temperature air flowing from bottom to top is shown in Figure 4-10. Sensor T200 is 9 inches under the rock surface, sensor T201 21 inches, and sensor T202 39 inches of the 60 inch rock depth.

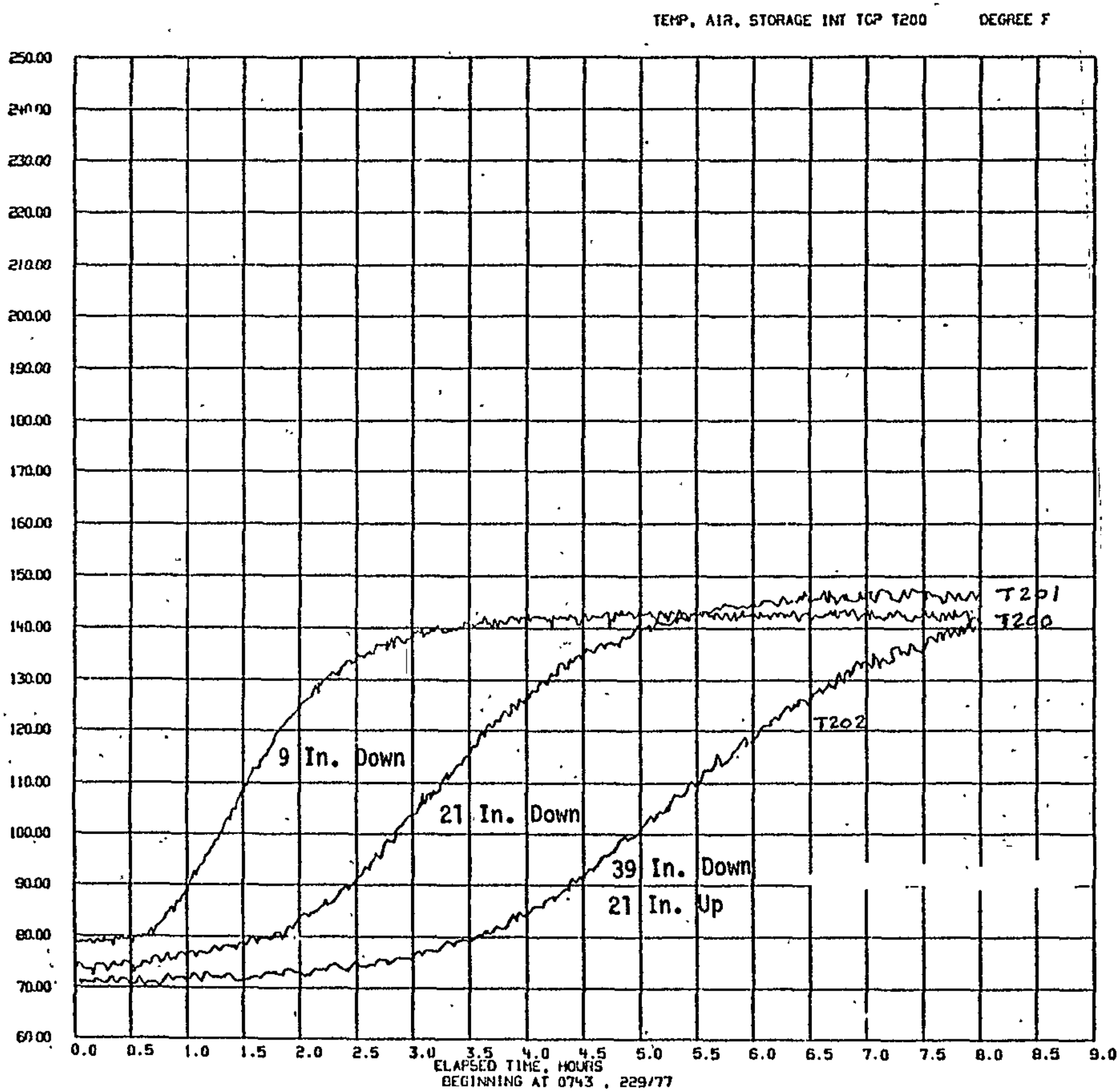


Figure 4-9 Charging Storage

Figure 4-10 Discharging Storage

Flow distribution was good. Of the two levels investigated, the variation 21 inches below the rock surface was greater than at 39 inches below the surface. See Figures 4-11 and 4-12 for the temperature distribution at the 21" level.

Marketable Subsystem Assessment

All marketable subsystems are suitable for system 1 design requirements with the following constraints.

The AHU with the 3/4 HP motor should not be selected for collector array sizes in excess of 400-450 Ft^2 (Gross).

Leakage across air control dampers is a continuing design problem. The AHU vendor had conducted extensive leak testing and had provided unique design features. Since high temperature abuse of the AHU may have contributed to the leakage problem, any final conclusion will wait until System 1A data is available. In the meantime, the missing damper seal in the test AHU will be replaced before operation at the 1B field site.

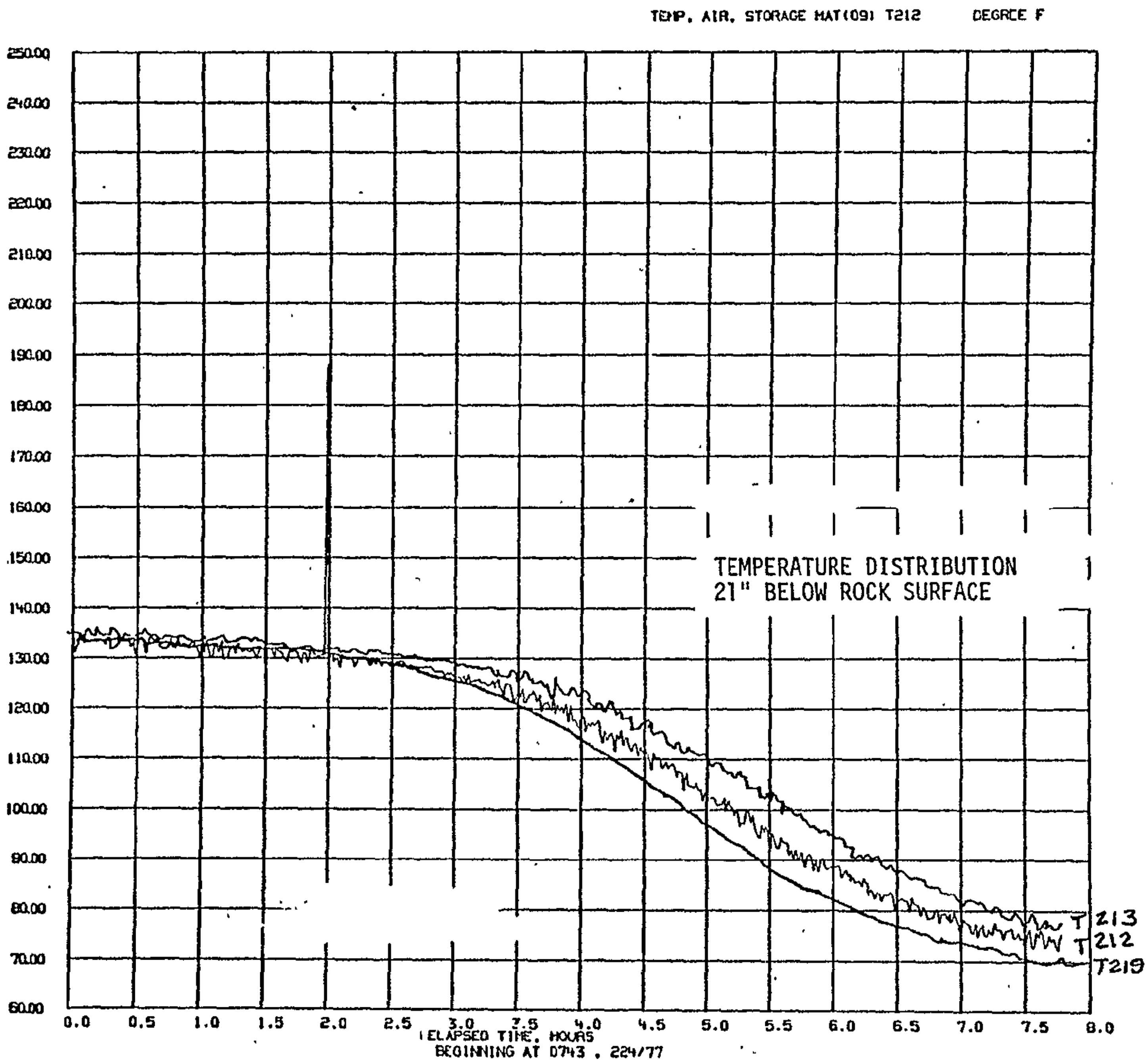


Figure 4-11 Discharge Flow Uniformity

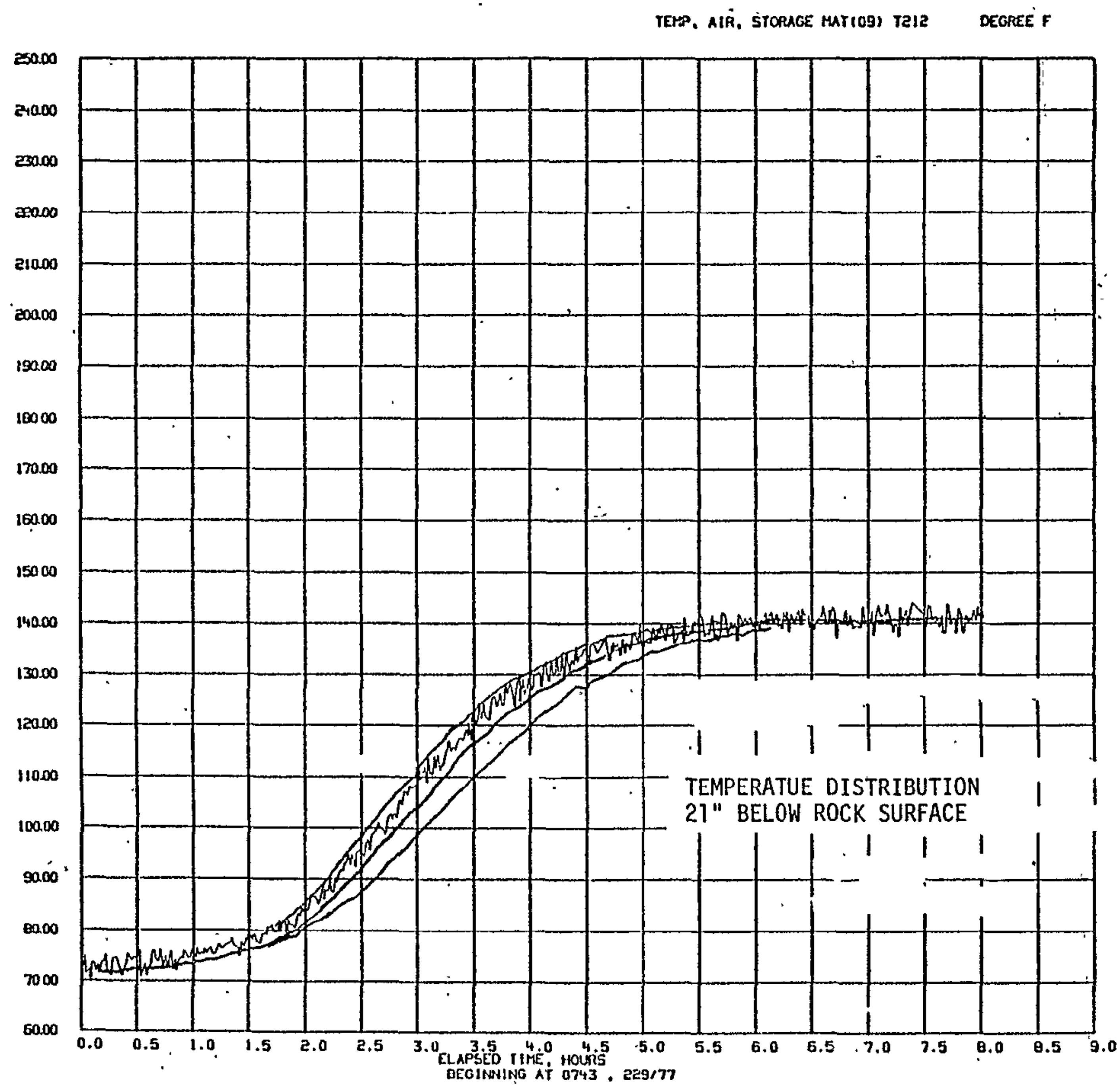


Figure 4-12 Charge Flow Uniformity

V. SYSTEM MEASUREMENTS

Electric Energy Required

Table 5-1 shows the amount of electric power used by the solar system during various operating modes. Also shown is a Coefficient of Performance (COP) defined as the ratio of solar energy delivered to the electrical energy expended by the solar components. The electric energy used to supply heat from storage when solar collectors could not satisfy the load has been charged against the test COP. This causes extremely low values for days of low insolation. Auxiliary energy is not considered.

System Pressure Drop

The system pressure drop measurements are not shown. Significance was not attached to these test data since duct intersections and area transitions made measurements subject to wide variation.

System Performance

Percent solar contribution, the primary measure of solar system performance, is weather and load profile dependent. Since the test data were recorded during late August and early September's high daytime temperature, it was necessary to extrapolate short term summer test data to yield equivalent year around data. A F-chart computer program obtained from the University of Wisconsin was used to process the projections. Percent solar contribution, based on F-chart projection of test derived system parameters, was 46%. The equivalent F-chart projection based on system design parameters is 53%. Test results 7% below the design projection is attributed primarily to degraded collector performance which resulted from low collector flow rate.

The solar contribution predicted using FCHART is expected to be lower than the actual installation performance. FCHART is a versatile but simplified simulation algorithm based on the TRNSYS simulation model. The more detailed TRNSYS simulation predicts a 58% solar contribution for SIMS Prototype System 1.

Table 5-1. Test COP Summary

1977 DATE	MODE		FAN AND PUMP ELECTRIC USE BTU	SOLAR BTU DELIVERED TO LOAD OR STORAGE	TEST COP*
8/31	SOLAR		28,225	416,565	14.7
9/1	SOLAR		27,679	360,734	13.
9/2	SOLAR		24,949	188,501	7.5
9/6	SOLAR		16,485	18,454	1.1
9/8	SOLAR		21,980	150,948	6.9
WINTER	SOLAR	(TOTAL)	119,318	1,135,202	9.5
9/9	W/O STORAGE		19,454	35,162	1.8
9/14	W/O STORAGE		19,522	50,338	2.6
9/12	W/STORAGE		24,437	49,687	2.0
9/13	W/STORAGE		12,730	17,290	1.4
SUMMER		(TOTAL)	76,143	152,477	2.0

APPENDIX A

OPERATIONAL FUNCTION TEST

1.0 PURPOSE

The purpose of this appendex is to present the test results obtained during the performance of an evaluation test program. The evaluation test program was conducted to determine the conformance of the system hardware to the requirements of Reference 2.7.

2.0 REFERENCES

2.1	NBS Technical Note 899	Development of Proposed Standards For Testing Solar Collectors and Thermal Storage Devices.
2.2	ASHRAE 93-P	Method of Testing Solar Collectors Based on Thermal Performance.
2.3	ASHRAE 94-P	Methods of Testing Thermal Storage Devices Based on Thermal Performance.
2.4	NBSIR 76-1137	Thermal Data Requirements and Performance Evaluation Procedures For The National Solar Heating and Cooling Demonstration Program.
2.5	MSFC MMI 5300.4C	Metrology and Calibration.
2.6	NAS8-32036	NASA/IBM Contract Verification Plan/ Procedure For Prototype Solar Energy Heating and Hot Water System Model No. 1.
2.7	MTCP-DC-SHAC-415	Test Procedure For Thermal Performance of System 1B.

3.0 MANUFACTURER

Collectors, Model EF-212	Solar Energy Products Company 121 Miller Road Avon Lake, Ohio 44012
Energy Transport System Series 20	Solar Control Corporation 5595 Arapahoe Road Boulder, Colorado 80302
Air To Water Heat Exchanger, Model SW2-18-18-8	Halstead-Mitchell Scottsboro, Al. 35768

3.0 MANUFACTURER (Continued)

80 Gallon Preheat Tank	W. L. Jackson Manufacturing Co., Inc. P. O. Box 11168 Chattanooga, Tenn. 37401
Circulating Pump, Model UP25-42	Grundfos Pumps Corp. 2555 Clovis Avenue Clovis, California 93612
Energy Transport Control, Model 75-176	Solar Control Corp. 5595 Arapahoe Road Boulder, Colorado 80302
Hot Water Differential Thermostat, Model 1106	Rho-Sigma 5108 Melvin Avenue Tarzana, California

4.0 DESCRIPTION OF TEST SYSTEM 1B

Solar Collectors - Soloron Solar Collectors, Model EF-212, are single glazed collectors with a nonselective absorber plate utilizing flowing air as a heat transfer medium. The absorber plate and box frame are aluminum and the insulation is one inch Isocyanurate foam board with thermal conductivity of 0.11 $BTU/FT^2 \cdot Hr \cdot {}^oF/Ft$. The total collector array area is 720 720 Ft^2.

Thermal Storage - A pebble bed unit made up of approximately 19.5 tons of washed river rock.

Air Handler - 3/4 HP centrifugal blower with three integral motorized air dampers.

Hot Water Preheating Subsystem - Components include an 80 gallon tank, an air to water heat exchanger pump, and integral controls.

A complete description of the test facility used in the performance of these tests is contained in WYLE TM 531-21.

5.0 TEST CONDITIONS AND TEST EQUIPMENT

5.1 Ambient Conditions

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

5.2 Instrumentation and Equipment

All transducers with the exception of the Eppley PSP pyranometer used in recording test data were calibrated by either NASA or AMC calibration laboratories as required by MSFC MMI 5300.4C. The PSP pyranometer was calibrated by Eppley.

The end-to-end accuracy of data shown for system testing is subject to an error analysis which accounts for all inaccuracies in the transducer, signal conditioning, signal transmission and computer processing methods. Since a formal systems error analysis has not been done, confidence in printout accuracies is established by spot checks obtained by installing calibrated "parallel" transducers and direct readouts at key points in the system and performing comparison checks from time to time before, during and after tests. The results of such checks together with a review of the data for anamolies would indicate that the data presented is suitable for the purpose intended.

A listing of the equipment used in each test is as follows:

System Operational Functional Test

Measurement	Transducer Manufacturer/Model	Transducer 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	Tektronic/630-NS	Full Scale ±2%
Volt Ohmmeter	Triplett/630-NS	Full Scale ±2%
Volt Ohm Milliammeter	Simpson/260	Full Scale ±2%

System Test

Measurement	Transducer Manufacturer/Model	Transducer Range/Accuracy
Pyranometer	Eppley/PSP	0-400 BTU/Hr·Ft^2 ±3%
Platinum Resistance Thermometers	Minco Hy-Cal Thermal Systems Hy-Cal	-50 to 400°F 40 to 100°F ±.9°F 60 to 250°F T 0 to 50°F ±.2°F.
Differential Pressure Sensor	Travis Corp./Model P8	0-2" H_2O ±.05% FS
Flow Meter Flow Converter	Potter Foxboro	0-10 GPM ±1% FS

6.0 TEST REQUIREMENTS AND PROCEDURES

6.1 System Operational Functional Test

Started: ______________________

Completed: ______________________

6.1.1 Performance Criteria Requirements

A system operational functional test shall be conducted on prototype system M/N 1B. 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:

- An operational test of the system's blower.
- An operational test of the sytem's mechanically operated dampers.
- A system check for air leaks.
- The measurement of the flow rate through and the pressure drop across the collector array.
- The measurement of the flow rate through and the pressure drop across the storage unit.
- The measurement of the system flow rate and the blower's head pressure drop for each of the system's operational modes.
- A system check of the domestic hot water subsystem for water leaks.
- An operational test of the domestic hot water subsystem.

6.1.2 Test Procedure

1. Install the prototype system M/N 1B on Test Bed No. 1.
2. Connect power to the system blower.
3. Manually override the controls for the dampers in the air handler. Insure that the dampers properly open and close. Check to make sure the dampers are properly seated when in the closed position.

5.0 TEST CONDITIONS AND TEST EQUIPMENT (Continued)

5.2 Instrumentation and Equipment (Continued)

System Test

Wind Velocity Sensor	Teledyne Geotech/M1567	.75-60 MPH ±.5%
Wind Direction Sensor	Teledyne Geotech/M1567	0-360°F ±1%
Air Velocity Sensor	Sierra	0-2000 FPM ±3% FS

6.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

6.1. System Operational Functional Test (Continued)

4. Operate the system blower and check for air leaks around the insulation joints.

5. Operate the system blower, set the dampers to flow air through the collectors, monitor the air flow rate through the collector array, and the pressure drop across the array.

6. Operate the system blower, set the dampers to circulate in a closed loop through the storage unit. Measure the air flow rate through the storage, and the pressure drop across the storage unit.

7. Operate the system blower, measure the system flow rate, and blower head pressure for each of the operational modes.

8. Pressurize the domestic hot water subsystem to approximately 150 PSI and check all joints for leaks.

9. Operate the domestic hot water subsystem pump and valves to verify their proper operation.

6.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

6.1.3 Results

1. All system components were found to be operating properly. All subsystems were pressurized without any leaks being discovered.

2. The pressure drop across the collector array was found to be:

   $P_{Coll} = 0.177" H_2O$ @ 1125 CFM

   The instrumentation sensor used for the pressure drop was PD102. The sensors used for the average air velocity reading were W600 and W601.

3. The pressure drop across the rock storage bed was found to be:

   $P_{STOR} = 0.093" H_2O$ @ 1100 CFM

   The instrumentation sensor used for the differential pressure was PD101. The sensors used for the average air velocity reading were W600 and W601.

4. The differential static pressure across the air handler and corresponding air flows for each operational mode were as follows:

• Storage bypass (summer operation w/o storage)	P = 0.28" H_2O @ 1125 CFM
• Collector to storage	P = 0.03" H_2O @ 1100 CFM
• Collector to load	P = 0.39" H_2O @ 1080 CFM
• Storage to load	P = 1.14" H_2O @ 1100 CFM

APPENDIX B

SIMULATED ENERGY FUNCTION

1-0 - 5.0 SEE APPENDIX A

6.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

6.2 System Test, Simulated Energy Input

6.2.1 Performance Criteria Requirements

The prototype System 1B shall be tested to evaluate the systems' capacity for control, storage and distribution to the load using controlled simulated energy inputs.

The primary objective of this test is to determine the operating characteristics of the storage bed using simulated energy inputs.

The test shall be conducted with simulated energy inputs to produce temperatures of 90, 125, and 150°F as measured in duct area that simulates the collector outlet.

Each simulated temperature shall be circulated throughout the system a sufficient amount of time to allow the system to stabilize.

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 1B will be monitored to provide the following data:

- Time required to charge the storage unit at each temperature.
- Energy supplied to the storage unit from the simulated energy input at each temperature.
- Time required to exhaust the storage unit after charging at each temperature.
- Energy supplied to the load device from the storage unit.
- Energy supplied to the hot water system while charging the storage at each temperature.

6.2.2 Test Procedure

This test consisted of a series of charge and discharge tests on the rock storage bed utilizing load conditioning available from a fan loop system located in the test article building of Test Bed 1 of the Solar Test Facility. This test was completely independent of the solar collector array as the load/simulated source was provided by facility equipment.

6.2.2 Test Procedure (Continued)

The fan system used for simulated heat input included F5, A 10 HP blower, CC-2, a 715,500 BTU/Hr cooling coil fed from the facility chiller, HC-4, a 388,800 BTU/Hr heating coil fed from the low temperature boiler, and AFCS-5, a pneumatically controlled air flow control station. The existence of both the heating and cooling coils in the fan system allowed for fine control of the air temperature.

The rock storage charge test was accomplished by flowing air through the closed loop system illustrated in Figure B1. The air was circulated into the top of the rock storage bed, charging the storage as it passed through the storage bed, and returned to the facility fan system where it was reheated to the preset temperature. Fan F5 was energized to boost the air velocity in the event the velocity did not meet the required value as set in the performance criteria requirements. (Reference 2.5).

The rock storage discharge test was accomplished by flowing air through the closed loop system illustrated in Figure B2. In this configuration the air was circulated into the bottom of the rock storage bed removing heat as it passed through the storage bed. The air then exited from the top of storage and returned to the facility fan system where the air temperature was reconditioned to seventy (70) °F. Fan F5 was energized to boost the air velocity in the event the velocity did not meet the required value as set in the performance criteria requirements. Presented below are the systems' manual damper positions required to accomplish each test.

1. To prepare for storage charge test

   - Open manual damper nos 3, 4, 7, 10, 12, 13

   - Close manual dampers nos 1, 2, 5, 6, 8, 9, 11

2. Adjust test facility's blower to ensure a flow rate of 1200 CFM ±150 CFM through out the system.

3. Circulate air at ambient temperature through the system until the system stabilizes.

4. Raise the temperature at the inlet of the storage unit to 90°F using the energy input simulator.

5. At end of day, deactivate the air handler blower and the energy input simulator.

6. To prepare for storage discharge test

   - Open damper nos 3, 4, 8, 9, 11, 13

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6.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

6.2.2 Test Procedure (Continued)

- Close damper nos 1, 2, 5, 6, 7, 10, 12

7. Adjust the load simulator to provide return air at 70°F.

8. At end of day, deactivate the air handler blower and the energy input simulator.

9. Repeat charge and discharge procedures for 125°F and 150°F.

10. Collect data throughout test on the data system located in Building 4646.

The last tests, utilizing the simulated heat input, consisted of a series of hot water subsystem charge tests. This test was also conducted with the collector array isolated from the other subsystems.

The hot water system consisted of a 80 gallon preheat tank, a air to water heat exchanger, a circulating pump, and a hot water differential thermostat.

The hot water charge test was accomplished by circulating air through the closed loop system illustrated in Figure 7. The air flowed through the air to water heat exchanger, heating the water as it passed through the heat exchanger, and was returned to the facility fan system where it was reheated to the preset temperature. Fan F5 was energized to boost the air velocity in the event the velocity did not meet the required value as set in the performance criteria requirements.

1. To prepare for hot water charge test

   - Open dampers nos 2, 5, 7, 10, 12

   - Close damper nos 1, 3, 4, 6, 8, 9, 11, 13

2. Adjust the test facility's blower to ensure a flow rate of 1200 CFM ±150 CFM throughout the system.

3. Flow city water through the preheat tank until the outlet temperature stabilizes.

4. Set inlet air temperature to the hot water heat exchanger to 90°F using the Breadboard Facility simulated energy input system. Run the system for four (4) hours.

5. Repeat the test with air inlet temperatures to the heat exchanger individually at 125°F and 150°F as each subsequent condition.

6.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

6.2.2 Test Procedure (Continued)

6. Collect data throughout the system's operation on the data system located in Building 4646.

6.2.3 Test Results

It should be noted that the storage bed charge and discharge tests were run on alternating days. The tests were restricted to the normal work day and therefore were not run until an inlet and outlet stabilization had occured. However, the data collected was sufficient to compute a time constant for each test.

Charge tests were run at 100°, 125°, and 150°F instead of 90°, 125°, and 150°F as specified in the test procedure (Reference (2.7)since high ambient temperatures precluded a charge test lower than 100°F. This series of tests was begun with a discharge test from approximately 135°F which was used as a replacement for the 125°F discharge test.

A substanial amount of water was discovered in the pebble bed storage before testing was begun due to leaks in the storage enclosure. These leaks were sealed and several days were spent ensuring that the pebble bed was dry by using the condensing coil located in fan system 5.

In an effort to approximate the amount of energy being expended as latent heat, relative humidity sensors were installed in the top duct (RH101) and bottom duct (RH112) of the pebble bed storage. It was also discovered during this time that the air velocity measurement to load (W101) was inoperative and therefore was removed. Air velocity sensor, W100, was utilized to measure velocity in the duct returning from the load.

The storage charge test to 150°F was run for a twenty-four (24) hour period although the data acquisition required shut down at the end of the normal workday. This resulted in a fully charged storage and a stabilized outlet temperature. The next two days were used for a discharge from 150°F until the outlet temperature had stabilized at 80°F.

All 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.

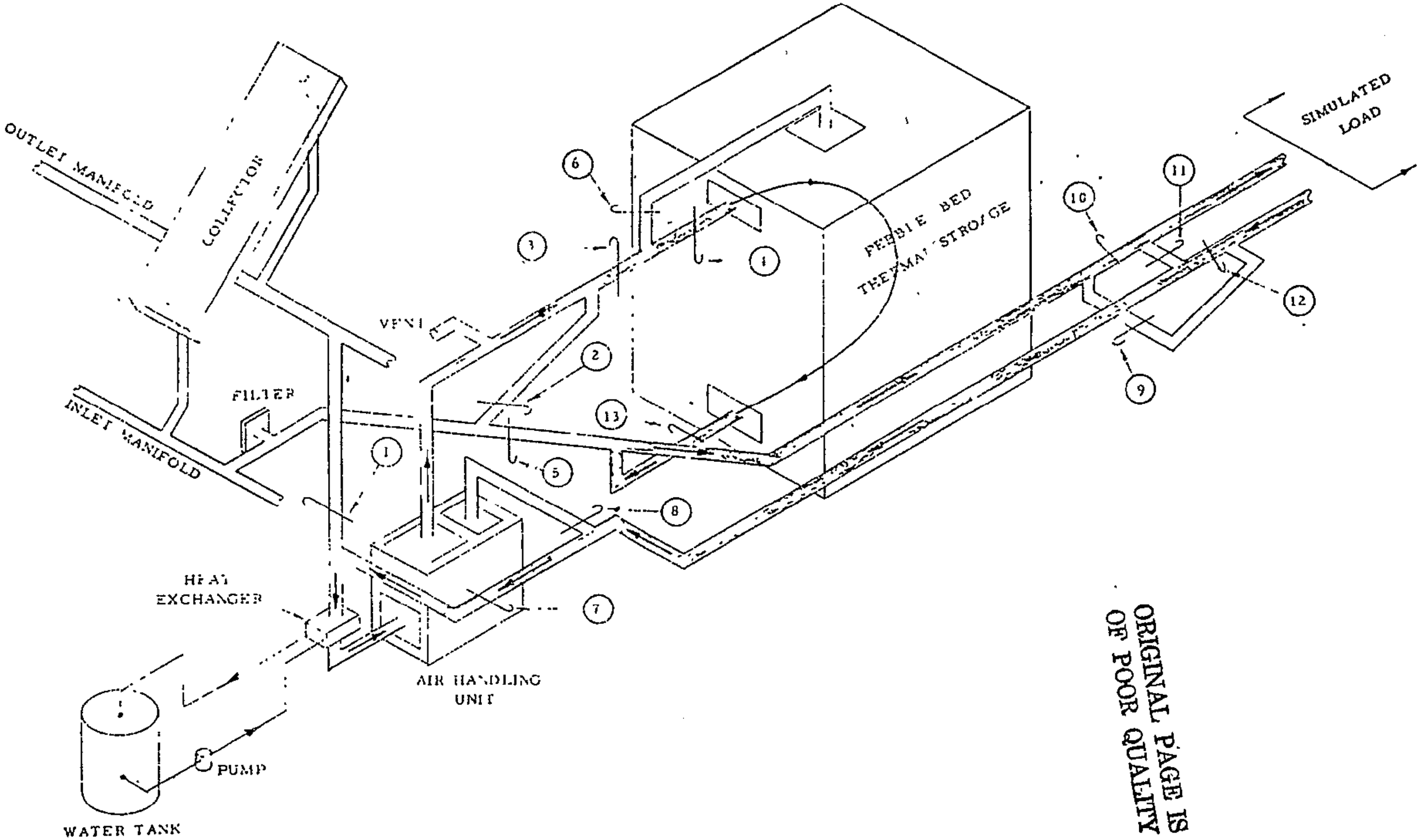

Figure 3-1. System 1B Flow Schematic for Simulated Charging of System

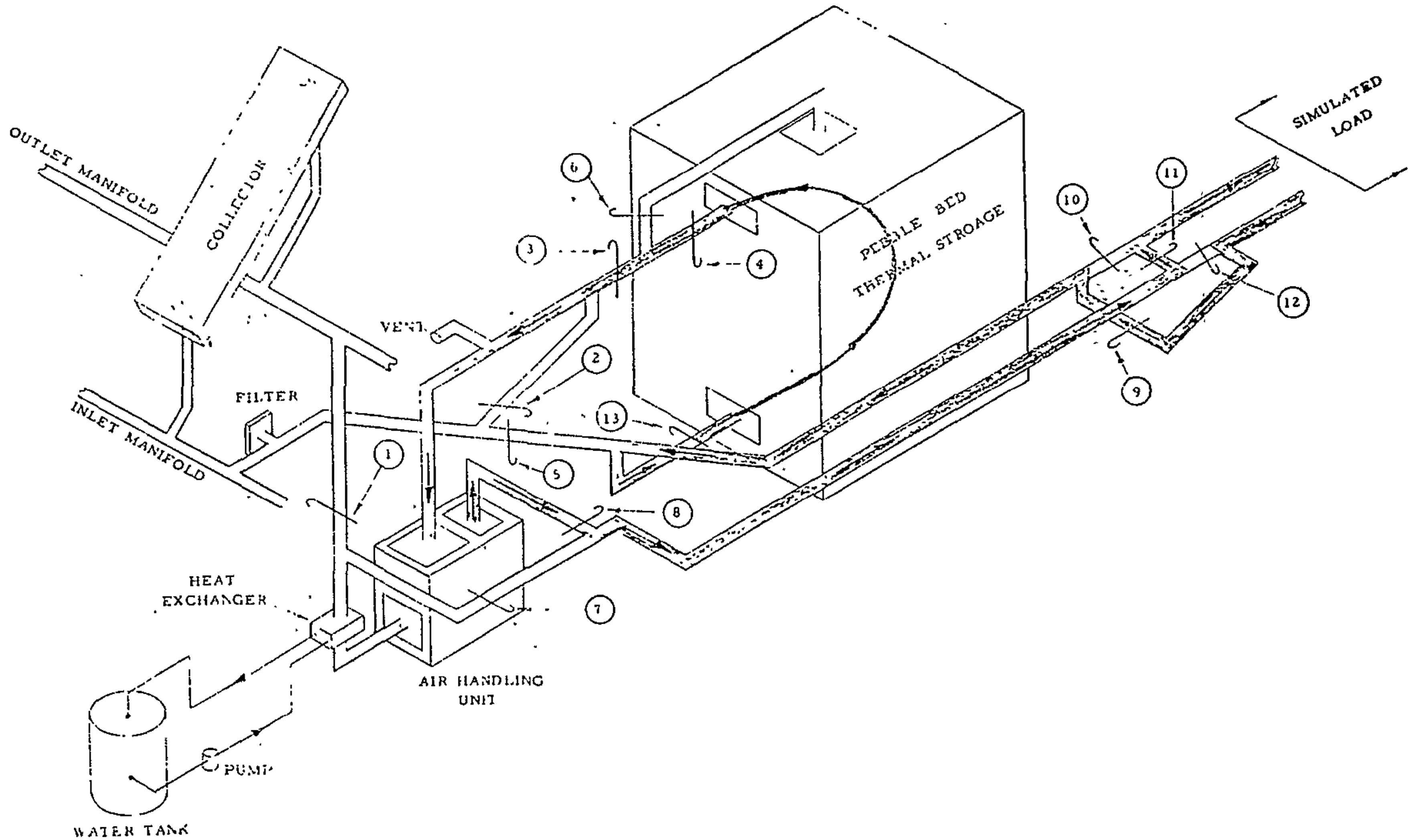

Figure B-2. System 1B Flow Schematic for Discharge Test Thermal Storage

TABLE B-1

PARAMETERS MEASURED DURING SYSTEM TESTING

Measurement	Parameter
Solar radiation	BTU/Hr/Ft^2 vs. time of day in hrs.
Wind speed/direction	MPH/direction vs. time of day (hrs)
Relative humidity	% vs. time of day in hours
Relative humidity, storage bottom	% vs. time of day in hours
Relative humidity, storage top	% vs. time of day in hours
Storage delta temperature	°F vs. time of day in hours
Hot water heat exchanger delta temperature, air side	°F vs. time of day in hours
Hot water heat exchanger delta temperature, liquid side	°F vs. time of day in hours
Domestic water heater, city water inlet to discharge delta temperature	°F vs. time of day in hours
Delta temperature across load	°F vs. time of day in hours
Ambient temperature	°F vs. time of day in hours
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
Storage inlet temperature	°F vs. time of day in hours
Storage outlet temperature	°F vs. time of day in hours
(3) Internal storage temperature	°F vs. time of day in hours
System air inlet temperature to load	°F vs. time of day in hours
System air outlet temperature from load	°F vs. time of day in hours
Hot water coil inlet temperature (water)	°F vs. time of day in hours
Hot water preheat tank temperature	°F vs. time of day in hours
City water supply temperature to hot water subsystem	°F vs. time of day in hours
Hot water system outlet temperature	°F vs. time of day in hours
System temporary shelter temperature	°F vs. time of day in hours
Air flow velocity through collectors	Ft/min. vs. time of day in hours
Air flow velocity through storage	Ft/min. vs. time of day in hours
Air flow velocity through load	Ft/min. vs. time of day in hours
Liquid flow hot water load	GPM vs. time of day in hours
Liquid flow, hot water subsystem	GPM vs. time of day in hours
System blower power	Watts vs. time of day in hours
Hot water subsystem power	Watts vs. time of day in hours
Storage delta pressure	In. H_2O vs. time of day in hours
Collector delta pressure	In. H_2O vs. time of day in hours

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1.0 - 5.0 SEE APPENDIX A

6.0 TEST REQUIREMENTS AND PROCEDURES

6.1 System Test, Winter Operation

Started: 30 August 77
Completed: 8 September 77

6.1.1 Performance Criteria Requirements

The prototype System 1B shall be operated in the normal winter mode. While operating in this mode, periodic demands will be made on the hot water subsystem.

The primary objective of this test is to obtain as much actual operating data as possible from prototype System 1B prior to its installation at the demonstration site.

During the system test, complete weather records will be kept. These will include total solar radiation, ambinent temperatures, wind speed and direction, relative humidity, barometric pressure and cloud cover. In addition, the prototype System 1B will be monitored to provide the following data:

- The total energy collected by the system per day.
- The total energy supplied to the domestic hot water subsystem.
- The total power required to operate the system per day.
- The total energy supplied to the load per day.
  - Direct from the collectors
  - From storage
- The systems' control functions (manual observation)

6.1.2 Test Summary, Winter Operation

The random weather conditions test consisted of running the system in its normal operation. Normal operation is primarily comprised of a winter condition and a summer condition. The winter condition can be further broken down to a collector to load configuration, a collector to storage configuration, and a storage to load configuration.

The winter condition was primarily concerned with meeting a load requirement, either directly from the collector array or indirectly through storage.

The collector to storage mode (Figure C-1) occurred when the collector temperature was greater than the storage temperature and there was no load requirement. This closed loop system circulated air

6.1.2 Test Summary, Outside Weather Conditions (Continued)

through the collectors and into the top of storage where it charged the rock storage bed before returning to the collectors. If the air flowing over the air-to-water heat exchanger was greater than the outlet temperature of the preheat tank, the circulating pump was energized thus charging the hot water system concurrently with the rock storage.

The collector to load mode (Figure C-2) occurred when there was a load requirement and when the collector surface temperature was greater than the storage temperature. This closed loop system circulated air directly from the collectors to the simulated load. The collector to load mode also allowed for charging of the hot water system using the same control logic as the collector to storage mode. The load was supplied by the same system that was used for the simulated heat input tests. In the absence of a thermostat to supply a load requirement, a single-pole switch was installed to establish the load requirement to the controller. In this mode fan F5 was used to boost the air velocity to satisfy the required value as prescribed in the Performance Criteria Requirements.

The final winter operating mode was the storage to load condition (Figure C-3). This mode occurs when there is a load requirement and when the storage temperature is greater than the collector temperature. Air is circulated into the bottom of the rock storage bed and exhausts from the top of storage and returns to the load. Load facility used to boost the air velocity to meet performance criteria.

6.1.3 Test Procedure

1. To run the system in its normal operation, winter conditions

   . Open dampers nos 1, 3, 4, 5, 8, 9, 11, 13

   . Close dampers nos 2, 6, 7, 10, 12

2. Energize system.

3. Turn hot water pump control to auto.

4. Put control switches to SOLAR and T_{CO}-OFF.

5. Put switch on top of air handler to W.

6. Every 30 minutes override the system controller to demand a system heating load requirement for 30 minutes by putting the thermostat switch on the control box to ON.

7. Every two (2) hours draw twelve (12) gallons of water from

6.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

6.1.3 Test Procedure (Continued)

the hot water system.

8. Deactivate the entire system at the end of the day.

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

6.1.4 Test Results

The winter mode tests were run subject to ambient conditions. The weather conditions during these tests ranged from mostly clear days to a day in which the majority of the test was run under overcast skies with rain.

A problem was encountered during these tests with the air handler dampers. On one day a pivot arm on one of the dampers broke loose. This problem was discovered immediately and fixed in time that it did not effect the day's testing. On an excessively wet day the system controls were operating improperly. This occurred during a day in which the system was completely depleted of energy and no tests were being performed. The control problem remedied itself and did not reoccur.

All 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. The analytical data shows the total energy supplied to the system and the total energy utilized by the system. A ratio of these quantities is also shown (Tables I thru V.

TABLE I.

TEST RESULTS

DATE 8/31/77 TEST IDENTIFICATION NORMAL OPERATION WINTER MODE

A. TOTAL ENERGY SUPPLIED

Power Consumption	8.27 KW·Hr x 3413 $\frac{BTU}{KW \cdot Hr}$ = 28225 BTU
Energy Collected	467659 BTU
Total	495884 BTU

B. TOTAL ENERGY UTILIZED

Storage To Load	22967 BTU
Collector To Load	206289 BTU
Collector To Storage*	178195 BTU
QH/Water	32081 BTU
Total	439532 BTU

*where $Q_{storage} = \left(\frac{\overline{W600}+\overline{W601}}{2} \frac{ft}{min}\right)\left(2.18\ ft^2\right)\left(t\ Hr\right)\left(60\ \frac{min}{hr}\right)\left(.071\ \frac{lb}{ft^3}\right)\left(.24\ \frac{BTU}{lb \cdot °F}\right)\left(\Delta T_{stor.}\ °F\right)$

$\frac{\text{TOTAL B}}{\text{TOTAL A}}$ = 0.89

QH/Water Load*		
1.	4917	BTU
2.	3195	BTU
3.	5455	BTU
4.	3551	BTU
Total For Day	17118	BTU

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*where $Q_{H/Water} = \left(\overline{W301}\ \frac{gal}{min}\right)\left(1.7\ min\right)\left(8.33_{C-4}\ \frac{lb}{gal}\right)\left(1.0\ \frac{BTU}{lb \cdot °F}\right)\left(\overline{TD301}\ °F\right)$

TABLE II

TEST RESULTS

DATE 9/1/77 TEST IDENTIFICATION NORMAL OPERATION

WINTER MODE

A. TOTAL ENERGY SUPPLIED

Power Consumption	8.11 KW·Hr x 3413 $\frac{BTU}{KW \cdot Hr}$ = 27679 BTU
Energy Collected	484195 BTU
Total	511874 BTU

B. TOTAL ENERGY UTILIZED

Storage To Load	34738 BTU
Collector To Load	163808 BTU
Collector To Storage*	161479 BTU
QH/Water	35447 BTU
Total	395472 BTU

$$\text{*where } Q_{storage} = \left(\frac{\overline{W600}+\overline{W601}}{2}\ \frac{ft}{min}\right)\left(2.18\ ft^2\right)\left(t\ Hr\right)\left(60\ \frac{min}{hr}\right)\left(.071\ \frac{lb}{ft^3}\right)\left(.24\ \frac{BTU}{lb \cdot {}^\circ F}\right)\left(\Delta T_{stor.}\ {}^\circ F\right)$$

$$\frac{\text{TOTAL B}}{\text{TOTAL A}} = 0.77$$

QH/Water Load*	1.	5380 BTU
	2.	1853 BTU
	3.	2893 BTU
	4.	5708 BTU
Total For Day		15834 BTU

$$\text{*where } Q_{H/Water} = \left(\overline{W301}\ \frac{gal}{min}\right)\left(1.7\ min\right)\left(8.33\ \frac{lb}{gal}\right)\left(1.0\ \frac{BTU}{lb \cdot {}^\circ F}\right)\left(\overline{TD301}\ {}^\circ F\right)$$

TABLE III

TEST RESULTS

DATE 9/2/77   TEST IDENTIFICATION NORMAL OPERATION WINTER MODE

A. TOTAL ENERGY SUPPLIED

Power Consumption 7.31 KW·Hr x 3413 $\frac{BTU}{KW \cdot Hr}$ =	24949 BTU
Energy Collected	187458 BTU
Total	212407 BTU

B. TOTAL ENERGY UTILIZED

Storage To Load	13540 BTU
Collector To Load	70936 BTU
Collector To Storage*	101159 BTU
Q H/Water	16406 BTU
Total	202041 BTU

$$*\text{where } Q_{storage} = \left(\frac{\overline{W600}+\overline{W601}}{2}\ \frac{ft}{min}\right)\left(2.18\ ft^2\right)\left(t\ Hr\right)\left(60\ \frac{min}{hr}\right)\left(.071\ \frac{lb}{ft^3}\right)\left(.24\ \frac{BTU}{lb\cdot{}^\circ F}\right)\left(\Delta T_{stor.}\ {}^\circ F\right)$$

$\frac{\text{TOTAL B}}{\text{TOTAL A}}$ = 0.95

Q H/Water Load*

1.	2573	BTU
2.	1765	BTU
3.	2660	BTU
4.		BTU
Total For Day	6998	BTU

$$*\text{where } Q_{H/Water} = \left(\overline{W301}\ \frac{gal}{min}\right)\left(1.7\ min\right)\left(8.33\ \frac{lb}{gal}\right)\left(1.0\ \frac{BTU}{lb\cdot{}^\circ F}\right)\left(\overline{TD301}\ {}^\circ F\right)$$

TABLE IV

TEST RESULTS

DATE 9/6/77 TEST IDENTIFICATION NORMAL OPERATION WINTER MODE

A. TOTAL ENERGY SUPPLIED

Power Consumption	4.83 KW·Hr x 3413 $\frac{BTU}{KW \cdot Hr}$ =	16485 BTU
Energy Collected		28087 BTU
Total		44572 BTU

B. TOTAL ENERGY UTILIZED

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Storage To Load	33637 BTU
Collector To Load	13751 BTU
Collector To Storage*	1542 BTU
QH/Water	3161 BTU
Total	52091 BTU

*where $Q_{storage} = \left(\frac{\overline{W600}+\overline{W601}}{2}\ \frac{ft}{min}\right)\left(2.18\ ft^2\right)\left(t\ Hr\right)\left(60\ \frac{min}{hr}\right)\left(.071\ \frac{lb}{ft^3}\right)\left(.24\ \frac{BTU}{lb \cdot °F}\right)\left(\Delta T_{stor.}\ °F\right)$

$\frac{TOTAL\ B}{TOTAL\ A}$ = 1.17 *NOTE: BECAUSE OF LOW SOLAR FLUX LEVEL THERMAL ENERGY STORED FROM PREVIOUS DAYS WAS DEPLETED.

QH/Water Load*	1.	705 BTU
	2.	737 BTU
	3.	267 BTU
	4.	649 BTU
Total For Day		1660 BTU

*where $Q_{H/Water} = \left(\overline{W301}\ \frac{gal}{min}\right)\left(1.7\ min\right)\left(8.33\ \frac{lb}{gal}\right)\left(1.0\ \frac{BTU}{lb \cdot °F}\right)\left(\overline{TD301}\ °F\right)$

TABLE V

TEST RESULTS

DATE 9/8/77 TEST IDENTIFICATION NORMAL OPERATION WINTER MODE

A. TOTAL ENERGY SUPPLIED

Power Consumption 6.44 KW·Hr x 3413 $\frac{BTU}{KW \cdot Hr}$ =	21980 BTU
Energy Collected	176428 BTU
Total	198408 BTU

B. TOTAL ENERGY UTILIZED

Storage To Load	10386 BTU
Collector To Load	35057 BTU
Collector To Storage*	98565 BTU
QH/Water	17326 BTU
Total	161334 BTU

$$*\text{where } Q_{storage} = \left(\frac{\overline{W600}+\overline{W601}}{2}\ \frac{ft}{min}\right)\left(2.18\ ft^2\right)\left(t\ Hr\right)\left(60\ \frac{min}{hr}\right)\left(.071\ \frac{lb}{ft^3}\right)\left(.24\ \frac{BTU}{lb \cdot °F}\right)\left(\Delta T_{stor.}\ °F\right)$$

$\frac{\text{TOTAL B}}{\text{TOTAL A}}$ = 0.81

QH/Water Load*	1.	905 BTU
	2.	451 BTU
	3.	1318 BTU
	4.	2973 BTU
Total For Day		5647 BTU

$$*\text{where } Q_{H/Water} = \left(\overline{W301}\ \frac{gal}{min}\right)\left(1.7\ min\right)\left(8.33\ \frac{lb}{gal}\right)\left(1.0\ \frac{BTU}{lb \cdot °F}\right)\left(\overline{TD301}\ °F\right)$$

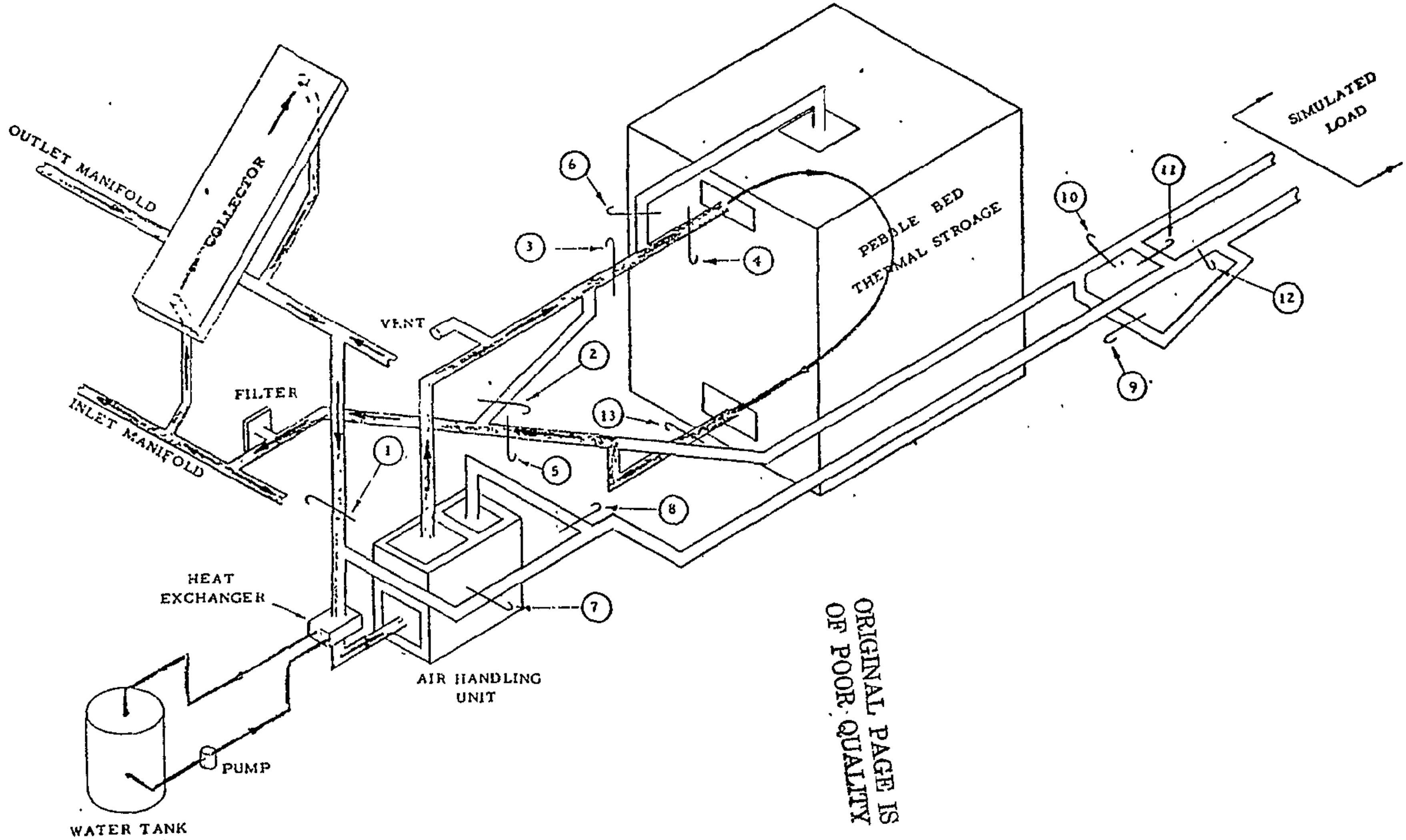

Figure C1. System 1B Flow Schematic for Winter Mode, Collector to Storage

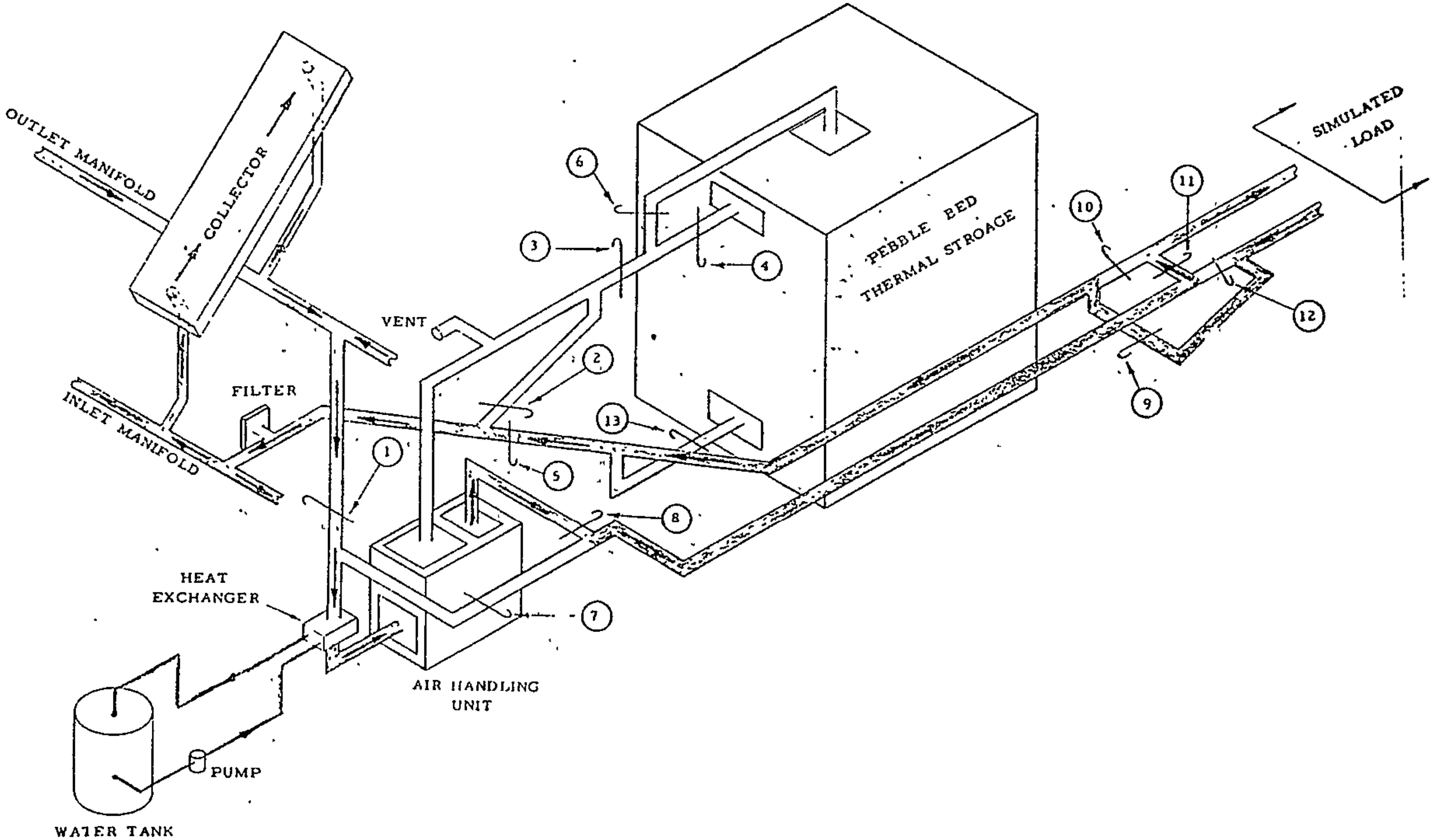

Figure C2. System 1B Flow Schematic for Winter Mode Collector to Load

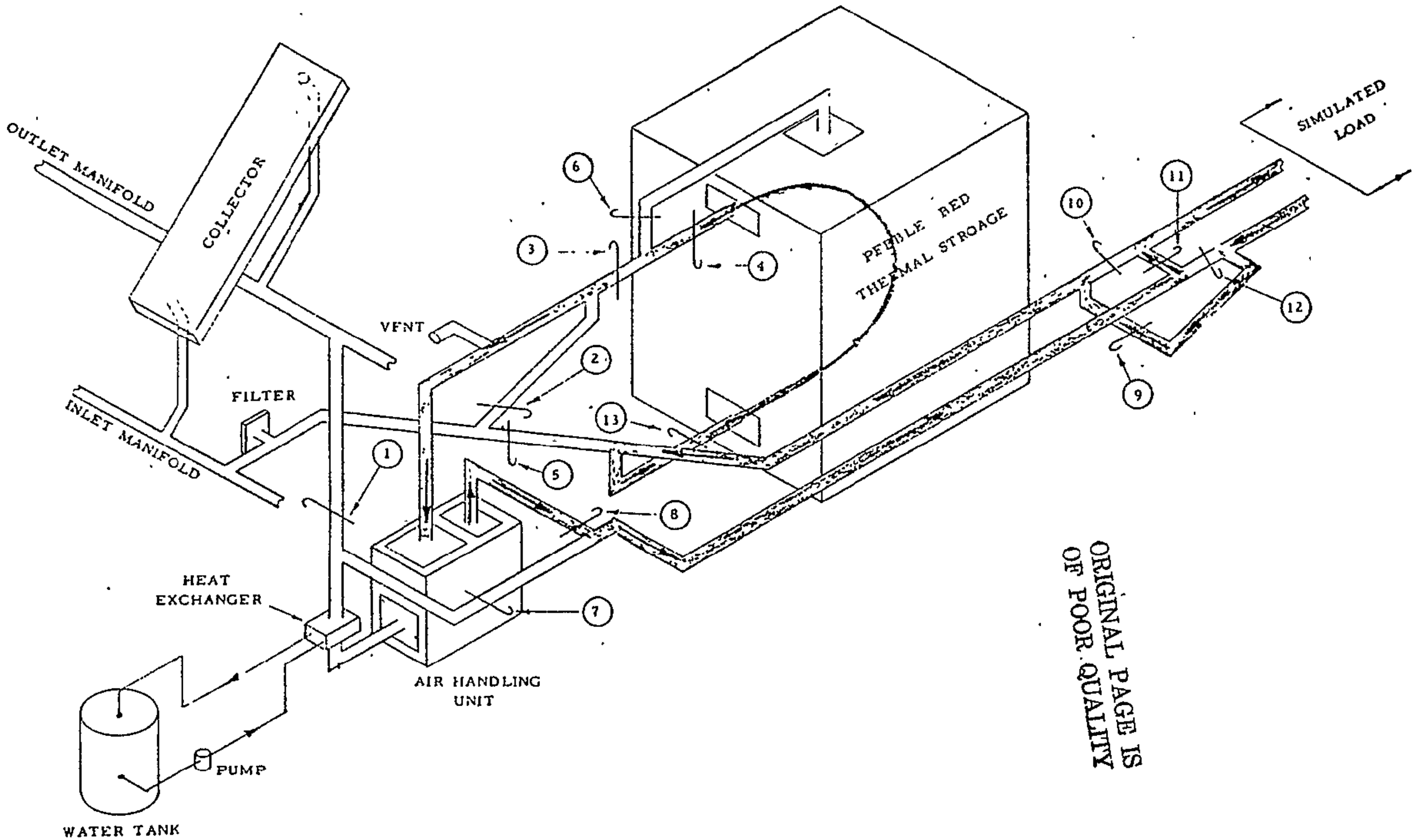

Figure C-3. System 1B Flow Schematic for Winter Mode Storage to Load

1.0 - 5.0 SEE APPENDIX A

6.0 TEST REQUIREMENTS AND PROCEDURES

6.1 System Test, Summer Operation

Started: 9 September 77
Completed: 15 September 77

6.1.1 Performance Criteria Requirements

The prototype System 1B shall be operated in the normal summer mode. While operating in this mode, periodic demands will be made on the hot water subsystem.

The primary objective of this test is to obtain as much actual operating data as possible from prototype System 1B prior to its installation at the demonstration site.

During the system test, complete weather records will be kept. These will include total solar radiation, ambient temperatures, wind speed and direction, relative humidity, barometric pressure and cloud cover. In addition, the prototype System 1B will be monitored to provide the following data:

- The total energy collected by the system per day.
- The total energy supplied to the domestic hot water subsystem.
- The total power required to operate the system per day.
- The systems' control functions (manual observation)

6.1.2 Test Summary, Summer Operation

The random weather conditions test consisted of running the system in its normal operation. The summer condition consists of a collector to hot water mode, a collector to storage mode and an attic vent mode.

The summer condition was primarily concerned with heating the domestic hot water system, keeping high stagnation temperatures off of the collectors, and charging storage perhaps to handle the lighter load requirements occurring in spring and autumn.

The collector to hot water mode (Figure D-1) is a short closed loop configuration that occurred when the collector temperature is higher than the outlet temperature of the preheat tank. Air was circulated from the collectors through the air to water heat exchanger and back to the collectors.

The collector to storage mode (Figure D-2) differs from the same configuration in the winter condition only in control logic. The summer operation version of this mode only occurred when the collector temperature is greater than the outlet temperature of

6.1.2 Test Summary, Outside Weather Conditions (Continued)

the preheat tank. The primary purpose, therefore, was to heat the domestic water system with any residual heat being used to charge the rock storage bed. The air was circulated from the collectors, across the heat exchanger, and through the rock storage bed. This left the storage charged to a lower temperature than in the winter condition but sufficient for the lighter load requirements of spring and autumn.

The final summer condition mode was the attic vent mode (Figure D-3) In this mode air was circulated through the collectors, when the collectors reached a predetermined temperature, to avoid a high temperature stagnation condition. Air was drawn from an open attic vent and circulated across the hot water system heat exchanger before being dumped back to the atmosphere. If the collector yemperature was greater than the outlet of the preheat tank the water system pump was energized to allow for charging of the water.

1. To run the system in its normal operation summer conditions without storage
   - Open dampers nos 1, 2
   - Close dampers nos 3, 4, 5, 6, 7, 8, 9, 10, 11 ,12, 13
2. Energize system.
3. Turn hot water pump control to auto.
4. Put control system switches to heat pump and T_{CO}-OFF.
5. Put switch on top of air handler to S.
6. Every two (2) hours draw twelve (12) gallons of water from the hot water system.
7. Deactiviate the entire system at the end of the day.
8. Throughout the systems' operation data will be collected on the data system in Building 4646.

1. To run the system in its normal operation summer conditions with storage.
   - Open dampers nos 1, 2, 3, 4, 5, 13
   - Close dampers nos 6, 7, 8, 9, 10, 11, 12
2. Energize the system.

6.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

6.1.2 Test Summary, Outside Weather Conditions (Continued)

3. Turn hot water pump control to auto.

4. Put control switches to heat pump and T_{CO}-OFF.

5. Put switch on top of air handler to S.

6. Every two (2) hours draw twelve (12) gallons of water from the hot water system.

7. Deactivate the entire system at the end of the day.

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

1. To run the system in its normal operation, summer conditions attic vent

   - Open damper no 1

   - Close dampers nos 2 through 13

2. Remove vent covers from attic inlet and outlet vent.

3. Energize the system.

4. Turn hot water pump control to Auto.

5. Put control switches to heat pump and T_{CO}-ON.

6. Put switch on top of air handler to S.

7. Every two (2) hours draw twelve (12) gallons of water from the hot water system.

8. Deactivate the entire system at the end of the day.

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

6.1.3 Test Results

The summer mode tests were run subject to ambient conditions. The weather conditions during these tests were mostly sunny with occasional partly cloudy skies.

It was the intention to draw a load on the system when it was in the configuration that charges the storage bed. This was to evaluate the possibility of using the summer mode configuration with storage to meet the heating loads that would occur in the spring

6.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

6.1.3 Test Results (Continued)

or autumn. However, the present system controls would not allow a load to be put on the system, therefore, this evaluation was not possible.

All 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.

TABLE I

PARAMETERS MEASURED DURING SYSTEM TESTING

Measurement	Parameter
Solar radiation	BTU/Hr/Ft^2 vs. time of day in hrs.
Wind speed/direction	MPH/direction vs. time of day (hrs)
Relative humidity	% vs. time of day in hours
Relative Humidity, storage bottom	% vs. time of day in hours
Relative humidity, storage top	% vs. time of day in hours
Storage delta temperature	°F vs. time of day in hours
Hot water heat exchanger delta temperature, air side	°F vs. time of day in hours
Hot water heat exchanger delta temperature, liquid side	°F vs. time of day in hours
Domestic water heater, city water inlet to discharge delta temperature	°F vs. time of day in hours
Delta temperature across load	°F vs. time of day in hours
Ambient temperature	°F vs. time of day in hours
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
Storage inlet temperature	°F vs. time of day in hours
Storage outlet temperature	°F vs. time of day in hours
(3) Internal storage temperature	°F vs. time of day in hours
System air inlet temperature to load	°F vs. time of day in hours
System air outlet temperature from load	°F vs. time of day in hours
Hot water coil inlet temperature (water)	°F vs. time of day in hours
Hot water preheat tank temperature	°F vs. time of day in hours
City water supply temperature to hot water subsystem	°F vs. time of day in hours
Hot water system outlet temperature	°F vs. time of day in hours
System temporary shelter temperature	°F vs. time of day in hours
Air flow velocity through collectors	Ft/min. vs. time of day in hours
Air flow velocity through storage	Ft/min. vs. time of day in hours
Air flow velocity through load	Ft/min. vs. time of day in hours
Liquid flow hot water load	GPM vs. time of day in hours
Liquid flow, hot water subsystem	GPM vs. time of day in hours
System blower power	Watts vs. time of day in hours
Hot water subsystem power	Watts vs. time of day in hours
Storage delta pressure	In. H_2O vs. time of day in hours
Collector delta pressure	In. H_2O vs. time of day in hours

TABLE II

TEST RESULTS

DATE 9/9/77 TEST IDENTIFICATION NORMAL OPERATION Summer mode w/o STORAGE

A. TOTAL ENERGY SUPPLIED

Power Consumption	5.70 KW-Hr x 3413 $\frac{BTU}{KW \cdot Hr}$ =	19454 BTU
Energy Collected		53337 BTU
Total		72791 BTU

B. TOTAL ENERGY UTILIZED

Storage To Load	10386 BTU	
Collector To Load	4857 BTU	
Collector To Storage*	10301 BTU	
QH/Water	35162 BTU	(A)
Total	60706 BTU	

$$\text{*where } Q_{storage} = \left(\frac{\overline{W600}+\overline{W601}}{2}\ \frac{ft}{min}\right)\left(2.18\ ft^2\right)\left(t\ Hr\right)\left(60\ \frac{min}{hr}\right)\left(.071\ \frac{lb}{ft^3}\right)\left(.24\ \frac{BTU}{lb\cdot°F}\right)\left(\Delta T_{stor.}\ °F\right)$$

$\frac{\text{TOTAL B}}{\text{TOTAL A}}$ = 0.83

QH/Water Load* (A)

1.	3389	BTU
2.	3979	BTU
3.	2912	BTU
4.		BTU
Total For Day	10280	BTU

$$\text{*where } Q_{H/Water} = \left(\overline{W301}\ \frac{gal}{min}\right)\left(1.7\ min\right)\left(8.33\ \frac{lb}{gal}\right)\left(1.0\ \frac{BTU}{lb\cdot°F}\right)\left(\overline{TD301}\ °F\right)$$

TABLE III

TEST RESULTS

DATE 9/12/77 TEST IDENTIFICATION NORMAL OPERATION Summer mode w/STORAGE

A. TOTAL ENERGY SUPPLIED

Power Consumption	7.16 KW·Hr x 3413 $\frac{BTU}{KW \cdot Hr}$ =	24437 BTU
Energy Collected		394000 BTU
Total		418437 BTU

B. TOTAL ENERGY UTILIZED

Storage To Load	___ BTU	
Collector To Load	___ BTU	
Collector To Storage*	320500 BTU	
QH/Water	49687 BTU	(A)
Total	370187 BTU	

*where $\dot{Q}_{storage} = \left(\frac{\overline{W600}+\overline{W601}}{2}\ \frac{ft}{min}\right)\left(2.18\ ft^2\right)\left(t\ Hr\right)\left(60\ \frac{min}{hr}\right)\left(.071\ \frac{lb}{ft^3}\right)\left(.24\ \frac{BTU}{lb \cdot {}^\circ F}\right)\left(\Delta T_{stor.}\ {}^\circ F\right)$

$\frac{TOTAL\ B}{TOTAL\ A}$ = 0.88

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QH/Water Load*	1.	3556 BTU	(A)
	2.	3302 BTU	
	3.	5529 BTU	
	4.	5923 BTU	
Total For Day		18310 BTU	

*where $Q_{H/Water} = \left(\overline{W301}\ \frac{gal}{min}\right)\left(1.7\ min\right)\left(8.33\ \frac{lb}{gal}\right)\left(1.0\ \frac{BTU}{lb \cdot {}^\circ F}\right)\left(\overline{TD301}\ {}^\circ F\right)$

TABLE IV

TEST RESULTS

DATE 9/13/77 TEST IDENTIFICATION NORMAL OPERATION summer mode w/STORAGE

A. TOTAL ENERGY SUPPLIED

Power Consumption 3.73 KW·Hr x 3413 $\frac{BTU}{KW \cdot Hr}$ = 12730 BTU

Energy Collected 149630 BTU

Total 162360 BTU

B. TOTAL ENERGY UTILIZED

Storage To Load ___ BTU

Collector To Load ___ BTU

Collector To Storage* 117440 BTU

QH/Water 17290 BTU (A)

Total 134730 BTU

*where $Q_{storage} = \left(\frac{\overline{W600}+\overline{W601}}{2}\ \frac{ft}{min}\right)\left(2.18\ ft^2\right)\left(t\ Hr\right)\left(60\ \frac{min}{hr}\right)\left(.071\ \frac{lb}{ft^3}\right)\left(.24\ \frac{BTU}{lb \cdot {}^\circ F}\right)\left(\Delta T_{stor.}\ {}^\circ F\right)$

$\frac{\text{TOTAL B}}{\text{TOTAL A}}$ = 0.83

QH/Water Load* 1. ___ BTU (A)

2. ___ BTU

3. ___ BTU

4. ___ BTU

Total For Day 12110 BTU

*where $Q_{H/Water} = \left(\overline{W301}\ \frac{gal}{min}\right)\left(1.7\ min\right)\left(8.33\ \frac{lb}{gal}\right)\left(1.0\ \frac{BTU}{lb \cdot {}^\circ F}\right)\left(\overline{TD301}\ {}^\circ F\right)$

TABLE V

TEST RESULTS

DATE 9/14/77 TEST IDENTIFICATION NORMAL OPERATION
summer mode w/o STORAGE

A. TOTAL ENERGY SUPPLIED

Power Consumption	5.72 KW·Hr x 3413 $\frac{BTU}{KW \cdot Hr}$ = 19522 BTU
Energy Collected	83429 BTU
Total	102951 BTU

B. TOTAL ENERGY UTILIZED

Storage To Load	___ BTU
Collector To Load	___ BTU
Collector To Storage*	___ BTU
QH/Water	50338 BTU Ⓐ
Total	50338 BTU

*where $Q_{storage} = \left(\frac{\overline{W600}+\overline{W601}}{2} \frac{ft}{min}\right)\left(2.18\ ft^2\right)\left(t\ Hr\right)\left(60\ \frac{min}{hr}\right)\left(.071\ \frac{lb}{ft^3}\right)\left(.24\ \frac{BTU}{lb \cdot {}^\circ F}\right)\left(\Delta T_{stor.}\ {}^\circ F\right)$

$\frac{\text{TOTAL B}}{\text{TOTAL A}}$ = 0.49

QH/Water Load*	1.	4730 BTU
	2.	2530 BTU
	3.	3964 BTU
	4.	5341 BTU
Total For Day		16565 BTU

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*where $Q_{H/Water} = \left(\overline{W301}\ \frac{gal}{min}\right)\left(1.7\ min\right)\left(8.33\ \frac{lb}{gal}\right)\left(1.0\ \frac{BTU}{lb \cdot {}^\circ F}\right)\left(\overline{TD301}\ {}^\circ F\right)$

TABLE VI

TEST RESULTS

DATE 9/15/77 TEST IDENTIFICATION NORMAL OPERATION ATTIC VENT MODE

A. TOTAL ENERGY SUPPLIED

Power Consumption	6.32 KW·Hr x 3413 $\frac{BTU}{KW \cdot Hr}$ =	21570 BTU
Energy Collected		21244 BTU
Total		42814 BTU

B. TOTAL ENERGY UTILIZED

Storage To Load	___ BTU	
Collector To Load	___ BTU	
Collector To Storage*	___ BTU	
QH/Water	26498 BTU	(A)
Total	26498 BTU	

*where $Q_{storage} = \left(\frac{W600+W601}{2}\ \frac{ft}{min}\right)\left(2.18\ ft^2\right)\left(t\ Hr\right)\left(60\ \frac{min}{hr}\right)\left(.071\ \frac{lb}{ft^3}\right)\left(.24\ \frac{BTU}{lb \cdot {}^\circ F}\right)\left(\Delta T_{stor.}\right)$

$\frac{\text{TOTAL B}}{\text{TOTAL A}}$ = 0.62

QH/Water Load*	1.	6635 BTU	(A)
	2.	3372 BTU	
	3.	4137 BTU	
	4.	4398 BTU	
Total For Day		18542 BTU	

*where $Q_{H/Water} = \left(W301\ \frac{gal}{min}\right)\left(1.7\ min\right)\left(8.33\ \frac{lb}{gal}\right)\left(1.0\ \frac{BTU}{lb \cdot {}^\circ F}\right)\left(TD301\ {}^\circ F\right)$

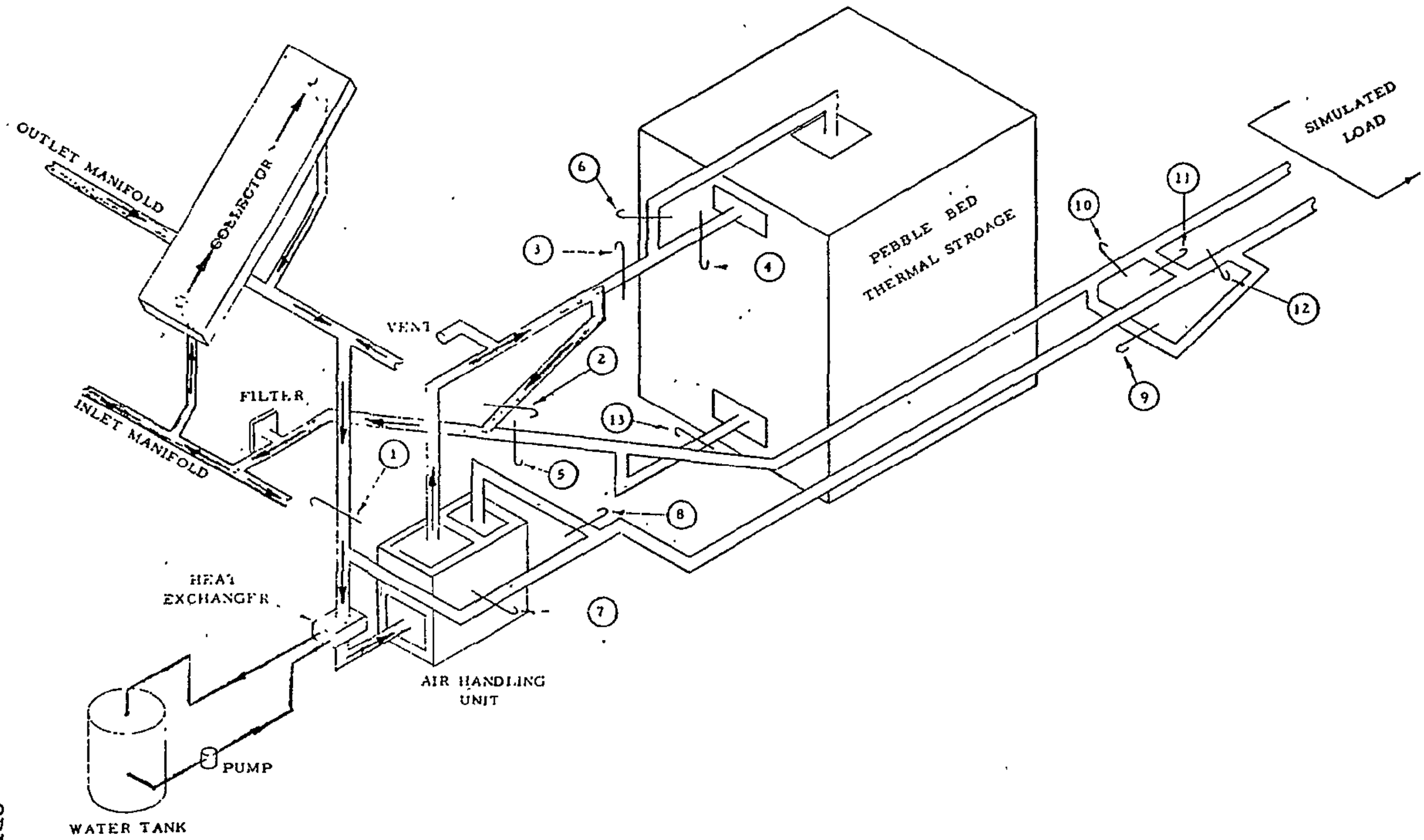

Figure D-1. System 1B Flow Schematic for Operational Test - Summer Mode

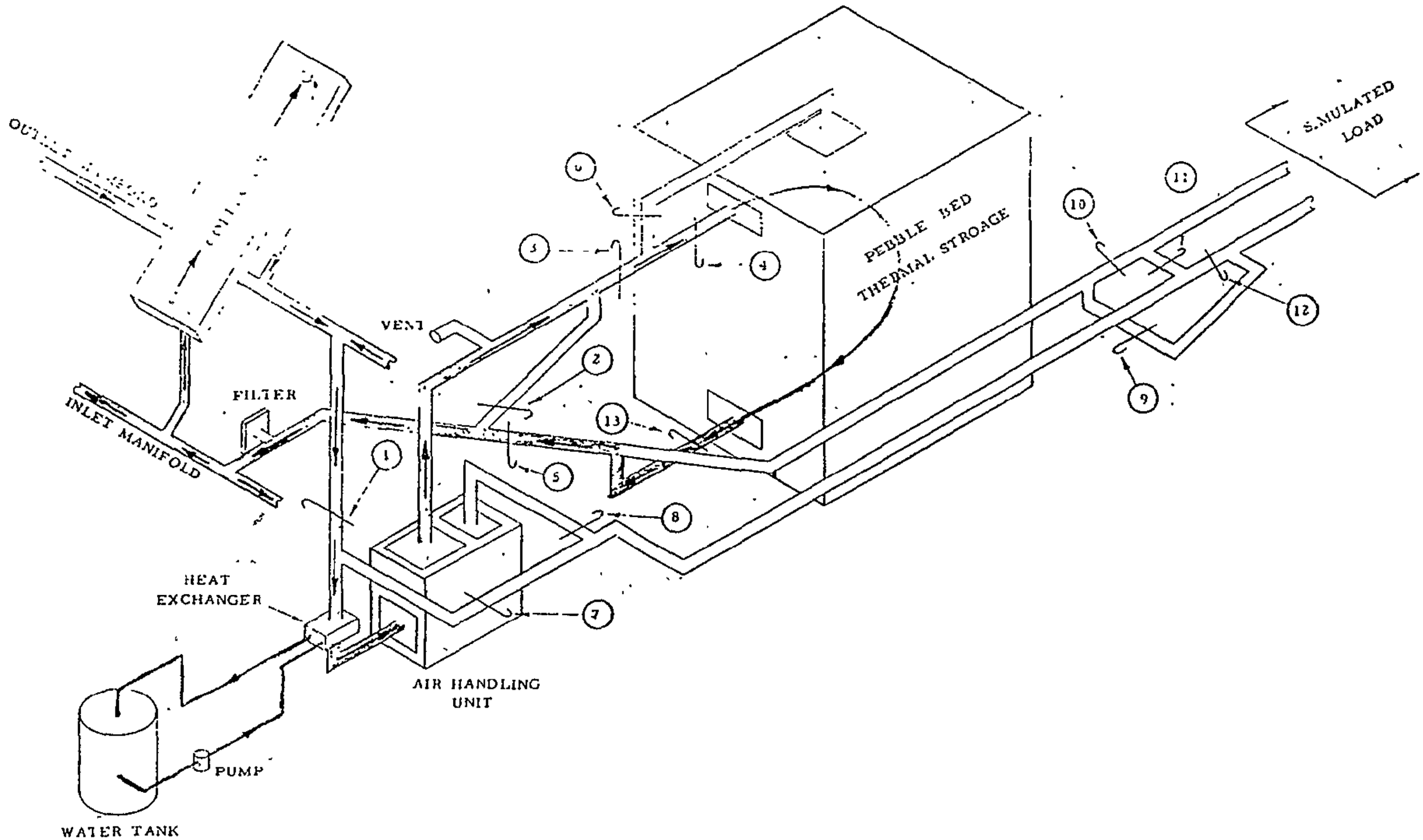

Figure D-2. System 1B Flow Schematic for Operational Tests in Collector to Storage Mode

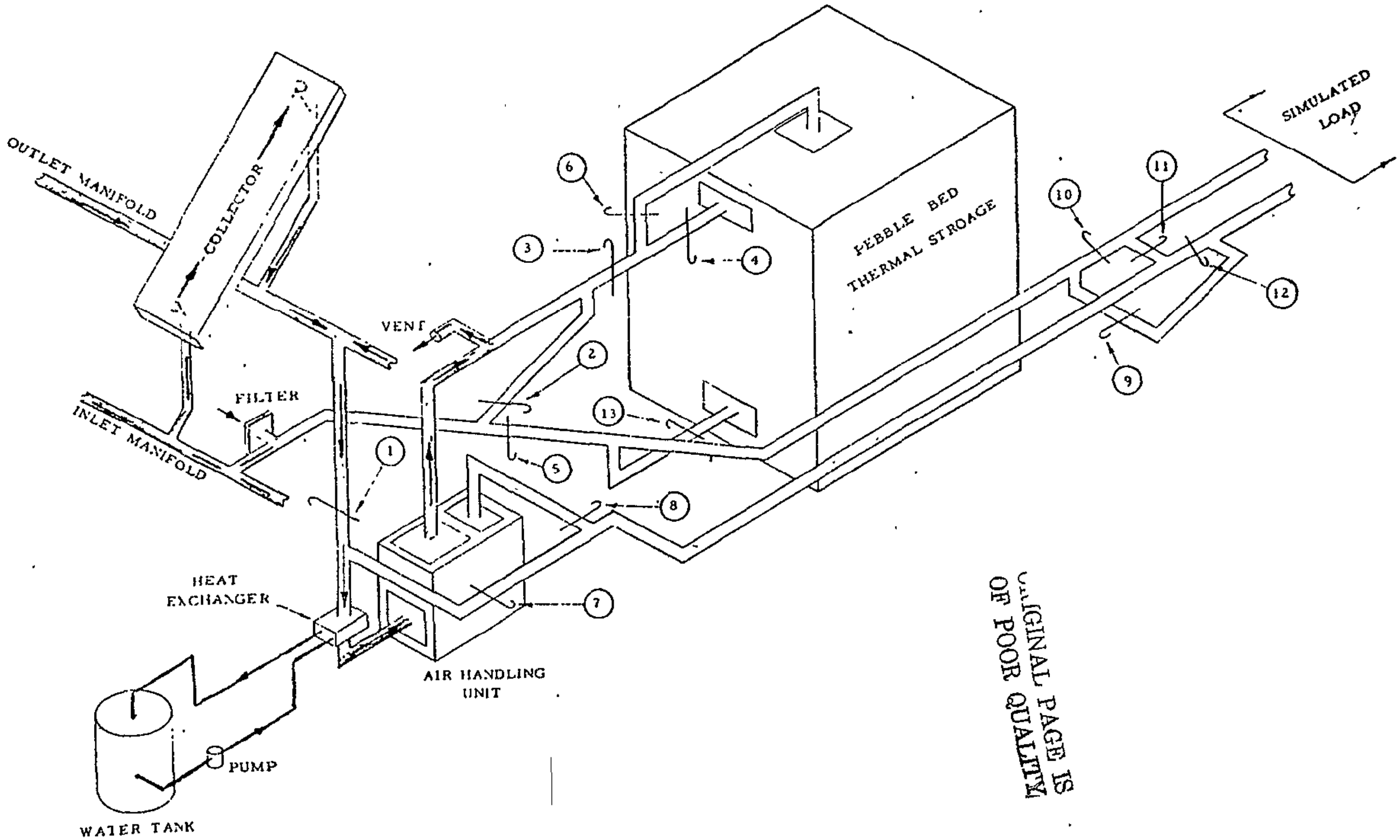

Figure D-3. System 1B Flow Schematic for Operational Tests in Attic Vent Mode

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