DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-161165

VERIFICATION TEST REPORT ON A SOLAR HEATING AND HOT WATER SYSTEM

Prepared by

Colt, Inc.
71-590 San Jacinto Drive
Rancho Mirage, CA 92270

Under Contract NAS8-32242 with

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

For the Department of Energy

(NASA-CR-161165) VERIFICATION TEST REPORT ON A SOLAR HEATING AND HOT WATER SYSTEM (Colt, Inc. of Southern California) 60 p HC A04/MF A01 CSCL 10A

N79-20493

Unclas
G3/44 17279

U.S. Department of Energy

Solar Energy

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.
DOE/NASA CR-161165

2. GOVERNMENT ACCESSION NO.

3. RECIPIENT'S CATALOG NO.

4. TITLE AND SUBTITLE
Verification Test Report on a Solar Heating and Hot Water System

5. REPORT DATE
July 21, 1978

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)

8. PERFORMING ORGANIZATION REPORT #

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Colt, Inc.
71-590 San Jacinto Drive
Rancho Mirage, CA 92270

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.
NAS8-32242

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. Mitchell Cash, George C. Marshall Space Flight Center, Alabama.

16. ABSTRACT

This document provides information on the development, qualification and acceptance verification of Colt, Inc. commercial solar heating and hot water systems and components. The verification includes the performances, the efficiencies and the various methods used, such as similarity, analysis, inspection, test, etc., that are applicable to satisfying the verification requirements.

Colt, Incorporated of Southern California has developed two commercial solar heating and hot water systems. The systems have been installed at Yosemite National Park, California, and Pueblo, Colorado. The systems consist of the following subsystems: collector, storage, transport, hot water, auxiliary energy, and controls.

17. KEY WORDS

18. DISTRIBUTION STATEMENT UC-59c
Unclassified-Unlimited

William A. Brooksbank Jr.
WILLIAM A. BROOKSBANK, JR.
Mgr, Solar Heating and Cooling Project Office

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	58	NTIS

MSFC - Form 3292 (Rev. December 1972)

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

CONTENTS

CONTENTS

TABLES, FIGURES, EXHIBITS

TABLES

FIGURES

EXHIBITS

INTRODUCTION

The verification test report is submitted as part of the Verification Plan, SHC 3024, submitted as part of NASA contract, NAS 8-32242, with Colt Inc. of Southern California, Energy Systems Division. Verification phase of this contract is divided into three sections: Development, Qualification and Acceptance. The Development and Qualification phases have been completed at the Colt Inc. Solar Test Facility located in Rancho Mirage, California. Acceptance is conducted at each of two Operational Test Sites, installed also as part of NAS 8-32242. The Operational Test Sites are located on an administration building at the Department of Transportation, Amtrac Highspeed Test Facility, located in Pueblo, Colorado, and also on the Visitors Center at the Yosemite National Park in California. These installations provide solar space heating with domestic water heating at the Pueblo Operational Test Site, and provisions for future domestic water heating at the Yosemite Operational Test Site. Each installation utilizes solar panels developed by Colt Inc. of Southern California.

The Colt solar panel has been designed from research and development conducted at the Los Alamos Scientific Laboratories in Los Alamos, New Mexico. As a result of approximately four years of Los Alamos technology, a highly efficient solar panel was developed utilizing a seam welded, pressure expanded, dual sheet, steel, flat plate absorber, coated with black chrome on a dull nickel substrate. This solar panel is being utilized at the Los Alamos Scientific Laboratories' new National Security and Resources Study Center. However, this solar collector panel proved to be costly to manufacture, and suppliers of primary components were not able to provide the same components on a production basis. At this time, during the beginning of the design phase, Colt modified the design to meet production limitations. Through intensive research, development and design, essential components of this steel panel were redesigned to allow for efficient production-line manufacture. Components for twenty two of these solar panels were purchased and assembled at Colt's Rancho Mirage test facility. Nineteen have been installed on the facility roof as part of the Development and Qualification Phase for the solar space and domestic hot water heating system tests.

The steel panel proved to be ineffective for two reasons: first, the panel weight was excessive. Each panel weighed 225 pounds, dry, and proved to be cumbersome and difficult to install on angled and elevated positions. Second, assembly and fabrication costs were higher than the solar market could tolerate. The retail price of this panel would have to be approximately $25.00 to $28.00 a square foot. For these reasons, Colt elected to retain the closed loop technology utilizing oil as the heat transfer fluid but redesign the solar panel using aluminum as the main structural element and for the absorber plate. The resulting design is today's production panel, which includes housing walls fabricated from 6063-T5 anodized aluminum extrusions. The absorber plate is an Olin Brass, Roll-Bond® aluminum plate, selectively coated with Caldwell Solar-sorb paint, C 10773/66. Fully assembled, the aluminum panel weighs 93 pounds, and can be retailed for $10.00 to $11.00 per square foot. Quantity production and automation of fabrication processes are expected to reduce these costs in the future.

The original scope of the contract called for Colt to assemble and install only three solar panels to conduct the Development phase testing with the plan that panels would be added or replaced, as required to utilize the Colt building as an Operational Test Site. It was subsequently decided to install all nineteen panels during Development and Qualification, to obtain full system test results. A decision was made later, by NASA, that the Colt facility would not be one of the two Operational Test Sites. The Acceptance phase will be concluded by analysis of the data collected from each of these Operational Test Sites.

A simplified Heating and Hot Water System Schematic is presented in Figure 1. The Verification Cross-Reference Matrix indicating Response Page Number is given as Figure 2.

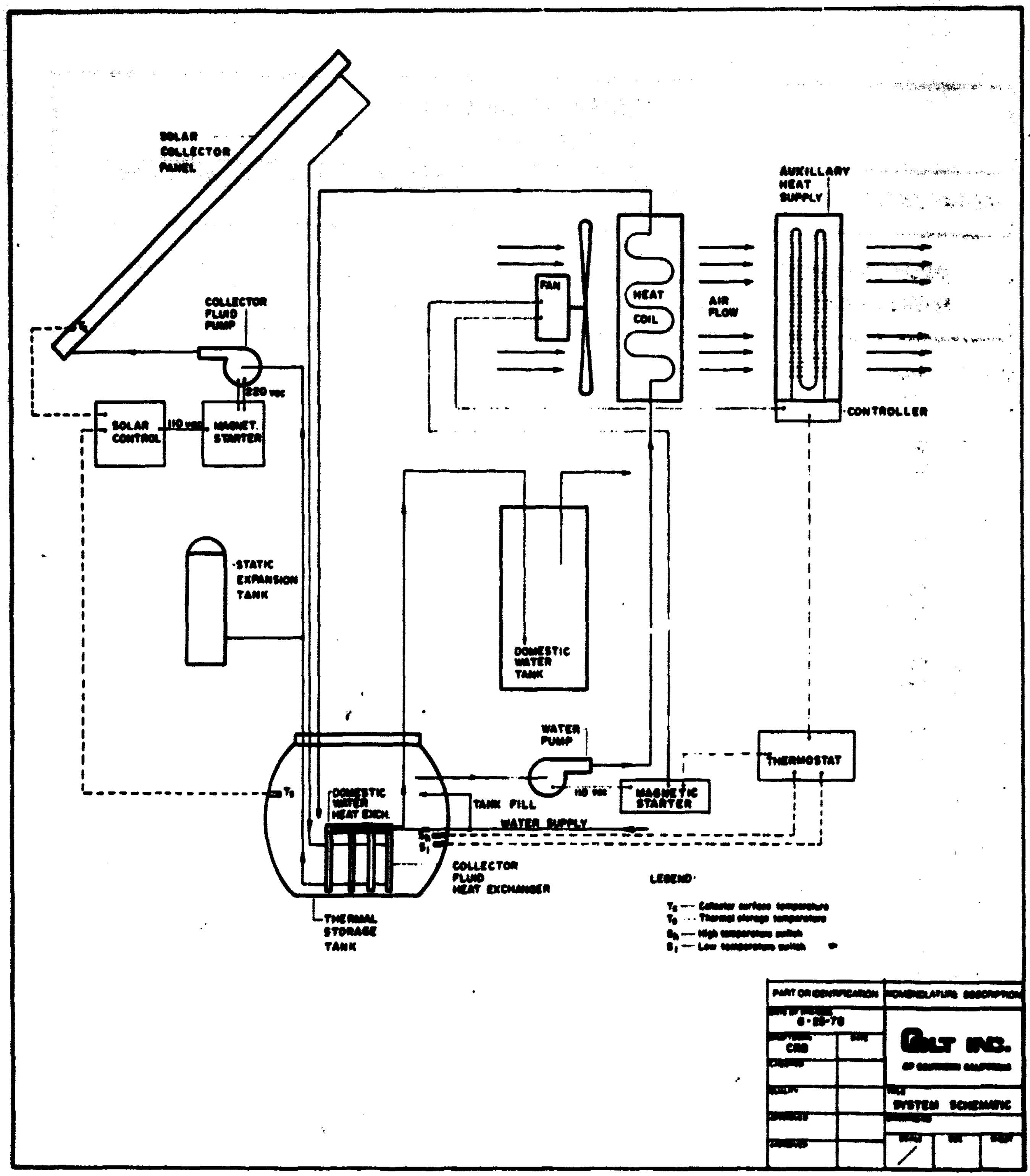

SOLAR COLLECTOR PANEL
COLLECTOR FLUID PUMP
220 VAC
SOLAR CONTROL
110 VAC
MAGNET. STARTER
STATIC EXPANSION TANK
FAN
HEAT COIL
AIR FLOW
AUXILLARY HEAT SUPPLY
CONTROLLER
DOMESTIC WATER TANK
WATER PUMP
110 VAC
MAGNETIC STARTER
THERMOSTAT
DOMESTIC WATER HEAT EXCH.
TANK FILL
WATER SUPPLY
COLLECTOR FLUID HEAT EXCHANGER
THERMAL STORAGE TANK
LEGEND
Tc — Collector surface temperature
Ts — Thermal storage temperature
Sh — High temperature switch
Sl — Low temperature switch
PART OR IDENTIFICATION
NOMENCLATURE DESCRIPTION
SYSTEM SCHEMATIC

FIGURE I

FIGURE 2

VERIFICATION CROSS REFERENCE MATRIX

VERIFICATION METHOD: 1. SIMILARITY 2. ANALYSIS 3. INSPECTION 4. TEST N/A NOT APPLICABLE

PERFORMANCE REQUIREMENT	VERIFICATION PHASE			RESPONSE PAGE NO.
	Development	Qualification	Acceptance	
1.1 Heating System Performance	4	1	4	1
1.2 HW System/Sub-System Performance	4	1	4,3	2
1.3 Collector Performance	4	1	4	2
1.4 Tnermal Storage Performance	4	1	4,3	4
1.5 Habitability of Occupied Spaces	2	1	3	11
1.6 Energy Transport Efficiency	4	1	3	11
1.7 Control	4	1	4	19
1.8 Auxiliary Energy	4	1	4	19
2.1 Systems Design Conditions	4	1	3	21
2.2 Mechanical Stresses	4	1	3	22
2.3 Leakage Prevention	4	1	4	23
2.4 Collector Adjustment	2	1	3	23
2.5 Sub-System Isolation	2	1	3	24
2.6 Heat Transfer Fluid Quality	2,4	1	3	24
2.7 Piping Supports	1,2	1	3	25

FIGURE 2

VERIFICATION CROSS REFERENCE MATRIX

VERIFICATION METHOD: 1. SIMILARITY 2. ANALYSIS 3. INSPECTION 4. TEST N/A NOT APPLICABLE

PERFORMANCE REQUIREMENT	VERIFICATION PHASE			RESPONSE PAGE NO.
	Development	Qualification	Acceptance	
2.8 Excessive Pressure and Temperature Protection	2,4	1	4	25
3.1 Structural Design Basis	2	1	3	26
3.2 Failure Loads and Load Capacity	2	1	3	26
3.3 Damage Control	1	1	3	29
3.4 Cyclic Loads	2	1	3	29
3.5 Cutting of Structural Elements	NA	NA	NA	29
3.6 Creep and Residual Deflections	2	NA	NA	29
3.7 Hail Resistance	2	1	3	30
3.8 Constraint Loads	2	1	3	30
3.9 Ponding Conditions	2	1	3	30
4.1 Plumbing and Electrical Installation	2	1	3	31
4.2 Fail-Safe Controls	4	1	4	31
4.3 Fire Safety	2	1	3	32
4.4 Toxic and Flammable Fluids	2	1	3	32
4.5 Safety Under Emergency Conditions	2	1	3	32

FIGURE 2

VERIFICATION CROSS REFERENCE MATRIX				
VERIFICATION METHOD: 1. SIMILARITY 2. ANALYSIS 3. INSPECTION 4. TEST N/A NOT APPLICABLE				
PERFORMANCE REQUIREMENT	VERIFICATION PHASE			RESPONSE PAGE NO.
	Development	Qualification	Acceptance	
4.6 Protection of Water and Circulated Air	2	1	3	33
4.7 Excessive Surface Temperatures	2	1	3	33
5.1 Effects of External Environment	2	1	3	34
5.2 Temperature and Pressure Resistance	2	1	3	34
5.3 Chemical Compatibility of Components	2	1	3	35
5.4 Components Involving Moving Parts	2	1	3	35
6.1 Accessibility For Maintenance and Servicing	2	1	3	36
6.2 Installation, Operation and Maintenance Manual	2	1	3	36
6.3 Repair and Service Personnel	2	1	3	36
7.1 Design	NA	2	3	37
7.2 Adequate Space	NA	2	3	37
7.3 Functioning of Facility and Site	NA	2	3	37

FIGURE 2

VERIFICATION CROSS REFERENCE MATRIX				
VERIFICATION METHOD: 1. SIMILARITY 2. ANALYSIS 3. INSPECTION 4. TEST N/A NOT APPLICABLE				
PERFORMANCE REQUIREMENT	VERIFICATION PHASE			RESPONSE PAGE NO.
	Development	Qualification	Acceptance	
7.4 Compatibility with Conventional Systems	NA	2	3	38
8.1 Interference with Mechanical Operation	NA	2	3	39
8.2 Mechanical and Electrical Functioning of Facility and Site	NA	2	3	39
8.3 Mechanical and Electrical Functioning of Connections	NA	2	3	39
9.1 Structural Integrity of Heating Systems	NA	2	3	40
9.2 Structural Integrity of Facility	NA	2	3	40
9.3 Structural Connections	NA	2	3	40
10.1 Safety of Facility and Site	NA	2	3	41
11.1 Durability and Reliability of H and HW Systems	NA	2	3	42
11.2 Durability and Reliability of Facilities and Site	NA	4	3	42

FIGURE 2

VERIFICATION CROSS REFERENCE MATRIX

VERIFICATION METHOD: 1. SIMILARITY 2. ANALYSIS 3. INSPECTION 4. TEST N/A NOT APPLICABLE

PERFORMANCE REQUIREMENT	VERIFICATION PHASE			RESPONSE PAGE NO.
	Development	Qualification	Acceptance	
11.3 Durability and Reliability of Connections	NA	4	3	42
12.1 Maintainability of Heating Systems	NA	2	3	43
12.2 Maintainability of Facility and Site	NA	2	3	43
12.3 Connections	NA	2	3	43
13.1 Visual Characteristics of Facility and Site	NA	2	3	44

1.0 FUNCTION - SYSTEMS AND COMPONENTS

1.1 HEATING SYSTEM PERFORMANCE

Colt has defined the following set of operating criteria: for thermal storage temperatures 90°F and below, solar space heating is not possible; for thermal storage temperatures of 105°F and higher, auxiliary space heat is not required; for thermal storage tank temperatures of 90°F - 105°F auxiliary space heat is supplemented by a solar pre-heat.

The solar test facility is a 3200 square foot building. Reference to the ASHRAE standards set forth in the 1973 Systems Handbook, established 1800 cubic feet per minute as the optimum air flow rate through the system heat duct. Solar space heating results are presented in Table 1.1-A.

FLOW RATE GPM	STORAGE TANK TEMPERATURE °F	AIR TEMPERATURE RISE PER PASS °F
9.2	108	20.5
9.4	115	23.6
9.3	125	28.6
9.3	137	34.7
9.4	151	39.1
9.3	156	45.2
9.0	170	48.2

TABLE 1.1-A
SPACE HEATING SYSTEM PERFORMANCE

The Table presents the temperature rise through the liquid-to-air heat coil located in the system air duct for thermal storage tank temperatures. Figure 1.1-A illustrates space heating performance and efficiency. This data was collected as part of the "Transient Thermal Storage Tank Test", (see section 1.4). Qualification is given by similarity. Acceptance will be given by testing of the operational test site installation.

1.2 HOT WATER SYSTEM/SUB-SYSTEM PERFORMANCE

Domestic water is heated by means of a copper tube heat exchanger submerged in the thermal storage tank, placed in-line between the domestic water supplied from the city and the domestic water storage tank. A thermal storage tank temperature of 150°F was established as the base temperature to measure system performance. The results indicate a temperature rise of 71.6°F, yielding an average domestic water tank temperature of 140°F. Anticipated thermal storage tank temperatures will generally be greater than 150°F, and thus domestic water storage temperature can be expected to be greater than 140°F, necessitating the installation of a water temperature tempering valve. Qualification is given by similarity. Acceptance will be given by testing of the operational test site installation.

1.3 COLLECTOR PERFORMANCE

The collector design point was for a 15°F rise per pass through the collector bank at design flow rate. Performance results indicate a 24°F temperature rise at design flow rate of 19 GPM. This data

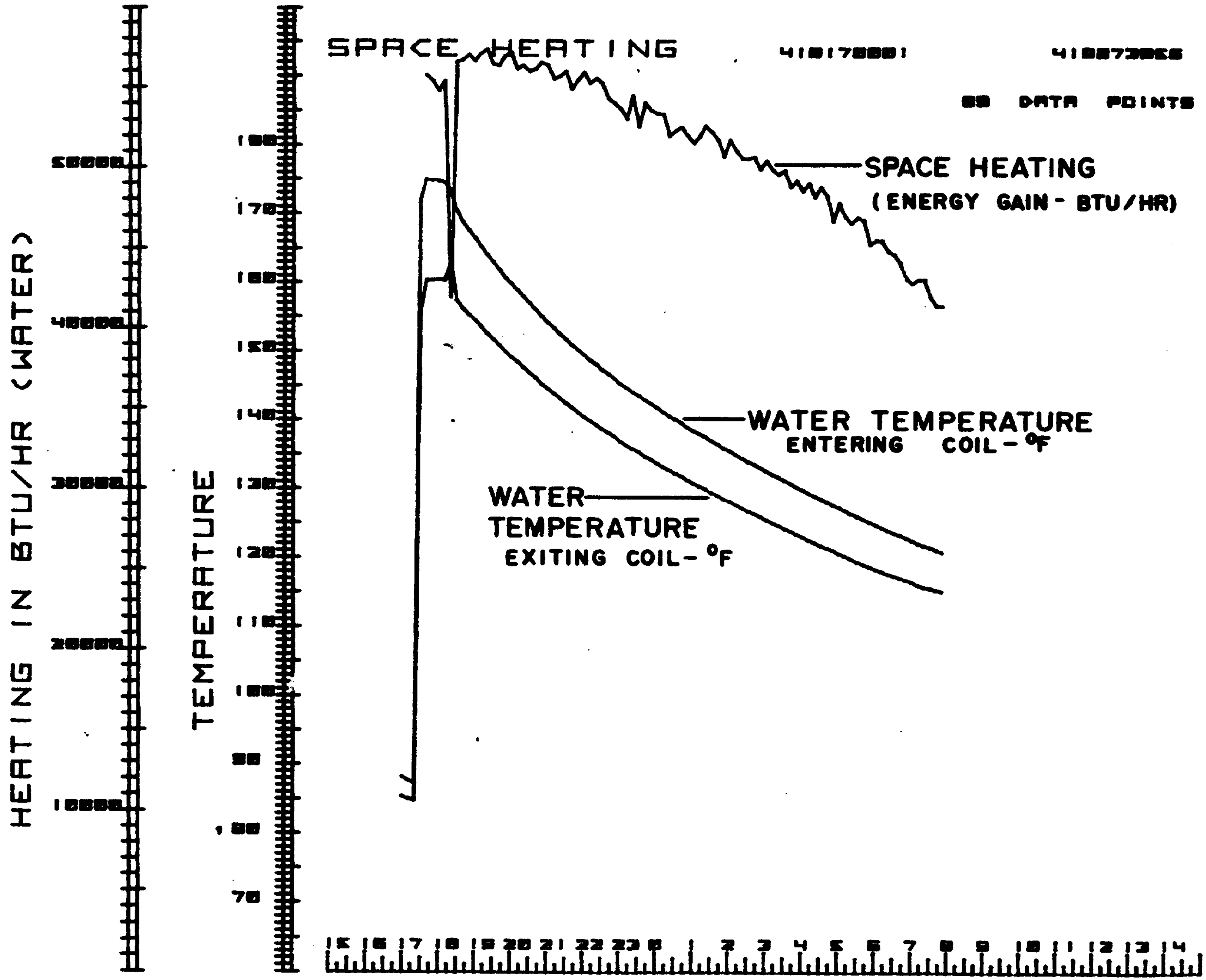

SPACE HEATING
SPACE HEATING
(ENERGY GAIN - BTU/HR)
WATER TEMPERATURE
ENTERING COIL - °F
WATER
TEMPERATURE
EXITING COIL - °F
DATA POINTS
HEATING IN BTU/HR (WATER)
TEMPERATURE

FIGURE 1.1-A

was collected with the following conditions: average ambient air temperature, 78°F; and average thermal storage tank temperature, 150°F. Results of varying collector flow rates on collector ΔT are presented in Table 1.3-A.

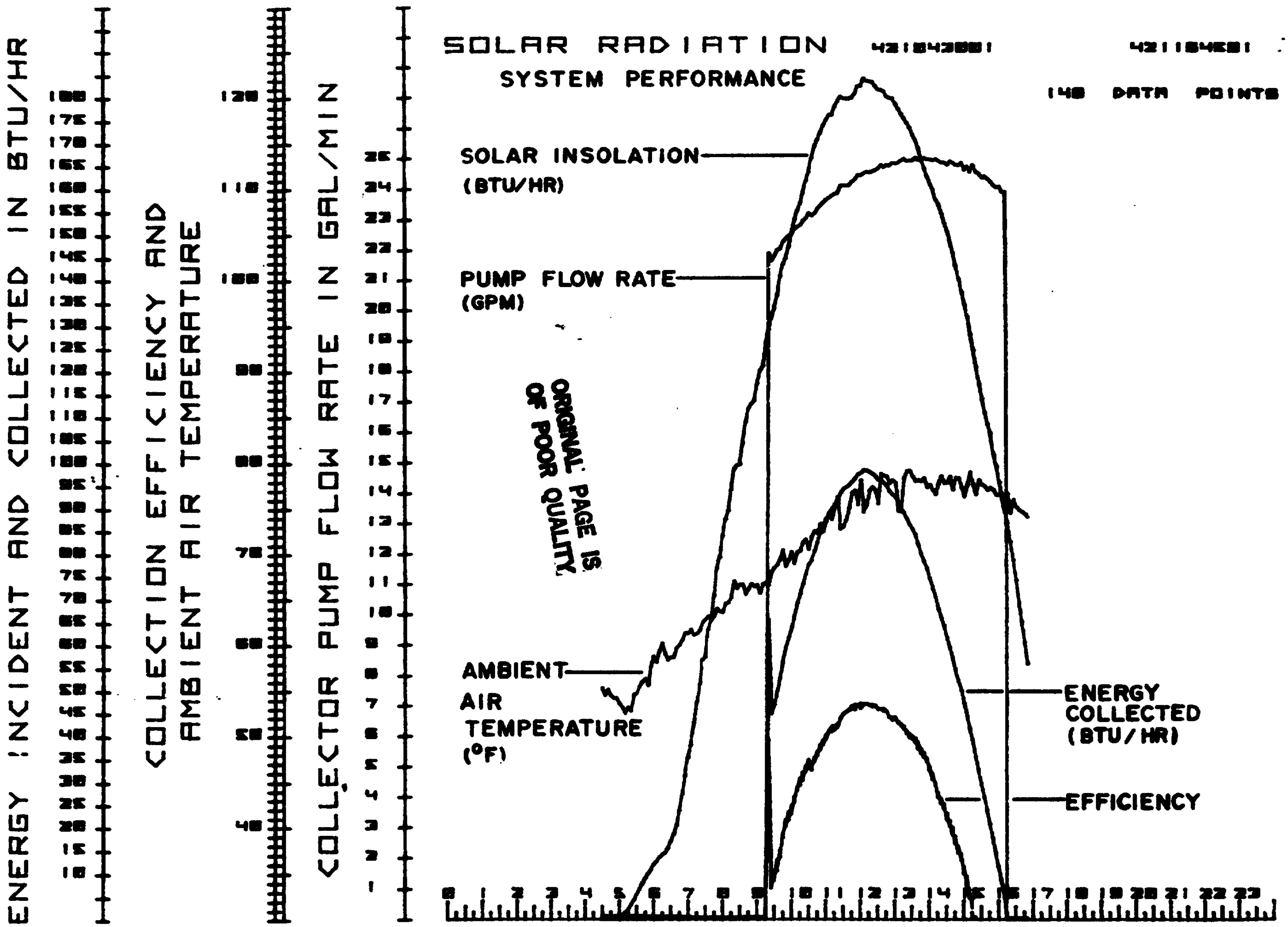
Figures 1.3-A through 1.3-C illustrate typical solar collection efficiencies. Figure 1.3-D is a comparative presentation of energy collected for varying pump flow rates between the Development and Qualification phase collectors. Figure 1.3-E presents the Qualification phase collector efficiency utilizing ASHRAE 93-77 plotting criterion. Qualification is given by similarity. Acceptance will be given by testing of the operational test site installation.

1.4 THERMAL STORAGE PERFORMANCE

Thermal storage tank heat loss was determined at two designated temperatures, 150°F and 170°F. Two distinct tests were conducted at these design temperatures. The first test was a static test, in which conductive heat loss through the vessel walls and polyurethane insulation to the surrounding earth was determined without any energy being added to the storage tank. The second test was a transient test, during which time the space heating system

COLLECTOR FLOW RATE GPM	AVERAGE TEMPERATURE RISE PER PASS °F
10	28.2
13	26.8
16	25.7
19	23.9
23	22.5

TABLE 1.3-A
COLLECTOR PERFORMANCE



SOLAR RADIATION
SYSTEM PERFORMANCE
DATA POINTS
ENERGY INCIDENT AND COLLECTED IN BTU/HR
COLLECTION EFFICIENCY AND AMBIENT AIR TEMPERATURE
COLLECTOR PUMP FLOW RATE IN GAL/MIN
SOLAR INSOLATION (BTU/HR)
PUMP FLOW RATE (GPM)
AMBIENT AIR TEMPERATURE (°F)
ENERGY COLLECTED (BTU/HR)
EFFICIENCY

FIGURE 1.3-A

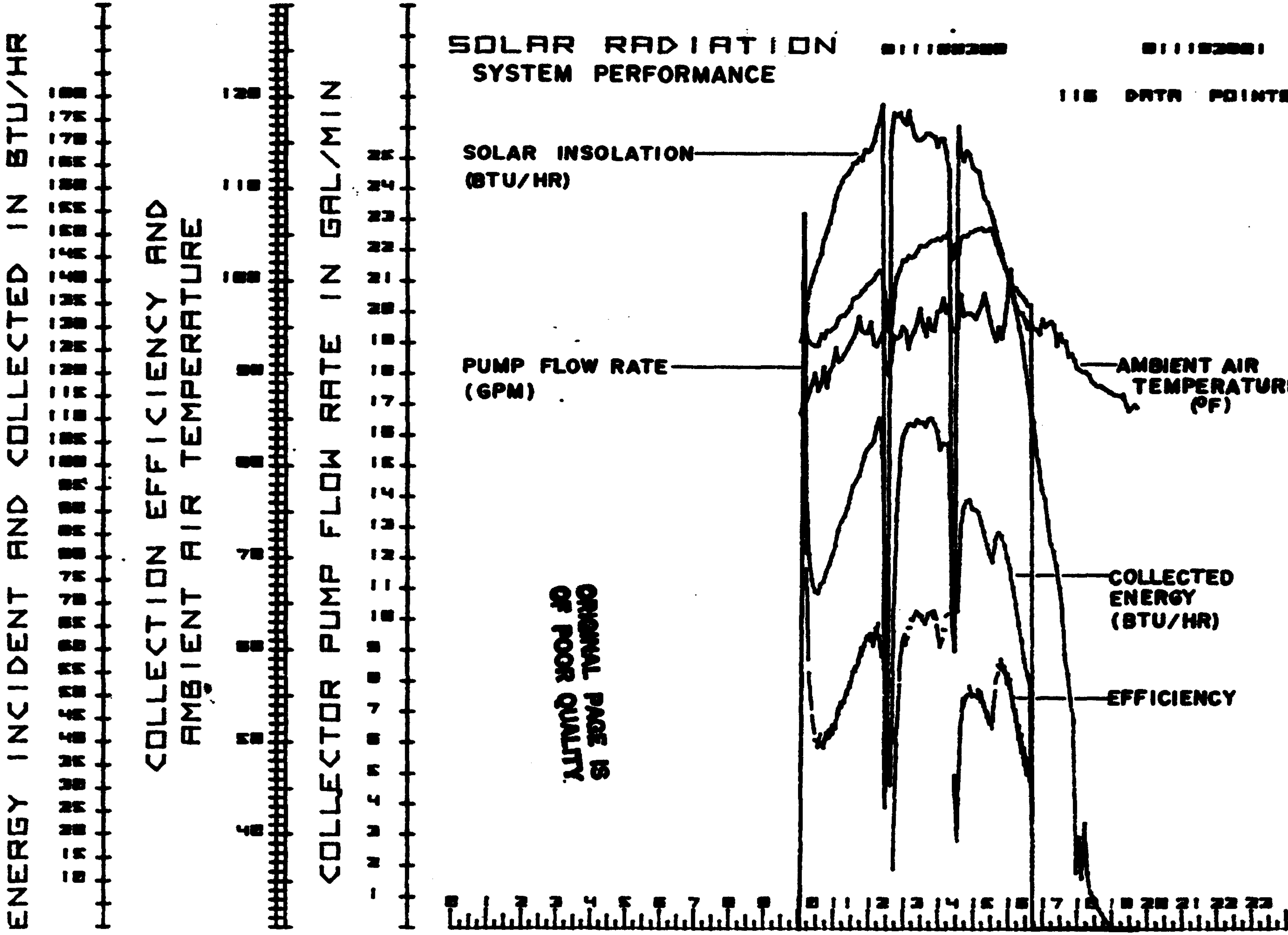

ENERGY INCIDENT AND COLLECTED IN BTU/HR
COLLECTION EFFICIENCY AND AMBIENT AIR TEMPERATURE
COLLECTOR PUMP FLOW RATE IN GAL/MIN
SOLAR RADIATION
SYSTEM PERFORMANCE
DATA POINTS
SOLAR INSOLATION (BTU/HR)
PUMP FLOW RATE (GPM)
AMBIENT AIR TEMPERATURE (°F)
COLLECTED ENERGY (BTU/HR)
EFFICIENCY
ORIGINAL PAGE IS OF POOR QUALITY

FIGURE 1.3-B

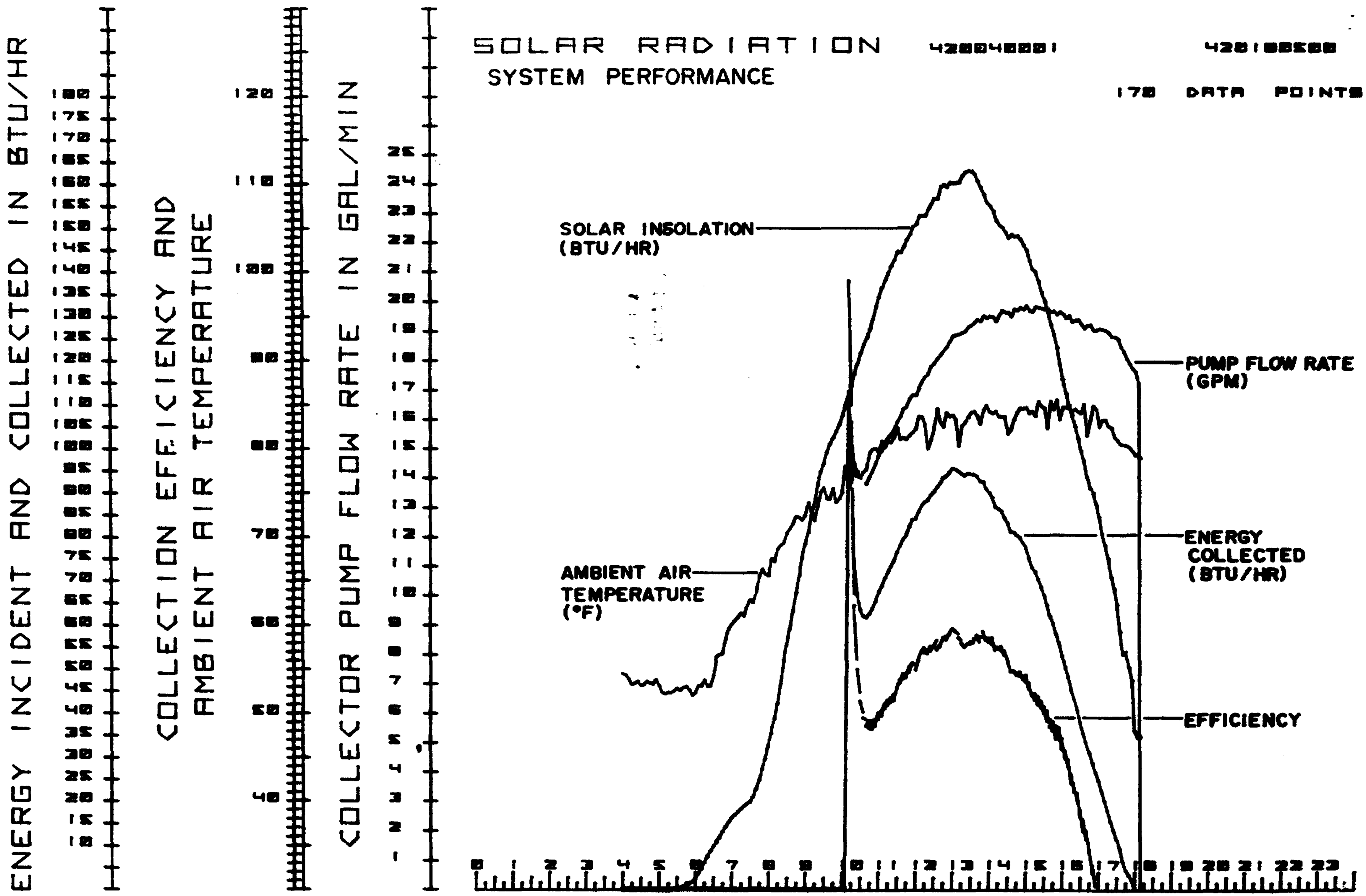
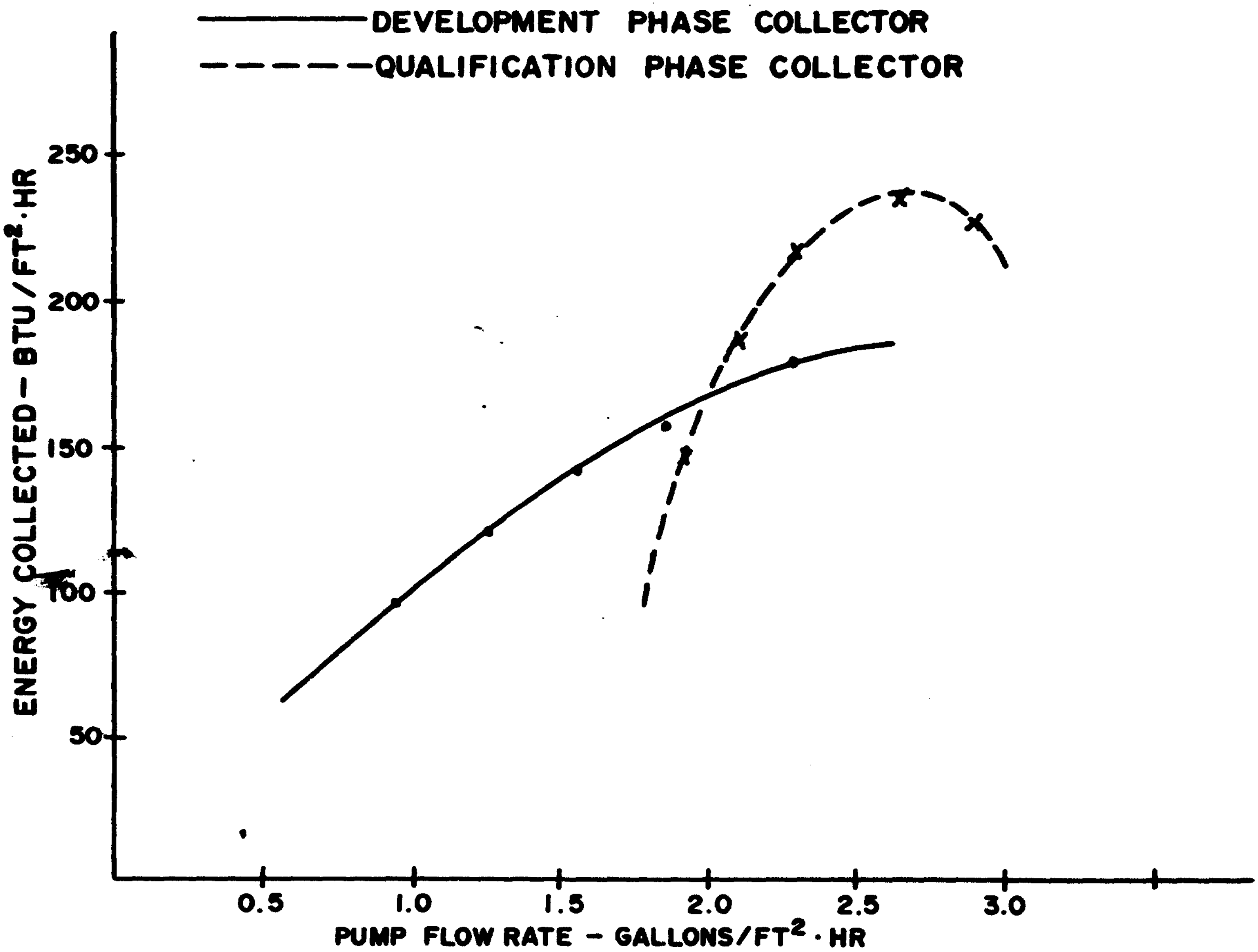
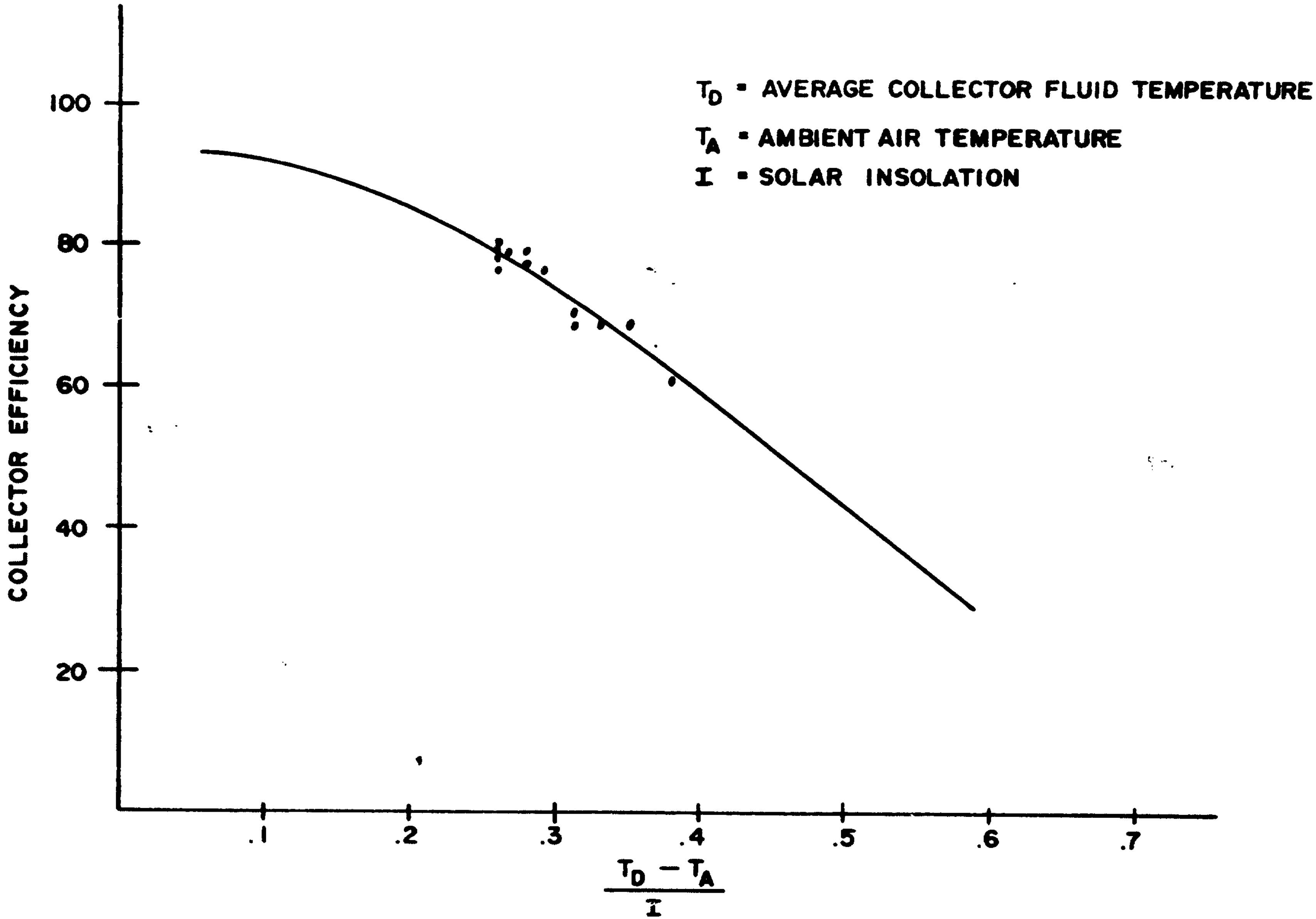

SOLAR RADIATION
SYSTEM PERFORMANCE
170 DATA POINTS
ENERGY INCIDENT AND COLLECTED IN BTU/HR
COLLECTION EFFICIENCY AND AMBIENT AIR TEMPERATURE
COLLECTOR PUMP FLOW RATE IN GAL/MIN
SOLAR INSOLATION (BTU/HR)
PUMP FLOW RATE (GPM)
ENERGY COLLECTED (BTU/HR)
AMBIENT AIR TEMPERATURE (°F)
EFFICIENCY

FIGURE 1.3 - C



DEVELOPMENT PHASE COLLECTOR
QUALIFICATION PHASE COLLECTOR
ENERGY COLLECTED – BTU/FT² · HR
250
200
150
100
50
0.5
1.0
1.5
2.0
2.5
3.0
PUMP FLOW RATE – GALLONS/FT² · HR

FIGURE 1.3-D



T_D = AVERAGE COLLECTOR FLUID TEMPERATURE
T_A = AMBIENT AIR TEMPERATURE
I = SOLAR INSOLATION
COLLECTOR EFFICIENCY
100
80
60
40
20
.1
.2
.3
.4
.5
.6
.7
$\frac{T_D - T_A}{I}$

FIGURE 1.3-E

within the thermal test facility was continuously operated. This test indicated thermal storage tank temperature degradation due to conduction through the vessel walls, combined with space heating by means of the liquid-to-air heat exchanger in the building heating air duct. Test results are shown in Tables 1.4-A and 1.4-B. Figures 1.4-A and 1.4-B graphically displays the 170°F data. Figure 1.4-C represents thermal storage performance during a period of solar energy collection. Qualification for thermal storage performance is given by similarity. Acceptance will be given by testing of the operational test site installation.

1.5 HABITABILITY OF OCCUPIED SPACES

The habitability of occupied spaces within the solar test facility is determined by analysis, coupled with visual inspection. There have been no instances of excessive heat or humidity within the solar test facility. Qualification is given by similarity. Acceptance will be given through inspection of the operational test site installation.

1.6 ENERGY TRANSPORT EFFICIENCY

Thermal losses in both the collector fluid collection/transfer loop and the thermal storage vessel fluid loop are given in Tables 1.6-A and 1.6-B. Qualification is given by similarity. Acceptance will be given by testing of the operational test site installation.

TYPICAL DAY TANK TEMP. 150 °F		TYPICAL DAY TANK TEMP 170°F	
TIME	AVERAGE TANK TEMPERATURE °F	TIME	AVERAGE TANK TEMPERATURE °F
16:40	156.1	20:00	170.7
18:40	155.8	21:00	170.2
20:40	155.2	22:00	169.8
22:40	154.6	23:00	169.3
00:39	153.9	00:00	168.9
2:39	153.3	00:59	168.5
4:39	152.9	1:59	168.1
6:39	152.0	2:59	167.7
8:39	151.5	3:59	167.3
		4:59	166.9
		5:59	166.5
		6:59	166.0

TABLE 1.4-A
STATIC THERMAL STORAGE TANK PERFORMANCE

TYPICAL DAY TANK TEMP 150 °F		TYPICAL DAY TANK TEMP 170°F	
TIME	AVERAGE TANK TEMPERATURE °F	TIME	AVERAGE TANK TEMPERATURE °F
17:00	150.9	17:00	172.7
19:00	145.4	19:00	165.8
21:00	136.5	21:00	157.8
23:00	131.0	23:00	150.9
00:59	126.2	00:59	144.9
2:59	121.9	2:59	138.3
4:59	118.0	4:59	127.0
6:59	114.4	6:59	121.2
7:59	112.8	7:59	120.9

TABLE 1.4-B
TRANSIENT THERMAL STORAGE TANK PERFORMANCE

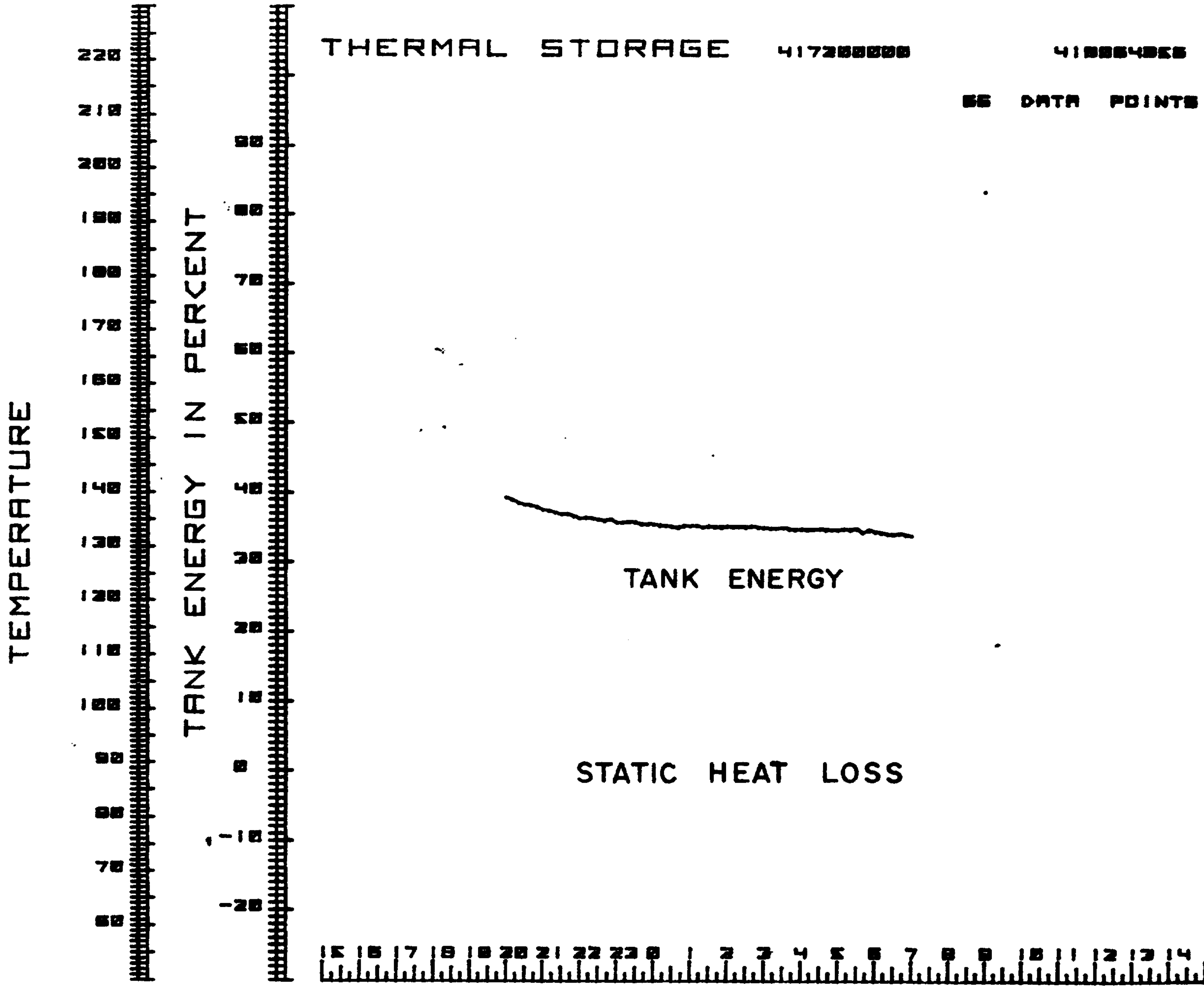
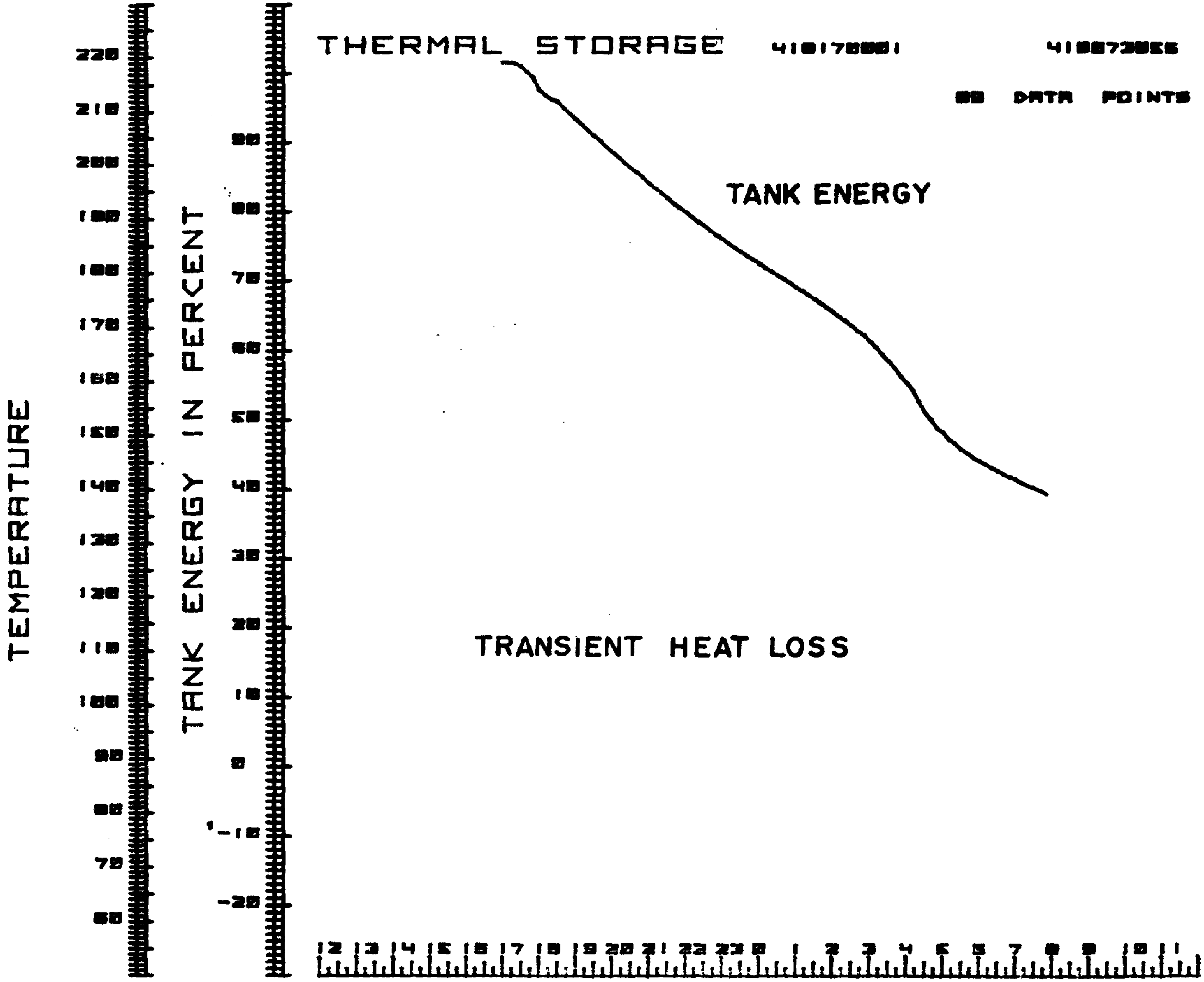

THERMAL STORAGE
DATA POINTS
TEMPERATURE
TANK ENERGY IN PERCENT
TANK ENERGY
STATIC HEAT LOSS

FIGURE 1.4-A


THERMAL STORAGE
DATA POINTS
TANK ENERGY
TRANSIENT HEAT LOSS
TEMPERATURE
TANK ENERGY IN PERCENT

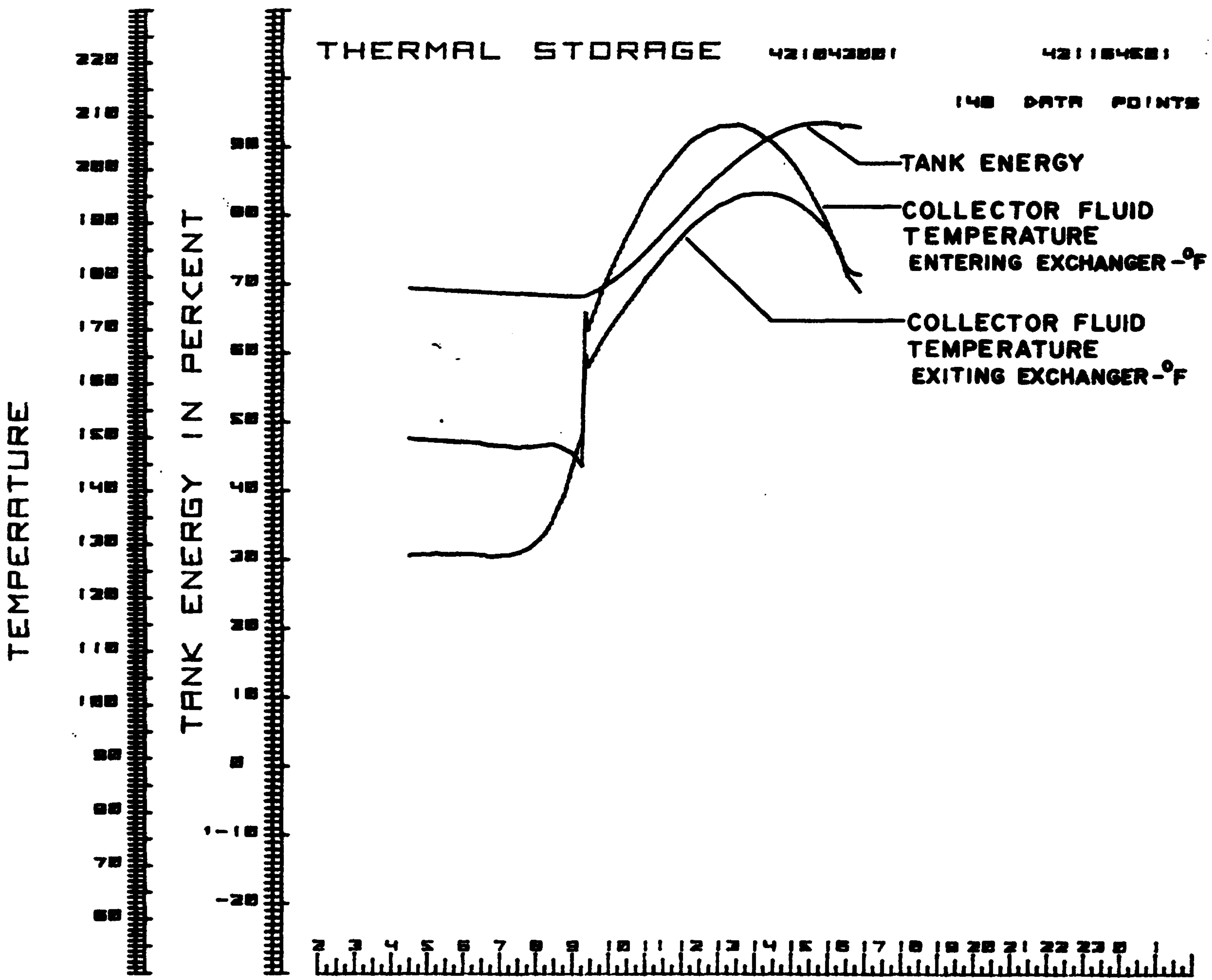

THERMAL STORAGE
140 DATA POINTS
TANK ENERGY
COLLECTOR FLUID TEMPERATURE ENTERING EXCHANGER-°F
COLLECTOR FLUID TEMPERATURE EXITING EXCHANGER-°F
TEMPERATURE
TANK ENERGY IN PERCENT

FIGURE 1.4 — C

TIME	FLOW RATE GPM	FLUID TEMPERATURE EXITING COLLECTOR °F	FLUID TEMPERATURE ENTERING EXCHANGER °F	ΔT °F
9:00	18.1	146.3	144.9	1.4
10:00	19.9	165.7	164.3	1.4
11:00	21.4	179.2	177.8	1.4
12:00	22.4	188.4	187.0	1.4
1:00	22.6	187.4	186.1	1.3
2:00	22.8	186.1	184.9	1.2
3:00	22.3	176.7	175.7	1.0
4:00	22.0	170.9	170.0	0.9

TABLE 1.6-A

THERMAL LOSS IN COLLECTOR FLUID LOOP

TIME	FLOW RATE GPM	WATER TEMPERATURE EXITING TANK °F	WATER TEMPERATURE ENTERING COIL °F	ΔT °F
17:30	7.8	173.2	171.7	1.5
19:30	10.0	163.2	163.1	.1
21:30	12.0	155.3	151.9	3.4
23:30	12.9	148.8	143.2	5.6
1:30	13.8	142.9	137.0	5.9
3:30	14.3	135.3	131.3	4.0
4:30	14.5	129.0	128.6	.4

TABLE 1.6 - B

THERMAL LOSS IN THERMAL STORAGE FLUID LOOP

1.7 CONTROL

Control of the heating and hot water systems has been tested and proven to operate as defined by design criteria. Control of the heating system is accomplished by means of temperature switches installed within the thermal storage vessel. One switch, which opens when the water temperature is 90°F and below, is in series with the control logic of the solar heating system, thus turning off solar heating when the water temperature is 90°F or below. A second switch is set to open when the water in the thermal storage vessel is 105°F and greater. This switch is set in the control logic of the auxiliary heating system, thus disabling the auxiliary system when water storage temperatures are 105°F and above. These switches have been tested repeatedly and function correctly. Both are part of the control logic of a standard room thermostat, allowing space temperatures to be set between 55°F and 90°F.

The domestic water storage tank is a standard electric hot water tank with thermostatic control to the auxiliary element allowing for 120°F to 140°F temperature water. Qualification of this phase is given by similarity. Acceptance will be given by testing of the operational test site installation.

1.8 AUXILIARY ENERGY

The electric resistance auxiliary heating system was tested by disabling the solar heating system and was conducted during a period of average room ambient temperature of 69.2°F. Air inlet and outlet temperatures were measured and resulted in an average air temperature rise of 10.3°F through the auxiliary heat source. Qualification is given by similarity. Acceptance will be given by testing of the operational test site installation.

2.0 MECHANICAL - SYSTEM AND COMPONENTS

2.1 SYSTEM DESIGN CONDITIONS

The solar energy collection system design criteria are as follows: total collector fluid flow rate, 19 gallons per minute; temperature rise per pass through collector bank, 15°F; and system operating pressure, approximately 30 PSI. The thermal storage fluid design criteria are as follows: water flow rate, 9.3 GPM, and air flow rate, 1800 CFM.

Test results referenced in Section 1.0, indicate that the system design criteria are met or exceeded, in all cases. Continuous operation has produced neither noise nor erosion-corrosion in the piping or ducts and associated fittings, in either the heat transfer fluid piping loop or in the thermal storage fluid piping loop. All components have operated without failure or rupture before, during, and since the verification test phase.

Fluid flow in the collector bank is controlled through balancing valves as part of the main manifold. Testing results referenced in Section 1.0, Table 1.3-A, show the collector ΔT for a wide range of flow rates.

Entrapped air is removed through a vent located at the high point in the heat transfer loop. Air is also purged continuously through an air scrubber and vent located within the system.

Adequate provision for the thermal expansion of the heat transfer fluids has been provided through the use of a 15 gallon expansion tank. Continued testing indicates this volume to be sufficient over the full range of operating temperatures and pressures experienced. Qualification of the system design conditions is given by similarity. Acceptance will be given through inspection of the operational test site installation.

2.2 MECHANICAL STRESSES

Testing of all system components has indicated that mechanical stresses that arise within the system do not cause damage or malfunction of the system or its components. There has been no vibration in piping, ducting, instrumentation lines or control devises. Vibration from moving parts within the pumps and air circulating fans has not produced any visable damage or excessive noise, nor has there been any water hammer in the fluid transfer lines.

Vacuum relief protection is of interest within the collector fluid transfer loop only. All components have been designed to withstand collapsing pressures if subjected to vacuum. The expansion tank within the loop has been ASME tested and approved. Vacuum relief protection is not necessary in any other fluid transfer loop, because these systems are operating at atmospheric pressure.

Adequate compensation for thermal expansion of the absorber plate was designed into the collector panel. Testing has validated the effectiveness of the design. Qualification of this section is given by similarity. Acceptance will be given through inspection of the operational test site installation.

2.3 LEAKAGE PREVENTION

All solar collectors were pre-tested at 1.5 M.E.O.P. There were no failures during these tests to date. Continued operation has produced no leaks in the thermal fluid storage transfer lines.

The domestic water system which is directly connected to the potable water supply system has not leaked. Testing and installation was performed in accordance with local codes.

The duct systems for transporting air have been designed in accordance with the standards contained in the ASHRAE Systems Handbook 1973. Testing of this system has indicated no discernable leaks. Qualification of this section is given by similarity. Acceptance will be given by testing of the operational test site installation.

2.4 COLLECTOR AJUSTMENT

The solar panels were installed on the solar test facility in accordance with the standards given in ASHRAE Handbook and Products Directory 1974. These criteria specified a collector tilt angle of 45° from horizontal. As the collectors have been installed in a single bank there is no mutual shadowing of collectors. Qualification of this section is given by similarity. Acceptance will be given through inspection of the operational test site installation.

2.5 SUB-SYSTEM ISOLATION

Both the collector fluid transfer and thermal storage fluid transfer sub-systems operate mutually exclusively of one another. Qualification of this section is given by similarity. Acceptance will be given through inspection of the operational test site installation.

2.6 HEAT TRANSFER FLUID QUALITY

The collector fluid specified for this installation is Shell Thermia C(33) mineral oil. This oil has had many years of proven experience in the process heat industry and must only be protected from an air interface at elevated temperatures to insure years of trouble free service. A standard bottom entry basket strainer is supplied as part of each system for the filtering and removel of contaminants. Entrapped air is continuously scrubbed and vented from the system (reference section 2.1). The air interface mentioned above is avoided by implementing a cold expansion tank.

System duct air is adequatly protected by filtration on the return air, or suction side of the fan.

Fluid treatment for the Shell Thermia C is not a concern as it retains its properties throughout its service life. Normal precautions required for freeze and boil protection are not necessary with the Shell Thermia C mineral oil, because of the very high (455°F) flash point, and low (10°F) pour point. Qualification is given by similarity. Acceptance will be given through inspection of the operational test site installation.

2.7 PIPING SUPPORTS

All piping has been installed in accordance with local plumbing codes and to standards consistant with the ASHRAE 1973 Systems Volume. Qualification is given by similarity. Acceptance will be given through inspection of the operational test site installation.

2.8 EXCESSIVE PRESSURE AND TEMPERATURE PROTECTION

The pressure relief valve supplied as part of the collector fluid loop plumbing is set at 50 PSI. It is vented to atmosphere and allows for fluid drain-off. The pressure relief valve was tested at 50 PSI and operated correctly. Qualification is given by similarity. Acceptance will be given by testing of the operational test site installation.

3.0 STRUCTURAL - SYSTEMS AND COMPONENTS

3.1 STRUCTURAL DESIGN BASES

The structural design of the heating and hot water systems including connections and supporting structural elements has been analyzed and installed according to architectural standards and nationally accepted codes. The Development and Qualification phases of this contract were conducted at the Colt Inc. Rancho Mirage California Test Facility. The Colt facility employed a roof integrated collector as compared to the flat roof truss mounted collectors, to be installed on each operational test site. Therefore, many of the structural requirements and criterion are dissimilar. Acceptance at the operational test site will be given through inspection.

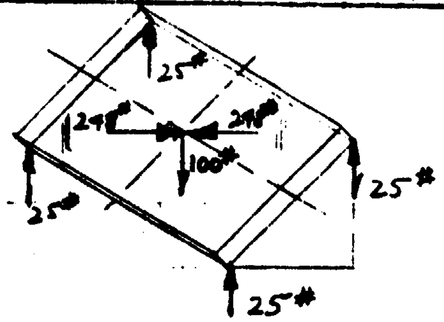
It is anticipated that the basic structural design criteria applicable in all three phases, Development, Qualification and Acceptance is the stress analysis of the Colt Inc. collector truss supports utilized at the operational test sites. This analysis has been completed and the results are indicated in Exhibits 3.1-A and 3.1-B. Included are the applicable safety factors incorporated into the structure design.

3.2 FAILURE LOADS AND LOAD CAPACITY

Ice loads and vehicular loads are not applicable in the Rancho Mirage Test Facility location. Acceptance at the operational test sites will be given through inspection.

STRESS ANALYSIS OF COLLECTOR SCREWS AND RIVETS

FORCE DIAGRAM

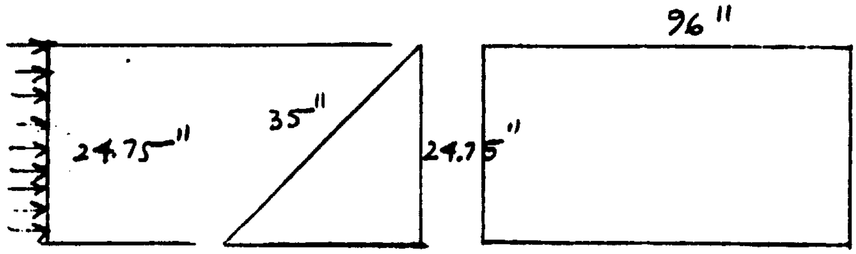


COLLECTOR WEIGHT : 100# (V)

WIND LOAD : 248#(H) (DISTRIBUTED LOAD; FOR ANALYSIS, CONSIDER AS CONCENTRATED LOAD AT CENTROID OF COLLECTOR)

CALCULATION OF WIND LOAD:

15 psf PROJECTED ON VERTICAL PLANE



$A_{pl} = \frac{96 \times 24.75''}{144\ in^2/ft^2} = 16.5\ ft^2$

$F_{pl} = 15\ \#/ft^2 \times 16.5\ ft^2 = 248\#$

ORIGINAL PAGE IS OF POOR QUALITY

TO SIMPLIFY ANALYSIS, CONSIDER TOTAL LOAD (WIND + COLL. WEIGHT) COUNTERACTED BY 4 EQUAL FORCES, ONE AT EACH CORNER OR AT EACH RIVET OR SCREW CONTACT.

ALLOWABLE SHEAR

PER RIVET ($\frac{3}{16}''\phi$)

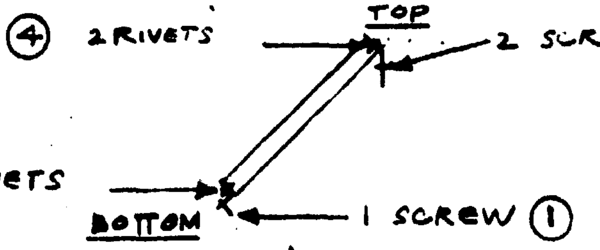
$F_{s_{ALLOW}} = 445 (.55) = \boxed{245\#}$ (445# = ULTIMATE SHEAR)

PER SCREW (#10 SELF TAP - 0.1389 ϕ) [$A = (0.1389)^2(.785) = .015$]

$F_{s_{ALLOW}} = (10{,}000)(.015) = \boxed{150\#}$

EXHIBIT 3.1-A

FACTOR OF SAFETY



$w/_{sup} = \frac{100}{4} = 25^{\#}(V)$

$W/_{sup} = \frac{248}{4} = 62^{\#}(H)$

◁ ← WIND

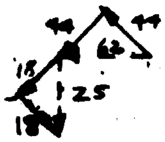
BOTTOM

SCREW (1)

① $F_s = 44 + 18 = 62^{\#}$

$N_{ALLOW} = \frac{150}{62} = \boxed{2.4}$

ALSO, WELD ASSISTS IN RESISTING SHEAR *



RIVETS (2)

② $F_s = 44 - 18 = 26^{\#}$

$N_{ALLOW} = \frac{(250)(2)}{26} = \boxed{19}$

SAME AS ①

TOP

SCREWS (2)

③ $F_s = 25^{\#}$

$N_{ALLOW} = \frac{(150)(2)}{25} = \boxed{12}$

RIVETS (2)

④ $F = 44 - 18 = 26^{\#}$

$N_{ALLOW} = \frac{(250)(2)}{26} = \boxed{19}$

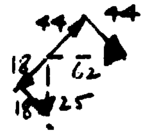
SAME AS ①

WIND → ▷

BOTTOM

① $F_s = 44 - 18 = 26^{\#}$

$N_{ALLOW} = \frac{150}{26} = \boxed{57}$



② $F_s = 44 + 18 = 62^{\#}$

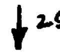
$N_{ALLOW} = \frac{(250)(2)}{62} = \boxed{8}$

SAME AS ①

TOP

③ $F_s = 25^{\#}$

$N_{ALLOW} = \frac{(150)(2)}{25} = \boxed{12}$



④ $F_s = 44 + 18 = 62^{\#}$

$N_{ALLOW} = \frac{(250)(2)}{62} = \boxed{8}$

SAME AS ①

*

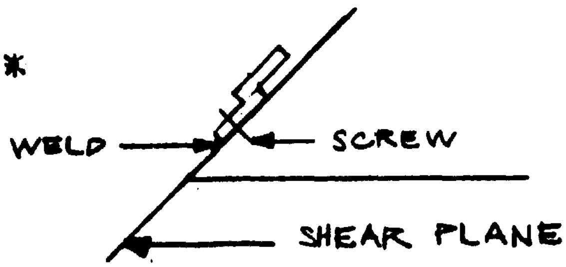


EXHIBIT 3.1-B

3.3 DAMAGE CONTROL

The structural elements and connections of the heating and hot water systems have been designed to withstand service loads without damage of unacceptable magnitude. Acceptance will be given through inspection of the operational test site installation.

3.4 CYCLIC LOADS

All structural elements and connections of the heating and hot water systems have been installed according to national plumbing codes and shall withstand the application of cycic loads expected during the service life. Acceptance at the operational test sites will be given through inspection.

3.5 CUTTING OF STRUCTURAL ELEMENTS

As there has been no cutting of structural elements at the Rancho Mirage Test Facility nor will there be cutting of structural elements at either of the operational test sites, this section is not applicable to the report.

3.6 CREEP AND RESIDUAL DEFLECTION

This section is neither applicable in the Development and the Qualification phase, nor is it applicable in the Acceptance phase. None of the loads imposed by the collector panels are sufficient to cause creep or residual deflection of any sort.

3.7 HAIL RESISTANCE

The heating and hot water system components and supporting structural elements exposed to the natural environment are capable of resisting impact by hail without unacceptable damage. This requirement is not applicable to the Rancho Mirage Test Facility, because of the total lack of hail in this climate. Actual analysis of this requirement at each operational test site is left for similarity to results of the analyses conducted at the Los Alamos Scientific Laboratories in Los Alamos, New Mexico. Los Alamos is in one of the highest hail impact areas in the world. Their collector which uses the same glazing, as the Colt collector, has not been damaged.

3.8 CONSTRAINT LOADS

The Colt facility was designed to accommodate the solar loads from all panels and piping. The analysis was signed by a professional engineer. Both the operational test sites utilized existing structures. All load calculations were made by the building owner and structure to support the collectors has been provided by the building owner.

3.9 PONDING CONDITIONS

Ponding conditions are not applicable in either the Development and Qualification, nor Acceptance phases of this contract. None of the roof surfaces, where collectors have been mounted, will permit ponding.

4.0 SAFETY - SYSTEMS AND COMPONENTS

4.1 PLUMBING AND ELECTRICAL INSTALLATION

The design and installation of the systems for heating and hot water and their components have been conducted in accordance with nationally recognized plumbing and electrical codes. Qualification is given by similarity. Acceptance will be given through inspection of the operational test site installation.

4.2 FAIL-SAFE CONTROLS

The heating and hot water systems have been designed to be fail-safe in the event of damage to the system components or in the event of a power failure. The oil circulating loop is designed to operate at a pressure of 25 - 30 PSI. A standard pressure relief valve, preset at 50 PSI, has been installed within this loop. This valve has been tested and does operate correctly when pressures exceed 50 PSI.

Each circulating pump is installed with a motor controller and individually resetable circuit-breaker switches. These switches are supplimented by individual back-up switches located at the main circuit breaker panel. The auxiliary resistance strip heater, located in the air duct work, is protected by two limiting thermostatic switches. One switch is automatically reset, the second switch must be manually reset. These switches were tested under the following conditions: the air flow circulating fan was disabled, and the resistance strip heater was switched on. The automatic thermostatic switch opened after two minutes of operation, and the manual thermostatic switch opened after an additional two minutes of operation. Qualification is given by similarity. Acceptance will be given by testing of the operational test site installation.

4.3 FIRE SAFETY

The design and installation of the heating and hot water system and their components provide the maximum level of fire safety which is consistant with applicable codes and standards. Qualification is given by similarity. Acceptance will be given through inspection of the operational test site installation.

4.4 TOXIC AND FLAMMABLE FLUIDS

The working collector fluid has been designated as Shell Thermia C(33). This is a non-toxic and essentially non-flammable fluid in temperature ranges in excess of 250% of the actual measured operating temperatures. Qualification is given by similarity. Acceptance will be given through inspection of the operational test site installation.

4.5 SAFETY UNDER EMERGENCY CONDITIONS

The design and installation of the heating and hot water systems does not impair the emergency movement of occupants of the facility or emergency personnel. Building exits and operating passageways are located in a manner to provide quick and efficient movement of building occupants during an emergency condition. Qualification is given by similarity. Acceptance will be given through inspection of the operational test site installation.

4.6 PROTECTION OF WATER AND CIRCULATED AIR

No material, form of construction, fixture, appurtenance or item of equipment has been employed that will support the growth of microorganisms or introduce toxic substances, impurities, bacteria or chemicals into the potable water and air circulation systems. Potable water in the domestic water heating sub-system is protected by a two boundry interface that has been set forth as a national standard through HUD prerequisits. Qualification is given by similarity. Acceptance will be given through inspection of the operational test site installation.

4.7 EXCESSIVE SURFACE TEMPERATURES

The collector set forth through the Development phase has recorded stagnation temperatures as follows: empty--423°F, full--374°F. The collector used in the Qualification phase develops temperatures approximately 50°F lower in each case as a result of the use of a semi-selective surface. As the collector working fluid, Shell Thermia C, can be safely operated in temperature ranges to 600°F, it is determined that temperatures of the exterior surfaces of the heating and hot water systems will not create a hazard. Acceptance will be given through inspection of the operational test site installation.

5.0 DURABILITY/RELIABILITY - SYSTEMS AND COMPONENTS

5.1 EFFECTS OF EXTERNAL ENVIRONMENT

The systems for space heating and domestic hot water heating and their various sub-assemblies are not affected by external environmental factors to any extent that will impair their function during their design life.

The Development phase solar panel housing is constructed of steel which has a baked enamel finish. The glazing material is smooth ASG Sunadex glass. The Qualification phase collector housing is constructed of 6063-T5, dark bronze anodized aluminum extrusions, a 3003-H14 aluminum back plate, and a cover plate of ASG Sunadex glass. In both cases all component materials have been selected to withstand external environmental effects throughout the expected design life. The glass cover plate material is smooth to provide for a minimum of dirt retention. Acceptance will be given through inspection of the operational test site installation.

5.2 TEMPERATURES AND PRESSURE RESISTANCE

System components are capable of performing their intended function for their design life when exposed to the temperatures and pressures that are developed within the system and sub-systems. Reference to sections 2.8 and 4.7 provides analyses already given through inspection of the operational test site installation.

5.3 CHEMICAL COMPATIBILITY OF COMPONENTS

All system components are manufactured from materials designed to be compatable with working fluids contacted. The collector heat transfer fluid is a non-toxic, non-corrosive mineral oil, and the only other working fluid is water. The collector fluid heat exchanger is manufactured from stainless steel sheet material. All fluid transport lines are copper with either copper or brass fittings. Qualification is given by similarity. Acceptance will be given through inspection of the operational test site installation.

5.4 COMPONENTS INVOLVING MOVING PARTS

All check valves, pumps, electric switches and similar components have been selected after research has determined that individual components will operate for their intended life span while subjected to the predetermined temperatures and pressures established as designed criteria within each system and sub-system. Qualification is given by similarity. Acceptance will be given through inspection of the operational test site installation.

6.0 MAINTAINABILITY - SYSTEMS AND COMPONENTS

6.1 ACCESSIBILITY FOR MAINTENANCE AND SERVICING

The system for space heating and domestic hot water heating has been designed and constructed to provide sufficient access for general maintenance, convenient servicing and monitoring of all system performance. All individual items of equipment and components are accessible for inspection, service, repair, removal or replacement without dismantling any adjoining major piece of equipment or sub-system. Appropriate access has been provided for sensors that are used for inspecting and checking essential system parameters, such as temperature, pressure and voltage. System maintenance and repair has been facilitated by conveniently located fill and drain valves. All essential filters have been located so as to provide for convenient cleaning and replacement. The hot water system has been valved to provide shut-off from the cold water supply. Qualification is given by similarity. Acceptance will be given through inspection of the operational test site installation.

6.2 INSTALLATION, OPERATION AND MAINTENANCE MANUAL

This manual has been provided and submitted on September 14, 1977.

6.3 REPAIR AND SERVICE PERSONNEL

Colt Inc. has developed a training program to include installation and maintenance of each operational test site equipment hardware. This training program has been submitted on September 14, 1977.

7.0 FUNCTION - FACILITIES AND SITES

7.1 DESIGN

This section is not applicable to the Development phase of this program. The solar test facility located in Rancho Mirage through which Qualification is given has been architecturally designed to be aesthetically pleasing. Consideration was given in the facility and site design to the utilization of passive solar energy wherever practical. Acceptance will be given through inspection of the operational test site installation.

7.2 ADEQUATE SPACE

The solar test facility has been designed to give adequate space to accommodate the solar heating and hot water systems. The roof portion, housing the solar collectors, is pitched at the 45° angle necessitated by the latitude of the site location and provides the 600 square feet necessary for the solar panels. The thermal storage vessel has been buried externally to the facility, located in a manner to provide accessibility for draining and repairing when necessary. Acceptance will be given through inspection of the operational test site installation.

7.3 FUNCTIONING OF FACILITY AND SITE

The use of the facility and site is not impaired in anyway by the heating and hot water system. All system components and equipment are located in a utilitarian section of the facility which is essentially non-usable space for the normal function of that facility. Acceptance will be given through inspection of the operational test site installation.

7.4 COMPATABILITY WITH CONVENTIONAL SYSTEMS

As the site selected was designed primarily as a solar test and manufacturing facility, compatibility has been assured through the initial engineering and architectural design phases. Acceptance will be given through inspection of the operational test site installation.

8.0 MECHANICAL - FACILITIES AND SITES

8.1 INTERFACE WITH MECHANICAL OPERATION

The facility and site elements do not prevent the proper mechanical functioning of the heating and hot water systems. Through analysis and inspection, engineering design has precluded the possibility of adjacent facilities and planting arrangements to block or shade the solar panels. Interior and exterior control sensors have been located to provide ambient conditions, and/or other operating parameters which are free of unnecessary interference from external factors, such as, shade and drafts. Acceptance will be given through inspection of the operational test site installation.

8.2 MECHANICAL AND ELECTRICAL FUNCTIONING OF FACILITY AND SITE

The mechanical and electrical operation of the facility or site is not affected by the heating and hot water systems. This analysis is given through inspection at each operational test site installation.

8.3 MECHANICAL AND ELECTRICAL FUNCTIONING OF CONNECTIONS

The connections between the heating and hot water systems and the facility function mechanically and electrically as intended. Plumbing connections between the solar components and the water service and waste disposal systems were installed in accordance with national standard plumbing codes as applicable. All electrical connections between the solar components and the electrical system of the facility are in accordance with the national electrical codes.

9.0 STRUCTURAL - FACILITIES AND SITES

9.1 STRUCTURAL INTEGRITY OF THE HEATING AND HOT WATER SYSTEMS

The facility is not unduely affected by the structural integrity of the heating and hot water systems. All solar components have been located so as to take into account any possible movements in adjacent structures which could cause damage. This analysis is given through inspection of each operational test site installation.

9.2 STRUCTURAL INTEGRITY OF FACILITY

The structural integrity of the facility and site elements will not be unduely affected by the heating and hot water systems. Review of the structural drawings, specifications and design calculations, as set forth in Chapter 3, combined with inspection of each operational test site, assures adequate structural capability for carrying the increased loads imposed by the solar components.

9.3 STRUCTURAL CONNECTIONS

Structural connections between solar components and the facility or site elements are capable of carrying the loads imposed by the solar components. Stress analyses have been conducted and the loads imposed have been compensated for in the engineering design for each operational test site.

10.0 SAFETY - FACILITIES AND SITES

10.1 SAFETY OF FACILITY AND SITE

The safe operation of the facility or site has not been affected by the heating and hot water systems. This has been determined through inspection of each operational test site installation.

11.0 DURABILITY/RELIABILITY - FACILITIES AND SITES

11.1 DURABILITY AND RELIABILITY OF THE HEATING AND HOT WATER SYSTEMS

The solar heating and hot water systems in each operational test site have been located in a manner so as to prevent any impairment of their intended function due to adjacent vegatation or structures.

11.2 DURABILITY AND RELIABILITY OF FACILITIES AND SITE

Care has been taken during installation so as to prevent any excessive deterioration of the roofing materials due to the presence of the roof mounted collector components. Care is also taken to assure water-tight integrity around all exterior penetrations.

11.3 DURABILITY AND RELIABILITY OF CONNECTIONS

The connections between the heating and hot water systems and the facility that are exposed to external environmental factors have been installed so as not to undergo changes that will impair their functions.

12.0 MAINTAINABILITY - FACILITIES AND SITES

12.1 MAINTAINABILITY OF HEATING AND HOT WATER SYSTEMS

The solar components at each operational test site have been installed in a manner so as not to prevent the practical maintainability of either the heating and hot water system components or the facility. All system components have been installed to allow for ease of servicing and/or replacement. Permanent maintenance accessories, such as, hose bibs, drains, etc., necessary for the maintenance of the heating and hot water system, have been provided.

12.2 MAINTAINABILITY OF FACILITY AND SITE

The solar components at each operational test site have been installed in such a manner as not to prevent the practical maintainability of the facility.

12.3 CONNECTIONS

The connections between the heating and hot water systems and the facility have been installed in a manner so as to be readily accessible for maintenance and replacement.

13.0 VISUAL CHARACTERISTICS - FACILITIES AND SITES

13.1 VISUAL CHARACTERISTICS - FACILITIES AND SITES

All solar heating and hot water system components have been architecturally integrated into each operational test site in a manner so as to be aesthetically pleasing. The effects of the solar sub-systems on the mass, scale, grid-pattern, texture and color of the facility have all been considered and incorporated into the design.

☆ U.S. GOVERNMENT PRINTING OFFICE 1979—640-081/477 REGION NO. 4