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LARGO HOT WATER SYSTEM LONG RANGE THERMAL PERFORMANCE TEST REPORT - ADDENDUM

Prepared by

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Under subcontract with IBM, Federal Systems Division, Huntsville, AL

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16. ABSTRACT

This report presents the test procedure used and the test results obtained during the long range thermal performance tests of the LARGO Solar Hot Water System under natural environmental conditions. Objectives of these tests were to determine the amount of energy collected, the amount of power required for system operation, system efficiency temperature distribution and system performance degradation.

For the initial thermal performance tests and results on the LARGO Solar Residential Hot Water System performed at the Marshall Space Flight Center's solar test facility, see DOE/NASA CR-150841.

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TABLE OF CONTENTS

SUMMARY

Long range thermal performance tests of the Largo Solar Residential Hot Water System were initiated on September 22, 1977, concurrent with results published in Reference 2.1, and terminated on August 16, 1978. The system was in continuous operation during this period, with the exception of approximately ten days to replace a broken cover plate and correct damage resulting from a failure of the freeze protection device. The freeze protection system was corrected and the tests were continued with no additional problems.

Visual deterioration of the system has been limited to two cracked cover plates, resulting from inadequate allowance for thermal expansion/contraction of the solar collector. No noticeable degradation in performance has been observed. A graphical presentation of the original thermal efficiency data for the collector and current data are shown in Figures 3 and 4, respectively.

The efficiency values are scattered due to transient ambient conditions and make a comparison difficult. A more accurate comparison of system performance can be made from Table I. The average daily system efficiency for the long range evaluation was approximately 25 per cent. The original testing period also yielded an average efficiency of approximately 25 per cent.

1.0 PURPOSE

The purpose of this report is to present the test procedures used and the test results obtained during the long range thermal performance tests of the Largo Solar Hot Water System under natural environmental conditions. The tests were conducted at the Test Bed No. 1 Facility of the Marshall Space Flight Center Solar Test Facility. The primary objectives of these performance evaluations are listed below:

- Determine the amount of energy collected by the system.
- Determine the power required to operate the system.
- Determine system efficiency.
- Determine temperature distribution within the tank (stratification).
- Determine system performance degradation.

The test program was conducted in accordance with References 2.1 and 2.2.

2.0 REFERENCES

2.1	DOE/NASA CR-150841	Largo Hot Water System Thermal Performance Test Report
2.2	ASHRAE 93-77	Method of Testing Solar Collectors Based on Thermal Performance

3.0 TEST REQUIREMENTS AND PROCEDURES

3.1 System Thermal Efficiency Requirements

Thermal performance evaluation criteria shall correspond to that of Reference 2.1. Measurements and data shall be accumulated over an operational period of approximately one year, under natural climatic conditions. The test shall be conducted at the Test Bed No. 1 Facility, as shown in Figure 1, using a simulated hot water load schedule. Complete weather records will be maintained, as well as the following test parameters:

1. Ambient temperature
2. Collector inlet liquid temperature
3. Collector outlet liquid temperature
4. Liquid flow rate
5. Insolation rate
6. Wind speed and direction
7. Auxiliary energy consumed by the system
8. Temperature profile within the domestic hot water tank

3.2 Test Procedure

1. Mount and instrument the system as shown in Figures 1 and 2.

2. Turn on city water supply to domestic water heater. Supply power to the freeze protection system, pump and domestic water heater.

3. Tests performed shall be on a 24 hour basis, with data accumulation during the normal work schedule. Monday through Friday, from 8:00 A.M. until 4:00 P.M.

4. The daily operational hot water loading sequence shall be a 21 gallon load at 8:00 A.M. and 12:00 Noon.

5. The water will be drained from the domestic water heater at a rate of 3 ± 0.2 GPM into a graduated container.

6. Throughout the test interval, data will be accumulated by the computerized data acquisition system in Building 4646.

4.0 ANALYSIS OF RESULTS

4.1 Thermal Performance Test

The analysis of data contained in this report is in accordance with the National Bureau of Standards recommended approach. This approach is outlined below.

The efficiency of a collector is stated as:

$$\eta = \frac{q_u/A}{I} = \frac{\dot{m}\, C_{tf}\, (t_{f,e} - t_{f,i})}{I} \qquad (1)$$

where:

q_u = rate of useful energy extracted from the solar collector (BTU/Hr)

A = Gross collector area (Ft^2)

I = Total solar energy incident upon the plane of the solar collector per unit time per unit area ($BTU/Hr \cdot Ft^2$)

$\dot{m}$ = Mass flow rate of the transfer liquid through the collector per unit area of the collector ($Lbm/Ft^2 \cdot Hr$)

C_{tf} = Specific heat of the transfer liquid (BTU/Lb·°F)

$t_{f,e}$ = Temperature of the transfer liquid leaving the collector (°F)

$t_{f,i}$ = Temperature of the transfer liquid entering the collector (°F)

Rewriting Equation (1) in terms of the total collector area yield:

$$\eta = \frac{(\dot{m}A)\, C_{tf}\, (t_{f,e} - t_{f,i})}{(IA)} = \frac{\dot{M}\, C_{tf}\, (t_{f,e} - t_{f,i})}{P_i} \qquad (2)$$

Notice that:

$P_i = IA$ = Total power incident on the collector

$\dot{m}A = \dot{M}$ = Total mass flow rate through the collector

Therefore, $\dot{M}\, C_{tf}(t_{f,e} - t_{f,i})$ = Total power collected by the collector.

4.0 ANALYSIS AND RESULTS (Continued)

4.1 Thermal Performance Test (Continued)

Substitution in Equation (2) results in:

$$\eta = \frac{Pabs}{Pinc} \tag{3}$$

where:

Pabs = Total collected power

Pinc = Total incident power

This value of efficiency is expressed as a percentage by multiplying by 100. This expression for percent efficiency is:

$$\text{Collector Efficiency} = \frac{Pabs}{Pinc} \times 100 \tag{4}$$

or from Equation (2), collector efficiency is defined by the equation:

$$\%\ Eff = \frac{\dot{M}\ C_{tf}\ (t_{f,e} - t_{f,i})}{Pinc} \times 100 \tag{5}$$

Each term in Equation (5) was measured and recorded independently during the test.

The mean value of efficiency was determined over a five-minute period during which the test conditions remained in a quasi-steady state. Each five-minute period constitutes one "data point" as is graphically depicted on a plot of percent efficiency versus

$$\left(t_i - t_a)/I \right)$$

where:

t_i = Liquid inlet temperature (°F)

t_a = Ambient temperature (°F)

I = Incident flux per unit area ($BTU/Hr \cdot Ft^2$)

The abscissa term $\left((t_i - t_a)/I\right)$ was used to normalize the effect of operating at different values of I, t_i and t_a. The results are shown graphically in Figures 3 and 4.

4.0 ANALYSIS AND RESULTS (Continued)

4.1 Thermal Performance Test (Continued)

Analyses were performed of data obtained from Largo system tests to evaluate thermal performance parameters. Equations used to evaluate the test data are indicated in the following paragraphs.

Solar Energy Available

The total daily solar energy available was calculated for the interval of time that the Largo system controller and simultaneously the data acquisition system were active.

$$Q_s = \int_{\tau_1}^{\tau_2} I001 A_c \, d\tau$$

where,

Q_s = Total daily solar energy available

A_c = Gross collector area

I001 = Measured solar insolation

τ = Time

Solar Energy Collected

The quantity of solar energy collected on a daily basis was evaluated by

$$Q_c = \int_{\tau_1}^{\tau_2} W370 C_p \ (T171 - T170) \, d\tau$$

where,

Q_c = Solar energy collected

W370 = Liquid flow rate

C_p = Specific heat

T171 = Collector fluid outlet temperature

T170 = Collector fluid inlet temperature

τ = Time

Hot Water Load

The total daily hot water loads were evaluated using the equation,

4.0 ANALYSIS AND RESULTS (Continued)

4.1 Thermal Performance Test (Continued)

$$Q_H = C_p \sum_{n=0}^{n} M_n (T372-T371)_n$$

where,

Q_H = Total daily hot water load

C_p = Specific heat

M = Mass of water during each load

(T372-T371) = Temperature difference between outlet to load and city water inlet during each load interval

Total Electrical Energy

The total electrical energy was the sum used by the hot water heater element and the pump.

$$Q_E = \int_{\tau_1}^{\tau_2} EP370 d\tau + \int_{\tau_1}^{\tau_2} EP371 d\tau$$

where,

Q_E = Total electrical energy used

EP370 = Electrical power of heater element

EP371 = Electrical power of pump

τ = Time

Overall Heat Transfer Loss Coefficient of Hot Water Tank

This parameter was evaluated by the recording of liquid temperature existing in the tank and the ambient air temperature over night on a strip chart. Temperature sensors used to establish liquid temperature profiles were used to determine a bulk average temperature transient and the overall loss coefficient was evaluated by,

$$U_L = \frac{V_t \rho C_p (\overline{T}i-\overline{T}f)}{\Delta\tau (\overline{T}w-\overline{T}a)}$$

where,

4.0 ANALYSIS AND RESULTS (Continued)

4.1 Thermal Performance Test (Continued)

U_L = Overall tank heat transfer coefficient

V_t = Volume of tank

ρ = Density

C_p = Specific heat

$\bar{T}i$ = Initial liquid bulk average temperature

$\bar{T}f$ = Final liquid bulk average temperature

$\Delta\tau$ = Time interval from initial to final conditions

$\bar{T}w$ = Arithmetic average temperature of bulk liquid for time interval

$\bar{T}a$ = Arithmetic average ambient air temperature for time interval

Test data was recorded over a 24 hour basis to evaluate the overall heat transfer loss coefficient (U_L) of the domestic water heater. This test data consisted of bulk average temperature of water in the tank and the ambient air temperature which are shown graphically in Figure 5 as functions of time. The overall tank heat transfer coefficient was determined to be 9.6 BTU/Hr·°F. This value was utilized to obtain the daily system losses indicated in Table I. Table I provides a summary of the long range thermal performance test results.

The average daily system efficiency for the long range performance evaluation was approximately 25 per cent. Daily values at the end and beginning of test correspond to this value, indicating no obvious degradation.

Typical temperature stratification effects are shown in Figure 6. It is apparent from this graph that a limited amount of mixing existed in the tank, prior to the 21 gallon load. Circulation of fluid through the tank by the system pump relaxes the stratification effects which existed prior to activation of the pump.

TABLE I

Summary of Largo Long Range Thermal Performance
(Daily Values Based on Approximate 8 Hour Working Day 8:00 AM to 4:00 PM)

Test Date	Total Solar Energy Available, BTU	Total Energy Collected, BTU	Daily Collector Efficiency, %	Total Electrical Energy Used, BTU	Daily System Losses, BTU	Daily System Efficiency, %
10/3/77	82518	22866	27.7	1792	2592	25
10/6/77	41170	10950	26.6	1703	691	25
10/14/77	79901	21429	28.8	1755	3758	22
4/21/78	73471	20100	27.36	5631*	3205	23
4/27/78	77788	23300	29.96	9625*	2842	26
5/22/78	34974	6170	17.64	1584	2841	10
5/23/78	41226	14300	34.69	1594	1313	32
5/25/78	59515	17100	28.73	1652	2243	25
6/13/78	59008	17900	30.33	1420	2202	27
6/14/78	67838	20200	29.78	1751	2995	25
6/15/78	59961	18200	30.35	1672	3261	25
6/20/78	41381	14500	35.04	1075	1647	31
6/21/78	41170	11400	27.70	1365	2611	21
6/22/78	46590	15500	33.27	1355	2256	28
6/23/78	52900	14700	27.79	1553	2321	23
6/27/78	59005	16700	28.30	1590	3164	23
6/29/78	57893	18400	31.78	1717	2304	28

* Auxiliary Electrical Heater Activated to Maintain Minimum Temperature

TABLE I (Continued)

Test Date	Total Solar Energy Available, BTU	Total Energy Collected, BTU	Daily Collector Efficiency, %	Total Electrical Energy Used, BTU	Daily System Losses, BTU	Daily System Efficiency, %
7/5/78	77162	17000	22.03	1160	1989	19
7/6/78	44596	7450	16.71	1587	3337	9
7/7/78	59872	18100	30.23	1754	2396	26
7/10/78	48880	14405	29.47	1485	3552	22
7/17/78	55510	14900	26.84	1198	2957	22
7/19/78	56550	18000	31.83	1563	2621	27
7/20/78	53898	17600	32.65	1618	3519	26
7/21/78	61351	17600	28.69	1567	3304	23
7/26/78	68997	21300	30.87	1638	3164	26
7/28/78	53850	16900	31.38	1471	2442	27

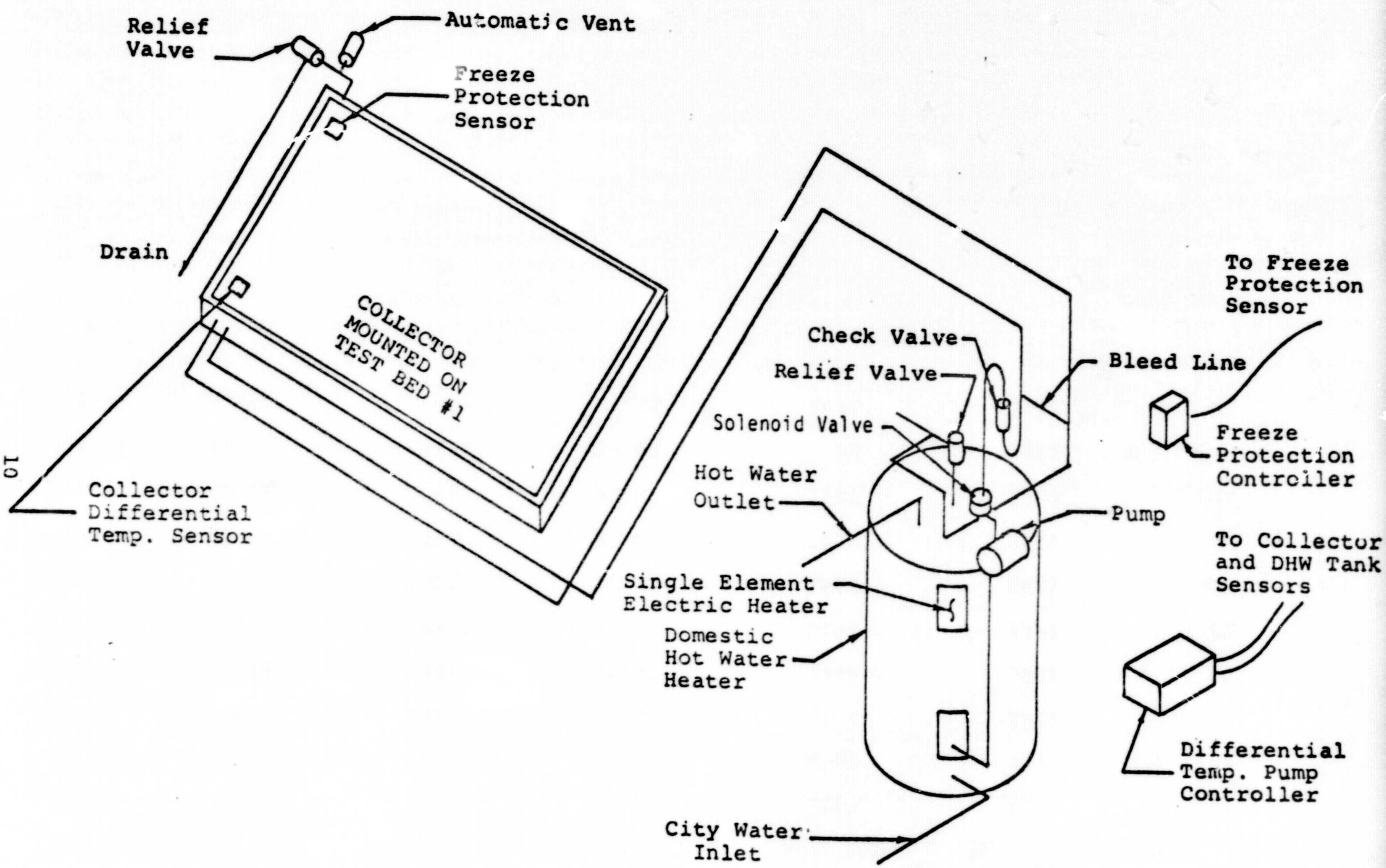

Figure 1. LARGO Solar Hot Water System Installation Schematic

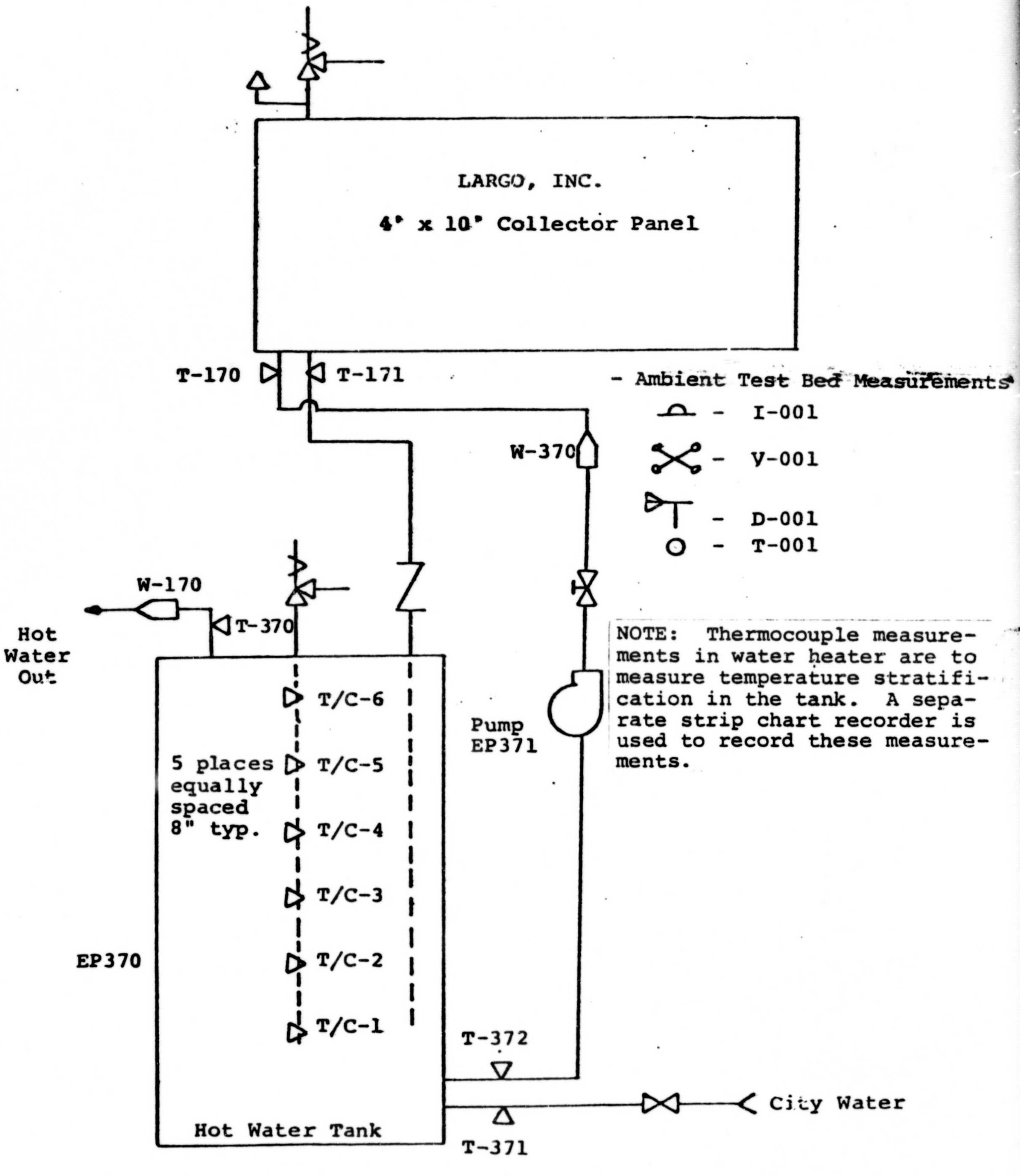

Figure 2. Sketch of Modified Piping on LARGO System with Instrumentation Locations

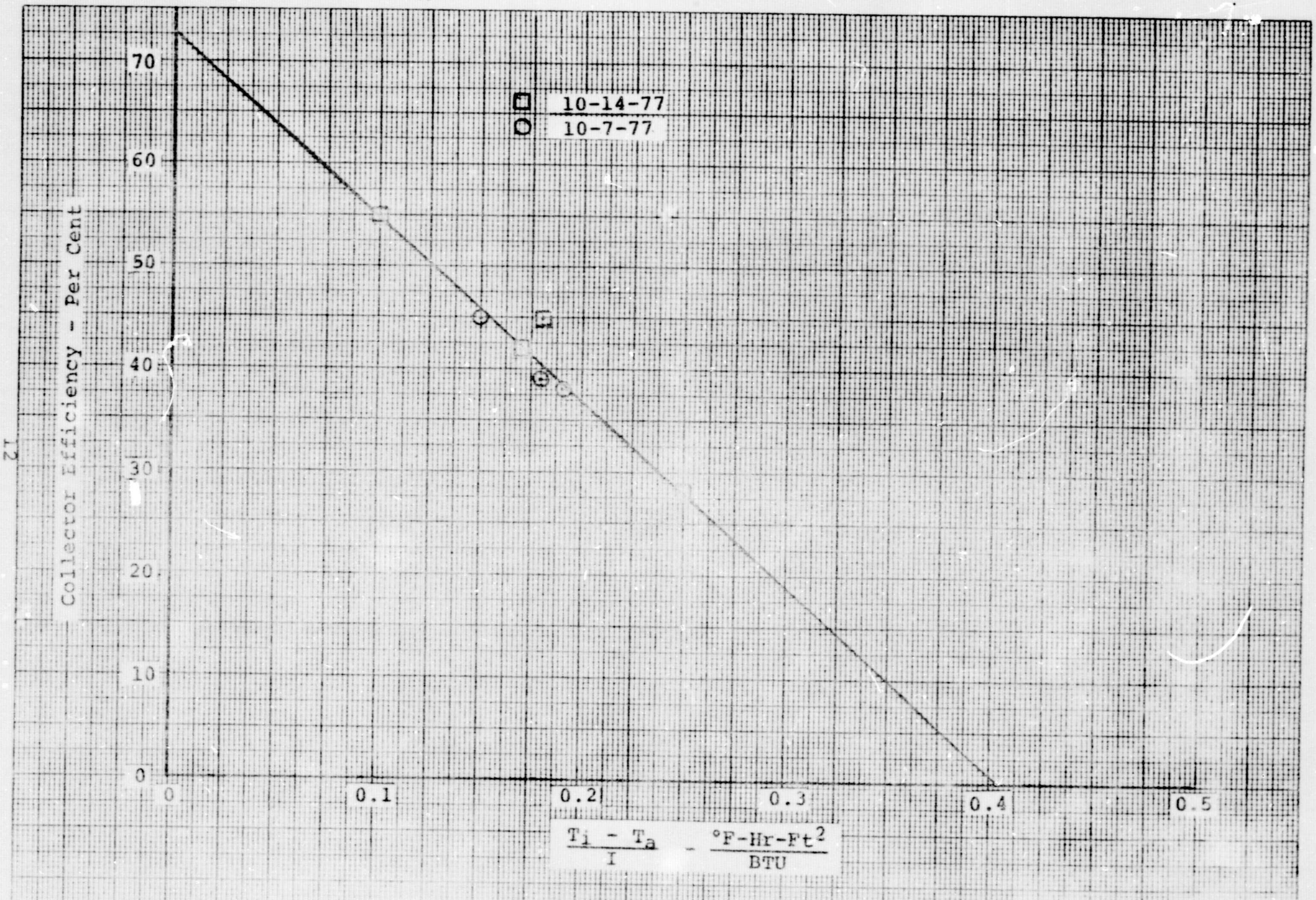

Figure 3. Largo Collector Thermal Performance During Initial Testing

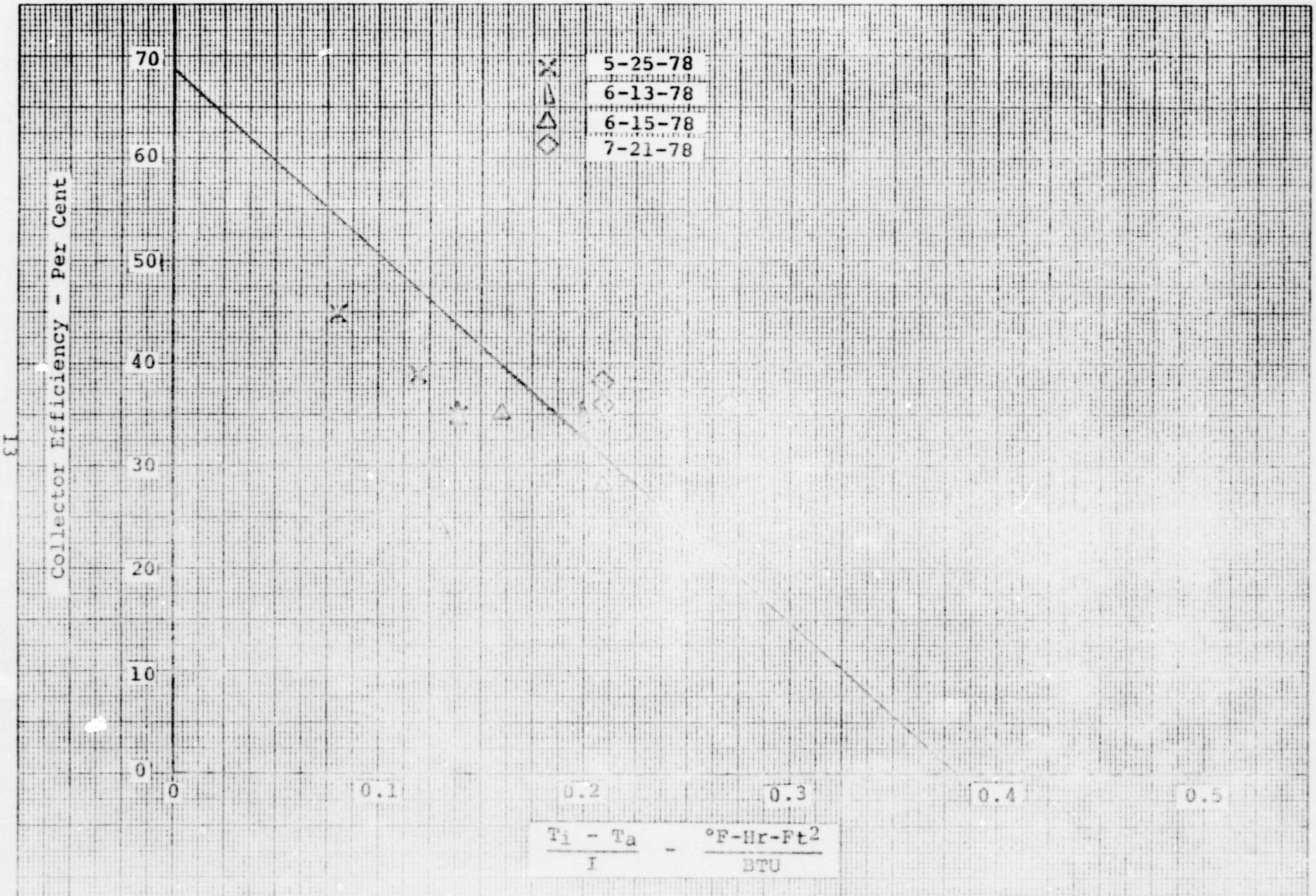

Figure 4. Largo Collector Thermal Performance During Long Range Testing

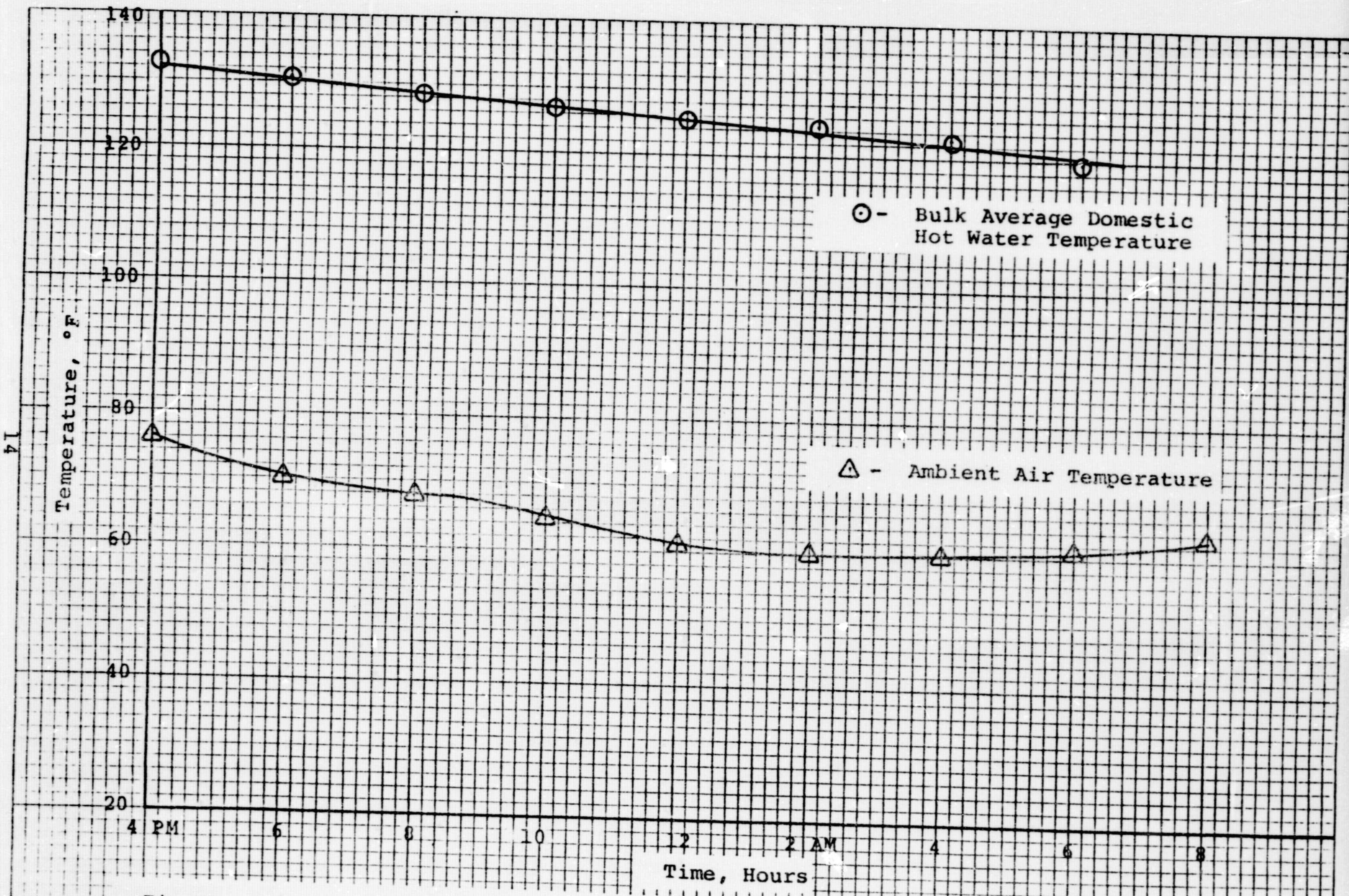

Figure 5. Plot of Measured Bulk Average Domestic Hot Water Temperature and Ambient Air Temperature Versus Time (9/28/77)

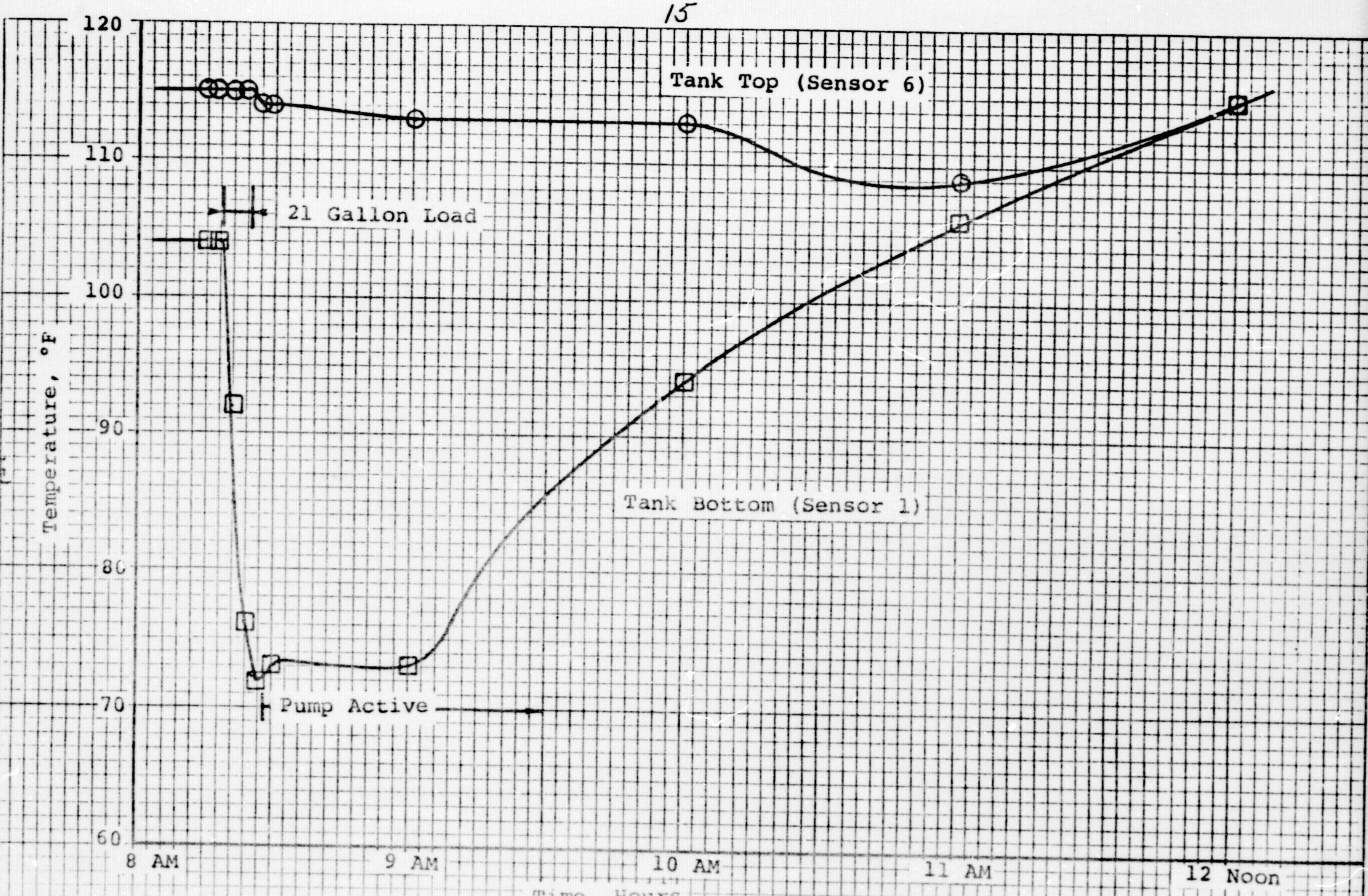

Figure 6. Typical Temperature Stratification Measurements During System Operation (October 13, 1977)