DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-161236

INDOOR TEST FOR THERMAL PERFORMANCE EVALUATION OF SEVEN ELCAM FIN-TUBE SOLAR COLLECTOR CONFIGURATIONS

Prepared by

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Contract NAS8-32036

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

For the U. S. Department of Energy

(NASA-CR-161236) INDOOR TEST FOR THERMAL PERFORMANCE EVALUATION OF SEVEN ELCAM FIN-TUBE SOLAR COLLECTOR CONFIGURATIONS (Wyle Labs., Inc.) 33 p HC A03/MF A01 CSCL 10A G3/44

N79-27657

Unclas 29221

U.S. Department of Energy

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SUMMARY

Thermal performance tests have been conducted on seven Elcam solar collector absorber plates. Three basic fin-tube designs, as shown in Figures 2 through 4, were evaluated, with the addition of thermal compound (Eccotherm TC-4) and turbulating deformations as parameters. The tests were conducted indoors utilizing the Marshall Space Flight Center Solar Simulator to eliminate large excursions in the available solar flux, wind, and ambient temperature. The absorber plates were also removed from the SUNSPOT #3200 collector enclosure and tested individually, using the apparatus shown in Figure 1. The individual testing eliminated the tedious effort required to balance the flow rate.

Results of the tests are shown graphically in Figures 5 through 12. Tables I through VII contain supporting test data recorded during the tests. Table VIII provides a summary of the test results, indicating efficiency as a function of inlet temperature.

1.0 PURPOSE

The purpose of this report is to present the test procedures used and the test results obtained in conducting an evaluation test program to determ ne the thermal performance of seven Elcam fin-tube solar collector absorber plate configurations. The tests were conducted utilizing the Marshall Space Flight Center Solar Simulator in accordance with the test procedures of Reference 2.1 and the test requirements of Reference 2.2.

2.0 REFERENCES

2.1	MTCP-FA-SHAC-400	Procedure for Operation of the MSFC Solar Simulator Facility
2.2	ASHRAE-93-77	Methods of Testing to Determine the Thermal Performance of Solar Collectors

3.0 MANUFACTURER

Elcam, Inc.
Santa Barbara, California

3.1 Description of Test Specimen

The test articles each consist of an absorber plate 5.9 inches wide by 83 inches long and a type M copper tube of 0.569 inch nominal inside diameter. No cover plate was used with any of the specimens. The uniqueness of each of the seven configurations is described below:

(1) The base fin shown in Figure 2. Extruded aluminum fin 0.0625 inch thick, coated with a black siliconized polyester baked or air dried enamel, snaps around the tube.

(2) Same as (1) except Eccotherm TC-4, heat transfer compound, was applied prior to snapping the tube into the fin.

(3) Same as (1) except a black chrome selective coating was used.

(4) The wraparound fin shown in Figure 3. A copper sheet 0.024 inch thick was secured around the tube. Eccotherm TC-4 was used between the fin and the tube. Coating same as (1). Pop rivets fastened the fin around the tube.

3.0 MANUFACTURER (Continued)

3.1 Description of Test Specimen (Continued)

(5) The integral tube-fin shown in Figure 4. A copper sheet 0.024 inch thick was used for fin and tube. The seam was silver soldered. The coating was the same as (1).

(6) Same as (2) except turbulating deformations were added to the tube. An approximate sine wave of 0.25 D amplitude and a period of 2 D, where D is the inside tube diameter. The frequency was 10 D.

(7) Same as (4) except the fin/tube material was 0.022 inch thick aluminum sheet.

4.0 TEST CONDITIONS AND TEST EQUIPMENT

4.1 Ambient Conditions

All tests were performed at ambient conditions existing in Building 4619 at the time of the tests.

4.2 Instrumentation and Equipment

All test equipment and instrumentation used in the performance of this test program comply with the requirements of MSFC MMI 5300.4C, Metrology and Calibration. A standard test setup is depicted in Reference 2.1.

Apparatus	Manufacturer/Model	Range/Accuracy
Liquid Loop	MSFC Supplied	0.1 - 1.12 GPM
Flowmeter	Foxboro/1/2 - 2 81T361	0.1 - 1.2 GPM ± 1%
Temperature Sensor	Analog Devices	0-500°F ± 0.1°F
Pyranometer	Eppley - PSP	0-800 $BTU/Ft^2 \cdot Hr$ (Class 1)
Strip Chart Recorder	Mosley 680	5-500 MV ± 2%
Solar Simulator	MSFC Supplied	See Reference 2.1

5.0 REQUIREMENTS, PROCEDURES AND RESULTS

5.1 Indoor Thermal Performance Evaluation Test Requirements

The requirements of this test were to obtain performance data at inlet temperatures of ambient, ambient + 50°F, and ambient + 100°F, with a controlled liquid flow rate of 0.15 GPM at solar flux levels of 300 BTU/Hr-Ft^2. The tests were repeated for a liquid flow rate of 0.30 GPM. The following data were recorded for the tests:

(1) Ambient temperature (°F)

(2) Solar flux (BTU/Hr-Ft^2)

(3) Liquid flow rate (GPM)

(4) Wind Speed (MPH)

(5) Liquid Inlet Temperature (°F)

(6) Liquid Outlet Temperature (°F)

Liquid temperature measurements were taken from locations identified in Figure 1.

5.2 Test Procedure

(1) Prepare test setup as shown in Figure 1; mounting specimen fixture on the test table at an angle of 45° with respect to the floor and connect instrumentation leads to the data acquisition system.

(2) Assure that the simulator lamp array is adjusted to a 45° angle with respect to the floor.

(3) Align the test table so that the test specimen's vertical centerline coincides with the vertical centerline of the lamp array and the distance from the test specimen to the plane of the lamp array lens is 9 feet.

(4) Assure that the data acquisition system is operational.

(5) Power up the simulator and establish a solar flux level of 300 BTU/Hr-Ft^2.

(6) Assure that the wind speed is 0 mph.

(7) Establish the required liquid flow rate of 0.15 GPM.

(8) Determine the ambient temperature.

5.0 REQUIREMENTS, PROCEDURES AND RESULTS

5.2 Test Procedure

(9) Adjust the liquid inlet temperature to equal the ambient air temperature.

(10) After steady state conditions have been established, record data at one minute intervals for five minutes.

(11) Repeat steps 8, 9, and 10, changing the liquid inlet temperature as stated in paragraph 5.1, until all of the specified data has been obtained.

(12) Repeat steps 8 through 11 with a liquid flow rate of 0.30 GPM.

(13) Upon completion of testing, power down the simulator and liquid loop.

5.3 Results

The results obtained during the testing of the seven configurations are shown graphically in Figures 5 through 11, respectively. A summary of the graphic results is shown in Figure 12. The supporting data obtained during the tests is shown in Tables I through VII, with a summary shown in Table VIII.

6.0 ANALYSIS OF RESULTS

6.1 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.

6.0 ANALYSIS AND RESULTS (Continued)

6.1 Thermal Performance Test (Continued)

Substitution in Equation (2) results in:

$$\eta = \frac{Pabs}{Pinc} \quad (3)$$

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:

$$\text{Collector Efficiency} = \frac{Pabs}{Pinc} \times 100 \quad (4)$$

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

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

Each term in Equation (5) was measured and recorded independently during the test. The calculated values of efficiency were determined at sixty-second intervals. 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·Ft^2)

The abscissa term $\left((t_i - t_a)/I\right)$ was used to normalize the effect of operating at slightly different values of I, t_i and t_a. The results are shown graphically in Figures 5 through 11 with the supporting test data given in Tables I through VII.

6.0 ANALYSIS AND RESULTS (Continued)

6.1 Thermal Performance Test (Continued)

Reference 2.2 uses the following terms relating to the graphical presentation of solar collector thermal efficiency data:

$F_R \alpha \tau$ = intercept of the efficiency curve on the ordinate axis

$F_R U_L$ = the negative of the slope of the efficiency curve

F_R = the solar heat removal factor

α = absorptance of the collector surface for solar radiation

τ = transmittance of the solar collector cover plate

U_L = solar collector heat transfer loss coefficient

No cover plate was used in these tests; therefore $\tau = 1$. The factors determining F_R and U_L are basically thermophysical properties - such as thermal conductivity, emissivity and absorptivity - geometry, and flow rate. The interrelations of these factors allow different configurations to perform better at different liquid inlet temperatures.

The selectively coated absorber plate did out perform all others in overall performance. Adding thermal compound did slightly increase F_R, but without a compensating decrease in U_L the overall efficiency was decreased. Table VIII contains a summary of the overall performance rankings and a comparison of performance at a low inlet temperature and a medium inlet temperature.

TABLE I

THERMAL PERFORMANCE TEST DATA
FOR ELCAM CONFIGURATION #1

Solar Flux BTU/Hr-Ft^2	Flow GPM	T_{in} (°F)	T_{out} (°F)	$T_{ambient}$	$T_{out}-T_{in}$	$\frac{T_{in}-T_{amb}}{I}$	Efficiency (Per Cent)
303.0	0.301	88.0	93.0	73.4	5.0	0.048	72.7
303.0	0.150	89.9	99.2	74.1	9.3	0.052	67.3
303.0	0.297	126.9	129.3	75.8	2.4	0.168	33.8
303.0	0.153	125.4	130.1	76.1	4.7	0.163	34.3
303.0	0.298	180.2	178.6	79.4	-1.6	0.333	-22.3
303.0	0.148	176.1	174.0	79.7	-2.1	0.318	-14.5

TABLE II

THERMAL PERFORMANCE TEST DATA
FOR ELCAM CONFIGURATION #2

Solar Flux BTU/Hr-Ft^2	Flow GPM	T_{in} (°F)	Tout (°F)	$T_{ambient}$	$T_{out}-T_{in}$	$\frac{T_{in}-T_{amb}}{I}$	Efficiency (Per Cent)
302.3	0.302	88.4	93.7	76.2	5.3	0.0404	76.5
302.3	0.151	90.5	100.6	77.2	10.1	0.0440	73.4
302.3	0.297	126.7	129.0	77.6	2.3	0.1624	32.5
302.3	0.151	125.2	130.3	79.3	5.1	0.1518	36.7
298.5	0.294	174.5	172.5	77.9	-2.0	0.3236	-27.98
298.5	0.151	170.6	168.5	79.1	-2.1	0.3065	-15.42

TABLE III

THERMAL PERFORMANCE TEST DATA FOR ELCAM CONFIGURATION #3

Solar Flux BTU/Hr-Ft^2	Flow GPM	T_{in} (°F)	T_{out} (°F)	$T_{ambient}$	$T_{out}-T_{in}$	$\frac{T_{in}-T_{amb}}{I}$	Efficiency (Per Cent)
298.9	0.299	87.9	93.7	80.3	5.8	.025	84.97
298.9	0.152	91.4	101.7	82.0	10.3	.031	76.30
298.9	0.299	129.8	133.2	83.5	3.4	.154	49.00
298.9	0.157	128.6	135.3	83.5	6.7	.150	50.63
298.9	0.293	185.9	186.0	84.2	.1	.340	1.39
298.9	0.146	181.8	183.0	84.6	1.2	.325	8.29

TABLE IV

THERMAL PERFORMANCE TEST DATA
FOR ELCAM CONFIGURATION #4

Solar Flux BTU/Hr-Ft^2	Flow GPM	T_{in} (°F)	T_{out} (°F)	$T_{ambient}$	$T_{out}-T_{in}$	$\frac{T_{in}-T_{amb}}{I}$	Efficiency (Per Cent)
299.7	0.302	87.7	92.2	77.8	4.5	.033	66.0
299.7	0.151	89.0	97.1	78.6	8.1	.034	59.4
299.7	0.302	131.5	133.2	79.9	1.7	.172	24.71
299.7	0.153	130.0	133.6	80.3	3.6	.165	26.55
299.7	0.298	181.6	179.7	82.2	-.9	.328	-12.69
299.7	0.154	177.2	176.4	82.9	-.8	.314	- 5.85

TABLE V

THERMAL PERFORMANCE TEST DATA FOR ELCAM CONFIGURATION #5

Solar Flux BTU/Hr-Ft^2	Flow GPM	T_{in} (°F)	T_{out} (°F)	$T_{ambient}$	$T_{out}-T_{in}$	$\frac{T_{in}-T_{amb}}{I}$	Efficiency (Per Cent)
299.4	0.293	88.7	94.3	83.5	5.6	.017	79.75
299.4	0.152	93.0	103.4	84.0	10.4	.020	76.88
299.4	0.301	125.4	127.7	74.0	2.3	.171	33.32
299.4	0.151	123.3	128.5	74.8	5.2	.161	37.81
299.4	0.302	181.8	180.4	78.7	-1.4	.344	-20.05
299.4	0.146	177.6	175.7	79.4	-1.9	.327	-13.10

TABLE VI

THERMAL PERFORMANCE TEST DATA
FOR ELCAM CONFIGURATION #6

Solar Flux BTU/Hr-Ft^2	Flow GPM	T_{in} (°F)	T_{out} (°F)	$T_{ambient}$	$T_{out}-T_{in}$	$\frac{T_{in}-T_{amb}}{I}$	Efficiency (Per Cent)
300.9	0.302	89.5	94.8	74.8	5.3	.048	77.41
300.9	0.149	88.9	99.9	83.3	11.0	.018	79.14
300.9	0.300	138.3	130.8	78.4	2.5	.165	35.92
300.9	0.151	134.4	138.9	84.7	4.5	.165	32.57
300.9	0.302	182.8	180.6	79.8	-2.2	.342	-31.36
300.9	0.146	183.4	180.6	86.2	-2.8	.323	-19.22

TABLE VII

THERMAL PERFORMANCE TEST DATA FOR ELCAM CONFIGURATION #7

Solar Flux BTU/Hr-Ft^2	Flow GPM	T_{in} (°F)	T_{out} (°F)	$T_{ambient}$	$T_{out}-T_{in}$	$\frac{T_{in}-T_{amb}}{I}$	Efficiency (Per Cent)
300.9	0.302	88.4	92.6	83.0	4.2	.017	61.34
300.9	0.153	89.9	97.5	83.8	7.6	.020	56.32
300.9	0.299	132.8	134.6	84.9	1.8	.159	25.76
300.9	0.152	131.8	135.1	85.4	3.8	.152	26.90
300.9	0.299	189.0	187.5	86.3	-1.5	.341	-21.14
300.9	0.154	184.9	183.3	86.5	-1.6	.327	-11.66

TABLE VIII

RANKING OF THE SEVEN ELCAM CONFIGURATIONS
BASED ON OVERALL PERFORMANCE

Overall Rank	Configuration No.	Overall Performance Factor *		Low Temperature Efficiency at $(T_i - T_a)/I = 0.05$		High Temperature Efficiency at $(T_i - T_a)/I = 0.20$	
		0.30 GPM	0.15 GPM	0.30 GPM	0.15 GPM	0.30 GPM	0.15 GPM
1	3	31.32	30.84	78.0	73.7	38.2	38.2
2	5	23.94	24.37	70.5	70.5	24.6	25.7
3	6	24.53	22.65	76.0	69.2	22.0	20.8
4	1	24.13	23.04	73.2	68.8	22.6	22.6
5	2	22.76	22.91	73.5	71.2	18.4	20.4
6	4	20.29	19.16	60.4	55.3	20.2	20.2
7	7	16.98	16.60	53.3	49.5	14.9	16.2

* Overall performance factor is the value of $\eta\left(\frac{T_i - T_a}{I}\right)$ integrated over the range of η = Max. to η = 0. This factor applicable for comparison purposes for this test only.

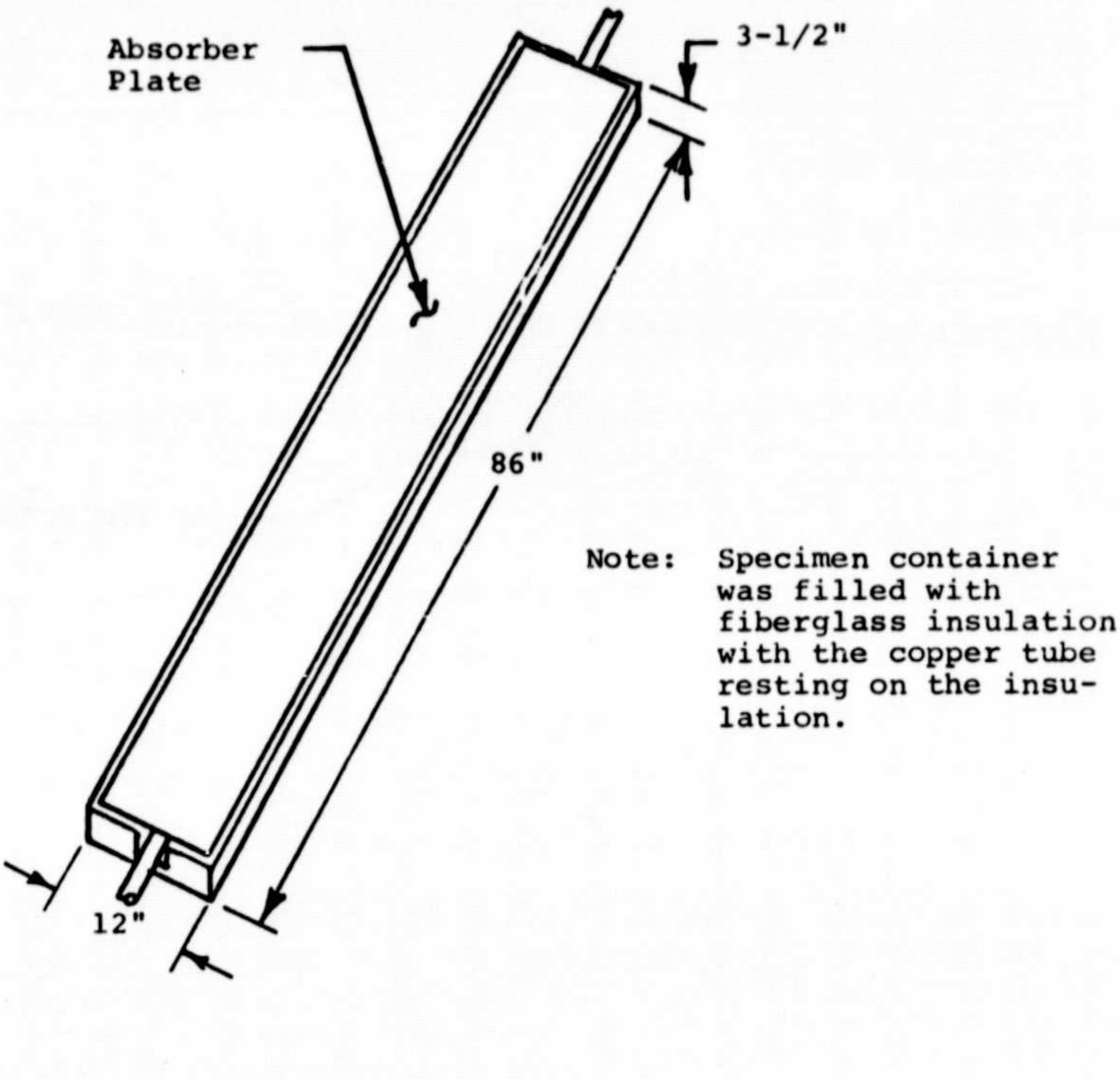


Figure 1. Schematic of Test Specimen and Supporting Apparatus

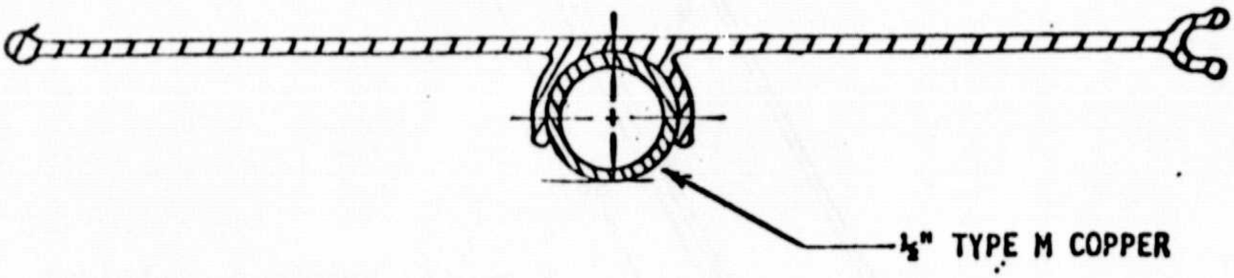


Figure 2. Basic Design for Elcam Configurations #1, #2, #3, and #6

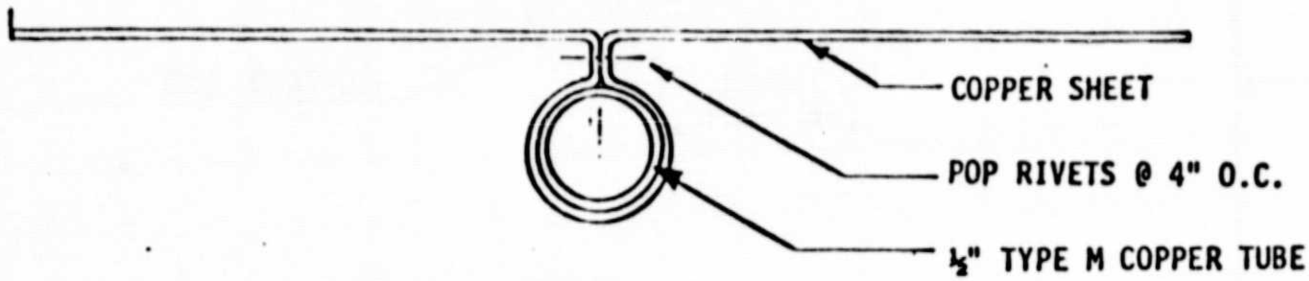
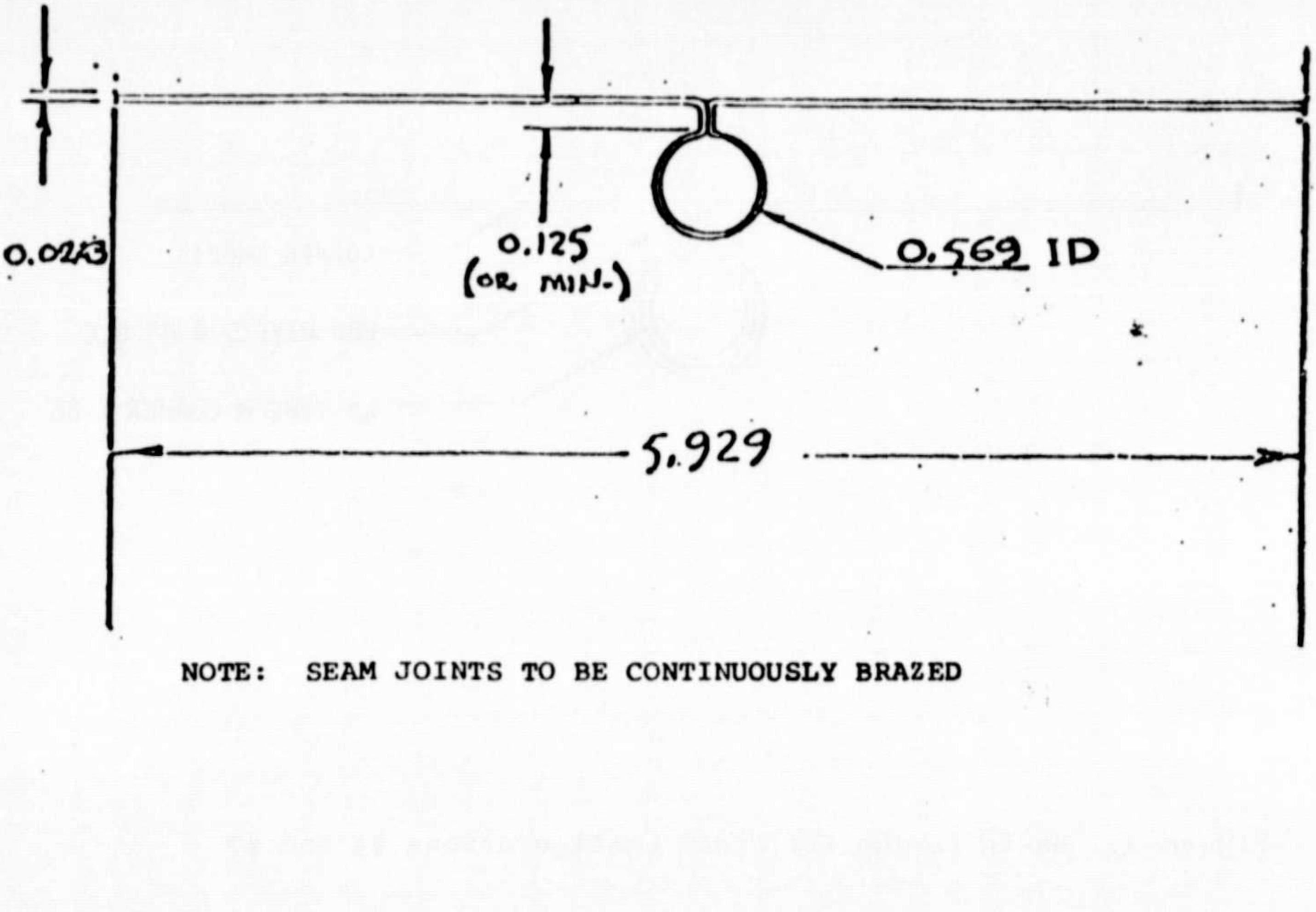


Figure 3. Basic Design for Elcam Configurations #4 and #7



NOTE: SEAM JOINTS TO BE CONTINUOUSLY BRAZED

Figure 4. Basic Design for Elcam Configuration #5

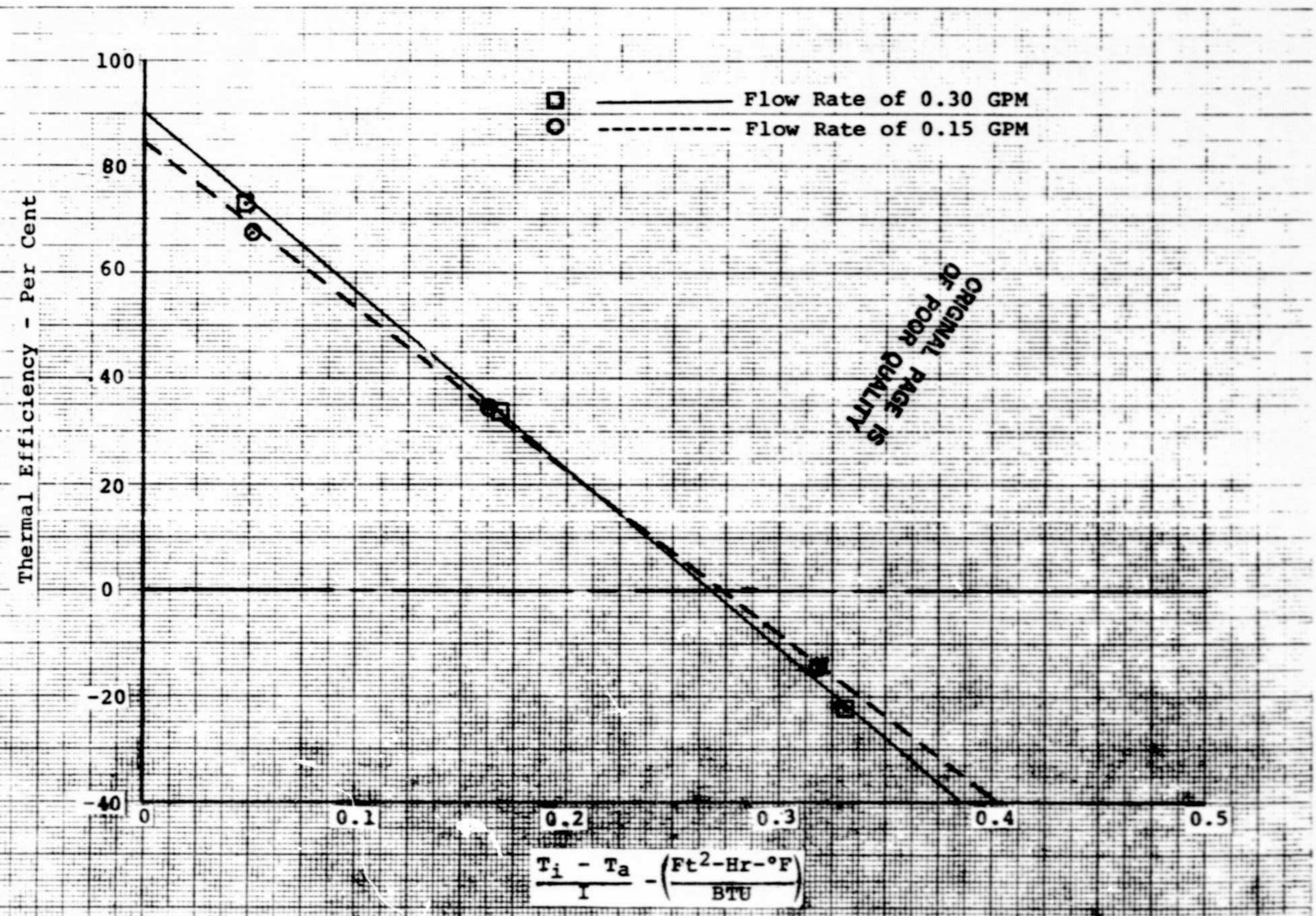


Figure 5. Indoor Thermal Performance Test Results for Elcam Fin-Tube Configuration #1

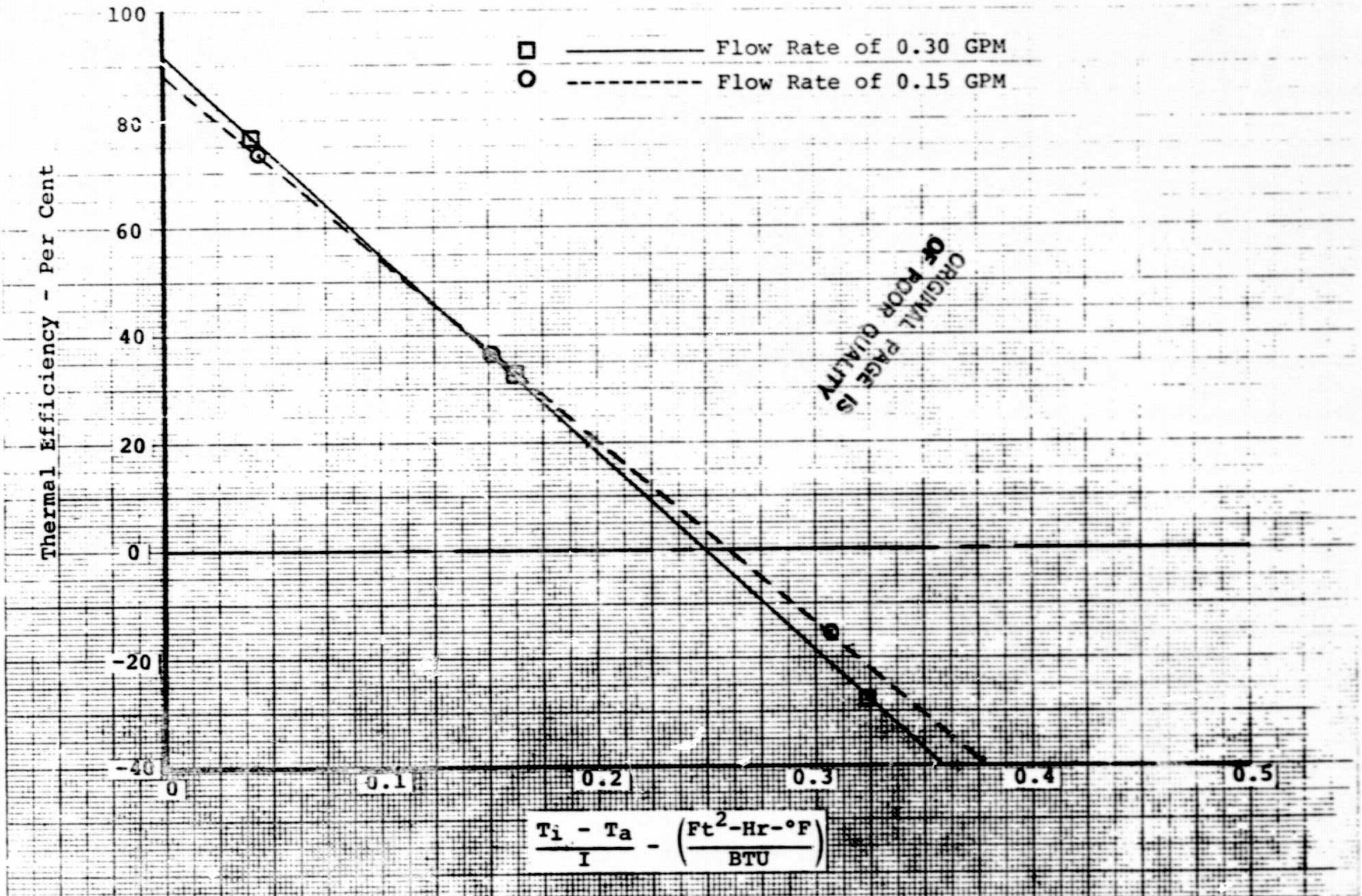


Figure 6. Indoor Thermal Performance Test Results for Elcam Fin-Tube Configuration #2

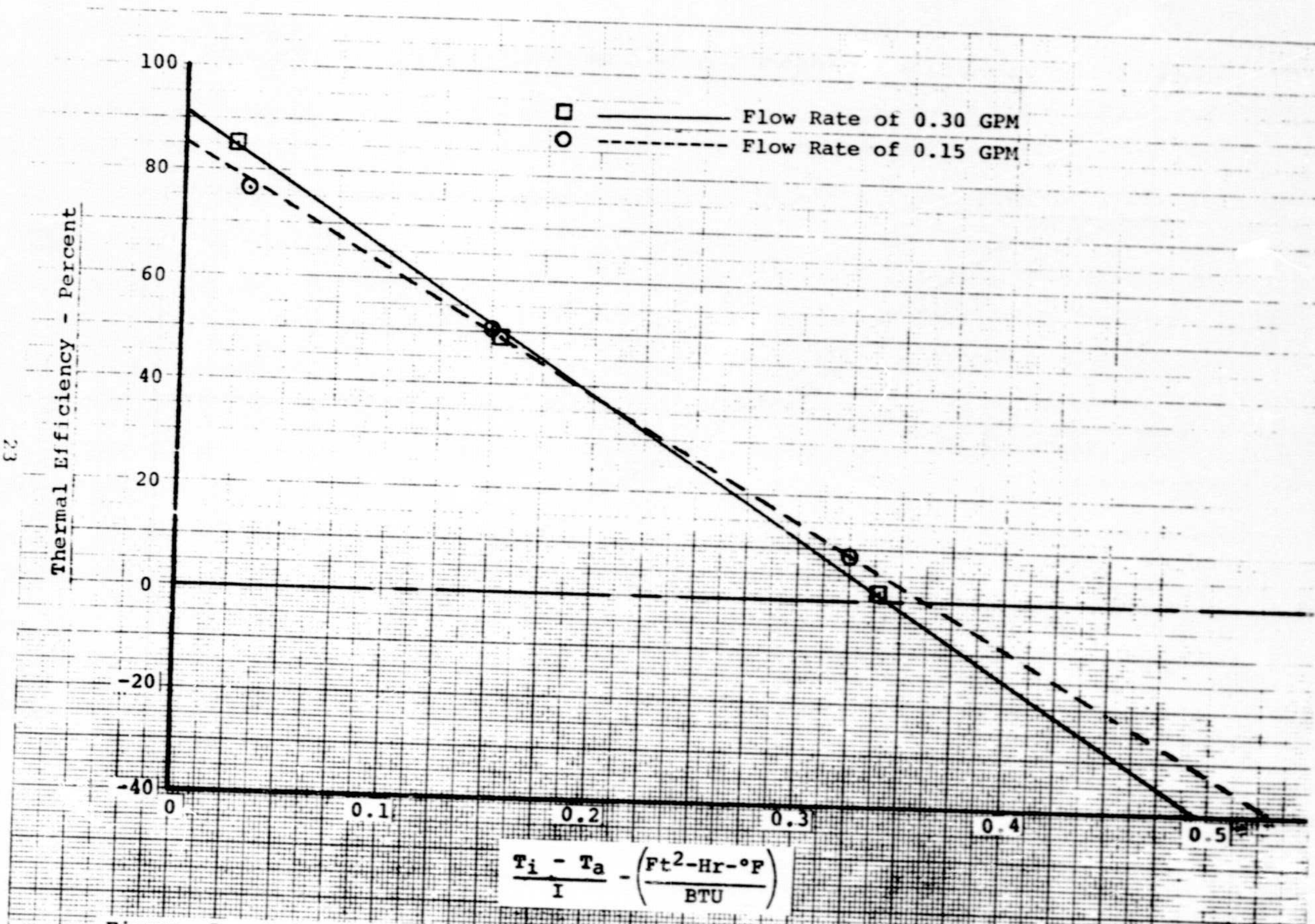


Figure 7. Indoor Thermal Performance Test Results for Elcam Fin-Tube Configuration #3

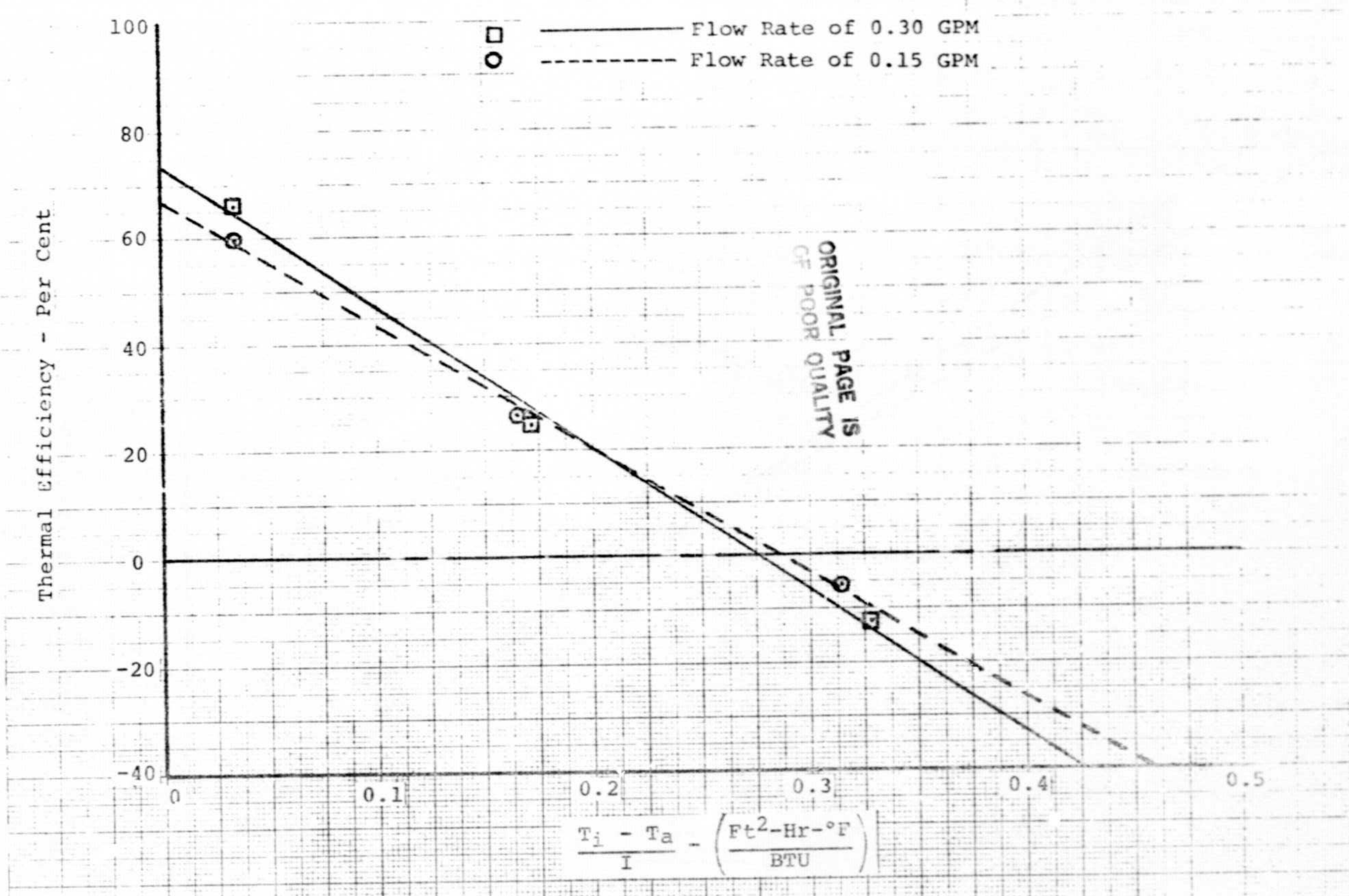


Figure 8. Indoor Thermal Performance Test Results for Elcam Fin-Tube Configuration #4

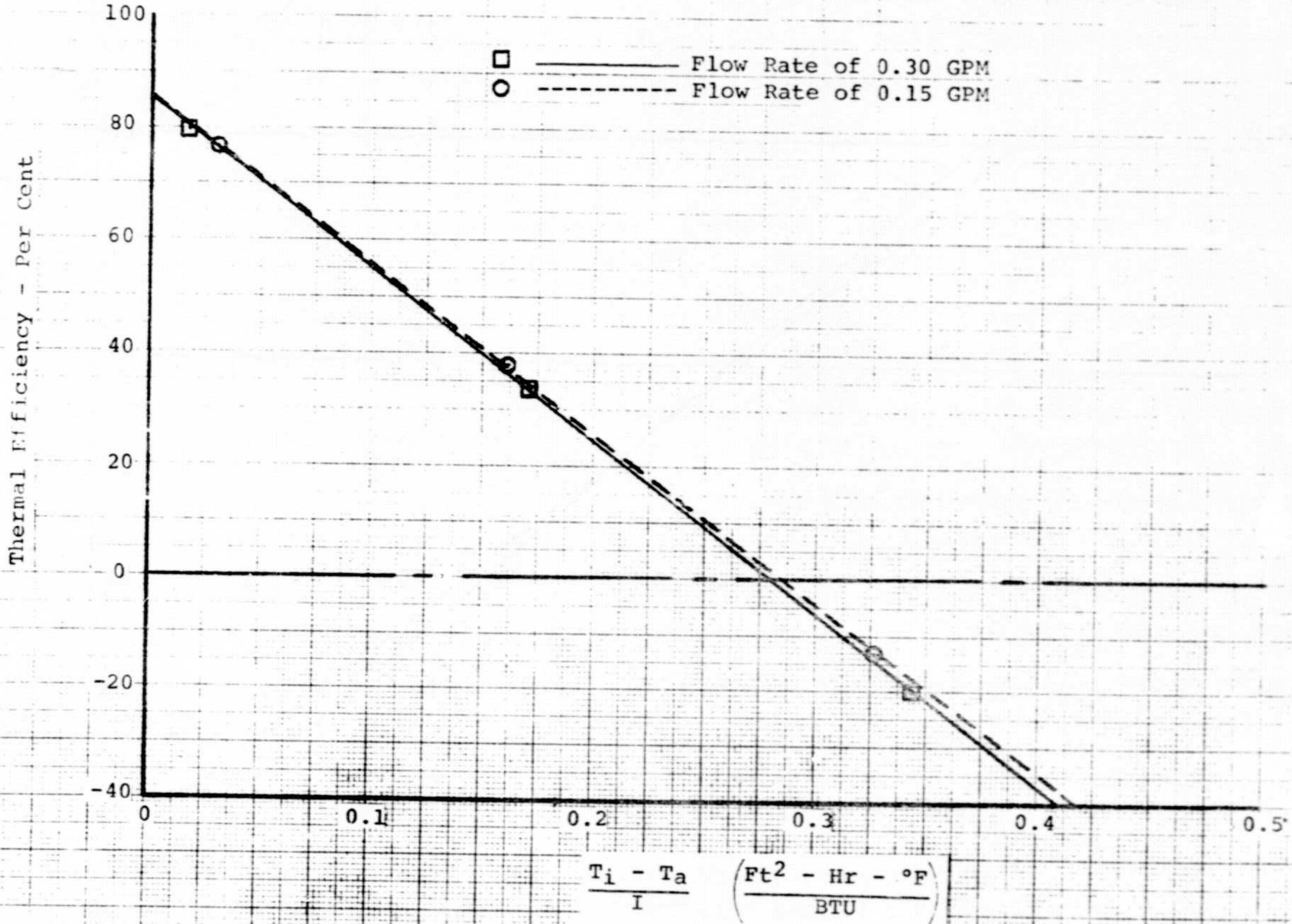


Figure 9. Indoor Thermal Performance Test Results for Elcam Fin-Tube Configuration #5

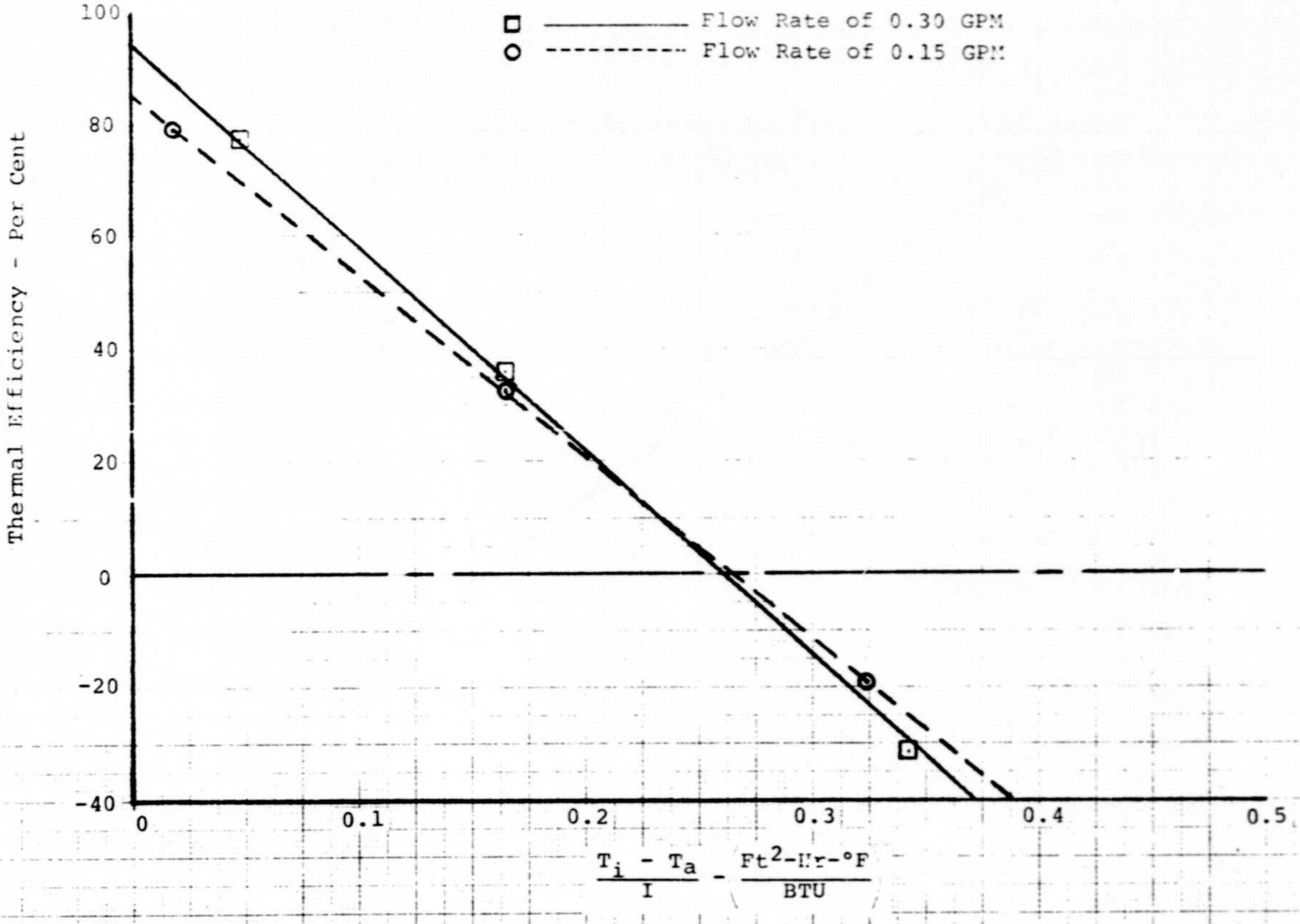


Figure 10. Indoor Thermal Performance Test Results for Elcam Fin-Tube Configuration #6

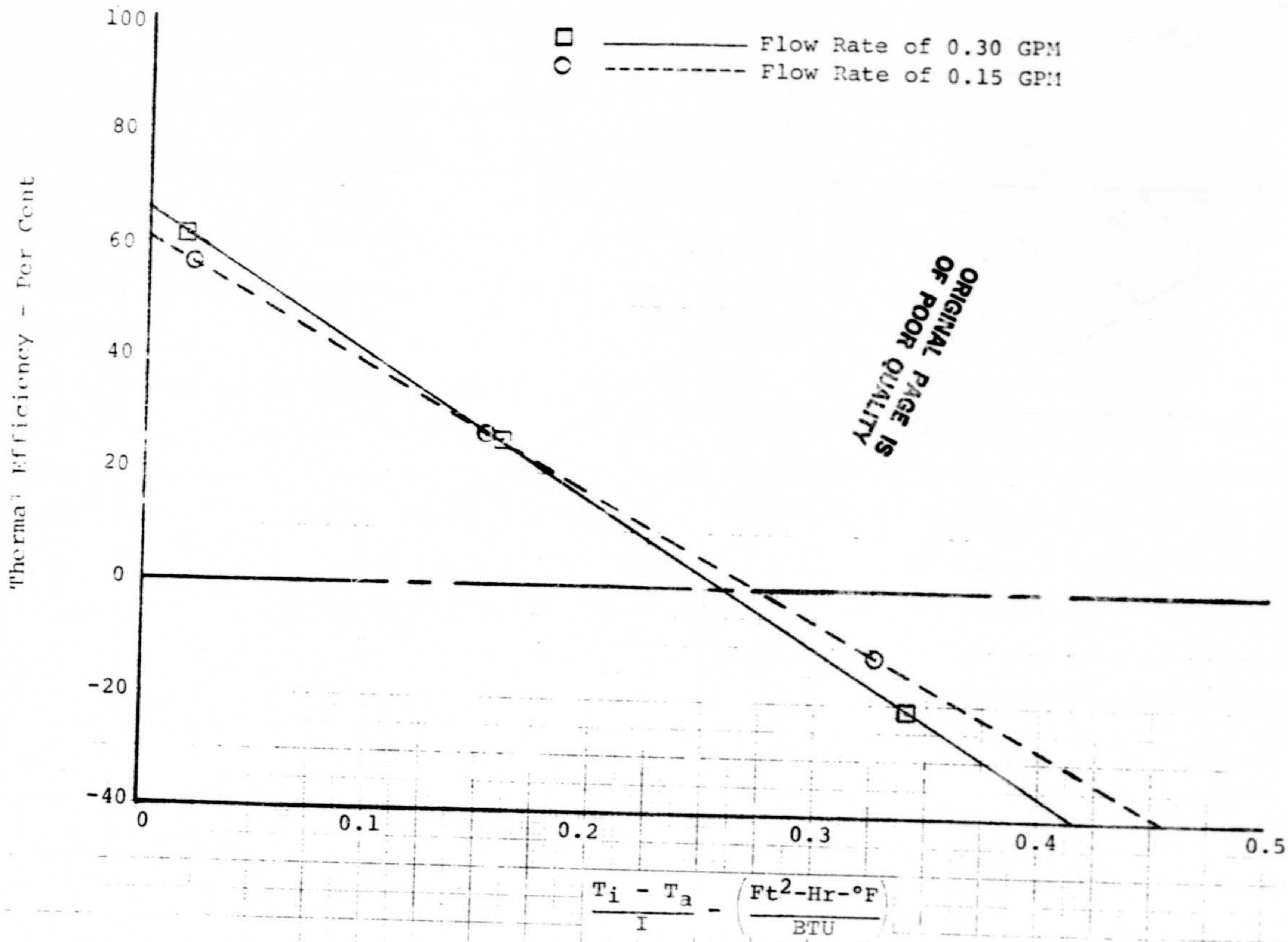


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Figure 11. Indoor Thermal Performance Test Results for Elcam Fin-Tube Configuration #7.

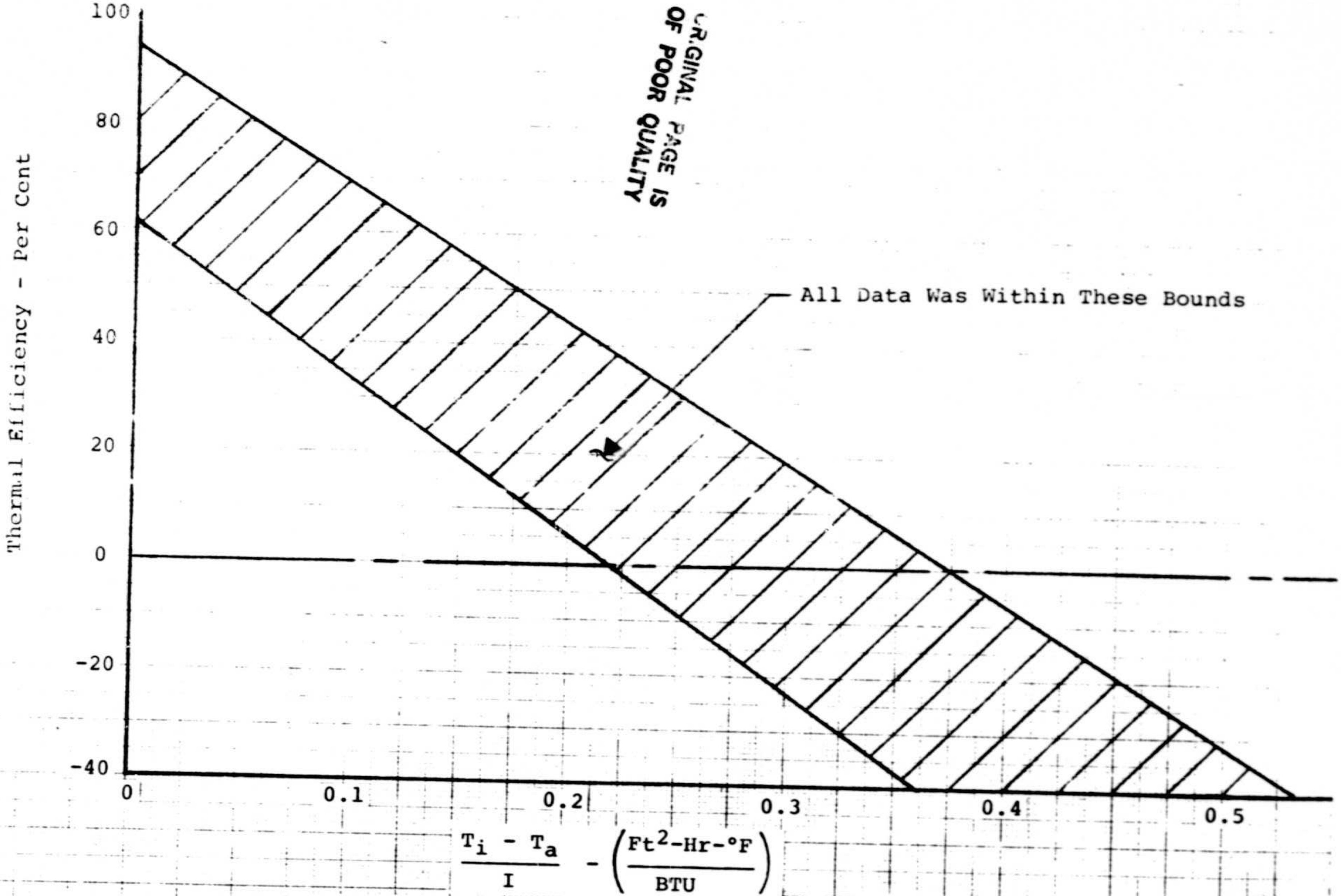

Figure 12. Summary of Thermal Performance Results for All Seven Elcam Configurations

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