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THERMAL PERFORMANCE OF MSFC HOT AIR COLLECTORS UNDER NATURAL AND SIMULATED CONDITIONS

Prepared by Wyle Laboratories, Solar Energy Systems Division, Huntsville, Ala.

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This work was done under the technical supervision of Charles N. Thomas of the Marshall Space Flight Center.

16. ABSTRACT

This report presents the procedures used and the results obtained from an evaluation test program conducted to determine the thermal performance and structural characteristics of selected MSFC-designed hot air collectors under both real and simulated environmental conditions. Five collectors, serial numbers 5, 6, 8, 10 and 11, were tested in the three-phased program. Phase one consisted of a series of outdoor tests to determine stagnation temperatures on a typical bright day and to determine each collector's ability to withstand these temperatures. Two of the collectors, S/N's 5 and 6, experienced structural deformation sufficient to eliminate them from the remainder of the test program. Of the three remaining collectors, S/N 10 was selected as the test article for the last two phases of the program. Phase two consisted of a series of outdoor tests to evaluate the thermal performance of collector S/N 10 under certain test conditions. The final phase of the program consisted of a series of indoor tests to evaluate the thermal performance of the collector under closely controlled simulated conditions.

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1.0 PURPOSE

The purpose of this report is to present the procedures used and the results obtained during the performance of an evaluation test program. The test program was conducted to determine the thermal performance and structural characteristics of selected MSFC designed hot air collectors under both real and simulated environmental conditions. The stagnation tests and outdoor performance tests were conducted under the direct supervision of MSFC ET-44 without benefit of a written procedure. The indoor performance tests were conducted in accordance with References 2.2 and 2.3. All tests were conducted in response to Reference 2.1.

2.0 REFERENCES

2.1	EP12-(75-23)	Testing of the MSFC Hot Air Collectors
2.2	MTCP-DC-SHAC-403	Test Procedure for the MSFC Solar Simulator Performance Test of MSFC Hot Air Collector S/N 10
2.3	MTCP-FA-SHAC-400	Procedure for Operation of the MSFC Solar Simulator
2.4	MSFC MMI-5300.4C	Metrology and Calibration

3.0 MANUFACTURER

National Aeronautics and Space Administration
Marshall Space Flight Center
Huntsville, Alabama

3.1 Description of Test Specimens

MSFC Hot Air Collectors, Serial Numbers 5, 6, 8, 10 and 11. The five collectors were identical except for the materials used to form the body. Collectors 5 and 6 were constructed of Olin 4 lb. foam while collectors 8, 10 and 11 were made of FSC 6850 foam. Absorber plates were 0.02" sheet metal coated with Caldwell black paint and each collector had a single cover made of standard glass. Each collector weighed approximately 21 pounds and had the following dimensions:

Width	38-1/8"
Length	74"
Depth	7"
Inlet and Outlet Ducts	3-5/8" by 15"

4.0 SUMMARY

Five MSFC designed hot air collectors, serial numbers 5, 6, 8, 10 and 11, were subjected to an Evaluation Test Program as described in detail in this report. The test program was conducted in three phases. Phase one consisted of a series of outdoor tests to determine stagnation temperatures experienced on a typical bright day and each collector's ability to withstand these temperatures. Two of the collectors, S/N's 5 and 6, experienced structural deformation sufficient to eliminate them from the remainder of the test program (See Table I). Of the three remaining collectors, S/N 10 was selected as the test article for the last two phases of the test program. Phase two consisted of a series of outdoor tests to evaluate the thermal performance of collector S/N 10 under the test conditions described in Table II. The results of these tests are shown in Tables III through VII. The final phase of the program consisted of a series of indoor tests to evaluate the thermal performance of the collector under closely controlled simulated conditions described in Table VIII. The results of these tests are shown in Tables IX through XVIII. A graphic presentation of the performance analysis of both indoor and outdoor test data is contained in Figures 1 through 4.

5.0 TEST CONDITIONS AND TEST EQUIPMENT

5.1 Location

Outdoor tests were conducted on the south side of Building 4620 and indoor tests were conducted with the solar simulator in Building 4619 at Marshall Space Flight Center, Huntsville, Alabama.

5.2 Ambient Conditions

All tests were performed at atmospheric pressures and temperatures existing at the test location during the period the test was being conducted.

5.3 Instrumentation and Equipment

All test equipment and instrumentation used for the performance of this test program complies with the requirements set forth in MSFC MMI-5300.4C, Metrology and Calibration. A listing of the equipment used for testing is as follows:

Stagnation Tests:

Apparatus	Manufacturer/Model	Range/Accuracy
32°F Reference Junction	KAYE/Model PRJR	32°F ± 0.09°F
Thermocouple	Type T	-300°F to + 700°F ± 1.8°F
LVDT	Moxon/Model D110-3-4	+5 in. to -0.5 in. ± 0.01 in.
Pyranometer	Eppley/Model 8-48	0 to 400 BTU/ Ft^2-Hr.

Outdoor Performance Test:

Apparatus	Manufacturer/Model	Range/Accuracy
32° Reference Junction	KAYE/Model PRJR	32°F ± 0.09°F
Thermocouple	Type T	-300°F to + 700°F ± 1.8°F
Flowmeter	Cox/Model GL32	30 to 250 ACFM ± 2%
Pressure Gauge	Wallace/Model FA145	0 to 50 PSI

5.0 **TEST CONDITIONS AND TEST EQUIPMENT** (Continued)

Pyranometer	Eppley/Model 8-48	0 to 400 BTU/ Ft^2-Hr. $\pm$ 5%
Anemometer	Weather Measurer/ W121-SD	0 to 100 MPH $\pm$ 2.5 MPH

Indoor Performance Tests:

Apparatus	Manufacturer	Range/Accuracy
150°F Reference Junction	Pace/Model 150	150°F $\pm$ 1°F
Thermocouple	Type T	-300°F to +700°F $\pm$ 1.8°F
Flowmeter	Cox/Model GL32	30 to 250 ACFM $\pm$ 2%
Pyranometer	Eppley/Model 8-48	0-400 BTU/Ft^2-Hr. $\pm$ 5%
Pressure Gauge	Wallace/Model FA145	0 to 50 PSI
Anemometer	Weather Measure/ W121-50	0 to 100 MPH $\pm$ 2.5 MPH

6.0 REQUIREMENTS, PROCEDURES AND RESULTS

6.1 Outdoor Stagnation Tests on MSFC Hot Air Collectors.

6.1.1 Requirements

The requirements of these tests were to obtain stagnation temperature data on MSFC Hot Air Collectors. An additional task was to monitor the dimensions of the collector during testing.

The following data was recorded for each stagnation test:

1) Solar Flux (BTU/Ft^2-Hr.)

2) Collector Absorber Plate temperature (°F) - 3 locations.

3) Collector Air Temperature between the absorber plate and the cover (°F).

4) Collector dimensional change (in.) - 6 locations.

6.1.2 Procedure

The outdoor stagnation tests on MSFC Hot Air Collectors were conducted without a written procedure at the direction and under the supervision of ET-44.

The directions given were to mount the collectors outdoors facing south at an angle to allow the solar radiation to be normal on the collector surface and expose the collector for at least three bright sunny days. The inlet and outlet ports were plugged and internal temperatures were to be measured at locations defined by Reference 2.1. Also, the dimensional changes of the collectors were to be monitored.

6.1.3 Results

A summary of the results of the stagnation tests is shown in Table I.

If the collector's dimension did not change significantly, the collector passed the stagnation test. However, if the collector's dimension changed enough to break seals and allow the transfer media to escape, then the collector was considered to have failed.

Two collectors, S/N 5 and S/N 6, failed the tests when exposed to solar fluxes typical on a bright day (240 BTU/Ft^2-Hr to 290 BTU/Ft^2-Hr).

6.0 REQUIREMENTS, PROCEDURES AND RESULTS (Continued)

6.2 Outdoor Thermal Performance Test of the MSFC Hot Air Collector S/N 10.

6.2.1 Requirements

The requirements of this test were to obtain thermal performance data under conditions described in Table II. Ⓐ

The following data was recorded for each test condition:

1) Collector inlet air temperature (°F)
2) Collector outlet air temperature (°F)
3) Collector absorber plate temperature (°F) - 3 locations.
4) Collector air temperature between the absorber plate and the cover (°F)
5) Flow rate through collector (ACFM)
6) Flowmeter air temperature (°F)
7) Ambient air temperature (°F)
8) Wind velocity (MPH)
9) Wind direction (Degrees)
10) Solar flux (total) (BTU/Ft^2-Hr.)

6.2.2 Procedure

The outdoor thermal performance tests on the MSFC Hot Air Collector S/N 10 were conducted under the supervision of MSFC ET-44 without a written procedure.

6.2.3 Results

The results of this test are depicted in Tables III through VII. The values shown for each data point were determined by averaging the data recorded for that point over a 15 minute period during which all test requirements were continuously met.

6.0 REQUIREMENTS, PROCEDURES AND RESULTS (Continued)

6.3 Solar Simulator Thermal Performance Test of MSFC Hot Air Collector S/N 10.

6.3.1 Requirements

The requirements of this test were to obtain thermal performance data under the conditions described in Table VIII. The following data was recorded for each condition.

1) Collector inlet air temperature (°F).
2) Collector outlet air temperature (°F).
3) Absorber plate temperature - 3 points (°F).
4) Air temperature between absorber plate and cover (°F).
5) Collector air flow rate (ACFM).
6) Flowmeter air temperature (°F).
7) Ambient temperature (°F).
8) Wind velocity (MPH).
9) Simulator flux (BTU/Ft^2-Hr.)

6.3.2 Procedure

1) Complete all pre-test requirements specified in Reference 2.2 and Reference 2.3.

2) Mount collector on simulator test table.

3) Connect instrument leads as prescribed in Reference 2.2 and assure data system is ready to accept and record data.

4) Connect and insulate ducting.

5) Assure that test table is aligned properly and is set at a 45° angle with respect to the floor.

6) Assure that lamp array is set at a 45° angle with respect to the floor.

7) Establish desired flow rate and inlet temperature.

8) Power-up simulator to obtain required solar flux level.

9) Record data for 5 minutes in stabilized condition.

10) Repeat steps 7, 8 and 9 until all test requirements have been met.

NOTE: At end of each daily test period, secure the simulator and assure proper log book entries are made.

When resuming operation of the simulator, assure compliance with Reference 2.3 and repeat Procedure steps as required to complete the test series.

6.3.3 Results

The results of this test are depicted in Tables IX through XVIII. The values shown for each data point were determined by averaging the data recorded for that point over a 15 minute period during which all test requirements were continuously met.

7.0 ANALYSIS

The analysis of the data contained in this report is in accordance with the National Bureau of Standards and ASHRAE recommended approach.

The efficiency of a collector is:

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

where

- q_u = rate of useful energy extracted from the solar collector (BTU/hr)
- A = overall cross sectional area of collector (ft^2)
- I = total solar energy incident upon the plant of the solar collector per unit time per unit area (BTU/Hr-Ft^2)
- $\dot{m}$ = mass flow rate of the transfer fluid through the collector per unit cross-sectional area of the collector (Lb/Ft^2-Hr)
- C_{tf} = specific heat of the transfer fluid (BTU/Lb °F)
- $t_{f,e}$ = temperature of the transfer fluid leaving the collector (°F)
- $t_{f,i}$ = temperature of the transfer fluid entering the collector (°F)

Rewriting equation (1) in terms of the collector area, we get:

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

Notice that

- P_i = IA = total power incident on the collector (BTU/Hr)
- $\dot{M}$ = $\dot{m}A$ = total mass flow rate through the collector (Lb/Hr)

For an air collector system, the mass flow rate is obtained by multiplying the density of the air with the volume flow rate of the air through collector.

$$\dot{M} = \rho_{tf}\dot{V} \qquad (3)$$

where

- ρ_{tf} = Density of the transfer fluid (Lb/Ft^3)
- $\dot{V}$ = Volume flow rate (SCFM)

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Since $\dot{M}C_{tf}(t_{f,e} - t_{f,i})$ = total power collected by the collector the collector efficiency can be expressed in

$$\eta = \frac{P_{abs}}{P_{inc}} \tag{4}$$

where

P_{abs} = total absorbed power

P_{inc} = total incident power

The present collector efficiency is defined as

$$\% \text{ eff} = \frac{\dot{M}\, C_{tf}(t_{f,e} - t_{f,i})}{P_i} * 100 \tag{5}$$

In order to compare the performance of different collectors, the efficiency curve is plotted against a normalized factor

$$x = \frac{(T_{ave} - T_{amb})}{I} \tag{6}$$

where

$T_{ave} = \dfrac{T_{f,i} + T_{f,e}}{2}$ (°F)

T_{amb} = Ambient temperature (°F)

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

The efficiency calculations were made for all test data and are presented in Table VII for outdoor test data and Table XVIII, indoor test data. A second order least square curve is usually fitted to the data at each flow rate due to variations in efficiency because of wind. However, due to the lack of sufficient wind data, no curve fitting will be attempted for the outdoor data. A second order fit was performed on the indoor data and is as follows. Ⓐ

The second order polynomial expressing collector efficiency as a function of the normalized factor is defined as:

$$\eta(x) = a_o + a_1 x + a_2 x^2$$

where $\eta(x)$ is the collector efficiency
x is the normalized factor
a_o, a_1, a_2 are the coefficients to be determined by the curve fit to test data.

A computer program was used to calculate the polynomial coefficients for each set of data presented in Table XVIII. Ⓐ

Figures 2 through 5 present plots of efficiency versus the normalized factor for each flow condition. The curves plotted are for the data from the indoor tests. Only the data points for the outdoor test are shown on these plots.

8.0 COMPARISON AND CONCLUSIONS

It was hoped that a direct comparison of the outdoor to indoor test data could be made; however, several factors make this very difficult. These are:

- The type of collector is extremely sensitive to wind variations.
- The anemometer was not very accurate, and its placement was questionable.
- The close proximity of structures to the test set up made determination of wind direction and velocity almost impossible. (See Figure 5.)

In addition to the problems with the outdoor data, the indoor flux is not as accurate as it needs to be for comparison. The reason for this is that the tests were run on the solar simulator with lamps near the end of their expected life. Consequently, lamps burned out at an increasing rate as the test progressed and for other than the initial test run the flux was an approximation based on the number of lamps burned out and the initial flux value as determined by a field map.

These two factors would make any conclusion comparing indoor to outdoor testing questionable; therefore, no such comparison was attempted.

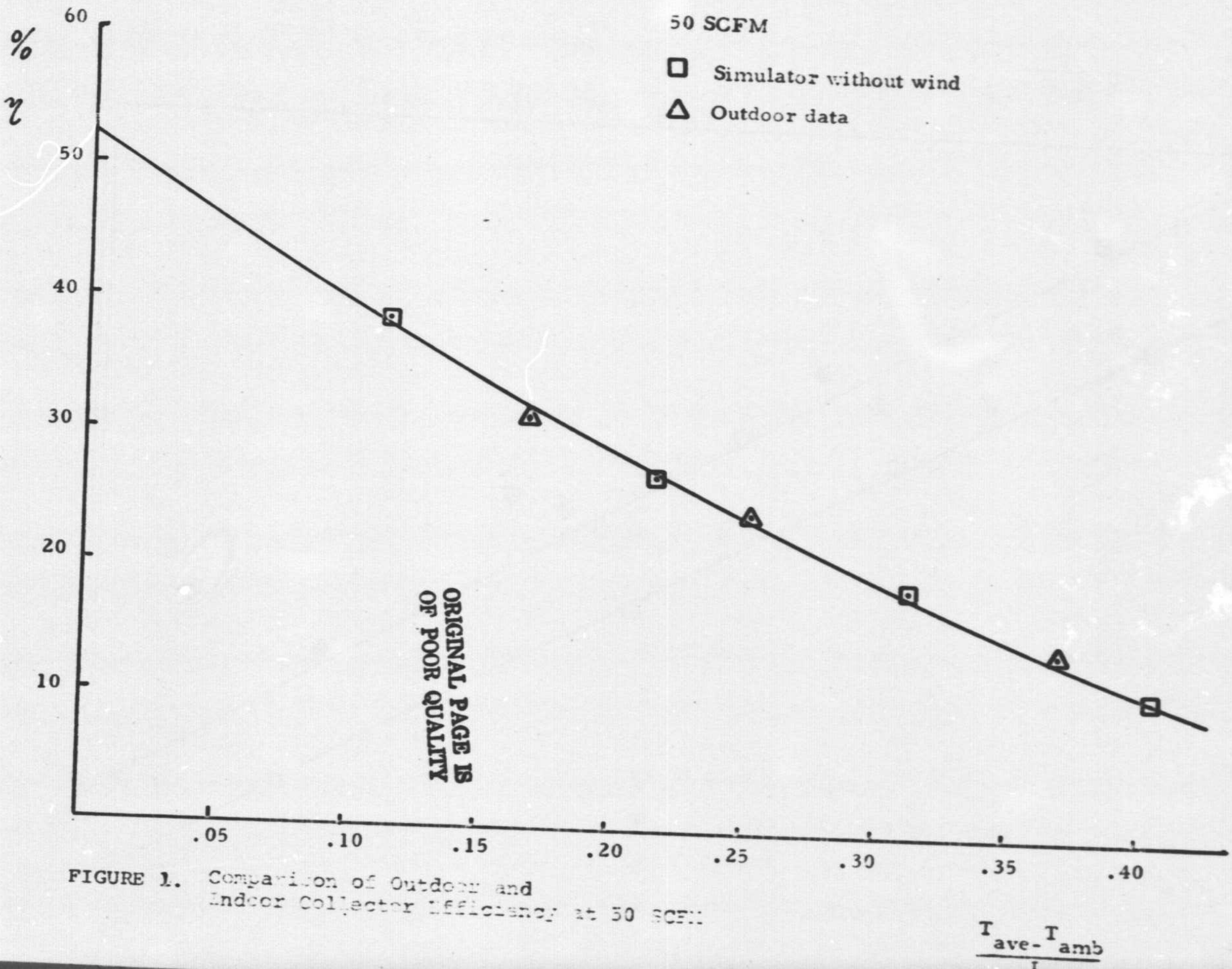

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FIGURE 1. Comparison of Outdoor and Indoor Collector Efficiency at 50 SCFM

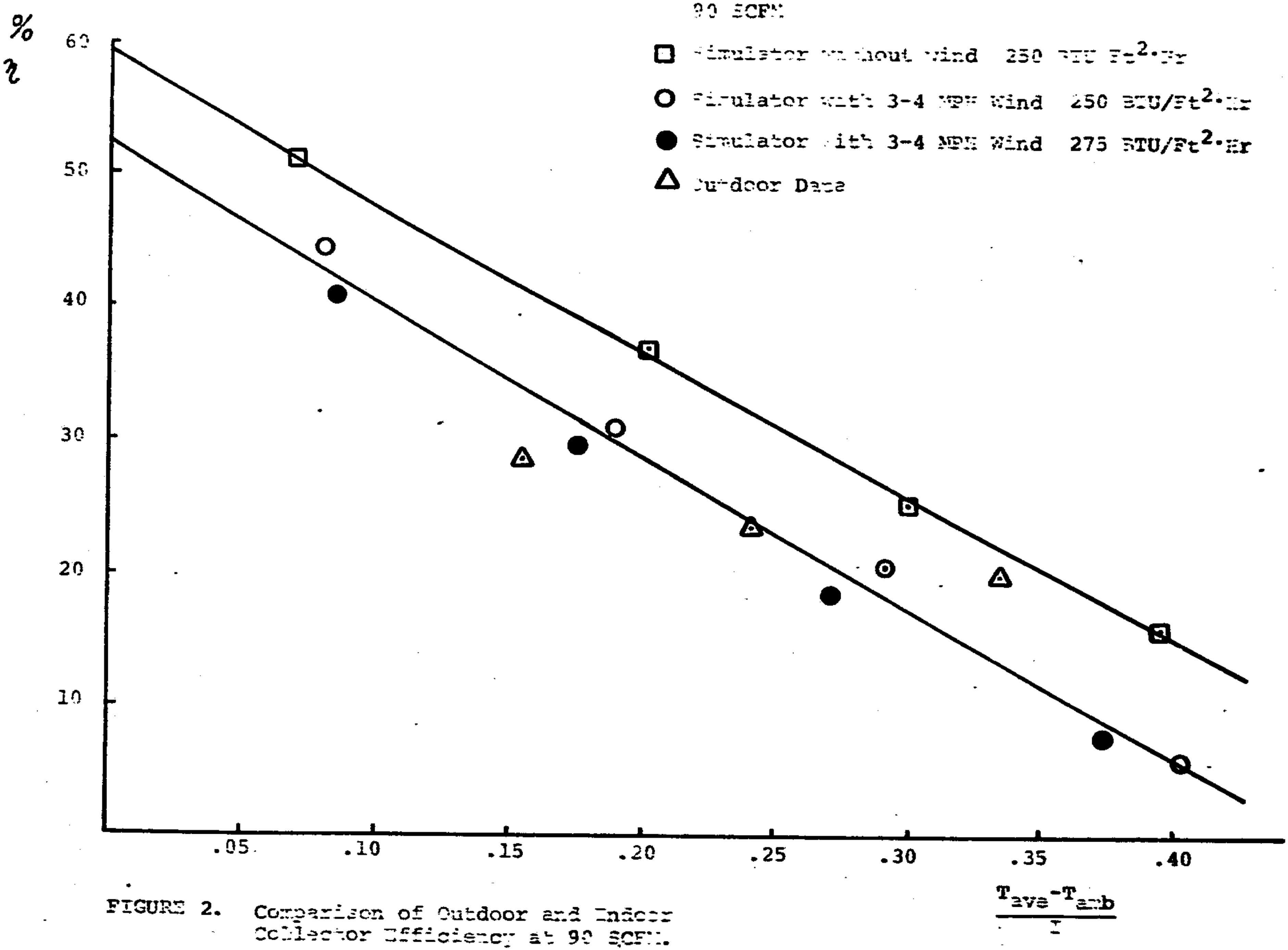

FIGURE 2. Comparison of Outdoor and Indoor Collector Efficiency at 90 SCFM.

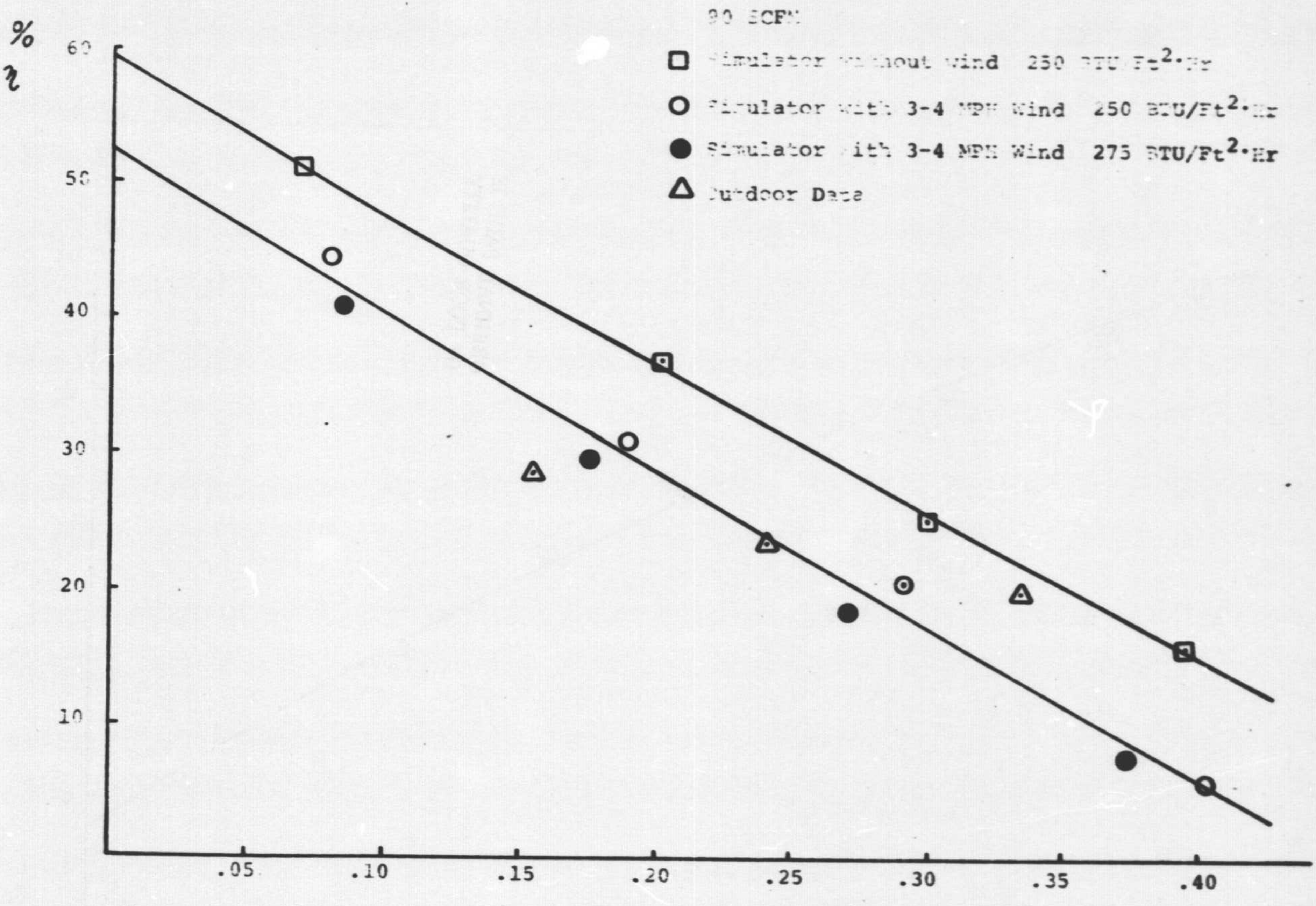

FIGURE 2. Comparison of Outdoor and Indoor Collector Efficiency at 90 SCFM.

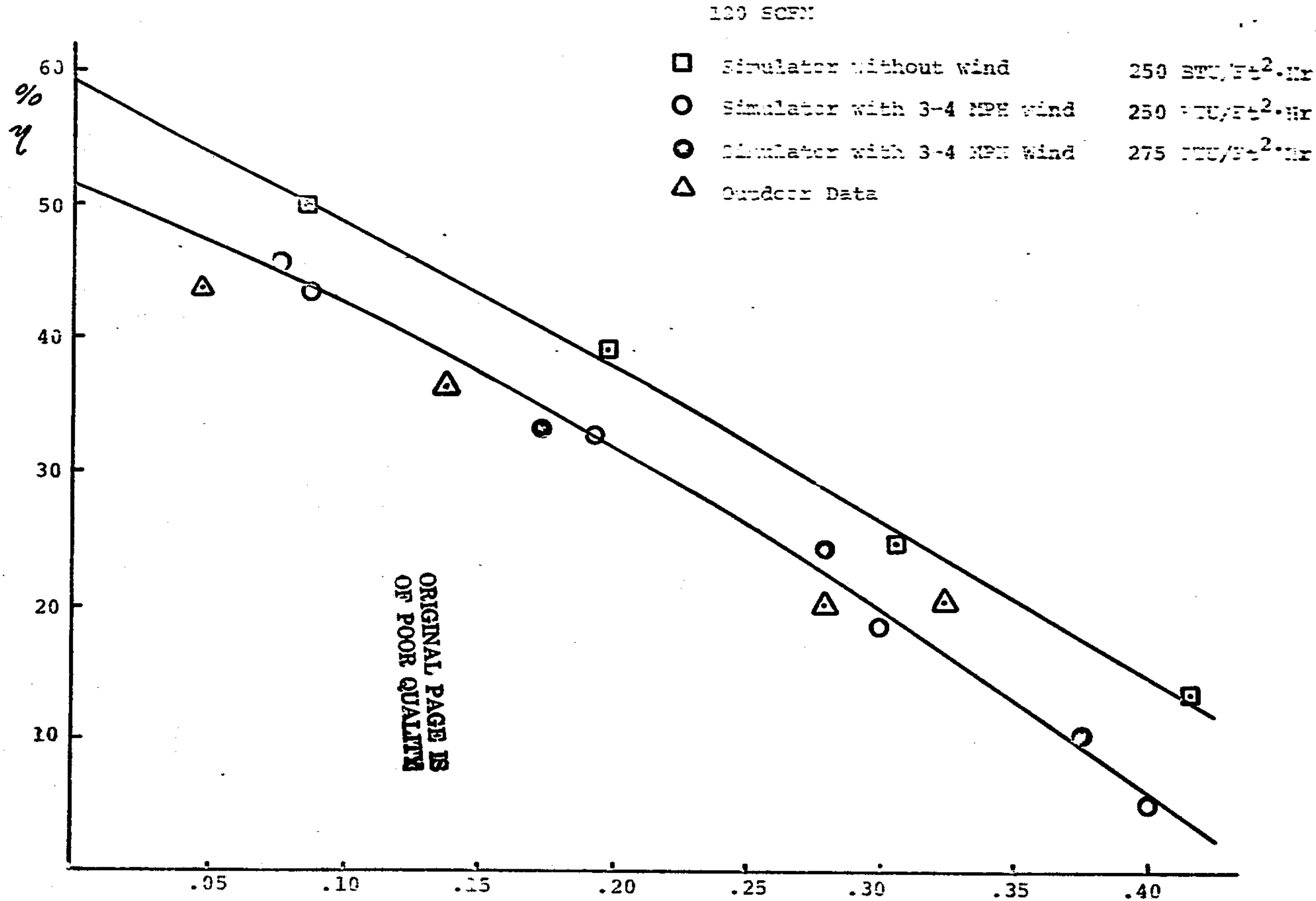

FIGURE 3. Comparison of Outdoor and Indoor Collector Efficiency at 120 SCFM.

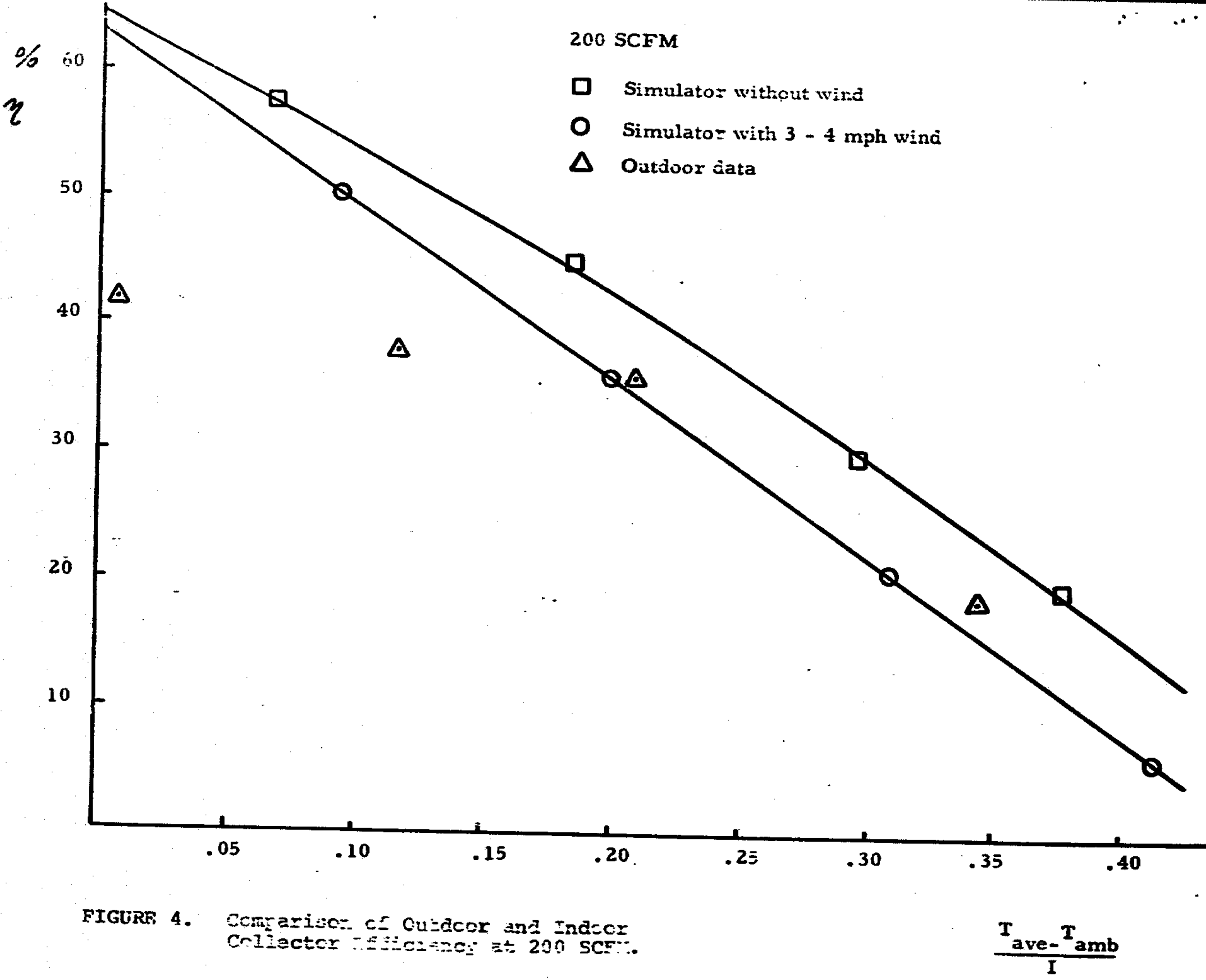

FIGURE 4. Comparison of Outdoor and Indoor Collector Efficiency at 200 SCFM.

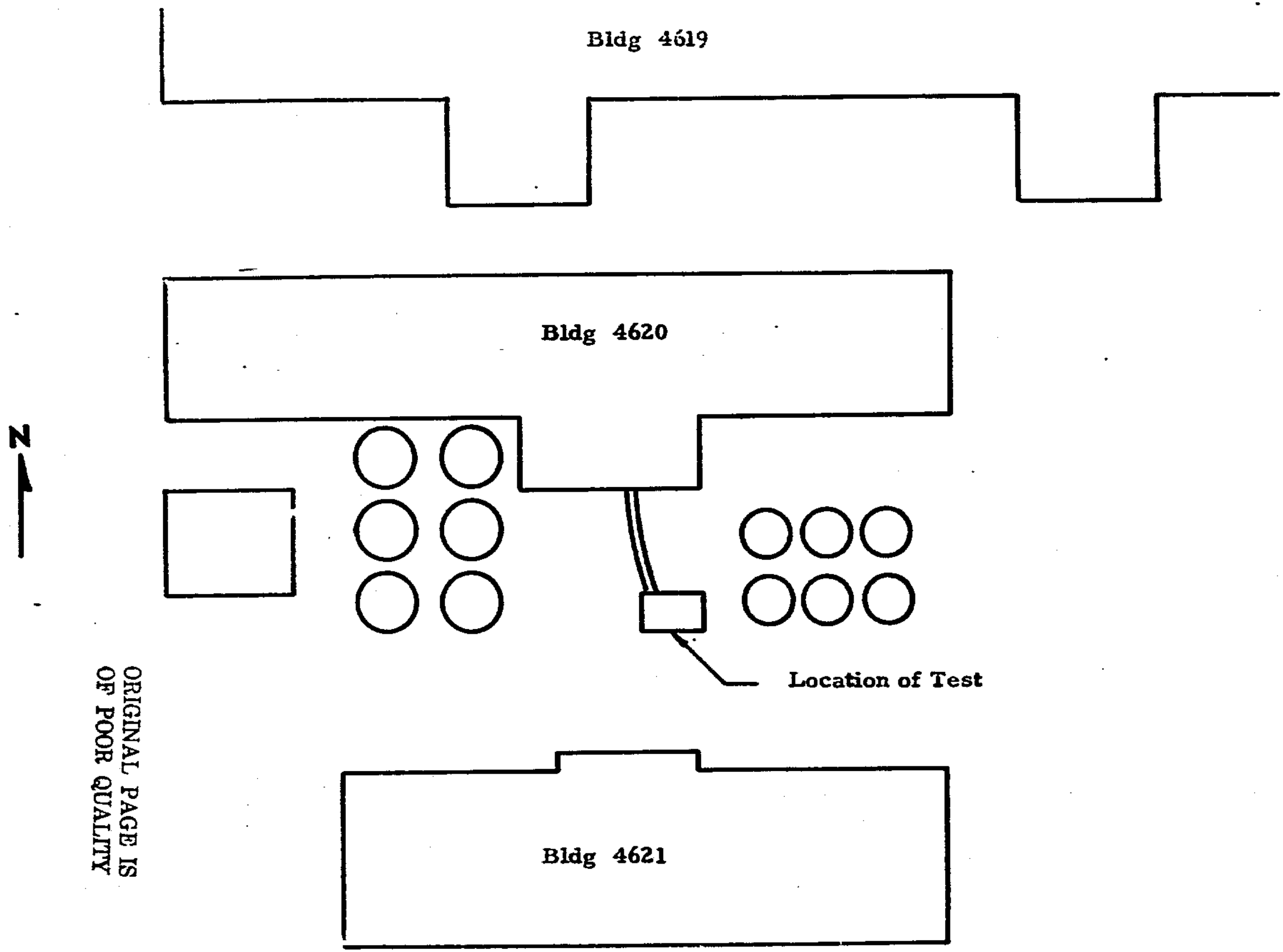

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FIGURE 5. Location of the Outdoor Thermal Performance Tests on MSFC Hot Air Collector S/N 10

TABLE I.

STAGNATION TEST RESULTS SUMMARY

Collector S/N	Maximum Absorber Temp. (°F)	Status	Comments
5	258	Failed	Foam expanded away from cover.
6	273	Failed	Foam expanded away from cover.
8	282	Passed	No visible change.
10	263	Passed	No visible change.
11	269	Passed	No visible change.

TABLE II.

OUTDOOR TEST CONDITIONS FOR MSFC HOT AIR COLLECTOR S/N 10

Inlet Temperature (°F)	Flow Rate (SCFM)	Solar Flux BTU/Ft^2-Hr
80, 110, 140, 170	50	240 to 300 Testing from 2 hours before Solar Noon to 2 hours after Solar Noon.
	90	
	120	
	200	

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TABLE III

OUTDOOR PERFORMANCE DATA AT 50 SCFM

INLET TEMPERATURE REQUIREMENTS		80°F*	110°F	140°F	170°F
Collector Inlet Temperature	(°F)		110.2	140.0	169.4
Collector Outlet Temperature	(°F)		138.5	163.2	181.9
Collector Outlet-Inlet Temperature	(°F)		28.3	23.2	12.5
Air Flow Rate	(SCFM)		49.7	49.8	50.0
Ambient Temperature	(°F)		80.0	81.4	83.4
Absorber Plate Temperature A	(°F)		171.8	192.2	202.5
Absorber Plate Temperature B	(°F)		181.0	200.9	209.4
Absorber Plate Temperature C	(°F)		189.0	208.2	212.6
Air Temperature Between Cover and Plate D	(°F)		176.4	188.9	190.2
Solar Flux	(BTU/Ft^2-Hr)		265.4	279.0	250.2

* Note: The collector outlet temperature sensor was improperly located, the data was considered invalid. A retest was not possible due to scheduling.

TABLE IV

OUTDOOR PERFORMANCE TEST DATA AT 90 SCFM

INLET TEMPERATURE REQUIREMENTS	80°F*	110°F	140°F	170°F
Collector Inlet Temperature (°F)		110.1	140.0	170.4
Collector Outlet Temperature (°F)		123.5	152.2	180.7
Collector Outlet-Inlet Temperature (°F)		13.4	12.1	10.3
Air Flow Rate (SCFM)		90.1	90.1	90.1
Ambient Temperature (°F)		78.4	80.5	83.2
Absorber Plate Temperature A (°F)		151.8	178.2	201.8
Absorber Plate Temperature B (°F)		158.2	185.2	213.9
Absorber Plate Temperature C (°F)		173.1	195.2	216.8
Air Temperature Between Cover and Plate D (°F)		158.1	170.5	195.7
Solar Flux (BTU/Ft^2-Hr.)		248.6	273.7	276.7

*Note: The collector outlet temperature sensor was improperly located; the data was considered invalid. A retest was not possible due to scheduling.

TABLE V

OUTDOOR PERFORMANCE TEST DATA AT 120 SCFM

INLET TEMPERATURE REQUIREMENTS	80°F	110°F	140°F	170°F
Collector Inlet Temperature (°F)	80.5	109.9	139.6	169.7
Collector Outlet Temperature (°F)	96.1	124.1	148.4	177.9
Collector Outlet-Inlet Temperature (°F)	15.6	14.1	8.7	8.2
Air Flow Rate (SCFM)	120.1	121.1	119.7	120.2
Ambient Temperature (°F)	76.0	78.6	77.4	79.6
Absorber Plate Temperature A (°F)	125.0	150.9	168.2	198.1
Absorber Plate Temperature B (°F)	143.5	169.3	184.1	209.2
Absorber Plate Temperature C (°F)	152.3	175.4	183.0	211.7
Air Temperature Between Cover and Plate D (°F)	151.5	167.9	161.7	193.2
Solar Flux (BTU/Ft^2-Hr)	255.4	276.0	251.8	290

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TABLE VI

OUTDOOR PERFORMANCE TEST DATA AT 200 SCFM

INLET TEMPERATURE REQUIREMENTS	80°F	110°F	140°F	170°F
Collector Inlet Temperature (°F)	78.0	109.8	140.2	170.0
Collector Outlet Temperature (°F)	88.0	118.8	148.9	174.4
Collector Outlet-Inlet Temperature (°F)	10.0	9.1	8.7	4.4
Air Flow Rate (SCFM)	198.2	198.8	199.6	199.1
Ambient Temperature (°F)	81.1	80.9	84.0	77.3
Absorber Plate Temperature A (°F)	113.0	140.9	167.9	188.5
Absorber Plate Temperature B (°F)	116.6	145.5	181.7	198.3
Absorber Plate Temperature C (°F)	133.3	157.8	184.9	196.8
Air Temperature Between Cover and Plate D (°F)	130.5	148.0	174.9	176.0
Solar Flux (BTU/Ft^2-Hr)	283.2	283.6	286.2	275.1

TABLE VII

OUTDOOR THERMAL EFFICIENCIES OF MSFC HOT AIR COLLECTOR S/N 10

FLOW RATE (SCFM)	INLET TEMP. (°F)	x (°F-Ft^2-Hr/BTU)	Efficiency η (%)
50	110 140 170	0.167 0.252 0.369	31.5 24.6 14.8
90	110 140 170	0.154 0.240 0.334	28.8 23.6 19.9
120	80 110 140 170	0.048 0.139 0.264 0.325	43.5 36.7 24.6 20.2
200	80 110 140 170	0.007 0.117 0.211 0.345	41.6 37.9 36.0 18.7

TABLE VIII

INDOOR TEST CONDITIONS FOR MSFC HOT AIR COLLECTOR #10

Inlet Temperature (°F)	Flow Rate (SCFM)	Solar Flux BTU/Ft^2-Hr	Wind Velocity MPH
80, 110, 140, 170	50	250	0
	90	250	0, 3 - 4
		275	3 - 4
	120	250	0, 3 - 4
		275	3 - 4
	200	250	0, 3 - 4

TABLE IX

INDOOR PERFORMANCE TEST DATA AT 50 SCFM
AND 250 BTU/Ft^2-Hr. (NO WIND)

INLET TEMPERATURE REQUIREMENTS	80°F	110°F	140°F	170°F
Collector Inlet Temperature (°F)	79.8	109.9	139.9	169.6
Collector Outlet Temperature (°F)	112.4	133.1	155.9	178.7
Collector Outlet-Inlet Temperature Difference (°F)	32.6	23.2	16.0	9.1
Air Flow Rate (SCFM)	49.9	49.7	49.8	49.7
Ambient Temperature (°F)	67.7	67.3	70.2	73.2
Absorber Plate Temperature (°F)	157.5	173.1	191.1	208.9
Absorber Plate Temperature (°F)	155.3	171.3	190.6	208.1
Absorber Plate Temperature (°F)	175.7	191.2	207.0	222.1
Air Temperature Between Cover and Plate (°F)	183.1	187.8	197.2	205.6
Solar Flux (BTU/Ft^2-Hr)	252.0	252.0	249.0	249.0
Wind Velocity* (MPH)	0	0	0	0

* Note: Measured at Three Locations.

TABLE X

INDOOR PERFORMANCE TEST DATA AT 90 SCFM
AND 250 BTU/FT^2-HR. (NO WIND)

INLET TEMPERATURE REQUIREMENTS	80°F	110°F	140°F	170°F
Collector Inlet Temperature (°F)	80.5	110.3	140.5	170.1
Collector Outlet Temperature (°F)	103.9	127.2	152.1	177.5
Collector Outlet-Inlet Temperature Difference (°F)	23.4	16.9	11.6	7.4
Air Flow Rate (SCFM)	90.6	90.0	89.9	89.3
Ambient Temperature (°F)	75.1	68.5	71.9	75.8
Absorber Plate Temperature (°F)	139.2	158.1	180.6	202.0
Absorber Plate Temperature (°F)	149.6	166.3	186.4	206.0
Absorber Plate Temperature (°F)	165.2	177.9	194.7	212.8
Air Temperature Between Cover and Plate (°F)	169.6	176.2	187.6	201.1
Solar Flux (BTU/Ft^2-Hr)	249.0	249.0	249.0	249.0
Wind Velocity* (MPH)	0	0	0	0

* Note: Measured at Three Locations.

TABLE XI

INDOOR PERFORMANCE TEST DATA AT 120 SCFM
AND 250 BTU/FT^2-HR. (NO WIND)

INLET TEMPERATURE REQUIREMENTS	80°F	110°F	140°F	170°F
Collector Inlet Temperature (°F)	80.1	110.6	140.4	170.0
Collector Outlet Temperature (°F)	97.7	124.4	149.4	174.8
Collector Outlet-Inlet Temperature Difference (°F)	17.6	13.8	9.0	4.8
Air Flow Rate (SCFM)	120.0	120.0	120.2	120.1
Ambient Temperature (°F)	67.2	67.2	67.6	67.7
Absorber Plate Temperature (°F)	129.2	151.9	174.1	195.3
Absorber Plate Temperature (°F)	137.8	160.7	179.6	199.0
Absorber Plate Temperature (°F)	147.1	166.9	184.3	203.6
Air Temperature Between Cover and Plate (°F)	157.6	171.4	180.4	192.3
Solar Flux (BTU/Ft^2-Hr)	252.0	252.0	252.0	252.0
Wind Velocity* (MPH)	0	0	0	0

* Note: Measured at Three Locations.

TABLE XII

INDOOR PERFORMANCE TEST DATA AT 200 SCFM
AND 250 BTU/FT^2-HR. (NO WIND)

INLET TEMPERATURE REQUIREMENTS	80°F	110°F	140°F	170°F
Collector Inlet Temperature (°F)	80.7	110.4	140.3	170.2
Collector Outlet Temperature (°F)	92.7	119.5	146.3	174.3
Collector Outlet-Inlet Temperature Difference (°F)	12.0	9.1	6.0	4.1
Air Flow Rate (SCFM)	200.4	199.8	199.1	198.8
Ambient Temperature (°F)	69.7	70.5	72.2	78.7
Absorber Plate Temperature (°F)	117.2	142.1	166.2	192.5
Absorber Plate Temperature	123.1	146.4	169.7	193.2
Absorber Plate Temperature (°F)	128.5	151.5	172.9	197.5
Air Temperature Between Cover and Plate (°F)	144.7	160.1	173.6	193.6
Solar Flux (BTU/Ft^2-Hr)	249.0	240.0	240.0	249.0
Wind Velocity* (MPH)	0	0	0	0

*Note: Measured at Three Locations.

TABLE XIII

INDOOR PERFORMANCE TEST DATA AT 90 SCFM
AND 250 BTU/FT^2-HR. (WITH WIND)

INLET TEMPERATURE REQUIREMENTS	80°F	110°F	140°F	170°F
Collector Inlet Temperature (°F)	80.4	110.2	139.2	169.4
Collector Outlet Temperature (°F)	101.1	125.1	148.6	172.1
Collector Outlet-Inlet Temperature Difference (°F)	20.7	14.9	9.4	2.7
Air Flow Rate (SCFM)	90.5	89.5	90.3	90.2
Ambient Temperature (°F)	70.6	70.5	70.2	69.2
Absorber Plate Temperature (°F)	134.9	155.7	173.7	192.4
Absorber Plate Temperature (°F)	146.2	164.5	180.9	195.9
Absorber Plate Temperature (°F)	157.5	170.2	186.2	201.0
Air Temperature Between Cover and Plate (°F)	153.2	163.2	172.0	179.8
Solar Flux (BTU/Ft^2-Hr)	250.0	250.0	250.0	250.0
Wind Velocity* (MPH)	3 - 4	3 - 4	3 - 4	3 - 4

* Note: Measured at Three Locations

TABLE XIV

INDOOR PERFORMANCE TEST DATA AT 120 SCFM
AND 250 BTU/FT^2-HR. (WITH WIND)

INLET TEMPERATURE REQUIREMENTS	80°F	110°F	140°F	170°F
Collector Inlet Temperature (°F)	80.6	110.2	140.0	169.9
Collector Outlet Temperature (°F)	96.0	121.7	146.5	171.8
Collector Outlet-Inlet Temperature Difference (°F)	15.4	11.5	6.5	1.9
Air Flow Rate (SCFM)	119.4	120.3	120.3	119.5
Ambient Temperature (°F)	66.1	67.2	68.2	69.0
Absorber Plate Temperature (°F)	127.2	147.1	168.7	190.1
Absorber Plate Temperature (°F)	136.4	158.1	175.6	193.1
Absorber Plate Temperature (°F)	141.7	161.4	178.4	196.3
Air Temperature Between Cover and Plate (°F)	140.9	154.9	165.8	176.7
Solar Flux (BTU/Ft^2-Hr)	250.0	250.0	250.0	250.0
Wind Velocity* (MPH)	3 - 4	3 - 4	3 - 4	3 - 4

* Note: Measured at Three Locations.

TABLE XV

INDOOR PERFORMANCE TEST DATA AT 200 SCFM AND
250 BTU/FT^2-HR. (WITH WIND)

INLET TEMPERATURE REQUIREMENTS	80°F	110°F	140°F	170°F
Collector inlet Temperature (°F)	80.2	109.9	139.9	170.1
Collector Outlet Temperature (°F)	90.9	117.5	144.3	171.4
Collector Outlet-Inlet Temperature Difference (°F)	10.7	7.6	4.4	1.3
Air Flow Rate (SCFM)	199.3	199.5	198.8	199.5
Ambient Temperature (°F)	62.1	63.7	65.2	67.8
Absorber Plate Temperature (°F)	113.0	136.4	159.9	183.9
Absorber Plate Temperature (°F)	117.9	138.7	160.0	182.2
Absorber Plate Temperature (°F)	122.9	144.3	166.3	187.8
Air Temperature Between Cover and Plate (°F)	129.5	143.2	156.5	169.9
Solar Flux (BTU/Ft^2-Hr.)	250.0	250.0	250.0	250.0
Wind Velocity* (MPH)	3 - 4	3 - 4	3 - 4	3 - 4

*Note: Measured at Three Locations.

TABLE XVI

INDOOR PERFORMANCE TEST DATA AT 90 SCFM
AND 275 BTU/FT^2-HR. (WITH WIND)

INLET TEMPERATURE REQUIREMENTS	80°F	110°F	140°F	170°F
Collector Inlet Temperature (°F)	80.4	110.2	140.5	170.4
Collector Outlet Temperature (°F)	101.6	125.4	149.9	174.2
Collector Outlet-Inlet Temperature Difference (°F)	21.2	15.2	9.4	3.8
Air Flow Rate (SCFM)	89.0	89.9	89.6	89.5
Ambient Temperature (°F)	70.6	72.6	73.9	75.6
Absorber Plate Temperature (°F)	136.5	156.4	176.5	196.4
Absorber Plate Temperature (°F)	147.9	165.7	183.5	200.9
Absorber Plate Temperature (°F)	161.0	176.1	191.3	207.4
Air Temperature Between Cover and Plate (°F)	156.8	167.1	177.0	185.3
Solar Flux (BTU/Ft^2-Hr.)	275.0	275.0	275.0	275.0
Wind Velocity* (MPH)	3 - 4	3 - 4	3 - 4	3 - 4

*Note: Measured at Three Locations.

TABLE XVII

INDOOR PERFORMANCE TEST DATA AT 120 SCFM AND 275 BTU/FT^2-HR. (WITH WIND)

INLET TEMPERATURE REQUIREMENTS	80°F	110°F	140°F	170°F
Collector Inlet Temperature (°F)	80.3	110.7	140.0	170.2
Collector Outlet Temperature (°F)	98.0	123.5	149.5	174.3
Collector Outlet-Inlet Temperature Difference (°F)	17.7	12.8	9.5	4.1
Air Flow Rate (SCFM)	120.3	120.4	120.0	119.7
Ambient Temperature (°F)	69.7	71.3	77.0	76.8
Absorber Plate Temperature (°F)	129.4	141.5	171.9	194.2
Absorber Plate Temperature (°F)	144.2	163.4	180.0	198.0
Absorber Plate Temperature (°F)	148.8	167.2	186.0	203.3
Air Temperature Between Cover and Plate (°F)	150.3	162.3	172.6	183.0
Solar Flux (BTU/Ft^2-Hr.)	275.0	275.0	275.0	275.0
Wind Velocity* (MPH)	3 - 4	3 - 4	3 - 4	3 - 4

* Note: Measured at Three Locations.

TABLE XVIII

INDOOR PERFORMANCE TESTS RESULTS AND ANALYSIS SUMMARY

Flow Rate SCFM	Solar Flux BTU/Ft^2-Hr	Inlet Temp. °F	$\frac{T_{ave}-T_a}{I}$	Tested Eff. %	Calc. Eff. %	Coefficient $\left(\eta = a_o+a_1x+a_2x^2\right)$
200	350	80	.068	57.3	57.4	a_o = .643
		110	.185	44.7	44.3	a_1 = .974
		140	.296	29.7	30.2	a_2 = .601
		170	.377	19.3	19.1	
200	250*	80	.094	50.3	50.3	a_o = .631
		110	.200	35.7	35.7	a_1 = -1.363
		140	.308	20.8	20.8	
		170	.412	6.3	6.3	a_2 = -.039
120**	250*	80	.088	44.3	45.6	
		110	.194	32.8	32.6	a_o = .514
		140	.300	18.7	19.8	
		170	.400	5.2	6.1	a_1 = -.819
	275*	80	.077	45.4	44.7	
		110	.174	33.1	34.8	a_2 = -.787
		140	.279	24.6	22.5	
		170	.375	10.5	9.7	
120	250	80	.086	49.9	50.2	a_o = .591
		110	.199	39.0	38.0	a_1 = -1.019
		140	.306	24.9	25.9	a_2 = -.218
		170	.416	13.3	13.0	

* 3 - 4 MPH Wind

** Use Eight Points to Determine the Coefficients

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TABLE XVIII (Continued)

INDOOR PERFORMANCE TESTS RESULTS AND ANALYSIS SUMMARY

Flow Rate SCFM	Solar Flux BTU/Ft^2-Hr	Inlet Temp. °F	$\frac{T_{ave}-T_a}{I}$	Tested Eff. %	Calc. Eff. %	Coefficient $\left(\eta = a_o + a_1x + a_2x^2\right)$
90	250	80	.069	51.0	51.1	a_o = .591
		110	.202	36.4	36.0	a_1 = -1.178
		140	.299	24.9	25.4	a_2 = .161
		170	.393	15.5	15.3	
90**	275*	80	.084	40.7	42.2	
		110	.174	29.3	31.3	
		140	.269	18.2	20.2	
		170	.372	7.5	8.5	a_o = .525
	250*	80	.080	44.3	42.7	
		110	.188	31.7	29.7	a_1 = -1.247
		140	.290	20.3	17.8	
		170	.400	5.8	5.4	a_2 = .172
90	250	80	.113	38.5	38.4	a_o = .522
		110	.215	27.1	27.5	
		140	.312	19.1	18.7	a_1 = -1.309
		170	.404	11.4	11.6	a_2 = .751

* 3 - 4 MPH Wind

** Use Eight Points To Determine the Coefficients

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