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EVALUATION OF "ALL-DAY EFFICIENCY" FOR SELECTED FLAT-PLATE AND EVACUATED TUBE COLLECTORS

Prepared by Wyle Laboratories
7800 Governors Drive West
Huntsville, AL 35807

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NASA-George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

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Summary

This document presents the detailed results of an evaluation of "all-day efficiency" computations for selected flat plate and evacuated tube collectors (i.e., the Sunworks Model LB5011 and Sunmaster Model DEC 8A, respectively). The computations are based on a modified version of the NBSIR 78-1305A procedure for "All-Day Collector Efficiency". The computations were performed month by month for actual solar-meteorological conditions at 36 sites selected from the NOAA Monthly Summary-Solar Radiation Data. Section I provides an introduction and background for the study. Section II presents the details of the modified all-day efficiency calculation procedure (based on NBSIR 78-1305A). Section III discusses the ASHMET and NOAA data bases for solar insolation and provides a justification for utilizing the available NOAA data base. Section IV presents details of the algorithm used to convert total (global) horizontal radiation to the collector tilt plane of the selected sites. Appendix 1 presents a graphical representation of the monthly all-day efficiencies for a typical year for each of the selected sites and for each of the two selected collectors. Appendix 2 presents tables of hourly insolation data for solar insolation in a horizontal and 45^{o} tilt plane for Huntsville, Alabama. This data is in support of the algorithm described in Section IV. Appendix 3 presents tables of the total monthly solar insolation available in the plane of the selected site collectors as calculated from the NOAA data base using the algorithm described in Section IV. Finally, Appendix 4 presents graphical comparison of the monthly all-day efficiencies for five selected sites using different insolation references.

I Introduction

Solar thermal collectors have been routinely tested for thermal performance at the Marshall Space Flight Center Solar Test Facility and other test facilities using the widely accepted ASHRAE 93-77 Standard Test Method (Ref. 1). This standard is generally applicable to the following solar thermal collectors: flat plate, evacuated tube, and low concentration ratio (i.e., less than 5 to 1) collectors such as those using compound parabolic cusp (CPC) reflectors. The performance of a solar thermal collector tested in accordance with ASHRAE 93-77 is exibited by data curve fits and/or graphical presentations of the solar collection efficiency (generally obtained at insolation levels of 200 $BTU/hr \cdot ft^2$ or greater at normal incidence), the collector thermal response time constant, irradiation incident angle modifier, and pressure drop. The results of the ASHRAE 93-77 collection efficiency tests are based on essentially instantaneous data points taken under steady test conditions near solar noon. Thus, an adequate comparison of one collector with another is extremely difficult since a comparison of instantaneous points on an efficiency curve may be misleading when applied to real, long-term solar meteorological conditions at specific sites.

The need for rating the thermal performance of solar collectors over usefully long time periods has been recognized and

I <u>Introduction</u> (Continued)

a procedure has been developed for generating the "all day efficiency" of solar thermal collectors for typical yearly conditions at specific locations. The U.S. Department of Commerce National Bureau of Standards (NBS) prepared an "All Day Collector Efficiency" methodology (NBSIR 78-1305A) utilizing the ASHRAE 93-77 test results as a basis. The all day collector efficiency methodology requires the following information for computation:

- Hourly insolation available in the plane of the collector
- Hourly ambient temperatures in the vicinity of the collector
- Collector fluid inlet temperatures
- Collector site and orientation (latitude, tilt, and deviation from true South (i.e., azimuth))
- ASHRAE 93-77 test results
- Effective gross area of collector.

Properly formulated, this information permits collectors of various design and performance levels to be evaluated for specific site application in a much more realistic manner. Thus, one-to-one ("apples and apples") comparisons may be made between collectors over typical yearly operating conditions. Although the computations may be made using desk-top calculators, a computer program has been developed to

I <u>Introduction</u> (Continued)

compute "average" all day collector efficiencies for typical solar thermal collectors at specific sites in the Federal in Solar Buildings Demonstration Program.

II Calculation Of All Day Performance

Calculation Methodology

The National Bureau of Standards (U.S. Department of Commerce) developed a simple, step-wise methodology to calculate the "all day performance" of solar collectors. The methodology utilizes the ASHRAE 93-77 (Ref. 1) solar collector thermal performance results for a given collector as the basis for the calculation procedure. The NBS methodology has been documented as NBSIR 78-1305A (Ref. 2) and is summarized in the following steps:

Step 1 - The following information must be assembled and inserted in Table 1 to obtain the all day performance of the solar collector for the time period of interest:

- ASHRAE 93-77 Thermal Performance Results (First order poststagnation thermal efficiency curve (slope and intercept), and incident angle modifier)

- Average hourly inlet fluid temperature to the collector (place in line 1. of Table 1).

- Average hourly ambient temperature (see note 1 below)

- Incident solar radiation in the plane of the collectors (see note 2 below)

II **Calculation Of All Day Performance** (Continued)

Calculation Methodology (Continued)

Note 1: Daily temperature profiles are not usually readily available. Thus, an approach had to be developed to utilize the available N.O.A.A. daily maximum and minimum temperatures for each month (NOAA, Reference 3). Since the daily maximum temperatures generally occur in mid-afternoon and minimum temperatures usually occur in the hours just preceding sunrise, the following procedure was developed for creating a reasonable all day temperature profile. Using temperature data given in Reference 3 for the location nearest to where the solar system will be installed, insert the appropriate average daily maximum value for each month in the 2:00 pm position of Table 1. In the 6:00 am position insert the appropriate average daily minimum temperature for the month. Subtract the minimum temperature from the maximum temperature value and divide by eight. Beginning with the 6:00 am minimum temperature add that calculated differential value for each hour to find the temperature profile values from 7:00 am to 2:00 pm. Use the calculated 1:00 pm value for the 3:00 pm position, the calculated 12:00 pm temperature for the 4:00 pm position, the 11:00 am value for 5:00 pm, and the 10:00 am value for the 6:00 pm position.

Calculation Methodology (Continued)

Note 2: The incident solar radiation on the collector plane is site specific and is dependent upon the hour of the day, the tilt of the collector, and the typical weather conditions of the site. Recommended solar radiation data is available in Reference 3 and Reference 4. Select the hourly data from a month in Reference 4 which approximates the daily average given in Reference 3 for applicable site locations. This data must be resolved into the tilt plane of the collector appropriate for each site and referenced to solar time. Insert these average hourly values in line 3 of Table 1. Total the individual values in the far right hand column.

Step 2 - Subtract Ta (ambient temperature in ^{o}F determined in Step 1) from Ti (inlet temperature in ^{o}F inserted in Step 1) and divide by I (the incident radiation on the collector plane found in Step 1) for each hour. Insert this result into line 4 of Table 1.

Step 3 - Using the results of an ASHRAE Standard 93-77 collector test made <u>after the 30 day no flow degradation test</u>, collector efficiency for each hour can be extracted from appropriate instantaneous efficiency curves using the operating point value determined in

Calculation Methodology (Continued)

step 2. Repeat for each hour by substituting in the appropriate quantity from line 4 of Table 1. Insert the collector efficiency values calculated in this step into line 5 of Table 1.

Step 4 - For situations where the collectors are oriented within a few degrees of due South and are at a slope approximating the latitude of the site, the solar hour angle absolute value should be inserted into line 6 of Table 1. The value for solar noon is 0^{o} with 15^{o} added to each hour on either side of solar noon (e.g., 15^{o} for 11:00, 30^{o} for 10:00, and 60^{o} for 16:00). For special situations where the collectors are oriented well off due South or are at a slope significantly different from the latitude, the angle of incidence of beam radiation can be calculated using equation 2.5.2 of Reference 5. The resultant incidence angles are inserted into line 6 of Table 1.

Step 5 - The incident angle modifier for each hour can be extracted from appropriate incident angle modifier curves. Using the incident angle value in degrees determined in step 4, determine the corresponding incident angle modifier value. The values of the

II **Calculation Of All Day Performance** (Continued)

Calculation Methodology (Continued)

incident angle modifier are inserted into line 7 of Table 1.

Step 6 - Subtract one (1.0) from the value determined in Step 5. Multiply that value times the value of the collector efficiency found at the intercept point, $(T_i - T_a)/I = 0$, of the ASHRAE 93-77 efficiency curve. Add the resulting value to the step 3 thermal efficiency. Insert these results into line 8 of Table 1.

Step 7 - Multiply the number found in step 6 times the hourly solar insolation value from line 3 of Table 1. Perform these calculations for each hour of the day. Total the resulting hourly values in the far right hand column.

Step 8 - Determine the collector "all-day" efficiency by dividing the daily total in line 9 of Table 1 by the total in line 3 of Table 1. This value should be inserted in line 10 of Table 1 under the Daily Total heading.

Note 3: Once the average collector efficiency is derived for each month for a range of inlet temperatures, this value, multiplied with insolation from Reference 1 resolved into the tilt plane on the collector produces the monthly expected energy output per square foot from the collector array at each location.

A mathematical representation of each line in Table 1 may be helpful in illustrating the procedure. The mathematical steps are as follows:

Line 1 of Table 1 - Insert fluid inlet temperature values, T_i (^oF). Use the same value of T_i for each separate case.

Line 2 of Table 1 - Insert ambient air temperatures, T_a (^oF), as determined from Note 1 of Step 1.

Line 3 of Table 1 - Insert incident radiation, I ($\frac{Btu}{hr \cdot ft^2}$), as determined from Note 2 of Step 1.

Line 4 of Table 1 - Compute $(T_i - T_a)/I$.

Line 5 of Table 1 - Compute efficiency, $\eta = A + B\left[(T_i - T_a)/I\right]$, where A and B are the first order, post stagnation thermal efficiency curve parameters. Alternatively, the efficiency may

II Calculation Of All Day Performance (Continued)

Calculation Methodology (Continued)

be determined from a plot of η versus $(T_i-T_a)/I$.

Line 6 of Table 1 - Insert incidence angles, θ, determined in Step 4.

Line 7 of Table 1 - Insert incident angle modifier ($K_{\alpha\tau}$) determined in Step 5.

Line 8 of Table 1 - Compute $(K_{\alpha\tau}-1)\ A + \left[A + B\ (T_i-T_a)/I\right]$.

Line 9 of Table 1 - Compute $I \times \left[(K_{\alpha\tau}-1)\ A + \left[A + B\ (T_i-T_a)/I\right]\right]$.

Line 10 of Table 1 - Compute daily collector efficiency,

$$\frac{\text{Sum of Total Daily Energy Output (Line 9 total)}}{\text{Sum of Total Daily Incident Radiation (Line 3 total)}}.$$

Appendix 1. is a graphic representation of the results of the "all day efficiency" calculations for thirty-one of thirty-six sites for both the Sunworks and Sunmaster collectors. The inlet temperature parameter was varied from 70°F to 230°F for each monthly calculation.

TABLE II-1. CALCULATION OF "ALL-DAY" SOLAR COLLECTOR EFFICIENCY

Calculations	Hour of the Day, Solar Time													Daily Total
	6:00	7:00	8:00	9:00	10:00	11:00	12:00	1:00	2:00	3:00	4:00	5:00	6:00	
1. Fluid Inlet Temp (Ti), °F	100	100	100	100	100	100	100	100	100	100	100	100	100	
2. Ambient Air Temp (Ta), °F	14.4	16.7	19.0	21.7	23.6	25.9	28.2	30.5	32.8	30.5	28.2	25.9	23.6	
3. Incident Radiation on Collector Plane, I	0	27	99	177	247	300	320	313	271	206	103	39	3	2105
4. Ti - Ta/I	0	3.085	.818	.445	.309	.247	.224	.222	.248	.337	.697	1.90	25.467	
5. Collector instantaneous thermal efficiency at normal incidence using data from lines 1, 2, & 3.	0	*.036	.308	.353	.369	.376	.379	.379	.376	.366	.322	*.178	*0	
6. Incidence angle between direct solar beam and outward drawn normal to collector plane, θd.	90°	75°	60°	45°	30°	15°	0°	15°	30°	45°	60°	75°	90°	
7. Incidenct angle modifier using the value θ from line 6.	*0.0	*.36	*.62	.68	.81	.97	1.0	.97	.81	.68	*.62	*.36	*0.0	
8. Calculation Step [(line 7 -1) x (ASHRAE 93 - 77 intercept point efficiency)] + line 5	0	0	.154	.223	.292	.364	.379	.367	.299	.236	.168	0	0	
9. Energy output from the collector, BTU/Hr·Ft² (line 3 x line 8).	0	0	15.25	39.47	72.12	109.20	121.28	117.69	81.03	48.62	17.30	0	0	621.96
10. Collector thermal efficiency (line 9 total/ line 3 total).														.295

Example Collector ASHRAE 93-77 Efficiency

$$\eta = .406 - .12 \left(\frac{Ti - Ta}{I} \right)$$

Example: 46° 52' N Lat.
45° Collector Tilt

*Estimated or extrapolated value

III Impact of Solar Insolation Reference

Many analysis tools for sizing or simulating solar system performance utilize solar insolation data developed by ASHRAE. The ASHRAE data characterize clear day available insolation in the horizontal plane on the 21st day of each month for several latitudes within the contiguous United States. Many users of this data recognize that using the clear day values for predictions always over predicts the monthly output of the solar system, due to the occurrance of clouds on many days each month.

The Solar Energy Research Institute (SERI) recognized the need for a cloudiness index for various locations within the United States to apply to the ASHRAE clear day data to make the predicted monthly available equal to measured data. SERI accomplished this noble task by developing a cloudiness factor reference for approximately 200 cities in the United States. The utilization of the ASHRAE clear day values multiplied by the cloudiness factor for predictions always under predicts the actual monthly output of the solar system.

The dilemma of over predicting or under predicting prompted a study reported herein where predictions of solar system performance are based on actual hourly data recorded by the National Oceanic and Atmospheric Administration (NOAA). A review of the SERI work for specific sites produced the typical total available insolation in the horizontal plane for each month based on a 25 year data base. The hourly and daily NOAA data were studied to find an actual month which had a total available in the horizontal plane which corresponded to the 25 year average for that month. Although NOAA has only accumulated three years of hourly data, it was fairly easy to compile a typical meteorological year for the NOAA sites.

Before the total horizontal insolation can be used for predicting the available insolation in the solar system collector tilt plane, the percentage of direct and diffuse insolation must be known. To do this accurately is a stand alone study and is reported in detail in Section IV of this document. For practical purposes a typical direct fraction profile for the total solar insolation on a clear day was assumed. The direct fraction profile was used to determine the direct and diffused solar insolation available for each hour of the day and the classical Liu and Jordan method was used to convert the horizontal insolation into that available in the collector tilt plane. Predictions were then calculated based on the ASHRAE clear day values on the 21st day of each month with daily interpolations, and also utilizing the NOAA hourly data base, with the clearest day of the month repeated for the number of days in the month. The results are shown in Tables III-1 and III-2 The results indicated, as expected, that if all days are clear, the prediction for the 21st day of each month is representative of the monthly average efficiency based on NOAA clear day performance. The predictions are for Bismarck, North Dakota and Caribou, Maine respectively in Tables III-1 and III-2. The number in the parenthesis indicates the difference from the NOAA clear day efficiency (maximum performance for one day during the month). Data are presented for three collector types and represent the highest possible all day efficiency for these collectors. The efficiency based on the average solar insolation (ASHRAE clear day times the cloudiness factor for each month) will be significantly less than that for the clear day except in months which are nearly all clear days. Tables III-3 and III-4 present the predicted efficiency for the ASHRAE average day and the corresponding NOAA hourly-daily insolation, producing a typical month. Again, the predictions are for Bismarck and Caribou respectively. The number in parenthesis indicates the difference from the NOAA typical month all day efficiency.

It is clearly shown that the performance prediction for the four cases agrees very well for the evacuated tube type. But performance is under-predicted for the flat plate and the trickle types as a result of their higher heat losses. The minimum solar radiation required to offset the collector heat loss for a given differential temperature between inlet and ambient, can be established for every solar collector. The

III Impact of Solar Insolation Reference (Continued)

three types of collectors under investigation have the intercept and slope listed below.

$\eta = .733 - .901\,P$	Flat plate
$\eta = .411 - .145\,P$	Evacuated tube
$\eta = .755 - 2.226\,P$	Trickle

where $P = \frac{Tin - Tamb}{I}$

The minimum solar radiation required for each collector to have positive energy gain with the inlet temperature at $70^{o}F$ and ambient temperature at $20^{o}F$ can be expressed as:

$$I_{min} = \frac{Tin - Tamb}{P_{max}} = \frac{70 - 20}{P_{max}}$$

$$\text{where } P_{max} = \frac{\text{intercept}}{\text{slope}}$$

therefore

$I_{min} = \frac{50}{.81} = 62$	Btu/hr ft^2	Flat plate
$I_{min} = \frac{50}{2.83} = 18$	Btu/hr ft^2	Evacuated tube
$I_{min} = \frac{50}{.34} = 147$	Btu/hr ft^2	Trickle

The difference between the trickle type collector and the evacuated tube collector is very distinct. The disagreement is greatest in the winter months with higher inlet temperatures, i.e. higher value of the parameter P. For the trickle type collector in Caribou, there was no energy gain with an inlet temperature greater than 90°F from November through March, based on the ASHRAE clear day times the cloudiness factor.

Figure III-1 shows a typical clear day solar radiation in February. To determine the average solar radiation for the month, the clear day radiation was multiplied by a cloudiness factor obtained from ASHRAE. The cloudiness factors vary from month to month and from one location to another. For instance, assume a value of .67 for Caribou, Maine. The actual average solar radiation for a day is shown by the dashed line in Figure III-1. Assuming the ambient temperature of 20°F and inlet temperature of 90°F, the minimum solar radiation, I_{min}, is 206 Btu/hr ft^2.

Therefore, the collector system can not generate any useful energy. However, in the real conditions, there were some clear days in the month for which the solar radiation is greater than 206 Btu/hr ft^2 to produce useful energy.

Appendix 4 presents a detailed graphical comparison of the "all-day" efficiency for the same collectors dicussed above at the same locations. (plus: Atlanta, Georgia; Nashville, Tennessee; and Washington, D.C.) for operating temperatures of 70°F and 90°F. The curves presented in Appendix 4 permit a comparison of the effect of insolation reference on the "all-day" collector efficiency. It is observed that the clear day insolation will over predict and the cloudy day insolation will underpredict the performance during the heating season.

In conclusion, the ASHRAE's clear day solar radiation can be used to predict the highest possible performance for a collector system during any month of the year. Unless the collector heat loss co-efficient is low, using clear day radiation times cloudiness factor to obtain an average solar radiation will under-predict the collector efficiency. Therefore, this method is not recommended for system evaluations. The only accurate manner of predicting solar system efficiency is utilizing actual hourly data which matches the average monthly available insolation for each specific site.

Flat Plate **Bismarck, ND**

T_{in}, °F	J	F	M	A	M	J	J	A	S	O	N	D
70°	51(-1)	51(-3)	54(-1)	59(-2)	63(0)	66(0)	72(1)	72(1)	68(2)	65(0)	58(-1)	52(-3)
80°	47(-2)	48(-3)	50(-2)	55(-3)	57(-1)	61(0)	66(0)	67(1)	64(2)	61(-1)	55(-1)	47(-5)
90°	43(-2)	45(-3)	47(-2)	51(-4)	53(-1)	56(0)	61(0)	62(1)	60(2)	57(-1)	51(-2)	43(-5)
100°	39(-3)	41(-4)	43(-3)	47(-4)	49(-1)	51(-1)	56(0)	58(1)	55(1)	54(-1)	48(-2)	39(-6)

Evacuted Tube **Bismarck, ND**

T_{in}, °F	J	F	M	A	M	J	J	A	S	O	N	D
70°	40(-1)	40(-1)	40(-1)	40(0)	39(1)	38(0)	40(1)	42(2)	42(1)	42(0)	42(0)	41(-1)
80°	40(0)	39(-1)	39(0)	39(-1)	38(0)	37(0)	39(1)	41(1)	42(2)	41(0)	41(0)	41(0)
90°	39(-1)	38(-1)	39(1)	38(-1)	37(0)	36(0)	38(0)	40(1)	41(1)	41(0)	41(0)	40(0)
100°	38(-1)	38(-1)	38(0)	36(0)	36(0)	36(0)	37(0)	40(2)	40(1)	40(0)	40(0)	39(-1)

Trickle Collector

T_{in}, °F	J	F	M	A	M	J	J	A	S	O	N	D
70°	25(-6)	29(-6)	37(-4)	51(-4)	61(-1)	71(0)	84(1)	81(1)	68(1)	59(-2)	43(-3)	26(-9)
80°	17(-8)	22(-7)	29(-5)	42(-5)	51(-1)	58(-1)	70(-1)	69(0)	58(1)	50(-2)	35(-4)	18(-11)
90°	11(-8)	16(-8)	22(-5)	33(-7)	41(-2)	48(-1)	58(-1)	58(0)	48(0)	42(-2)	27(-6)	12(-9)
100°	06(-8)	10(-8)	16(-4)	25(-8)	32(-2)	39(-1)	48(-2)	49(0)	39(-1)	33(-4)	20(-6)	06(-12)

TABLE III-1 Comparison of ASHMET All Day (Clear) Efficiency with NOAA Clear Day Result in Bismarck, North Dakota.

Flat Plate — Caribou, Maine

T_{in}, °F		F	M	A	M	J	J	A	S	O	N	D
70°	49(0)	51(2)	52(0)	57(1)	61(-1)	64(1)	67(0)	69(1)	64(2)	63(2)	59(1)	51(2)
80°	45(0)	48(3)	48(0)	53(1)	57(0)	58(1)	61(0)	64(1)	60(2)	59(2)	55(1)	47(2)
90°	42(0)	44(3)	45(0)	49(0)	52(-1)	54(2)	57(1)	59(0)	56(2)	55(2)	52(2)	43(2)
100°	38(0)	40(2)	41(-1)	45(0)	48(-1)	50(2)	52(0)	55(1)	52(2)	51(2)	49(2)	39(1)

Evacuated Tube — Caribou, Maine

T_{in}, °F	J	F	M	A	M	J	J	A	S	O	N	D
70°	40(0)	40(1)	39(0)	40(1)	38(1)	37(0)	39(0)	42(1)	42(2)	42(1)	42(1)	42(1)
80°	40(0)	39(0)	39(1)	39(1)	38(0)	37(1)	38(0)	41(1)	41(1)	41(0)	42(1)	41(0)
90°	39(0)	39(1)	38(0)	38(0)	37(0)	36(1)	37(0)	40(1)	40(1)	41(1)	41(1)	40(0)
100°	38(0)	38(0)	37(0)	37(0)	36(-1)	35(-1)	37(0)	39(0)	39(1)	40(1)	40(1)	40(1)

Trickle Collector — Caribou, Maine

T_{in}, °F	J	F	M	A	M	J	J	A	S	O	N	D
70°	21(-1)	27(4)	31(-2)	45(0)	59(1)	65(2)	71(1)	73(1)	58(2)	52(3)	44(3)	25(2)
80°	14(-2)	20(4)	24(-2)	36(0)	48(-1)	54(2)	59(1)	61(1)	49(2)	43(2)	36(3)	18(1)
90°	08(-3)	14(4)	17(-2)	28(0)	38(-2)	44(2)	49(1)	51(0)	39(1)	35(3)	28(3)	10(-1)
100°	04(-3)	09(4)	12(-2)	20(-1)	30(-1)	34(0)	39(0)	41(0)	31(1)	27(2)	20(3)	05(-1)

TABLE III-2 Comparison of ASHMET All Day (Clear) Efficiency with NOAA Clear Day Results in Caribou, Maine.

Flat Plate

Bismarck, ND

T_{in}, °F	J	F	M	A	M	J	J	A	S	O	N	D
70°	36(9)	39(-5)	45(-6)	54(-1)	60(-2)	66(1)	72(0)	73(1)	68(1)	64(1)	52(0)	39(8)
80°	30(-11)	34(-5)	40(-7)	48(-2)	54(-2)	59(0)	66(0)	67(0)	62(0)	58(0)	47(-1)	33(-10)
90°	25(-12)	28(-7)	35(-8)	42(-3)	48(-3)	53(-1)	60(0)	61(0)	57(0)	54(1)	42(-1)	27(-12)
100°	19(-15)	24(-8)	30(-10)	36(-5)	43(-4)	47(-2)	55(0)	56(0)	52(-1)	49(1)	36(-3)	21(-14)

Evacuated Tube

Bismarck, ND

T_{in}, °F	J	F	M	A	M	J	J	A	S	O	N	D
70°	38(-1)	37(-1)	38(-1)	38(0)	38(-1)	38(0)	40(0)	42(1)	42(0)	42(0)	41(0)	39(-1)
80°	36(-2)	36(-1)	37(-1)	37(0)	37(-1)	36(-1)	39(0)	41(1)	41(0)	41(0)	40(0)	38(-1)
90°	35(-2)	35(-1)	36(-1)	36(0)	35(-2)	35(0)	38(0)	40(1)	40(0)	40(0)	39(0)	37(-2)
100°	34(-3)	34(-1)	35(-2)	35(0)	34(-2)	34(-1)	37(0)	39(0)	40(1)	39(1)	38(0)	36(-2)

Tickle Collector

Bismarck, ND

T_{in}, °F	J	F	M	A	M	J	J	A	S	O	N	D
70°	02(-20)	08(-13)	20(-13)	40(-5)	57(-3)	71(0)	85(0)	83(0)	67(0)	56(1)	29(-5)	05(-18)
80°	00(-17)	02(-14)	11(-15)	27(-8)	44(-4)	56(-1)	70(-1)	69(0)	54(-2)	44(0)	18(-8)	00(-18)
90°	00(-12)	00(-11)	04(-16)	16(-10)	31(-7)	43(-2)	56(-1)	56(-1)	43(-3)	33(-2)	09(-11)	00(-13)
100°	00(-8)	00(-8)	00(-14)	07(-11)	20(-9)	31(-4)	45(-1)	45(-2)	33(-4)	24(-3)	02(-13)	00(-9)

TABLE III-3 Comparison of ASHMET All Day (Average) Efficiency with NOAA Average Day Results in Bismarck, North Dakota.

Flat Plate — Caribou, Maine

T_{in}, °F	J	F	M	A	M	J	J	A	S	O	N	D
70°	27(-9)	35(-8)	41(-5)	50(0)	58(-1)	62(0)	66(0)	69(1)	60(0)	54(2)	42(-5)	28(-8)
80°	21(-10)	30(-9)	36(-5)	43(-1)	51(-1)	55(0)	59(1)	61(1)	54(1)	46(0)	33(-9)	21(-10)
90°	15(-12)	25(-10)	31(-6)	37(-2)	44(-3)	48(-1)	52(1)	55(1)	48(-2)	39(-2)	25(-12)	15(-12)
100°	10(-14)	19(-12)	26(-7)	31(-4)	38(-4)	42(-2)	46(1)	49(0)	42(-3)	33(-3)	18(-15)	08(-16)

Evacuated Tube — Caribou, Maine

T_{in}, °F	J	F	M	A	M	J	J	A	S	O	N	D
70°	36(-1)	37(-2)	37(-1)	38(0)	37(0)	37(0)	38(0)	41(1)	41(1)	40(0)	39(0)	38(1)
80°	35(-1)	36(-2)	36(-1)	37(0)	36(0)	35(-1)	37(0)	40(1)	40(1)	39(1)	37(-1)	36(0)
90°	34(-1)	35(-2)	35(-1)	36(0)	35(0)	34(0)	36(1)	39(1)	39(1)	38(1)	36(-1)	35(0)
100°	33(-1)	34(-[illegible])	35(-1)	35(0)	33(-1)	33(0)	35(1)	38(1)	38(1)	37(1)	35(-1)	33(-1)

Trickle Collector — Caribou, Maine

T_{in}, °F	J	F	M	A	M	J	J	A	S	O	N	D
70°	00(-11)	03(-14)	12(-11)	30(-3)	52(-1)	63(1)	71(1)	73(1)	50(-2)	33(-4)	09(-18)	00(-13)
80°	00(-6)	00(-11)	05(-11)	17(-7)	36(-5)	47(-1)	55(2)	56(0)	36(-5)	20(-7)	00(-20)	00(-9)
90°	00(-3)	00(-7)	00(-11)	08(-9)	22(-9)	33(-4)	40(0)	41(-3)	24(-7)	09(-10)	00(-13)	00(-5)
100°	00(-1)	00(-3)	00(-7)	01(-11)	11(-12)	20(-8)	27(-2)	28(-6)	13(-10)	01(-12)	00(-8)	00(-2)

TABLE III-4 Comparison of ASHMET All Day (Average) Efficiency with NOAA Average Day Results in Caribou, Maine.

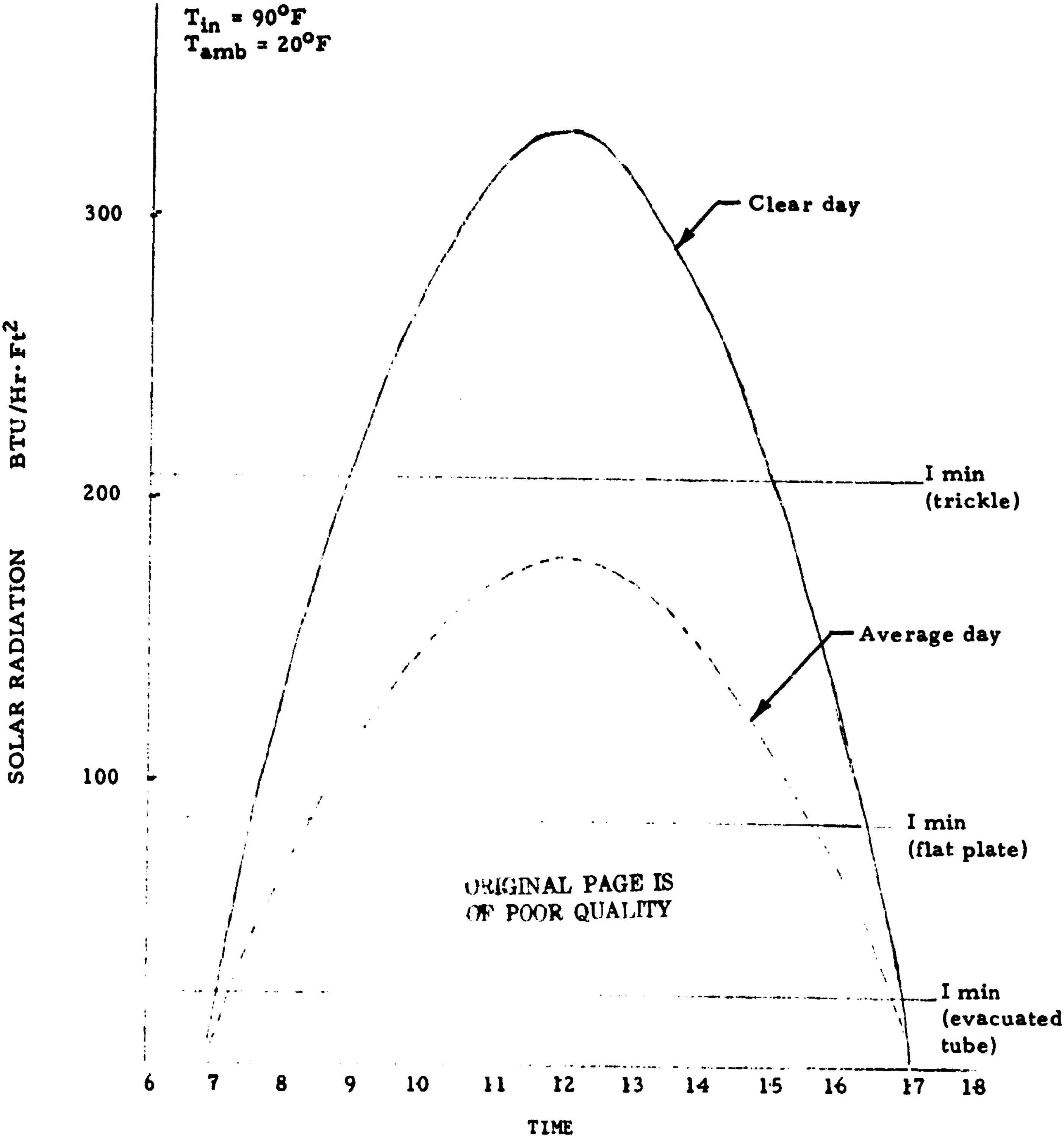


Figure III-1 ASHMET Clear Day and Average Day Solar Radiation in February on 60° Tilt Surface at 48° North Latitude and the Minimum Solar Radiation Required for Three Types of Collectors.

IV Prediction Of Total Insolation On A Tilted Surface

The efficiency of a solar collection system is proportional to its incoming solar energy. Therefore, the prediction of the availability and quantity of radiation on the collector surface is extremely important to an engineer, designer, or researcher for their system design, evaluations or performance simulations.

There are many weather stations in the United States; that measure solar radiation. However, at most of them, only total solar radiation on a horizontal surface is recorded. This is the case for NOAA (National Oceanic and Atmospheric Administration), which publishes a monthly summary of solar radiation data for several sites. To convert these hourly data from a horizontal surface to the collector tilt plane is a State-of-the-Art Science. Numerous authors have presented their methods, among them, Liu & Jordan's method is the most widely used. To apply Liu & Jordan's technique, one must know the total and diffused solar radiation on the horizontal plane. Unfortunately, the diffused solar radiation on the horizontal plane is rarely available. In addition, determination of the diffused radiation using a shadow band reouires periodic adjustment of the altitude angle and additional equipment (pyranometer, recorder).

One of the purposes of a recent project at the MSFC Solar Test Facility was to investigate a method to convert solar radiation from the horizontal to the tilt plane knowing only the total solar radiation. This algorithm will then be utilized in the evaluation of system designs. Solar radiation has been recorded at two-minute intervals for 10-12 hours, depending on the season. On a fixed surface, horizontal total and tilt total (45 degrees) and on a tracking plane, direct, total and diffused radiation were measured. These hourly data were tabulated monthly.

Figure 1 shows a typical clear day where TOT (total), NIP (direct normal), and DIF (diffuse) were measured in the tracking plane and HOR and 45T were the total radiation on the horizontal surface and 45 degree tilt surfaces, respectively.

Liu & Jordan's equation to convert from the horizontal surface to a tilt surface is given below:

$$G_T = (G_H - D_H)\frac{\cos\theta}{\sin\alpha} + D_H \cos^2\left(\frac{s}{2}\right) + \rho G_H \sin^2\left(\frac{s}{2}\right) \quad (1)$$

where G_T = Global radiation on tilt surface.

G_H = Global radiation on horizontal surface.

D_H = Diffused radiation on horizontal surface.

θ = Solar incident angle.

α = Solar altitude angle.

s = Surface tilt angle.

ρ = Ground reflectance.

From equation 1, it is obvious that D_H must be known to determine G_T, the radiation on the tilt surface. The diffused radiation on a horizontal surface, D_H, is seldom measured. Without the diffused radiation data. Equation (1) can not be utilized to calculate the global radiation on a tilted surface, another measurement not normally taken.

An algorithm has been developed which determines the diffused fraction for each hour, based on hourly total horizontal radiation only. A typical, hourly direct solar fraction, the ratio of direct to total solar radiation, for the clearest day of a month for the month of February through June in Huntsville, Alabama are presented in Figure 2. Although these hourly direct fractions varied from month to month, only one profile was useo to simplify this algorithm. This general profile is the average of these five month's values. Knowing the direct fraction for each hour of the day, the diffused fraction may be determined as follows:

$$f_{dif} = 1 - f_{dir} \qquad (2)$$

This direct fraction profile will be varied from location to location, but its deviation shall not be large because this profile is based on the clearest day of that location. Therefore, the profile listed below might be applicable to all locations in the United States.

Time	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17
Direct Fraction	.80	.85	.87	.88	.89	.89	.88	.87	.85	.80

The hourly profile was applied to one day of the month which has the maximum total solar radiation on a horizontal surface for that hour. It can be demonstrated by examining Table IV-1, May 1981. Comparing the total solar radiation on horizontal surface for the same hour of each day of the month, indicated that the 21st day of May has the maximum values. Therefore, the standard direct fraction profile was assigned to this day. However, it is not necessary that the profile be applied to every hour of the same day. Therefore, any other day the solar radiation for the hour did not reach the maximum indicated that the sky is either hazy, intermittent or cloudy. Intuitively, under those conditions the direct solar fraction will decrease, and the diffused solar fraction increases.

A detailed comparison of the hourly radiation values to the maximum value of the month indicated an analytical relationship. Figures 3 through 6 show that for the month of April, 1981, the diffused fraction versus the total radiation for every hour

MAY -1981 HUNTSVILLE, ALABAMA TILT = 0

TOTAL RADIATION FOR EACH HOUR ENDING SOLAR TIME (BTU/FT2)

DAY	8	9	10	11	12	13	14	15	16	17	TOT
1	72	132	172	208	248	254	253	212	166	71	1788
2	127	193	248	288	306	309	286	246	190	122	2315
3	128	193	252	277	246	195	211	207	182	120	2011
4	106	151	198	265	294	286	274	214	135	108	2031
5	65	148	174	201	184	197	206	164	97	29	1465
6	29	46	26	53	28	41	74	55	21	15	388
7	17	52	120	139	210	176	166	174	122	70	1246
8	27	70	110	138	138	214	265	216	185	115	1478
9	83	170	220	221	231	275	199	110	78	42	1629
10	48	75	85	34	219	102	157	224	107	112	1163
11	5	16	31	82	34	17	34	35	34	32	320
12	40	67	146	230	311	310	289	248	192	122	1955
13	111	193	231	268	273	303	267	234	181	117	2178
14	42	73	82	282	222	217	127	154	189	89	1477
15	76	49	59	94	70	110	179	223	192	78	1130
16	34	78	124	201	70	84	76	113	34	16	830
17	3	11	11	26	27	23	22	68	91	75	357
18	41	169	228	246	293	282	189	109	87	21	1665
19	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0
21	138	203	256	293	312	314	288	250	196	131	2381
22	130	199	255	290	309	308	285	248	194	129	2347
23	133	196	247	289	302	292	267	225	133	72	2156
24	121	190	244	280	209	278	255	218	179	107	2081
25	49	98	191	205	172	106	59	127	98	50	1155
26	12	32	58	88	102	123	130	100	74	52	771
27	10	64	167	177	84	152	160	184	138	94	1230
28	128	189	247	294	226	252	160	164	193	122	1975
29	118	150	149	260	277	194	198	175	172	95	1788
30	109	177	231	273	241	219	169	162	124	78	1783
31	96	163	202	254	251	55	91	17	15	15	1159
MEAN	72	122	164	205	203	196	184	168	131	79	

Table IV-1 Total Radiation for May 1981, Huntsville, Alabama (Tilt = 0) of the day can be best fitted by a square function. For example, at 11 am on May 31 the total solar radiation is 254 Btu/hr·ft^2. Comparing this to the maximum of 293 Btu/hr·ft^2, the diffused fraction for this hour is determined as

$$f_{dif} = 1 - .88 * \left(\frac{254}{293}\right)^2 = .34$$

The diffused radiation is determined by multiplying the total radiation with the diffused fraction:

$$D_H = G_H * f_{dif} + 254 * .34 = 86 \text{ Btu/hr}\cdot\text{ft}^2.$$

Substituting D_H and G_H into equation (1) with known θ, α, s, and ρ, the global radiation on a tilted surface can be predicted.

Using the data obtained at MSFC, the February through July, 1981 data were evaluated. The results are shown in Figure 7 through 12. In general, it agrees fairly well with measured data for all types of days (clear, partly cloudy and cloudy days). The average deviation from measured values is within 15 Btu/hr·ft^2. The method does under predict the solar radiation on tilted surfaces for higher radiation levels.

Appendix 2. shows the measured day-time hourly total radiation at a 0^0 and 45^0 tilt angle for Huntsville, Alabama from February 1981 through June 1981.

Appendix 3. shows the calculated average monthly insolation in the collector tilt plane for thirty-one of the thirty-six sites.

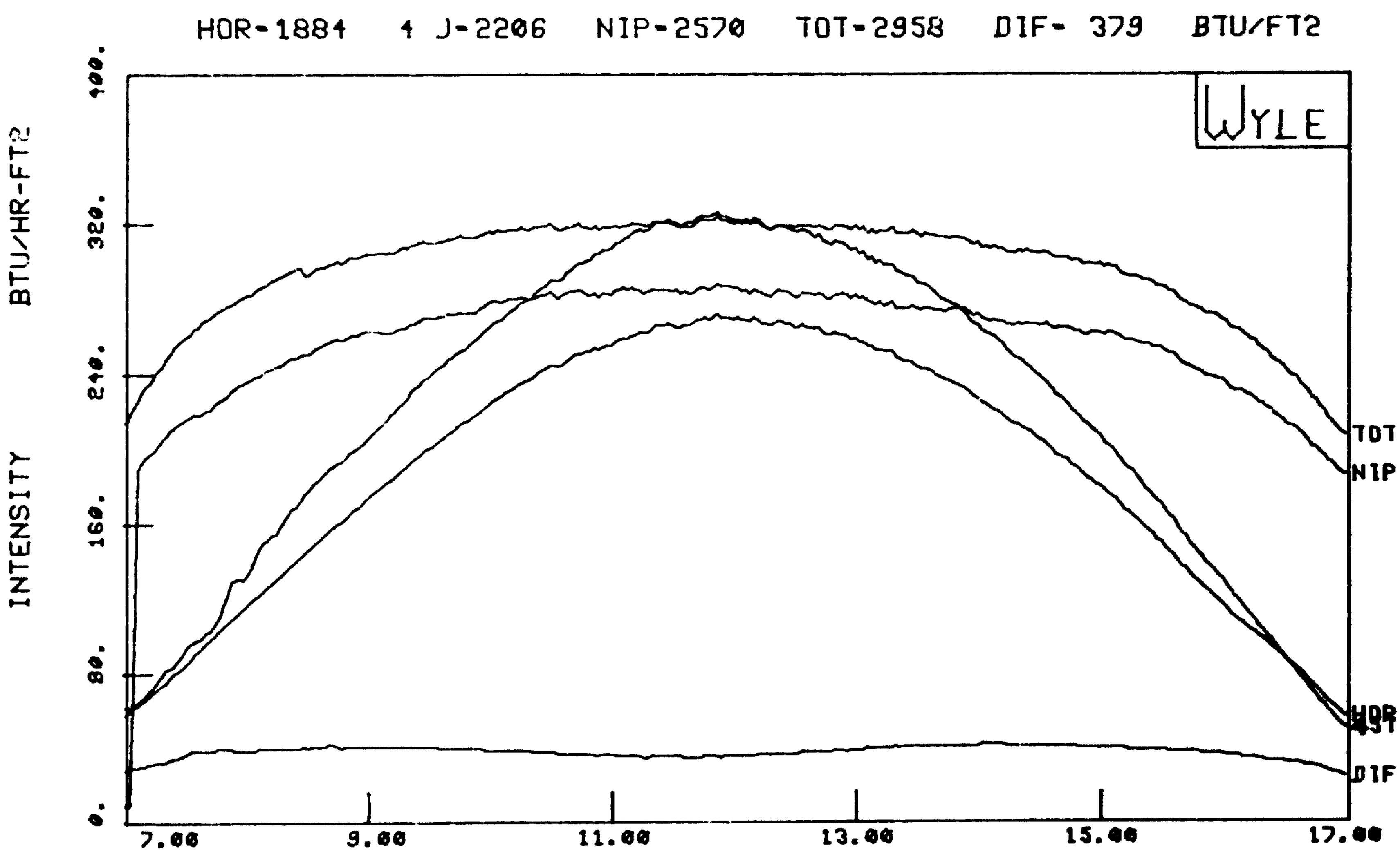


FIGURE IV-1
SOLAR RADIATION MEASUREMENT SEP-10-81

DIRECT FRACTION FOR THE MOST CLEAR DAY OF EACH MONTH IN HUNTSVILLE, AL

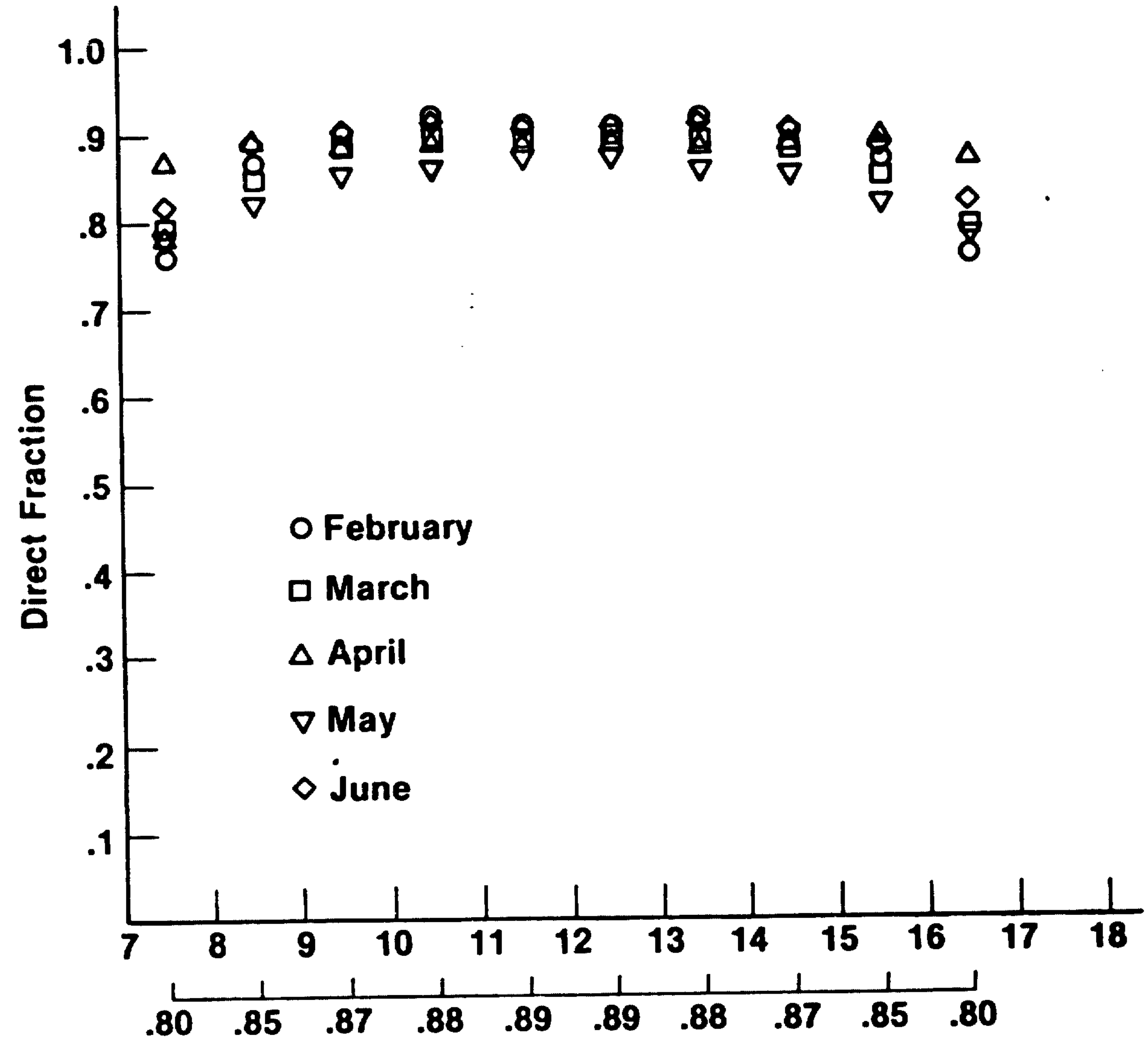


FIGURE IV-2

HOUR OF THE DAY 8-9 AND 15-16
MONTH OF APRIL 1981

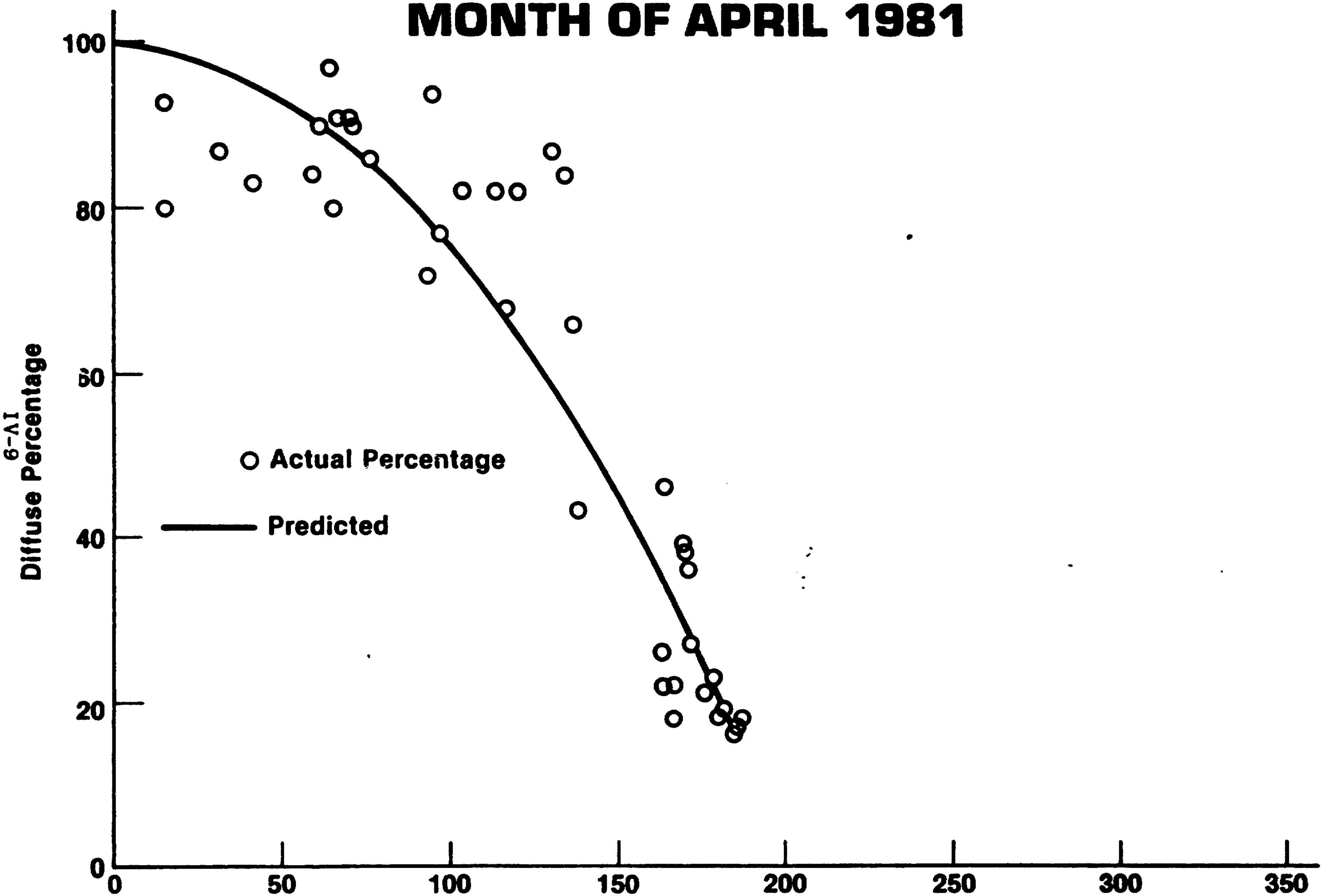


FIGURE IV-3

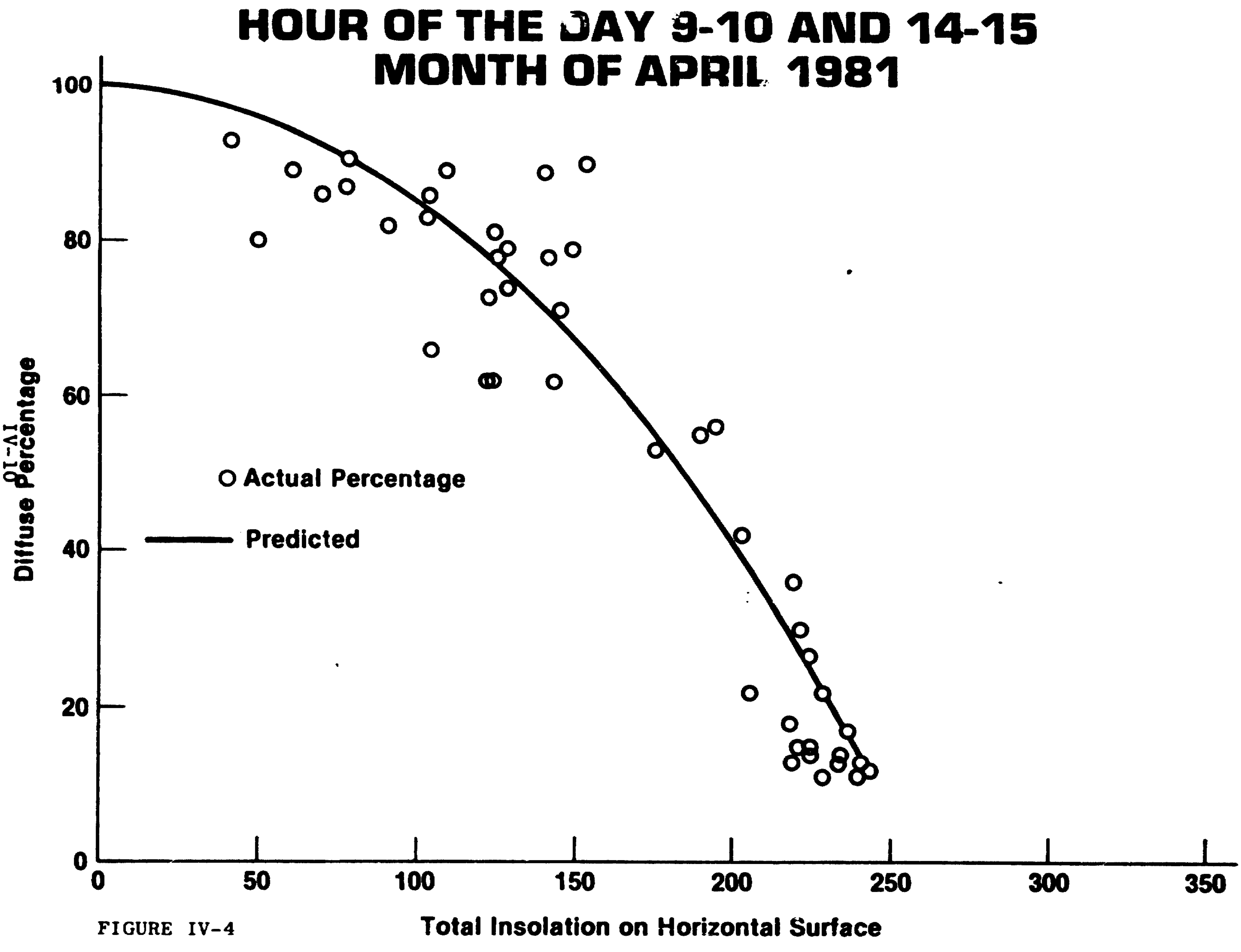

HOUR OF THE DAY 9-10 AND 14-15
MONTH OF APRIL 1981
Diffuse Percentage
Actual Percentage
Predicted
Total Insolation on Horizontal Surface
0
20
40
60
80
100
0
50
100
150
200
250
300
350

FIGURE IV-4

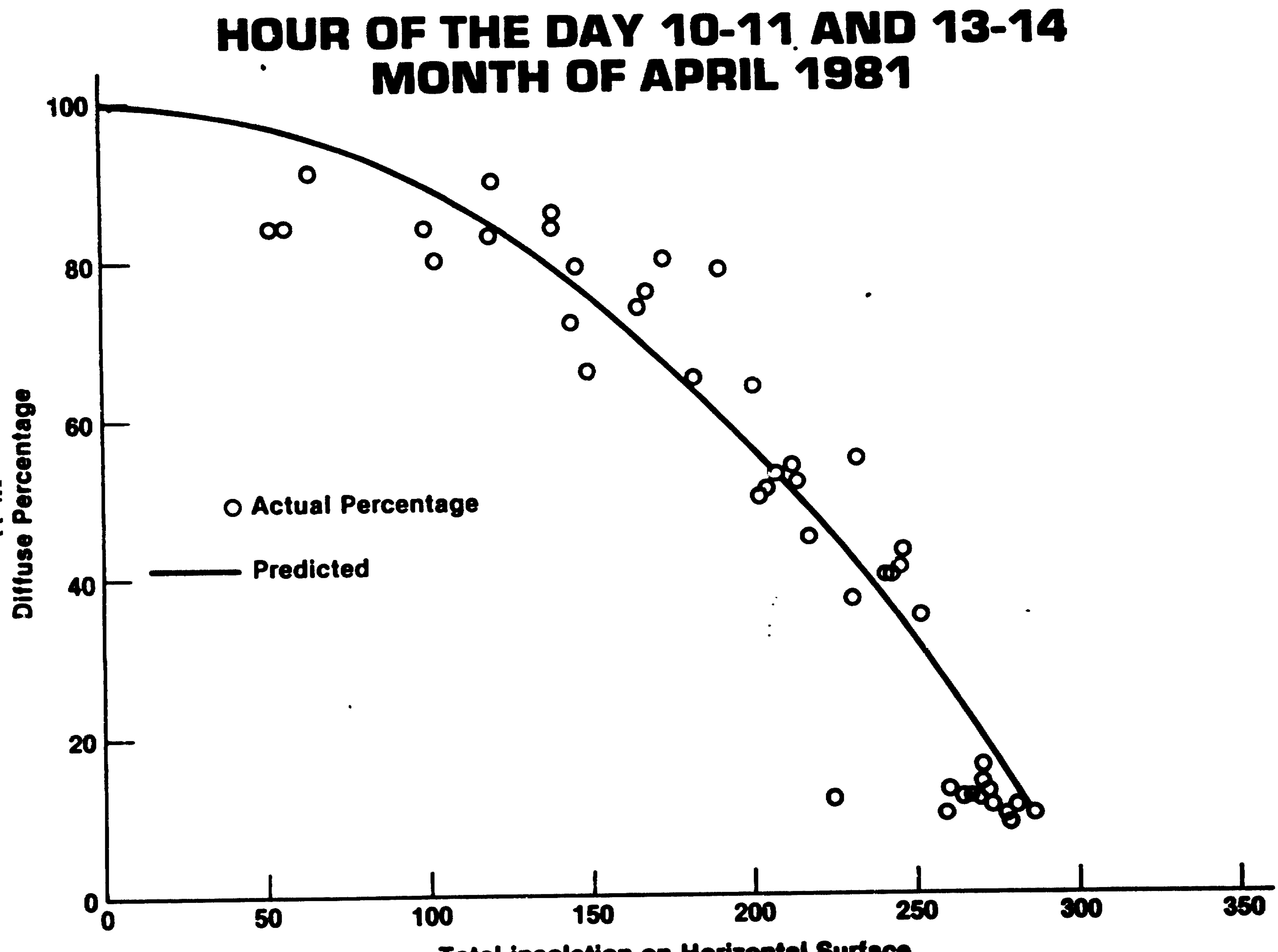

HOUR OF THE DAY 10-11 AND 13-14
MONTH OF APRIL 1981
Actual Percentage
Predicted
Diffuse Percentage
Total insolation on Horizontal Surface
0
20
40
60
80
100
50
150
200
250
300
350

FIGURE IV-5

HOUR OF THE DAY 11-12 AND 12-13 MONTH OF APRIL 1981

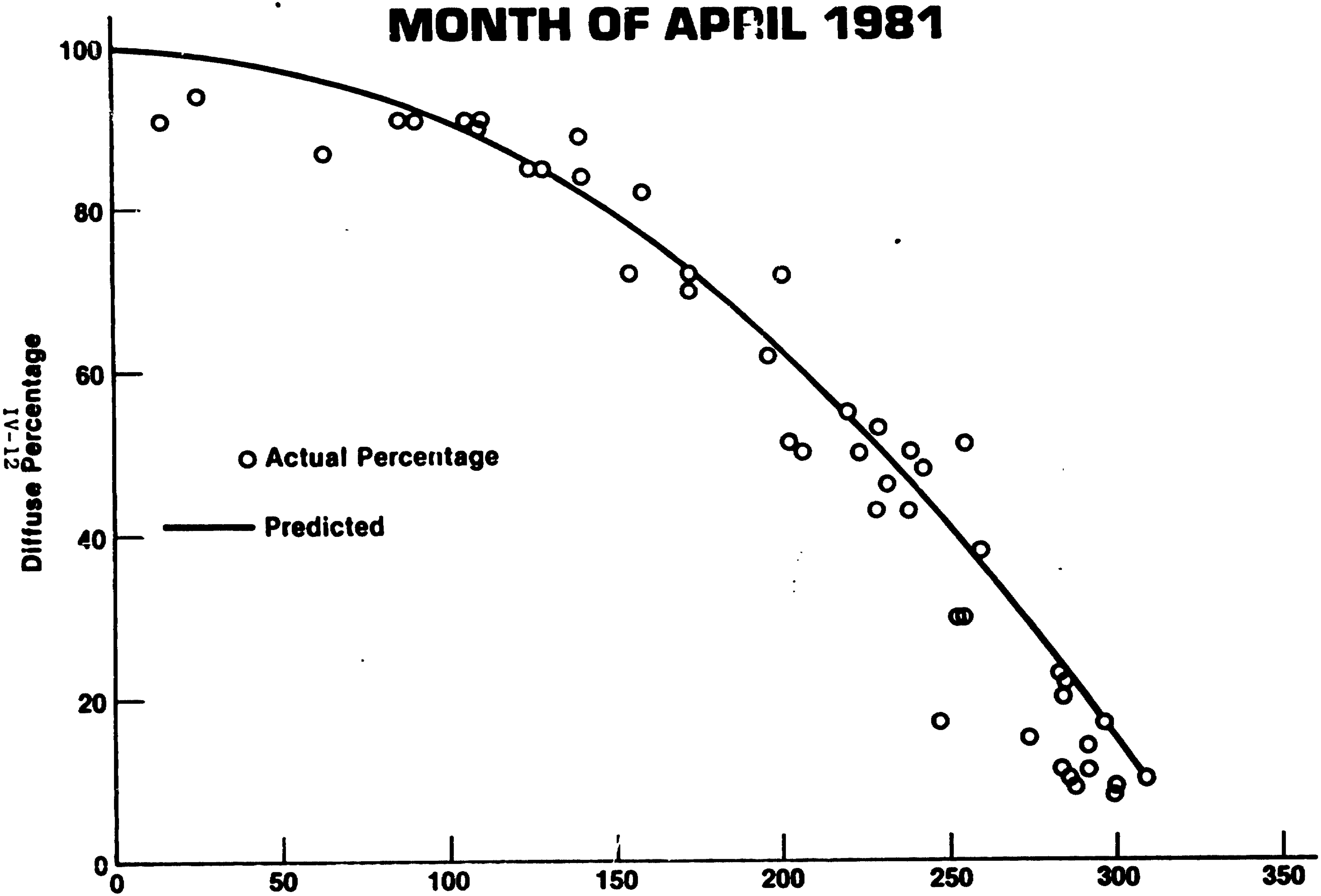


FIGURE IV-6

FEBURARY-1981

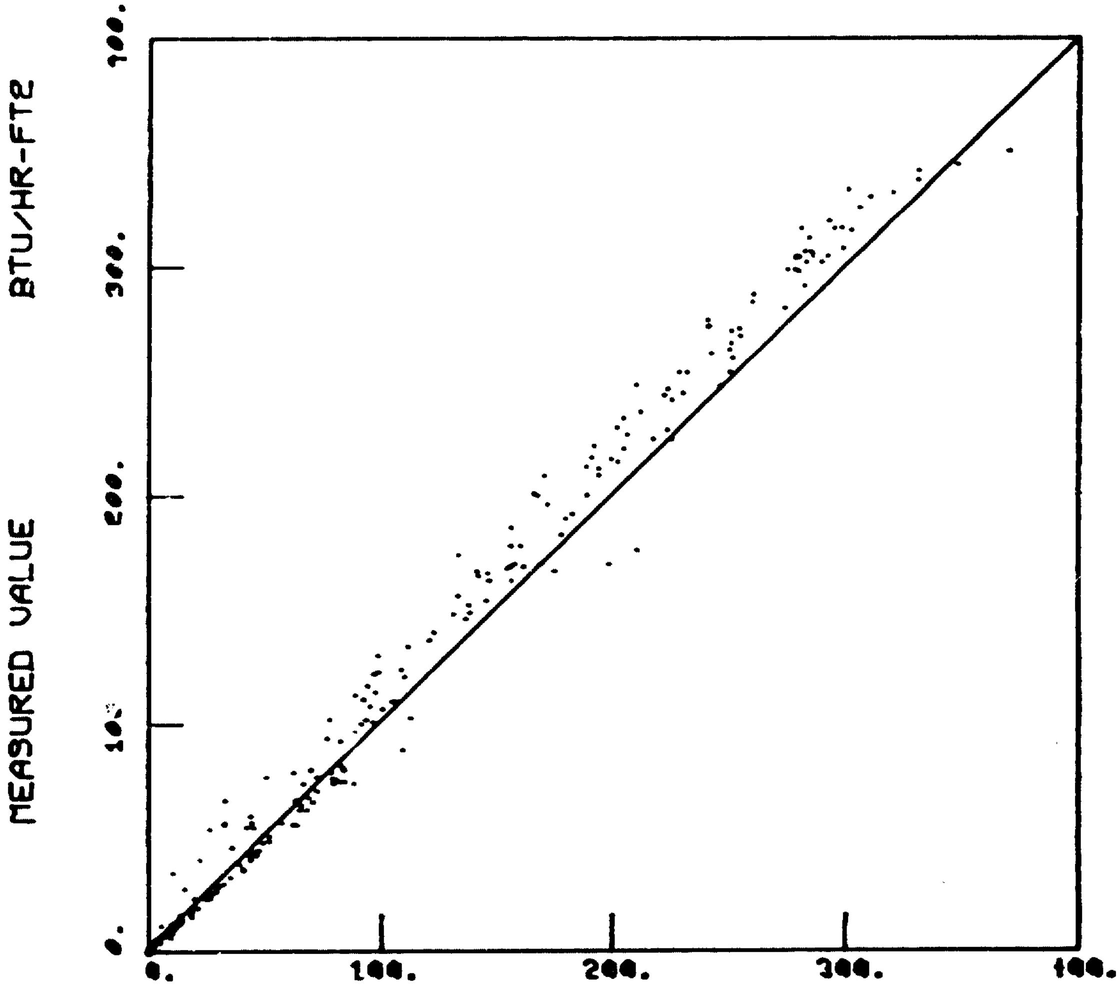


FIGURE IV-7 PREDICTED VALUE ON 45 DEG SURFACE

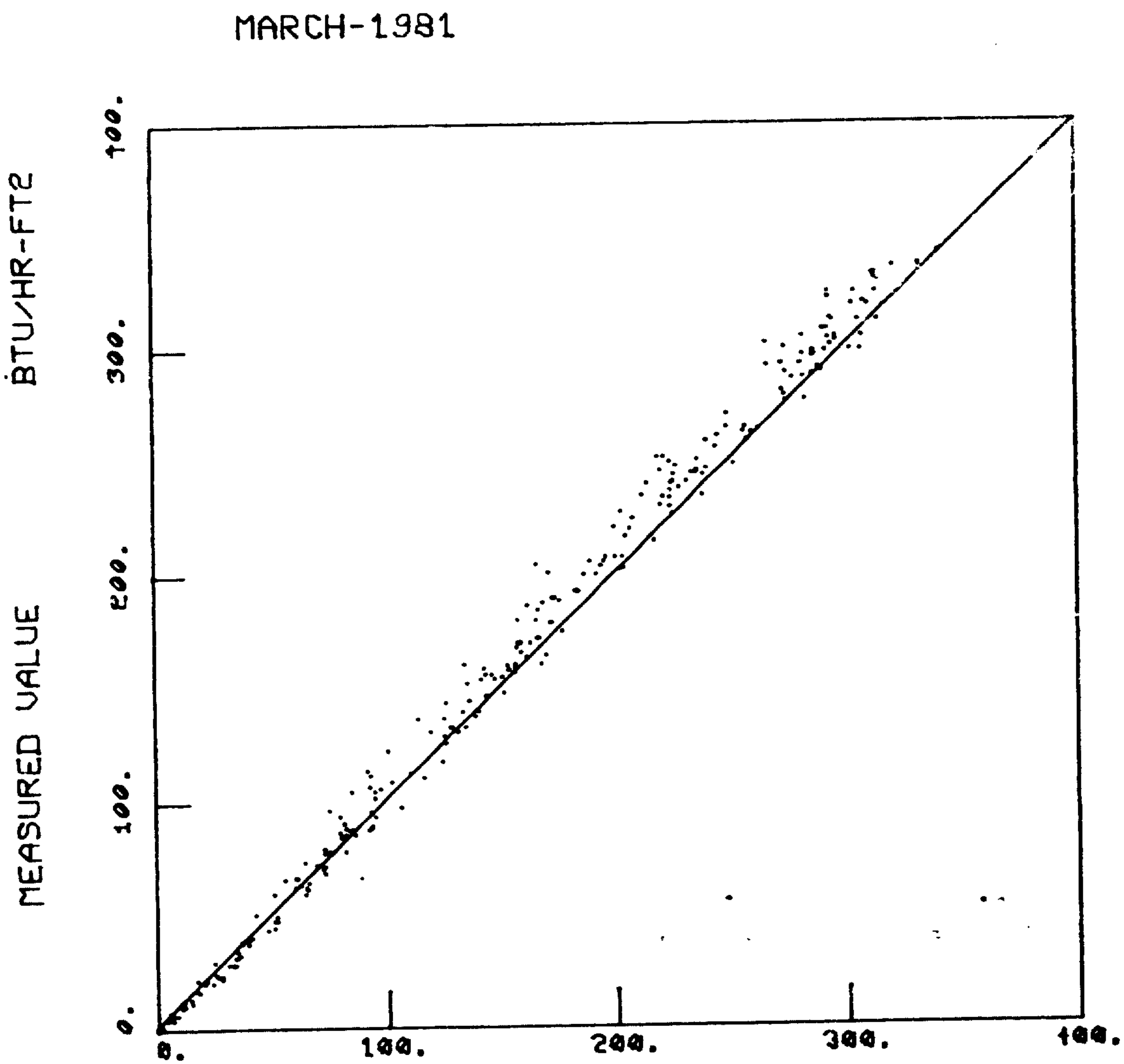


FIGURE IV-8 PREDICTED VALUE ON 45 DEG SURFACE

APRIL-1981

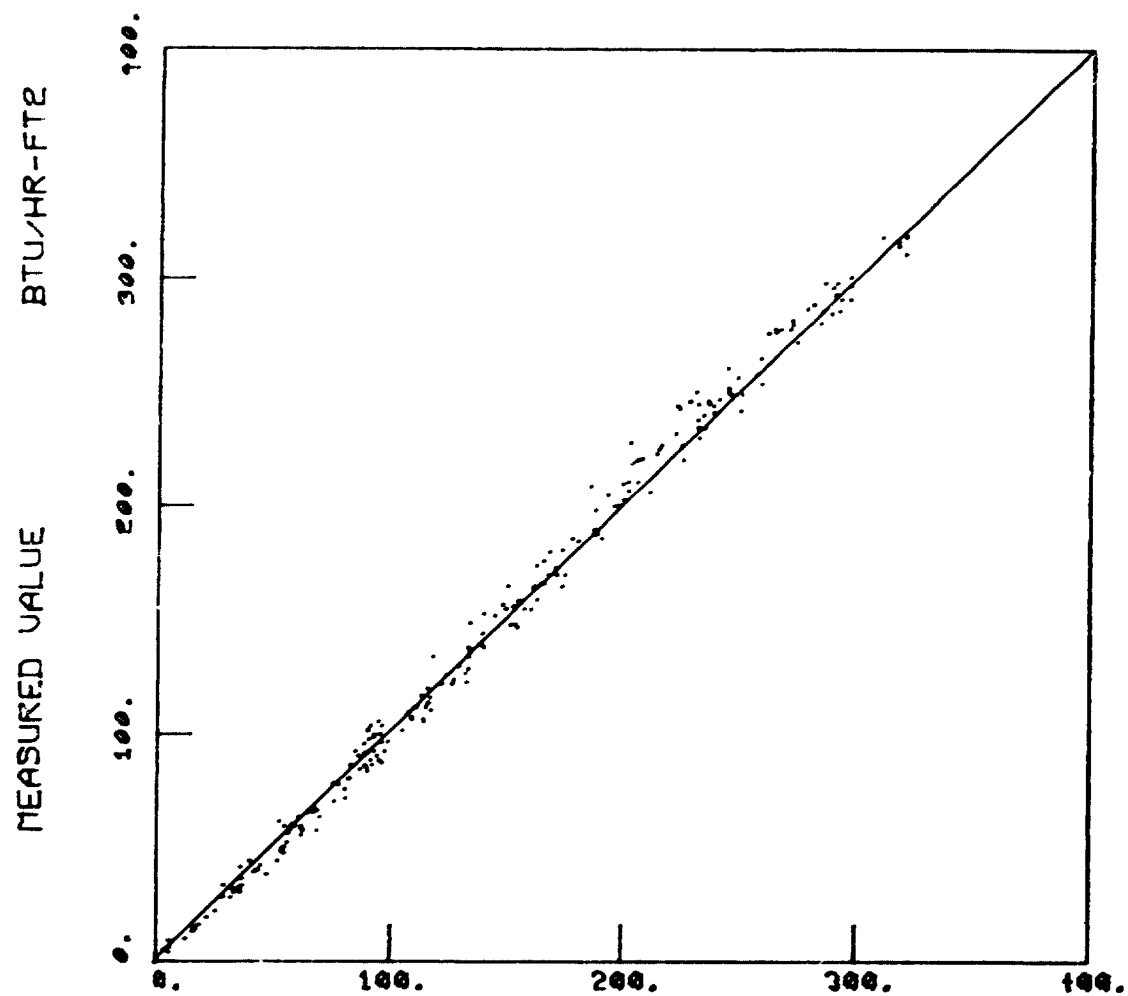


FIGURE IV-9 PREDICTED VALUE ON 45 DEG SURFACE

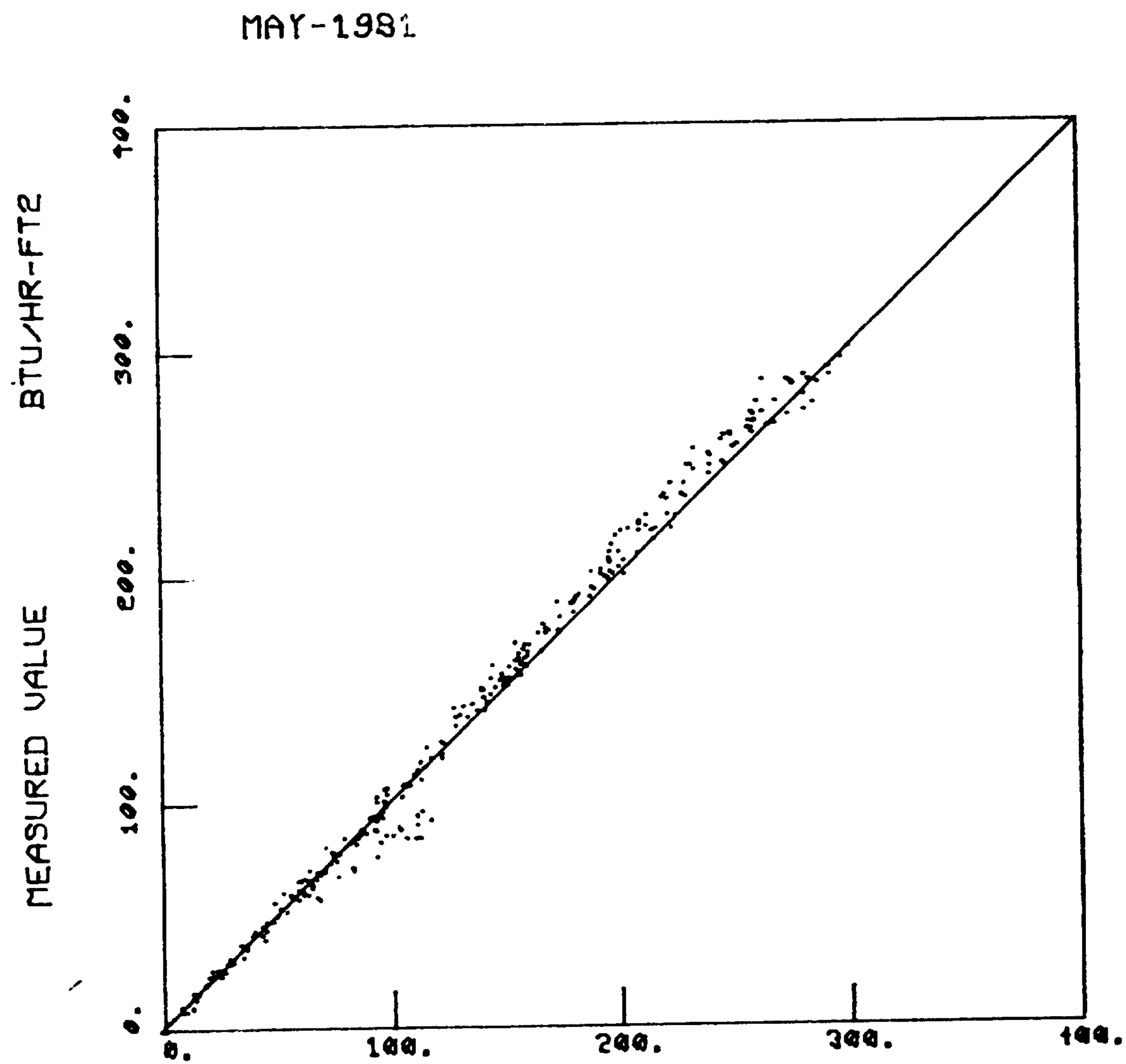


FIGURE IV-10 PREDICTED VALUE ON 45 DEG SURFACE

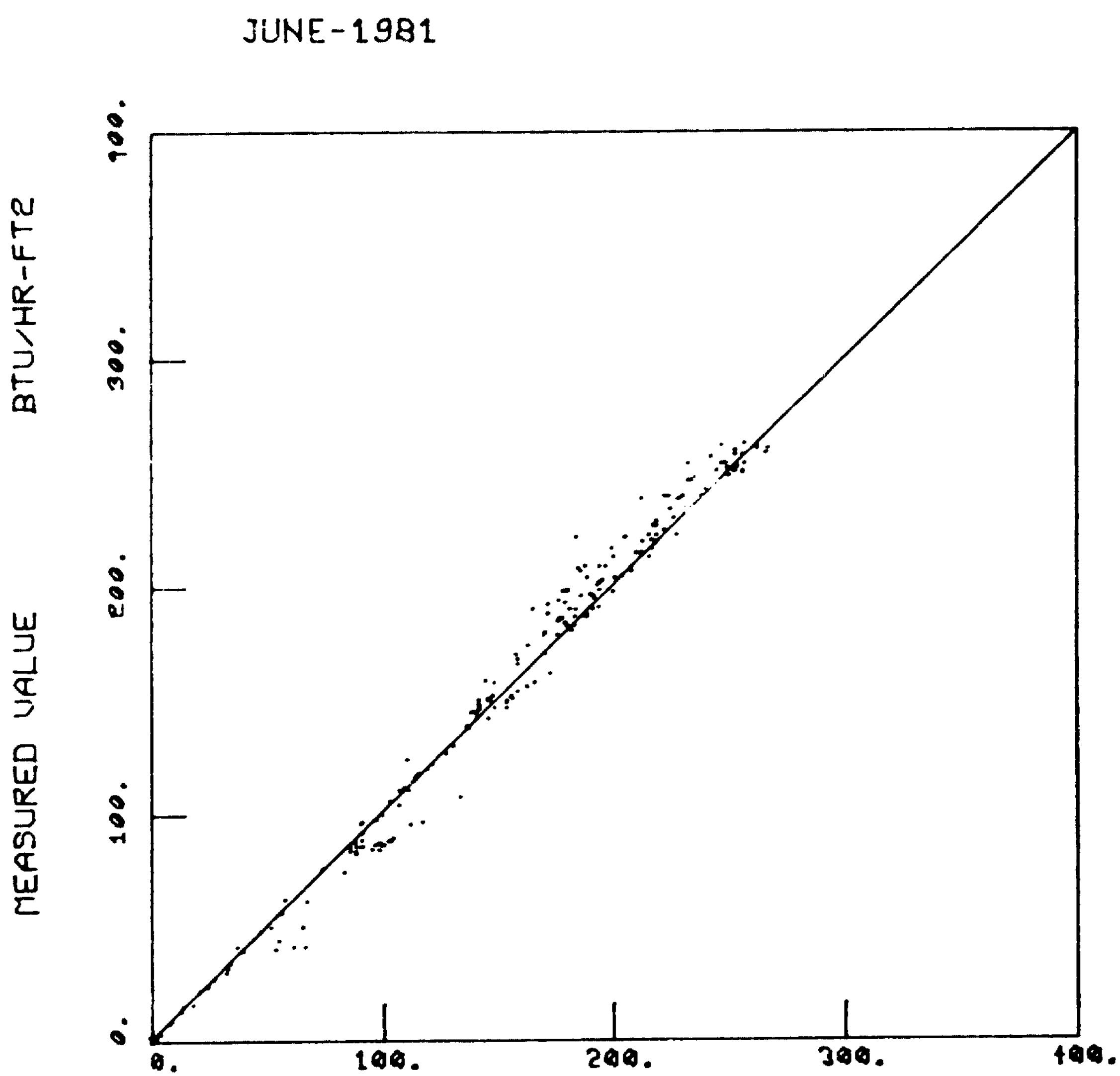


FIGURE IV-11 PREDICTED VALUE ON 45 DEG SURFACE

JULY-1981

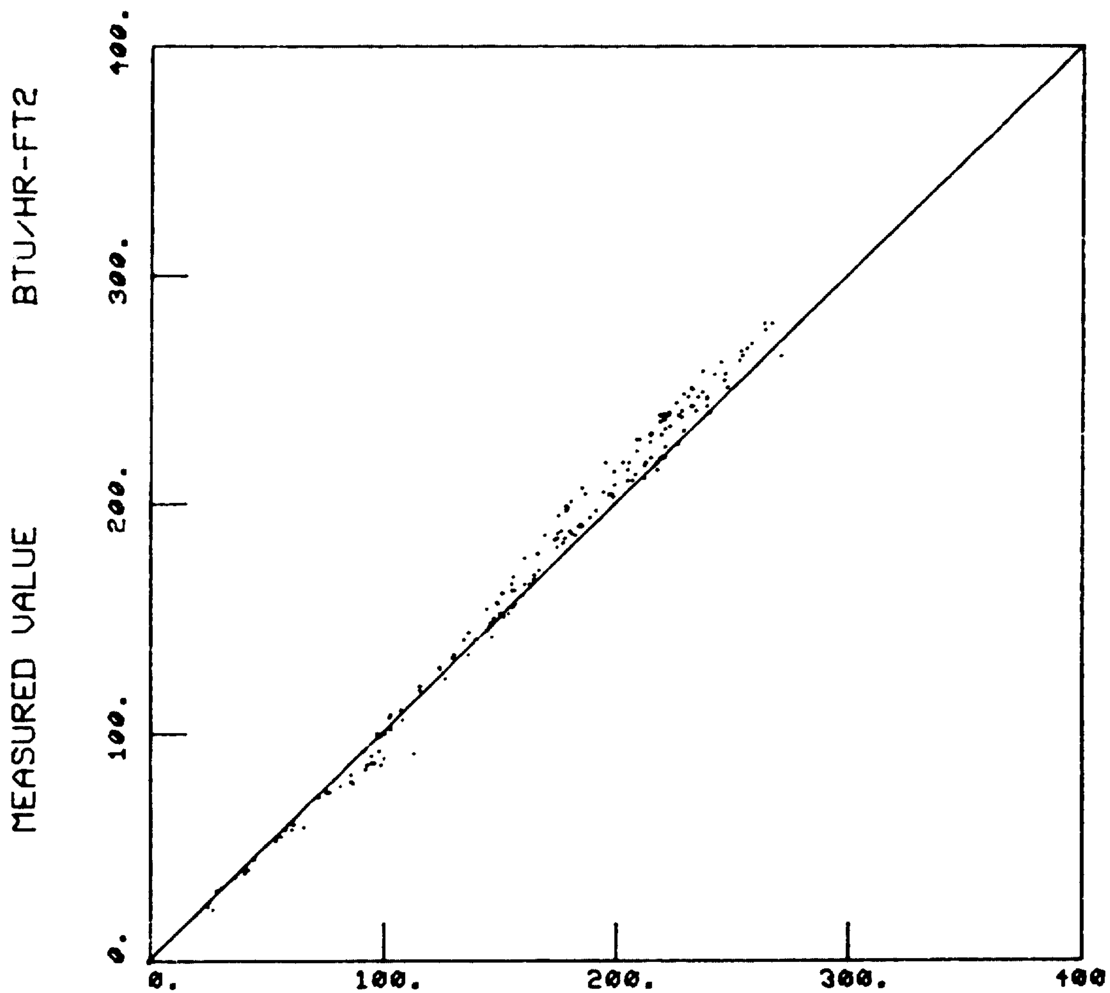


FIGURE IV-12 PREDICTED VALUE ON 45 DEG SURFACE

(V) REFERENCES

(1) ASHRAE STANDARD 93-77. "Methods of Testing To Determine the Thermal Performance of Solar Collectors". This standard is available from the American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., Publications Sales Department, 345 E 47th Street, New York, NY 10017.

(2) NBSIR 78-1305A, "Provisional Flat Plate Solar Collector Testing Procedures: First Revision". This document can be ordered from the National Technical Information Service (NTIS), Springfield, Virginia, 22151.

(3) SERI/SP-755-789, "Insolation Data Manual" which provides monthly average solar radiation, temperature degree-day and a global cloud factor. This document can be obtained from the U.S.Government Printing Office, Washington, DC 20402.

(4) "Monthly Summary Solar Radiation Data" for hourly insolation data. Subscription available from the US Department of Commerce, National Oceanic & Atmospheric Administration, Environmental Data & Information Service, National Climatic Center, Asheville, NC 28801.

(5) Duffie, J.A., and W.A. Beckman, "Solar Energy Thermal Process", John Wiley and Sons, New York, 1974.

APPENDIX 1

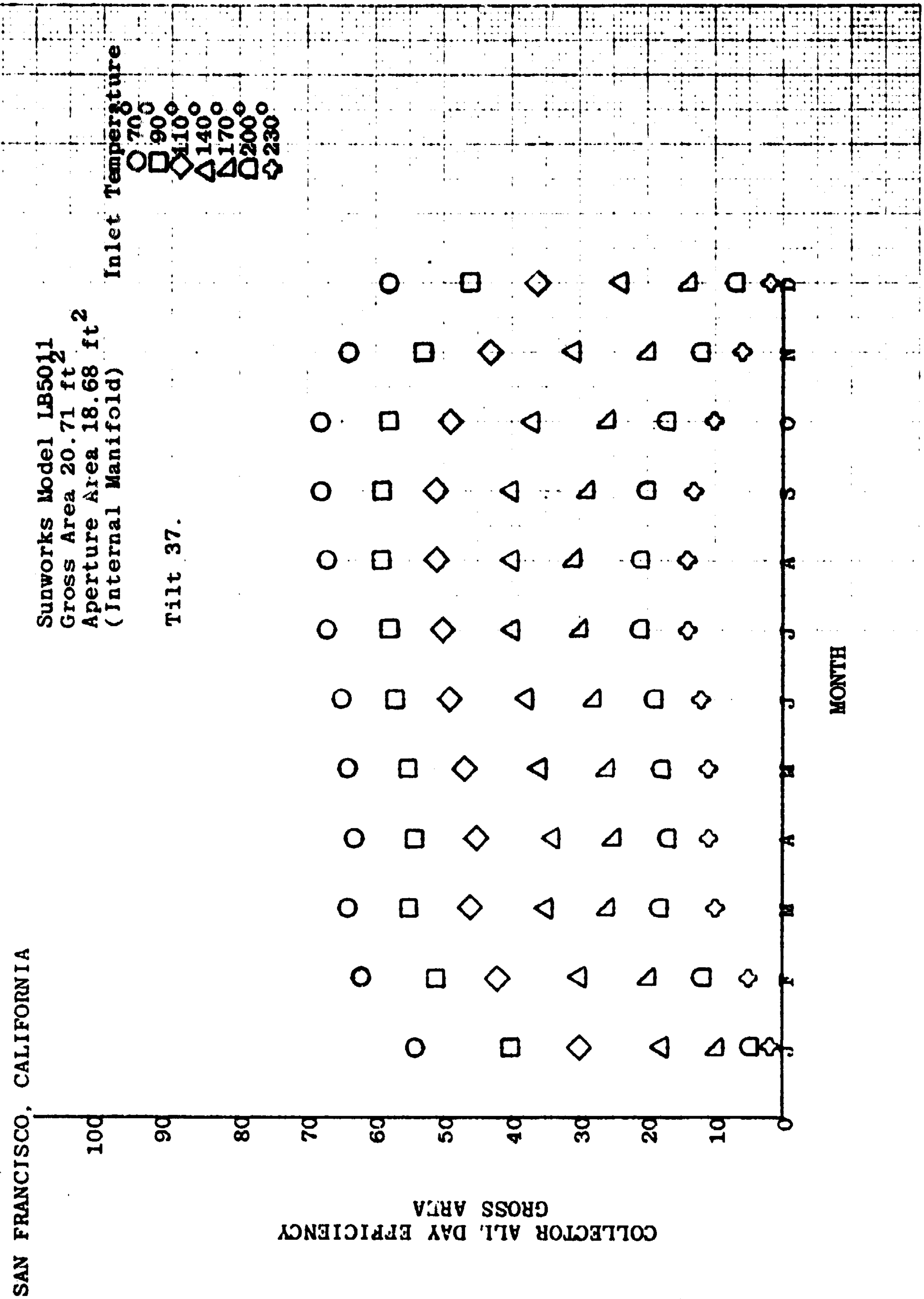
MONTHLY ALL - DAY EFFICIENCIES

for

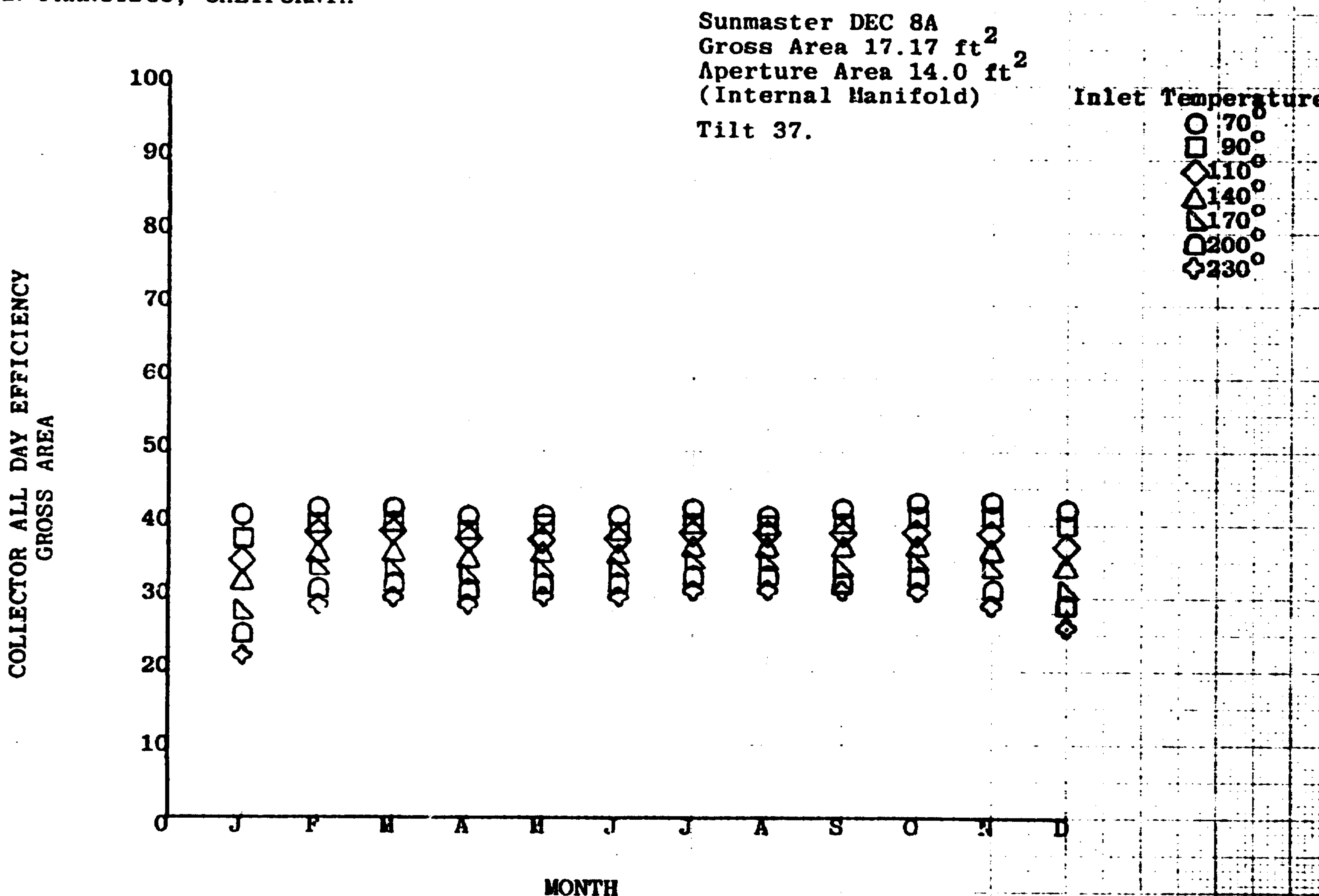
SOLAR THERMAL COLLECTORS

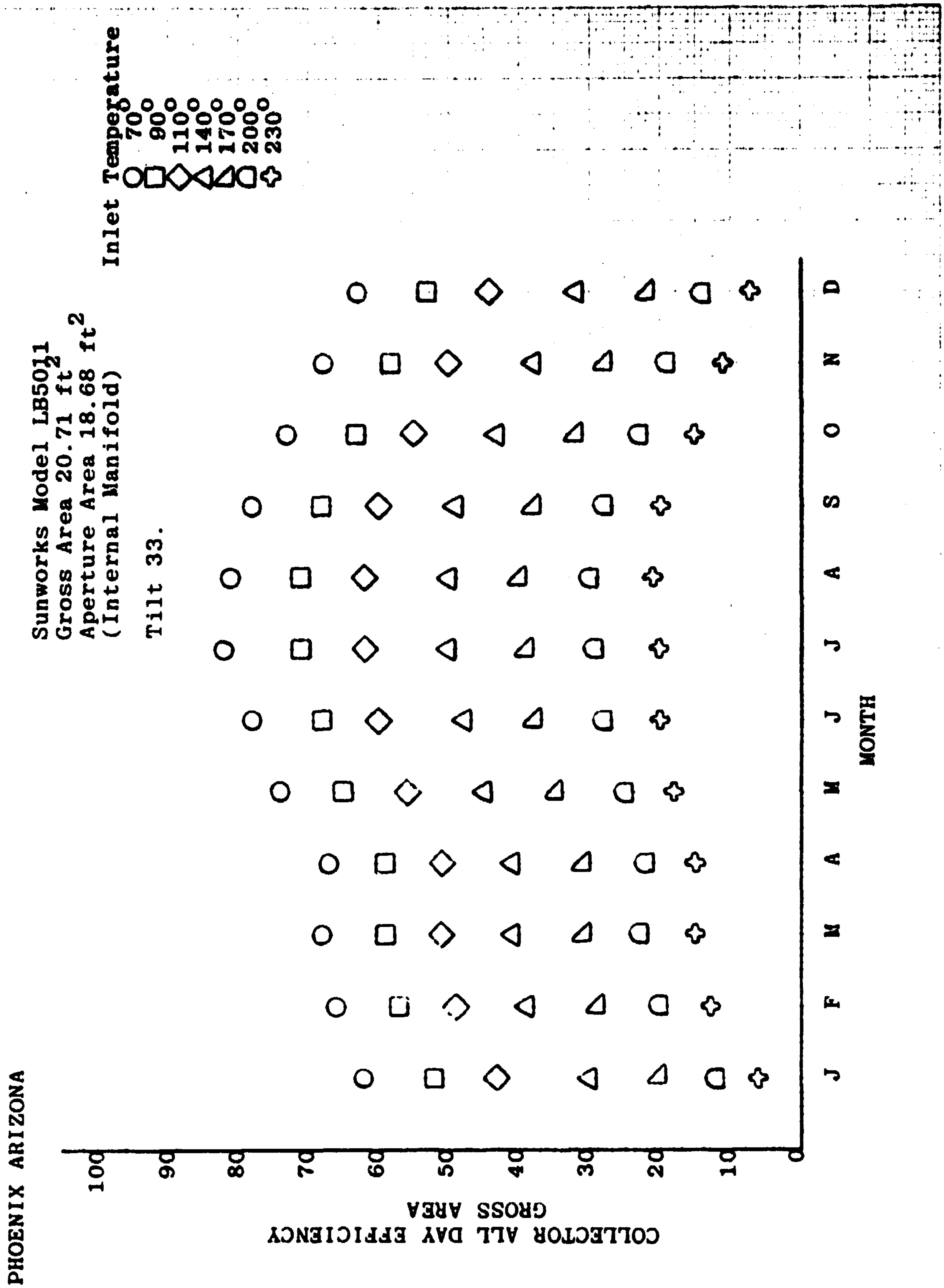
at

SELECTED SITES


SAN FRANCISCO, CALIFORNIA
Sunworks Model LB5011
Gross Area 20.71 ft^2
Aperture Area 18.68 ft^2
(Internal Manifold)
Tilt 37.
Inlet Temperature
70°
90°
110°
140°
170°
200°
230°
COLLECTOR ALL DAY EFFICIENCY
GROSS AREA
100
90
80
70
60
50
40
30
20
10
0
MONTH

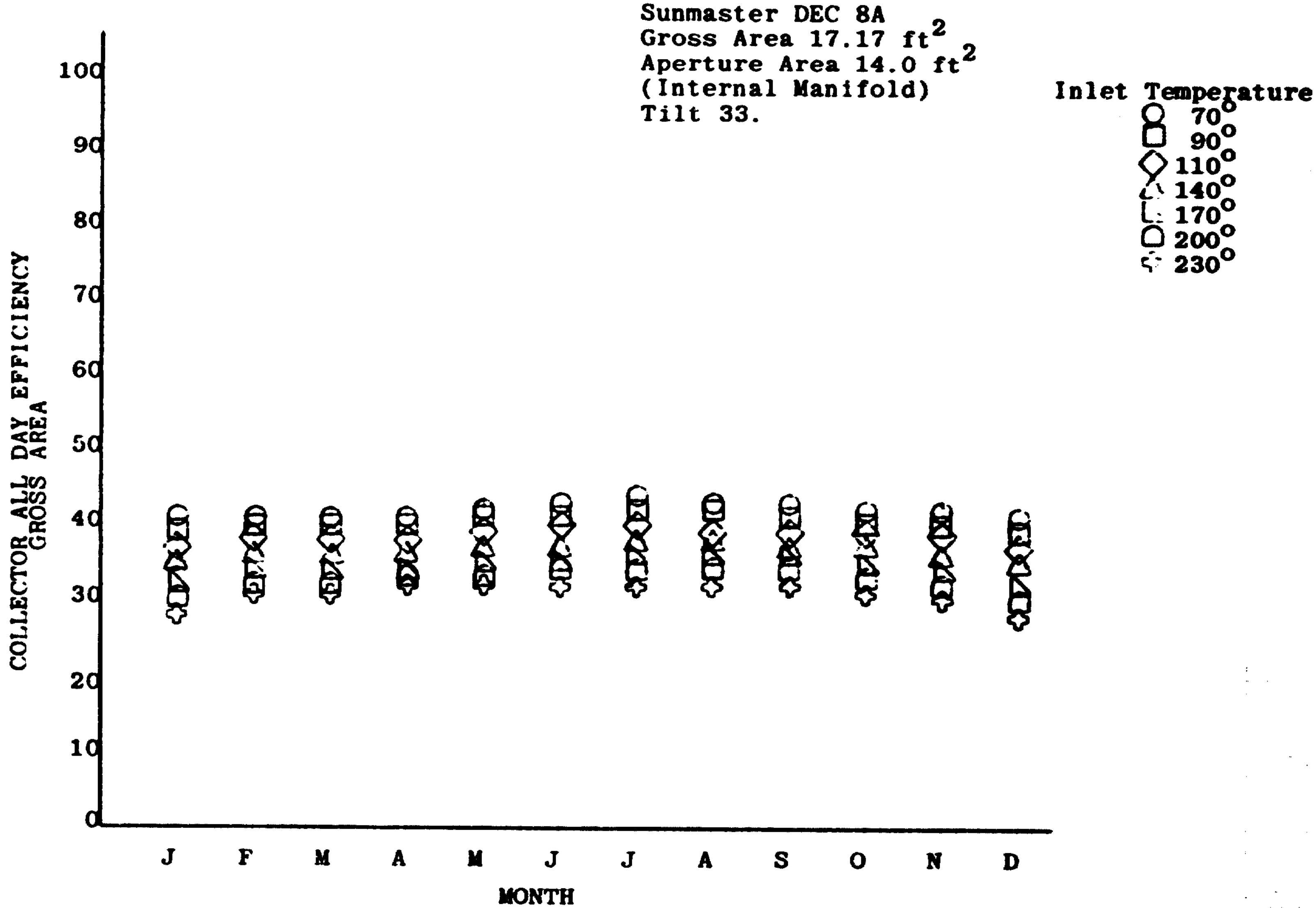
SAN FRANCISCO, CALIFORNIA



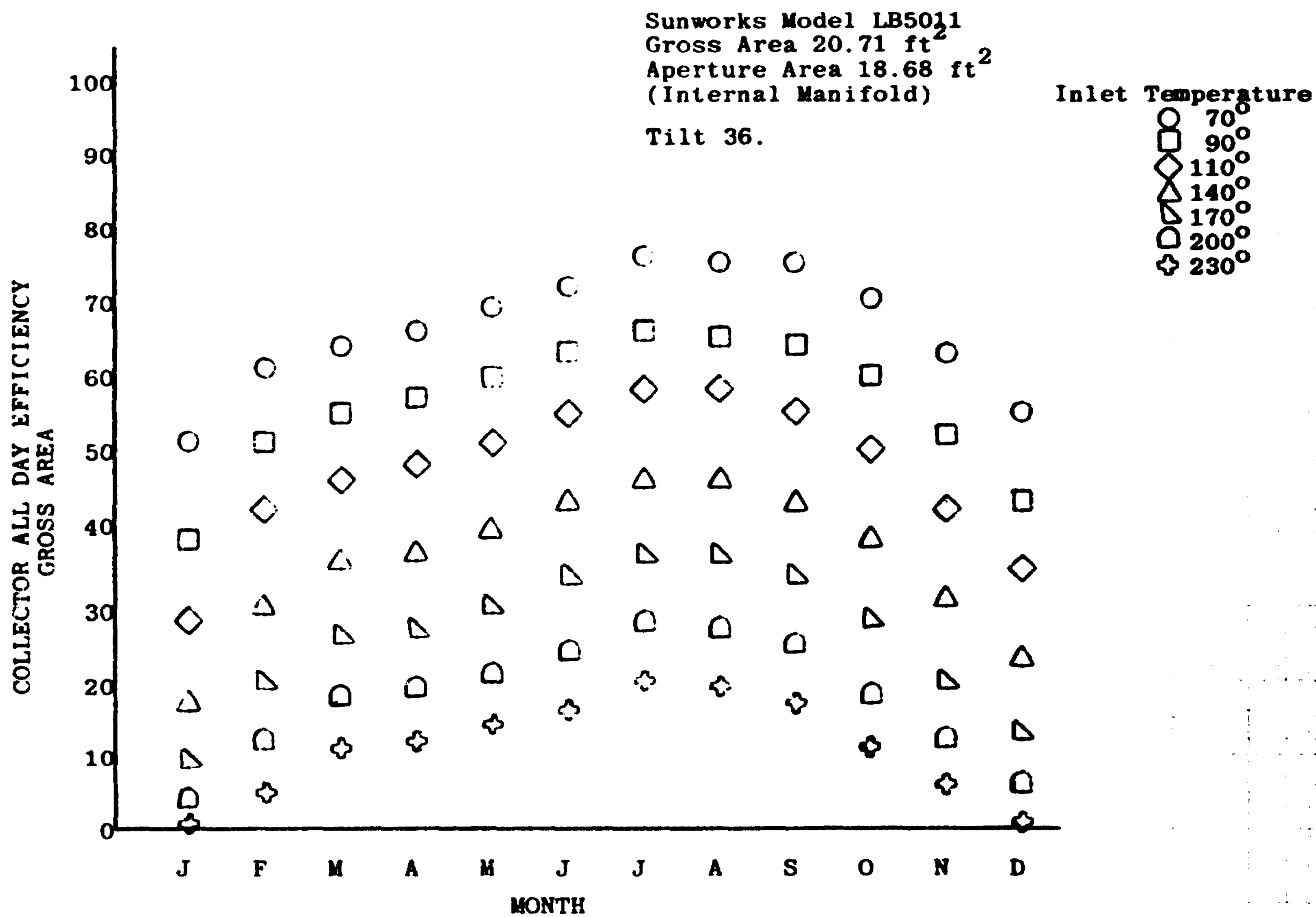


PHOENIX ARIZONA
Sunworks Model LB5011
Gross Area 20.71 ft2
Aperture Area 18.68 ft2
(Internal Manifold)
Tilt 33.
Inlet Temperature
70°
90°
110°
140°
170°
200°
230°
COLLECTOR ALL DAY EFFICIENCY
GROSS AREA
100
90
80
70
60
50
40
30
20
10
0
J F M A M J J A S O N D
MONTH

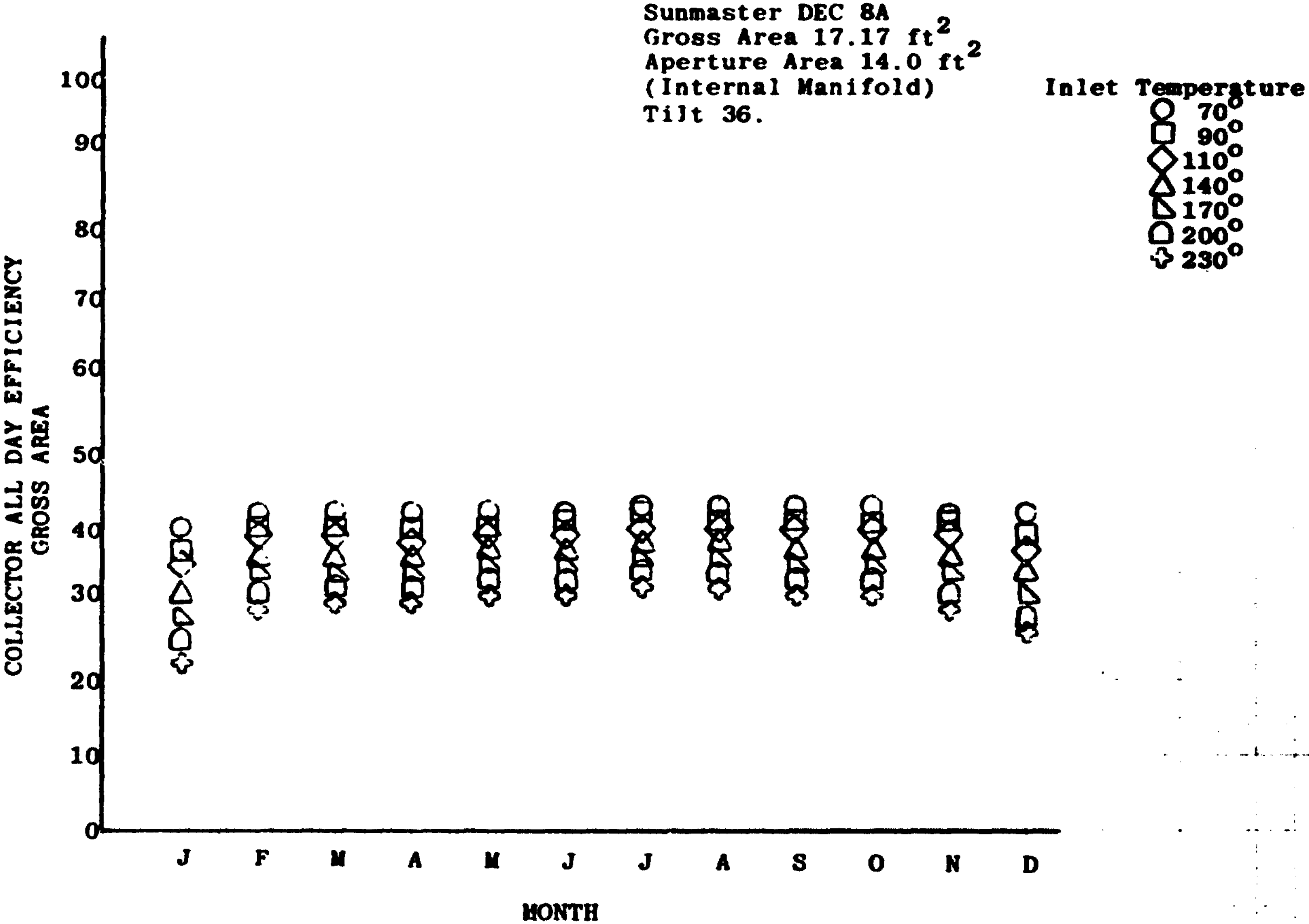
PHOENIX, ARIZONA



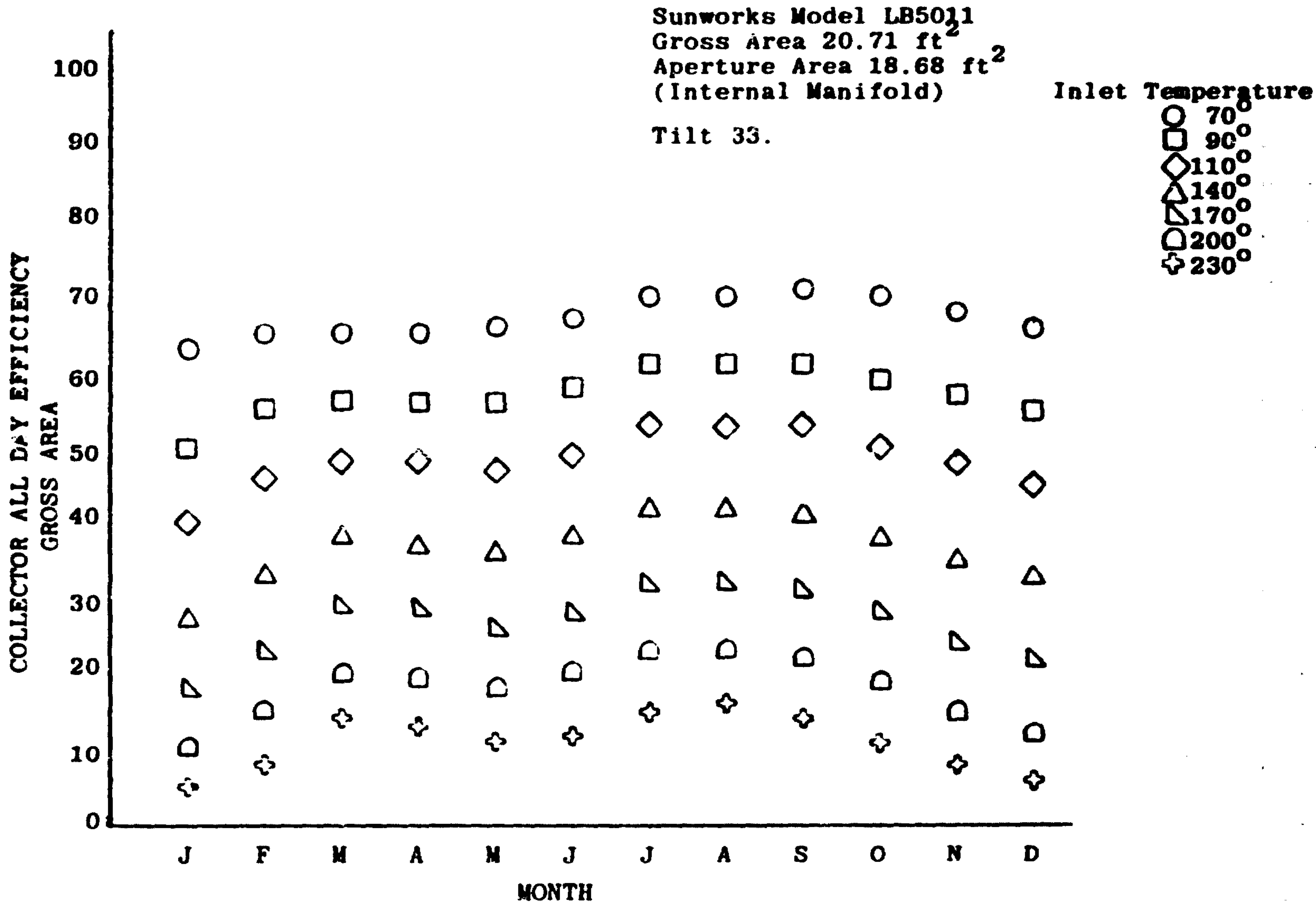
FRESNO, CALIFORNIA

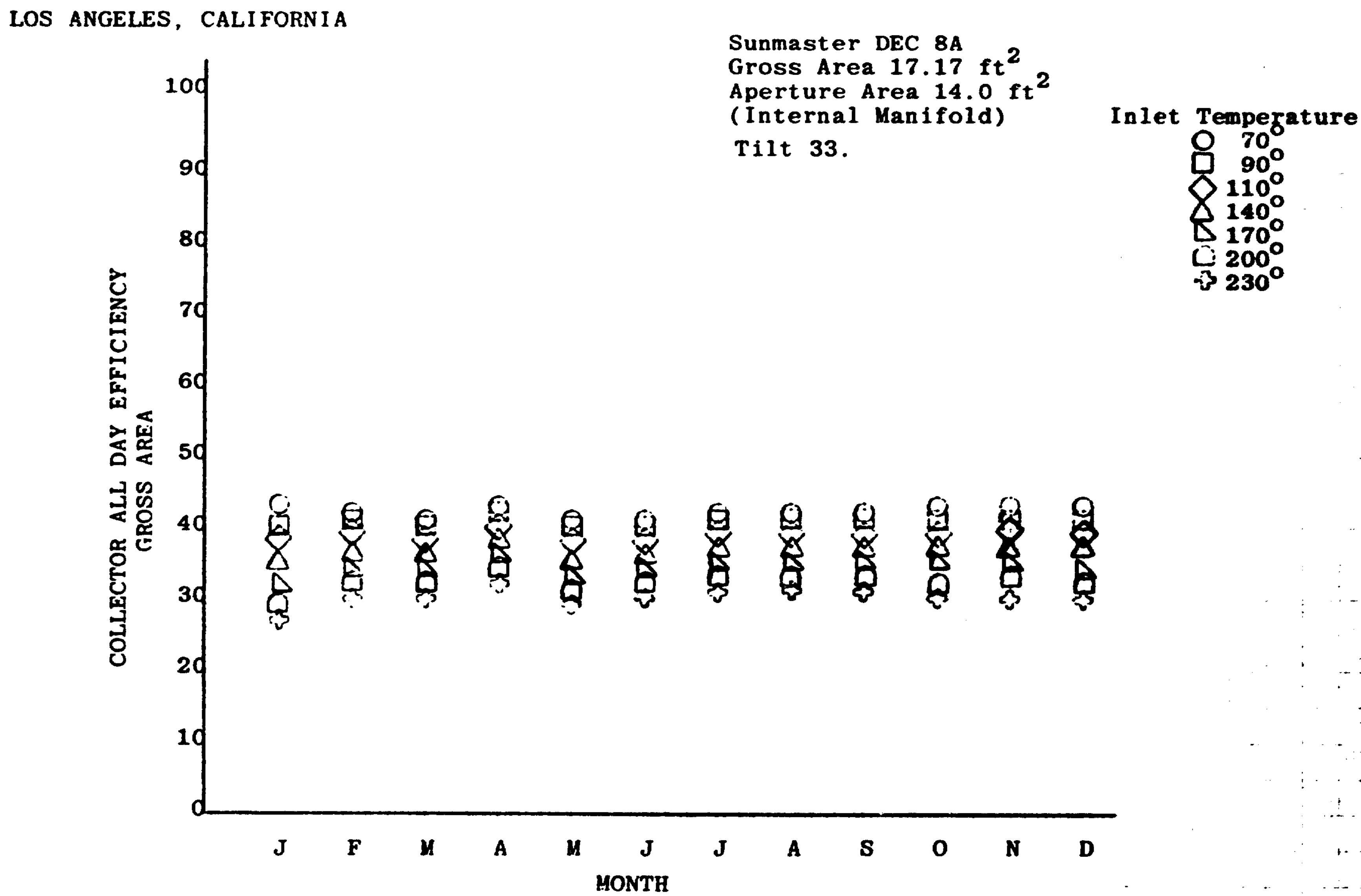


FRESNO, CALIFORNIA

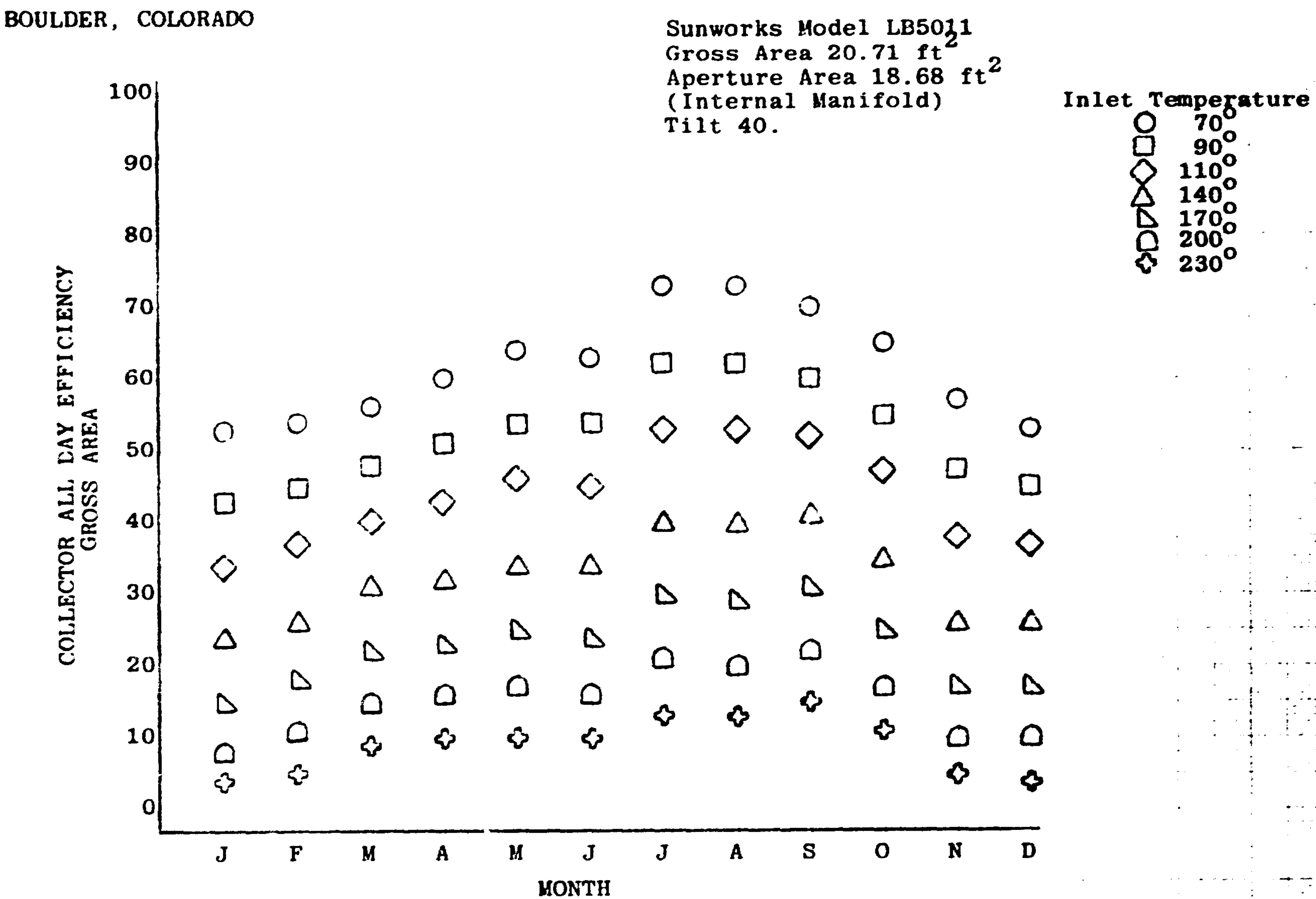


LOS ANGELES, CALIFORNIA

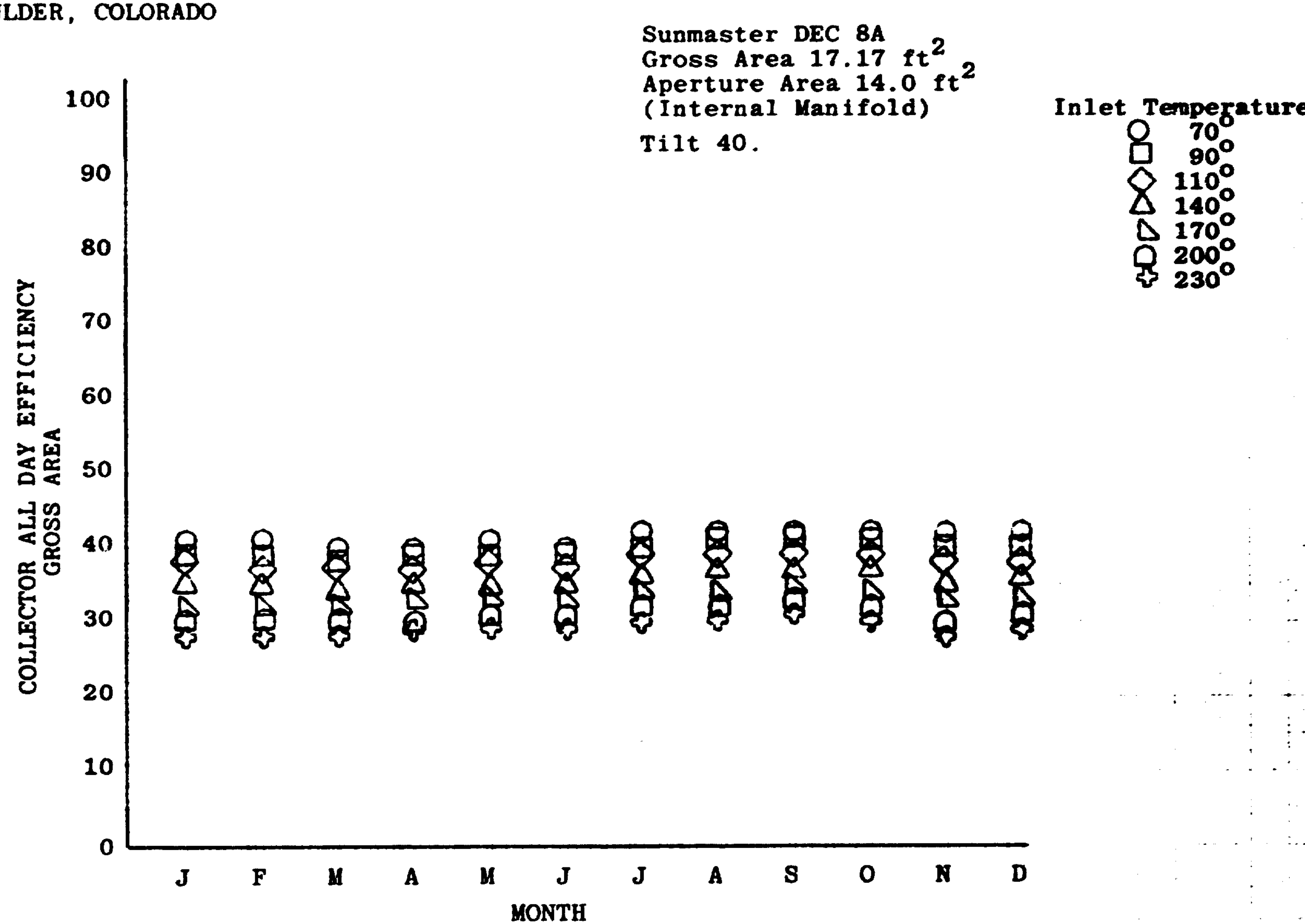




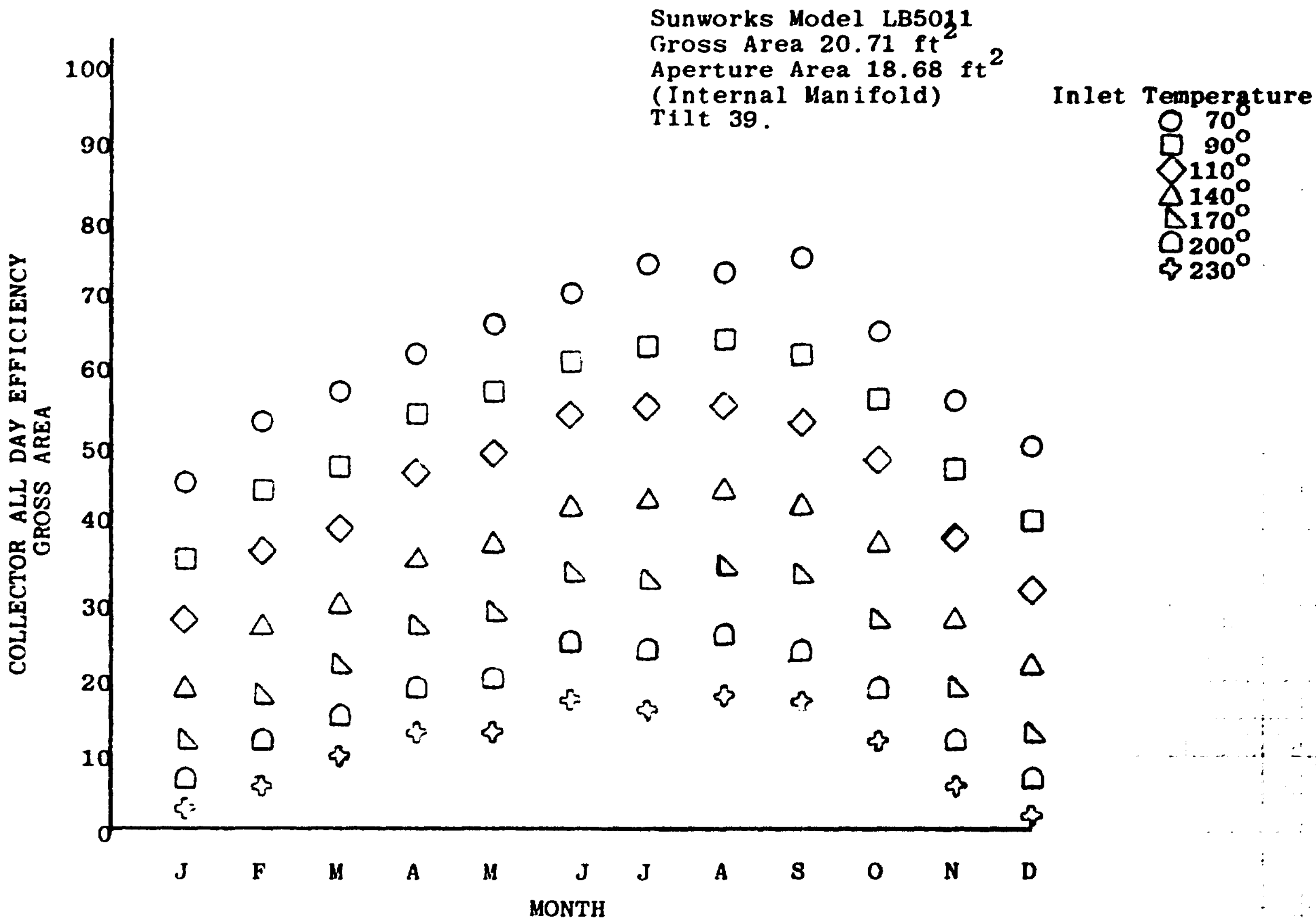
LOS ANGELES, CALIFORNIA
Sunmaster DEC 8A
Gross Area 17.17 ft^2
Aperture Area 14.0 ft^2
(Internal Manifold)
Tilt 33.
Inlet Temperature
70°
90°
110°
140°
170°
200°
230°
COLLECTOR ALL DAY EFFICIENCY GROSS AREA
0
10
20
30
40
50
60
70
80
90
100
J F M A M J J A S O N D
MONTH


BOULDER, COLORADO
Sunworks Model LB5011
Gross Area 20.71 ft^2
Aperture Area 18.68 ft^2
(Internal Manifold)
Tilt 40.
Inlet Temperature
70°
90°
110°
140°
170°
200°
230°
COLLECTOR ALL DAY EFFICIENCY GROSS AREA
100
90
80
70
60
50
40
30
20
10
0
J F M A M J J A S O N D
MONTH

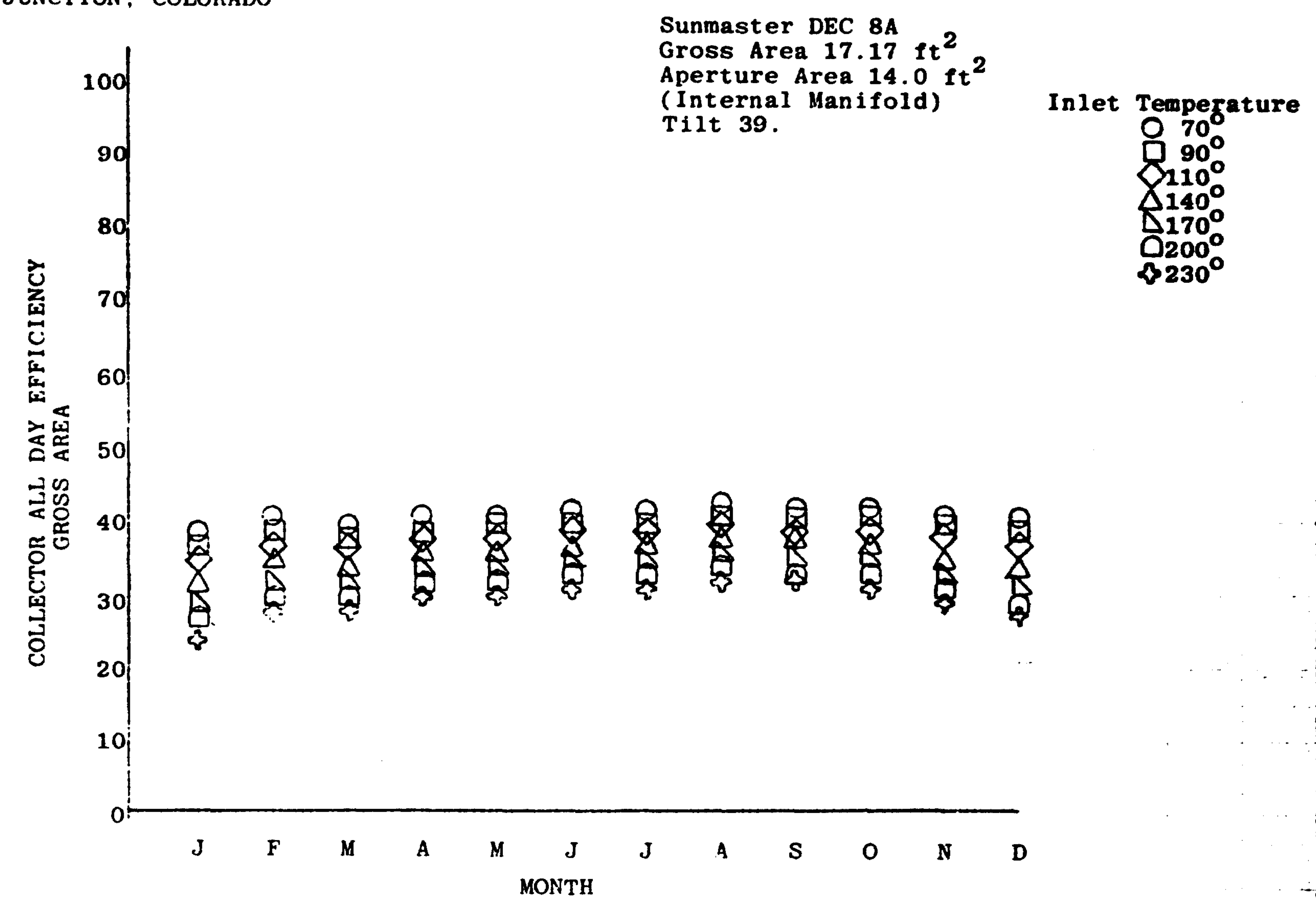
BOULDER, COLORADO



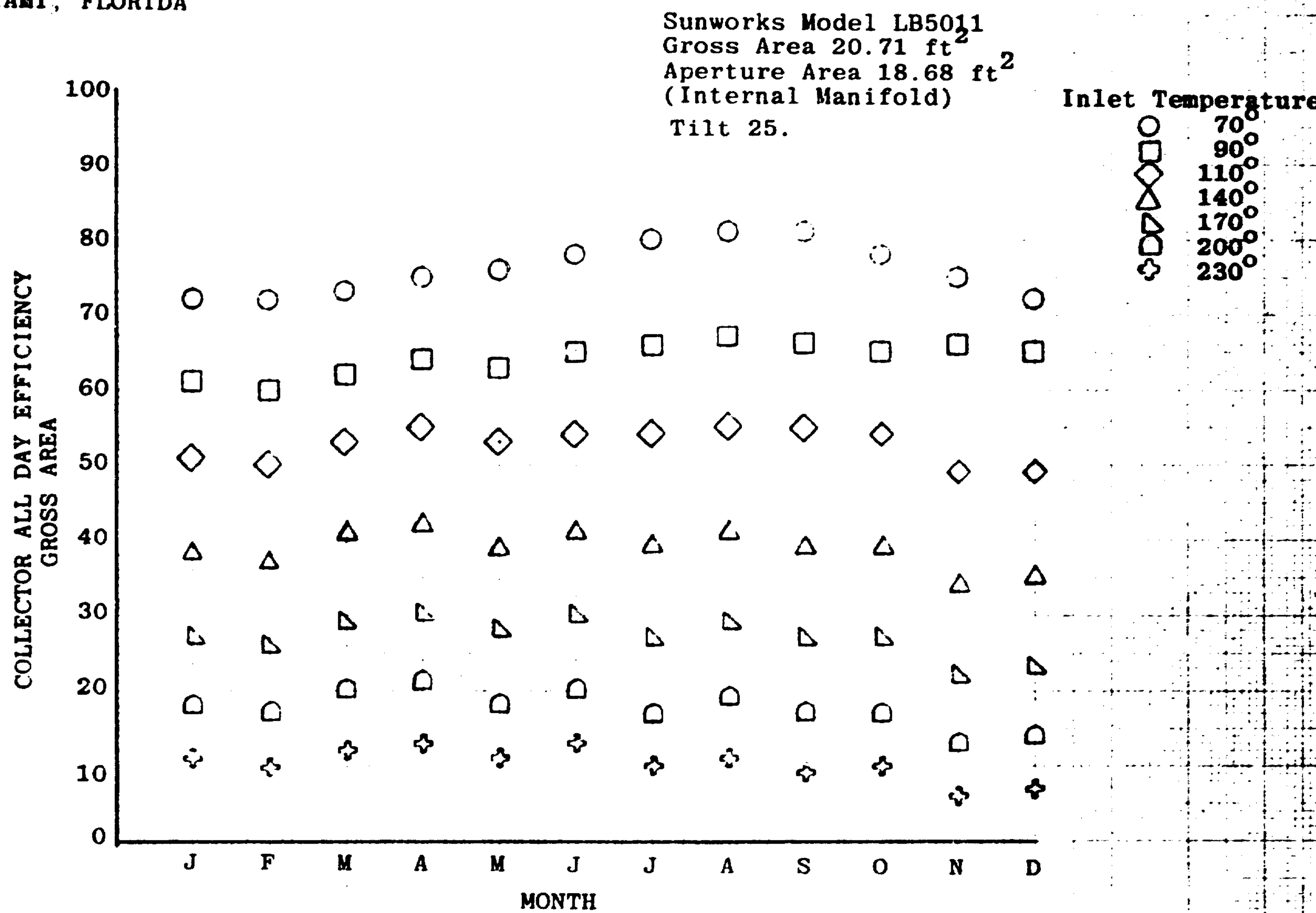
GRAND JUNCTION, COLORADO



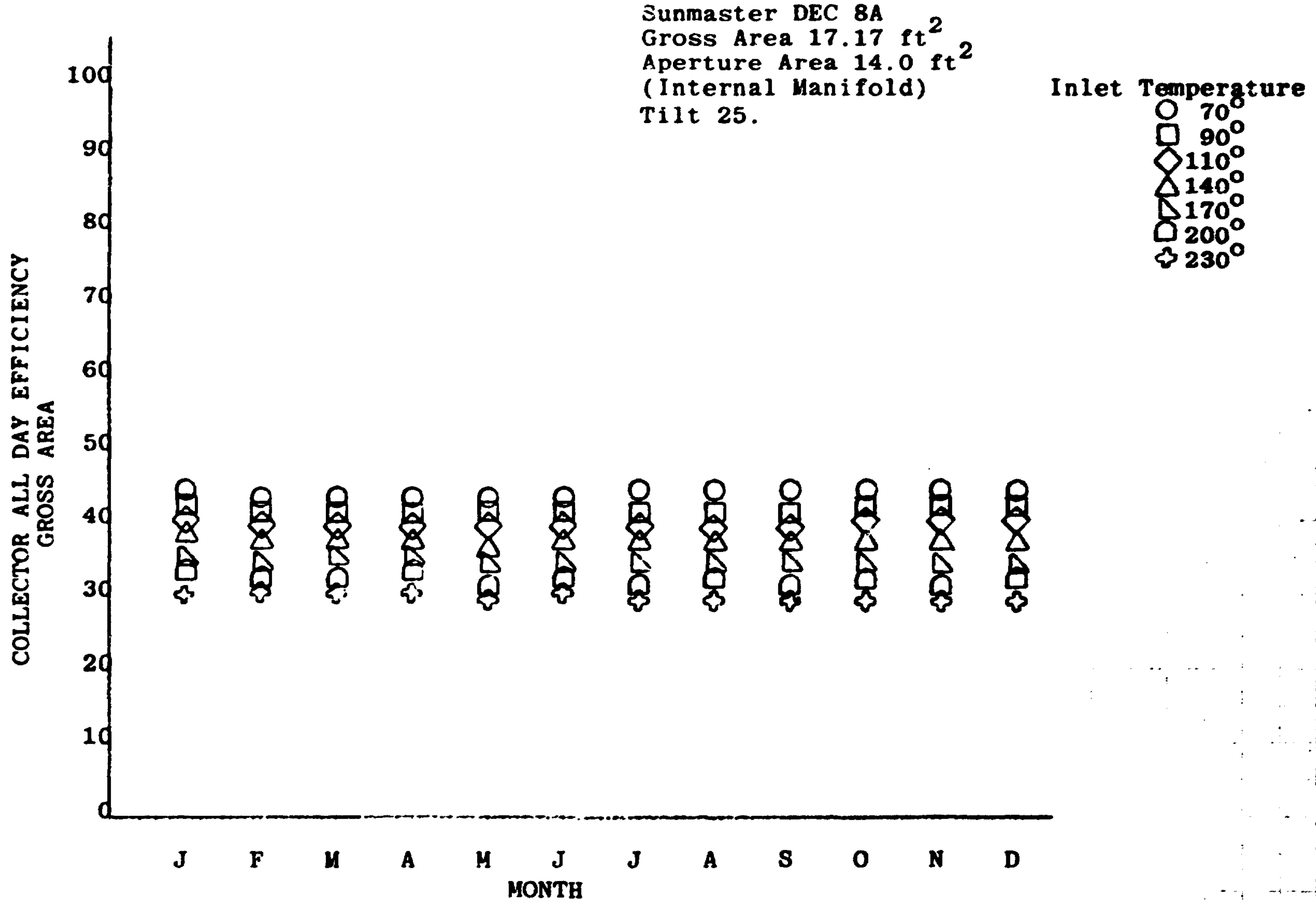
GRAND JUNCTION, COLORADO

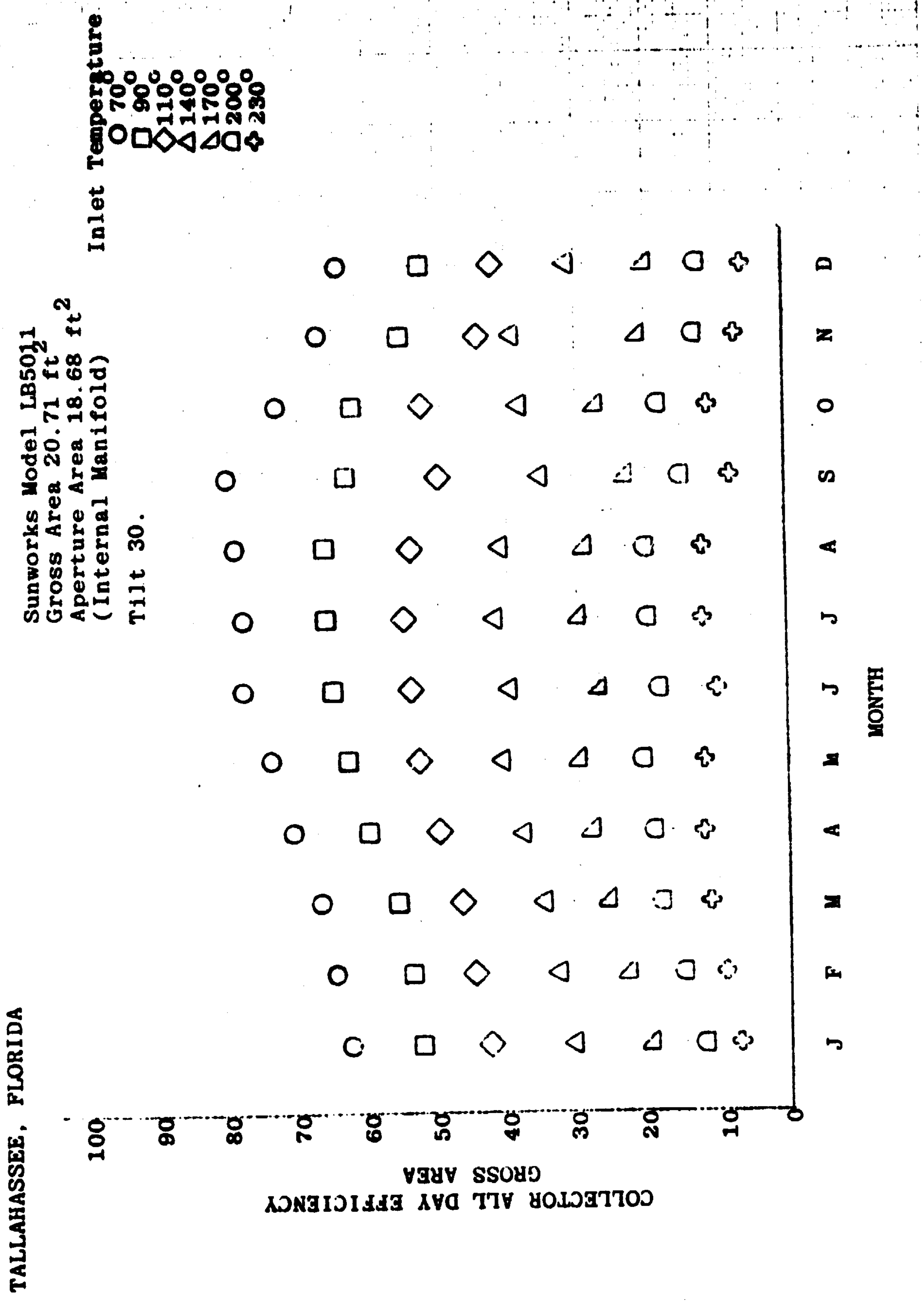


MIAMI, FLORIDA



MIAMI, FLORIDA





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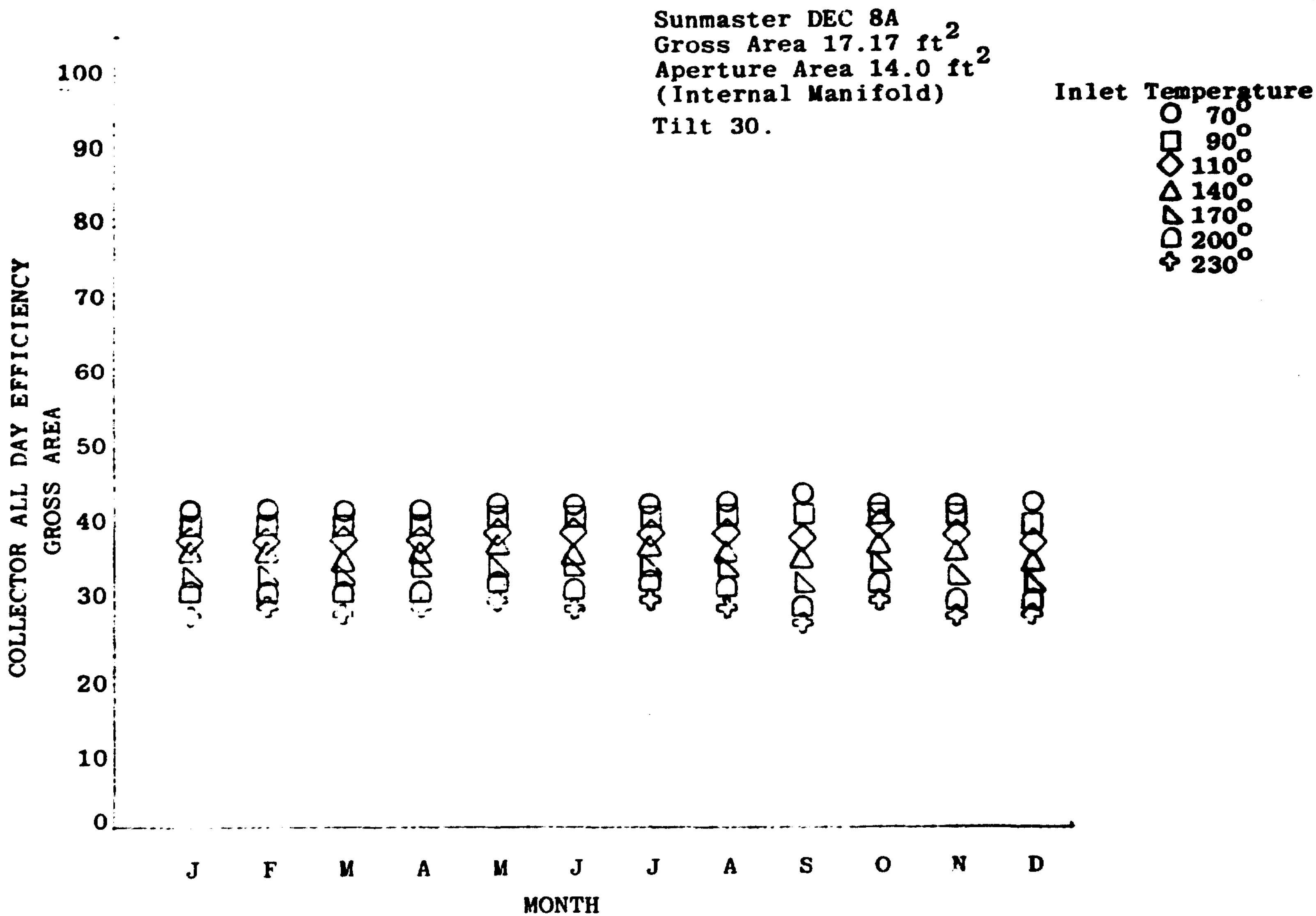
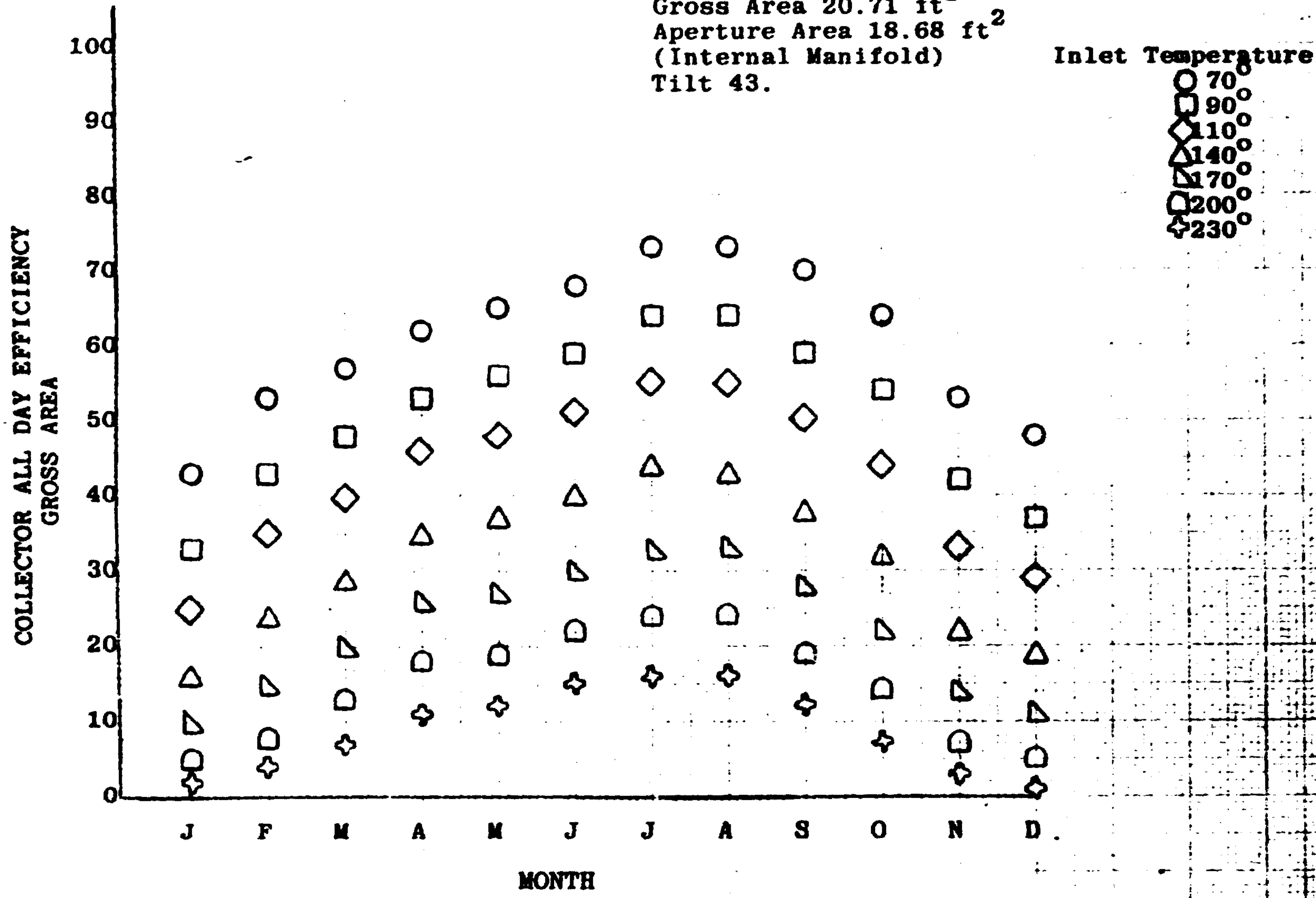
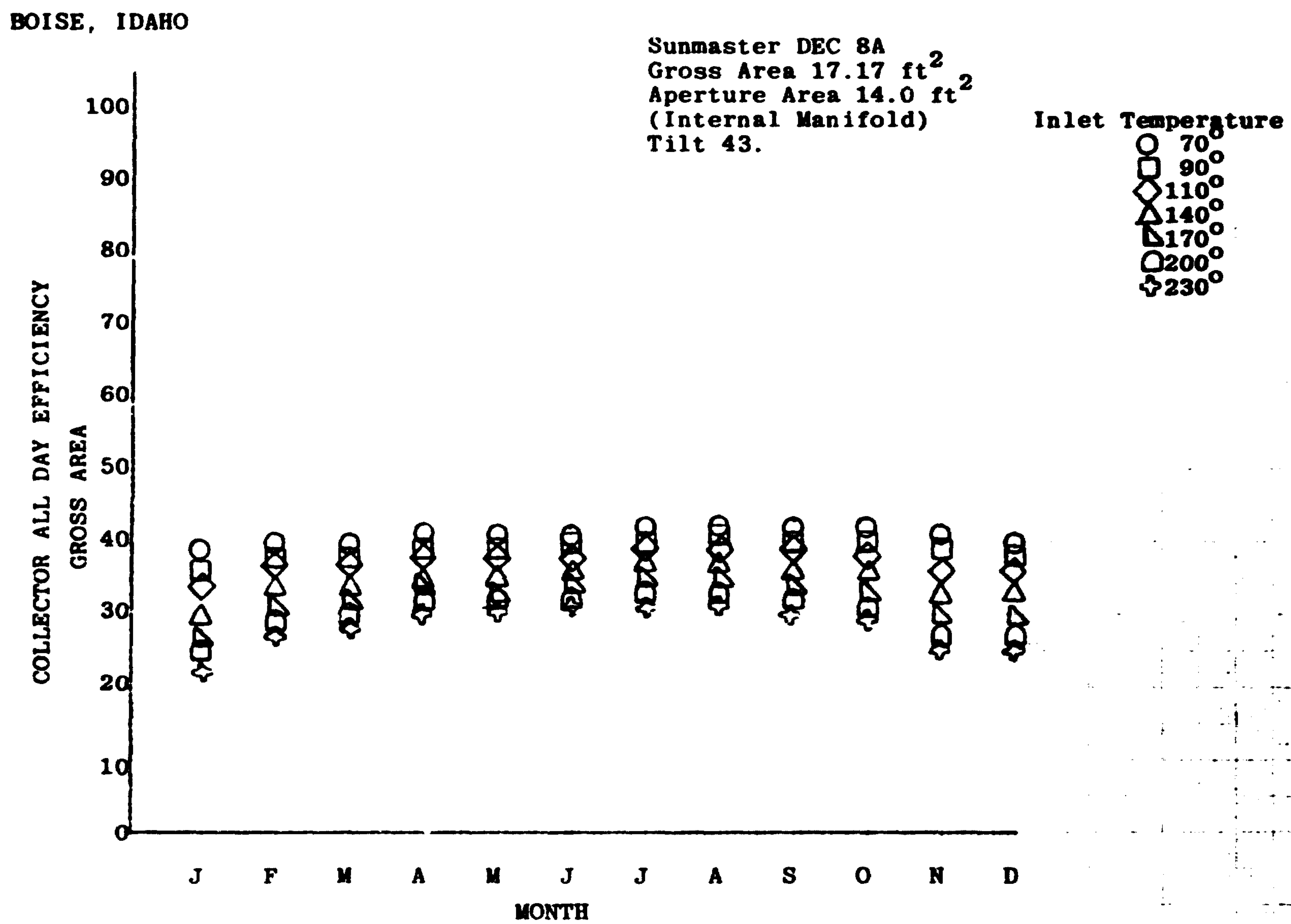
TALLAHASSEE, FLORIDA



BOISE, IDAHO

Sunworks Model LB5011
Gross Area 20.71 ft^2
Aperture Area 18.68 ft^2
(Internal Manifold)
Tilt 43.




BOISE, IDAHO
Sunmaster DEC 8A
Gross Area 17.17 ft²
Aperture Area 14.0 ft²
(Internal Manifold)
Tilt 43.
Inlet Temperature
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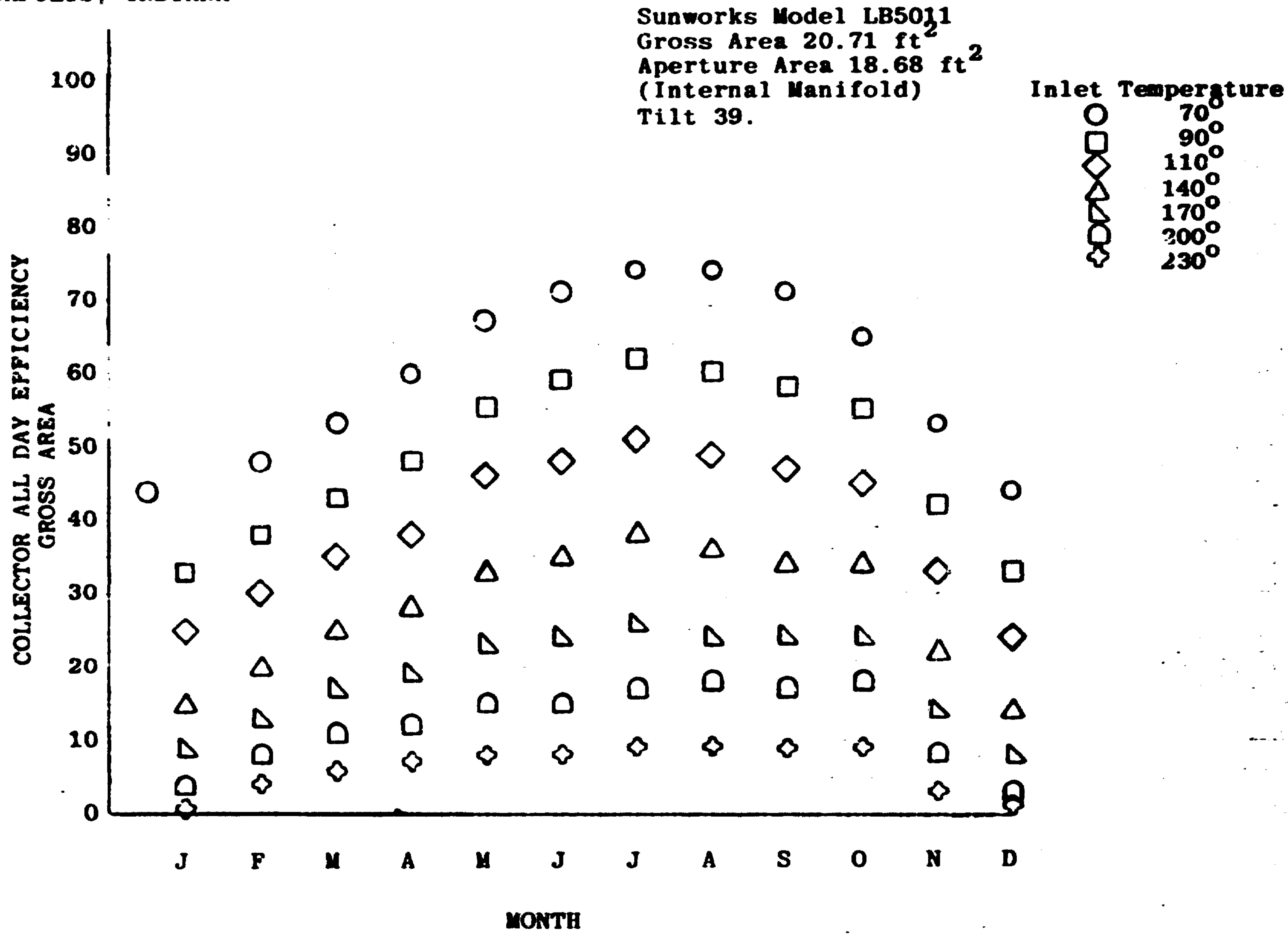
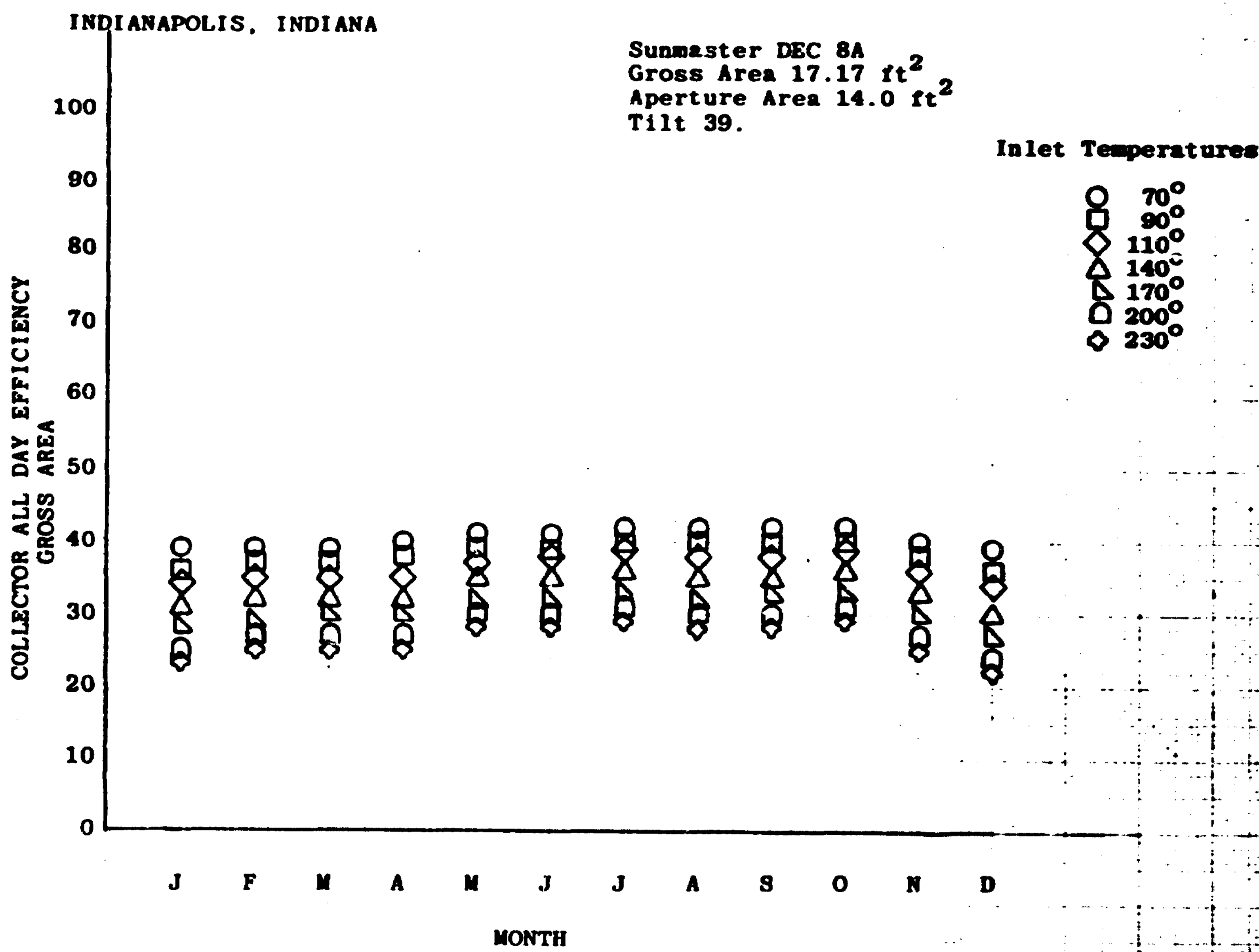
MONTH

INDIANAPOLIS, INDIANA





INDIANAPOLIS, INDIANA
Sunmaster DEC 8A
Gross Area 17.17 ft2
Aperture Area 14.0 ft2
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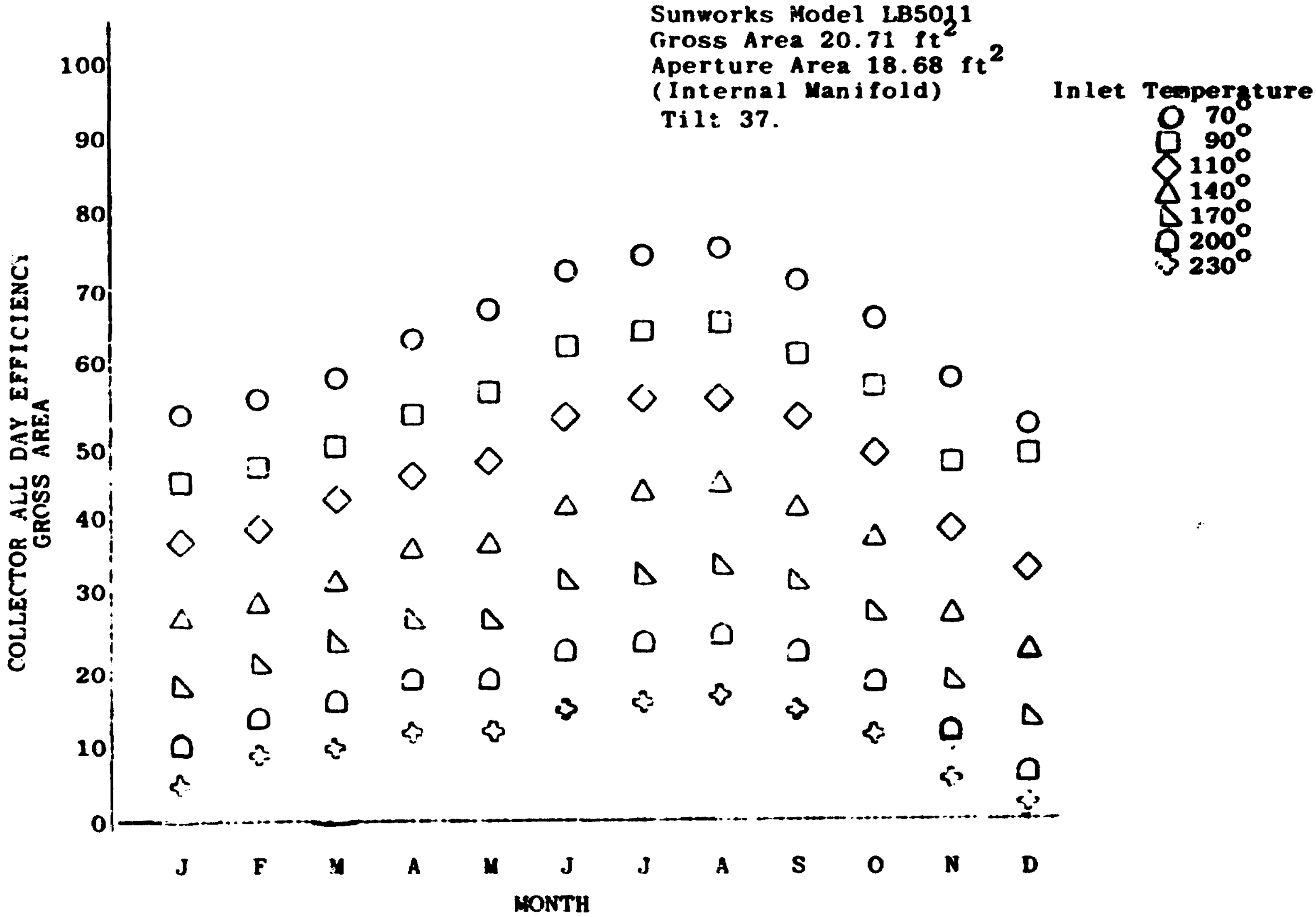
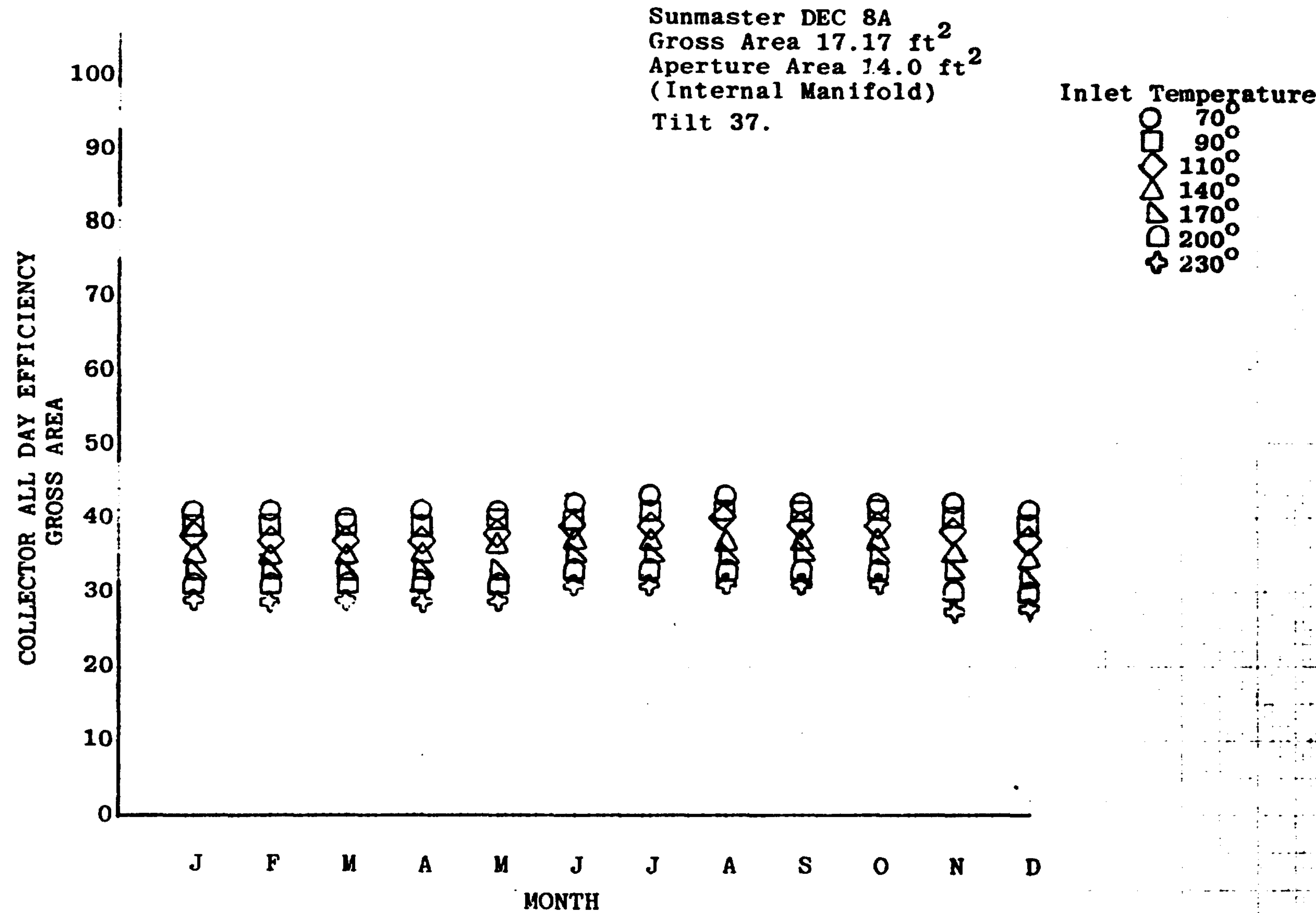
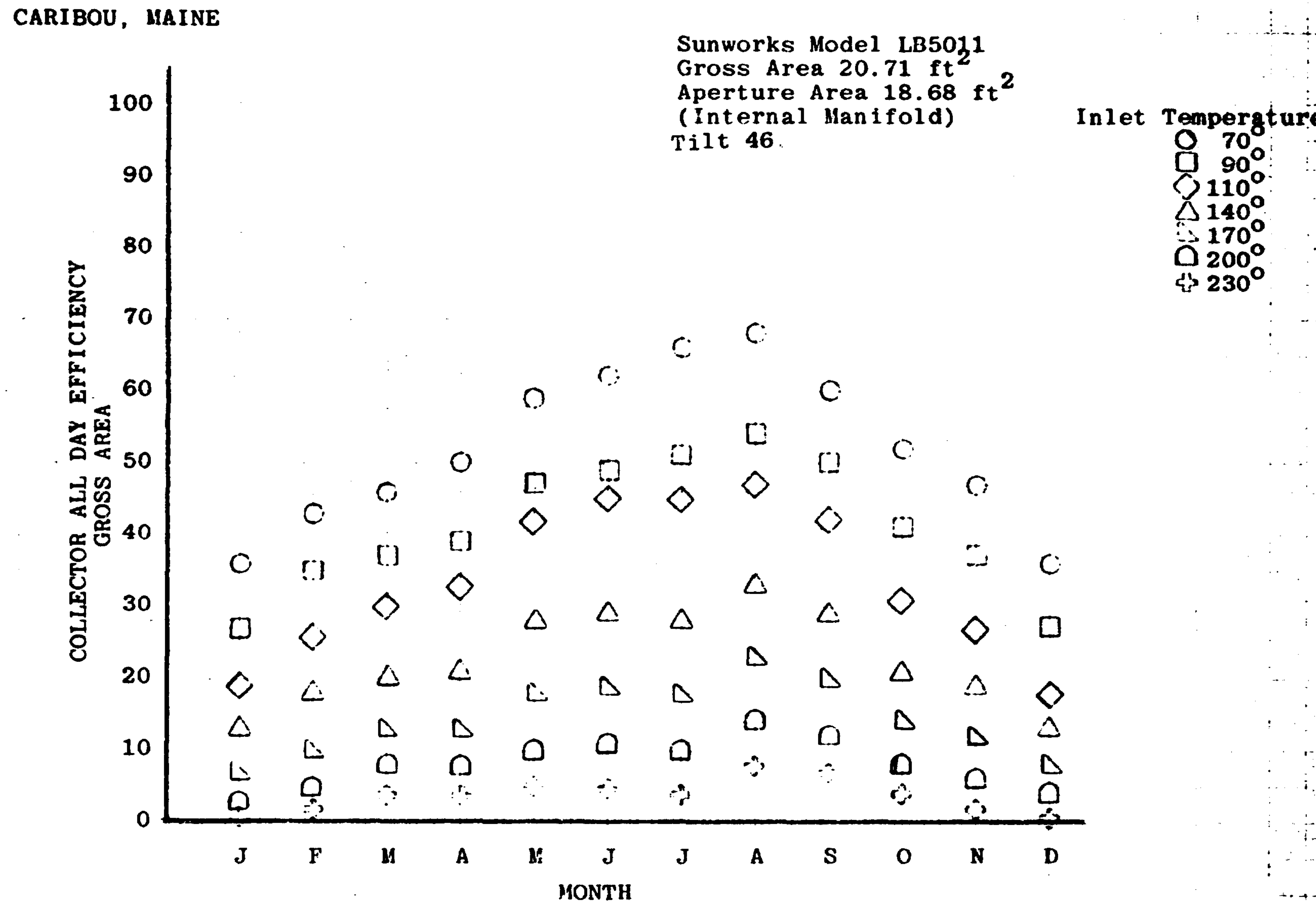
DODGE CITY, KANSAS



DODGE CITY, KANSAS




CARIBOU, MAINE
Sunworks Model LB5011
Gross Area 20.71 ft²
Aperture Area 18.68 ft²
(Internal Manifold)
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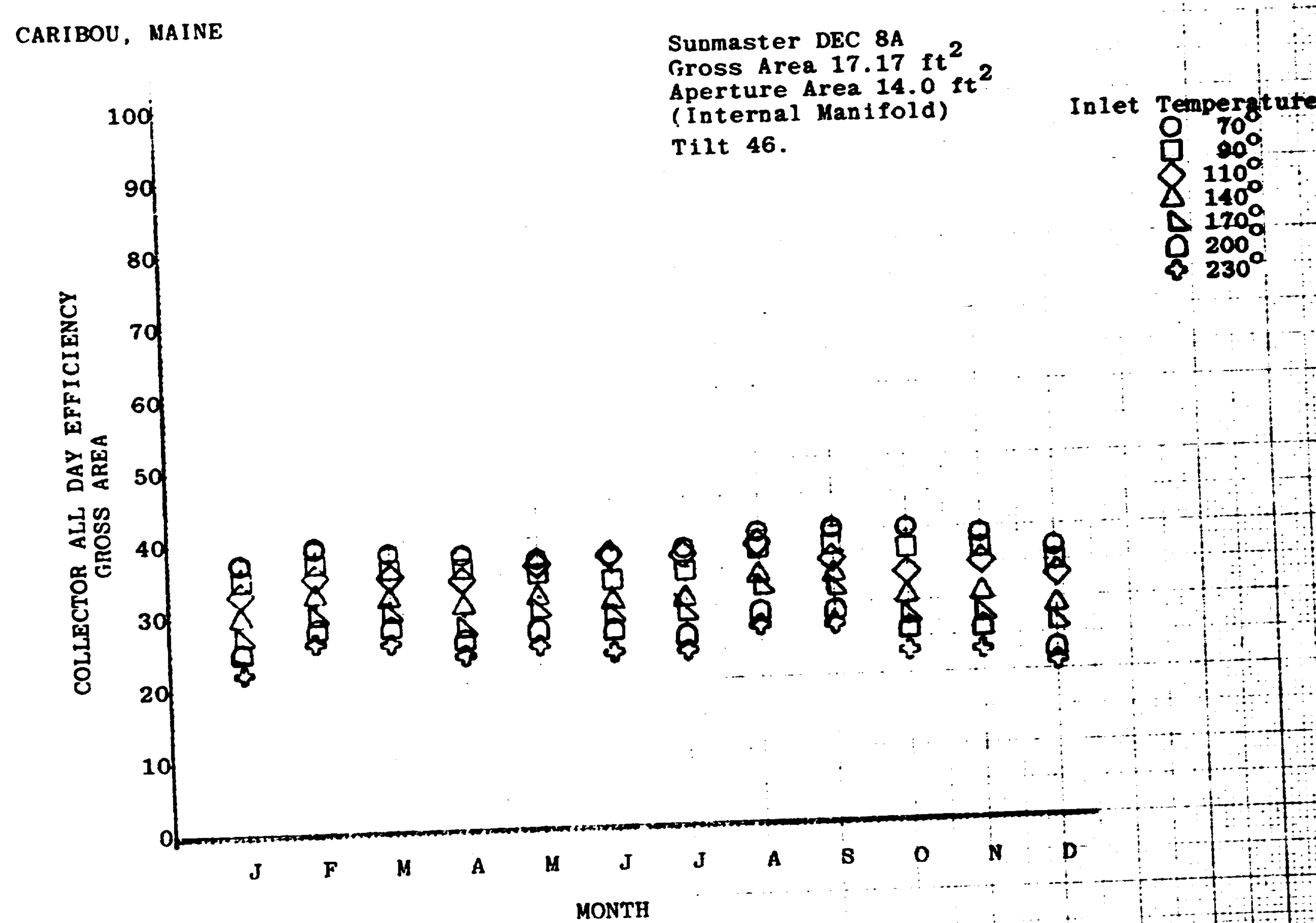

CARIBOU, MAINE
Sunmaster DEC 8A
Gross Area 17.17 ft2
Aperture Area 14.0 ft2
(Internal Manifold)
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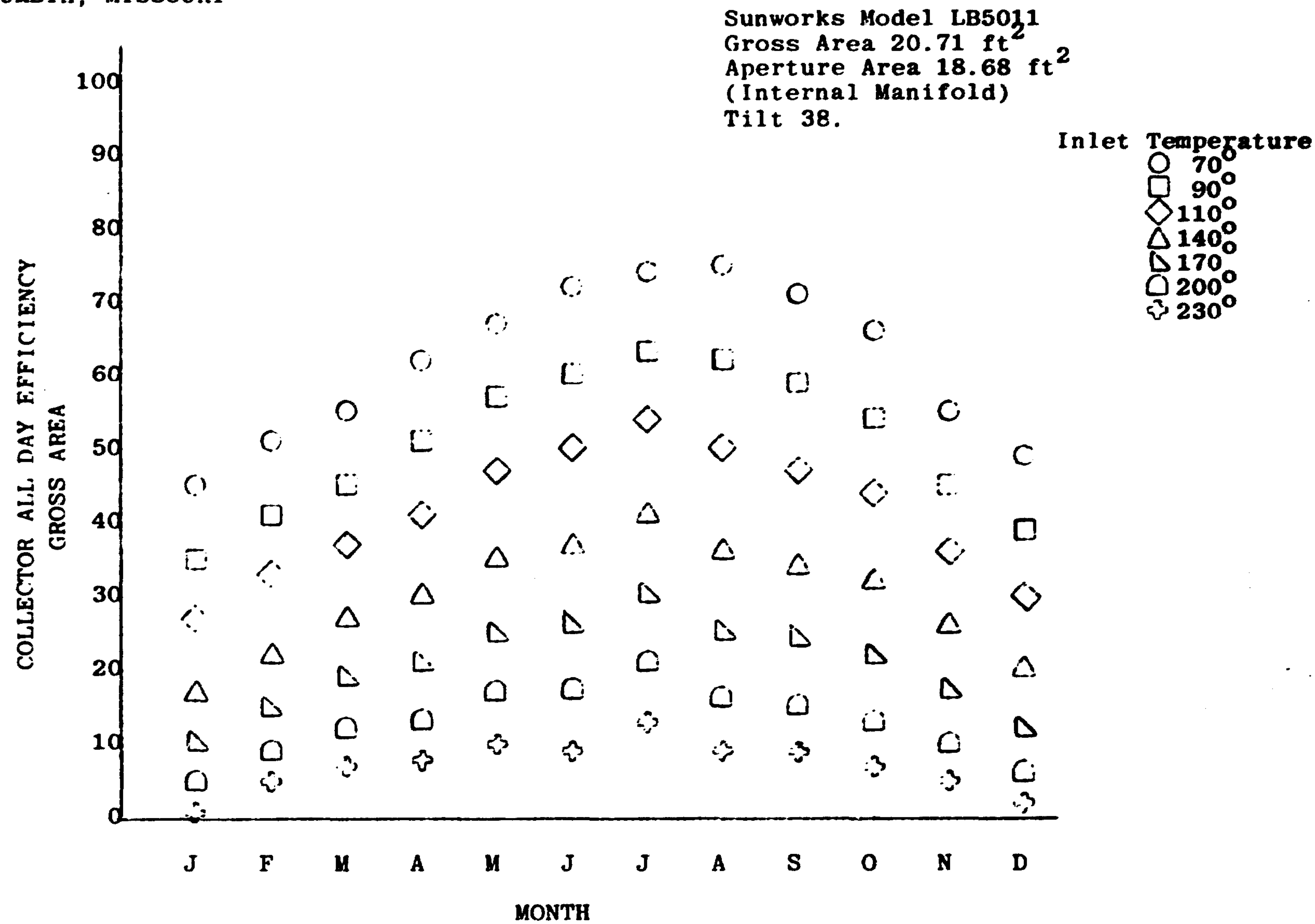
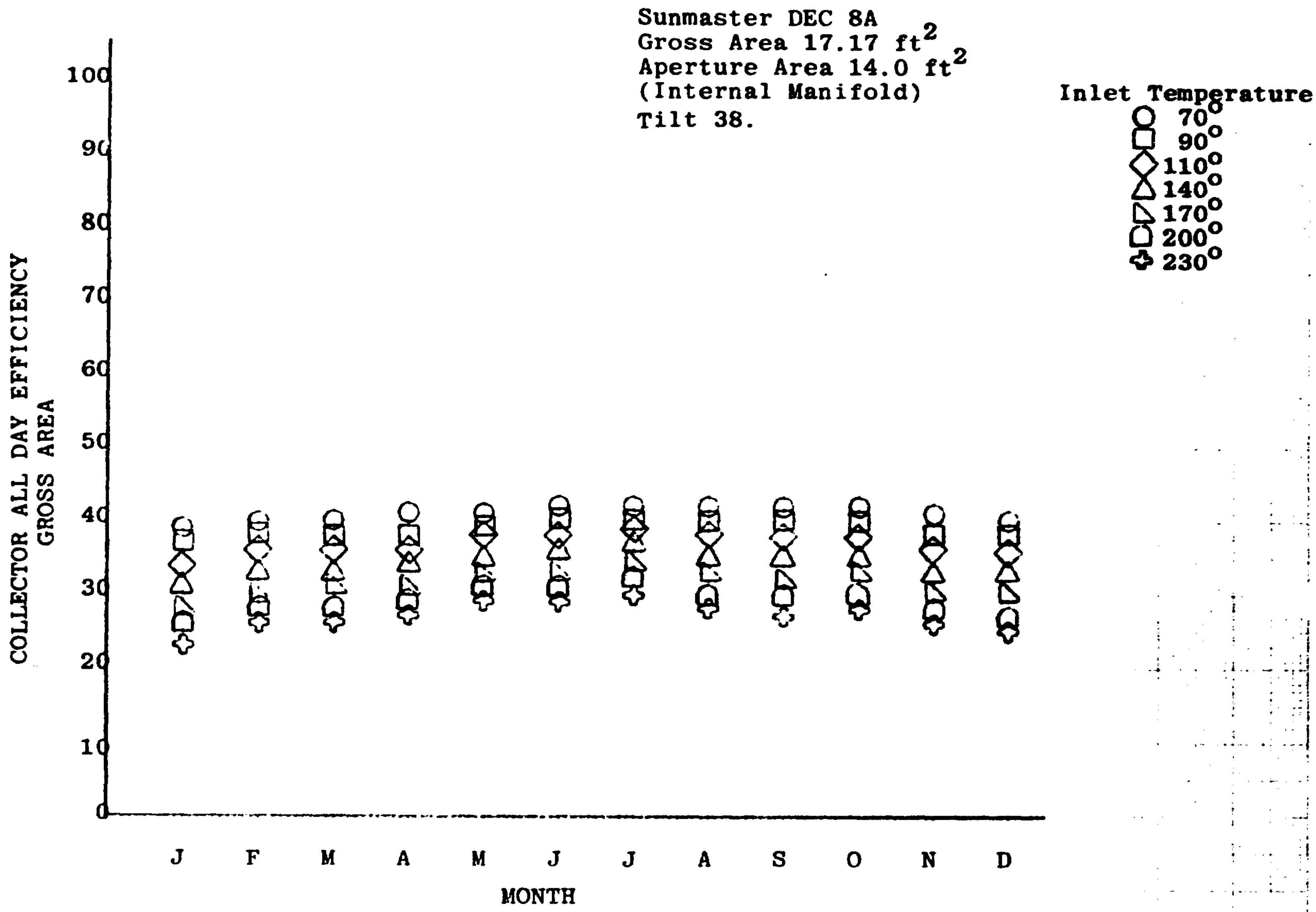
MONTH

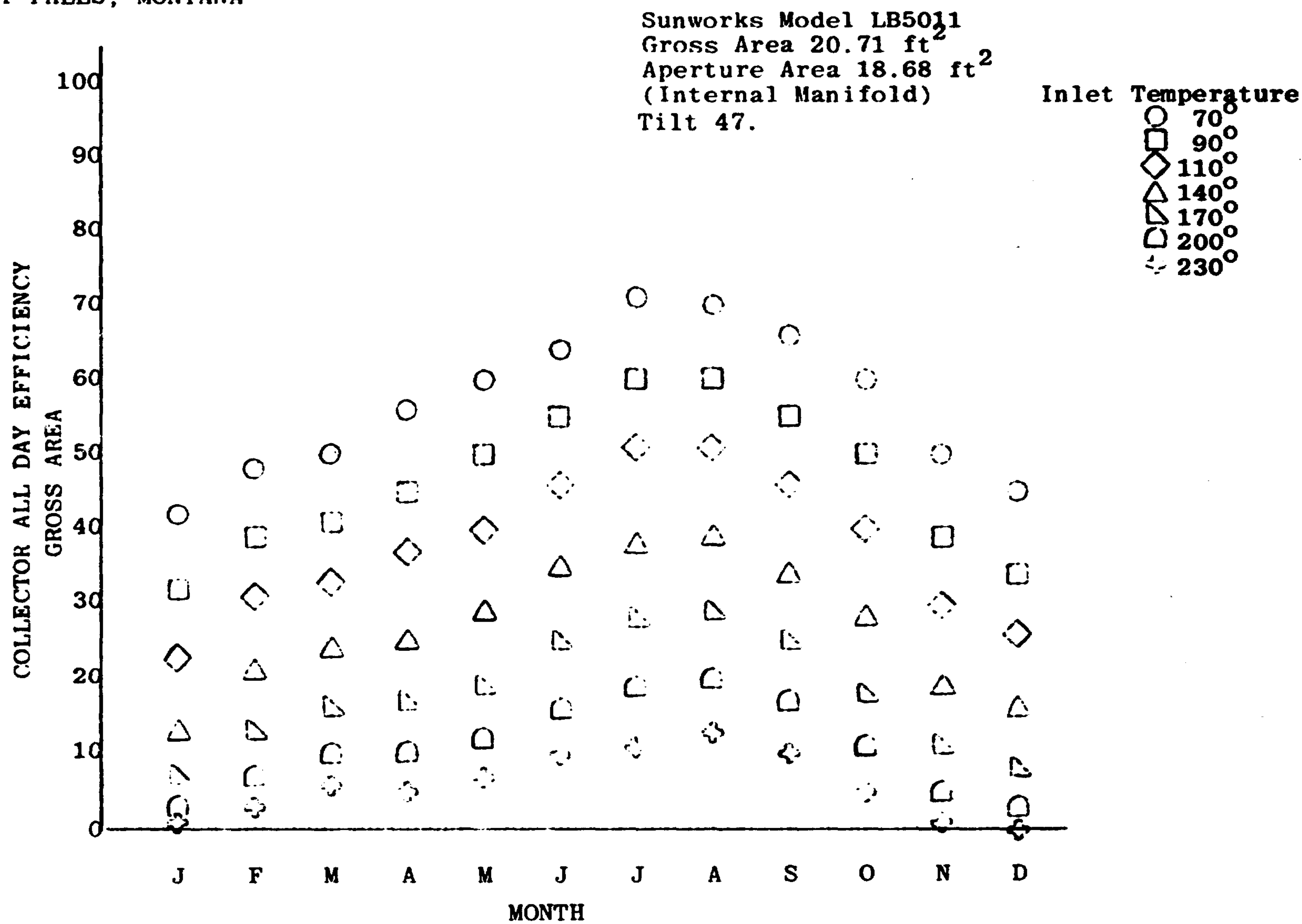
COLUMBIA, MISSOURI

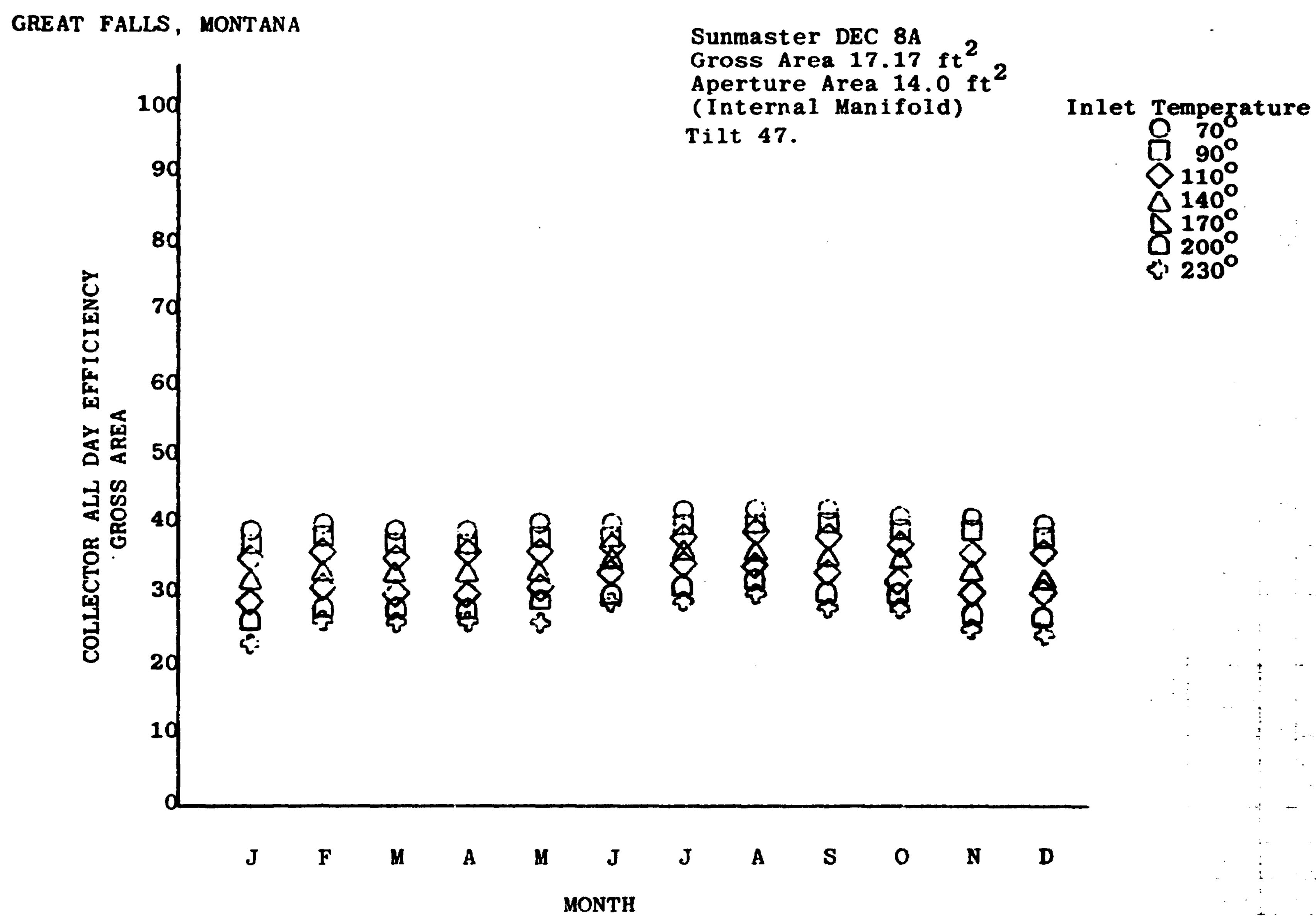


COLUMBIA, MISSOURI



GREAT FALLS, MONTANA




GREAT FALLS, MONTANA
Sunmaster DEC 8A
Gross Area 17.17 ft2
Aperture Area 14.0 ft2
(Internal Manifold)
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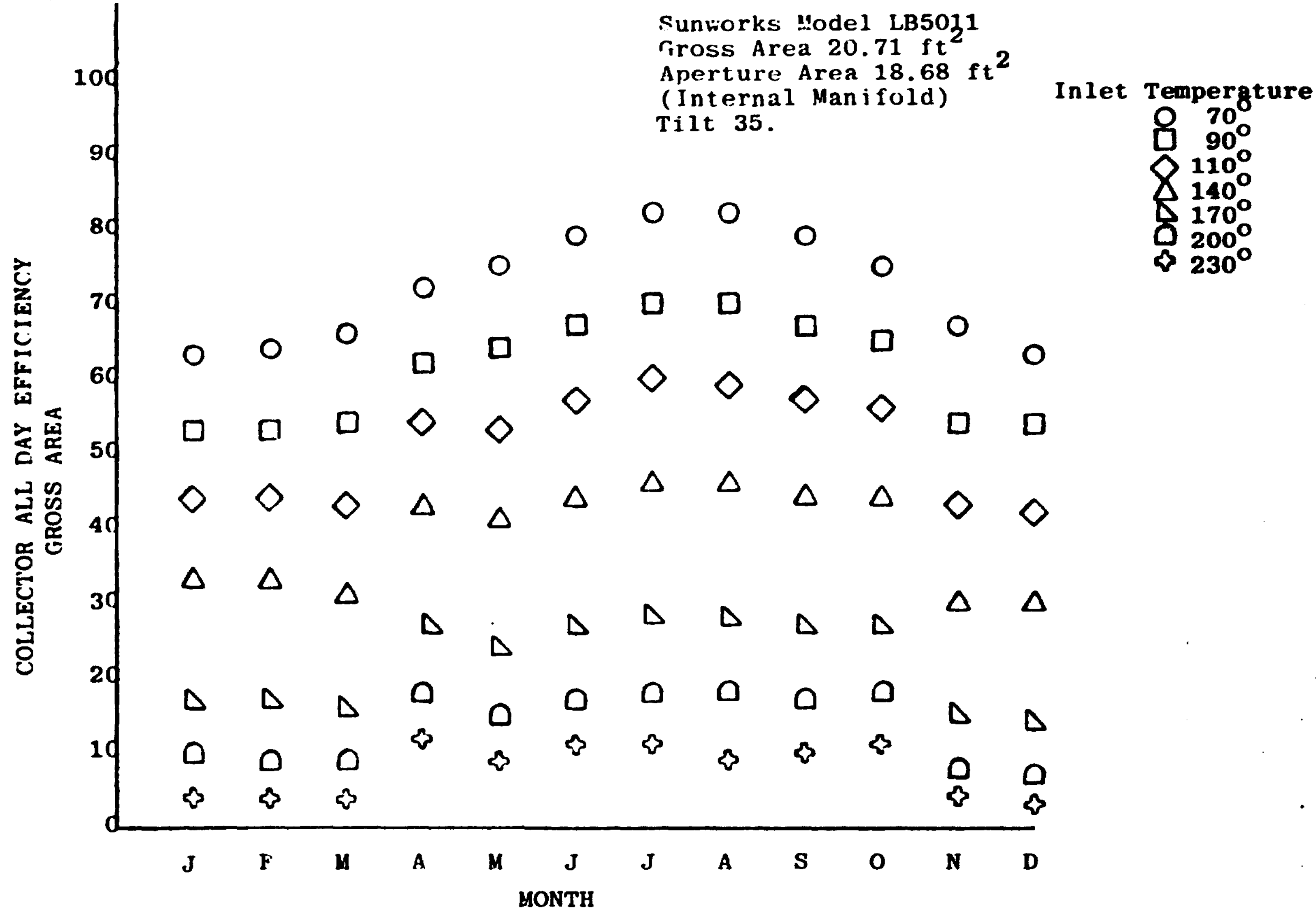
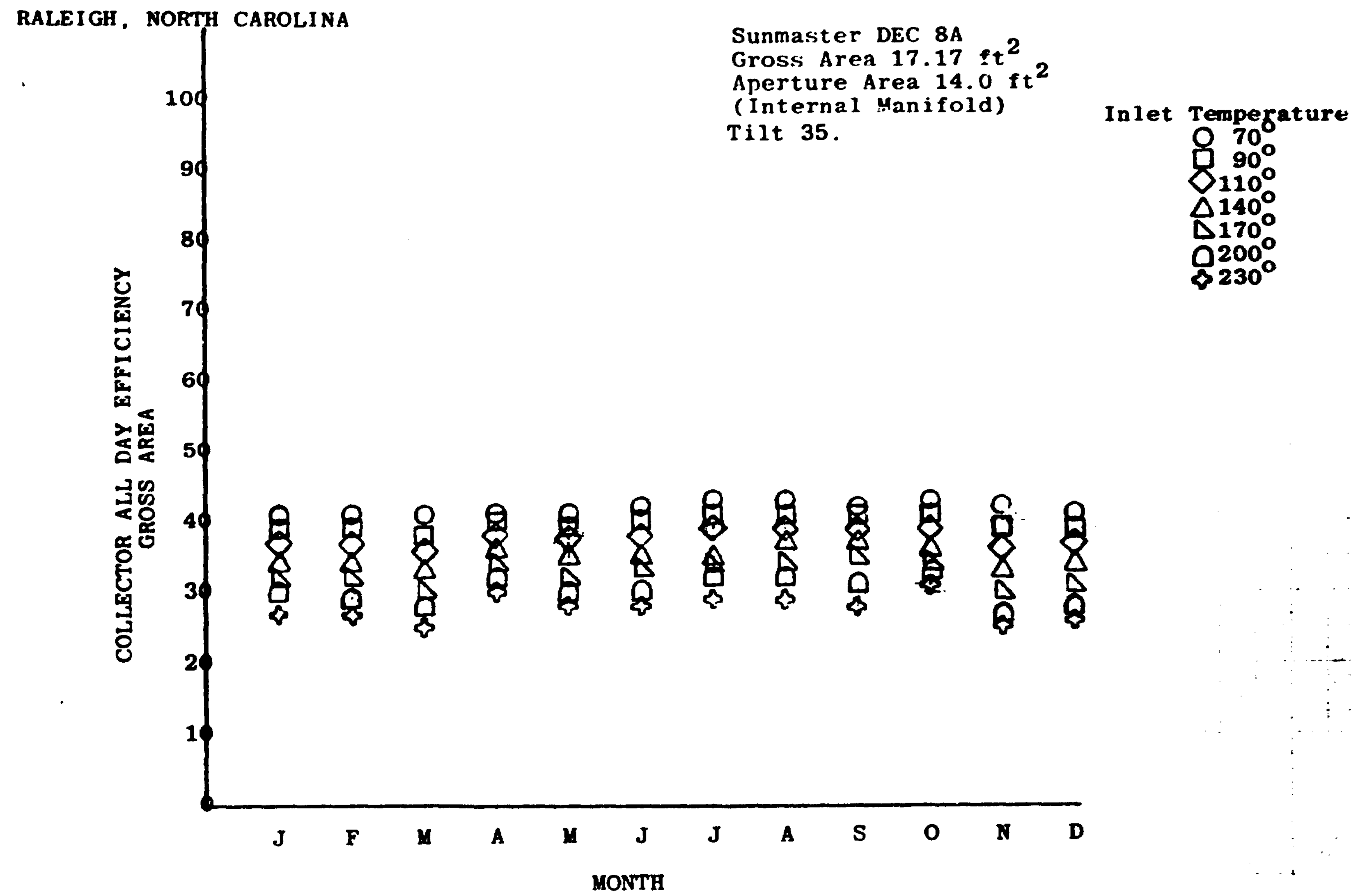
MONTH

RALEIGH . NORTH CAROLINA




RALEIGH, NORTH CAROLINA
Sunmaster DEC 8A
Gross Area 17.17 ft2
Aperture Area 14.0 ft2
(Internal Manifold)
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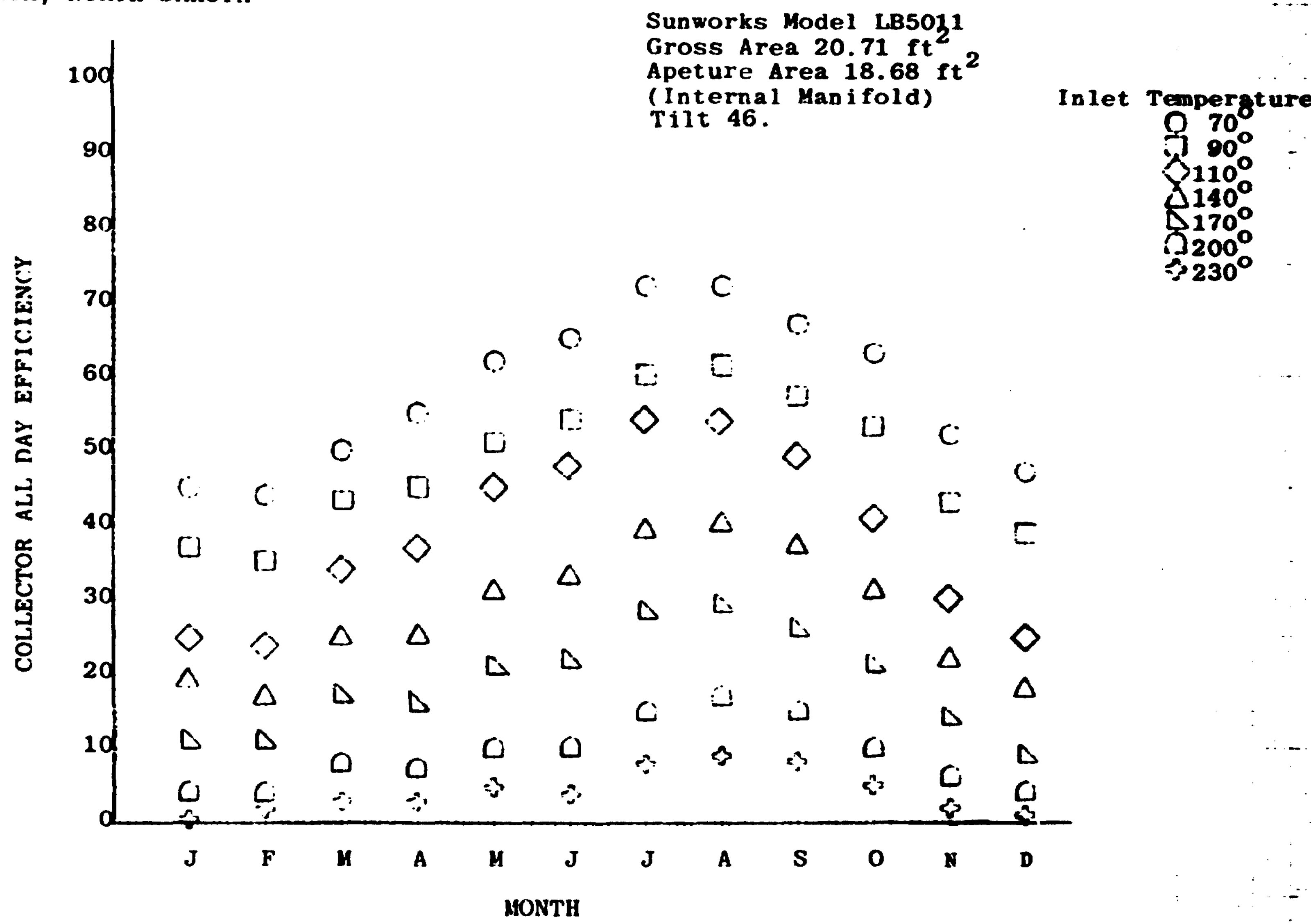
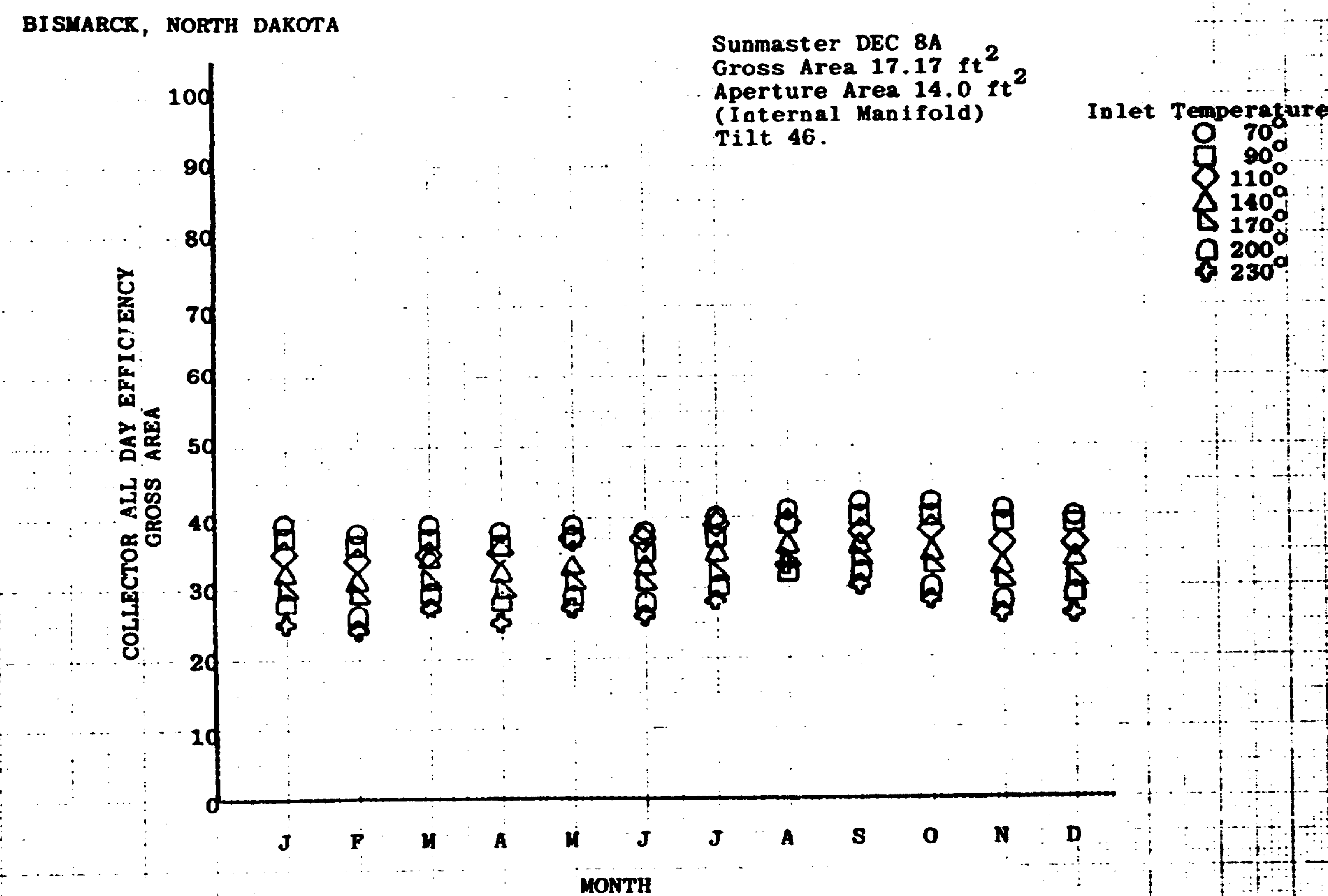
MONTH

BISMARCK, NORTH DAKOTA




BISMARCK, NORTH DAKOTA
Sunmaster DEC 8A
Gross Area 17.17 ft²
Aperture Area 14.0 ft²
(Internal Manifold)
Tilt 46.
Inlet Temperature
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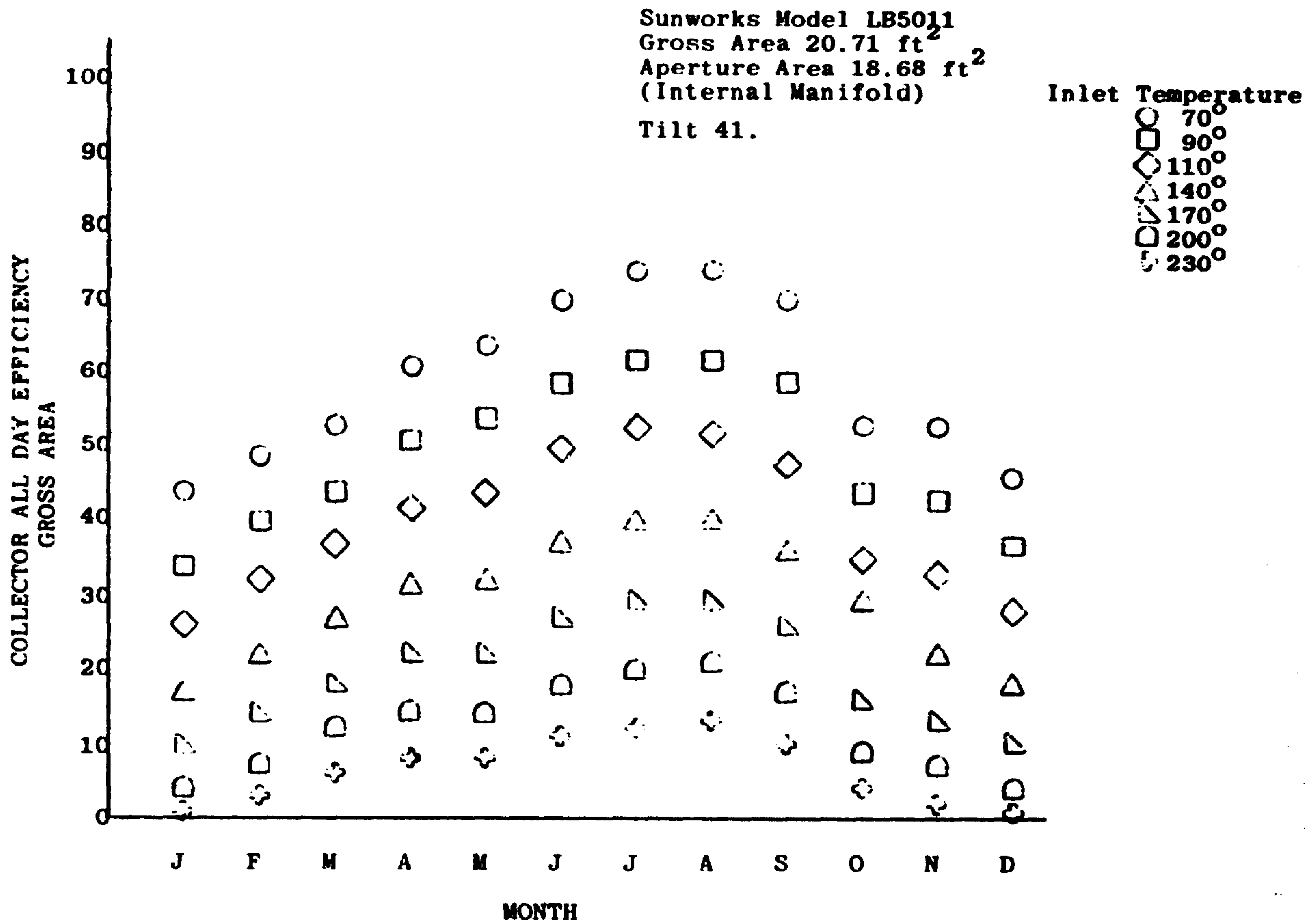
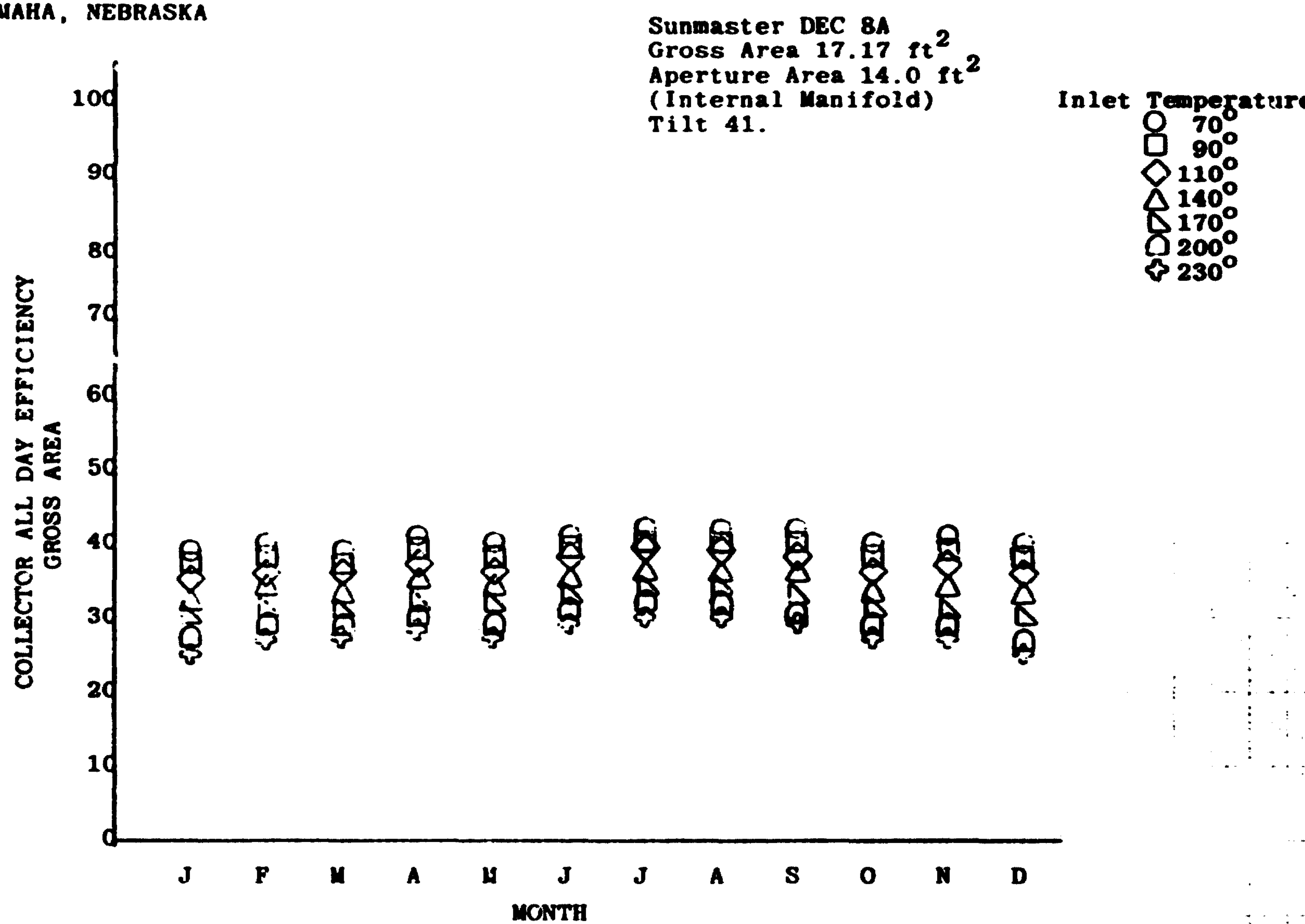
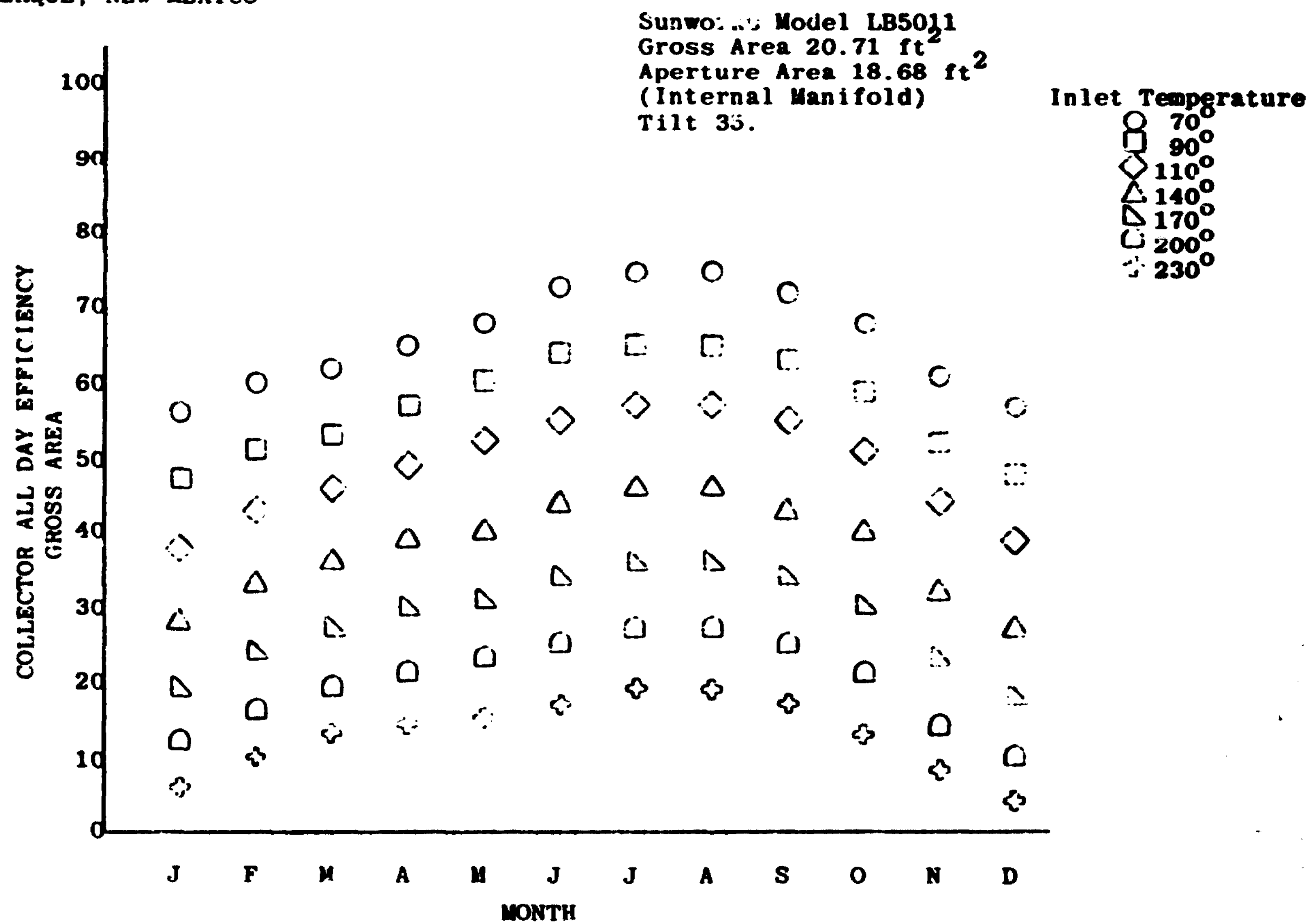
OMAHA, NEBRASKA



OMAHA, NEBRASKA



ALBUQUERQUE, NEW MEXICO



ALBUQUERQUE, NEW MEXICO

Sunmaster DEC 8A
Gross Area 17.17 ft^2
Aperture Area 14.0 ft^2
(Internal Manifold)
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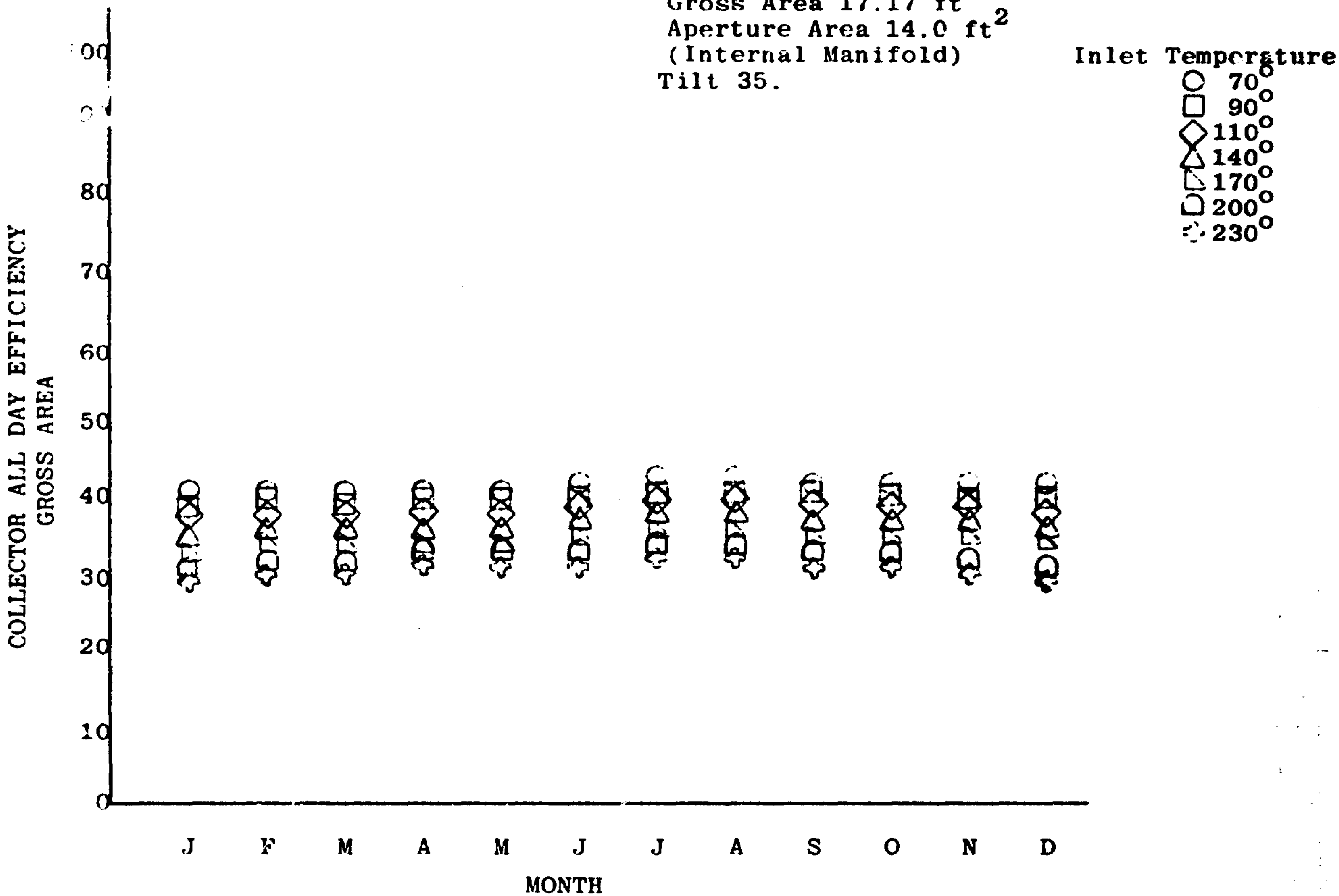
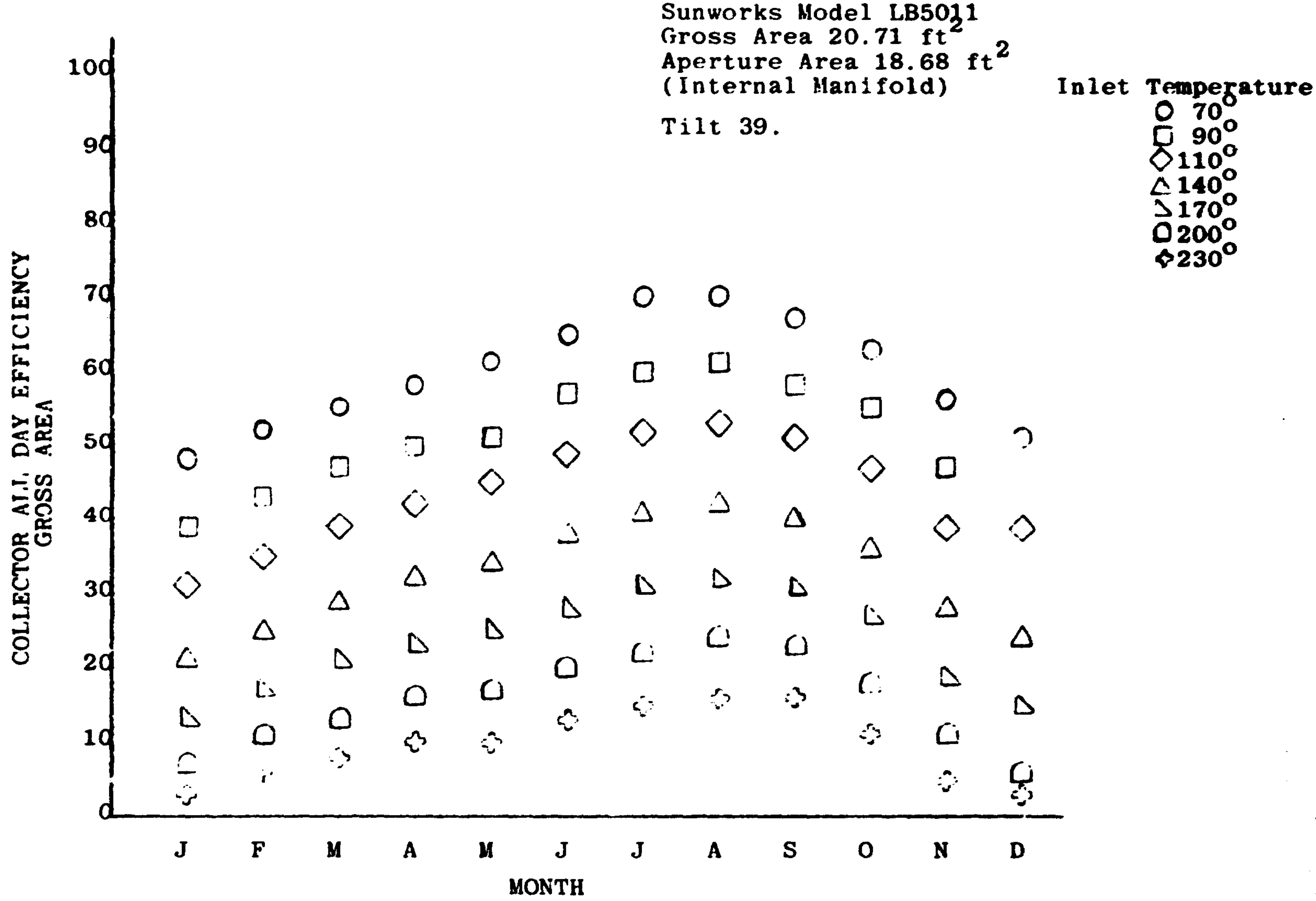


ELY, NEVADA


Sunworks Model LB5011
Gross Area 20.71 ft^2
Aperture Area 18.68 ft^2
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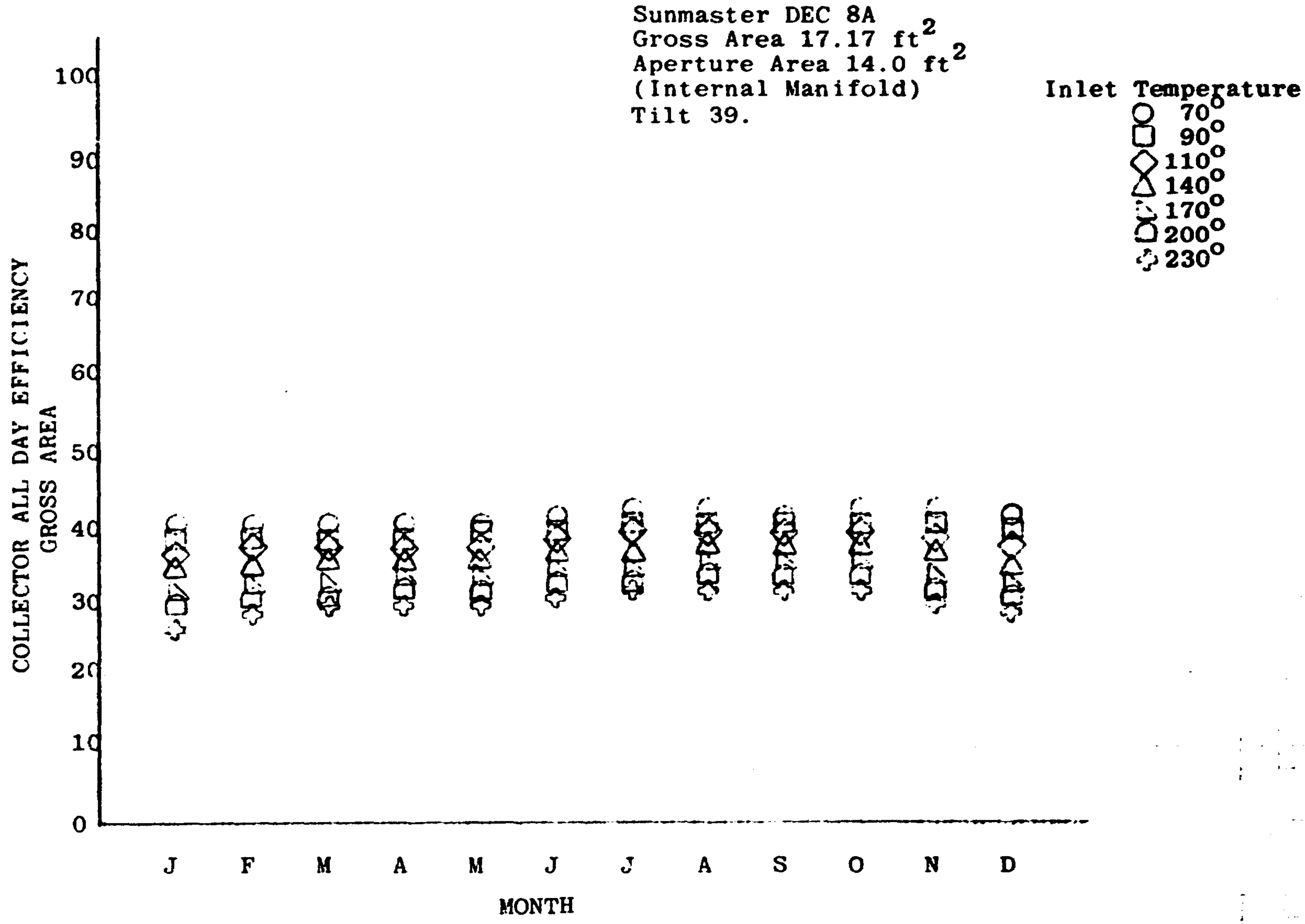
ELY, NEVADA


Sunmaster DEC 8A
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Aperture Area 14.0 ft²
(Internal Manifold)
Tilt 39.
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COLLECTOR ALL DAY EFFICIENCY
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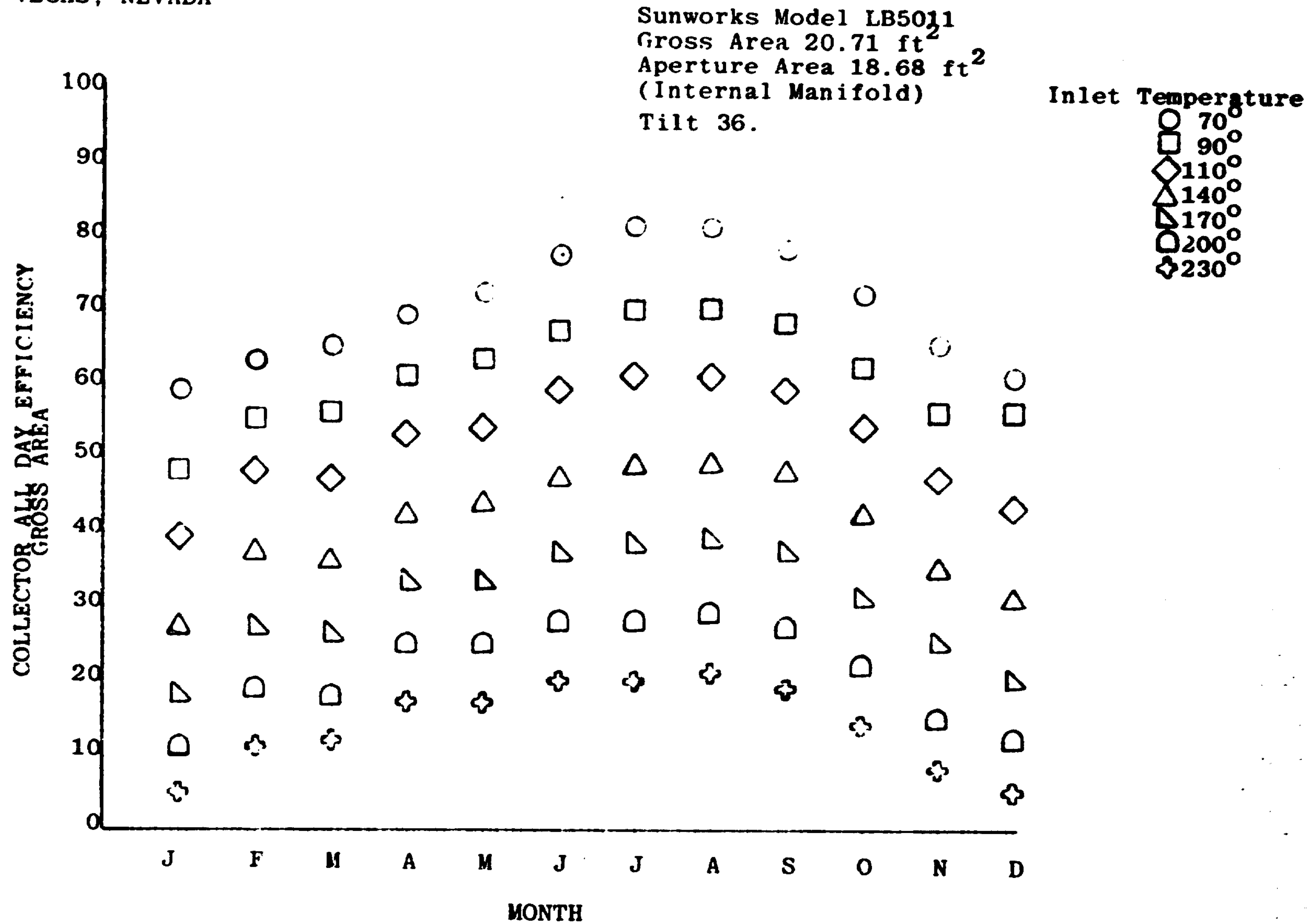
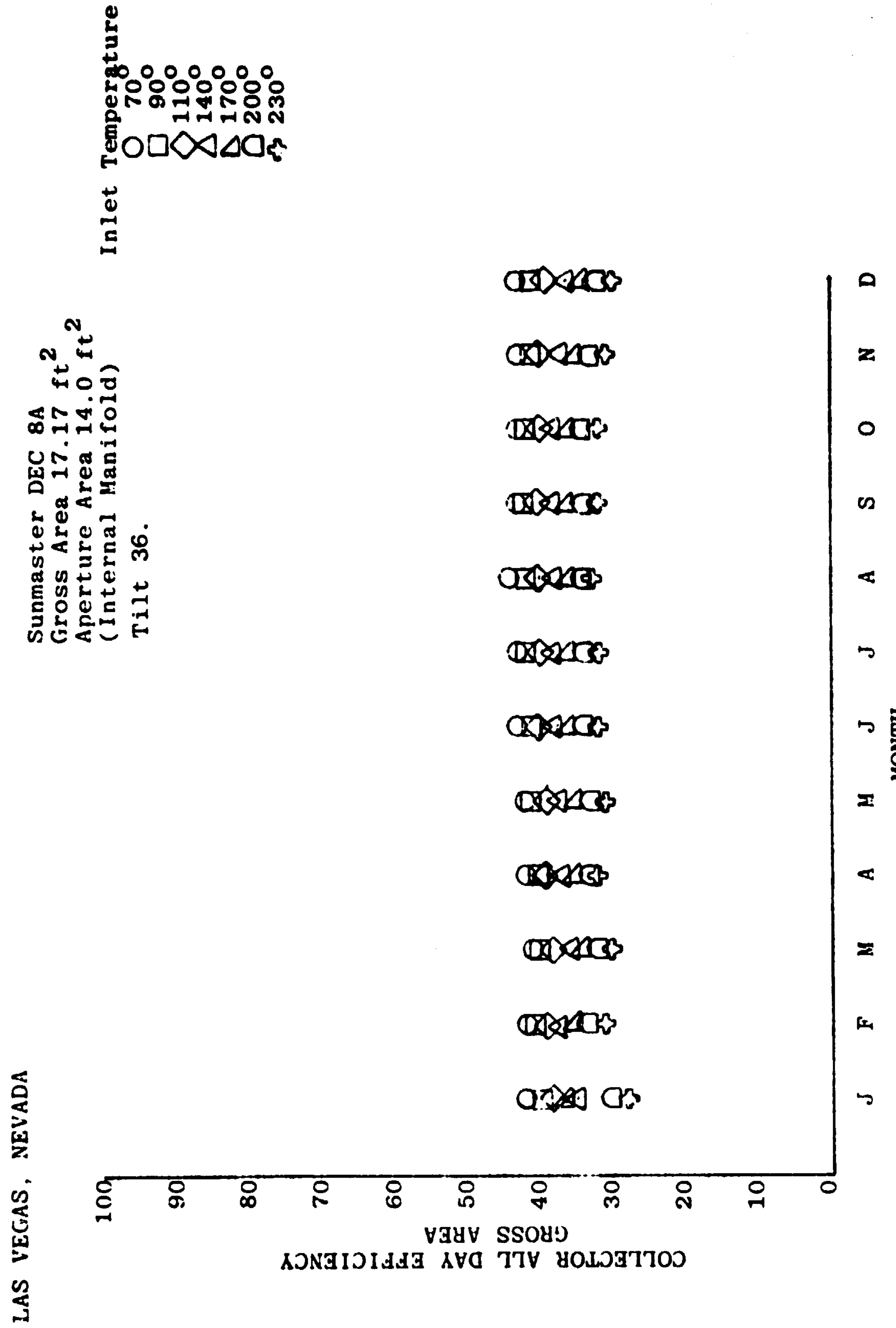
LAS VEGAS, NEVADA




LAS VEGAS, NEVADA
Sunmaster DEC 8A
Gross Area 17.17 ft²
Aperture Area 14.0 ft²
(Internal Manifold)
Tilt 36.
Inlet Temperature
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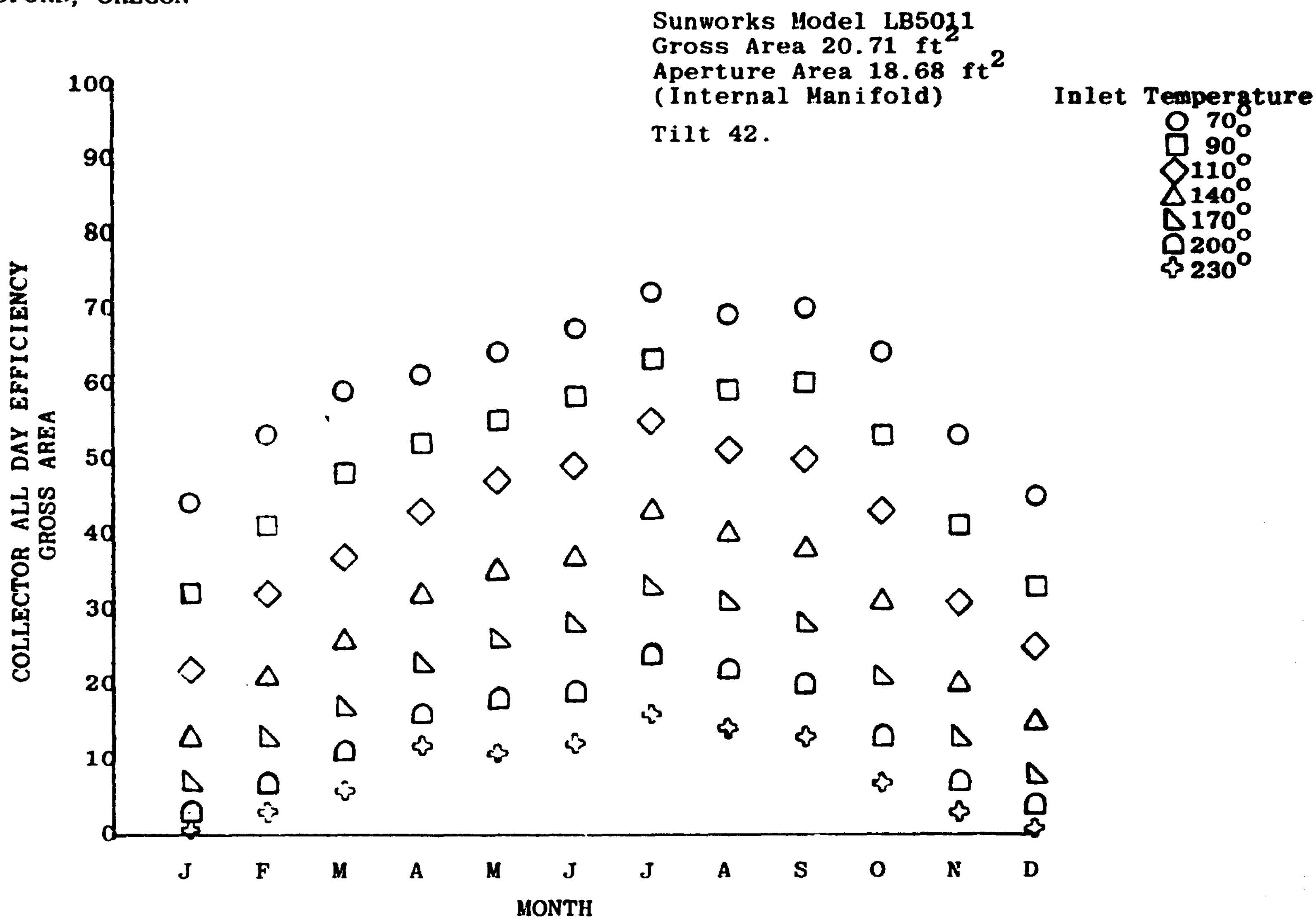
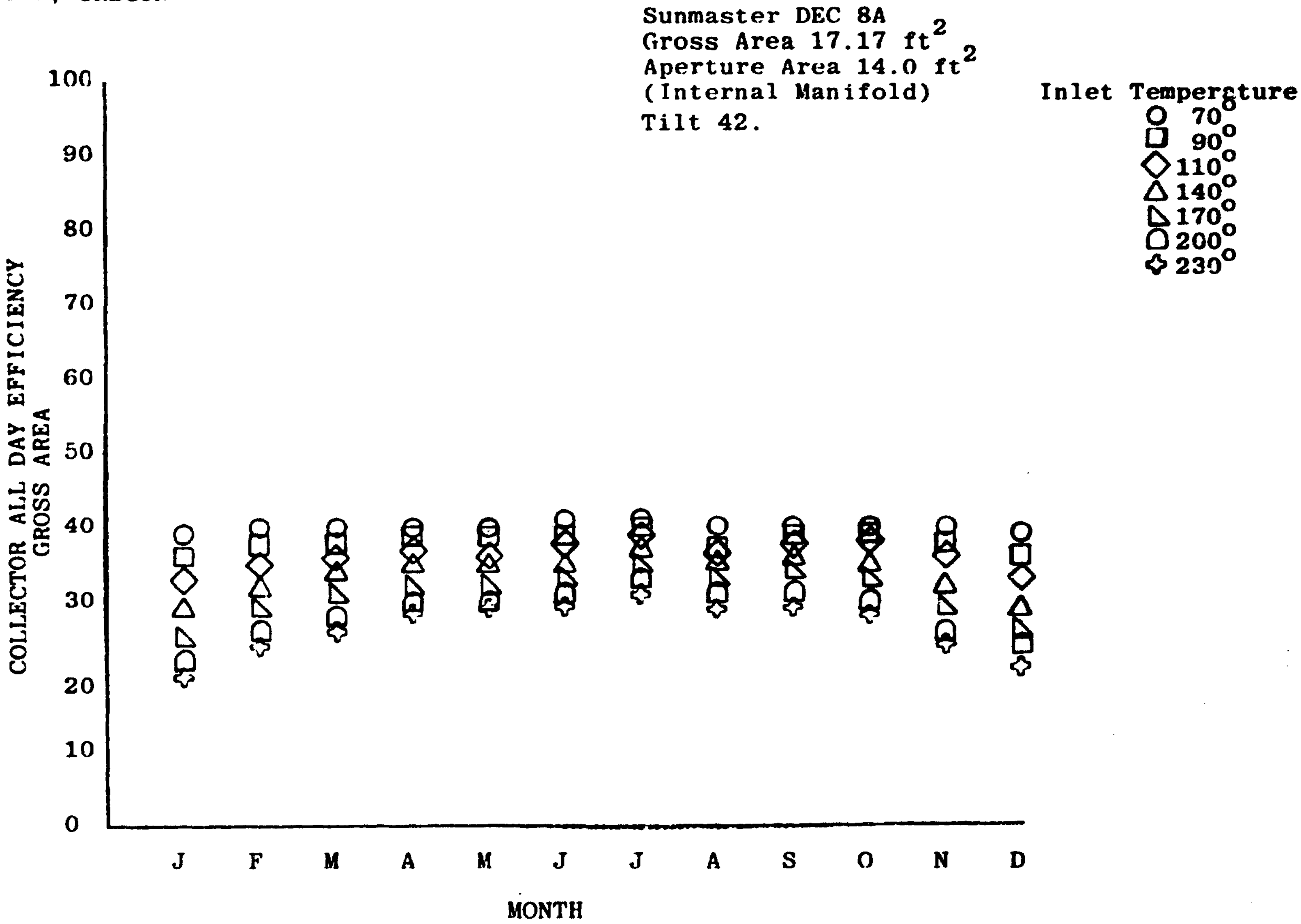
MONTH

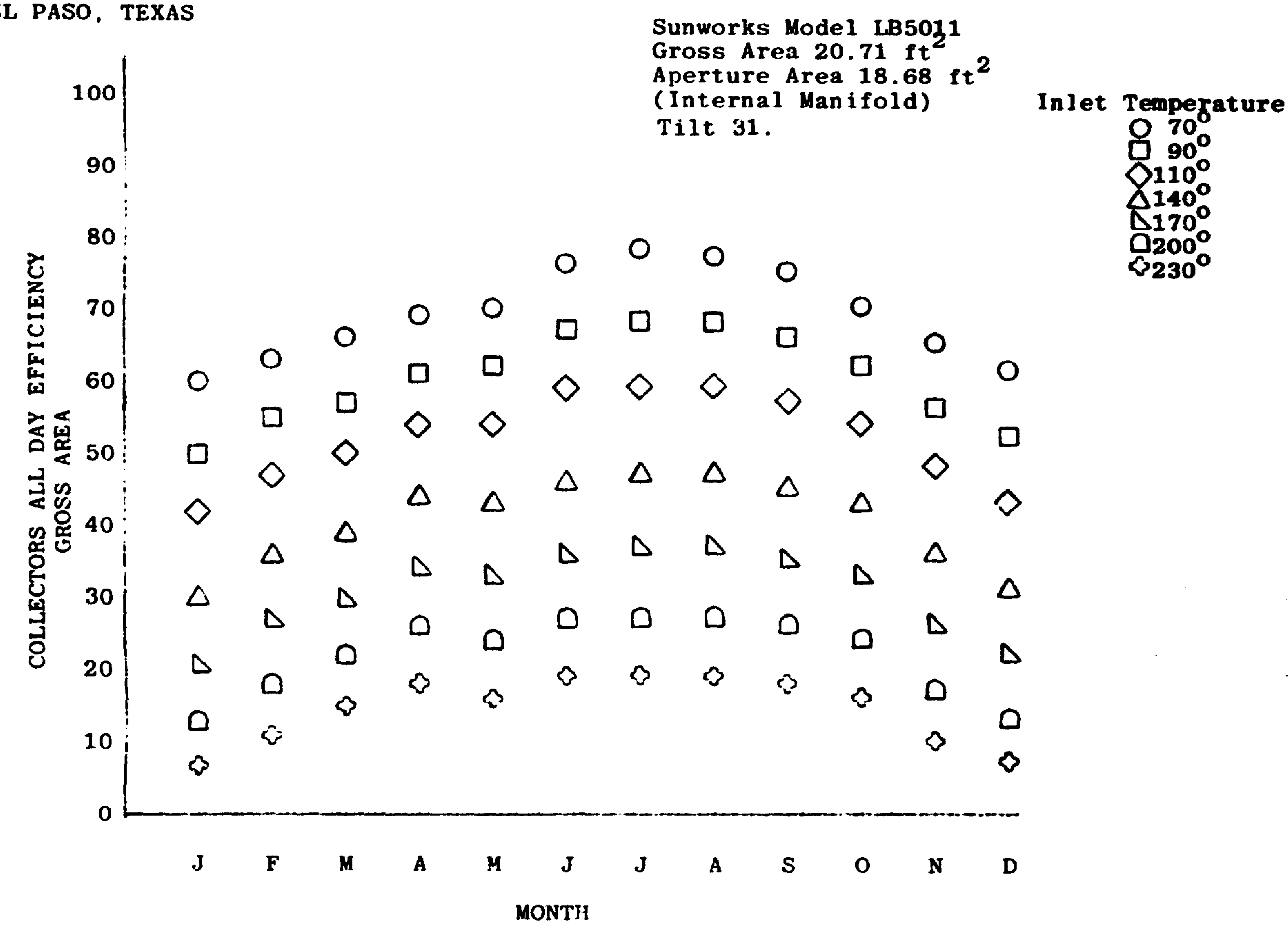
MEDFORD, OREGON



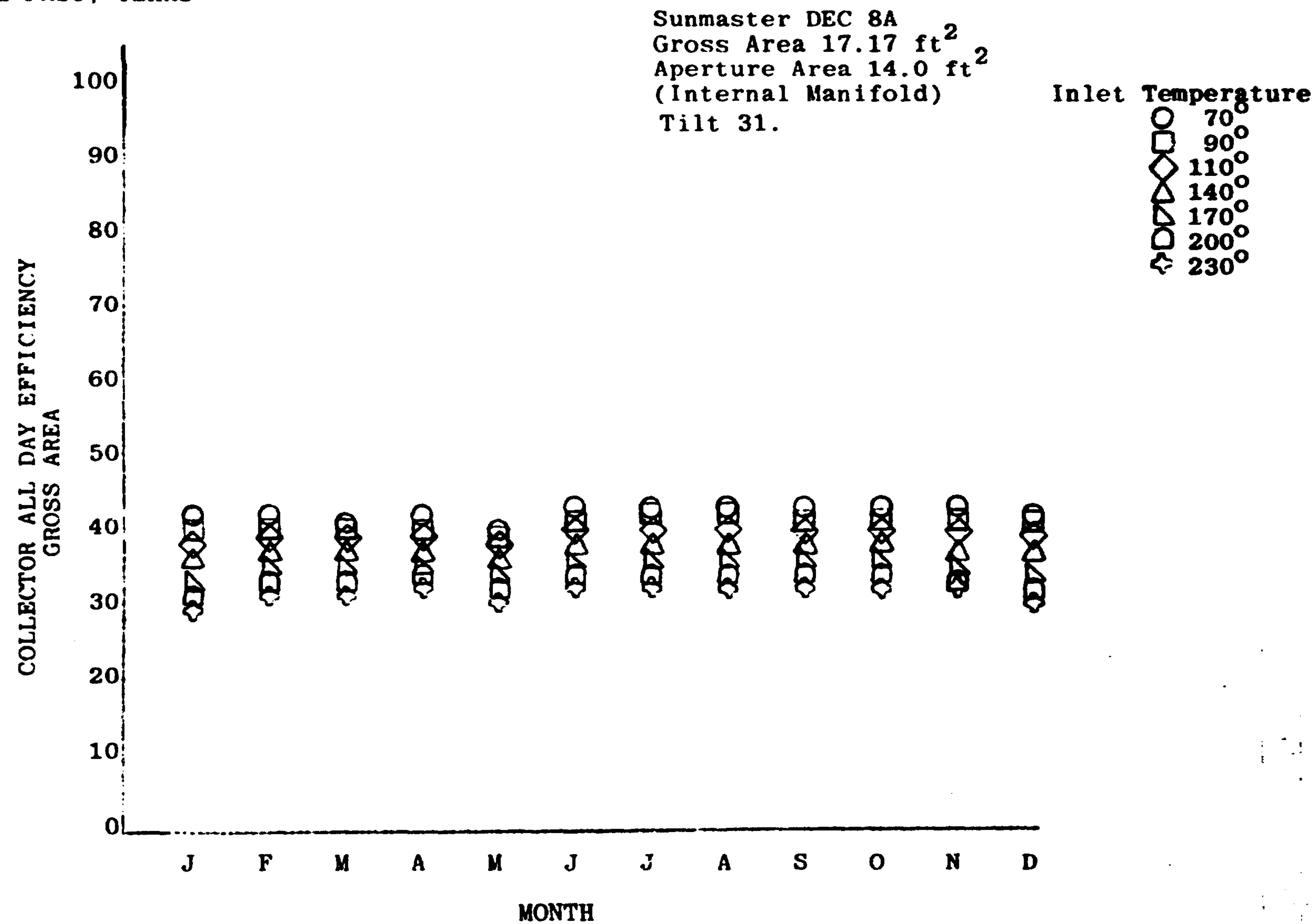
MEDFORD, OREGON

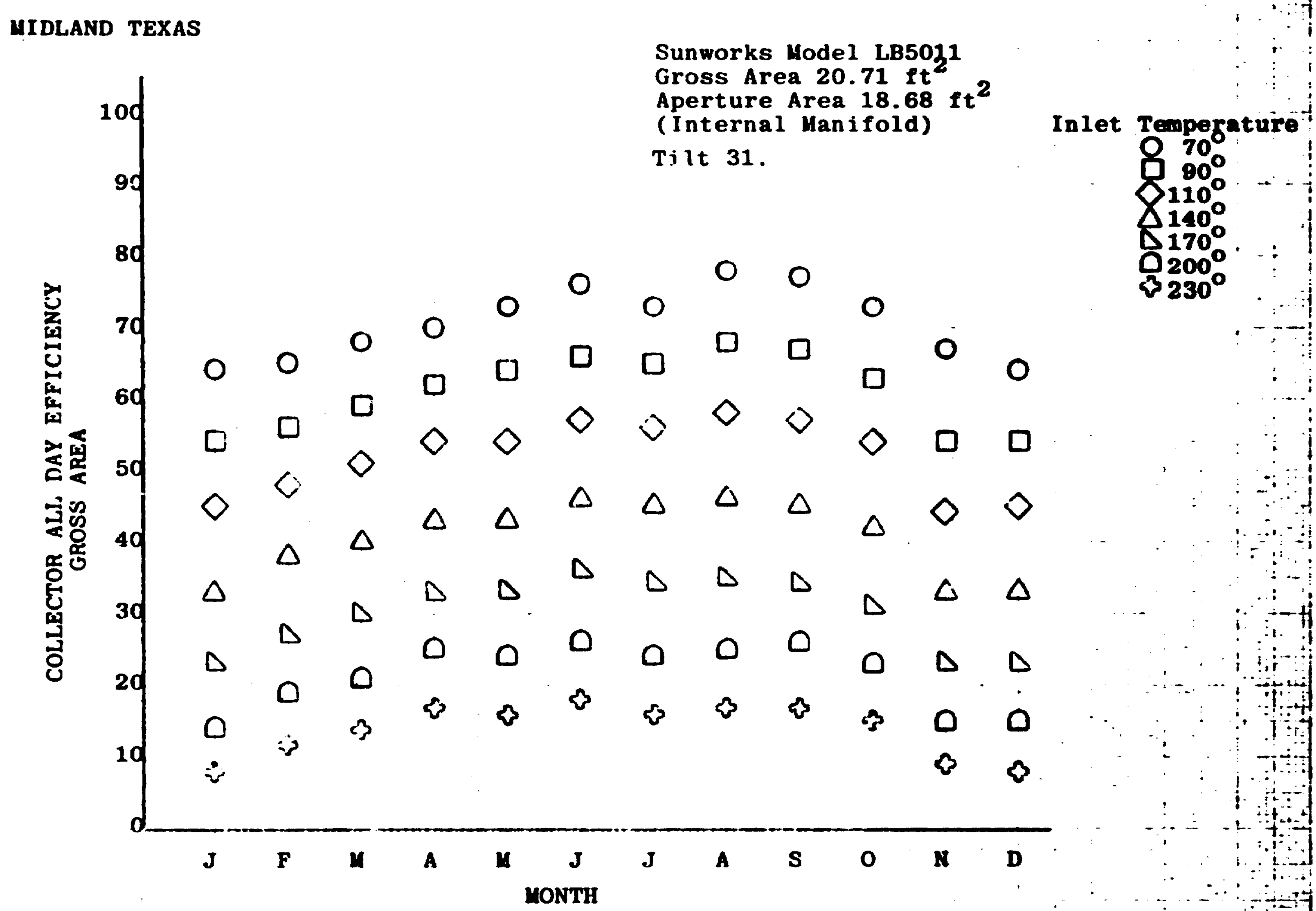


EL PASO, TEXAS



EL PASO, TEXAS





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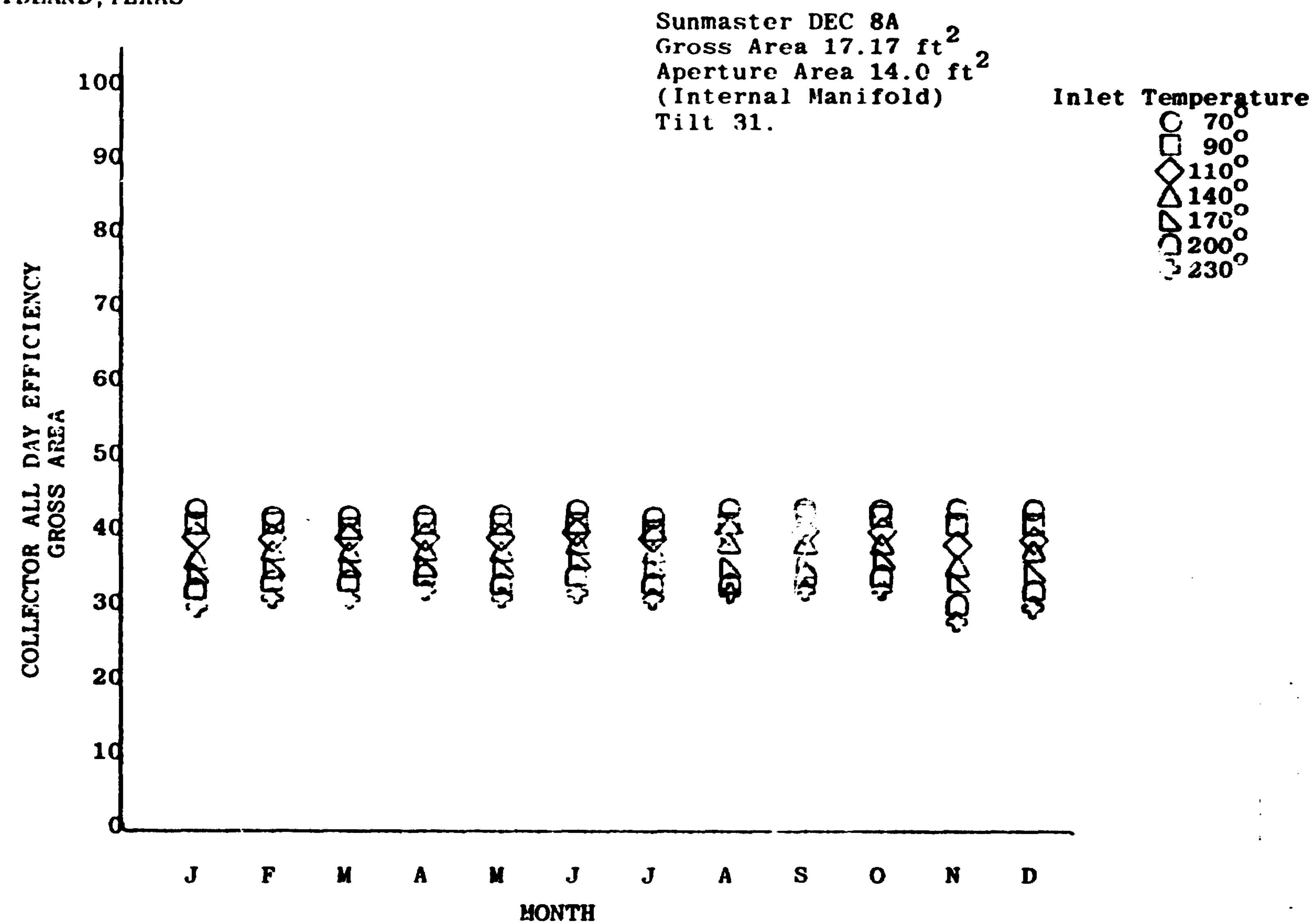
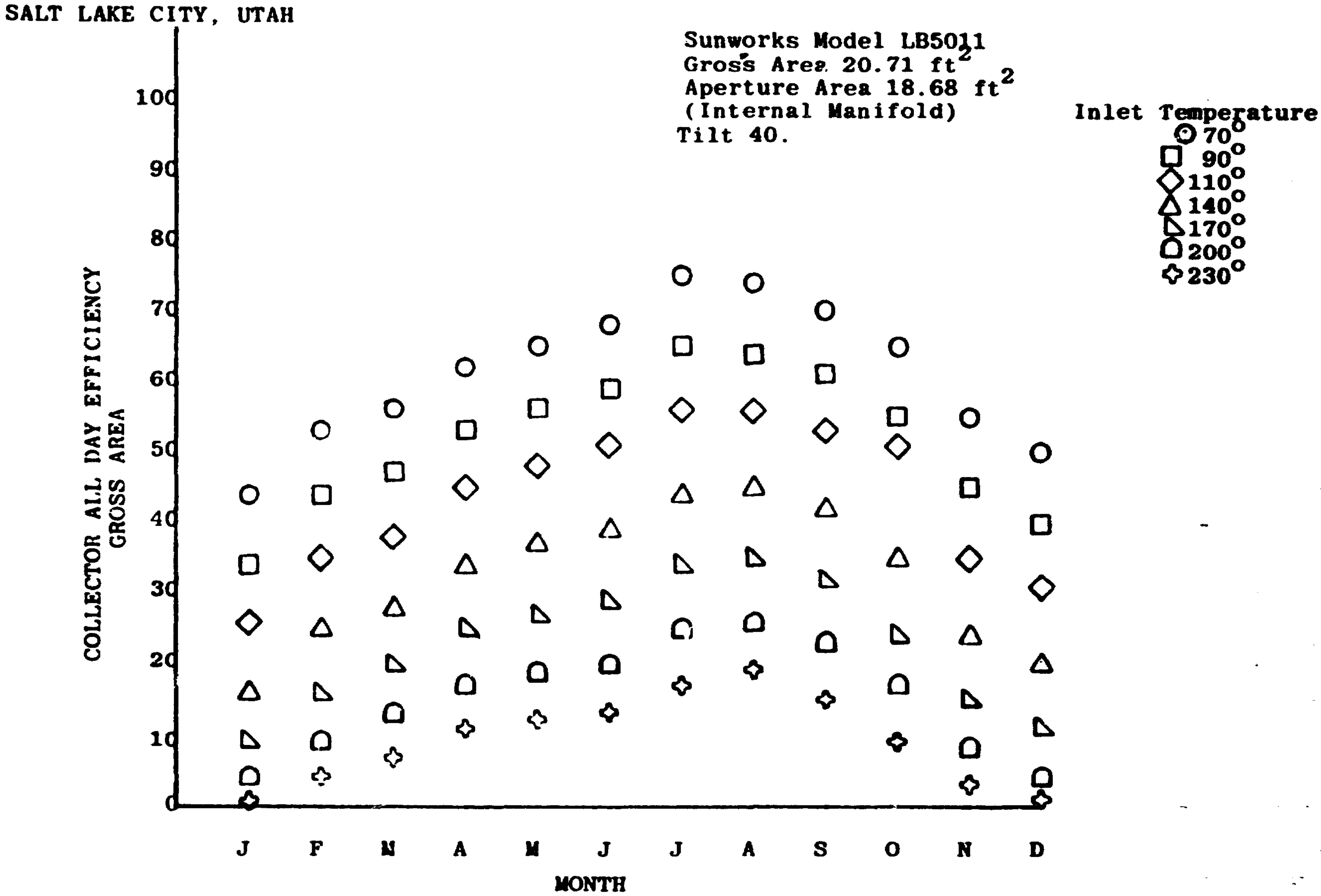
MIDLAND, TEXAS




SALT LAKE CITY, UTAH
Sunworks Model LB5011
Gross Area 20.71 ft2
Aperture Area 18.68 ft2
(Internal Manifold)
Tilt 40.
Inlet Temperature
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COLLECTOR ALL DAY EFFICIENCY
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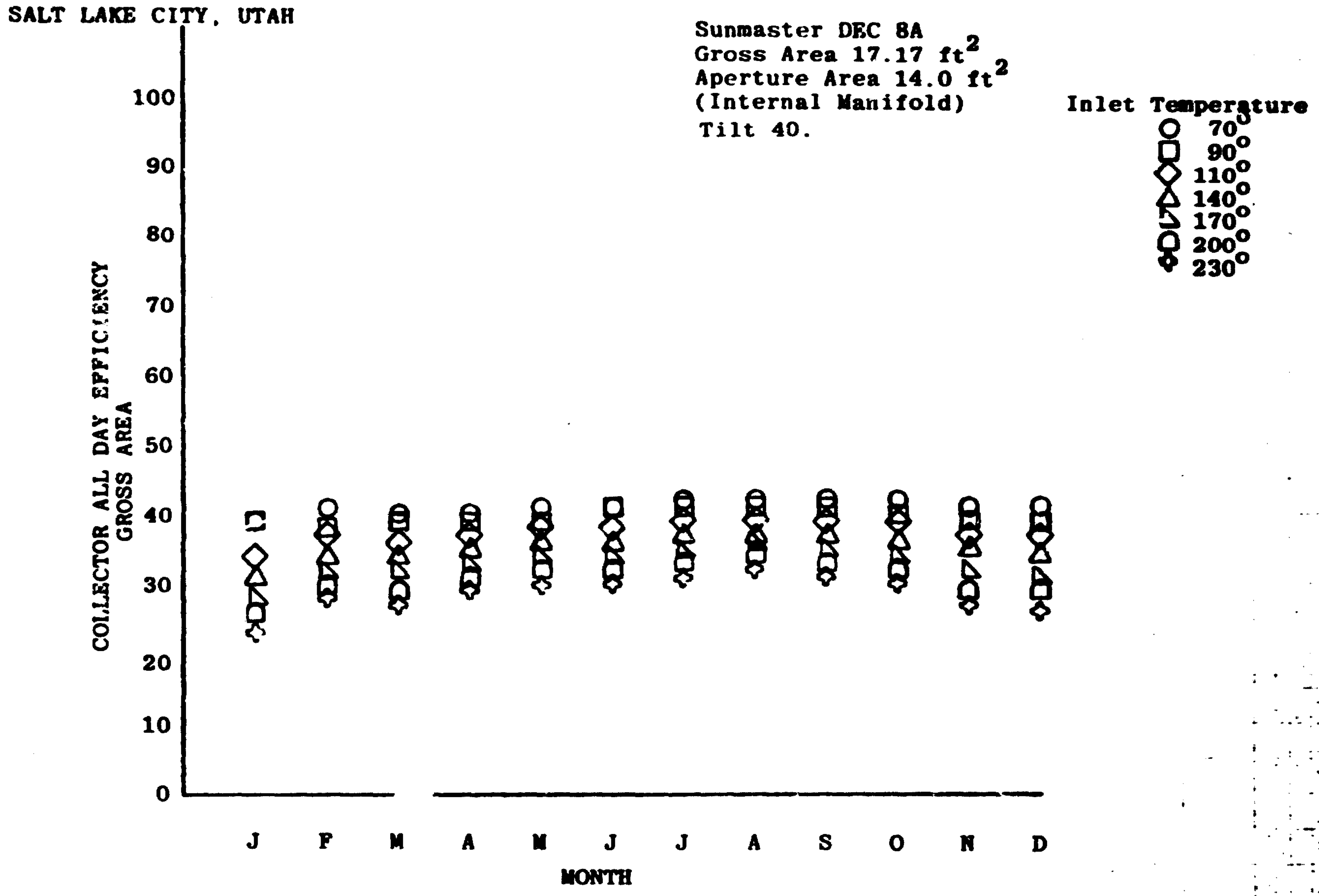

SALT LAKE CITY, UTAH
Sunmaster DEC 8A
Gross Area 17.17 ft²
Aperture Area 14.0 ft²
(Internal Manifold)
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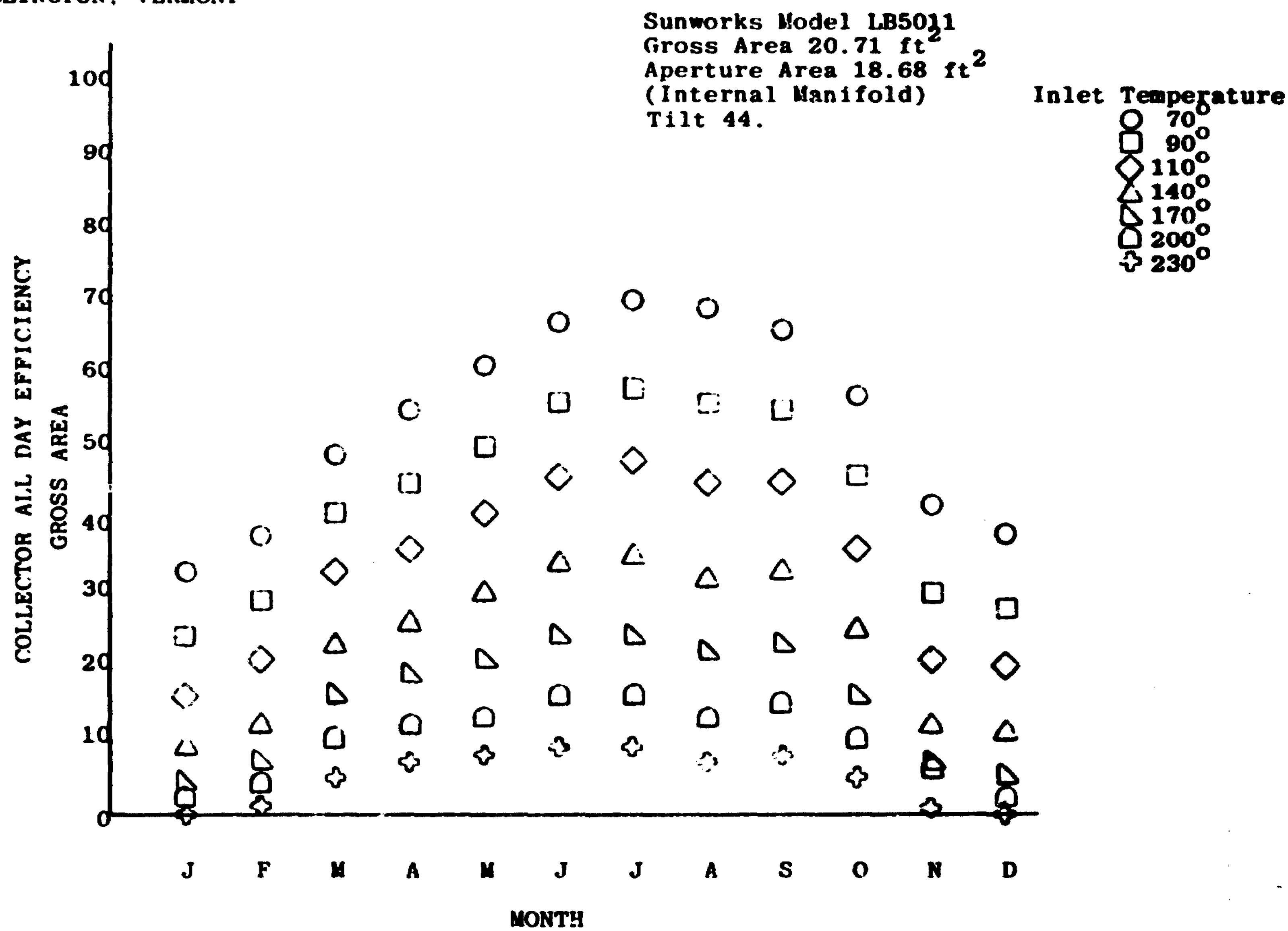
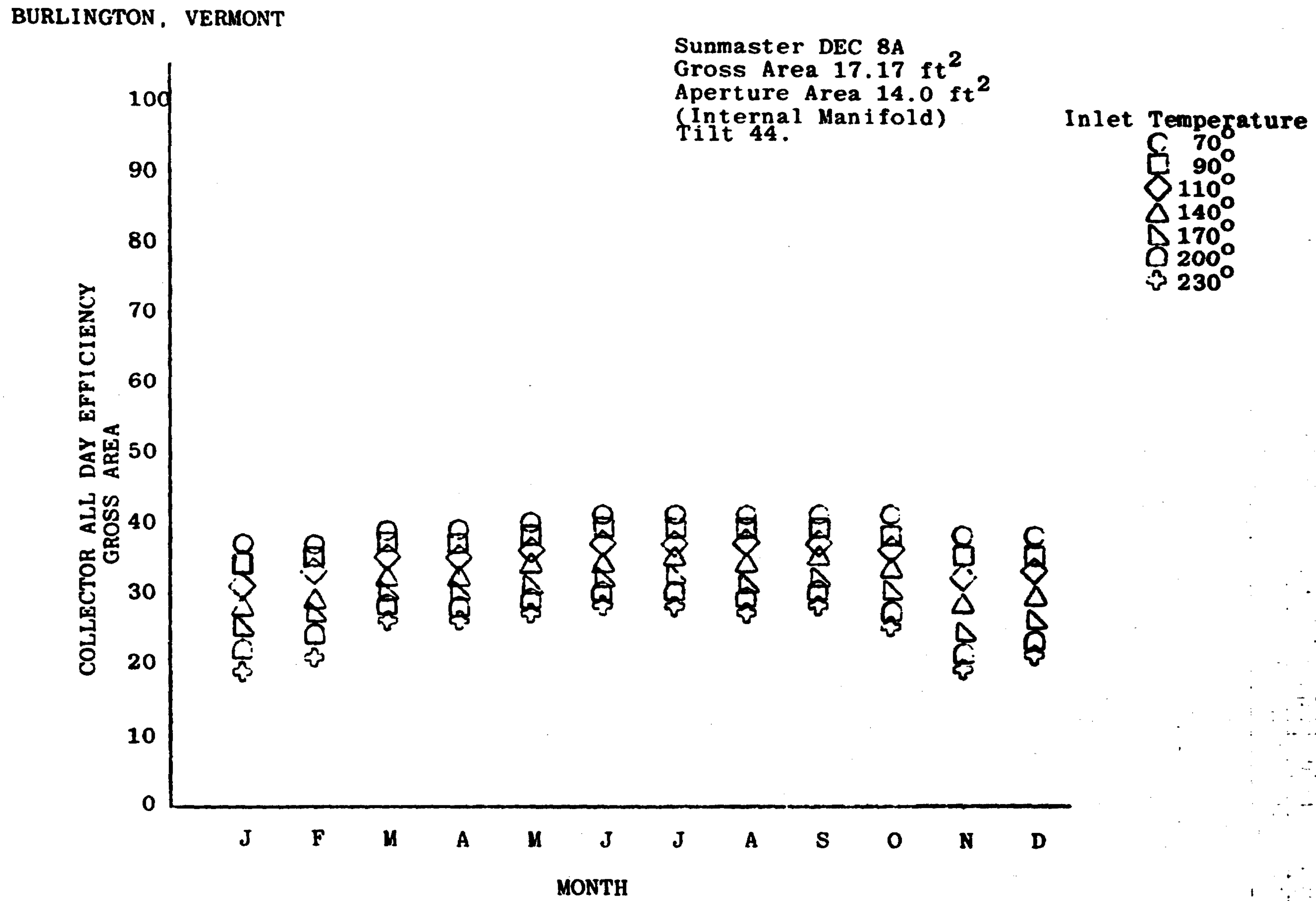
J F M A M J J A S O N D
MONTH

BURLINGTON, VERMONT




BURLINGTON, VERMONT
Sunmaster DEC 8A
Gross Area 17.17 ft2
Aperture Area 14.0 ft2
(Internal Manifold)
Tilt 44.
Inlet Temperature
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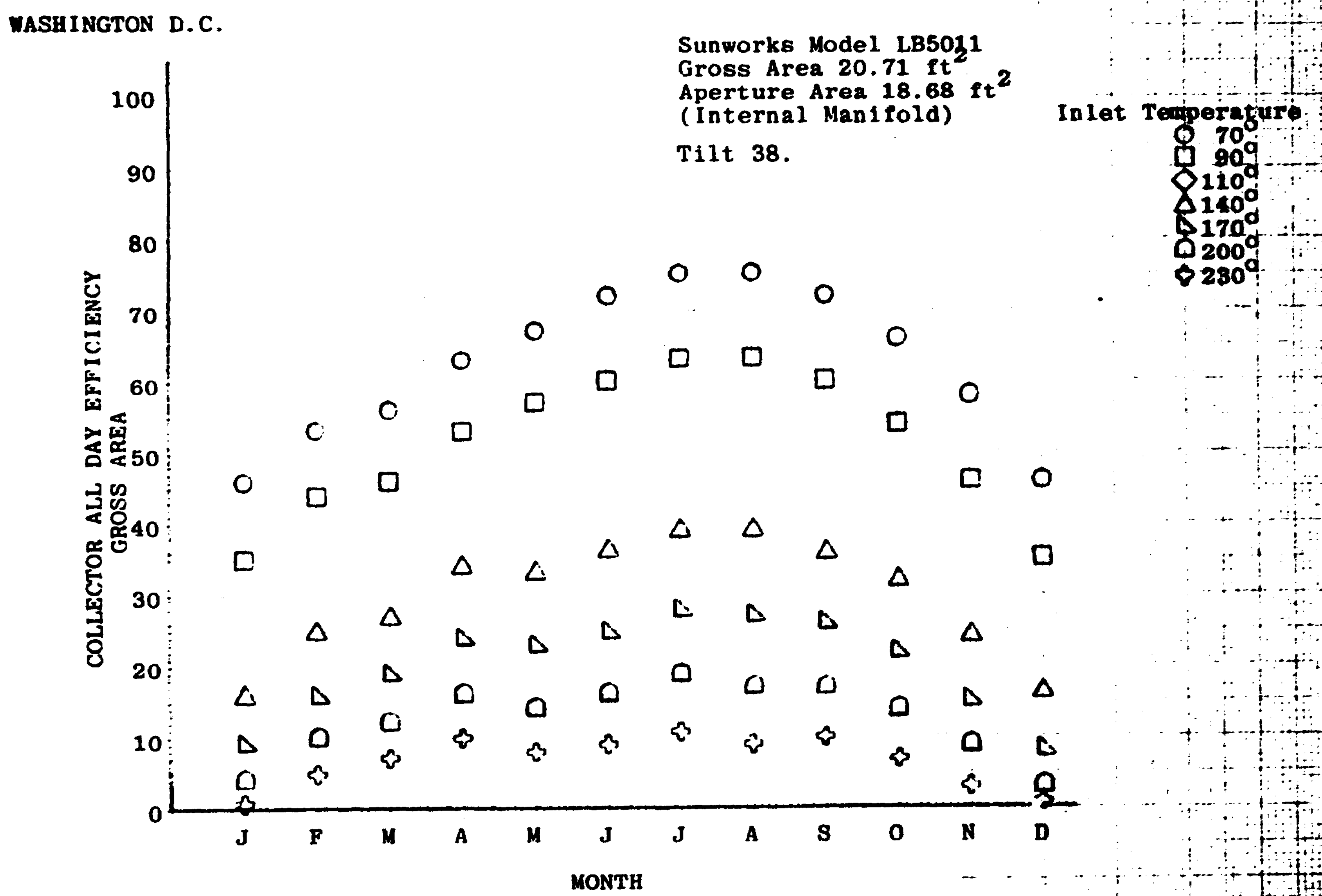
WASHINGTON D.C.
Sunworks Model LB5011
Gross Area 20.71 ft2
Aperture Area 18.68 ft2
(Internal Manifold)
Tilt 38.
Inlet Temperature
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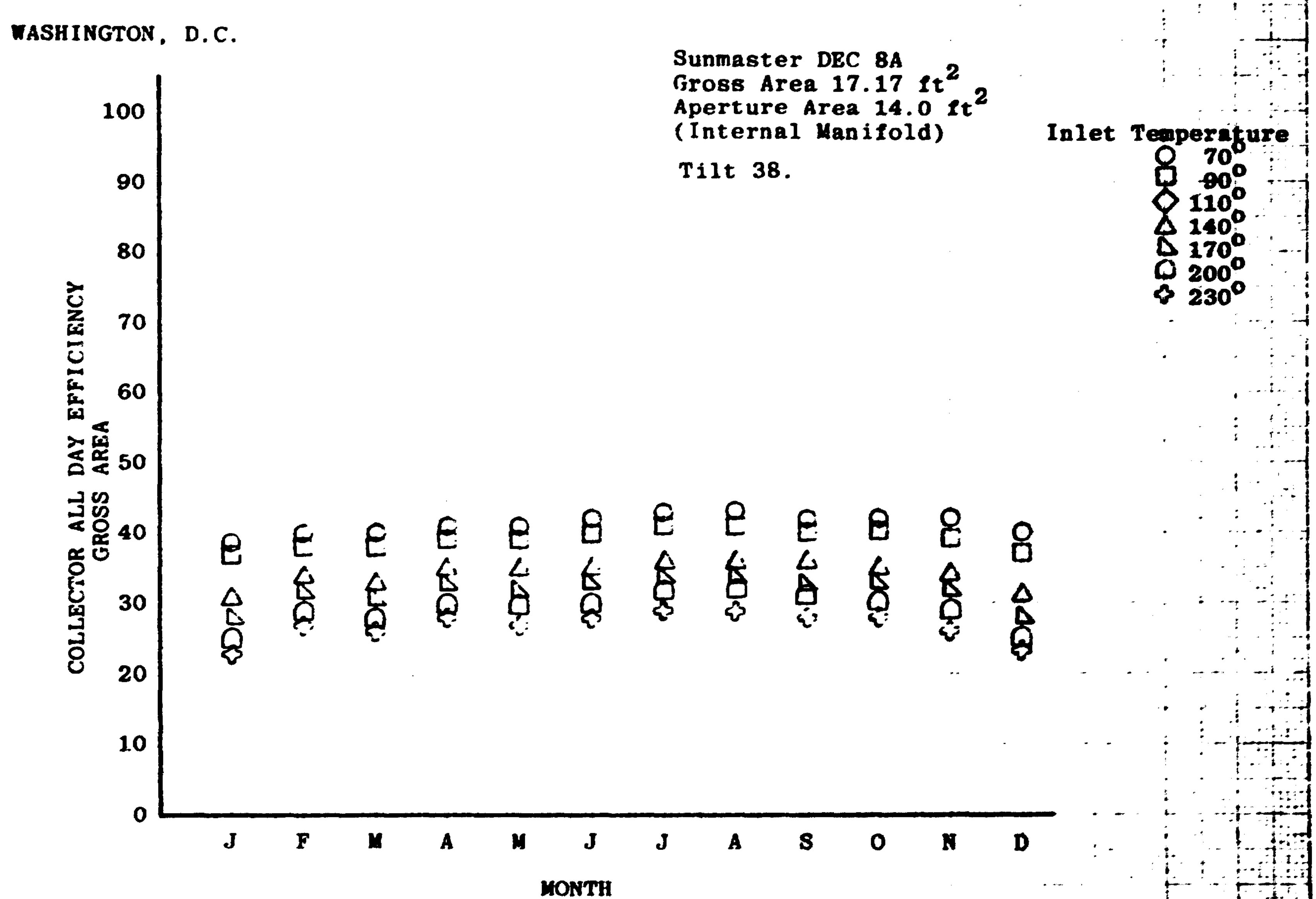
WASHINGTON, D.C.
Sunmaster DEC 8A
Gross Area 17.17 ft²
Aperture Area 14.0 ft²
(Internal Manifold)
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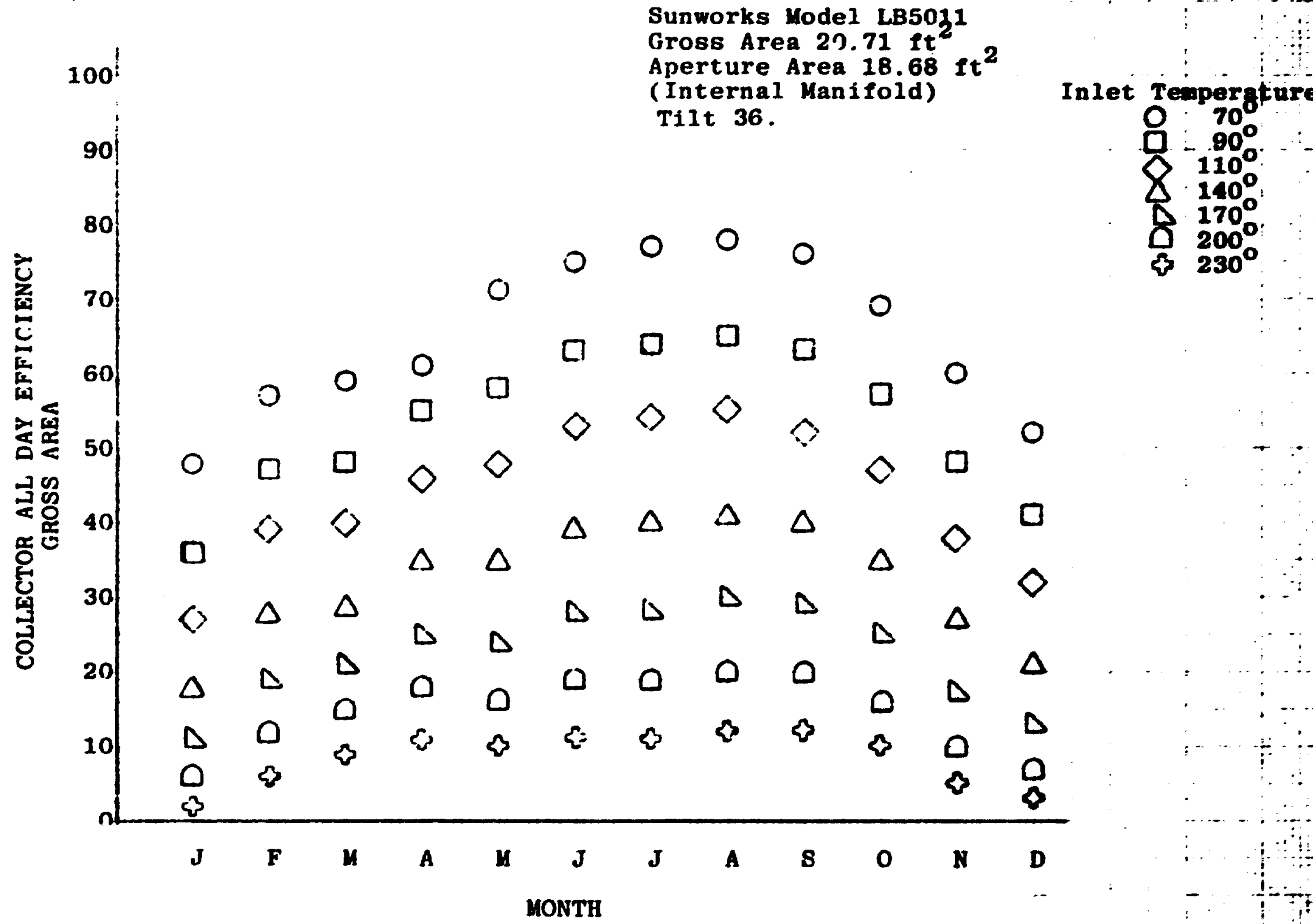
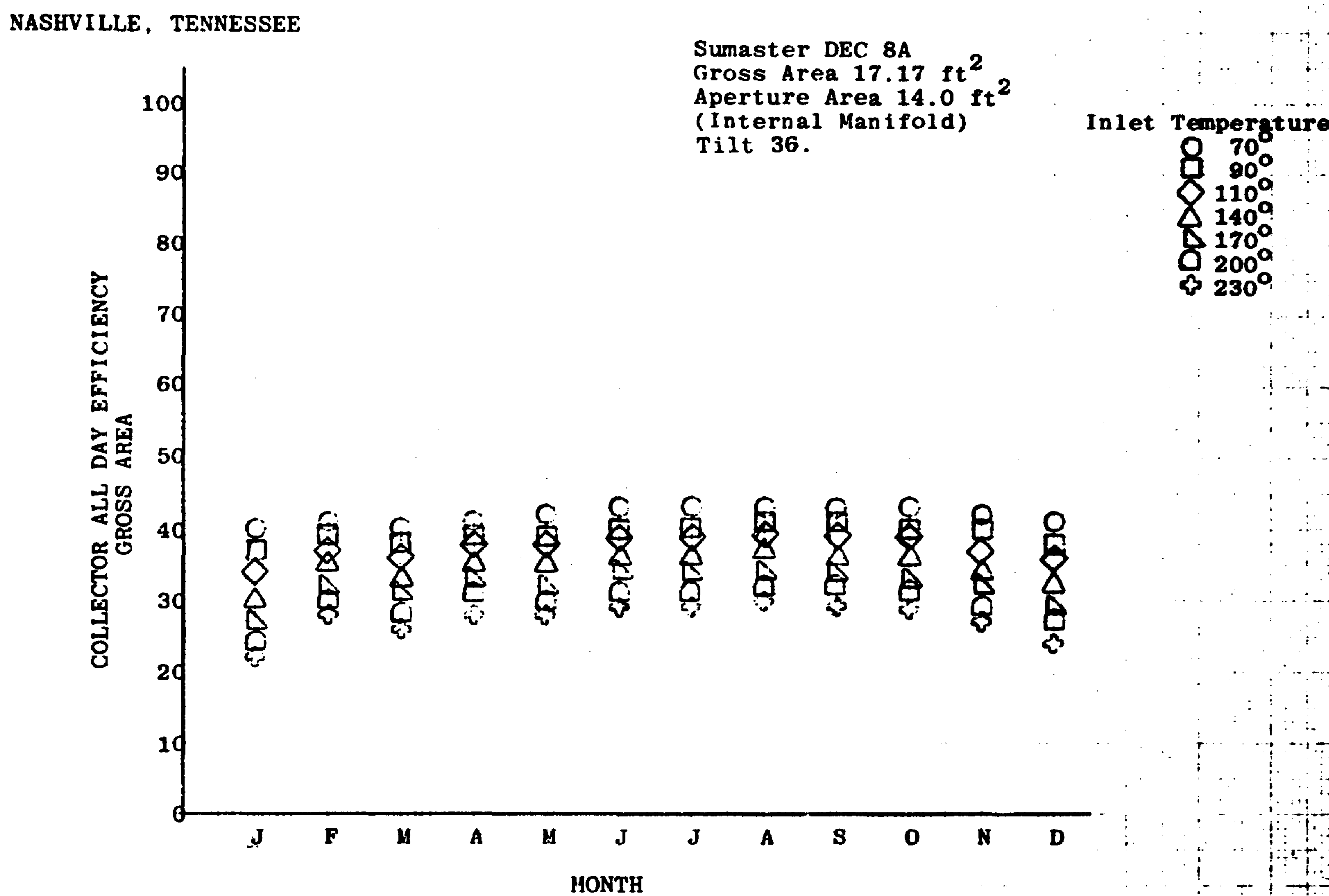
NASHVILLE, TENNESSEE




NASHVILLE, TENNESSEE
Sumaster DEC 8A
Gross Area 17.17 ft²
Aperture Area 14.0 ft²
(Internal Manifold)
Tilt 36.
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COLLECTOR ALL DAY EFFICIENCY GROSS AREA
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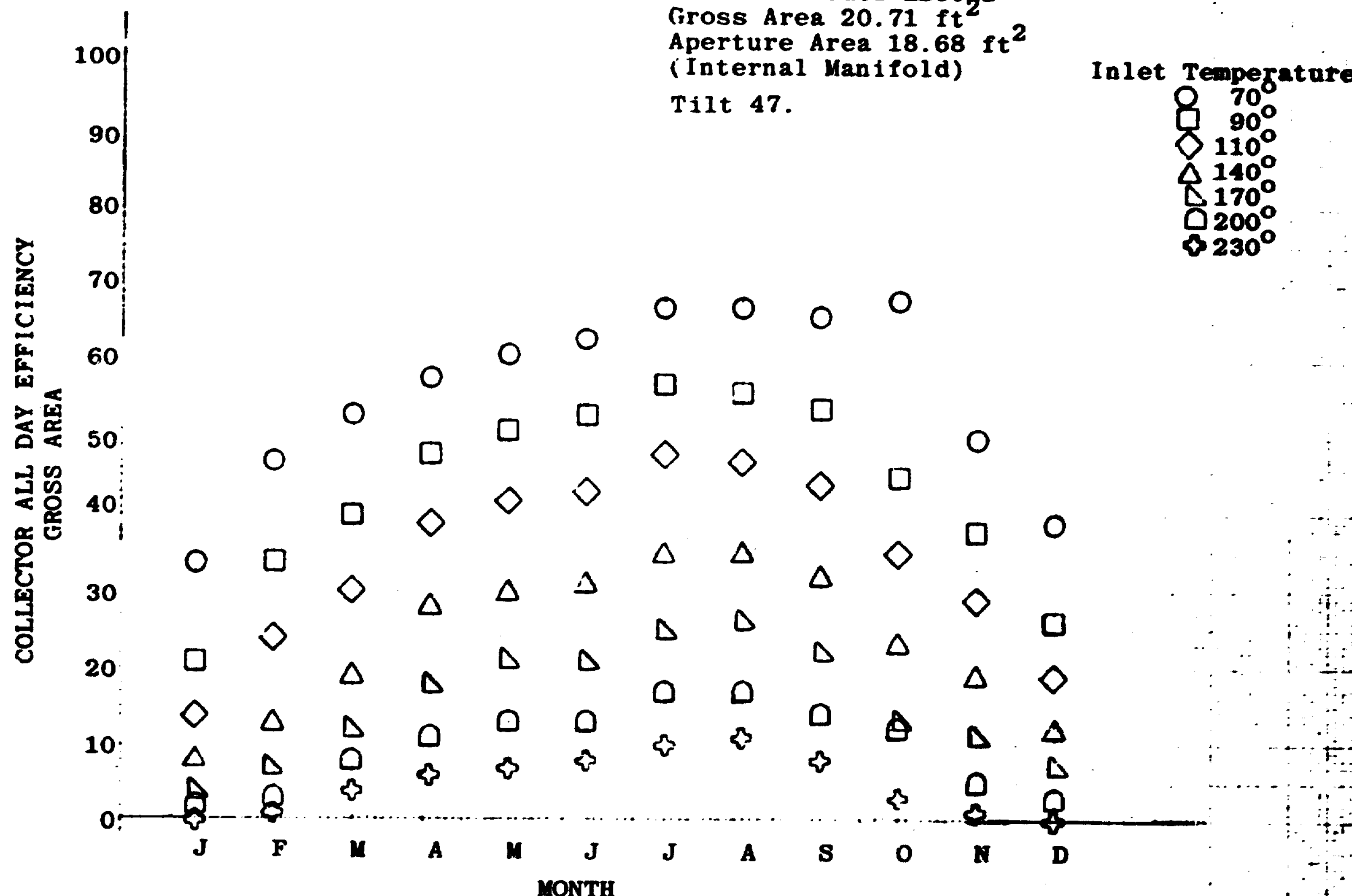
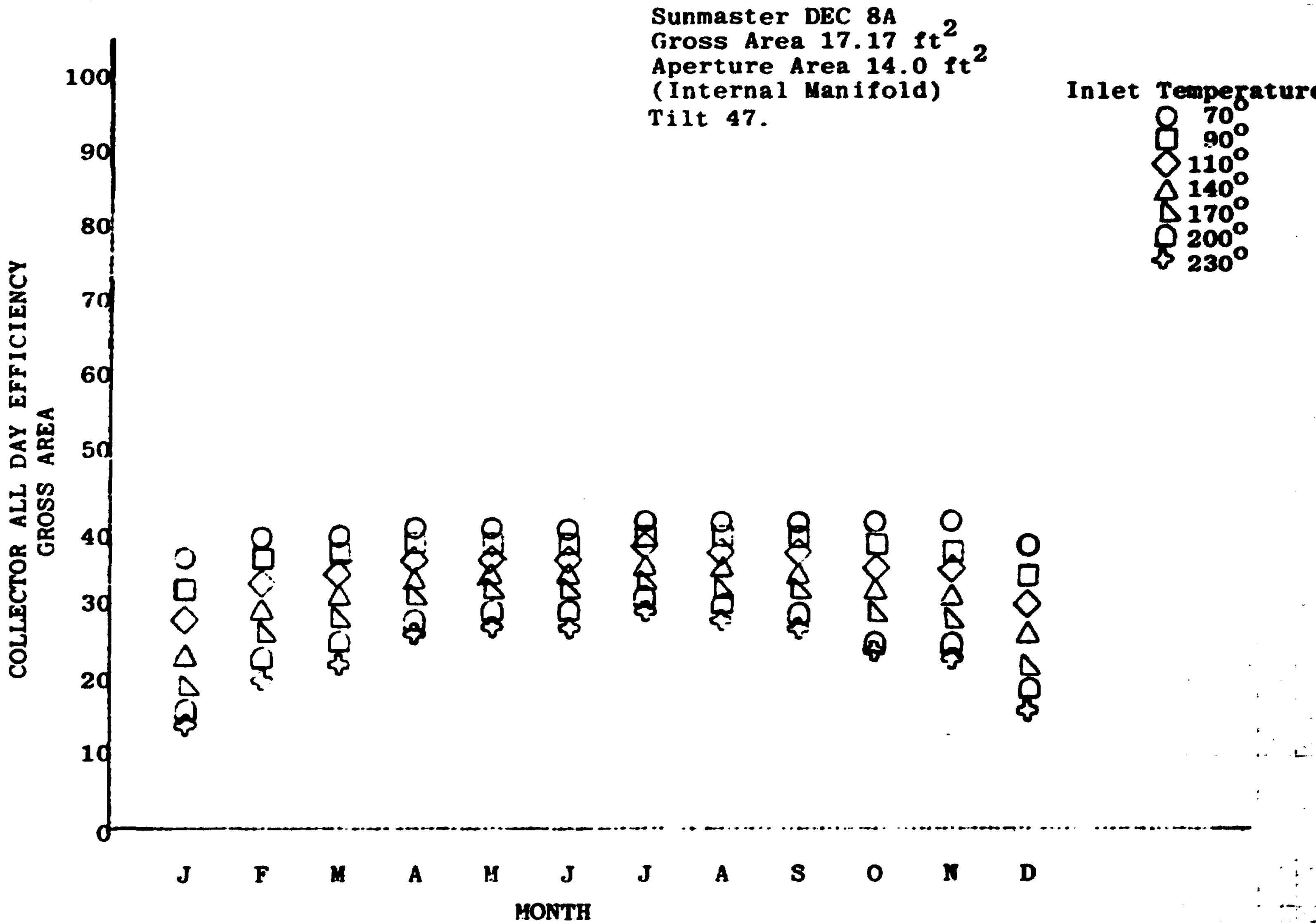
MONTH

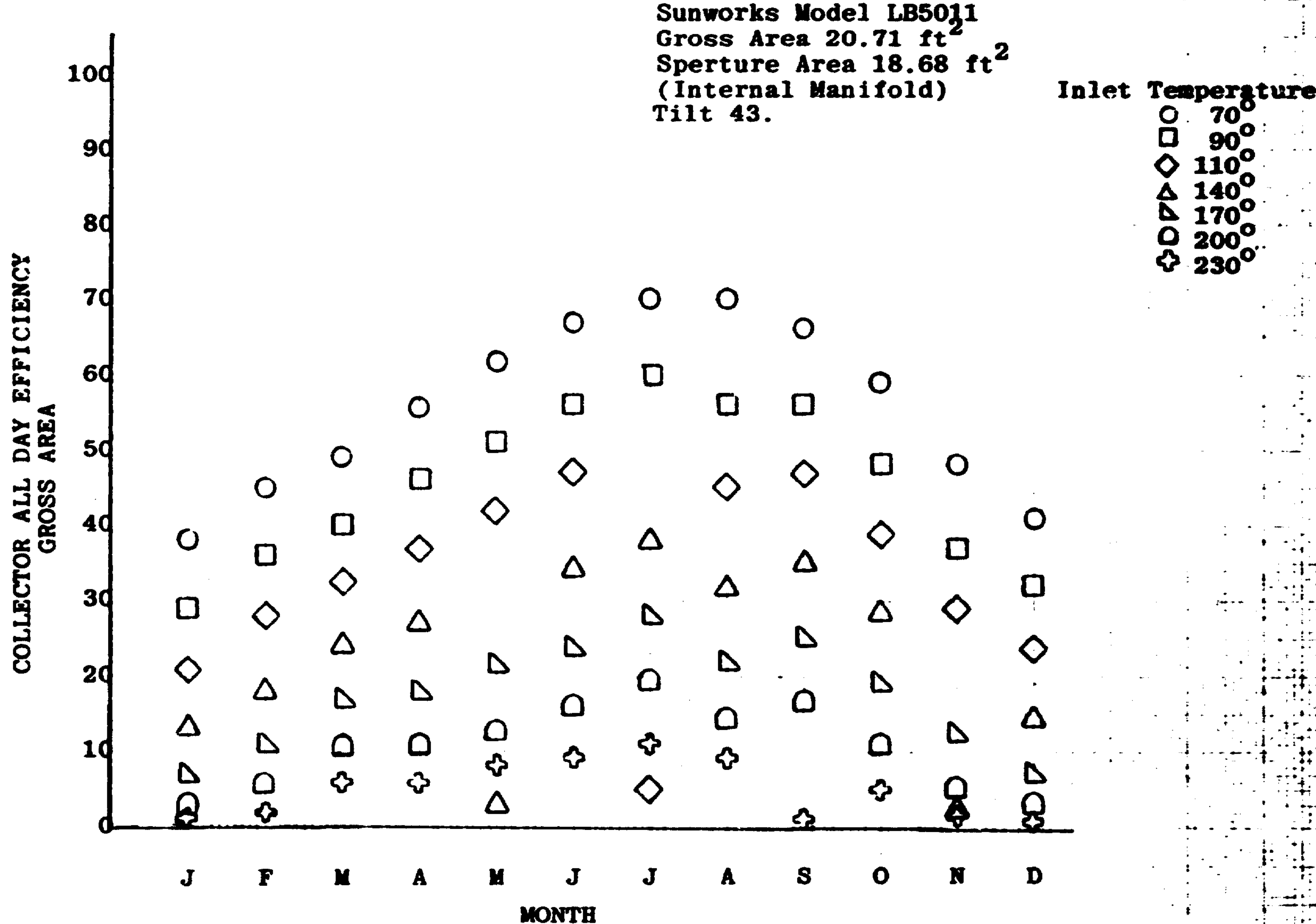
SEATTLE/TACOMA, WASHINGTON



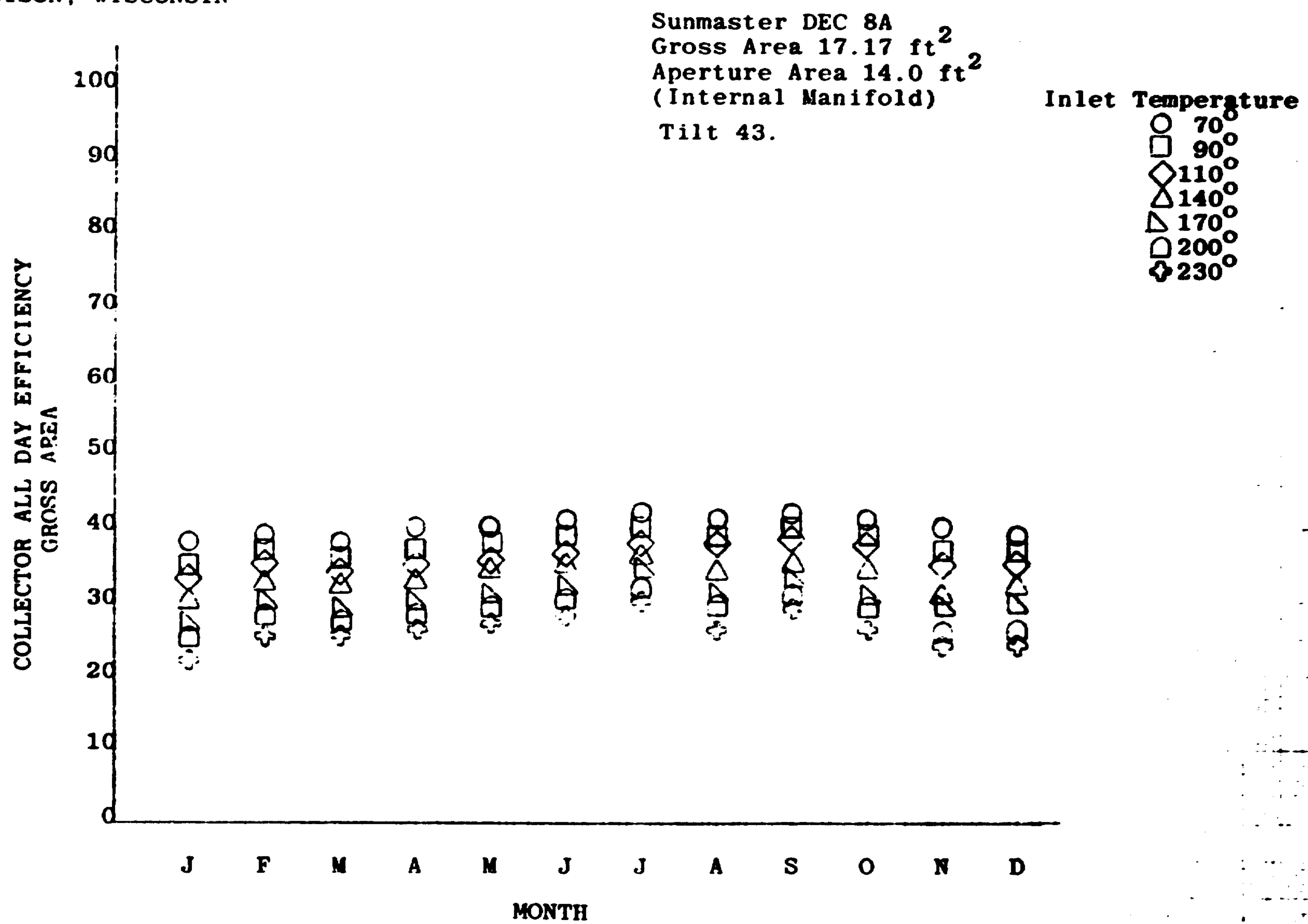
SEATTLE/TACOM, WASHINGTON

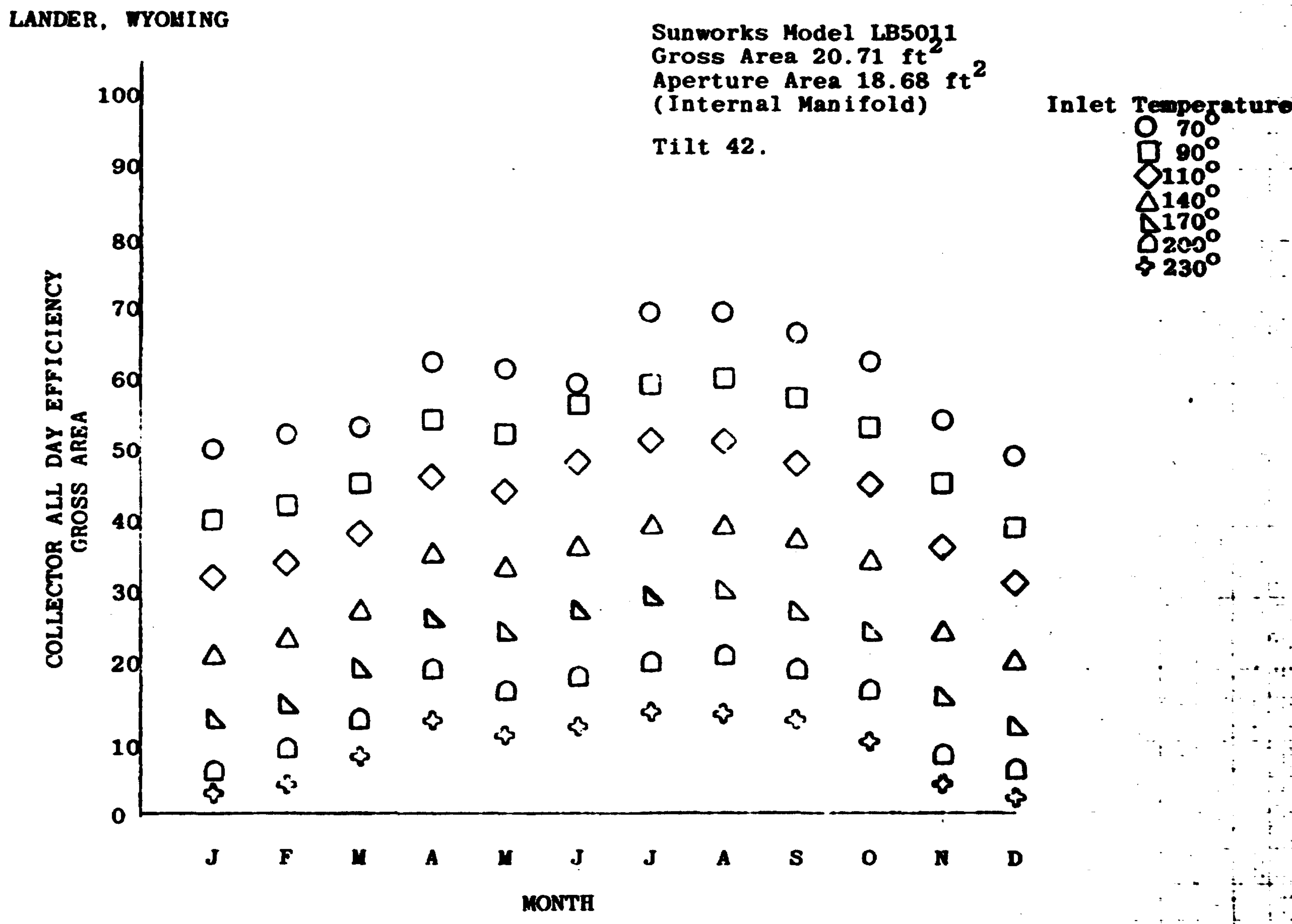


MADISON, WISCONSIN

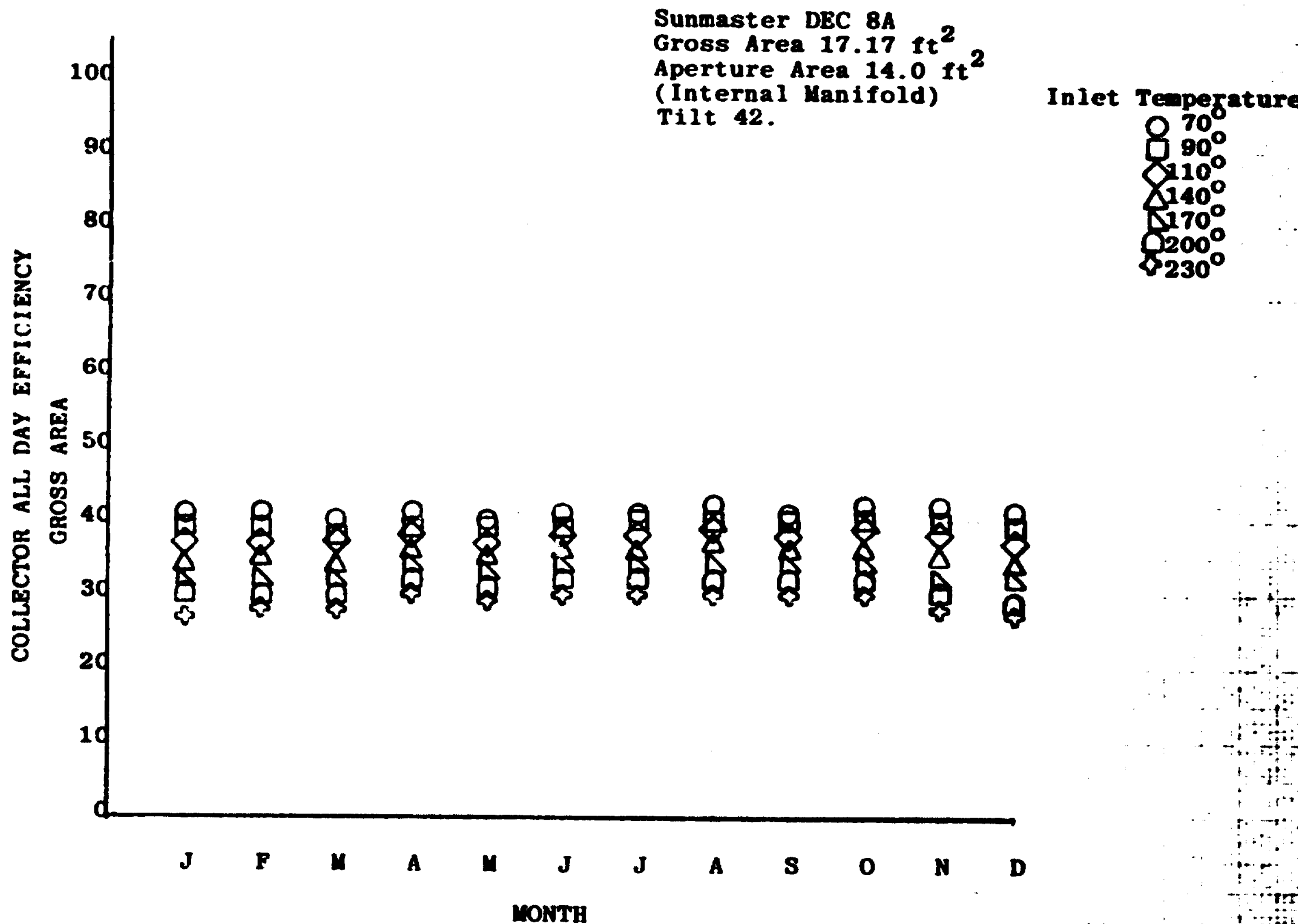


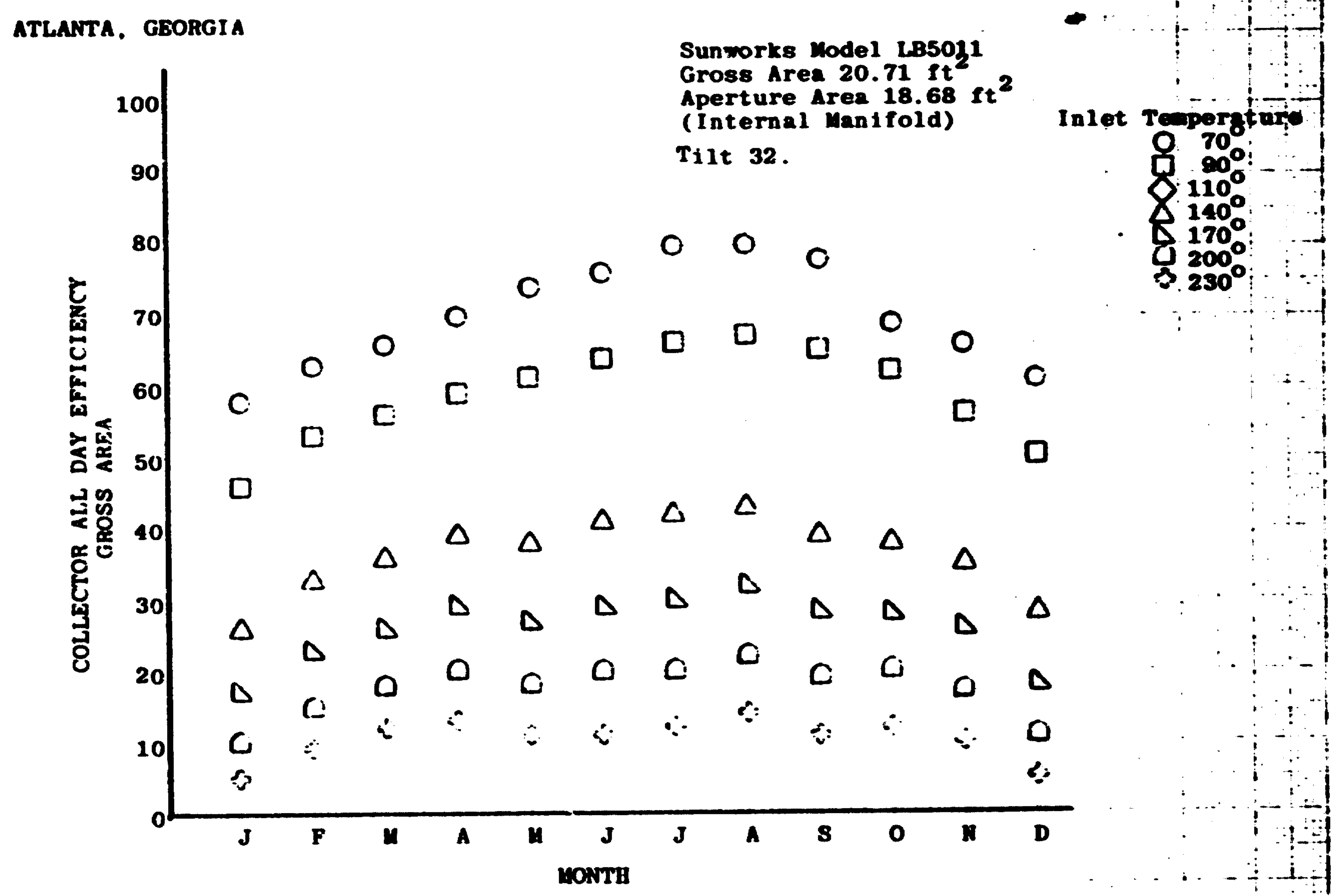
MADISON, WISCONSIN




LANDER, WYOMING
Sunworks Model LB5011
Gross Area 20.71 ft2
Aperture Area 18.68 ft2
(Internal Manifold)
Tilt 42.
Inlet Temperature
70°
90°
110°
140°
170°
200°
230°
COLLECTOR ALL DAY EFFICIENCY
GROSS AREA
100
90
80
70
60
50
40
30
20
10
0
J F M A M J J A S O N D
MONTH

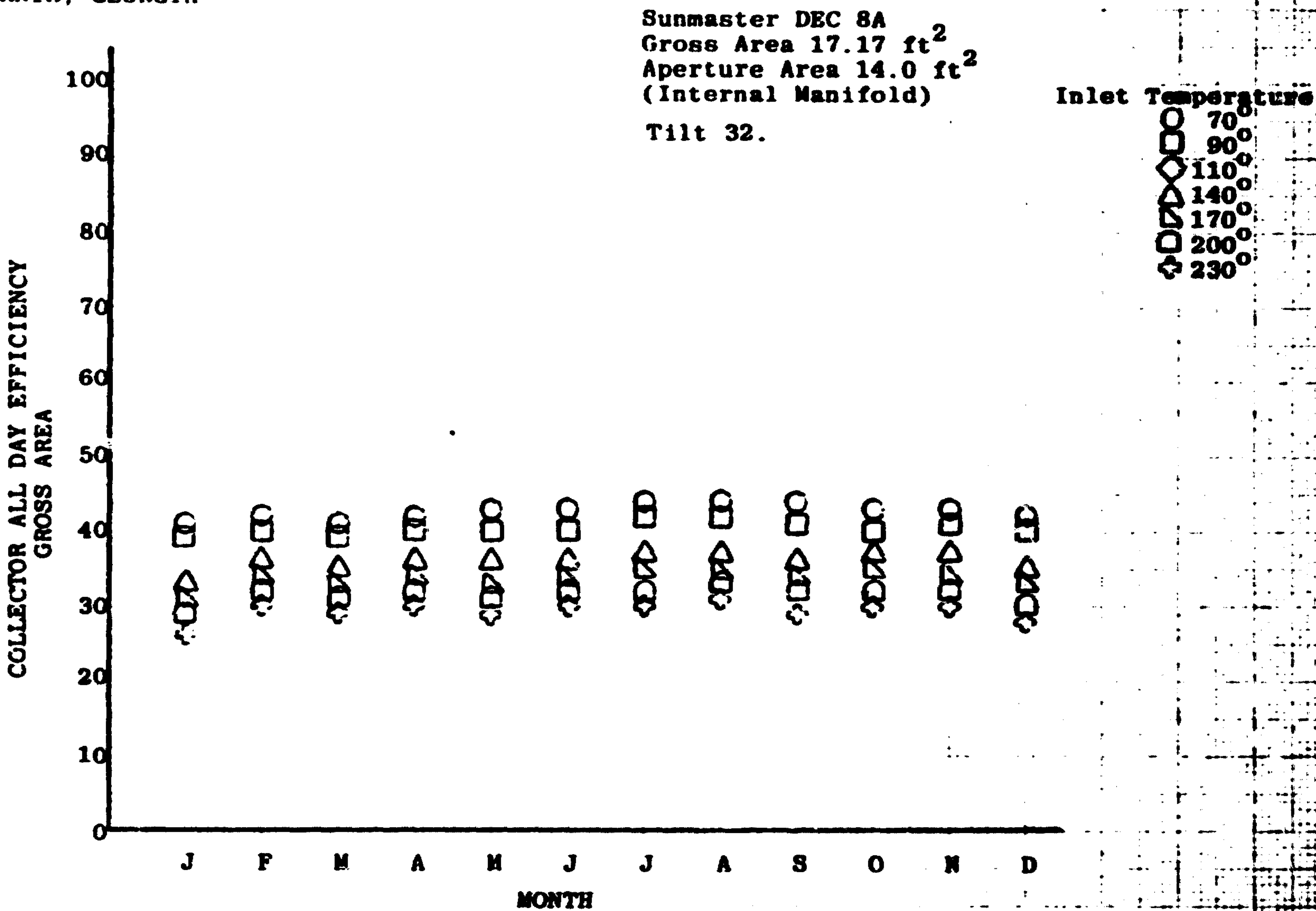
LANDER, WYOMING





ORIGINAL PAGE IS OF POOR QUALITY

ATLANTA, GEORGIA



APPENDIX 2

HOURLY INSOLATION DATA

for

HORIZONTAL & 45° SURFACES

in

HUNTSVILLE, ALABAMA

FEBRUARY-1981 HUNTSVILLE, ALABAMA TILT = 0

TOTAL RADIATION FOR EACH HOUR ENDING SOLAR TIME (BTU/FT2)

DAY	8	9	10	11	12	13	14	15	16	17	TOT
1	0	1	4	6	3	2	13	8	4	0	41
2	0	33	50	55	95	94	93	85	93	11	609
3	53	114	154	183	204	204	185	145	90	23	1355
4	48	76	118	183	240	224	183	124	95	23	1314
5	33	82	139	189	192	178	106	88	70	17	1044
6	13	45	89	147	163	157	176	138	86	23	1037
7	9	14	29	41	53	84	48	16	14	2	310
8	25	58	126	187	211	210	191	153	99	29	1289
9	47	114	142	171	132	128	147	79	49	10	1019
10	0	1	5	8	13	13	13	49	23	2	127
11	6	33	65	76	108	101	120	75	81	34	699
12	39	106	148	186	191	191	195	148	103	34	1341
13	21	78	94	135	153	167	158	79	41	11	937
14	12	36	65	107	144	169	145	103	81	33	895
15	15	93	74	98	87	87	68	79	51	9	661
16	9	14	19	26	46	64	53	47	12	4	294
17	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0
20	0	109	18	206	228	225	203	162	107	45	1303
21	48	100	165	205	205	214	187	102	43	11	1280
22	2	8	23	14	16	33	22	17	35	19	189
23	37	0	0	163	197	234	179	163	105	29	1107
24	55	120	176	217	240	239	214	175	118	33	1587
25	54	106	169	210	224	226	126	137	111	0	1363
26	7	108	161	200	221	221	196	154	78	43	1389
27	47	105	153	173	172	220	195	163	103	44	1375
28	26	48	70	75	87	85	31	22	13	2	459
MEAN	24	64	90	130	145	148	129	100	68	19	

FEBRUARY-1981 HUNTSVILLE,ALABAMA TILT = 45

TOTAL RADIATION FOR EACH HOUR ENDING SOLAR TIME (BTU/FT2)

DAY	8	9	10	11	12	13	14	15	16	17	TOT
1	0	2	4	6	4	2	11	7	3	0	39
2	0	27	43	48	100	111	108	117	169	35	758
3	89	176	270	317	340	336	304	245	163	67	2307
4	74	114	186	305	351	345	282	196	169	56	2078
5	55	177	254	317	319	182	156	123	111	24	1718
6	13	57	130	213	222	200	267	227	148	57	1534
7	8	13	24	33	43	76	41	13	12	2	265
8	54	79	219	313	337	334	302	248	170	77	2133
9	75	170	249	274	167	149	192	81	51	9	1417
10	0	2	5	7	11	10	11	44	20	2	112
11	6	29	67	71	110	107	156	102	134	80	862
12	106	200	244	299	274	272	305	225	167	80	2172
13	41	122	110	178	209	230	215	93	37	10	1245
14	11	30	56	103	163	234	223	137	121	65	1143
15	17	140	77	101	82	75	56	79	49	8	684
16	8	12	15	20	39	57	45	43	11	3	253
17	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0
20	0	178	28	307	331	326	298	242	168	80	1958
21	94	174	254	299	288	304	262	124	36	7	1842
22	2	5	19	11	12	26	18	14	29	17	153
23	55	0	0	217	277	333	247	229	154	46	1558
24	102	190	264	316	342	338	308	254	183	60	2357
25	97	165	254	302	320	317	177	201	170	0	2003
26	12	166	237	285	307	305	273	216	113	68	1982
27	74	152	212	221	209	292	260	225	146	66	1857
28	24	43	63	63	76	74	26	16	9	0	394
MEAN	46	110	149	210	224	228	206	159	115	41	

MARCH-1981 HUNTSVILLE, ALABAMA TILT = 0

TOTAL RADIATION FOR EACH HOUR ENDING SOLAR TIME (BTU/FT2)

DAY	8	9	10	11	12	13	14	15	16	17	TOT
1	14	30	72	100	149	153	144	85	31	11	789
2	37	101	177	216	237	237	214	171	111	45	1546
3	50	89	160	183	180	135	140	96	51	25	1109
4	2	2	6	7	9	15	25	17	6	8	97
5	21	26	43	72	38	81	41	39	29	14	404
6	42	131	180	227	250	239	181	142	122	57	1571
7	55	115	189	210	235	230	181	125	55	34	1429
8	35	76	190	196	252	252	229	186	130	65	1611
9	71	137	195	236	257	255	232	188	131	64	1766
10	68	122	185	226	249	248	226	185	125	61	1695
11	0	0	0	0	0	0	0	0	0	0	0
12	77	144	173	227	254	201	141	78	120	61	1476
13	55	113	153	219	253	197	231	172	111	36	1540
14	77	145	205	246	267	267	242	200	140	72	1861
15	64	125	140	147	129	132	35	21	9	14	816
16	73	118	158	190	253	259	249	152	145	79	1676
17	81	147	203	245	266	262	240	196	137	72	1849
18	0	20	46	78	73	163	116	18	13	3	530
19	83	150	0	163	282	240	204	172	113	60	1467
20	81	149	209	251	271	271	0	0	0	76	1308
21	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0
24	53	129	200	249	172	212	244	154	140	80	1633
25	79	133	188	211	216	210	187	0	29	44	1297
26	80	145	191	227	261	260	240	200	130	54	1788
27	45	129	182	225	250	253	232	158	103	62	1639
28	80	147	200	244	265	263	209	180	124	66	1778
29	65	126	135	124	162	200	114	57	32	9	1024
30	45	147	215	257	280	275	236	212	154	88	1909
31	93	158	215	255	261	260	234	199	154	73	1902
MEAN	56	113	155	193	213	213	176	126	90	49	

MARCH-1981 HUNTSVILLE, ALABAMA TILT = 45

TOTAL RADIATION FOR EACH HOUR ENDING SOLAR TIME (BTU/FT2)

DAY	8	9	10	11	12	13	14	15	16	17	TOT
1	12	25	62	90	148	180	155	79	23	7	781
2	38	137	252	302	325	322	292	235	152	60	2115
3	66	105	200	220	208	133	147	94	44	21	1238
4	1	2	5	6	8	13	21	14	5	7	82
5	22	22	39	60	29	80	33	32	24	11	352
6	51	180	246	305	333	308	208	168	160	73	2032
7	74	161	251	271	297	289	202	131	48	29	1753
8	32	97	246	237	333	331	298	245	172	88	2079
9	114	190	261	312	336	331	298	245	172	86	2345
10	105	86	234	300	325	319	286	238	158	79	2130
11	0	0	0	0	0	0	0	0	0	0	0
12	123	193	221	293	319	252	159	69	140	78	1847
13	67	137	185	265	299	240	293	208	129	35	1858
14	106	193	263	312	337	336	299	249	175	89	2359
15	72	156	156	154	118	126	29	17	7	12	847
16	94	144	188	228	313	320	305	187	179	96	2054
17	112	190	259	308	330	325	291	241	166	85	2307
18	0	18	38	73	65	164	113	12	10	2	495
19	107	189	0	205	343	293	241	206	131	67	1782
20	67	12	74	121	145	146	0	0	0	88	653
21	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0
24	48	145	240	297	201	250	277	170	157	86	1871
25	89	154	217	244	248	234	206	0	30	40	1462
26	91	170	225	265	304	301	276	227	138	50	2047
27	41	140	204	256	279	287	262	170	109	63	1811
28	87	170	231	281	305	303	230	200	133	63	2003
29	64	133	131	111	159	203	98	45	24	5	973
30	39	161	247	290	318	312	264	235	165	88	2119
31	102	179	244	288	296	297	259	215	161	71	2112
MEAN	79	151	213	264	292	291	240	170	122	64	

APRIL-1981 HUNTSVILLE, ALABAMA TILT = 0

TOTAL RADIATION FOR EACH HOUR ENDING SOLAR TIME (BTU/FT2)

DAY	8	9	10	11	12	13	14	15	16	17	TOT
1	59	163	218	259	287	285	264	222	163	95	2015
2	94	167	225	265	286	284	260	218	138	66	2003
3	74	113	153	176	159	141	123	78	58	42	1117
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	142	229	269	292	247	224	242	167	100	1912
7	0	0	0	0	0	0	0	0	0	0	0
8	92	76	125	119	125	173	99	149	61	37	1056
9	0	15	42	56	195	106	138	125	65	68	810
10	85	131	141	200	243	203	204	190	117	75	1589
11	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0
14	102	0	33	246	238	253	230	124	20	64	1310
15	41	63	79	165	207	155	144	144	164	105	1267
16	71	134	146	213	173	129	146	146	119	64	1341
17	20	31	62	64	110	92	101	108	71	37	696
18	44	67	105	182	201	239	245	195	103	48	1429
19	76	130	142	211	232	220	207	176	97	72	1563
20	7	7	129	173	86	63	102	91	41	19	718
21	53	130	192	241	283	255	232	123	70	40	1619
22	68	95	153	139	140	111	118	70	22	35	951
23	40	93	104	167	26	15	51	50	15	40	601
24	113	184	242	277	41	308	286	243	186	119	1999
25	121	187	241	281	284	285	252	225	178	106	2160
26	117	181	235	273	292	292	270	206	172	95	2133
27	122	185	240	278	299	300	277	234	180	113	2228
28	113	170	237	273	278	297	270	229	171	104	2142
29	5	9	103	149	46	223	217	203	169	114	1238
30	104	136	219	242	260	229	201	222	176	119	1908
MEAN	67	108	158	204	199	204	194	167	113	74	

APRIL-1981 HUNTSVILLE,ALABAMA TILT = 45

TOTAL RADIATION FOR EACH HOUR ENDING SOLAR TIME (BTU/FT2)

DAY	8	9	10	11	12	13	14	15	16	17	TOT
1	62	181	246	286	319	318	291	241	170	91	2205
2	100	186	252	291	316	314	285	235	144	64	2187
3	68	110	157	170	148	123	106	64	45	34	1025
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	153	250	286	311	265	238	254	165	89	2011
7	0	0	0	0	0	0	0	0	0	0	0
8	93	67	112	108	107	166	84	138	50	29	954
9	0	11	33	39	188	88	124	114	61	60	718
10	79	126	127	200	249	203	207	188	112	66	1557
11	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0
14	96	0	34	242	244	258	230	117	16	51	1288
15	32	48	58	147	210	152	134	138	155	87	1161
16	60	122	137	211	159	111	129	136	107	53	1225
17	15	23	49	51	93	81	87	100	58	33	590
18	37	59	99	171	186	245	247	190	93	40	1367
19	66	116	130	211	227	206	200	166	85	59	1466
20	7	5	114	155	71	60	86	72	31	14	615
21	43	120	185	235	281	249	220	112	59	32	1536
22	57	81	139	122	122	97	102	56	17	29	822
23	31	76	89	148	20	11	41	41	11	32	500
24	98	170	240	272	42	318	298	245	173	97	1953
25	104	180	250	287	289	289	261	223	165	91	2139
26	104	174	244	278	293	296	278	205	158	78	2108
27	106	176	246	280	297	301	282	232	164	92	2176
28	102	165	243	277	278	298	276	227	156	87	2109
29	6	10	102	149	45	221	219	198	155	92	1197
30	87	134	228	246	257	225	209	220	158	93	1857
MEAN	80	138	209	270	264	271	257	217	139	82	

MAY -1981 HUNTSVILLE, ALABAMA TILT = 0

TOTAL RADIATION FOR EACH HOUR ENDING SOLAR TIME (BTU/FT2)

DAY	8	9	10	11	12	13	14	15	16	17	TOT
1	72	132	172	208	248	254	253	212	166	71	1788
2	127	193	248	288	306	309	286	246	190	122	2315
3	128	193	252	277	246	195	211	207	182	120	2011
4	106	151	198	265	294	286	274	214	135	108	2031
5	65	148	174	201	184	197	206	164	97	29	1465
6	29	46	26	53	28	41	74	55	21	15	388
7	17	52	120	139	210	176	166	174	122	70	1246
8	27	70	110	138	138	214	265	216	185	115	1478
9	83	170	220	221	231	275	199	110	78	42	1629
10	48	75	85	34	219	102	157	224	107	112	1163
11	5	16	31	82	34	17	34	35	34	32	320
12	40	67	146	230	311	310	289	248	192	122	1955
13	111	193	231	268	273	303	267	234	181	117	2178
14	42	73	82	282	222	217	127	154	189	89	1477
15	76	49	59	94	70	110	179	223	192	78	1130
16	34	78	124	201	70	84	76	113	34	16	830
17	3	11	11	26	27	23	22	68	91	75	357
18	41	169	228	246	293	282	189	109	87	21	1665
19	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0
21	138	203	256	293	312	314	288	250	196	131	2381
22	130	199	255	290	309	308	285	248	194	129	2347
23	133	196	247	289	302	292	267	225	133	72	2156
24	121	190	244	280	209	278	255	218	179	107	2081
25	49	98	191	205	172	106	59	127	98	50	1155
26	12	32	58	88	102	123	130	100	74	52	771
27	10	64	167	177	84	152	160	184	138	94	1230
28	128	189	247	294	226	252	160	164	193	122	1975
29	118	150	149	260	277	194	198	175	172	95	1788
30	109	177	231	273	241	219	169	162	124	78	1783
31	96	163	202	254	251	55	91	17	15	15	1159
MEAN	72	122	164	205	203	196	184	168	131	79	

MAY -1981 HUNTSVILLE, ALABAMA TILT = 45

TOTAL RADIATION FOR EACH HOUR ENDING SOLAR TIME (BTU/FT2)

DAY	8	9	10	11	12	13	14	15	16	17	TOT
1	66	125	171	201	247	249	254	207	151	62	1733
2	106	177	249	284	296	301	285	235	167	95	2195
3	107	179	256	286	249	188	200	194	161	93	1913
4	89	139	188	263	288	286	277	207	120	87	1944
5	60	142	166	192	175	189	202	154	85	24	1389
6	27	42	24	48	27	33	71	48	20	15	355
7	17	46	108	126	203	165	154	159	108	58	1144
8	27	66	94	122	120	206	262	208	161	88	1354
9	70	155	214	220	222	268	191	99	69	36	1544
10	44	66	79	31	204	94	150	211	95	89	1063
11	6	17	27	72	31	17	32	30	30	30	292
12	38	59	134	220	288	292	277	227	160	86	1781
13	101	170	221	260	258	286	250	210	152	86	1994
14	38	67	81	272	207	201	118	144	163	68	1359
15	63	46	54	83	61	97	167	202	162	59	994
16	32	67	108	184	60	74	70	104	31	14	744
17	4	11	11	27	25	24	21	59	78	64	324
18	38	151	218	234	267	263	176	101	78	20	1546
19	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0
21	93	170	236	272	276	285	268	221	156	85	2062
22	95	168	235	271	273	280	265	220	156	85	2048
23	97	164	227	265	271	266	245	199	115	60	1909
24	89	160	224	262	191	257	236	195	148	77	1839
25	42	84	175	190	155	103	61	113	82	40	1045
26	9	26	51	75	87	109	111	88	65	44	665
27	9	53	161	158	77	138	147	164	116	72	1095
28	91	157	223	268	201	227	145	144	155	85	1696
29	90	127	138	241	249	176	182	155	141	71	1570
30	83	150	211	253	216	198	152	141	103	58	1565
31	72	143	189	241	221	57	85	16	10	11	1045
MEAN	63	115	165	208	201	197	187	165	119	65	

JUNE -1981 HUNTSVILLE, ALABAMA TILT = 0

TOTAL RADIATION FOR EACH HOUR ENDING SOLAR TIME (BTU/FT2)

DAY	8	9	10	11	12	13	14	15	16	17	TOT
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	63	105	130	201	199	247	197	56	1198
5	66	87	169	163	209	125	221	217	135	43	1435
6	28	61	99	161	161	136	226	136	121	76	1205
7	28	44	105	146	104	76	116	243	126	40	1028
8	32	47	160	248	219	205	193	204	143	125	1576
9	78	161	179	209	292	218	208	227	183	117	1872
10	127	128	157	242	207	240	247	156	123	37	1664
11	118	128	132	100	21	3	16	55	75	92	740
12	111	171	183	247	245	253	239	227	150	73	1899
13	38	40	119	215	214	209	234	171	197	127	1564
14	0	0	0	0	0	0	0	0	0	0	0
15	0	132	226	266	289	289	249	230	185	125	1991
16	127	179	197	221	288	275	237	174	129	99	1926
17	102	144	171	282	258	299	257	246	193	133	2085
18	0	102	248	285	304	304	283	243	190	129	2088
19	126	187	232	243	206	37	234	105	33	15	1418
20	109	114	170	229	160	103	186	210	144	117	1542
21	129	187	237	254	286	282	280	224	188	123	2190
22	125	186	247	212	204	274	266	231	173	100	2018
23	134	194	242	265	292	295	277	239	188	131	2257
24	133	191	139	175	292	292	274	239	185	124	2044
25	120	176	222	250	274	260	269	162	186	106	2025
26	137	199	254	289	305	304	294	276	242	187	2487
27	79	139	200	248	280	298	259	190	217	119	2029
28	72	132	191	239	256	294	125	213	180	131	1833
29	5	11	12	18	26	68	208	174	229	114	865
30	65	103	205	249	203	286	279	221	186	137	1934
MEAN	80	124	175	213	220	216	226	202	165	102	

JUNE -1981 HUNTSVILLE,ALABAMA TILT = 45

TOTAL RADIATION FOR EACH HOUR ENDING SOLAR TIME (BTU/FT2)

DAY	8	9	10	11	12	13	14	15	16	17	TOT
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	41	97	115	179	179	209	148	47	1015
5	57	76	150	159	222	124	207	192	107	35	1329
6	25	51	86	148	146	120	204	118	99	59	1056
7	25	42	89	127	92	62	100	208	98	34	877
8	28	40	145	220	191	198	190	174	108	81	1375
9	51	108	152	190	254	190	185	194	142	78	1544
10	87	104	139	220	183	209	222	130	99	33	1426
11	86	111	117	86	17	2	14	49	70	71	623
12	84	145	166	221	213	223	217	198	114	52	1633
13	33	35	106	187	188	187	209	150	153	89	1337
14	0	0	0	0	0	0	0	0	0	0	0
15	0	111	199	240	251	252	222	199	142	80	1696
16	87	147	171	202	251	240	213	151	101	68	1631
17	75	122	158	262	223	263	223	203	143	77	1749
18	0	84	215	254	259	261	247	201	142	77	1740
19	85	147	198	214	181	31	209	86	31	14	1196
20	83	98	152	204	142	96	168	180	117	79	1319
21	87	149	205	225	249	246	247	190	145	76	1819
22	88	150	215	187	183	248	240	196	133	65	1705
23	89	154	207	235	250	253	240	196	139	76	1839
24	89	151	206	244	251	252	239	197	139	75	1843
25	85	142	195	227	243	230	240	138	144	73	1717
26	90	156	219	258	261	262	257	239	198	136	2076
27	42	97	162	217	251	258	227	170	183	93	1700
28	42	96	158	215	234	260	112	188	156	106	1567
29	4	9	10	16	23	63	186	150	192	93	746
30	45	88	186	229	184	254	254	193	157	106	1696
MEAN	66	118	183	231	229	225	238	204	154	85	

APPENDIX 3

TOTAL MONTHLY SOLAR INSOLATION AVAILABLE

in the

COLLECTOR PLANE

for

SELECTED SITES

Average Monthly Insolation in the Collector Tilt Plane

(BTU/Ft^2)

Month / Station	J	F	M	A	M	J	J	A	S	O	N	D
San Franciso, CA	24323	37400	53879	55992	64193	67678	69787	70729	57672	53316	40911	30313
Phoenix, AZ	39871	52122	62978	63920	65494	65831	64696	66609	63536	55989	48600	42363
Fresno, CA	34054	36991	53541	55731	64070	67583	69650	70408	57337	52792	40244	29791
Los Angles, CA	32190	42031	59161	58030	55288	64978	69230	65659	59884	50416	47035	42406
Boulder, CO	38163	41840	54557	55670	58885	56662	58596	56188	59111	50312	37437	37876
Grand Junction, CO	29837	39828	49546	61565	63943	71564	66424	66734	65247	56851	40720	37200
Miami FL,	47120	40984	55763	57311	50893	50151	49323	47156	44000	46034	39111	41861
Tallahassee, FL	40637	40066	46206	49738	55298	50670	54836	50638	35030	48311	36903	35553
Honolulu, HI												
Boise, ID	23385	35621	47750	63096	63286	66870	67559	65414	50177	45829	27405	26142

Average Monthly Insolation in the Collector Tilt Plane

(BTU/Ft^2)

Station \ Month	J	F	M	A	M	J	J	A	S	O	N	D
Indianapolis, IN	24490	29170	35955	35184	51220	50430	51131	44250	40955	42905	23174	21318
Dodge City, KS	44236	42362	55013	56744	53301	61736	64009	62779	57572	52670	39459	37396
Lake Charles LA												
Caribou, ME	26757	39056	45061	35566	47458	44092	42341	47364	41191	26577	23319	22905
Columbia, MO	26310	35375	43145	40230	54004	49947	59360	46665	40440	42369	27870	26685
Great Falls, MT	27513	32997	44167	44450	50463	57673	56510	57968	43653	40632	28659	26049
Raliegh, NC	32416	34897	38814	53875	48622	50081	52389	51478	46942	51280	26811	28669
Bismark, ND	31620	31145	45815	42965	52731	54882	62128	60229	50179	41429	28752	31561
Omaha, NE	33826	37153	45954	48426	51463	53615	58198	54312	43933	42081	32065	30011
Albuquerque, NM	43478	49999	62311	65419	69031	68005	69215	68226	61877	59900	49425	44954

Average Monthly Insolation in the Collector Tilt Plane

(BTU/Ft^2)

Station \ Month	J	F	M	A	M	J	J	A	S	O	N	D
Ely, NV	37463	41593	57048	61208	66477	67301	66542	68567	66321	57807	43233	40269
Las Vegas, NV	38304	53909	54806	69083	68775	70077	68418	69307	63757	58769	48388	42187
Medford, OR	19786	25564	42217	50681	60815	59844	68447	61562	48964	41237	24810	17946
Pittsburgh, PA												
Brownsville, TX												
El Paso, TX	46119	52315	63484	72224	71131	65940	67181	66314	63247	65994	53899	46454
Midland, TX	44369	50107	61708	67673	63972	68347	66604	62494	58905	53642	33768	43287
Salt Lake City, UT	25669	38561	47765	56181	63022	63587	67007	69113	63122	49413	34740	32461
Sterling, VA												
Burlington, VT	24590	32785	37374	32704	47458	43194	41476	46392	41996	28684	23766	20814

Average Monthly Insolation in the Collector Tilt Plane

(BTU/Ft^2)

Station \ Month	J	F	M	A	M	J	J	A	S	O	N	D
Washington, DC	24730	37187	39536	46587	48383	48128	52146	51727	44965	39030	31380	22451
Nashville, TN	22351	36460	38380	46565	46683	51673	51939	52427	45103	41713	29881	26456
Seattle-Tacoma, WA	12176	19441	30691	44553	53372	51463	55578	50024	41090	28479	18613	12249
Madison, WI	23006	35114	39516	38600	49006	52312	58167	43581	46793	36627	24517	26502
Lander, WY	39403	41451	55416	59711	63087	64622	61861	61894	58730	53144	36960	35120
Atlanta, GA	29186	40672	49169	51693	50473	54867	51071	53589	44774	48810	42908	37510

APPENDIX 4

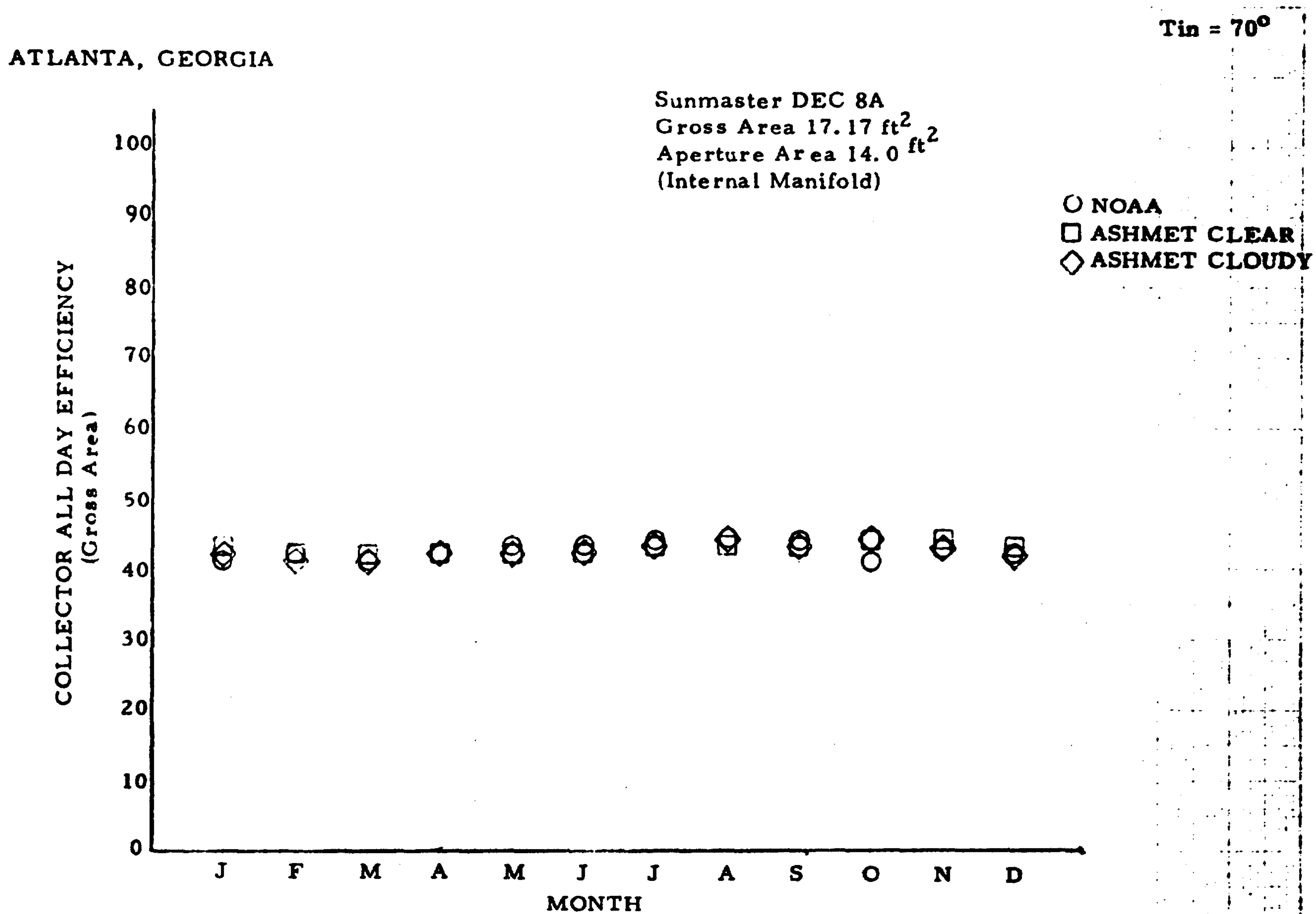
ALL - DAY COLLECTOR EFFICIENCIES BASED

on

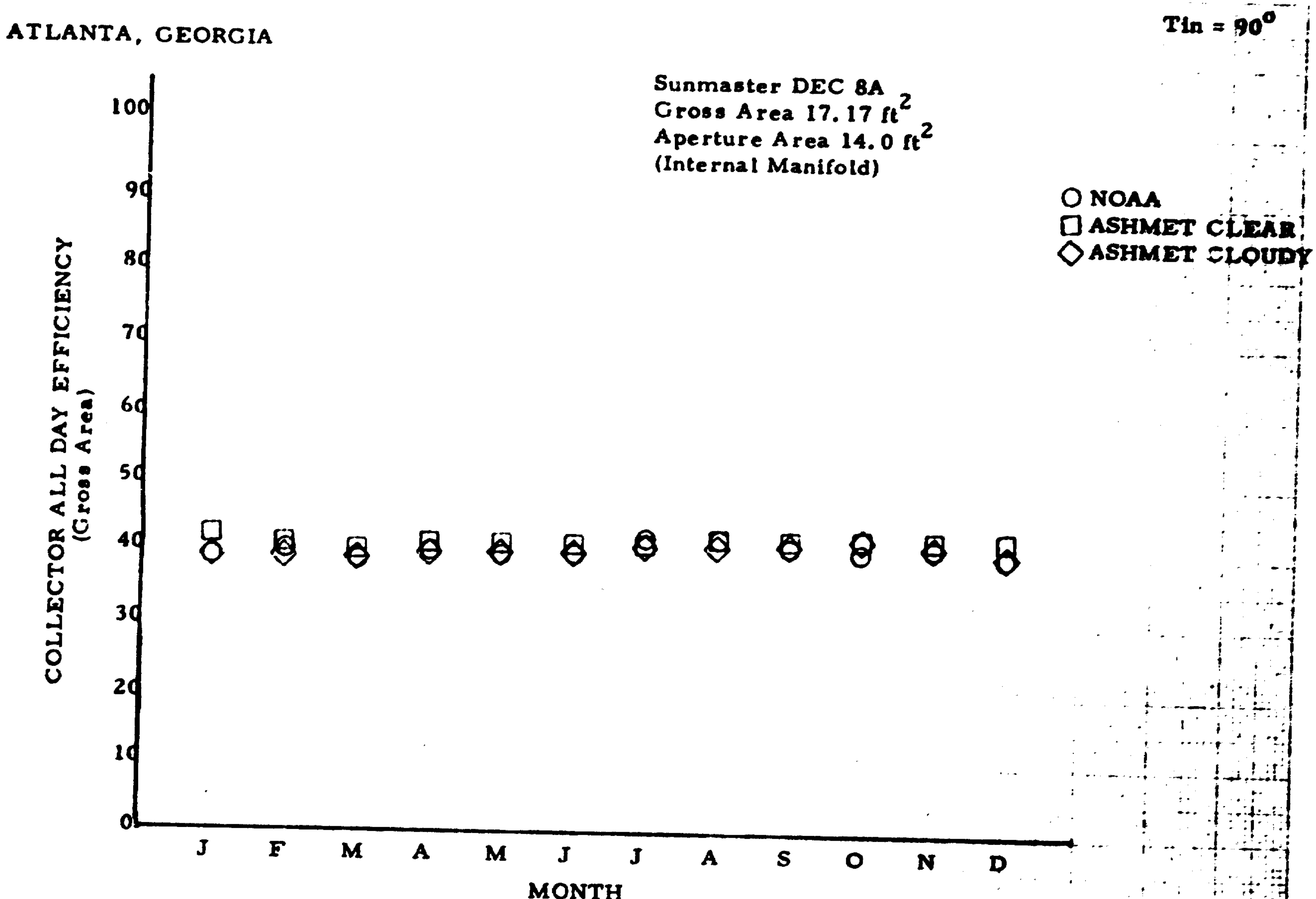
ACTUAL NOAA INSOLATION COMPARED

to

ASHMET CLEAR AND CLOUDY DAYS



ALL DAY COLLECTOR EFFICIENCY UTILIZING VARIOUS INSOLATION DATA



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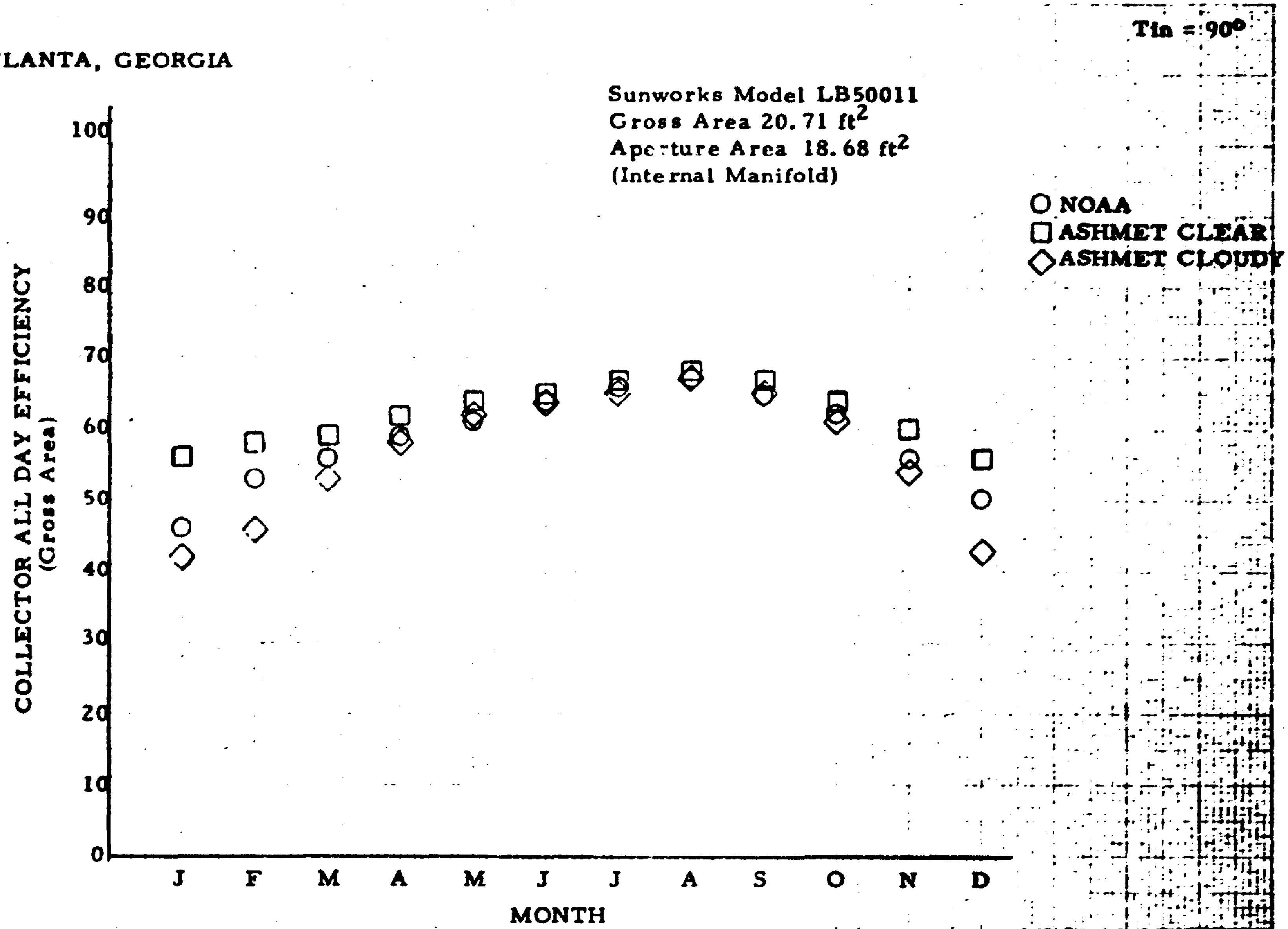
ATLANTA, GEORGIA



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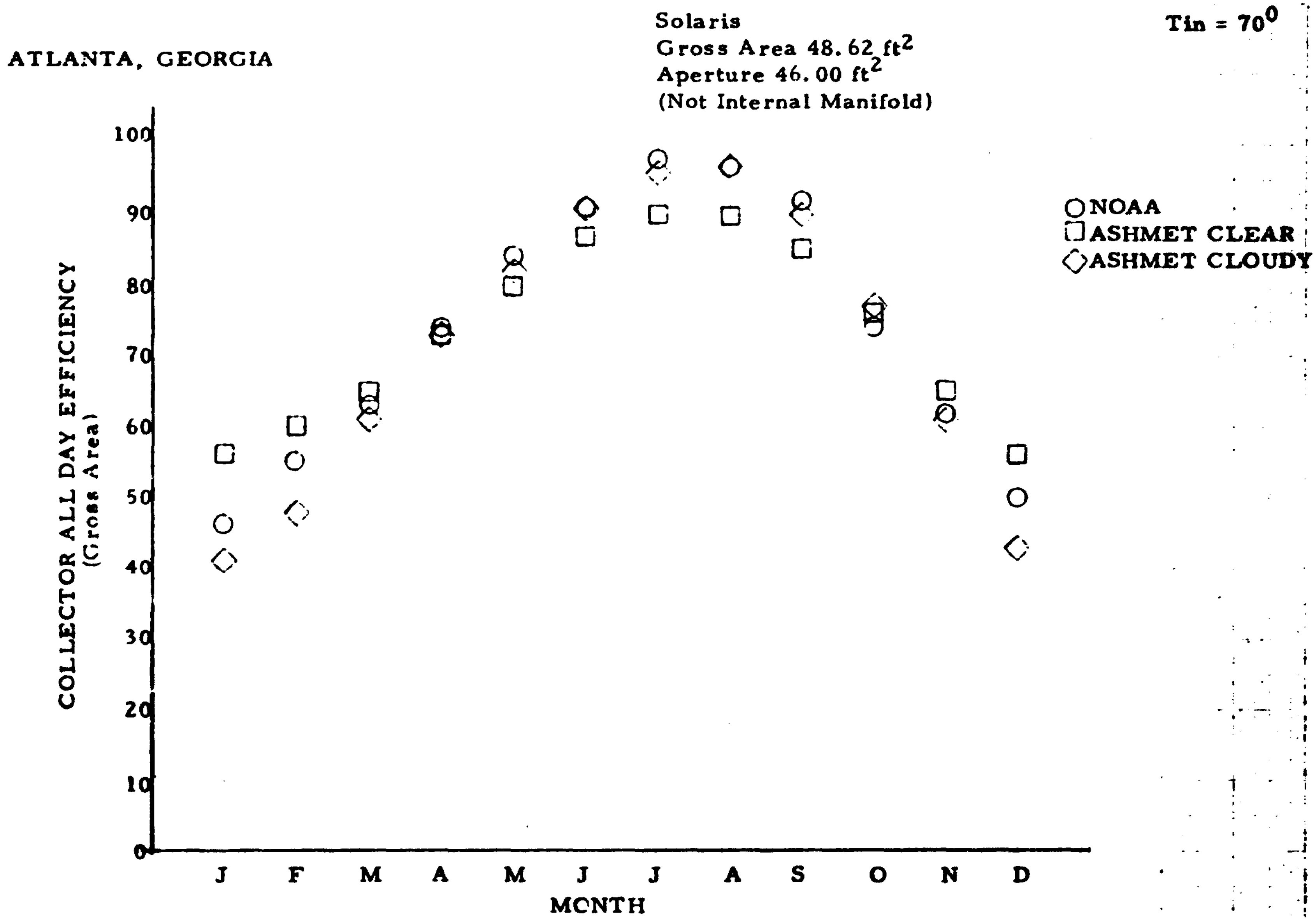

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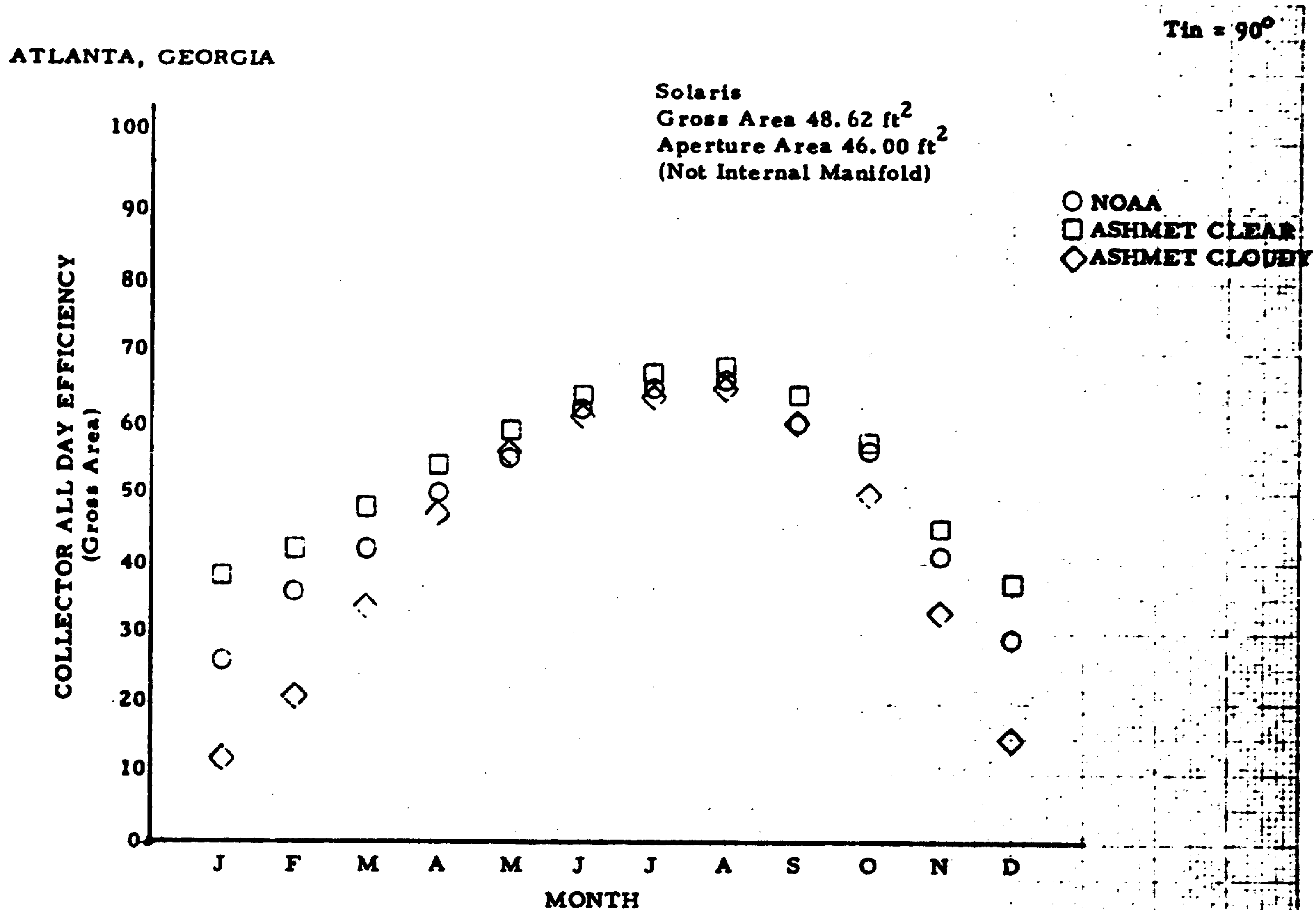

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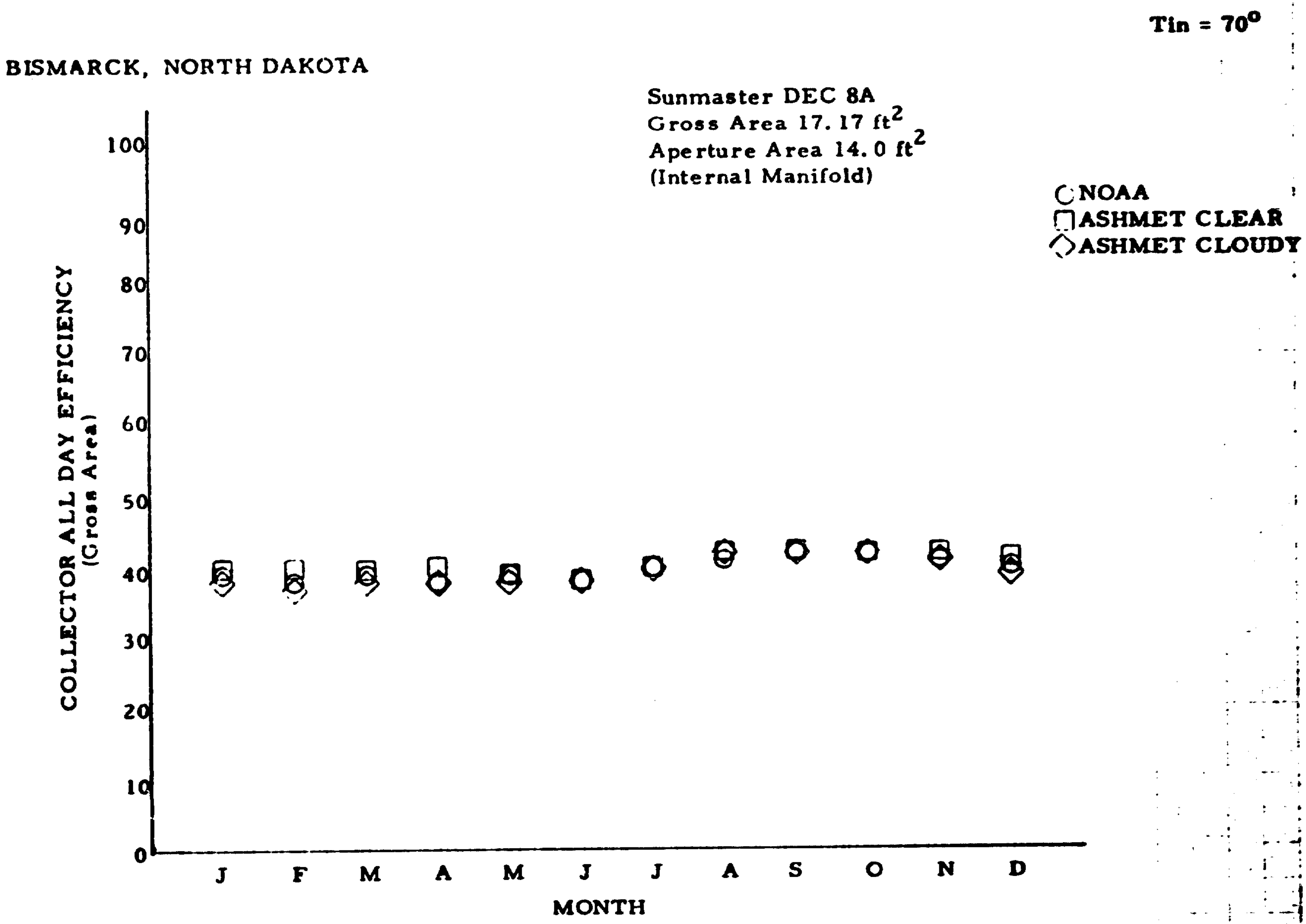

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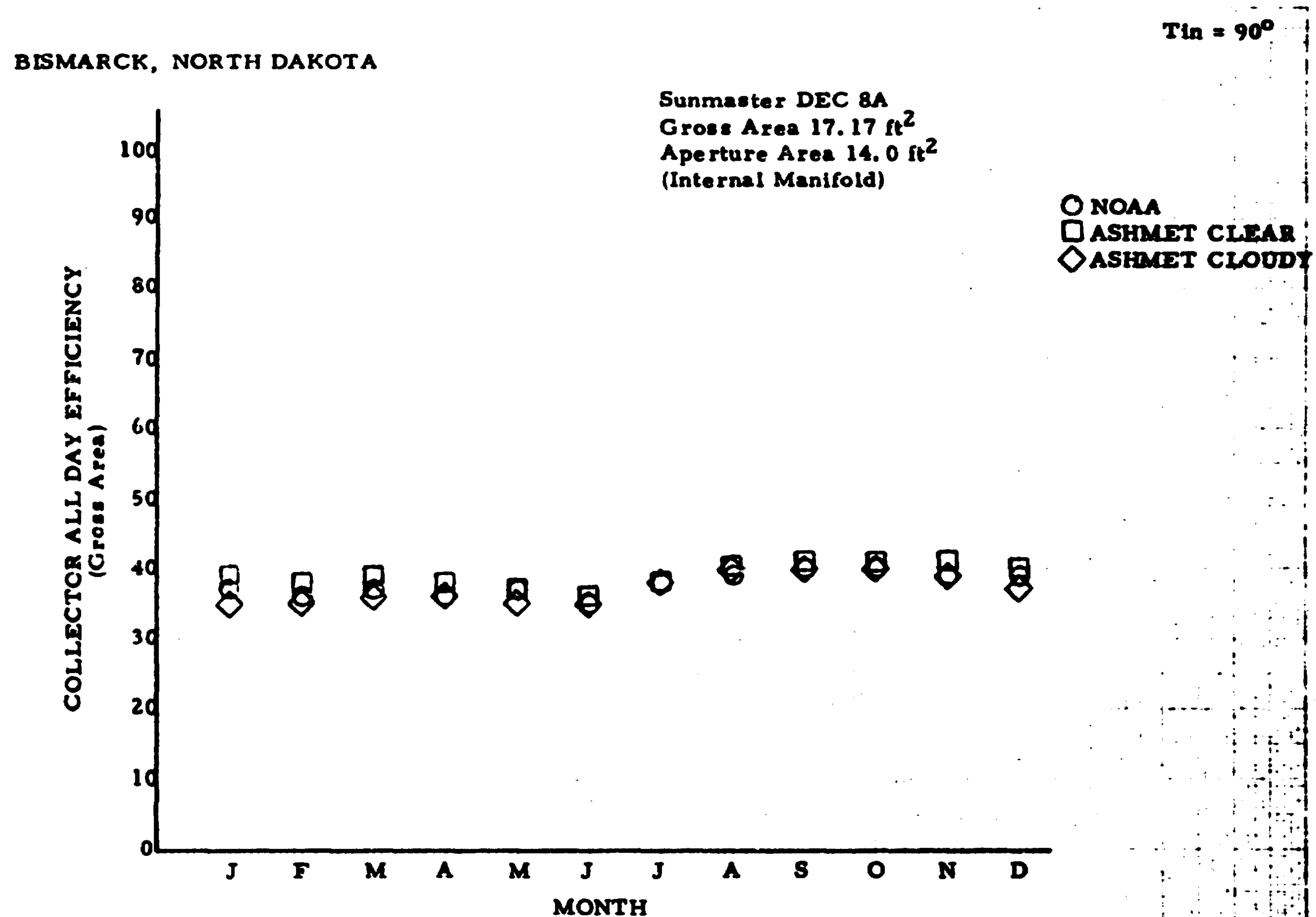

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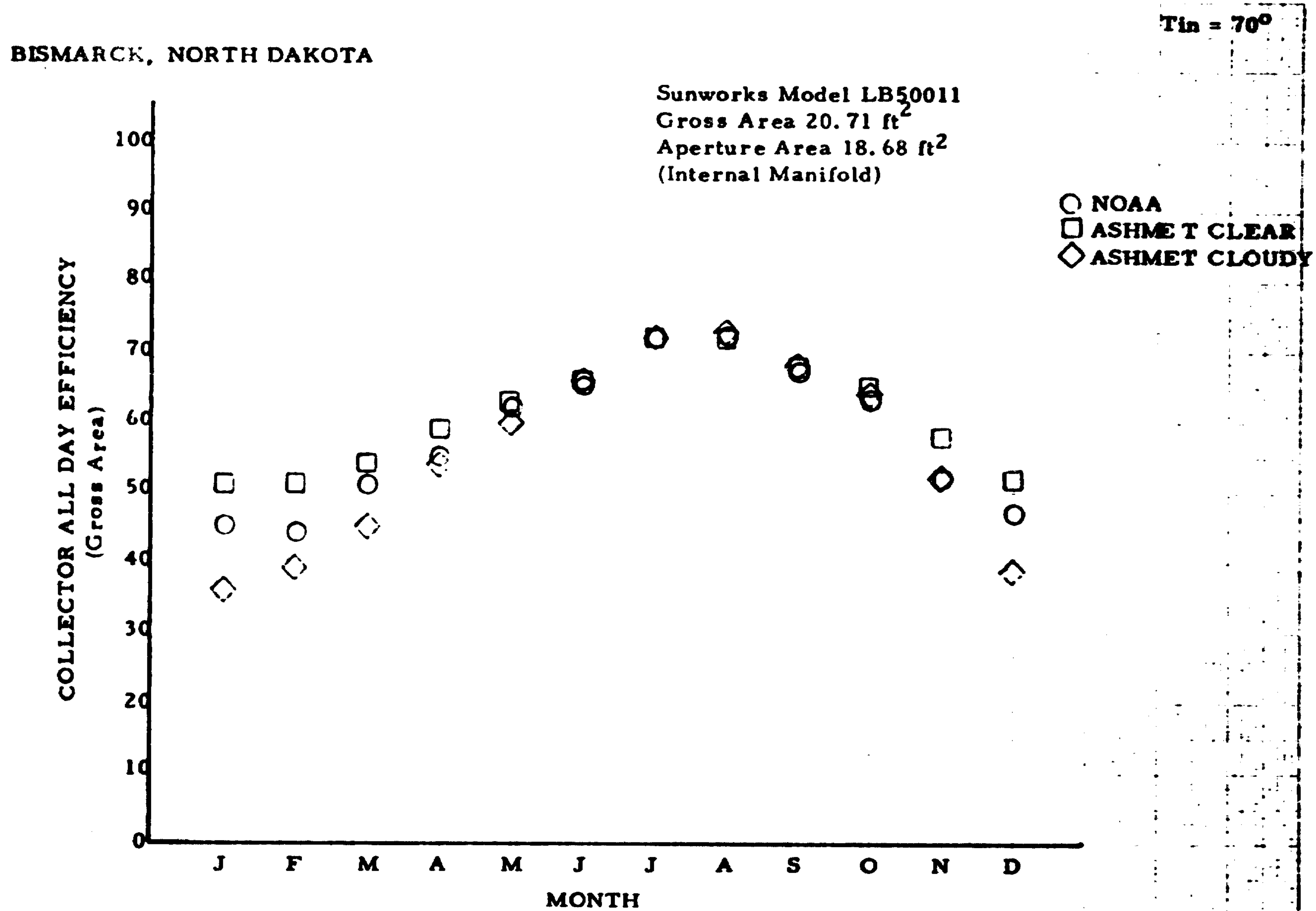

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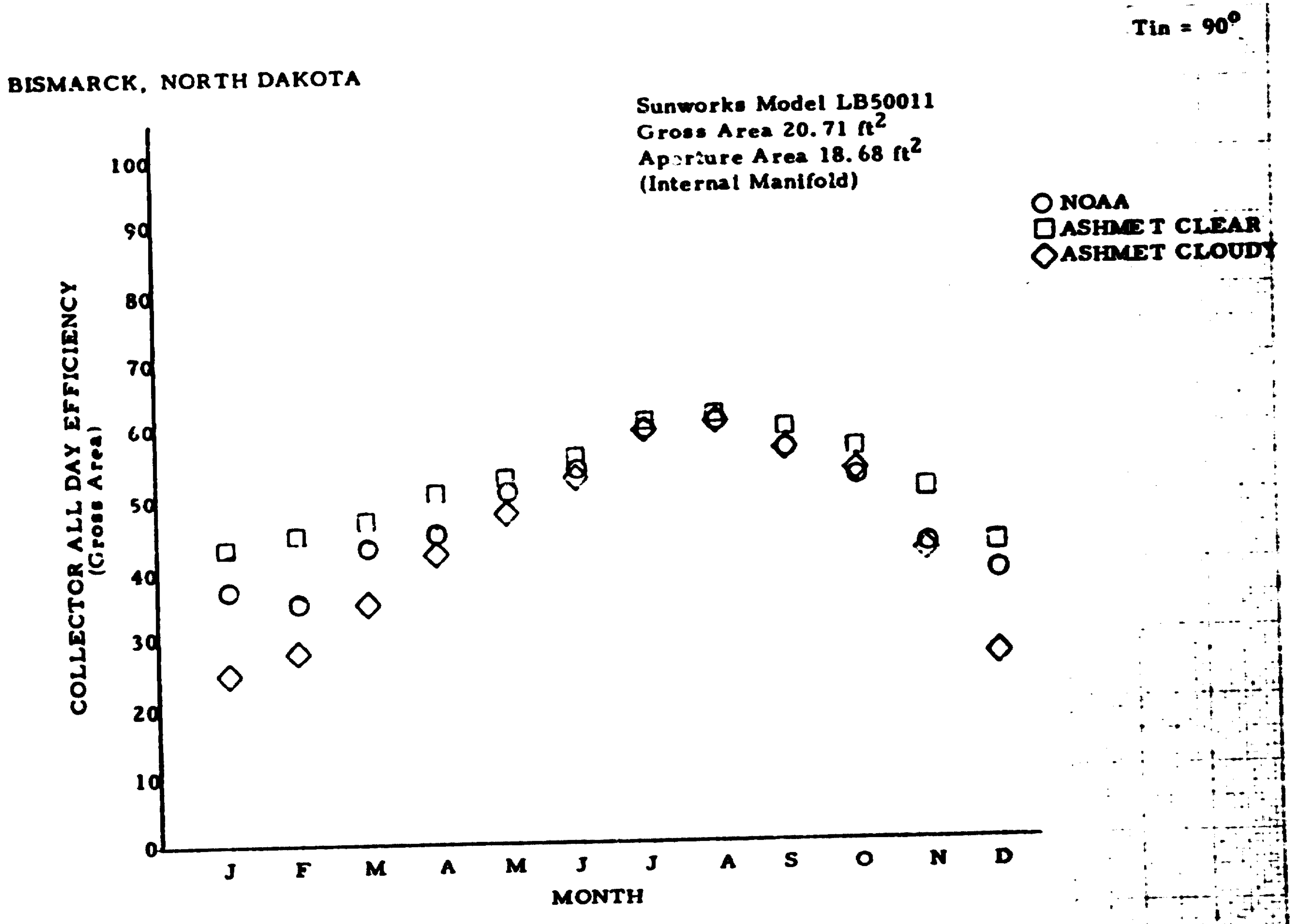

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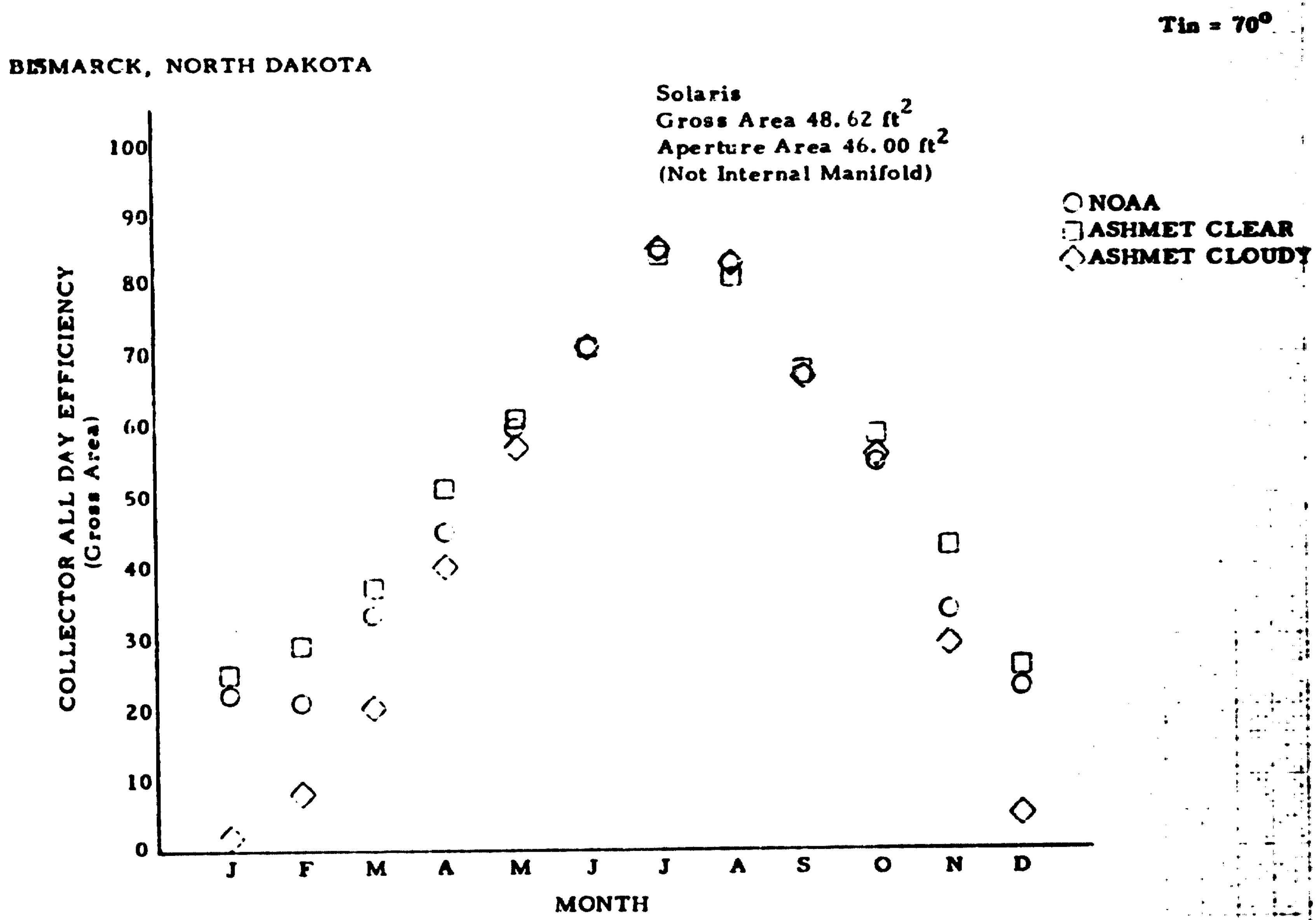

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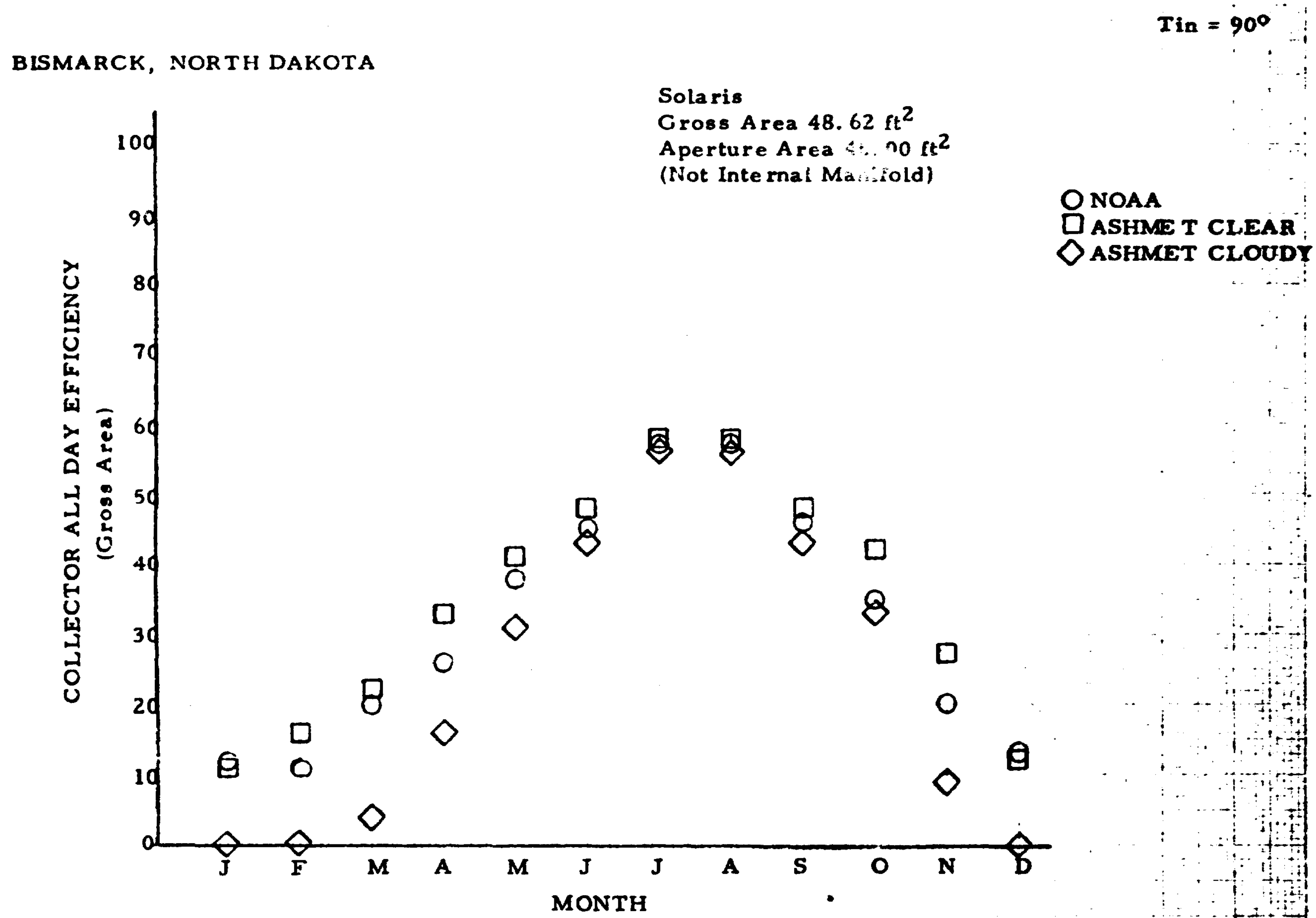

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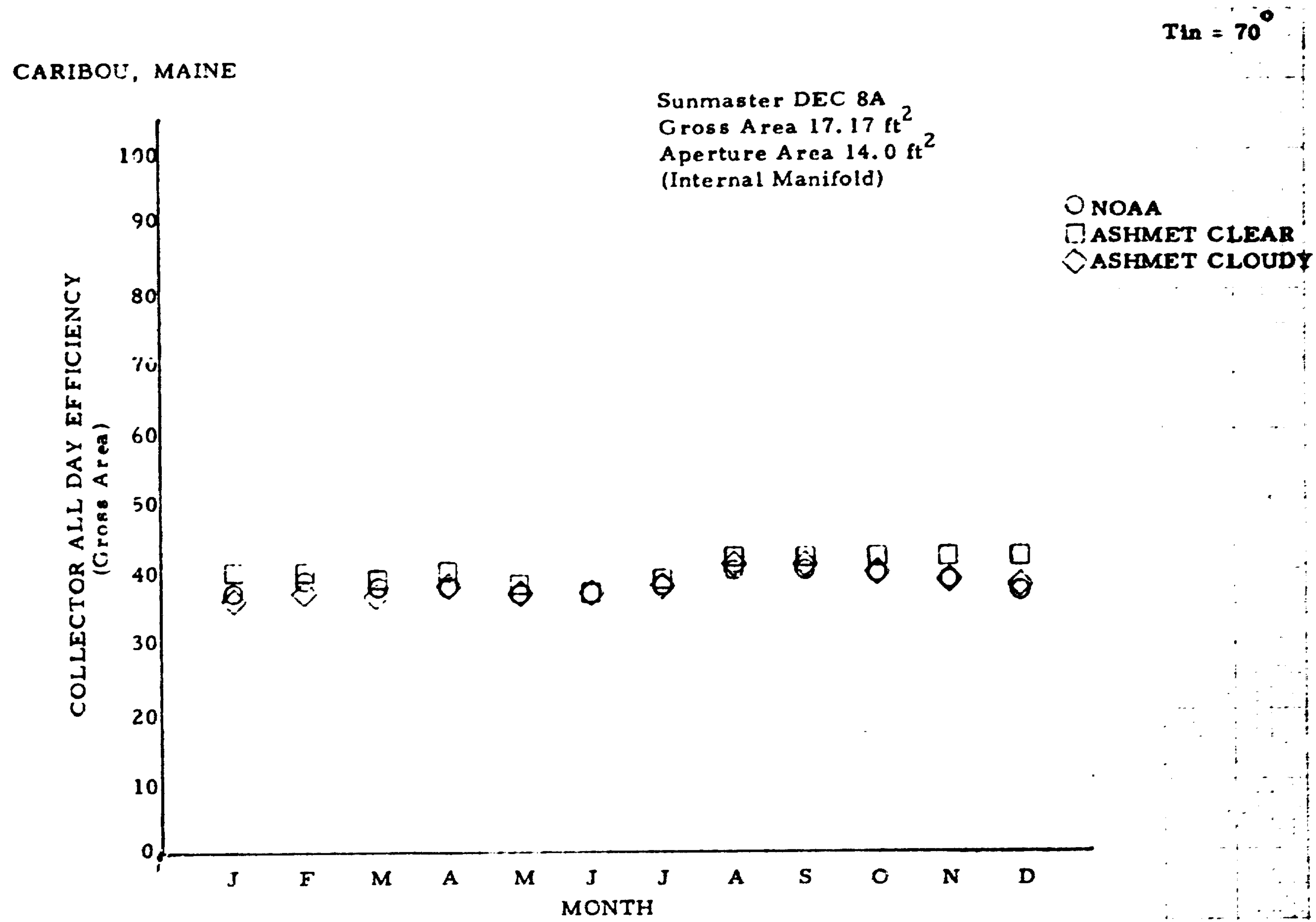

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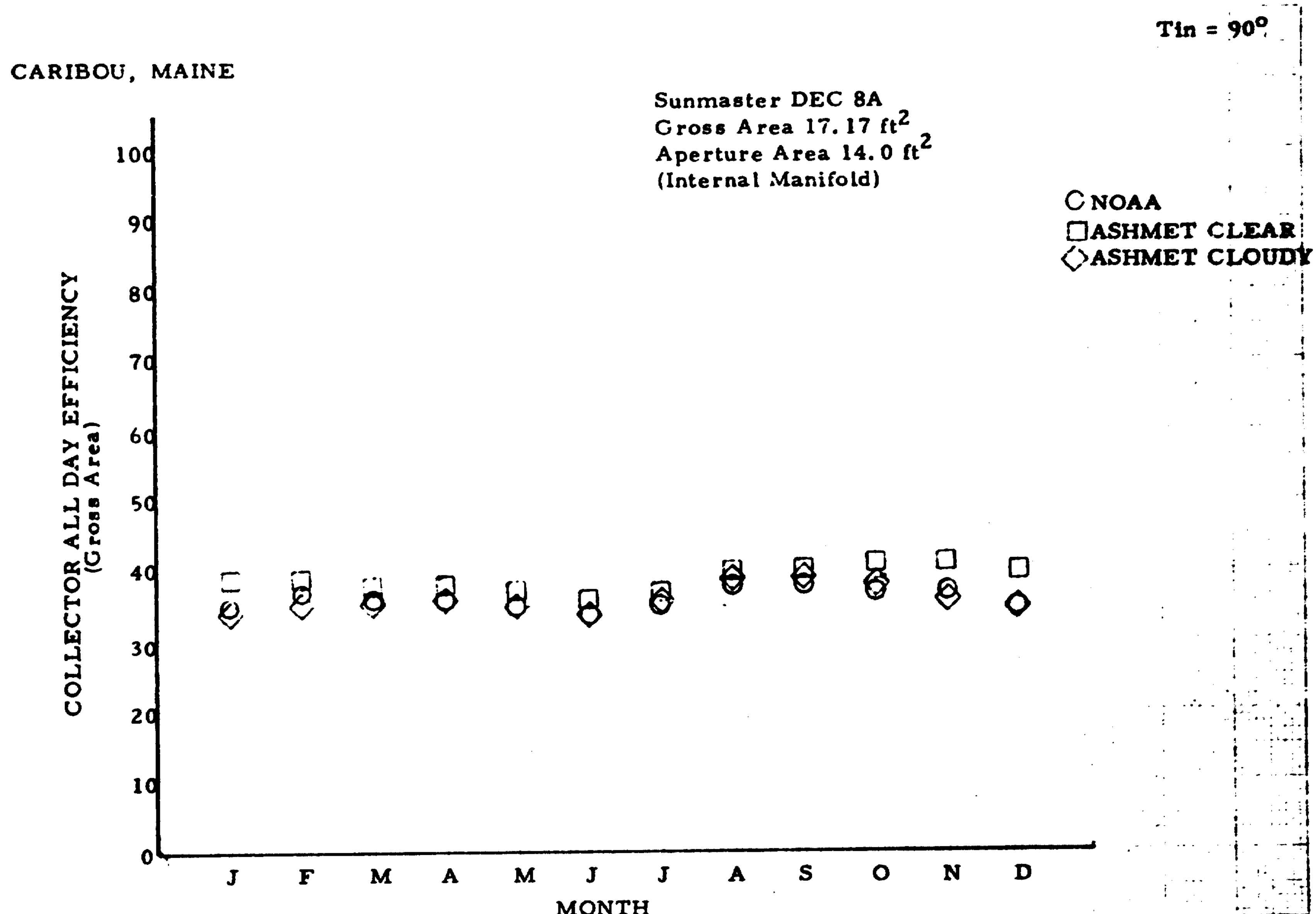

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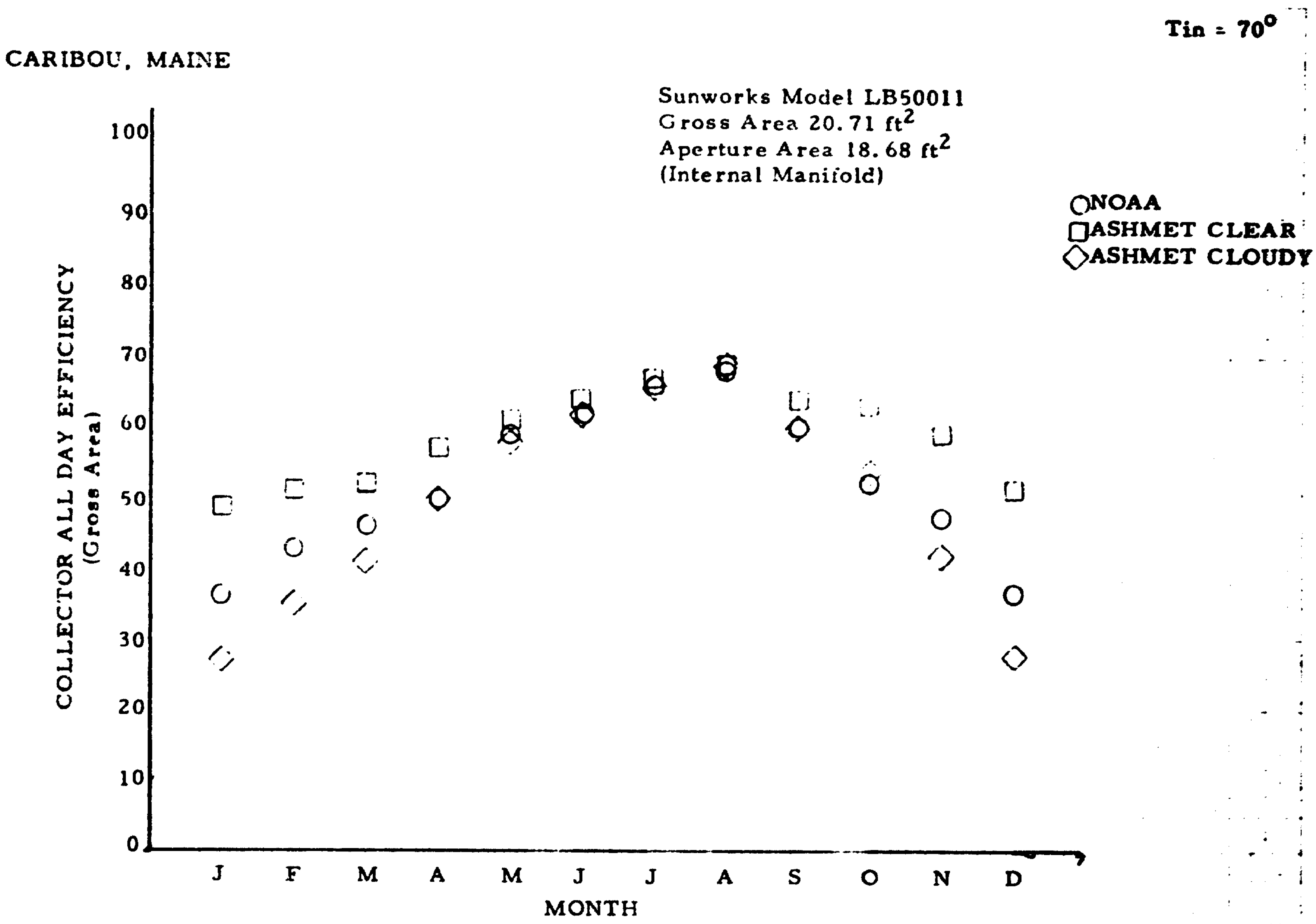

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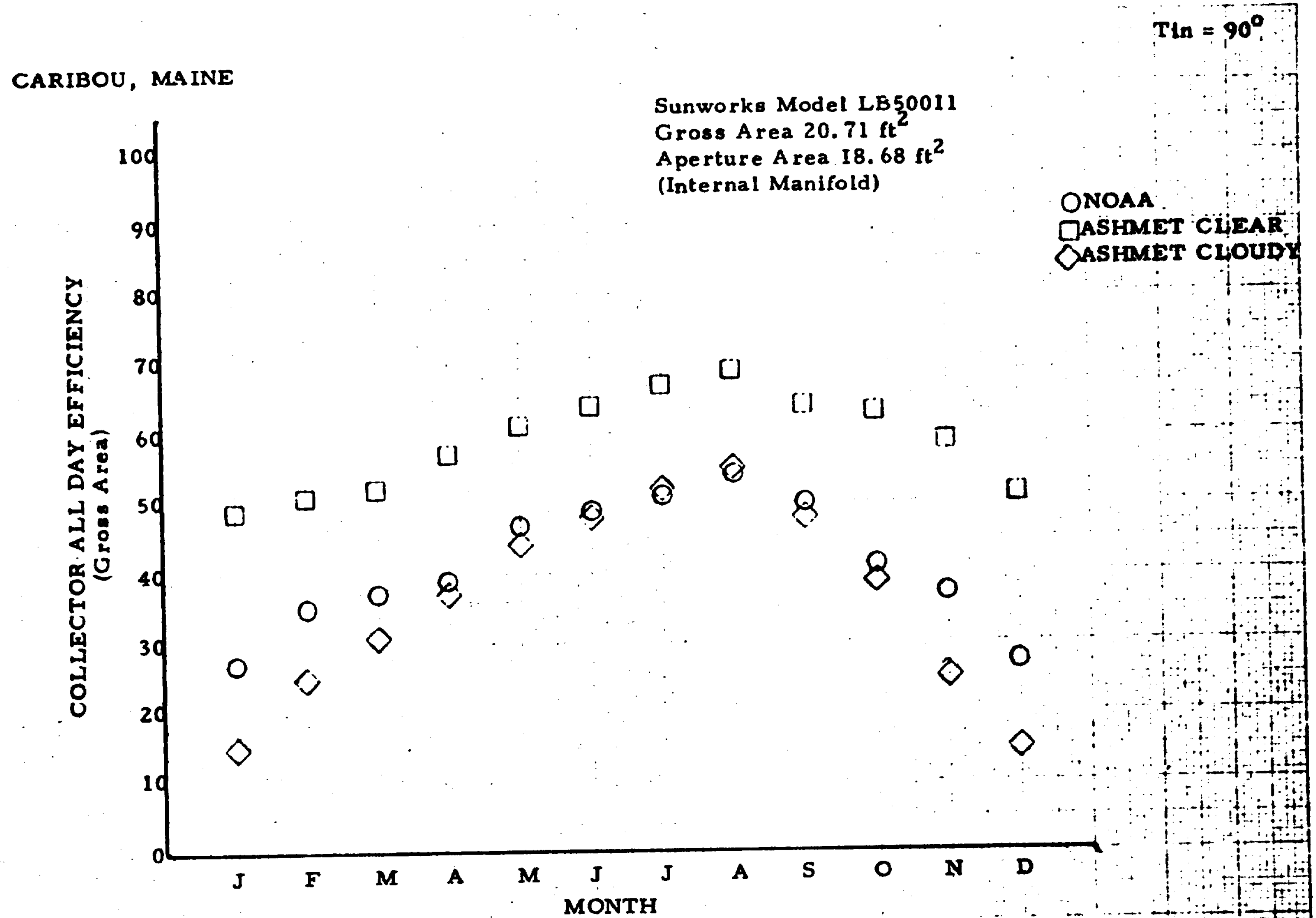

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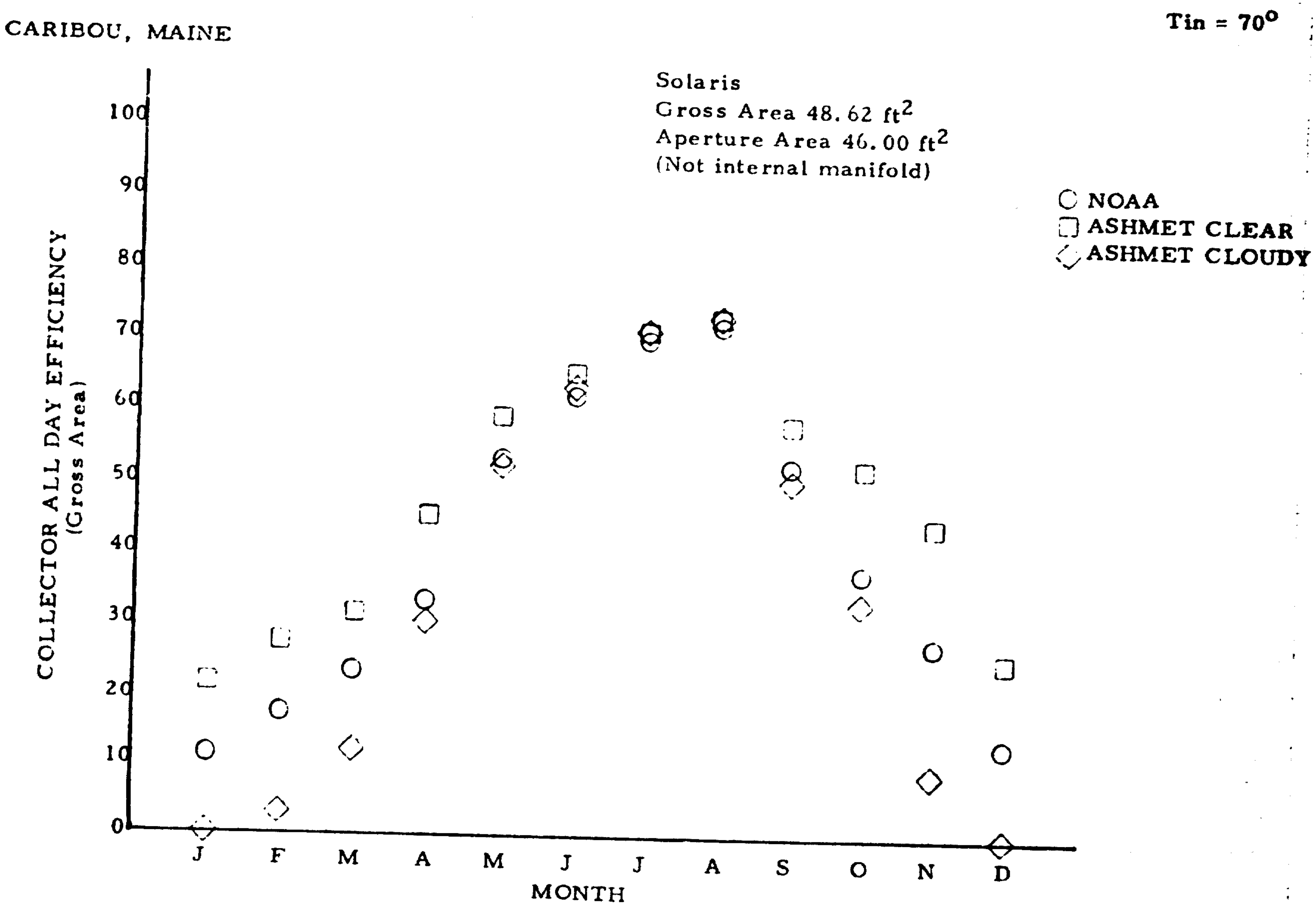
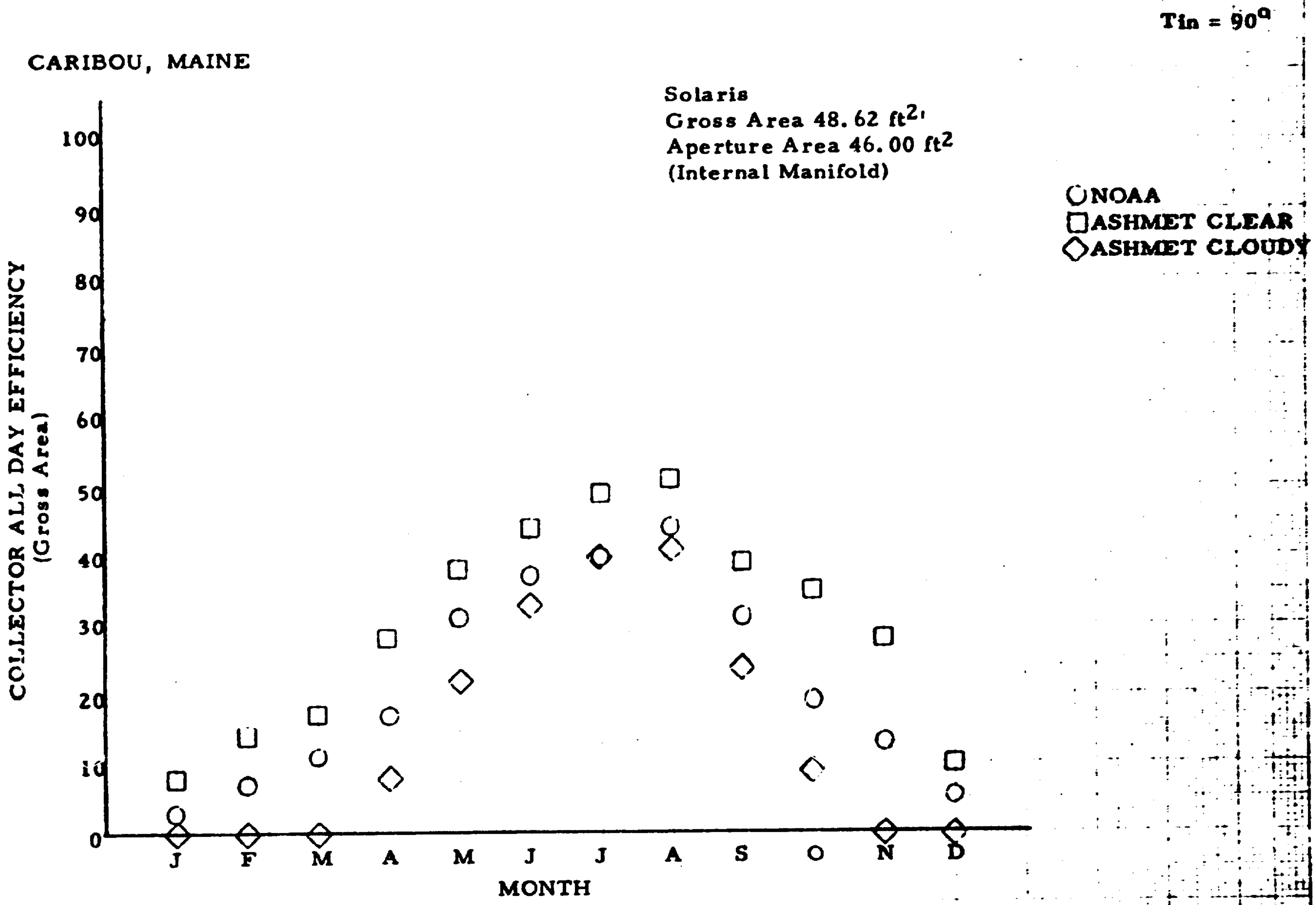
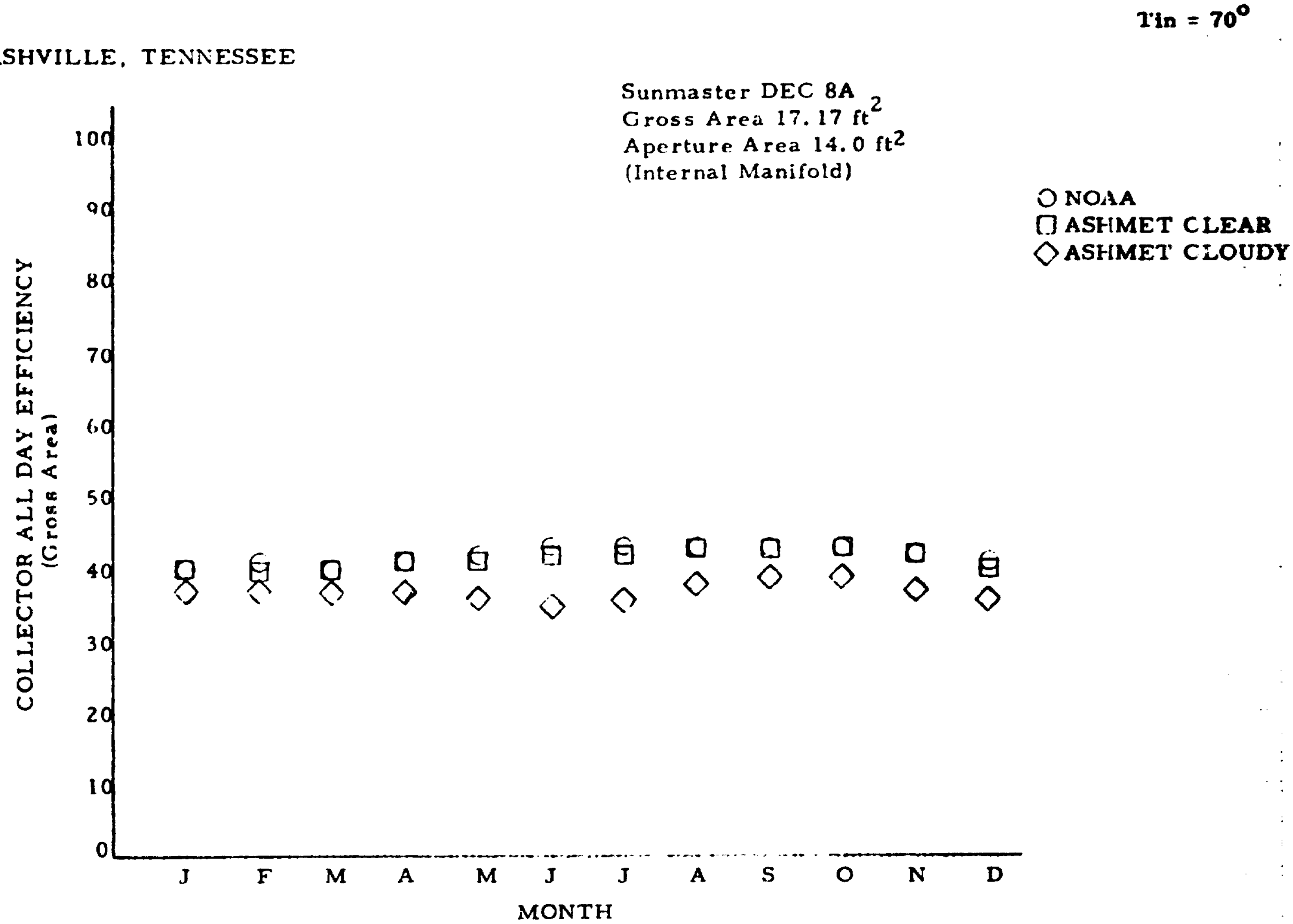


, ALL DAY COLLECTOR EFFICIENCY UTILIZING VARIOUS INSOLATION DATA



ALL DAY COLLECTOR EFFICIENCY UTILIZING VARIOUS INSOLATION DATA

NASHVILLE, TENNESSEE



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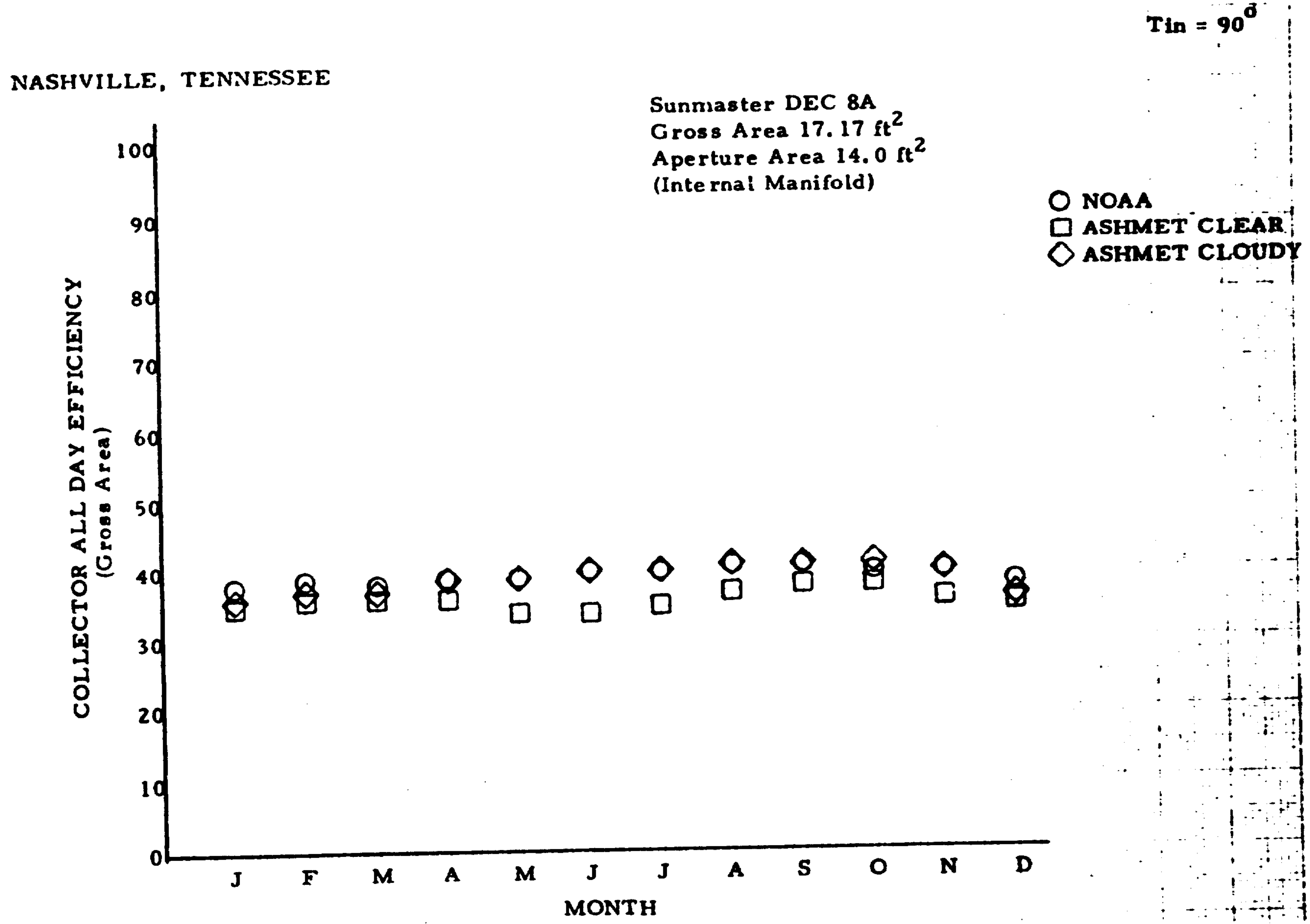

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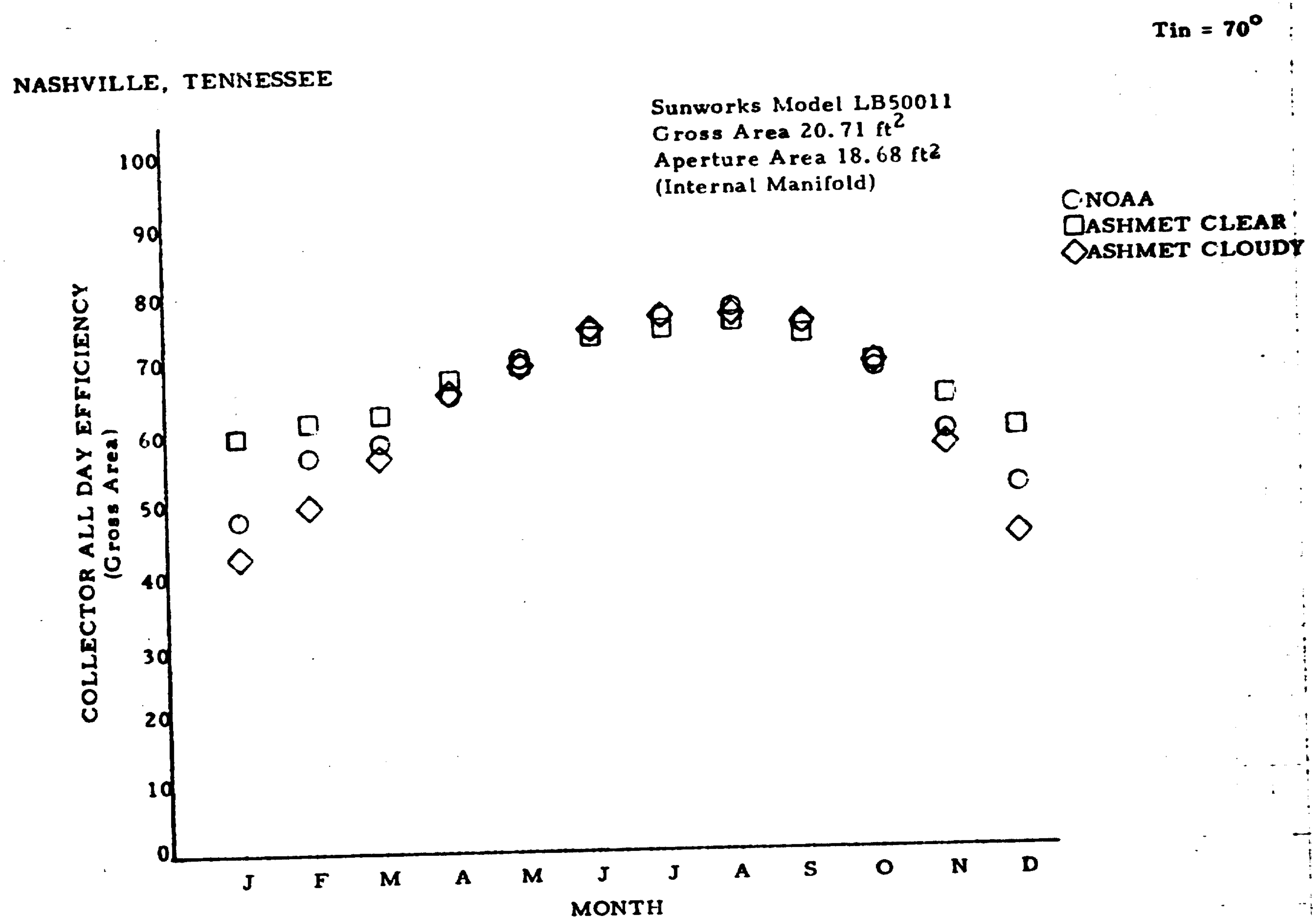

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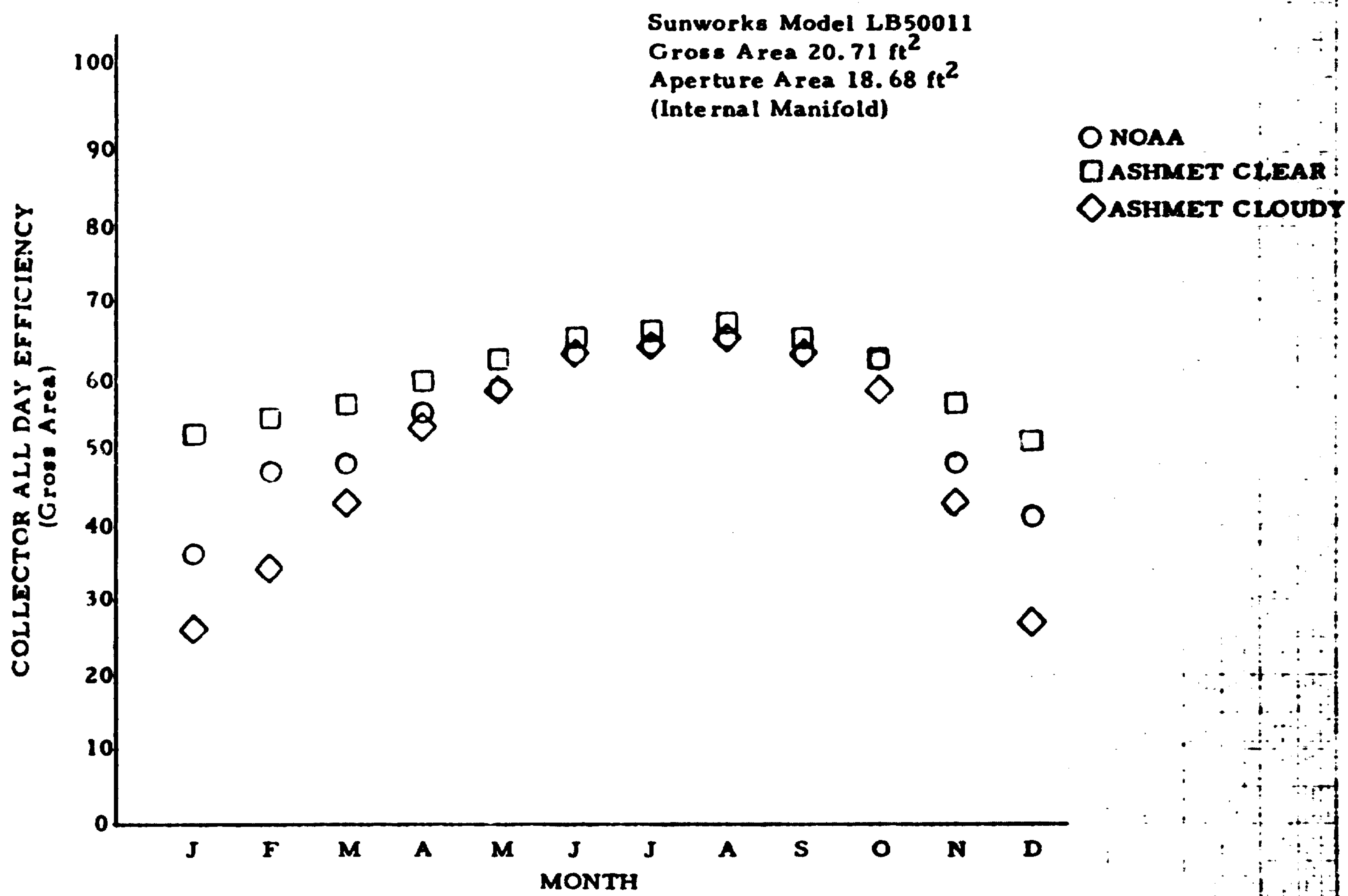
NASHVILLE, TENNESSEE

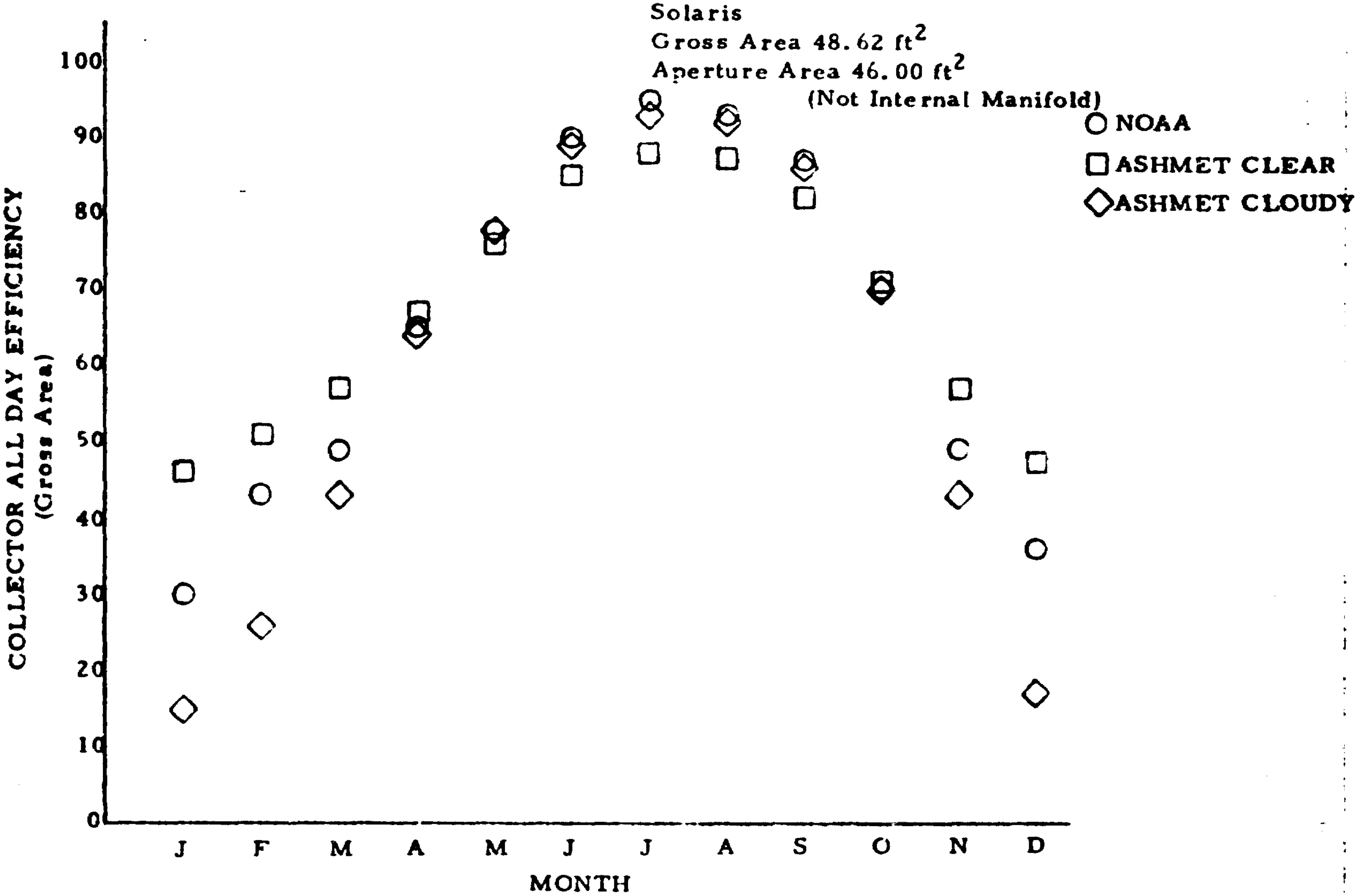
Tin = 90°



ALL DAY COLLECTOR EFFICIENCY UTILIZING VARIOUS INSOLATION DATA

NASHVILLE, TENNESSEE

Tin = 70°



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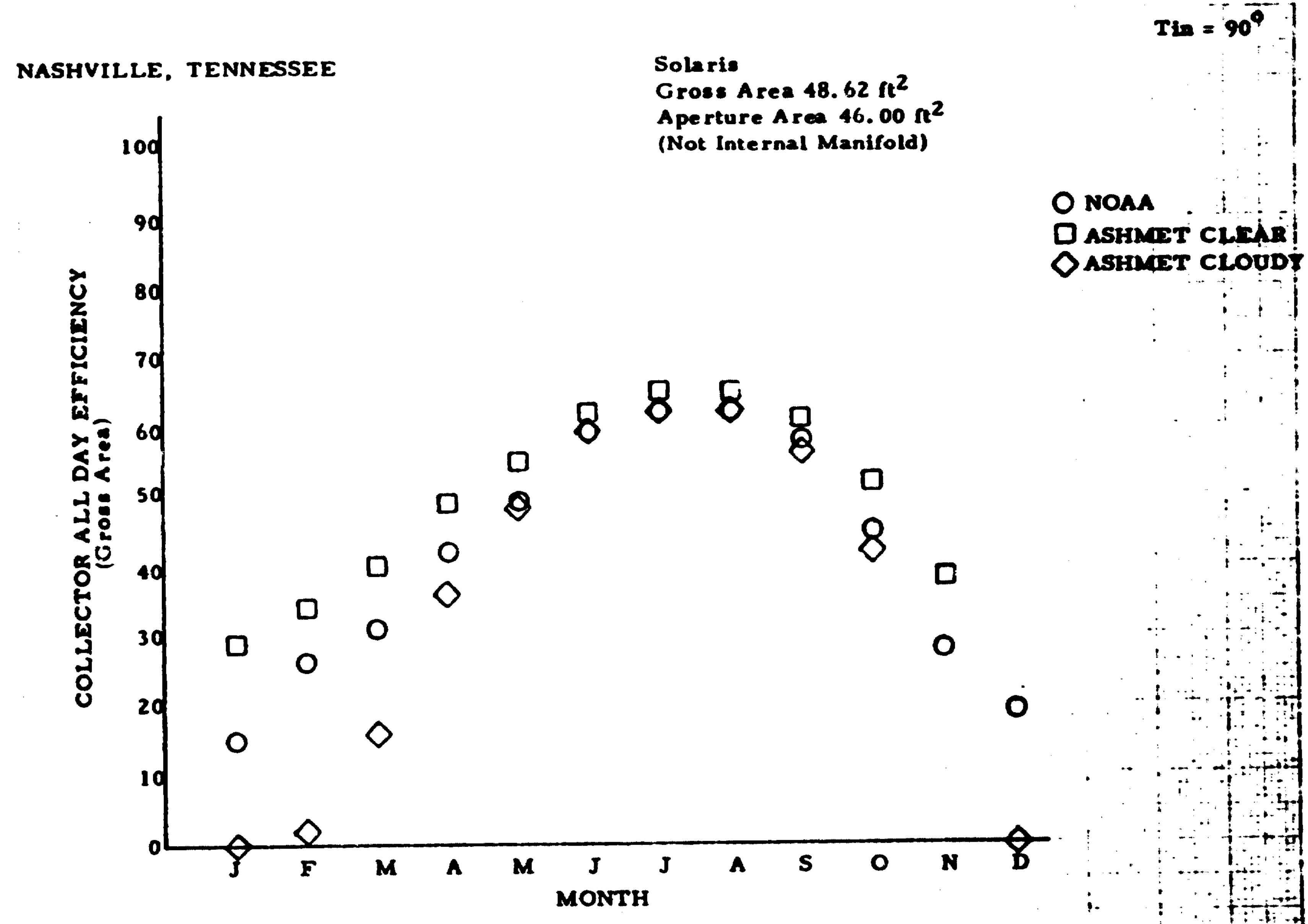

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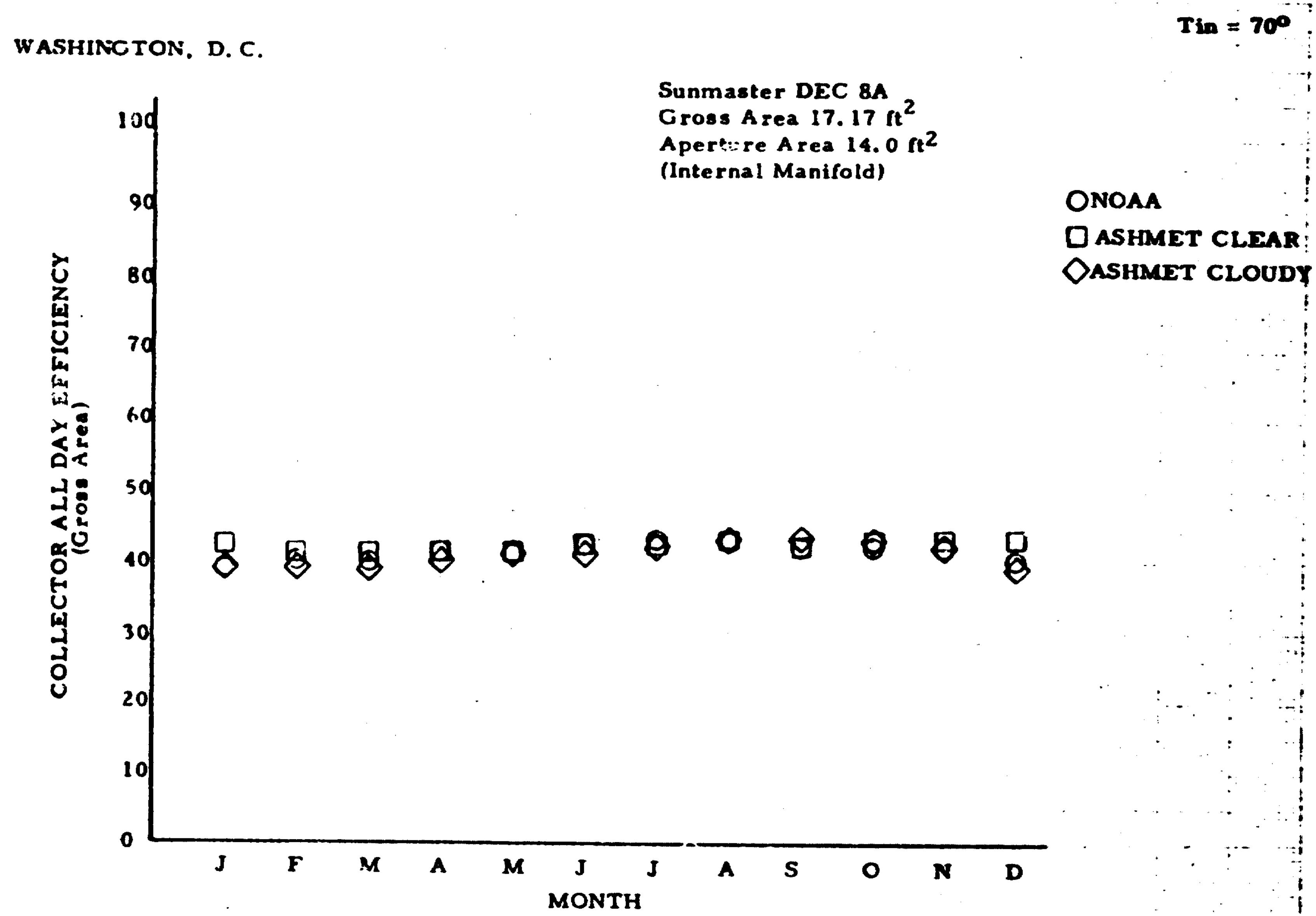

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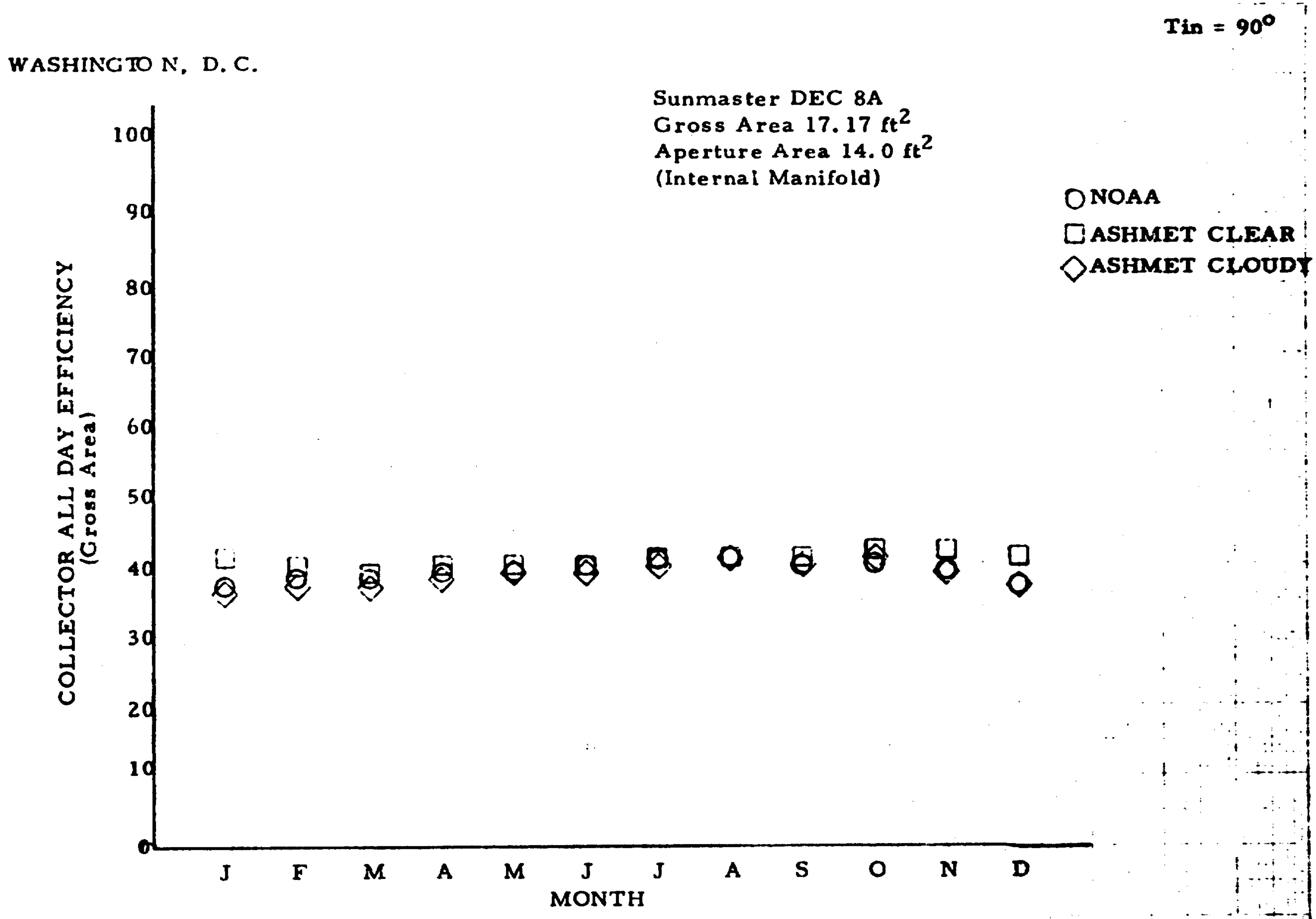
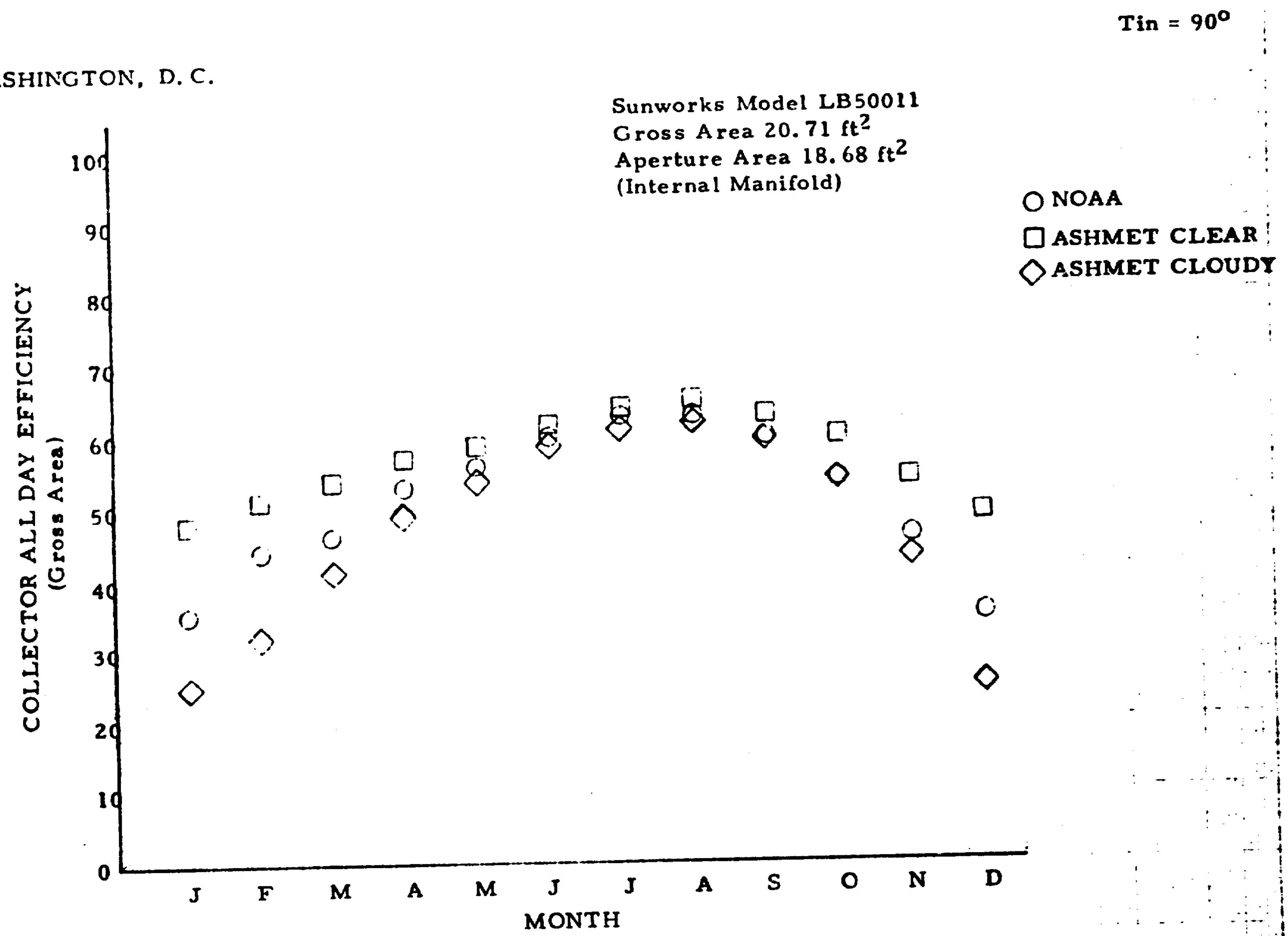


ALL DAY COLLECTOR EFFICIENCY UTILIZING VARIOUS INSOLATION DATA

WASHINGTON, D.C.



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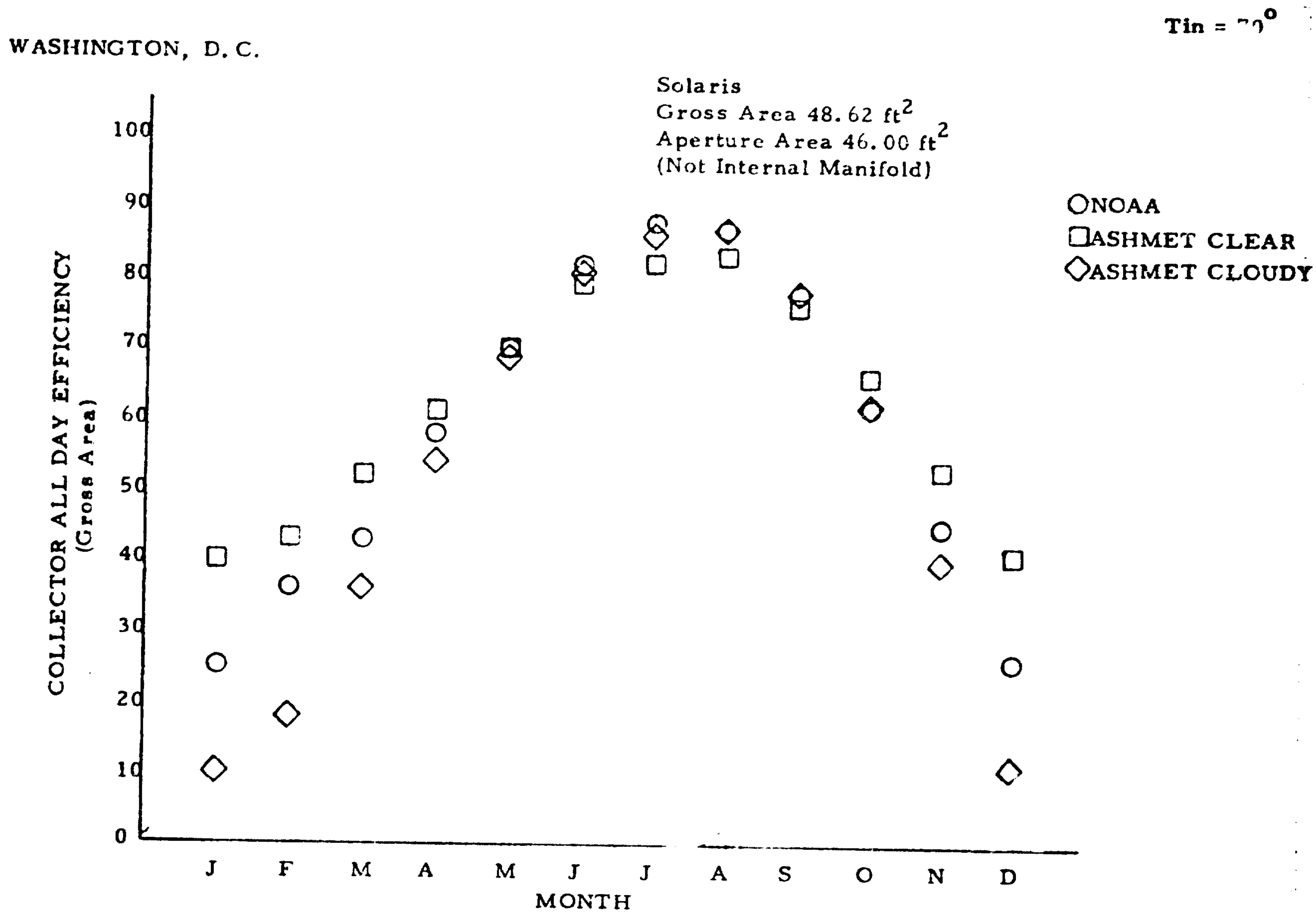

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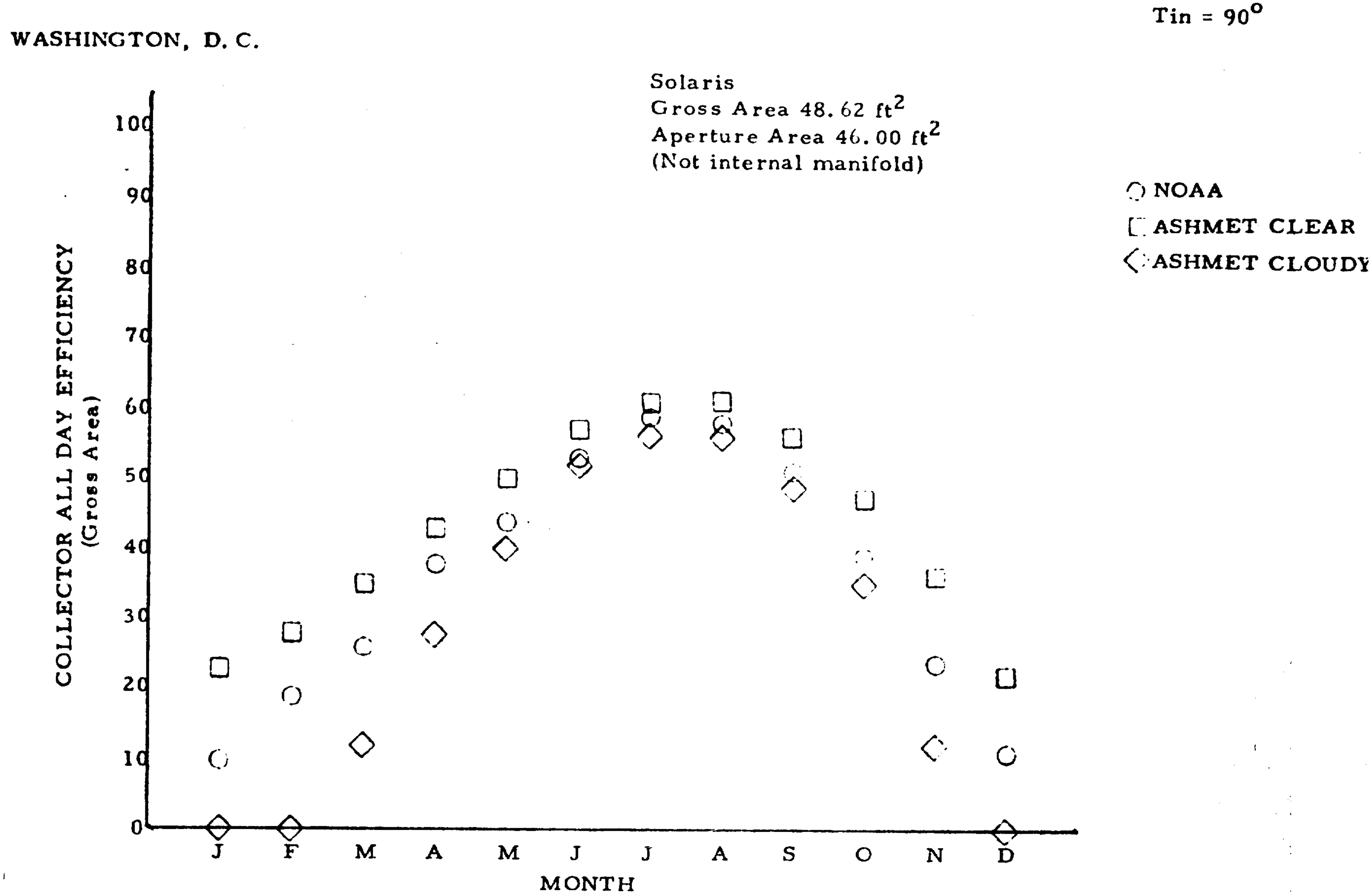

ALL DAY COLLECTOR EFFICIENCY UTILIZING VARIOUS INSOLATION DATA