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STUDIES ON DAYLIGHT AVAILABILITY

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DAYLIGHT AVAILABILITY

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Synopsis

To utilize solar energy advantageously for the lighting and heating of buildings, additional data are required on the availability of daylight and solar heat for variously oriented surfaces, and for numerous geographical locations. This study presents data on daylight availability at Ann Arbor, Michigan, for the period March, 1953, to March, 1954, and correlates these data with theoretical considerations and climatological data as recorded by the U. S. Weather Bureau.

Introduction

Only meager data are available on the variability of exterior daylight intensities. References on this subject are widely scattered[1,2,3,5,6] and only a few of these[3,5,6] are available as illumination literature. To afford additional data in this direction, a study was undertaken on the availability of daylight at Ann Arbor, Michigan, for a period to include all seasons, these findings then correlated with theoretical considerations and climatological data as recorded by the U. S. Weather Bureau. Measurements recorded are for the period March, 1953, to March, 1954.

Recording Equipment

All measurements were made with a group of five photocells (Fig. 1) mounted on the roof of the Daylighting Laboratory, The University of Michigan, so that an unobstructed view of the sky could be obtained, the cells facing north, south, east, west, and toward the zenith. The supporting shield, painted flat black, reduced the light reflected from the "ground" to a minimum of approximately four per cent.

The photoelectric cells were model 856, as supplied by the Weston Electrical Instrument Corporation.[4] Each cell was equipped with a Viscor filter to provide it with the same spectral sensitivity as the human eye, and was placed in a water-tight case. A metallic film filter and depolished flashed opal disc were sealed in place over the face of each cell.

A multipoint Speedomax Recorder, with appropriate shunts, was used for the recording. Each of the five circuits was provided with five shunts so that the Recorder response could be varied as the photocell response varied. The values of the shunts and the density of the metallic film filter for each cell were selected so that the Recorder response was directly proportioned to the illumination incident on the cell.

The photocell case and the opal disc were so designed that the unit obeyed the cosine law of illumination. The maximum error of this corrected unit for undirectional illumination is four per cent, and that occurs for an angle of incidence of 80 degrees. For measuring the illumination due to a uniform hemispherical source, such as a sky having a uniform brightness, this photocell has an error of less than one per cent.

The photocells were initially calibrated and periodically checked with 1000- and 5000-watt incandescent lamps of known candlepower. For the higher intensities, corresponding to direct sunlight conditions, the photocells and metallic film filters were calibrated separatly and then combined to avoid errors due to lack of application of the inverse square law.

Data Recorded

Data were collected with weatherproof cells during most of the working days from March 1, 1953, to March 1, 1954, regardless of exterior weather conditions. The number of days in each month for which data are available are:

Month	Number of Days
March, 1953	18
April, 1953	20
May, 1953	19
June, 1953	22
July, 1953	22
August, 1953	20
September, 1953	19
October, 1953	17
November, 1953	20
December, 1953	21
January, 1954	19
February, 1954	21
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Tabulation of Data

Since the recorder provided approximately one intensity reading per photocell each minute, more data were collected on the recorder charts than could reasonably be analyzed for this study. Consequently, it was decided that footcandle readings for each photocell would be selected on a 15-minute-interval basis, from 8 a.m. to 5 p.m. each day. Such a tabulation gave the intensity of daylight, in footcandles, every 15 minutes, on north, south, east, and west vertical surfaces, and on a horizontal surface.

One aim of this study was to correlate the recorded intensities with the degree of cloudiness and percentage of possible sunshine as specified by the U. Weather Bureau. The nearest weather station to Ann Arbor is at Willow Run, whic records the degree of cloudiness but not the percentage of possible sunshine. The U. S. Weather Bureau indicates the degree of cloudiness as tenths of the entire sky, 0 to 3 tenths being clear, 4 to 7 tenths partly cloudy, and 8 to 10 tenths cloudy. These data were obtained for the entire year from the Weather Bureau Station at Willow Run.

An overcast sky is one for which the cloud formation is so dense that all vertical surfaces are equally illuminated. As the cloud density decreases, the sky brightness becomes non-uniform, and consequently the variation in vertical surface illumination with orientation of the surface becomes greater.

In an attempt to obtain some correlation between the measured intensities and the degree of cloudiness, the readings were classified on the basis of the ratio of maximum to minimum vertical surface illumination. The classes are as follows:

Class	Ratio $\frac{\text{Max}}{\text{Min}}$
A	1.0 to 1.5
B	1.5 to 2.5
C	2.5 to 3.5
D	> 3.5

May 5, 1953, was one of the days during which all four of these conditions existed. Figure 2 shows the variation of the illumination on the four vertical surfaces and on the horizontal surface, with the readings marked according to the above classification. The readings were plotted as recorded; no attempt was made to account for light reflected to the vertical surfaces from a particular foreground.

Every reading, for the entire year, on the 15-minute-interval basis, was classified in this manner. Table I shows a comparison, for each month, of the following:

1. Percentage of all days, designated as cloudy, partly cloudy, and clear by the U. S. Weather Bureau.

2. Percentage of all days for which recordings were made, designated as cloudy, partly cloudy, and clear by the U. S. Weather Bureau.

3. Sky cover, in tenths, for the entire month.

4. Sky cover, in tenths, for the days for which recordings were made.

5. Percentage of the total number of readings, 8 a.m. to 5 p.m. designated as being in classes A, B, C, and D.

This table indicates that the distribution of cloudy, partly cloudy, and clear days for the recorded periods is just about the same as for the entire year. The table also indicates that the days designated as cloudy by the U. S. Weather Bureau are not all overcast days. On the average, it takes the sum of Class A, Class B, and Class C conditions to equal approximately the percentage of days designated as cloudy.

To obtain maximum information from these data, they have been tabulated in several different ways. Each tabulation will be presented and explained in the following sections.

In the consideration of the increase in vertical surface illuminations due to light reflected from a foreground, it has been assumed that (1) the quantities measured included a negligible amount due to ground reflection because of the black shield, and (2) for a foreground with a reflectance of 25 per cent, the increase in north, south, east, and west vertical surface illuminations would equal 12.5 per cent of the horizontal surface illumination.

Time-Intensity Graphs

In the daylighting of schools, offices, small factories, shopping centers, and the like, it is of interest to know what percentage of the time of occupancy the exterior illumination of a particular surface is above a specific value. Such a presentation has been made for the periods 8:30 a.m. to 3:30 p.m. for the entire year, and for the school year (September through May), and for 8 a.m. to 5 p.m. for the entire year. In plotting these data, the morning and afternoon values for east and west exposures have been kept separate. These data are presented in Figs. 3 to 8 as follows:

Figure	Coverage	Foreground Reflectance
3	8:30 a.m. to 3:30 p.m. - School Year	Negligible
4	8:30 a.m. to 3:30 p.m. - School Year	25%
5	8:30 a.m. to 3:30 p.m. - Entire Year	Negligible
6	8:30 a.m. to 3:30 p.m. - Entire Year	25%
7	8:00 a.m. to 5:00 p.m. - Entire Year	Negligible
8	8:00 a.m. to 5:00 p.m. - Entire Year	25%

Average Illumination

The average illuminations for classifications A, B, C, and D, for the period 8:30 a.m. to 3:30 p.m., were calculated for each month. These averages for each exposure, without and with consideration of ground-reflected light, are presented in Table II. This table also shows the average illumination for each exposure for the sum of Classes A, B, and C and for the sum of Classes A, B, C, and D; the averages are weighted on the basis of percentages of time involved.

The average illuminations for all conditions for the period 8:00 a.m. to 5:00 p.m. are given in Table III, again without and with consideration of ground-reflected light.

Overcast and Cloudy Sky Conditions

Overcast and cloudy sky conditions are of particular interest because it is generally considered that for these periods exterior illumination is inadequate for daylighting purposes. This opinion is prevalent in connection with the daylighting of schools. Table IV shows the average external illuminations for each month for the school period 8:30 a.m. to 3:30 p.m., for the overcast, and cloudy sky conditions. Overcast sky conditions are represented by Class A and cloudy sky conditions, by Classes A, B, and C. The vertical surface illumination is given as the average of the values for north, south, east, and west exposures.

Table IV also gives the ratio of horizontal surface illumination to vertical surface illumination for each month.

Sun and Clear Sky Conditions

It is also of interest to consider the variation in exterior illumination for a cloudless day. One day each month was selected as being the best from this point of view, and the data were plotted. Four of these graphs are presented as follows:

Figure 9	March 20, 1953
Figure 10	June 23, 1953
Figure 11	September 28, 1953
Figure 12	December 16, 1953

These data were plotted without consideration of additional ground-reflected light.

As an indication of the total luminous energy that is incident directly on the specific surface during the period of one day, between the hours given, the area under each of these curves was measured, and the results, in 1000 lumen-hours, are listed in Table V. In Fig. 13, these same values of total luminous energy are plotted against noon-sun altitude for the day of measurement; the altitude scale is divided into two parts to separate the values for the two halves of the year. For convenience, the altitude scale is also divided into months with specific dates designated. The continuous curves are drawn to give some indication of the total luminous energy, 8:00 a.m. to 5:00 p.m., for any clear day of the year.

Exterior Daylight Intensities of 1000 and 2000 Footcandles

In a paper[6] on the availability of daylight at Port Allegany, Pennsylvania, data were presented showing the number of hours per day, between 8:00 a.m. and 5:00 p.m., that the illumination of particular surfaces was above 1000 and 2000 footcandles for each month. To allow direct comparison of these data with the data for Ann Arbor, a similar analysis has been made of the Ann Arbor data; the results are presented in Fig. 14.

Discussion of Results

Some previous papers[7] on the availability of daylight and solar radiation have attempted to relate the average intensity for cloudy days to the average intensity for cloudless days through the percentage of possible sunshine. In the absence of percentage of possible sunshine figures for Ann Arbor, approximate values have been obtained by averaging the available figures for East Lansing and Detroit. Utilizing these figures, an attempt will be made to relate cloudy day conditions to those for cloudless days.

From Fig. 13 it is possible to determine the average illumination, I_o, for

each month, 8:00 a.m. to 5:00 p.m. for each exposure, assuming that all days are cloudless or reasonably so. Then the average illuminations shown in Tables II and III can be related to these to obtain the ratios listed in Table VI, where R_1 is the ratio of the average illumination for strictly overcast sky conditions (Class A) to I_o, R_2 is the ratio of the average illumination for cloudy sky conditions (Classes A, B, and C) to I_o, and R_3 is the ratio of the average illuminations for all conditions to I_o.

Angström[8] has suggested that an equation of the form $Q/Q_o = a + bS$ represents the relation between sunshine, S (expressed as a fraction of the possible number of hours), and the ratio of the average radiation, Q, on a horizontal surface to the corresponding average radiation, Q_o, during cloudless days, where a and b are constants. Using the data of Table VI for a horizontal surface, it appears that

$$I = I_o (0.32 + 0.68 S) \quad , \qquad (1)$$

is a reasonable expression, where I_o is the average illumination for the month, assuming all days to be cloudless, and I is the average illumination for the month having 100S per cent of possible sunshine. The values of I_o, R_1I_o, 0.32 I_o, R_3I_o, and I for the 12 months are shown in Fig. 15. Setting a = 0.32 indicates that when S = 0 the sky is overcast and the average illumination is 0.32 I_o. It appears that the agreement of 0.32 I_o to R_1I_o and I to R_3I_o is quite good, considering the uncertainty in S.

Reference to Table VI will indicate, however, that an equation of this form cannot be used to represent the conditions for a vertical surface since R_1 is not a constant or nearly so. An equation that represents fairly well the conditions for the south vertical surface is:

$$I = I_o [S + 0.95 (1-S) \sin^2 \alpha/2] \quad , \qquad (2)$$

where α is the average noon sun altitude for each month. The values of I_o, R_1I_o, R_3I_o, 0.95 $I_o \sin^2 \alpha/2$, and I for the 12 months are shown in Fig. 16.

A similar expression

$$I = I_o [S + 0.44 (1-S) \sin \alpha/2] \quad , \qquad (3)$$

represents the conditions for east exposure in the forenoon and for west exposure in the afternoon, values of I_o, $R_1 I_o$, $R_3 I_o$, $0.44\ I_o \sin \alpha/2$, and I are given in Fig. 17.

Equations (1), (2), and (3) represent fairly well the data of Table VI, and were formed to give $I = I_o$ when $S = 1.0$, and average values for overcast sky conditions when $S = 0$. Equations (2) and (3) are for direct light only, and do not attempt to include an added vertical surface component due to ground-reflected light.

Since total radiation intensities were not measured at Ann Arbor or Willow Run during the period the data of this paper were collected, these daylight intensities cannot be related to total radiation.

When the distribution of brightness of an overcast sky has been measured, it can generally be represented by $B_\theta = B (a + b \sin \theta)$, where B_θ is the sky brightness at an altitude θ, B is the sky brightness at the zenith, and a and b are constants. It is because of such facts that Class A conditions were selected as those for which the ratio of maximum to minimum vertical surface illumination did not exceed about 1.5. Values of the constants a and b that have been used are $a = 0.4$, $b = 0.6$, and $a = 1/3$, $b = 2/3$. An integration of this expression for an unobstructed horizontal surface and for an unobstructed vertical surface gives a ratio for total horizontal to total vertical surface illumination of 2.42 and 2.52, respectively, for the two sets of constants. In Table IV such ratios are presented for average values of horizontal and vertical surface illumination for Class A conditions and for the sum of conditions of Classes A, B, and C. It will be observed that these ratios for the summer months agree quite well with the theoretical values; however, for the winter months the ratios are close to 2.0, which is the theoretical ratio for a sky of uniform brightness.

In the daylighting of buildings, the interior illumination is usually related to the exterior illumination of the surfaces containing the fenestrations. Some attempt has been made to establish average values for exterior illuminations due to overcast sky conditions; values of 500 and 1000 footcandles have been used for vertical surfaces, and 1000 and 2500 footcandles for a horizontal surface. The data of this study indicate that for strictly overcast sky conditions, and with average foreground reflectance, the average vertical surface illumination, between 8:30 a.m. and 3:30 p.m. is 1140 footcandles for the entire year and 960 footcandles for the school year. The corresponding figures for a horizontal surface are 2030 footcandles for the entire year and 1670 footcandles for the school year. For the period of 8:00 a.m. to 5:00 p.m. the figures, of course, will be somewhat lower. In any case, these data indicate that 1000 footcandles for a vertical surface and 2000 footcandles for a horizontal surface are reasonable averages for this location.

It should be realized, however, that minimum exterior illumination conditions do not only relate to overcast skies. Clear sky conditions for vertical surfaces not receiving direct sunlight or appreciable ground-reflected light should also be included. Comparison of Class D and Class A averages for north exposure, Table II, indicates that they are comparable. When the ground-reflected light is appreciable, the overcast sky conditions do represent the minimum.

One reason for establishing an average minimum exterior illumination is that for this value the interior illumination should be just adequate for the task involved. The percentage of time for which the exterior illumination, for all conditions, is above a specified level is given in Figs. 3, 4, 5, 6, 7, and 8. In the case of 1000 footcandles for a vertical surface and 2000 footcandles for a horizontal surface, Fig. 8 indicates that for the period 8:00 a.m. to 5:00 p.m. for the entire year, these values will be exceeded 67 per cent of the time for a horizontal surface and 75 per cent of the time for a vertical surface with south exposure.

In considering such figures, it should be realized that the data of this study are for one of the three districts in the United States having the lowest percentage of possible sunshine.

The U. S. Weather Bureau[9] extensively records solar radiation on a horizontal surface and collects illumination data at only a few geographical locations. More extensive data, showing total radiation and illumination for vertical surfaces, are required to obtain a correlation between solar heat and luminous energy intensities and atmospheric conditions. Recording devices designed specifically for such research are needed to avoid the time-consuming methods of tabulation and analysis used in presenting the data of this study.

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RECORD OF CLOUDINESS

8:00 a.m. to 5:00 p.m.—March 1953 through February 1954

Month	Percent of All Days			Percent of Measured Days			Sky Cover		Percent of Readings			
	Cloudy	Partly Cloudy	Clear	Cloudy	Partly Cloudy	Clear	All Days	Measured Days	Class A	Class B	Class C	Class D
March	84	10	6	88	6	6	8.6	8.7	47	16	9	28
April	74	13	13	70	10	20	7.6	7.2	34	13	5	48
May	58	29	13	68	26	6	7.2	7.9	40	17	7	36
June	40	43	17	41	36	23	6.2	5.9	17	13	10	60
July	29	42	29	32	41	27	5.5	5.5	20	13	10	57
August	23	26	51	20	20	60	4.2	3.8	7	7	5	81
Sept	20	37	43	16	42	42	4.3	4.2	10	10	4	76
Oct	23	23	54	24	12	64	4.0	3.8	17	4	2	77
Nov	53	17	30	55	15	30	6.3	6.3	37	11	6	46
Dec	64	23	13	52	29	19	7.5	6.8	37	10	8	45
Jan	74	16	10	84	5	11	8.2	8.7	70	6	4	20
Feb	61	14	25	57	19	24	7.1	7.0	50	8	2	40
Avg	50	25	25	50	22	28	6.4	6.3	32	11	6	51

TABLE I

AVERAGE ILLUMINATION IN FOOTCANDLES
Classes A, B, C, and D—8:30 a.m. to 3:30 p.m.

	Class	Number of 1/4 hr	Percent of Time	Horizontal	Foreground Reflectance—Neg				Foreground Reflectance—25%			
					North	South	East	West	North	South	East	West
January 1954	A	374	68	720	340	380	350	370	430	470	440	460
	B	37	7	1560	570	1190	720	900	770	1390	920	1100
	C	23	4	2750	730	1960	1190	940	1070	2300	1530	1280
	D	112	21	2740	730	4810	2000	1400	1070	5150	2340	1740
	Average Classes A,B,C			900	380	530	420	440	490	640	540	560
	Average Classes A,B,C,D			1300	450	1430	755	645	610	1590	920	810
February 1954	A	284	50	1140	550	610	550	590	690	750	690	730
	B	44	8	2600	860	1970	1330	1170	1180	2300	1650	1490
	C	12	2	2340	790	2230	1510	1160	1080	1520	1800	1450
	D	229	40	3370	580	5260	2340	1490	1000	5680	2760	1910
	Average Classes A,B,C			1390	600	830	690	670	770	1000	860	840
	Average Classes A,B,C,D			2180	590	2600	1350	1000	860	2870	1620	1270
March 1953	A	223	50	2200	890	1000	930	940	1170	1280	1200	1210
	B	15	3	3020	1040	1700	1320	1420	1420	2080	1700	1800
	C	52	12	4080	1110	3250	1940	1850	1620	3760	2450	2360
	D	158	35	5720	840	5330	3730	2010	1550	6040	4440	2720
	Average Classes A,B,C			2580	930	1450	1140	1130	1260	1770	1460	1450
	Average Classes A,B,C,D			3680	900	2810	2050	1440	1360	3270	2510	1900
April 1953	A	196	33	2590	990	1110	1030	1100	1310	1430	1350	1420
	B	91	16	4110	1230	2220	1670	1720	1740	2730	2180	2230
	C	28	5	5330	1240	3070	2220	2020	1910	3740	2890	2690
	D	272	46	6790	910	4520	3060	2830	1760	5370	3910	3680
	Average Classes A,B,C			3310	1080	1610	1330	1370	1490	2020	1740	1780
	Average Classes A,B,C,D			4910	1000	2950	2130	2040	1610	3660	2740	2650

TABLE II

	Class	Number of 1/4 hr	Percent of Time	Horizontal	Foreground Reflectance—Neg				Foreground Reflectance—25%			
					North	South	East	West	North	South	East	West
May 1953	A	230	41	2740	1050	1170	1130	1150	1390	1510	1470	1490
	B	81	15	4270	1500	2160	1730	1740	2030	2690	2260	2270
	C	42	7	5500	1510	3060	2070	2430	2200	3750	2760	3120
	D	205	37	7870	1190	4220	2590	3350	2170	5200	3570	4330
	Average Classes A,B,C			3400	1210	1620	1380	1430	1630	2040	1800	1850
	Average Classes A,B,C,D			5050	1200	2580	1830	2140	1830	2210	2460	2770
June 1953	A	104	17	3260	1230	1540	1390	1320	1640	1950	1800	1730
	B	97	16	4770	1290	2270	1750	1750	1890	2870	2350	2350
	C	74	12	7570	1490	3580	2430	2500	2440	4530	3380	3450
	D	340	55	8450	1160	3920	3630	2910	2220	4980	4690	3970
	Average Classes A,B,C			4950	1320	2310	1800	1800	1940	2930	2420	2420
	Average Classes A,B,C,D			6880	1230	3200	2810	2410	2090	4060	3670	3270
July 1953	A	140	23	3240	1080	1490	1260	1330	1470	1880	1650	1720
	B	86	14	4610	1340	2290	1890	1830	1920	2870	2470	2410
	C	66	11	7540	1310	3510	2310	2390	2250	4450	3250	3330
	D	321	52	7930	1150	3270	3740	3060	2140	4460	4730	4050
	Average Classes A,B,C			4580	1210	2190	1680	1730	1780	2760	2250	2300
	Average Classes A,B,C,D			6320	1180	2850	2750	2420	1970	3640	3540	3210
August 1953	A	38	7	2910	1190	1440	1050	1320	1550	1800	1410	1680
	B	38	7	3500	1180	1980	1410	1470	1620	2420	1850	1910
	C	28	5	5250	1080	2610	1650	2340	1740	3270	2310	3000
	D	468	81	7650	1000	4610	3890	2430	1950	5560	4840	3380
	Average Classes A,B,C			3740	1160	1900	1320	1630	1630	2370	1790	2100
	Average Classes A,B,C,D			6910	1030	4100	3400	2280	1890	4960	4260	3140

TABLE II (continued)

	Class	Number of 1/4 hr	Percent of Time	Horizontal	Foreground Reflectance—Neg				Foreground Reflectance—25%			
					North	South	East	West	North	South	East	West
September 1953	A	52	10	2480	970	1280	1140	1050	1280	1590	1450	1360
	B	59	11	2670	920	1620	1050	1400	1250	1950	1380	1730
	C	29	6	3810	990	2490	1390	1890	1470	2970	1870	2370
	D	377	73	6650	790	5680	3530	2540	1620	6510	4360	3370
	Average Classes A,B,C			2780	970	1700	1150	1370	1320	2050	1500	1720
	Average Classes A,B,C,D			5610	840	4610	2890	2220	1540	5310	3590	2920
October 1953	A	81	17	1200	510	570	560	560	660	720	710	710
	B	22	5	2000	720	1360	970	1220	970	1610	1220	1470
	C	9	2	2930	870	2500	1250	1730	1240	2870	1620	2100
	D	368	76	5210	650	6350	2980	2810	1300	7000	3630	3460
	Average Classes A,B,C			1500	610	920	730	810	800	1110	920	1000
	Average Classes A,B,C,D			4320	640	5050	2440	2330	1180	5590	2980	2870
November 1953	A	205	37	1130	510	640	550	600	650	780	690	740
	B	50	9	2040	740	1630	1140	1000	990	1880	1390	1250
	C	28	5	2470	720	2410	1460	920	1030	2720	1770	1230
	D	265	49	3080	560	5190	2360	1570	950	5580	2750	1960
	Average Classes A,B,C			1430	580	990	750	710	760	1170	930	890
	Average Classes A,B,C,D			2240	570	3050	1540	1130	850	3330	1820	1410
December 1953	A	211	39	820	370	470	420	440	470	570	520	540
	B	55	10	1590	600	1300	800	940	800	1500	1000	1140
	C	40	7	1980	660	1900	1030	1140	910	2150	1280	1390
	D	239	44	2350	510	4290	1660	1350	800	4580	1950	1640
	Average Classes A,B,C			1100	460	790	570	620	600	930	710	760
	Average Classes A,B,C,D			1650	480	2330	1050	940	690	2540	1260	1150

TABLE II (concluded)

AVERAGE ILLUMINATION IN FOOTCANDLES
8:00 a.m. to 5:00 p.m.

Month	Horizontal	Foreground Reflectance—Neg				Foreground Reflectance—25%			
		North	South	East	West	North	South	East	West
Jan 1954	1140	420	1420	630	680	560	1560	770	820
Feb 1954	2120	530	2640	1130	1300	790	2900	1390	1560
March 1953	3450	840	2530	1660	1680	1270	2960	2090	2110
April 1953	4560	860	2650	1900	2150	1430	3220	2470	2720
May 1953	4920	1110	2140	1850	2050	1720	2750	2460	2660
June 1953	6180	1120	2800	2750	2580	1890	3570	3520	3350
July 1953	6190	1130	2680	2770	2690	1900	3450	3540	3460
August 1953	6400	980	3750	3150	2710	1780	4550	3950	3510
Sept 1953	5050	760	4260	2770	2660	1390	4890	3400	3290
Oct 1953	3900	570	4660	2050	2510	1060	5150	2540	3000
Nov 1953	2020	475	2720	1150	1230	730	2970	1400	1480
Dec 1953	1470	420	2170	870	910	600	2350	1050	1090
Avg	3950	770	2870	1890	1930	1260	3360	2380	2420

TABLE III

AVERAGE ILLUMINATION

Overcast and Cloudy Sky Conditions—8:30 a.m. to 3:30 p.m.

Month	Class A			Classes A+B+C			Class A	Classes A+B+C
	Avg V.S.I.		Avg H.S.I.	Avg V.S.I.		Avg H.S.I.	H.S.I./V.S.I.	
	Neg Grd (FtC)	25% Grd (FtC)	(FtC)	Neg Grd (FtC)	25% Grd (FtC)	(FtC)	Neg Grd	
Jan 1954	360	450	720	440	550	900	2.00	2.04
Feb 1954	580	720	1140	700	870	1390	1.97	1.99
March 1953	940	1220	2200	1160	1480	2580	2.34	2.22
April 1953	1060	1380	2590	1350	1760	3310	2.44	2.45
May 1953	1130	1470	2740	1410	1830	3400	2.42	2.41
June 1953	1370	1780	3260	1810	2430	4950	2.38	2.73
July 1953	1290	1680	3140	1700	2270	4580	2.43	2.69
August 1953	1250	1610	2910	1500	1970	3740	2.33	2.49
Sept 1953	1110	1420	2480	1300	1650	2780	2.24	2.14
Oct 1953	550	700	1200	770	960	1500	2.18	1.95
Nov 1953	580	720	1130	760	940	1430	1.95	1.88
Dec 1953	430	530	820	610	750	1100	1.91	1.80
Average Entire Year	890	1140	2030	1130	1460	2640	2.22	2.23
Average School Year	750	960	1670	940	1200	2040		

V.S.I. — Vertical Surface Illumination
H.S.I. — Horizontal Surface Illumination

TOTAL LUMINOUS ENERGY
1000 Lumen-Hours
Sun and Clear Sky—8:00 a.m. to 5:00 p.m.

Date	South	East	West	Horizontal
Jan 22, 1954	51.6	16.1	18.1	24.2
Feb 17, 1954	54.5	20.1	22.7	34.2
March 20, 1953	52.1	30.4	27.5	54.3
April 21, 1953	37.6	27.8	29.4	69.3
May 28, 1953	31.8	33.0	24.5	76.5
June 23, 1953	25.9	31.2	25.0	78.5
July 24, 1953	33.2	34.7	29.7	77.7
August 20, 1953	41.3	32.6	32.6	66.8
Sept 28, 1953	53.7	28.2	28.5	50.8
Oct 29, 1953	58.1	20.4	24.9	35.7
Nov 17, 1953	49.7	17.0	17.8	25.2
Dec 16, 1953	47.5	14.2	15.6	20.5

TABLE V

COMPARISON OF CLOUDY AND CLOUDLESS DAYS
8:00 a.m. to 5:00 p.m.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Percent Possible Sunshine	31	44	38	43	52	70	75	76	75	70	40	32
Avg Noon Sun Alt	27.5	35	46	57	66	70.5	69	62	51	40	30	25.5
Horizontal Surface												
I_o	2700	3720	5500	7280	8250	8640	8560	7670	6250	4670	3110	2310
R_1	0.23	0.30	0.38	0.33	0.32	0.34	0.36	0.36	0.36	0.23	0.33	0.32
R_2	0.29	0.36	0.44	0.42	0.40	0.52	0.53	0.45	0.40	0.29	0.42	0.43
R_3	0.42	0.57	0.63	0.63	0.60	0.72	0.72	0.83	0.81	0.83	0.65	0.64
South Vertical Surface												
I_o	5600	5900	5640	4560	3600	3170	3420	4420	5450	6170	5840	5280
R_1	0.068	0.103	0.16	0.22	0.27	0.42	0.41	0.30	0.22	0.086	0.098	0.083
R_2	0.094	0.143	0.23	0.32	0.37	0.64	0.60	0.39	0.29	0.138	0.150	0.140
R_3	0.25	0.45	0.45	0.58	0.59	0.88	0.78	0.85	0.78	0.76	0.47	0.41
East or West Vertical Surface												
I_o	1800	2300	2900	3170	3170	3170	3360	3560	3330	2750	2080	1670
R_1	0.144	0.26	0.31	0.33	0.35	0.44	0.41	0.35	0.35	0.20	0.25	0.23
R_2	0.171	0.31	0.38	0.42	0.44	0.58	0.54	0.43	0.40	0.27	0.31	0.32
R_3	0.28	0.53	0.58	0.64	0.62	0.84	0.81	0.82	0.82	0.83	0.57	0.53
I_o*	3200	4100	5000	5700	5600	5700	5000	6300	6000	5000	3670	2830
R_1*	0.109	0.134	0.19	0.18	0.20	0.24	0.21	0.17	0.19	0.112	0.15	0.15
R_3*	0.28	0.46	0.47	0.56	0.52	0.76	0.73	0.77	0.76	0.80	0.50	0.47

*For east in a.m. or west in p.m.

TABLE VI

LIST OF FIGURES

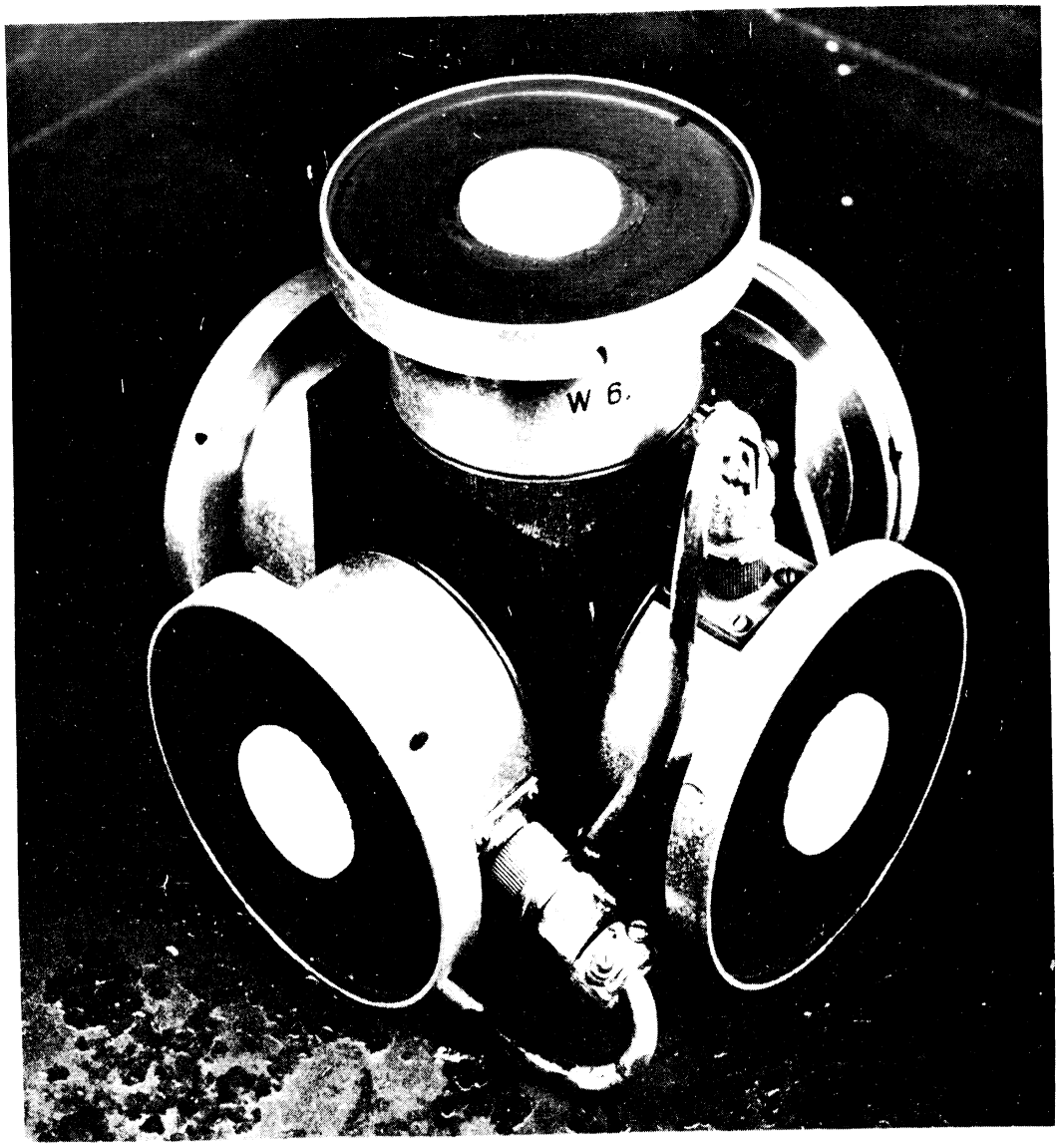


Fig. 1. Photocell arrangement.

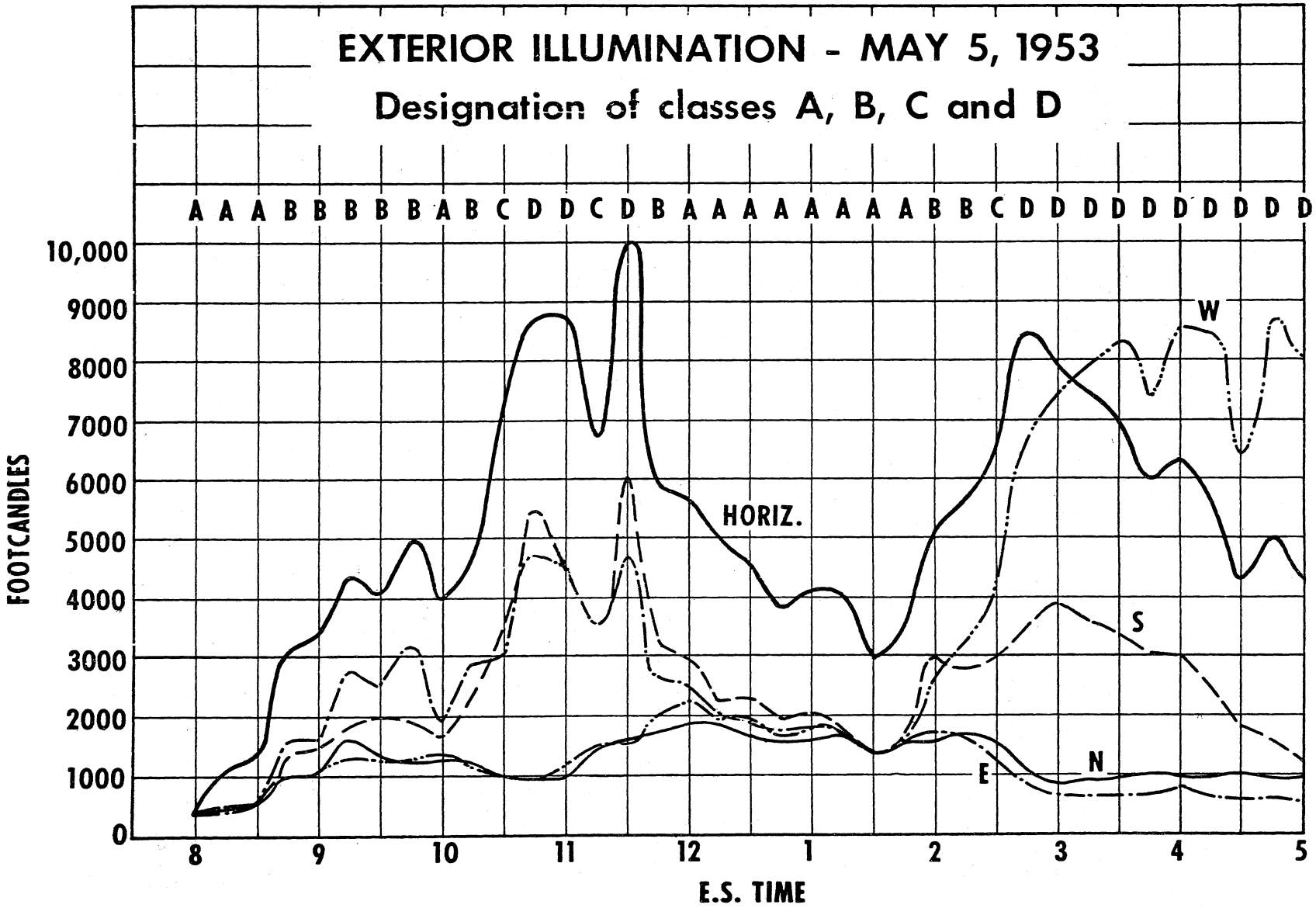

EXTERIOR ILLUMINATION - MAY 5, 1953
Designation of classes A, B, C and D
A A A B B B B B A B C D D C D B A A A A A A A B B C D D D D D D D D D
FOOTCANDLES
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
HORIZ.
W
S
N
E
8
9
10
11
12
1
2
3
4
5
E.S. TIME

Fig. 2

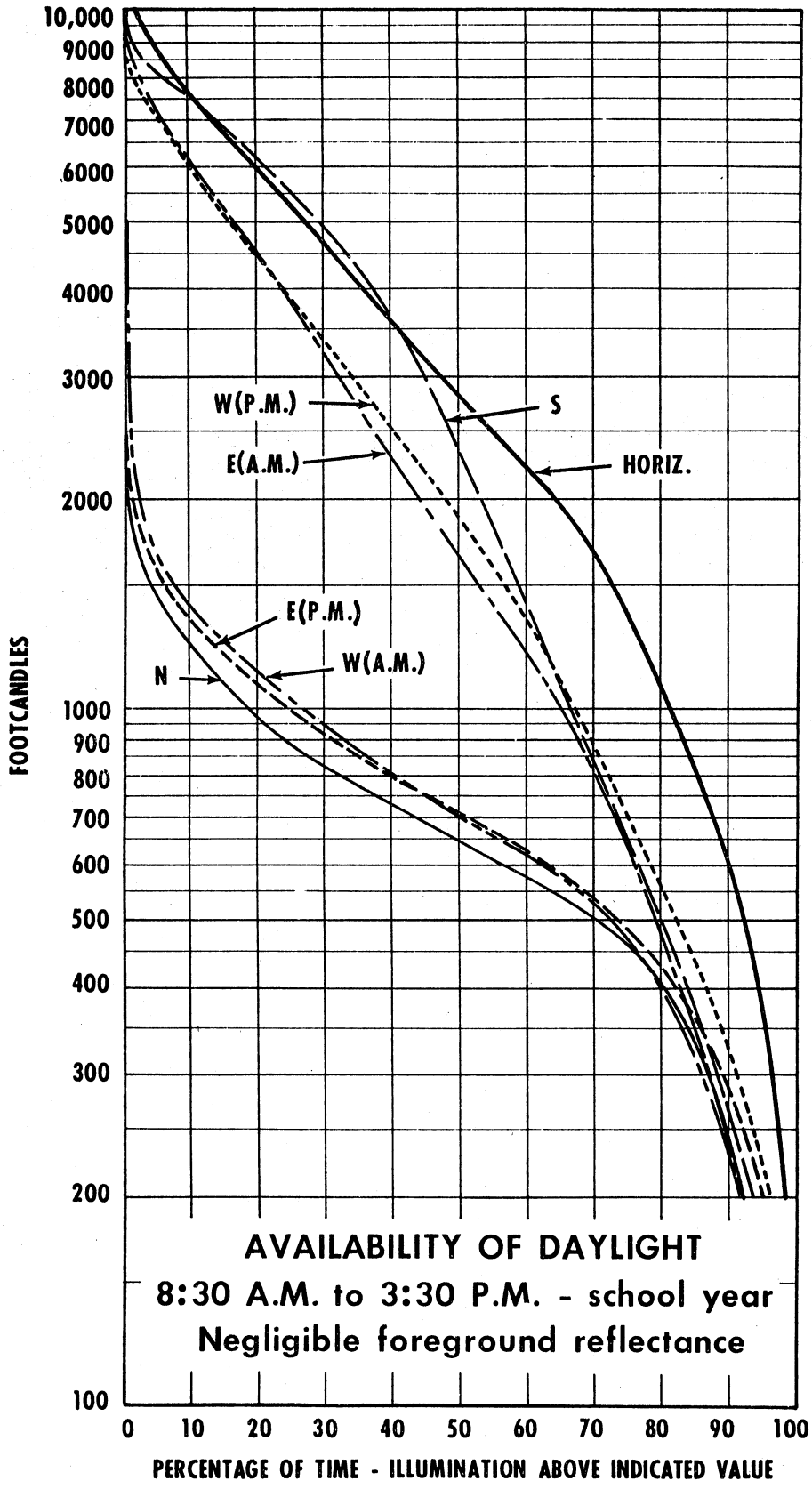

10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
FOOTCANDLES
W(P.M.)
S
E(A.M.)
HORIZ.
E(P.M.)
W(A.M.)
N
AVAILABILITY OF DAYLIGHT
8:30 A.M. to 3:30 P.M. - school year
Negligible foreground reflectance
0
10
20
30
40
50
60
70
80
90
100
PERCENTAGE OF TIME - ILLUMINATION ABOVE INDICATED VALUE

Fig. 3

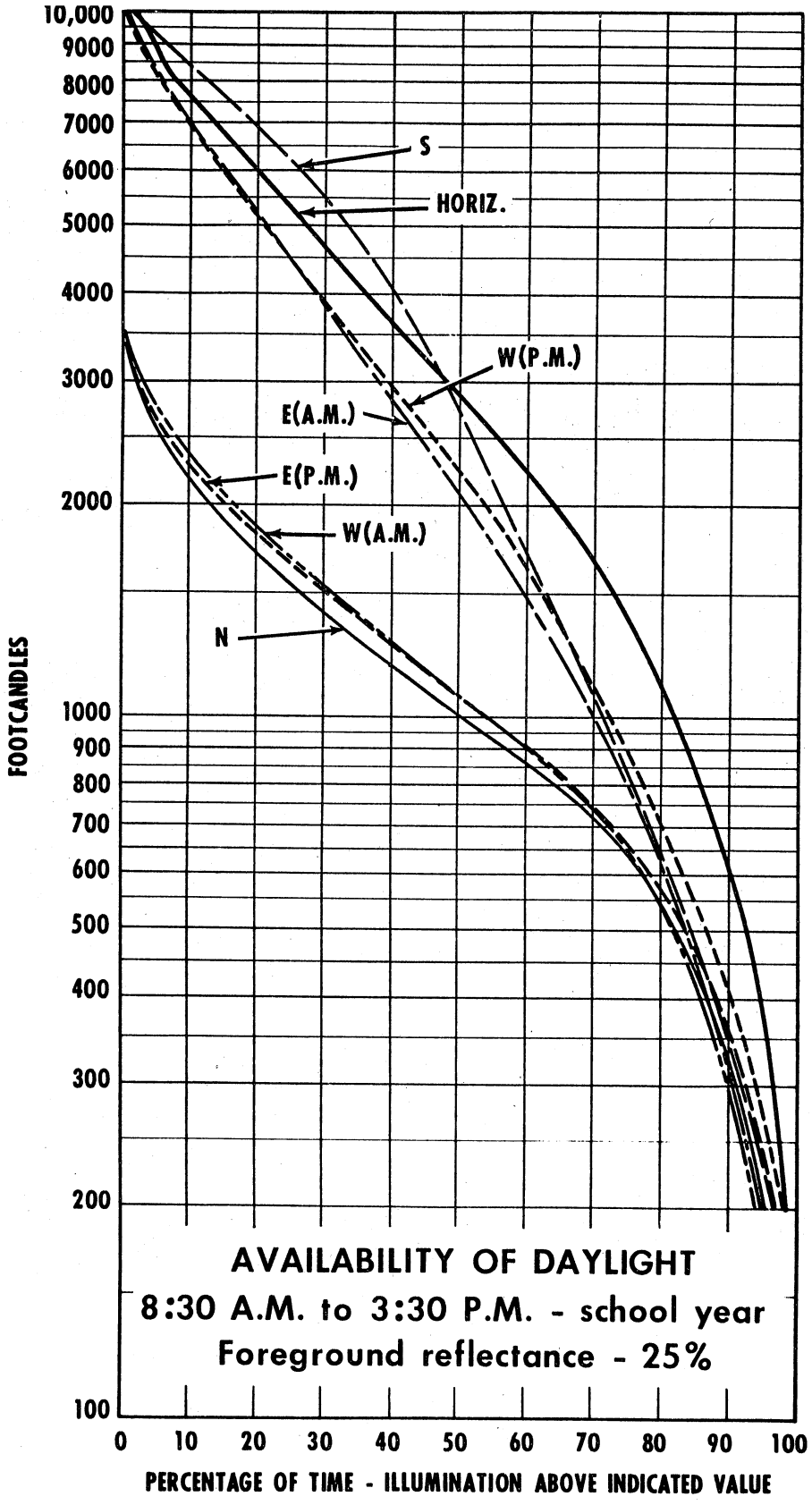

10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
FOOTCANDLES
S
HORIZ.
W(P.M.)
E(A.M.)
E(P.M.)
W(A.M.)
N
AVAILABILITY OF DAYLIGHT
8:30 A.M. to 3:30 P.M. - school year
Foreground reflectance - 25%
0
10
20
30
40
50
60
70
80
90
100
PERCENTAGE OF TIME - ILLUMINATION ABOVE INDICATED VALUE

Fig. 4

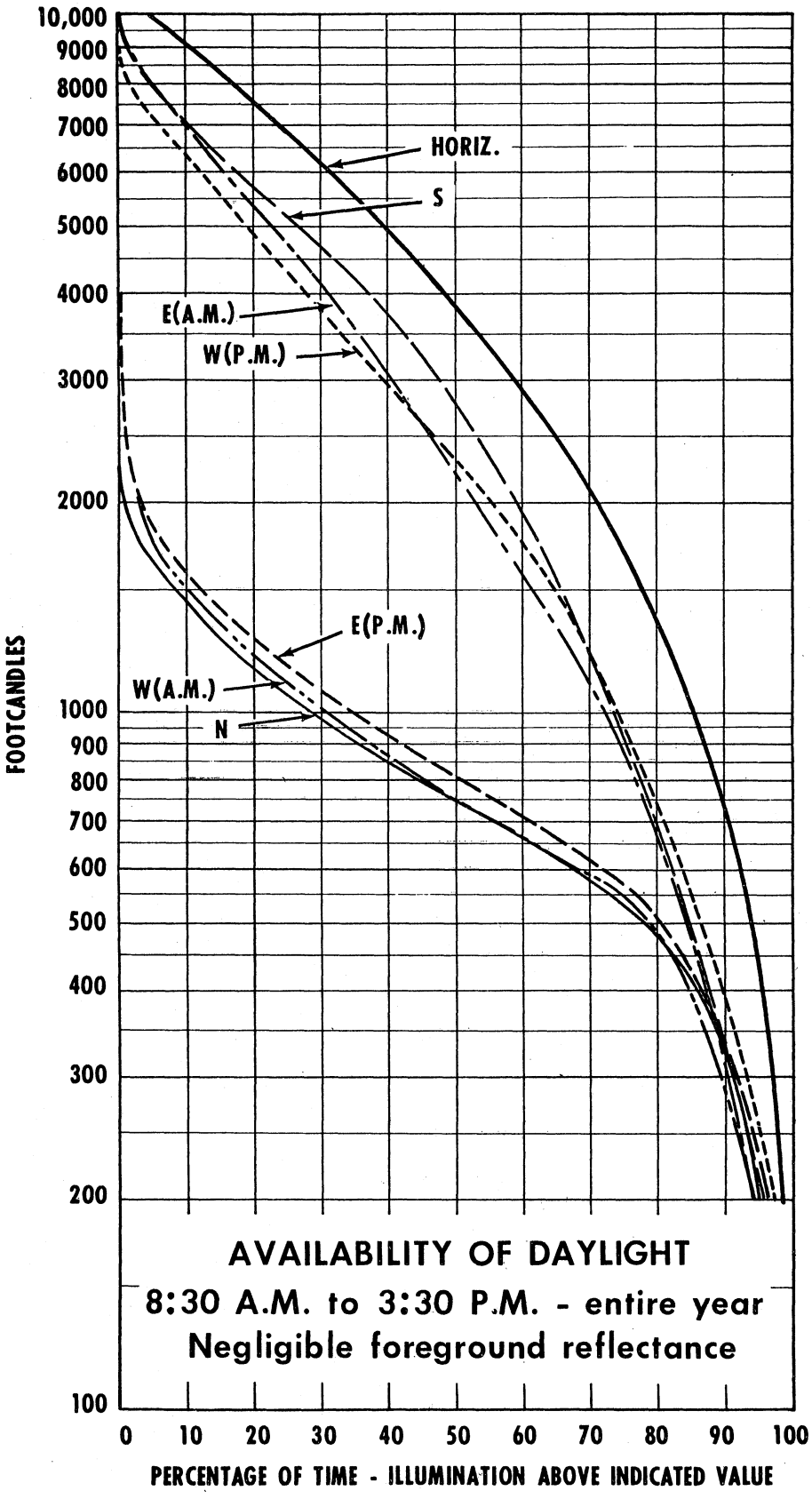

10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
FOOTCANDLES
HORIZ.
S
E(A.M.)
W(P.M.)
E(P.M.)
W(A.M.)
N
AVAILABILITY OF DAYLIGHT
8:30 A.M. to 3:30 P.M. - entire year
Negligible foreground reflectance
0
10
20
30
40
50
60
70
80
90
100
PERCENTAGE OF TIME - ILLUMINATION ABOVE INDICATED VALUE

Fig. 5

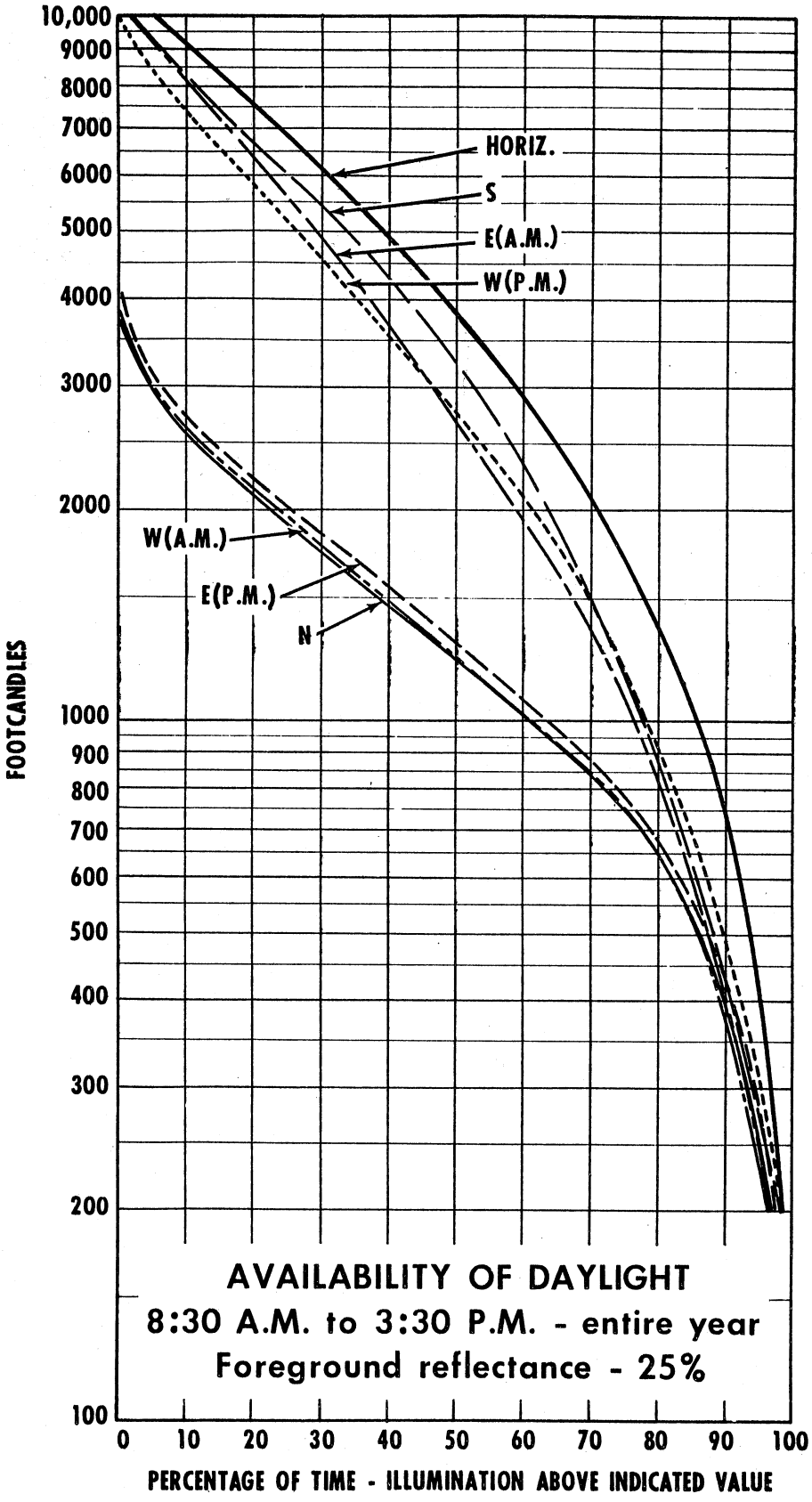

10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
FOOTCANDLES
HORIZ.
S
E(A.M.)
W(P.M.)
W(A.M.)
E(P.M.)
N
AVAILABILITY OF DAYLIGHT
8:30 A.M. to 3:30 P.M. - entire year
Foreground reflectance - 25%
0
10
20
30
40
50
60
70
80
90
100
PERCENTAGE OF TIME - ILLUMINATION ABOVE INDICATED VALUE

Fig. 6

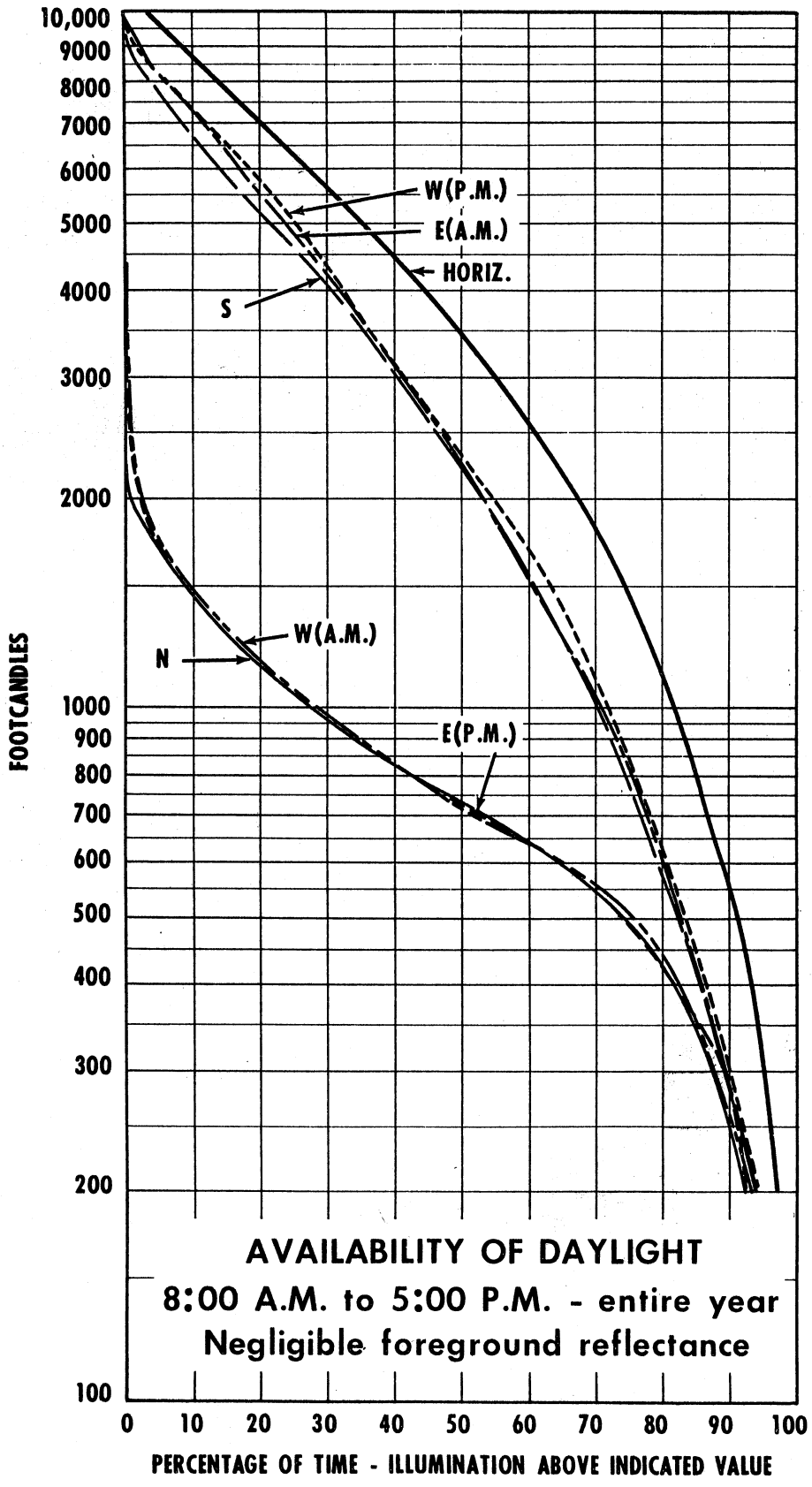

10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
FOOTCANDLES
W(P.M.)
E(A.M.)
HORIZ.
S
W(A.M.)
N
E(P.M.)
AVAILABILITY OF DAYLIGHT
8:00 A.M. to 5:00 P.M. - entire year
Negligible foreground reflectance
0
10
20
30
40
50
60
70
80
90
100
PERCENTAGE OF TIME - ILLUMINATION ABOVE INDICATED VALUE

Fig. 7

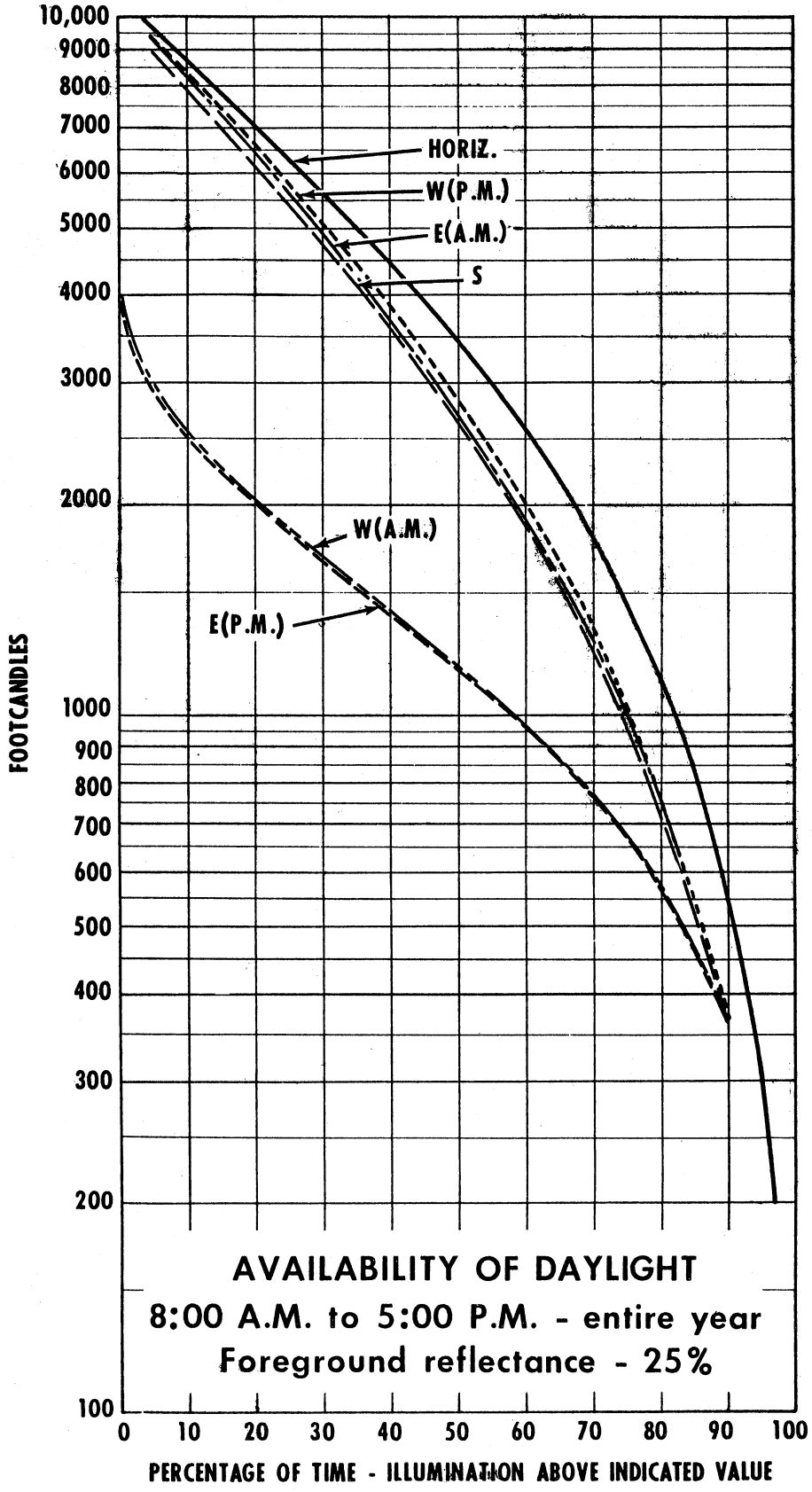

10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
FOOTCANDLES
HORIZ.
W(P.M.)
E(A.M.)
S
W(A.M.)
E(P.M.)
AVAILABILITY OF DAYLIGHT
8:00 A.M. to 5:00 P.M. - entire year
Foreground reflectance - 25%
0
10
20
30
40
50
60
70
80
90
100
PERCENTAGE OF TIME - ILLUMINATION ABOVE INDICATED VALUE

Fig. 8

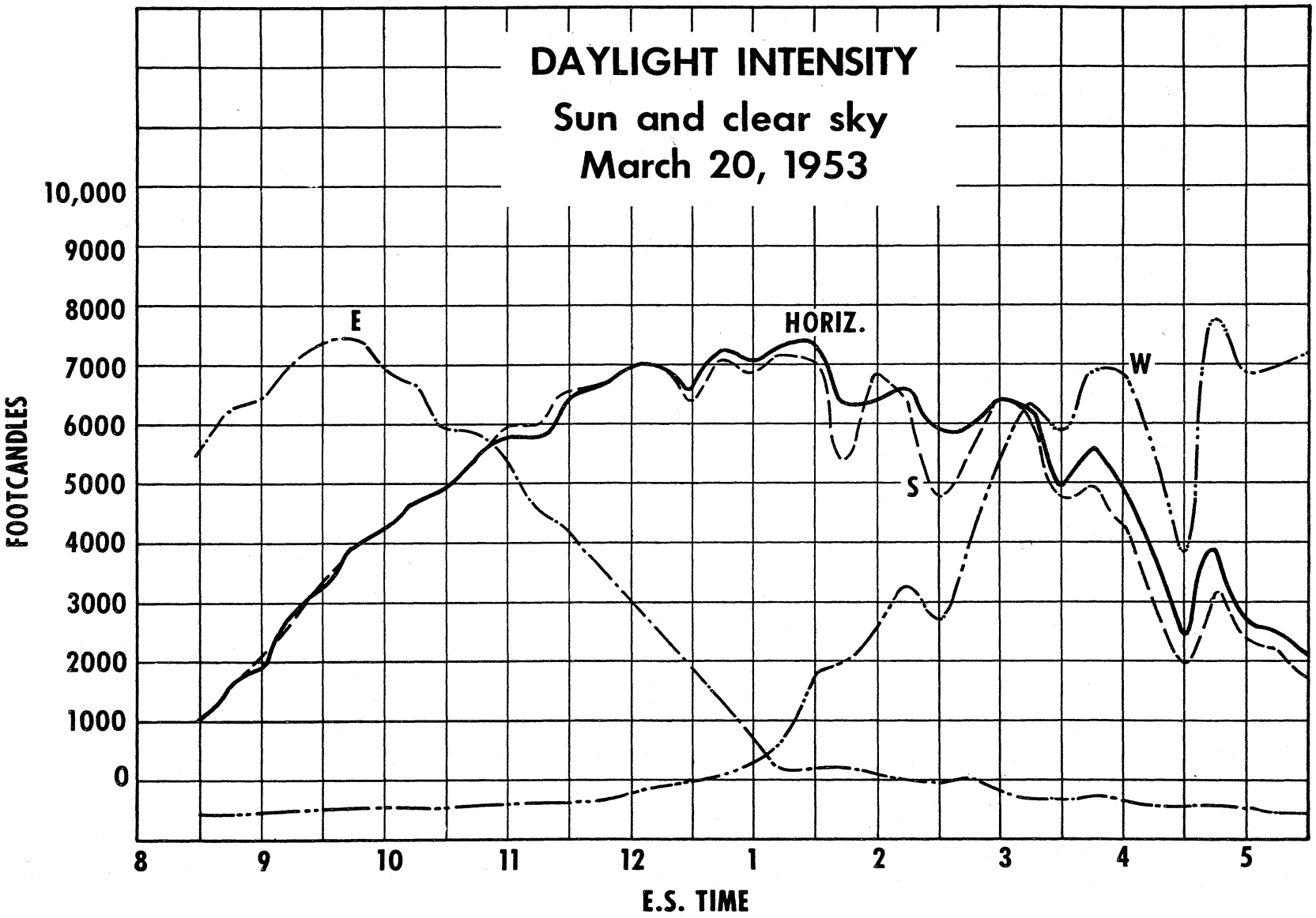

DAYLIGHT INTENSITY
Sun and clear sky
March 20, 1953
FOOTCANDLES
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
E
HORIZ.
W
S
8
9
10
11
12
1
2
3
4
5
E.S. TIME

Fig. 9

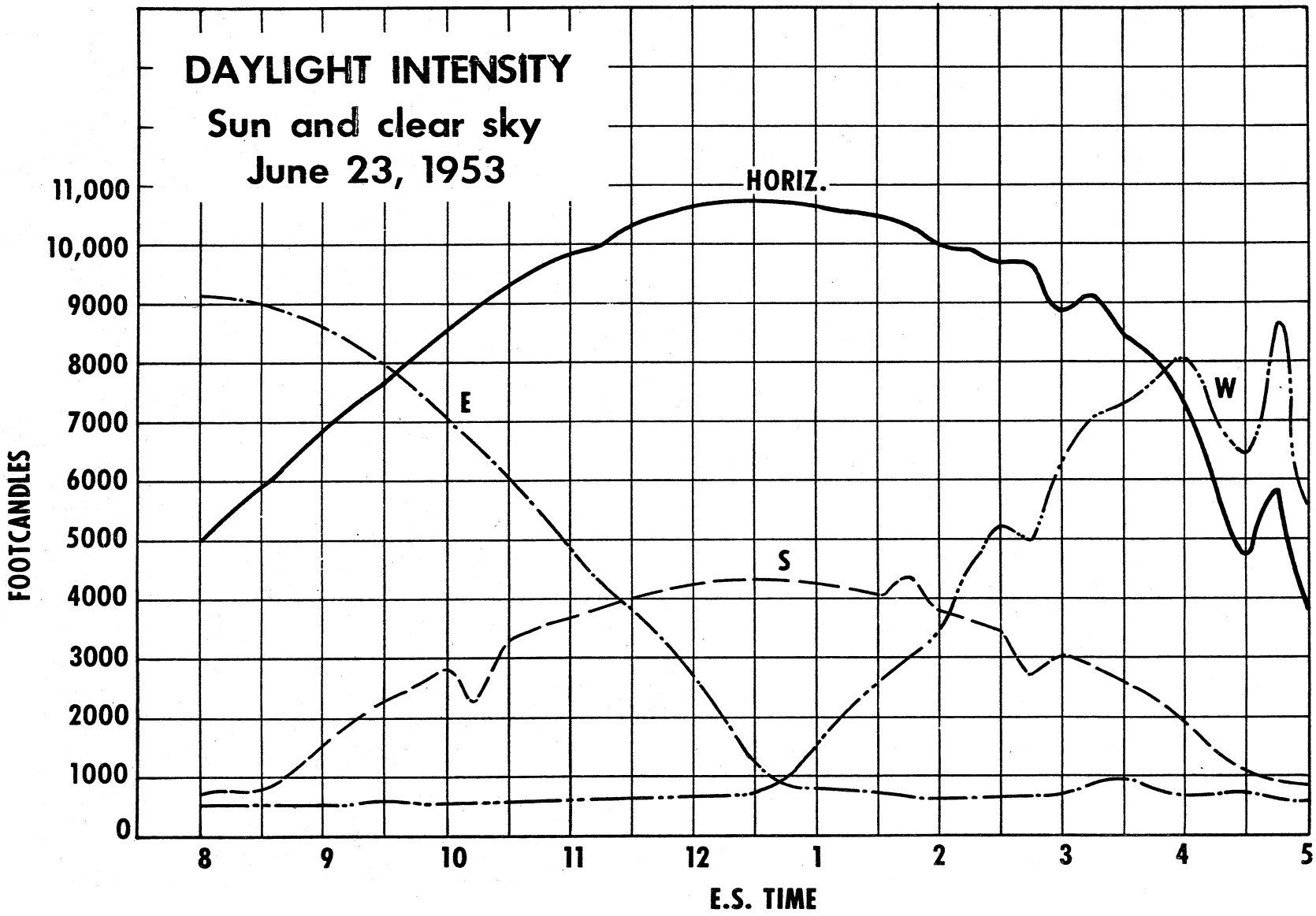

DAYLIGHT INTENSITY
Sun and clear sky
June 23, 1953
HORIZ.
E
S
W
FOOTCANDLES
11,000
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
8
9
10
11
12
1
2
3
4
5
E.S. TIME

Fig. 10

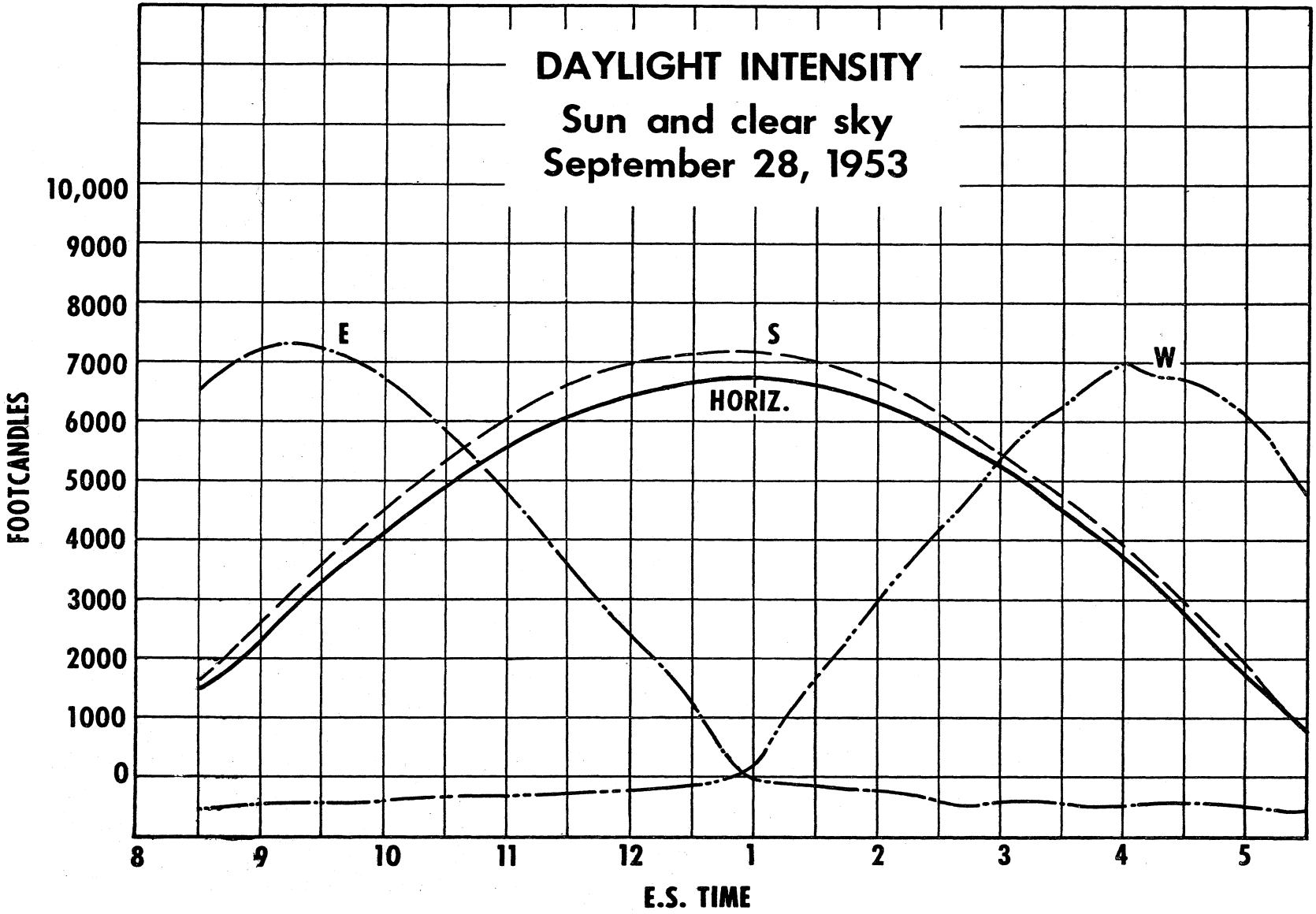

DAYLIGHT INTENSITY
Sun and clear sky
September 28, 1953
FOOTCANDLES
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
E
S
W
HORIZ.
8
9
10
11
12
1
2
3
4
5
E.S. TIME

Fig. 11

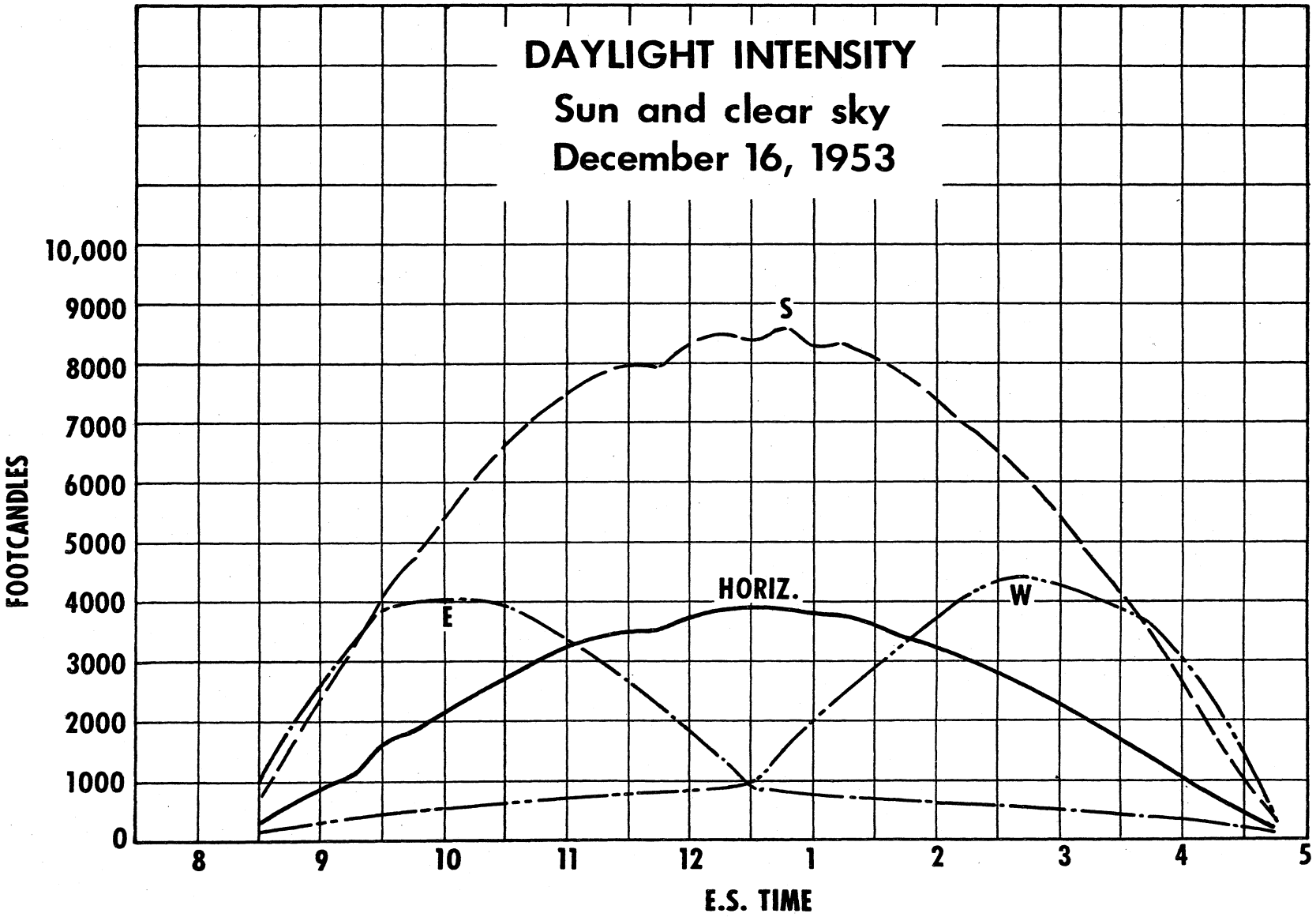

DAYLIGHT INTENSITY
Sun and clear sky
December 16, 1953
FOOTCANDLES
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
S
E
HORIZ.
W
8
9
10
11
12
1
2
3
4
5
E.S. TIME

Fig. 12

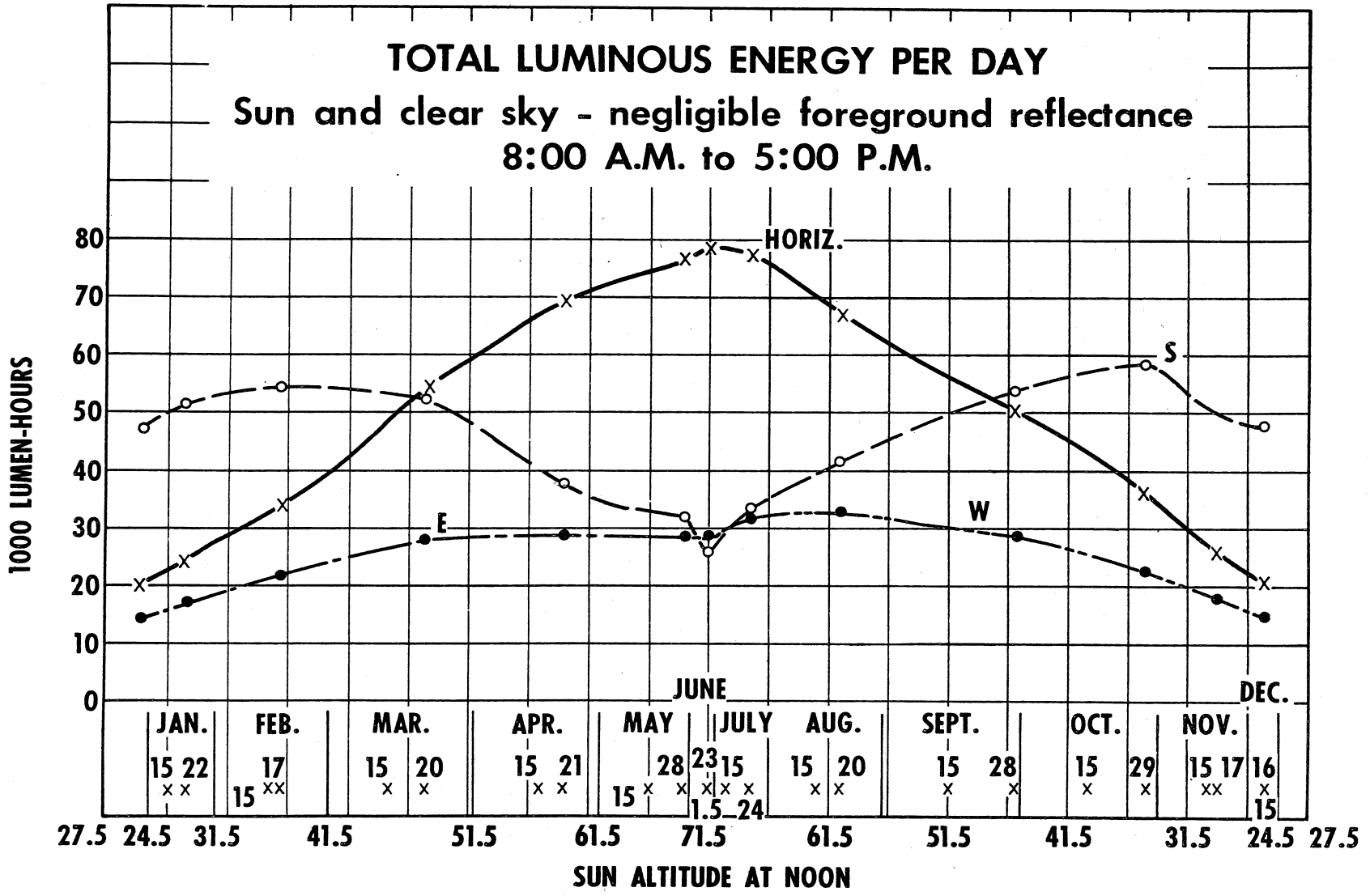

TOTAL LUMINOUS ENERGY PER DAY
Sun and clear sky - negligible foreground reflectance
8:00 A.M. to 5:00 P.M.
1000 LUMEN-HOURS
80
70
60
50
40
30
20
10
0
HORIZ.
S
E
W
JUNE
DEC.
JAN. 15 22
FEB. 15 17
MAR. 15 20
APR. 15 21
MAY 15 28
JULY 1.5 23 15 24
AUG. 15 20
SEPT. 15 28
OCT. 15 29
NOV. 15 17 16 15
27.5 24.5 31.5 41.5 51.5 61.5 71.5 61.5 51.5 41.5 31.5 24.5 27.5
SUN ALTITUDE AT NOON

Fig. 13

AVERAGE NUMBER HOURS PER DAY - 8:00 A.M. to 5:00 P.M.
Illumination above 1000 and 2000 FTC.

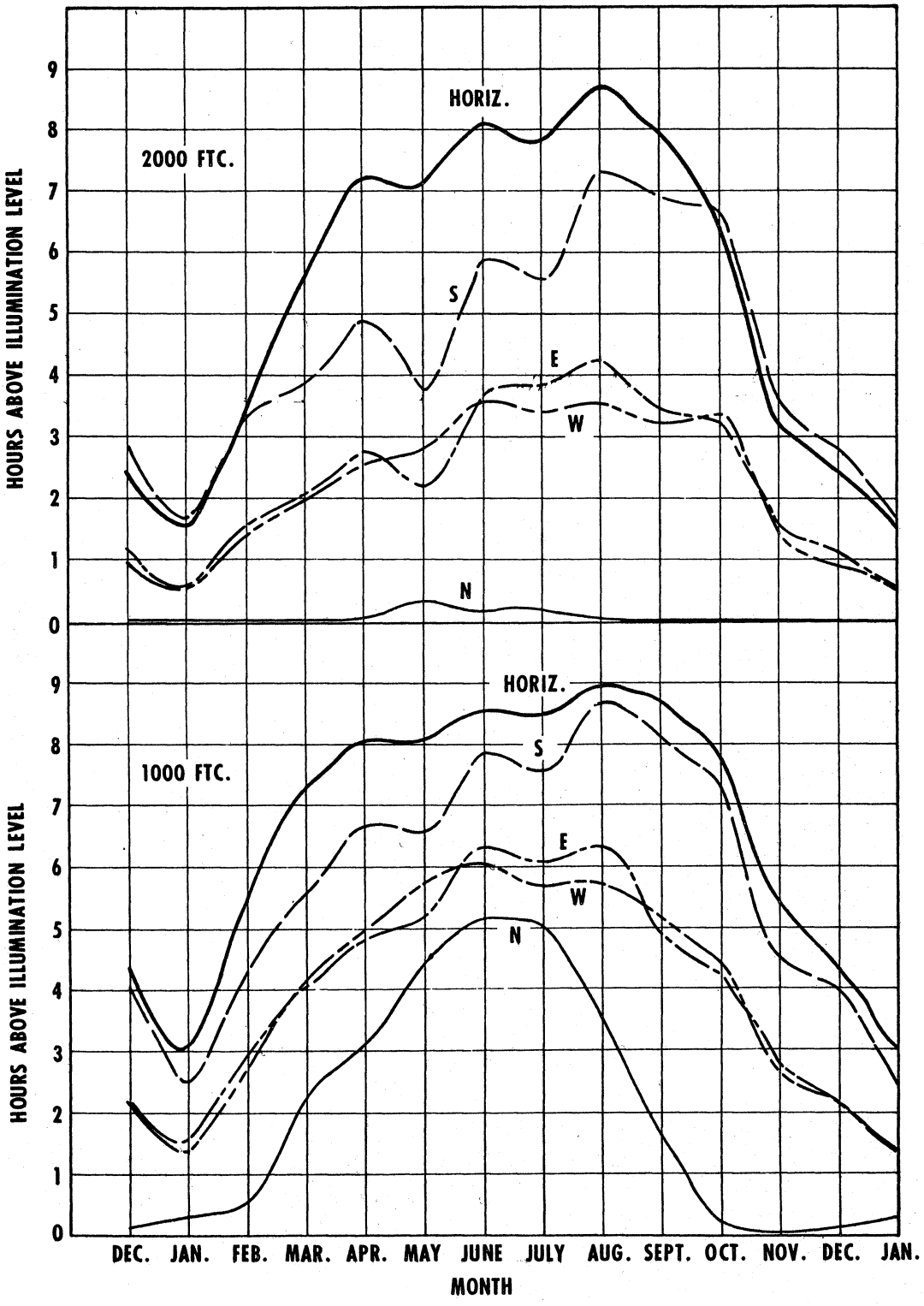


Fig. 14

AVERAGE ILLUMINATION
Horizontal surface - 8:00 A.M. to 5:00 P.M.
Calculated and measured
$I = I_0 (0.32 + 0.68\ S)$

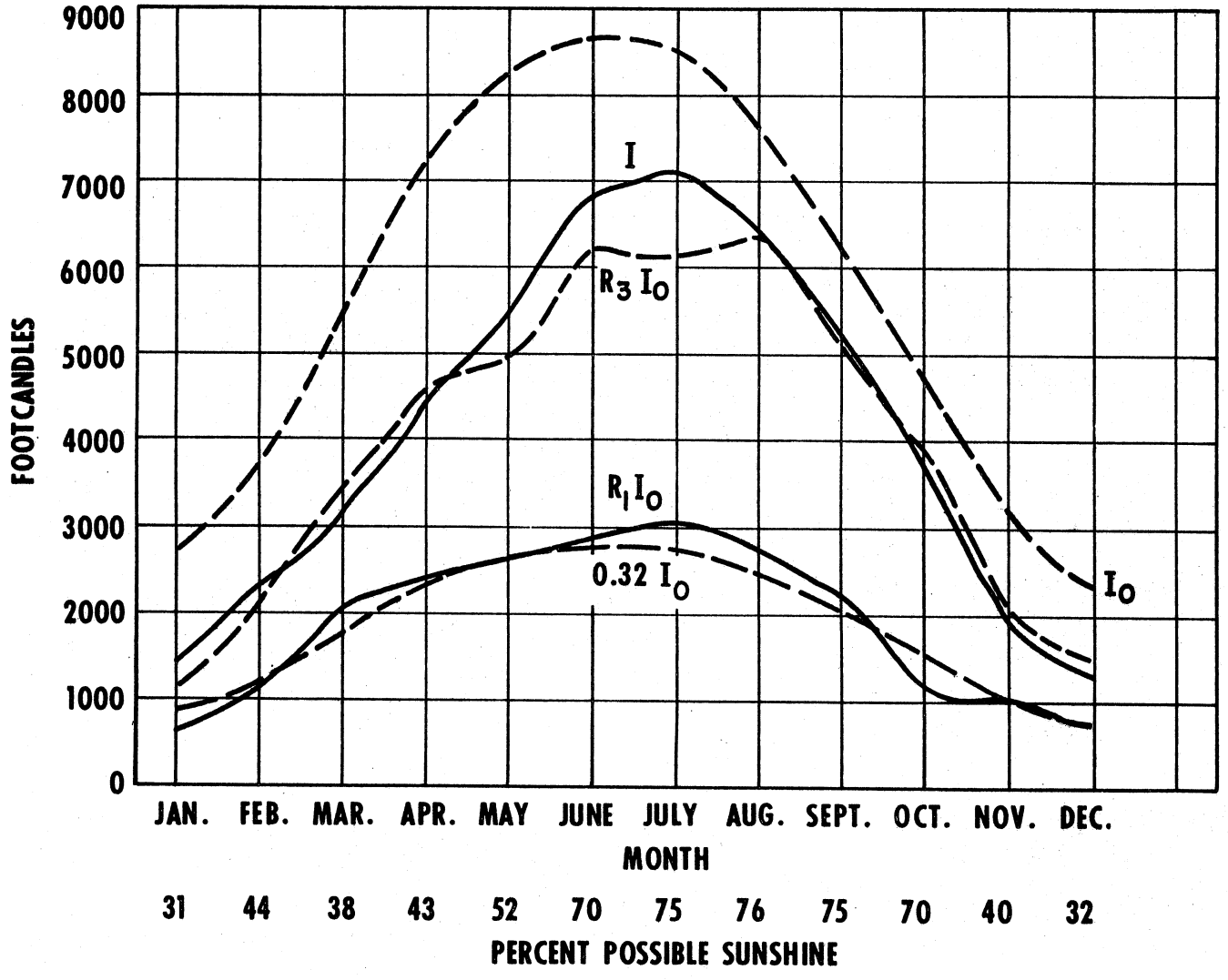


Fig. 15

AVERAGE ILLUMINATION

South vertical surface - 8:00 A.M. to 5:00 P.M.

Calculated and measured

$$I = I_0 [S + 0.95 (1 - S) \sin^2 \alpha/2]$$

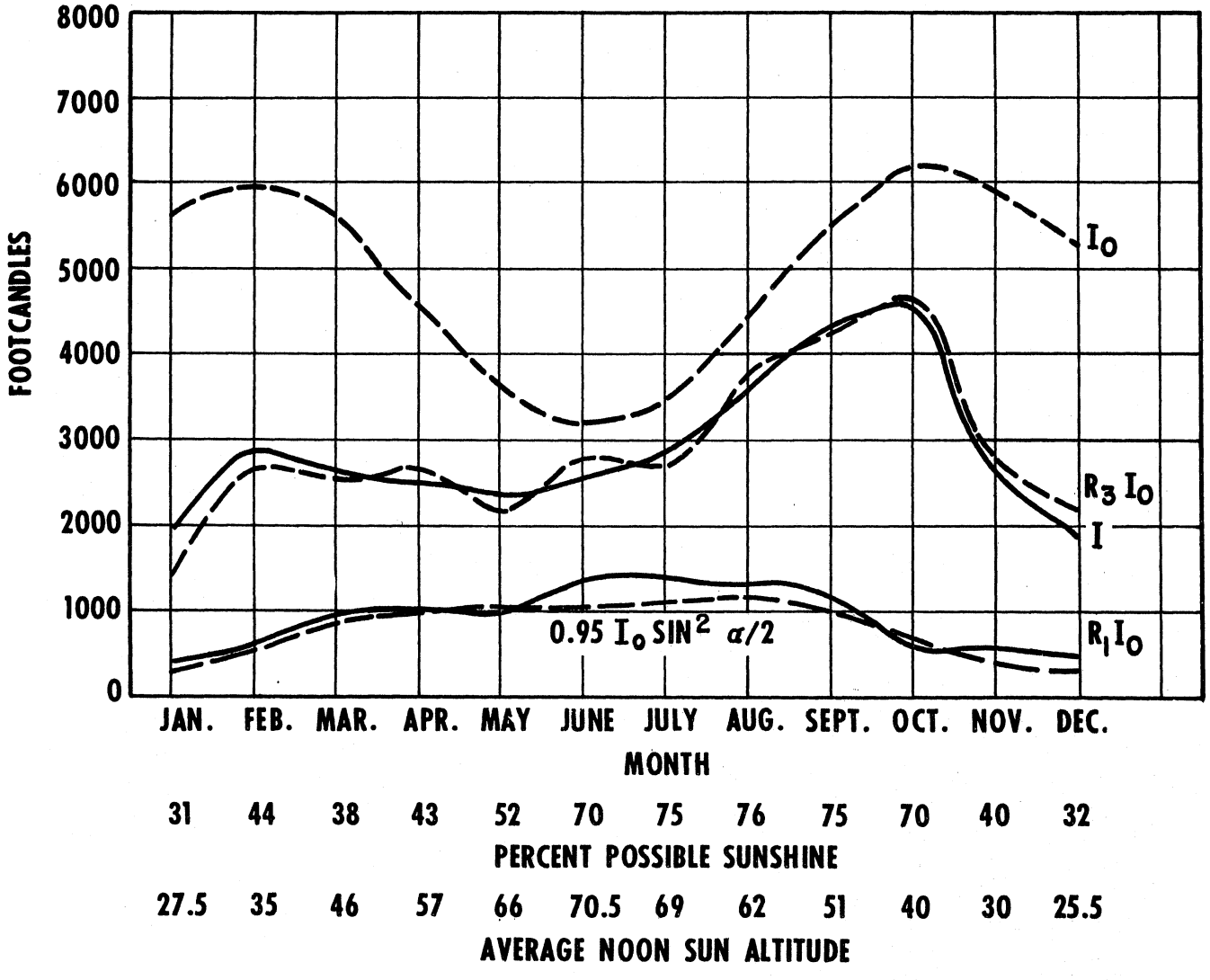


Fig. 16

AVERAGE ILLUMINATION

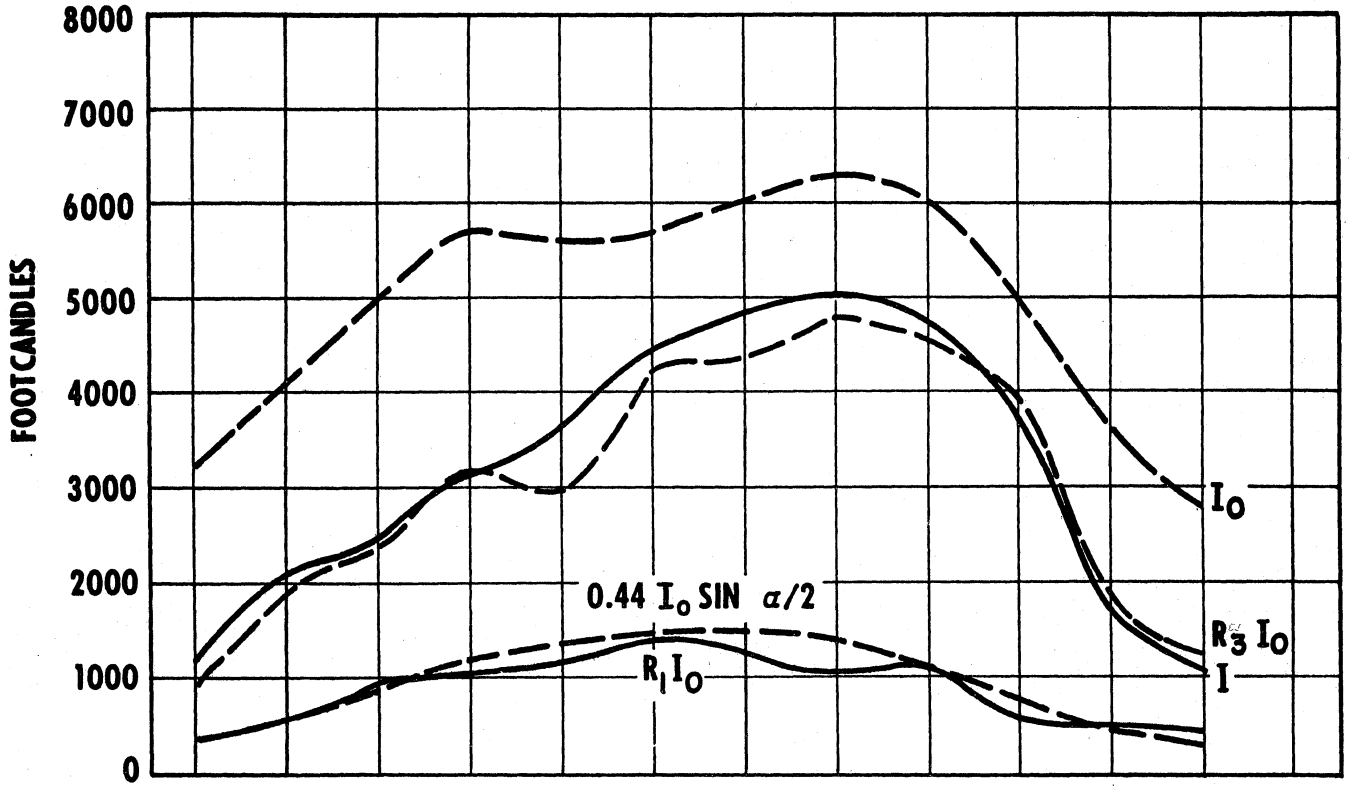
East vertical surface in A.M.

West vertical surface in P.M.

8:00 A.M. to 5:00 P.M.

Calculated and measured

$I = I_0 [S + 0.44(1 - S) \sin \alpha/2]$



31	44	38	43	52	70	75	76	75	70	40	32

PERCENT POSSIBLE SUNSHINE

27.5	35	46	57	66	70.5	69	62	51	40	30	25.5

AVERAGE NOON SUN ALTITUDE

Fig. 17