Solar climate of the Swedish territory. Selected problems

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ABSTRACT

Calculation methods based on the available photometric and actinometric measurements which allow for a rapid and simple way of obtaining the necessary data concerning conditions of radiation and daylight have been adapted for determining some selected problems of "Solar Climate of the Swedish Territory". In these methods all the components of radiation and daylight are expressed as a function of solar altitude. Therefore it is very important to have an easy and simple way of determining the solar altitudes for different latitudes, months and hours. For this reason a special diagram has been elaborated. The present diagrams make it possible to determine the intensity of radiation and daylight for every point of the Swedish territory (not only for the points of measurements) and also for clear sky conditions (not only for average conditions during the observation period).

Preface

The components of external climate such as intensity, duration and spectrum of radiation and daylight are important and they have a considerable influence on man. From the published research results it is known that solar radiation and daylight activate different endocrine glands, important for efficient activity of our organism. Variability of radiation and daylight stimulates the psychological as well as intellectual activity of man.

The relation between architecture and radiation climate is never more evident than in the daily discussions which arise concerning illumination, fuel consumption, window design, orientation of façades, insolation through roof-lights, obstructions to sunlight, etc. The temperature, to which mankind is very sensitive, depends on radiation.

Recently there has been observed a growing tendency to delve into the secrets of nature when one tries to solve different problems of town-planning, architecture, lighting and air-conditioning of the interiors, etc. (Pleijel, 1954; Aronin, 1959; Hutin, 1968; Chróścicki, 1969).

But the data concerning the determination of changes of the intensity of radiation and daylight per unit of time, have not been found so far. Only fragmentary measurement materials at different geographical points are available (Dorno, 1921; Kimball, 1924; Aurén, 1930; Blackwell, 1953; Sauberer, 1956; Dogniaux, 1954, Wörner, 1962; Oleszyński, 1965; Dresler, 1962; Lunelund, 1924 et al.)

In principle, the results of those observations have given us daily, monthly or yearly sums of "total" radiation and daylight intensity on a horizontal plane, average conditions during an observation period. These data include the influence of physical, geographical and meteorological factors of a given measurement point.

All the above publications have given only a general picture of radiation and daylight climate of one region or another. But when one wants to resolve problems which require a knowledge of the values of radiation and daylight intensity for given meteorological conditions at a particular moment at a given geographical point, the above-mentioned results cannot be used because the data being measured differ considerably from the average values for prolonged periods several years lasting.

The fact that these problems are in most cases neglected or mishandled is due to defective knowledge about natural radiation, and also because present methods of calculation are laborious, difficult and slow. Having found that daylight level outdoors does not depend on the geographical latitude of the place of measurement or on its altitude (Bartyneva & Guseva, 1957; Bartyneva & Polakova, 1965; Drummond, 1958; Dogniaux, 1960; Berliand, 1962; Day, 1961; Sharonov, 1958) the writer worked out calculation methods based on the available photometric and actinometric measurements which allow for a rapid and simple way of obtaining the necessary data concerning conditions of daylight level at any geographical point (Chróścicki, 1968).

Three components of daylight have been given: (*a*) "total" illumination, *Ec*, generated by sun and sky; (*b*) "direct" illumination, *Eb*, generated by sun only; (*c*) "diffuse" illumination *Er*, generated by sky only. (Similar nomenclature with reference to three components of radiation is used below)

A fairly good agreement between the measured values and the calculated different components of daylight (Chróścicki, 1968) encouraged the author to adapt the basic idea and to work out the same calculation method concerning the different components of solar radiation.

The present work dealing with some selected problems of "Solar Climate of the Swedish Territory" is an attempt at a practical application of the above-mentioned calculation methods and a verification of these methods by using the Swedish measurements of radiation and daylighintensity.

This work is, at the same time, a continuation of Dr Gunnar Pleijel's work *The Computation of Natural Radiation in Architecture and Town Planning* (1954). The meteorological basic material on which Dr Pleijel based his study consisted mainly of the measurements and recordings made by Professor Harald Lunelund at the University of Helsinki. I have had an opportunity to use the genuine Swedish measurements for my work.

Given time values are true solar time.

Solar radiation

As basic material for the analysis the measurements of "total" radiation on a horizontal plane, average values during the periods of observation from ten stations; Kiruna, Luleå, Teg, Frösön, Karlstad, Stockholm, Torslanda, Visby, Svalöv and Malmö, were used. All the points of measurement of radiation and daylight intensity analysed in this work are shown in Fig. 1.

The formulae for "total", "direct" and "diffuse" radiation for clear sky conditions on a horizontal plane have been verified on the basis of Russian measurements (Barashkova & others, 1961). From these measurements suitable data were selected for latitudes 54°–68° (which cover the entire Swedish territory) and confronted with the adequate solar altitude. The results are shown in Fig. 6.

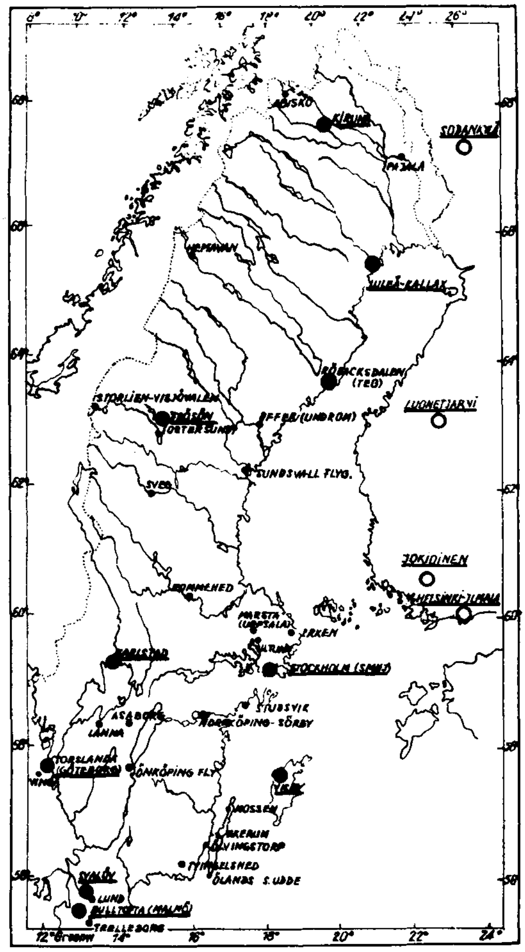

Fig. 1.

Since one can have doubts whether Russian measurements can be adapted for Swedish territory, additional verification with the use of measurements of "total" radiation on selected clear days in Stockholm has been made. In Fig. 6 we can see a good agreement between Russian and Swedish measurements.

The measurements for verification of the formulae for "total" radiation on a horizontal plane

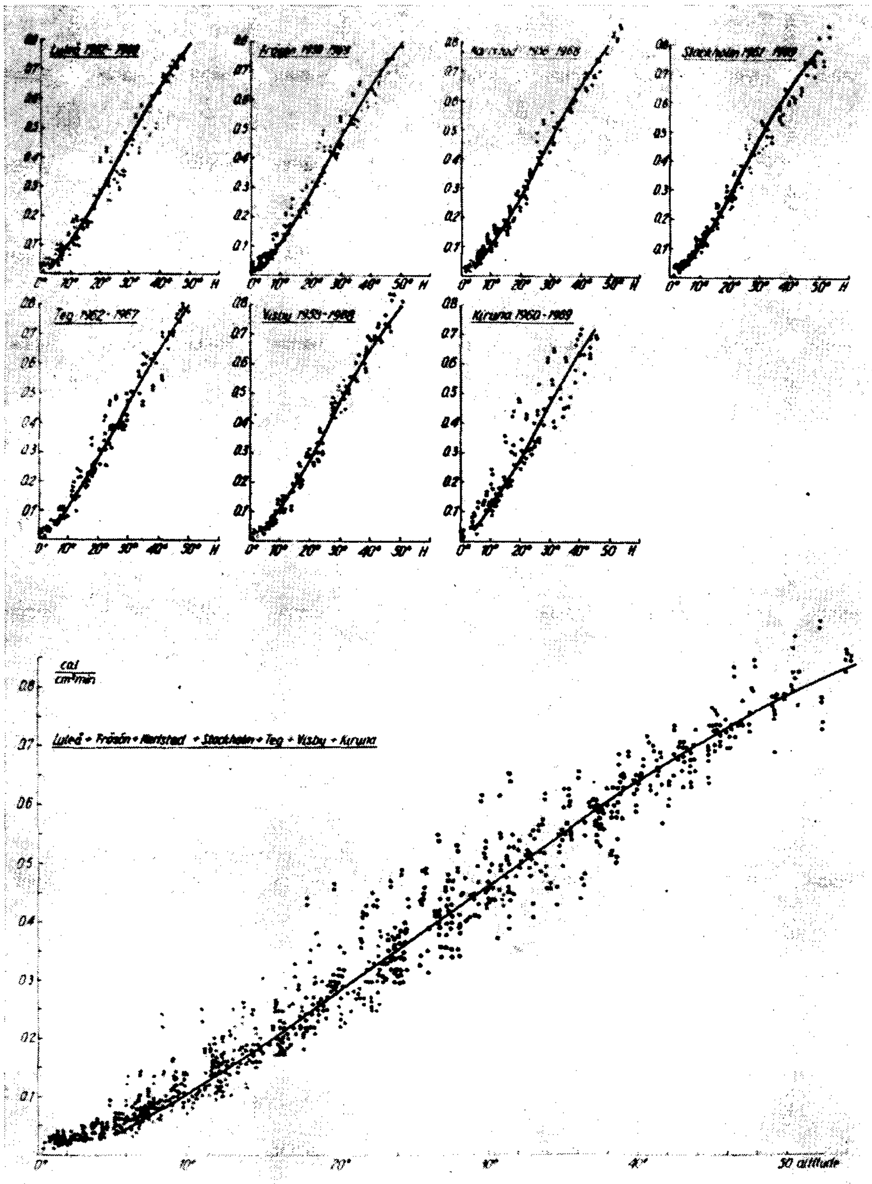

Fig. 2.

—average conditions during the period of observation for ten stations, evenly distributed over the entire territory of Sweden, are shown in Figs. 2 and 3. From these figures we can see that all measurement stations in Sweden can be divided into two groups with slightly different results. One group, containing seven stations, Kiruna, Luleå, Teg, Frösön, Karlstad, Stockholm, Visby, has approximately the same results and the other group, Torslanda, Malmö, Svalöv, also has approximately the same results.

When we put together measurements from all the ten stations (Fig. 4) the results differ by about $\pm 5\%$ from the above-mentioned two groups.

It is interesting that the results concerning

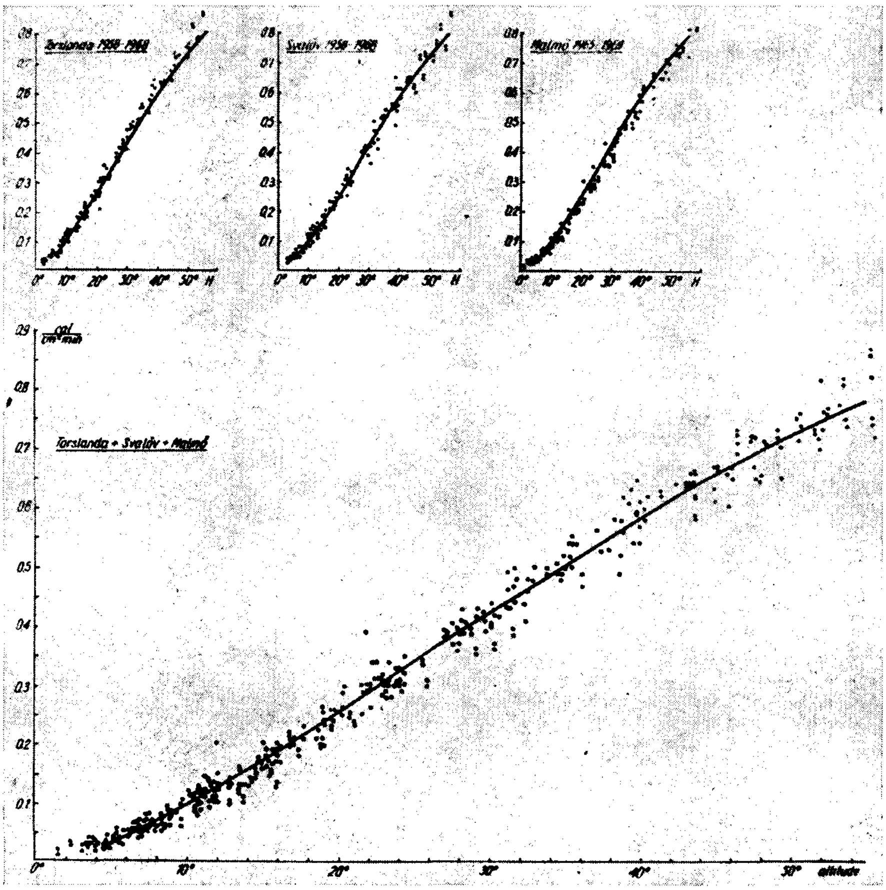

Fig. 3.

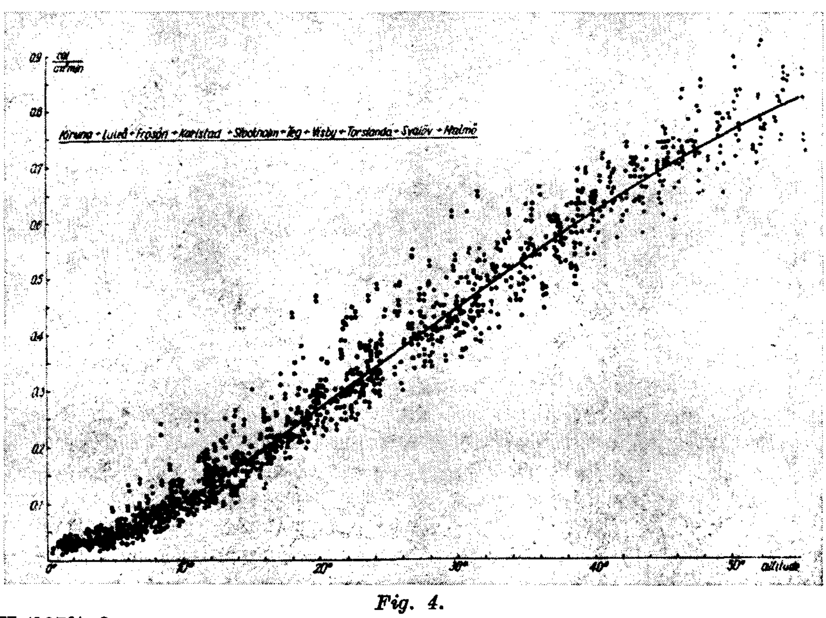

Fig. 4.

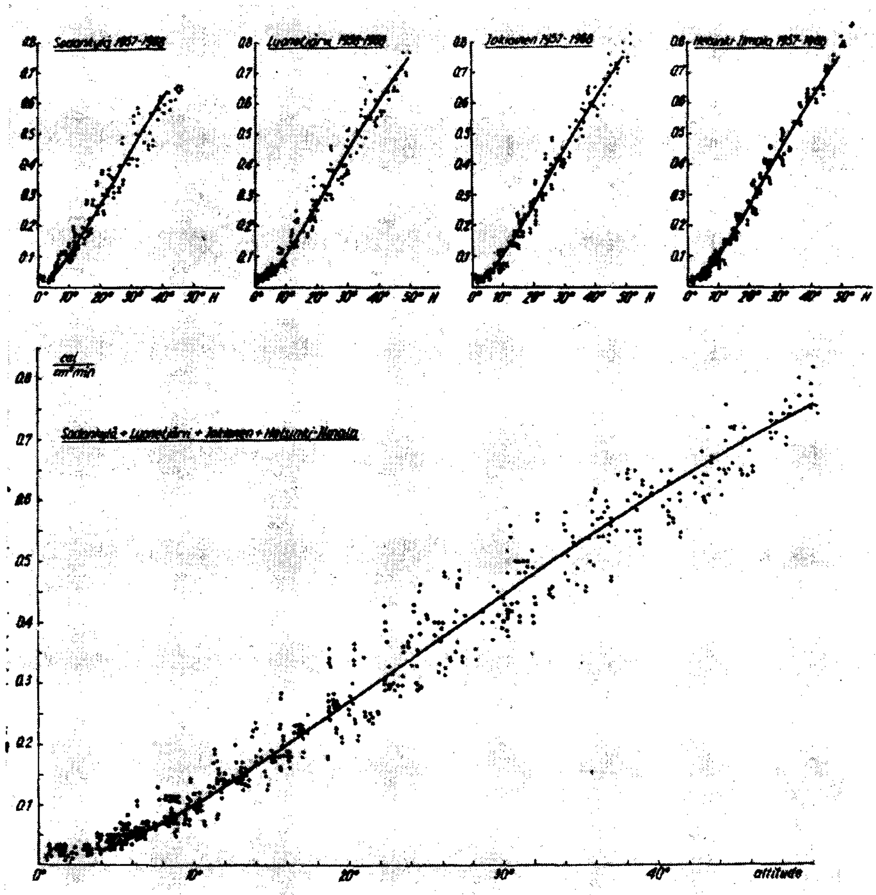
altitude

Fig. 5.

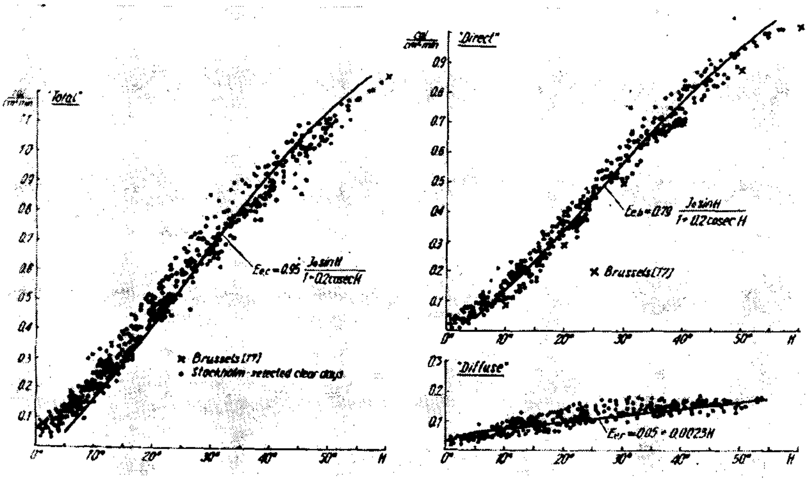
"Total"
"Direct"
"Diffuse"
× Brussels [77]
• Stockholm - selected clear days

Fig. 6.

the ten stations, i.e., for the entire Swedish territory, are exactly the same as the results of prolonged measurements of "total" radiation in Finland, see Fig. 5. This is why the author suggests the acceptance of these results as a basis for the entire Swedish territory, in spite of the results received from the seven stations situated on the larger part of the Swedish territory are higher than the proposed basis by 5%.

The formulae have been worked out for all the components of radiation:

1. "Total" radiation for clear sky conditions on a horizontal plane[1] (the curve 1 in Fig. 7)

$$Ee, c = 0{,}95\ \frac{Jo \sin H}{1 + 0.2 \operatorname{cosec} H} \quad \text{cal/cm}^2\ \text{min}$$

[1] $J_0 = 1.98$ cal/cm² min – the solarconstant $H =$ solar attitude in degrees

2. "Direct" radiation for clear sky conditions on a horizontal plane (the curve 2 in Fig. 7)

$$Ee, b = 0.79\ \frac{Jo \sin H}{1 + 0.2 \operatorname{cosec} H} \quad \text{cal/cm}^2\ \text{min}$$

3. "Diffuse" radiation for clear sky conditions on a horizontal plane (the curve 6 in Fig. 7)

$$Ee, r = 0.05 + 0.0023\ H \quad \text{cal/cm}^2\ \text{min}$$

4. "Total" radiation on a horizontal plane, average conditions during the periods of observation at seven stations, Kiruna, Luleå, Teg, Frösön, Karlstad, Stockholm, Visby (the curve 3 in Fig. 7)

$$Ee = 0.66\ \frac{Jo \sin H}{1 + 0.2 \operatorname{cosec} H} \quad \text{cal/cm}^2\ \text{min}$$

5. "Total" radiation on a horizontal plane, average conditions during the periods of observation at three stations, Torslanda, Svalöv, Malmö (the curve 4 in Fig. 7)

$$Ee = 0.60\ \frac{Jo \sin H}{1 + 0.2 \operatorname{cosec} H} \quad \text{cal/cm}^2\ \text{min}$$

6. "Total" radiation on a horizontal plane, average conditions during the periods of observation at the ten above-mentioned stations, suggested for the whole territory of Sweden (the curve 5 in Fig. 7)

$$Ee = 0.63\ \frac{Jo \sin H}{1 + 0.2 \operatorname{cosec} H} \quad \text{cal/cm}^2\ \text{min}$$

7. "Total" radiation on a horizontal plane, average conditions during the periods of observation at four Finnish stations, Sondakylä, Luonetjärvi, Jokioinen, Helsinki-Ilmala

$$Ee = 0.63\ \frac{Jo \sin H}{1 + 0.2 \operatorname{cosec} H} \quad \text{cal/cm}^2\ \text{min}$$

The resultant curves of the relationship between all the components of radiation on a horizontal plane and the solar altitude are shown in Fig. 7.

The formula

$$Ee = 0.63\ \frac{Jo \sin H}{1 + 0.2 \operatorname{cosec} H}$$

proposed for "total" radiation on a horizontal plane (average conditions) provides a simple method of re-calculating at different latitudes the values of total radiation measured at the ten stations. The results of the calculation are shown in Fig. 8.

On the basis of these data for latitude 60°, the curves showing the mean periods with "total" radiation on a horizontal plane exceeding 0.05, 0.15, 0.25, 0.35, 0.45, 0.55, 0.65, 0.745 cal/cm² min (Fig. 9) and mean number of hours with "total" radiation on a horizontal plane exceeding 0.05, 0.15, 0.25, 0.35, 0.45, 0.55, 0.65, 0.75 cal/cm² min (Table 1) were elaborated as just one from many other possible examples.

Table 1. *Mean number of hours with "total" radiation on a horizontal plane exceeding, 0.05, 0.15, 0.25, 0.35, 0.45, 0.55, 0.65, 0.75, cal/cm² min, for latitude 60°, average conditions*

	cal/cm² min							
Month	0.05	0.15	0.25	0.35	0.45	0.55	0.65	0.75
I	105	–	–	–	–	–	–	–
II	190	112	–	–	–	–	–	–
III	300	245	186	105	–	–	–	–
IV	368	318	267	210	150	84	–	–
V	462	400	347	300	248	189	130	–
VI	485	445	372	324	276	225	177	102
VII	483	425	272	319	266	217	167	80
VIII	431	469	316	263	204	142	80	–
IX	344	279	222	165	102	–	–	–
X	264	186	102	–	–	–	–	–
XI	141	–	–	–	–	–	–	–
XII	50	–	–	–	–	–	–	–

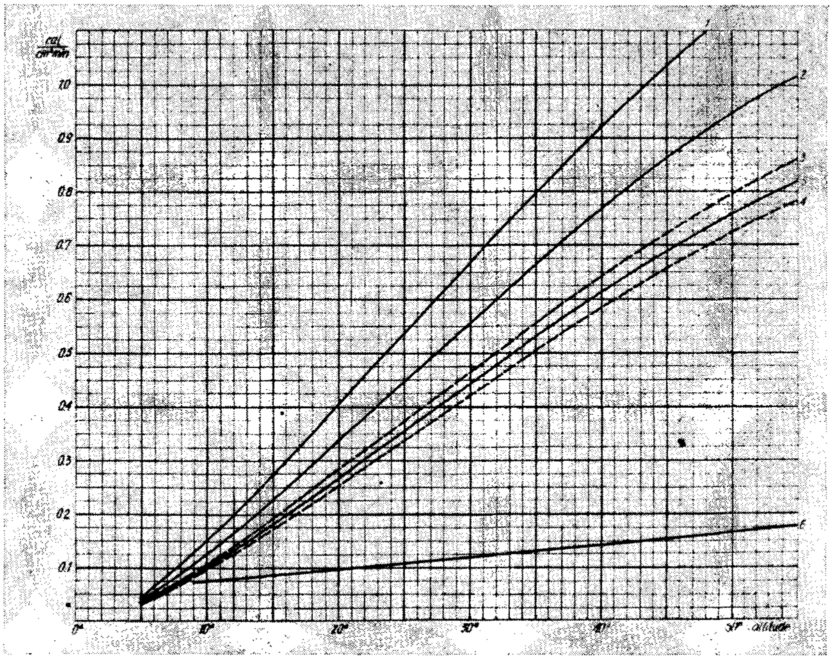
cal/cm²min
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0°
10°
20°
30°
40°
50° altitude
1
2
3
4
5
6

Fig. 7.

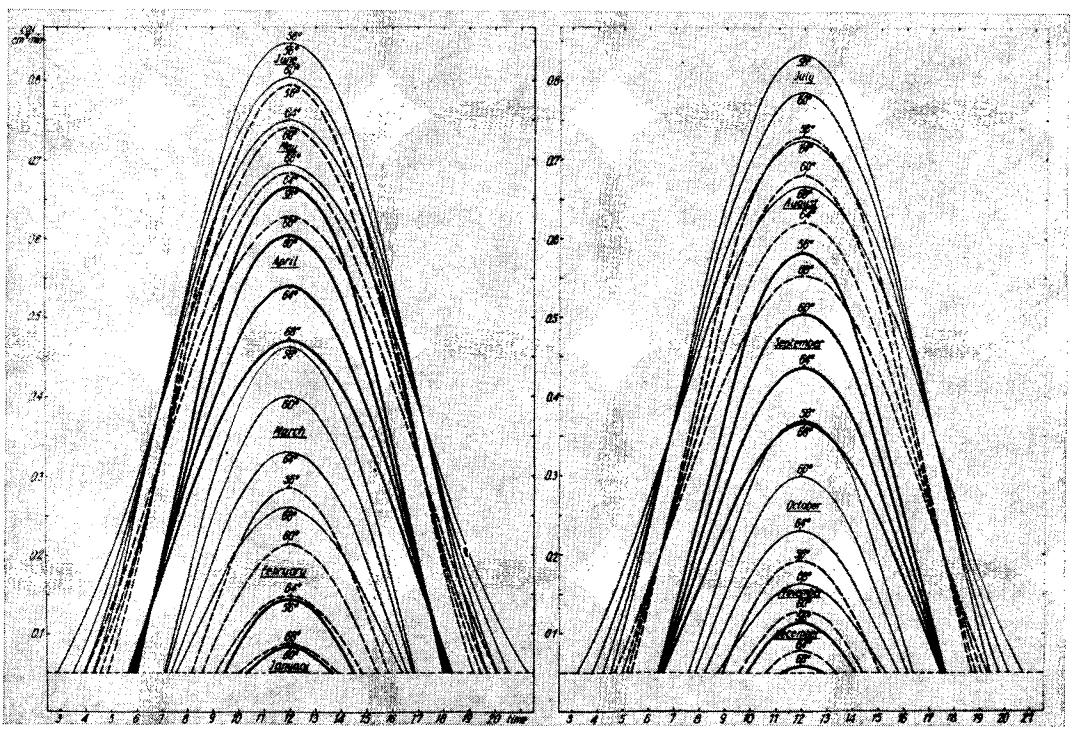
cal/cm²min
June
May
April
March
February
January
July
August
September
October
November
December
time

Fig. 8.

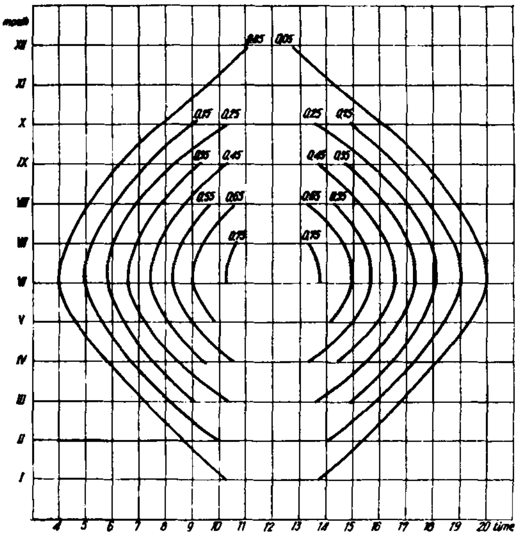

Fig. 9.

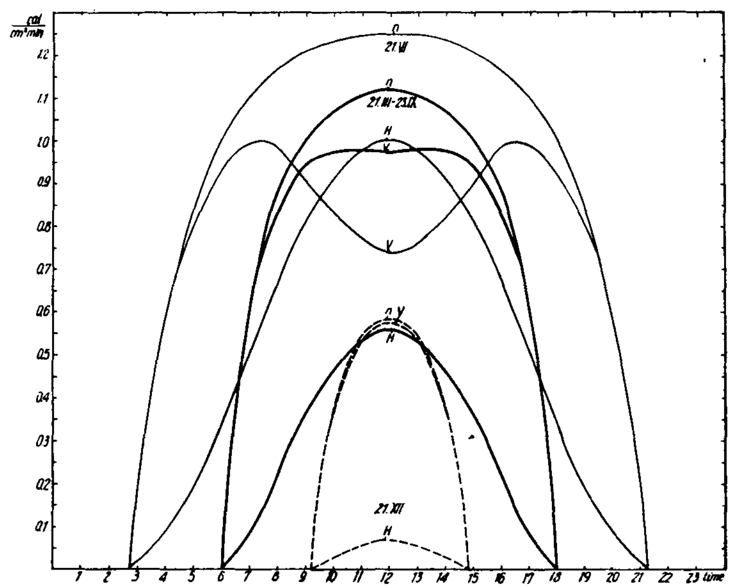

Fig. 10.

In addition, for special dates of the year, 21 June, 21 December (summer and winter solstice) and 21 March, 23 September (vernal and autumnal equinox) "direct" radiation for clear sky conditions on differently situated planes was calculated. The results are shown in Fig. 10.

Daylight

The measurements for verification of the formula for "total" illumination on a horizontal plane, average conditions during the periods of observation for three stations, Kiruna, Stock-

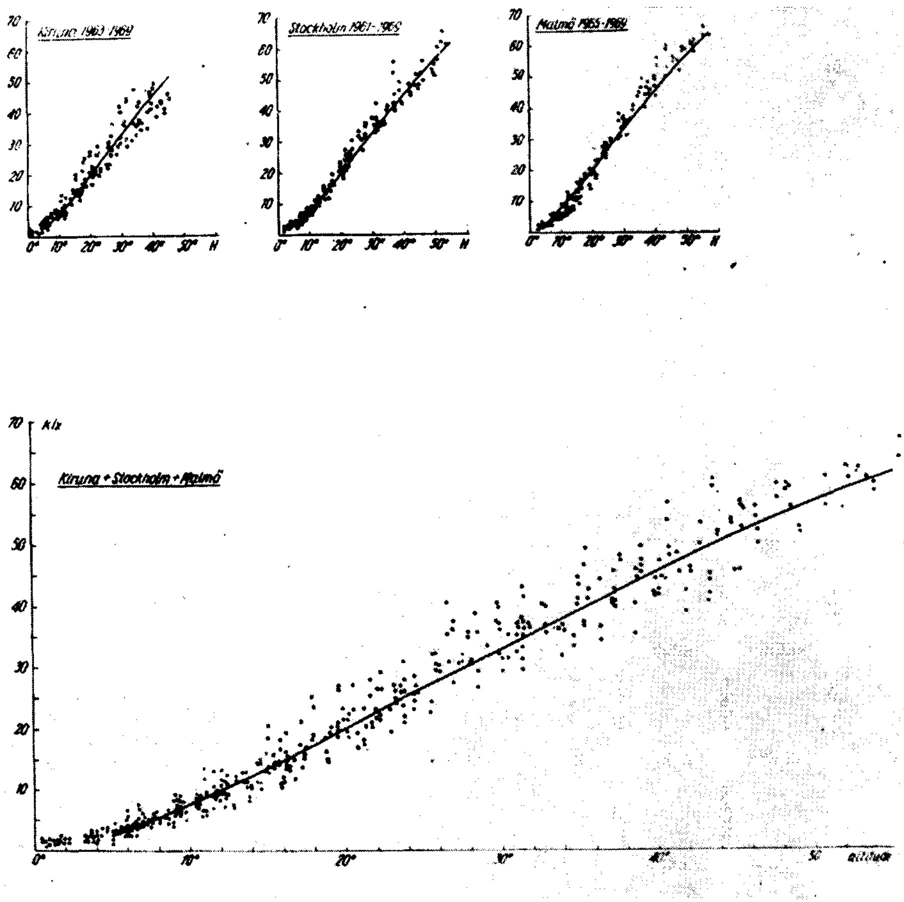

Fig. 11.

holm, and Malmö, situated at three widely-spread points of the Swedish territory, are shown in Fig. 11.

The formulae for "total", "direct" and "diffuse" illumination for clear sky conditions on a horizontal plane and the formula for "illumination equivalent" of solar radiation (for clear sky conditions on a horizontal plane) have been substantiated in the publication (Chróścicki, 1968).

In the present work only the final corrected results are quoted.

The formulae have been worked out for all the components of daylight:

1. "Total" illumination for clear sky conditions on a horizontal plane (the curve 1 in Fig. 14)

$$Ec = 62\,\frac{Jo \sin H}{1 + 0.2 \operatorname{cosec} H}\,10^3\,\mathrm{lx}$$

2. "Direct" illumination for clear sky conditions on a horizontal plane (the curve 2 in Fig. 14)

$$Eb = 51\,\frac{Jo \sin H}{1 + 0.2 \operatorname{cosec} H}\,10^3\,\mathrm{lx}$$

3. "Diffuse" illumination for clear sky conditions on a horizontal plane (the curve 4 in Fig. 14)

$$Er = (3 + 0.17\,H)\,10^3\,\mathrm{lx}$$

4. "Illumination equivalent" of "total", "direct" and "diffuse" radiation for clear sky conditions on a horizontal plane (the curve in Fig. 12)

$$e_w = 41\,400\,H^{0.1252}\,\mathrm{lx}\,/\mathrm{cal/cm^{-2}\,min^{-1}}$$

Additionally, in this work detailed calculations of daylight intensity for clear sky condi-

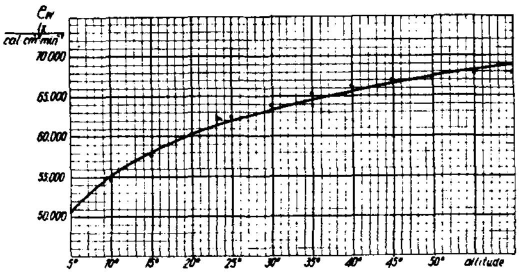

Fig. 12.

tions on a horizontal plane by using the formula for "illumination equivalent" and Russian measurements of solar radiation (Barashkova et al. 1961) were elaborated for latitudes 56°–68° N.

Also, additional verification on the use of measurements of "total" illumination on selected clear days in Stockholm has been made. The results are shown in Fig. 13. In this figure we can observe a fairly good agreement between the values of all the components of daylight for clear sky conditions calculated by using the "illumination equivalent" with the ones determined by using the above-mentioned formulae.

The resultant curves of the relationship between all the components of daylight on a horizontal plane and the solar altitude are shown in Fig. 14.

As measurements of daylight intensity in Sweden have been undertaken only at three stations, Kiruna, Stockholm and Malmö, the problem

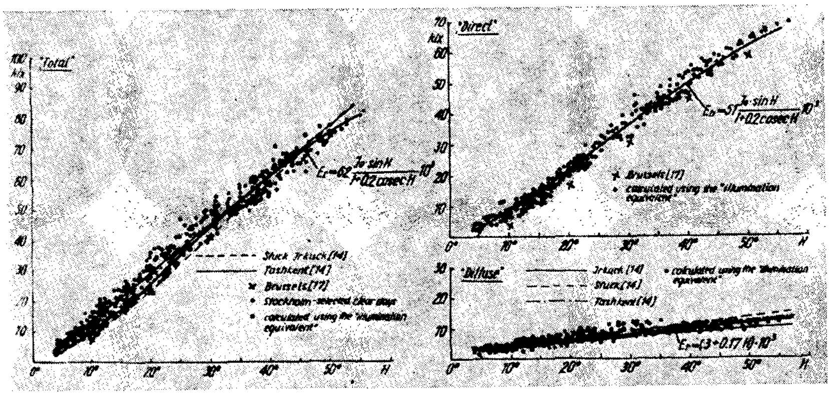

Fig. 13.

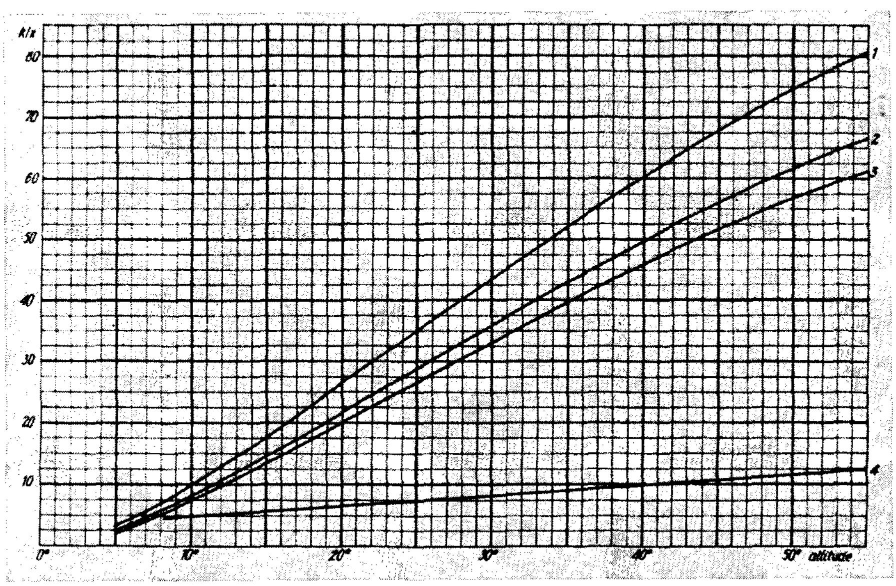

Fig. 14.

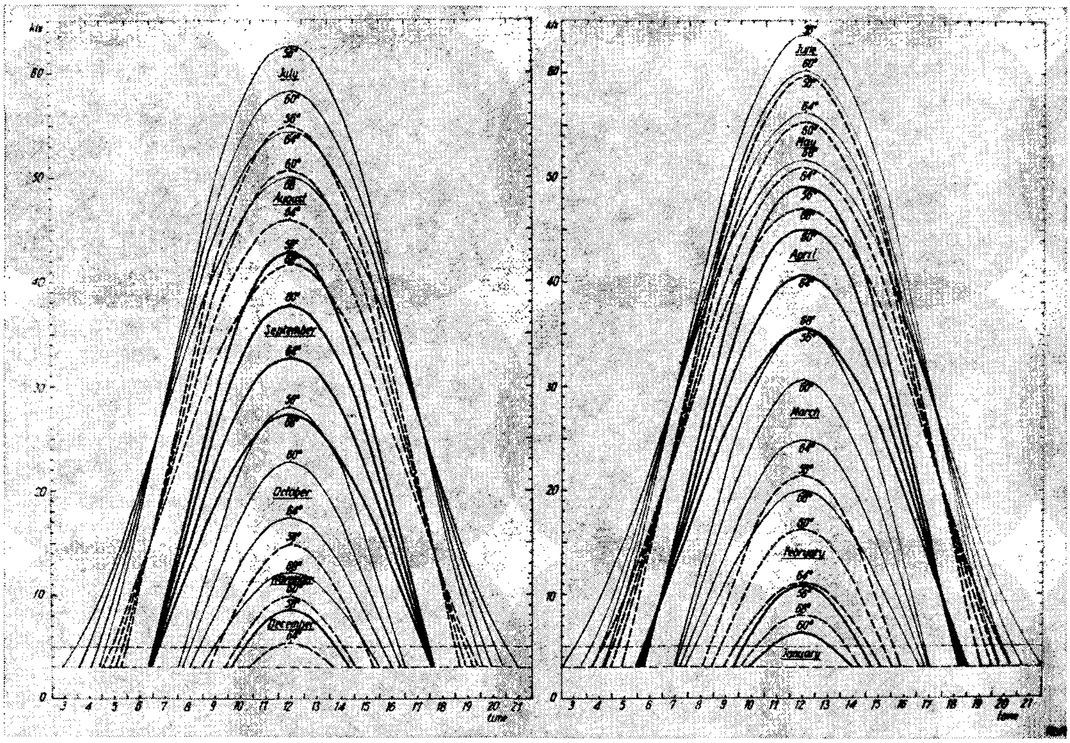

Fig. 15.

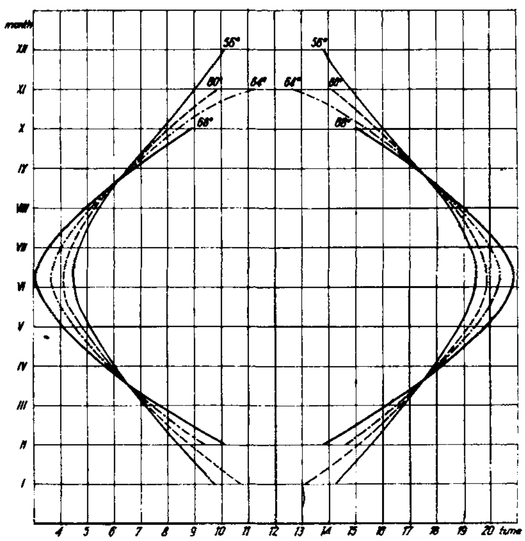

Fig. 16.

arose as to how the results of observations obtained at those three points could be re-calculated for the entire territory of Sweden. As a result of the analysis of the Swedish measurement materials, we proposed the following formula for "total" illumination on a horizontal plane, average conditions during the period of observations (the curve 3 in Fig. 14).

$$E = 47 \frac{Jo \sin H}{1+0.2 \operatorname{cosec} H} 10^3 \,\mathrm{lx}$$

This formula gives us a simple way to re-calculate at different latitudes the values of "total" illumination measured at three stations. The results of the calculation are shown in Fig. 15.

On the basis of these data for latitudes 56°, 60°, 64°, 68° N, the curves showing the mean periods with "total" illumination on a horizontal plane exceeding 5 000 lx (Fig. 16) and the mean number of hours with "total" illumination on a horizontal plane exceeding 5 000 lx (Table 2) were elaborated. This gives us a possibility to calculate the number of hours of exploitation of artificial lighting dependent on periods of utilization of interior and latitudes.

In additional, for special dates of the year, 21 June, 21 December (summer and winter solstice)

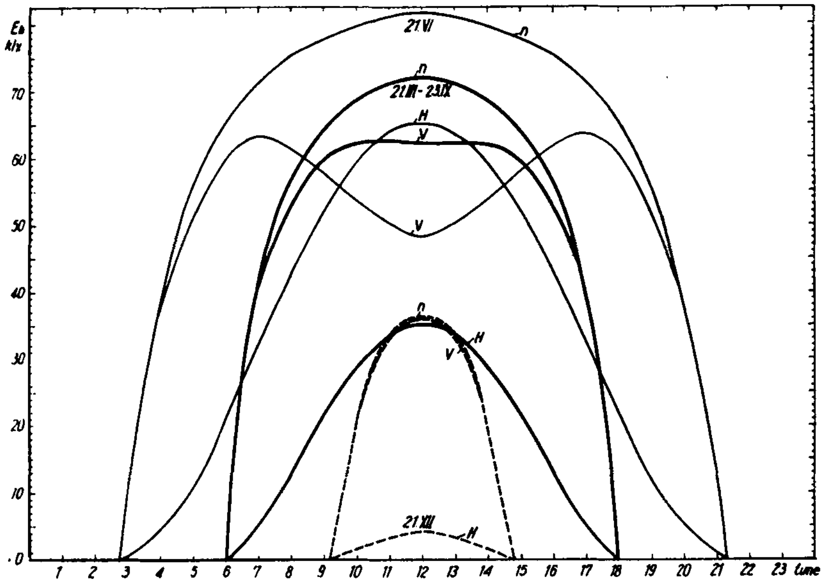
Eb
klx
70
60
50
40
30
20
10
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Fig. 17.

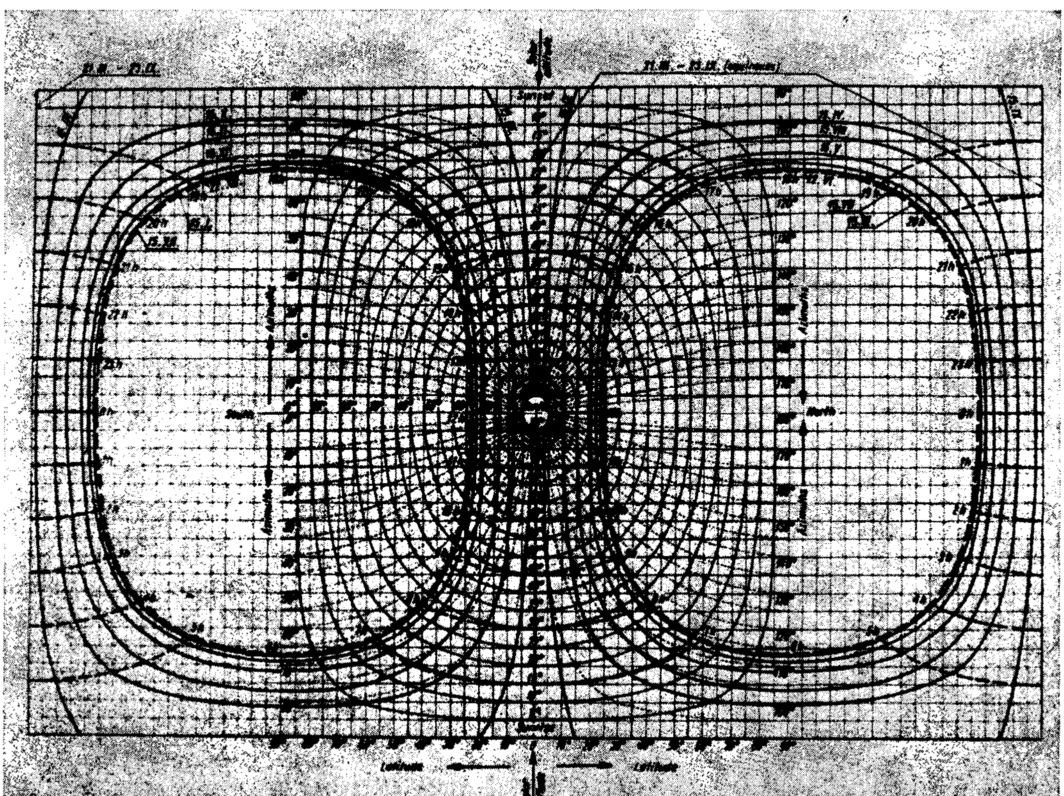

Fig. 18.

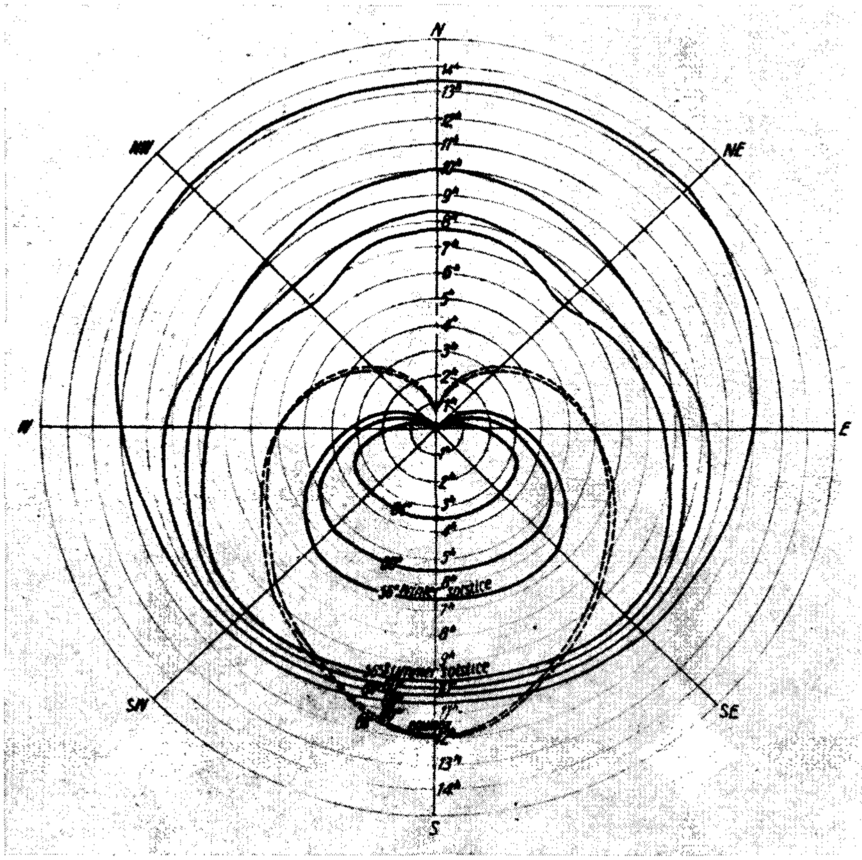

Fig. 19.

Table 2. *Mean number of hours with "total" illumination on a horizontal plane exceeding 5 000 lx, for latitudes 56°, 60°, 64°, 68°, average conditions*

	Latitude			
Month	56°	60°	64°	68°
I	140	75	–	–
II	202	179	148	98
III	298	293	289	264
IV	354	360	366	378
V	425	447	462	483
VI	450	471	498	531
VII	453	472	496	522
VIII	403	412	425	437
IX	324	318	315	321
X	254	245	220	192
XI	174	128	42	–
XII	112	–	–	–

and 21 March, 23 September (vernal and autumnal equinox) "direct" illumination for clear sky conditions on different situated planes was calculated. The results are shown in Fig. 17.

Solar altitude and insolation

Since all the components of radiation and daylight are expressed as a function of solar altitude, it is very important to have an easy and simple way of determining the solar altitudes for different latitudes, months and hours.

Therefore a special diagram (Dourgnon, 1966; Chróścicki, 1968) for determining azimuths and altitudes of sun, dependent on latitudes, dates, and hours, is given in Fig. 18.

In addition, for special dates of the year, 21 June, 21 December (summer and winter solstice) and 21 March, 23 September (vernal and autumnal equinox) the curves showing the greatest possible insolation as the function of orientation of elevations are shown in Fig. 19.

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СОЛНЕЧНЫЙ КЛИМАТ ШВЕДСКОЙ ТЕРРИТОРИИ

Вычислительные методы, основанные на доступных результатах фотометрических и актинометрических измерениях, позволяющие в простой и доступный способ быстро получить необходимые для практических применений данные, касающиеся так условий радиации, как и наружной освещенности были использованы для определения «Солнечного климата территории Швеции«.

Вследствие того, что в этих методах все компоненты радиации и наружной освещенности были представлены как функции высоты солнца стало существенным, чтобы иметь в диспозиции понятный и прямой метод определения высоты солнца для разных дат, часов и географических координат.

Для этого разработано особенный график.

Представленные графики дают возможность определения интенсивности радиации и наружной освещенности не только в пунктах измерений, а также в любом пункте территории Швеции, дают возможность определения данных не только для реальных условий, выступающих во время измерений, но и тоже для условий безоблачного неба.