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REDLINE VERSION

INTERNATIONAL STANDARD

colour inside

Classification of environmental conditions –
Part 2-4: Environmental conditions appearing in nature – Solar radiation and temperature

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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CLASSIFICATION OF ENVIRONMENTAL CONDITIONS –

Part 2-4: Environmental conditions appearing in nature – Solar radiation and temperature

FOREWORD

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International Standard IEC 60721-2-4 has been prepared by IEC technical committee 104: Environmental conditions, classification and methods of test.

This second edition cancels and replaces the first edition published in 1987 and Amendment 1:1988. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) Figures updated including the addition of global irradiation information,

b) Format updated.

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CLASSIFICATION OF ENVIRONMENTAL CONDITIONS –

Part 2-4: Environmental conditions appearing in nature – Solar radiation and temperature

1 Scope

This part of IEC 60721 presents a broad division into types of solar radiation areas. It is intended to be used as part of the background material when selecting appropriate severities of solar radiation for product applications.

All types of geographical areas are covered, except areas with altitudes above 5 000 m.

~~When selecting severities of solar radiation for product applications, the values which are given in IEC 60721-1 should be applied.~~

~~2 Object~~

This document also serves to define limiting severities of solar radiation to which products are liable to be exposed during transportation, storage and use.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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4 General

Solar radiation can affect products primarily by the heating of material and their environment or by photochemical degradation of material.

~~The~~ Solar radiation, especially its ultraviolet content ~~of solar radiation~~, causes photochemical degradation of most organic materials. Elasticity and plasticity of certain rubber compounds and plastic materials are affected. Optical glass may become opaque.

Solar radiation bleaches out colours in paints, textiles, paper, etc. This can be of importance, for example for the colour-coding of components.

The heating of material is ~~the most important effect~~ a consequence of exposure to solar radiation. The presentation of severities of solar radiation is therefore related to the power density radiated towards a surface, or irradiance, expressed in W/m^2.

An object subjected to solar radiation will attain a temperature that depends primarily on the surrounding air temperature, the energy radiated from the Sun, and the incidence angle of the radiation on the object. Other factors, for example wind and heat conduction to mountings, can be of importance. In addition, the absorptance α_s of the surface for the solar spectrum is of importance.

An artificial air temperature t_s may be defined, which, under steady-state conditions, results in the same surface temperature of an object as the combination of the actual air temperature t_u and the solar radiation of the irradiance E.

An approximate value can be obtained from the following equation:

$$t_s = t_u + \frac{\alpha_s \cdot E}{h_y}$$

The coefficient h_y is the heat transfer coefficient for the surface, in W/(m^2 · °C). It includes thermal radiation to the surroundings, heat conduction of the surface material and convection due to wind.

The absorptance α_s, depends on the thermal colour, the reflectance and the transmittance of the surface.

Typical clear sky values for common materials are:

α_s = 0,7

h_y = 20 W/(m^2 · °C)

E = 900 W/m^2

resulting in an "over temperature" due to solar radiation of about 30 °C. It can then be seen that an error of 10 % in the estimation of the intensity of the solar radiation will influence the temperature involved by less than 5 °C. Therefore, there is no need in this classification for extremely accurate severities of solar radiation and minor factors affecting the heat radiated have therefore been disregarded here.

The heating effect is caused mainly by short-term radiation of high intensity, i.e. the solar radiation around noon on cloudless days. Such values are presented in Table 1.

It may also be of interest to identify the lowest possible value of atmospheric radiation during clear nights in order to determine the “under temperature” of products exposed to the night sky.

~~Such values are given in figure 1.~~

5 Solar radiation physics

The electromagnetic radiation from the Sun to the Earth covers ~~a rather broad~~ the spectrum from the ultraviolet to the near infra-red. Most of the energy reaching the surface of the Earth is in the wavelength range of 0,3 µm to 4 µm with a maximum in the visible range around 0,5 µm. Typical spectra are shown in Figure 1.

The amount of radiant energy from the Sun which falls upon the unit area of a plane normal to the Sun's rays just outside the atmosphere at the mean distance from the Earth to the Sun is called the solar constant. Its value is ~~approximately 1,37 kW/m²~~ 1 367 W/m^2 .

The distance from the Earth to the Sun varies during the year, and consequently the radiation varies~~ from approximately 1,41 kW/m² in January to approximately 1,32 kW/m² in July~~.

Approximately 99 % of the energy of the Sun is emitted at wavelengths below 4 μm. Most of the energy below 0,3 μm is absorbed by the atmosphere and does not reach the surface of the Earth. Further absorption and scattering of the radiation takes place, due to particles and gases, during passage through the atmosphere. The scattering of the direct solar radiation in the atmosphere results in diffuse radiation from the sky. Thus, the energy received at a certain place on Earth is the sum of the direct solar radiation and the diffuse solar radiation, which is referred to as "global radiation". From the point of view of heating effects, this sum is of interest and the levels given in this document are therefore related to global radiation.

6 Levels of global radiation

6.1 Maximum levels

The maximum level of global radiation on a clear day occurs at noon. The highest value of the power achieved on a cloudless day at noon at a surface perpendicular to the direction of the Sun depends on the content of aerosol particles, ozone and water vapour in the air. It varies considerably with geographical latitude and type of climate.

The global radiation on a surface perpendicular to the direction of the Sun ~~may~~ can reach a value of 1 120 W/m² in a range of 280 nm to 3 000 nm at noon on a cloudless day with approximately 1 cm of water vapour content, 2 mm of ozone and aerosols of β = 0,05, where β is the Ångström turbidity coefficient. The value 1 120 W/m² is typical for flat land far away from industrial areas and from large cities at solar elevations exceeding 60°.

NOTE 1 The water vapour content of a vertical column of the atmosphere is measured as the height, in centimetres, of the corresponding precipitated water. Analogously, the ozone content of a vertical column of the atmosphere is measured as the height of the corresponding ozone column at normal temperature and pressure. The scattering and absorption by aerosol particles is expressed by the Ångström turbidity coefficient, which is the optical depth of the atmosphere with respect to extinction of monochromatic radiation of wavelength λ = 1 μm.

NOTE 2 During partly clouded days the global solar irradiation can increase up to 1 300 W/m² for a few minutes. This short-term phenomenon occurs when the Sun comes out behind the clouds and the radiation is reflected from the edges of the clouds.

The direct solar radiation decreases with increasing turbidity. Turbidity is high in subtropical climates and in deserts where the concentration of particles in the air is high. It is also high in large cities and low in mountainous areas.

The levels in Table 1 are recommended for application as peak values of global irradiance at noon, experienced by a surface perpendicular to the direction of the Sun in a cloudless sky. The level varies only by a few per cent within the hours nearest to noon and can therefore be assumed to be representative for a few hours at a time.

Table 1 – Typical peak values of global irradiance (in W/m² from a cloudless sky)

Area	Large cities	Flat land	Mountainous areas
Subtropical climates and deserts	700	750	1 180
Other areas	1 050	1 120	1 180

6.2 Mean monthly and annual global solar radiation

Whilst the maximum heating effect of solar radiation on a surface is normally dependent on short-term irradiance around noon, the photochemical effects are related to radiation, integrated over time, i.e. irradiation. For the purpose of comparison, daily global irradiation is the most convenient and commonly used value.

In December, the monthly mean average of daily irradiation reaches approximately 10,8 kWh/m^2 close to the South Pole, because of the duration of daylight. Outside the Antarctic area, daily levels reach approximately 8,4 kWh/m^2.

The highest annual mean averages of daily global irradiation, up to 6,6 kWh/m^2, are found mainly in desert areas.

6.3 Simultaneous values of maximum air temperatures and solar radiation

The lowest values of the turbidity coefficient β are found in cold air masses. Therefore, the levels in Table 1 do not occur at the highest values of air temperature.

~~It may be assumed that global irradiance does not reach more than 80 % of the values given in table 1 at the maximum air temperatures given in IEC 60721-2-1.~~

6.4 World distribution of daily global irradiation

For the distribution of daily global irradiation, see Annex A.

7 Minimum levels of atmospheric radiation at night

In cloudless nights when the atmospheric radiation is very low, objects exposed to the night sky will attain surface temperatures below the surrounding air temperature.

The theoretical temperature T_0, in kelvins, of an object in equilibrium with the atmospheric radiation is given by Boltzmann's law:

$$T_0 = \left(\frac{A}{\sigma}\right)^{1/4}$$

where

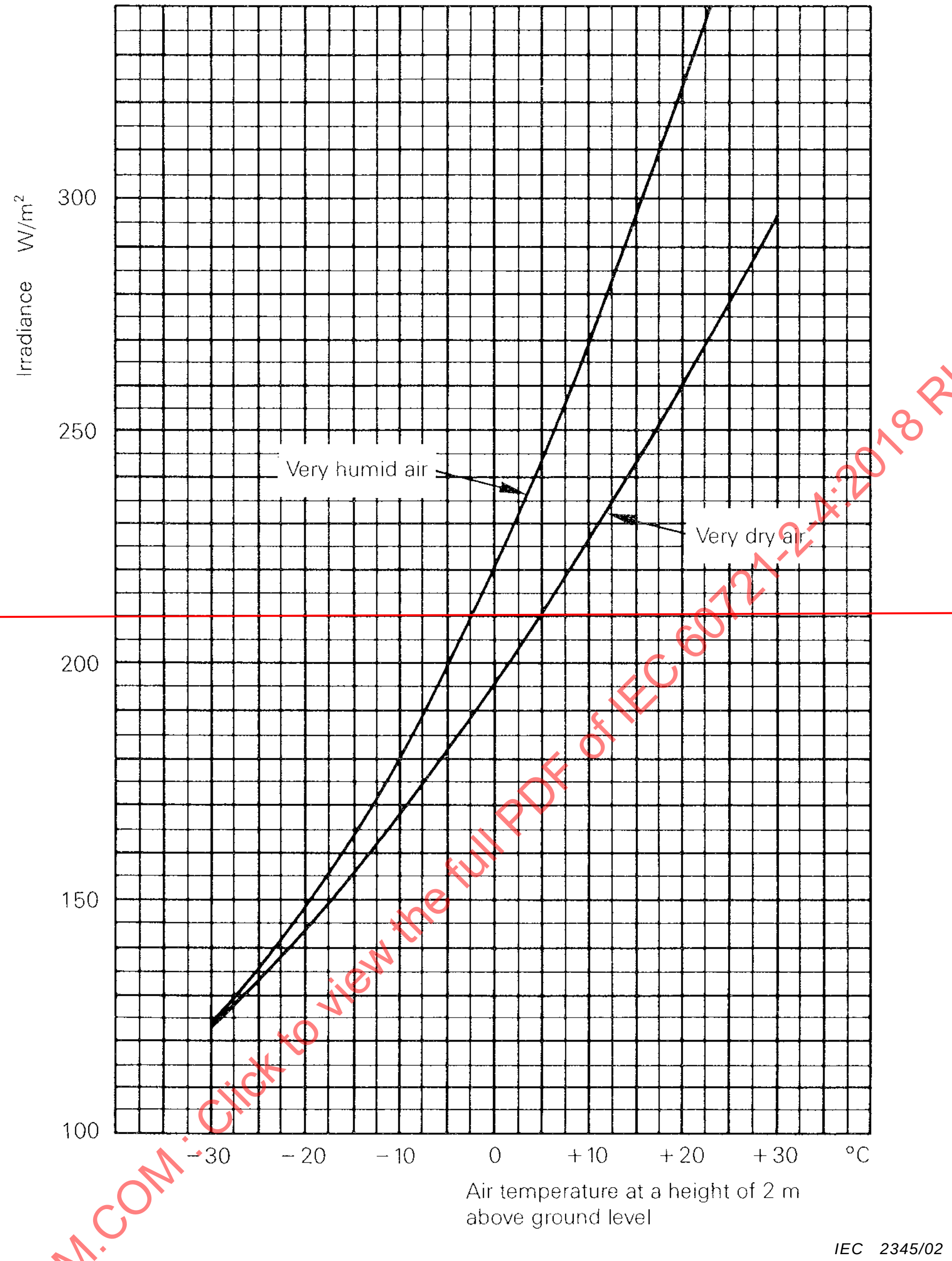
σ is Stefan-Boltzmann's constant, 5,67 · 10^{-8} W/(m^2 · K^4);

A is the atmospheric radiation in W/m^2 ~~(see figure 1)~~.

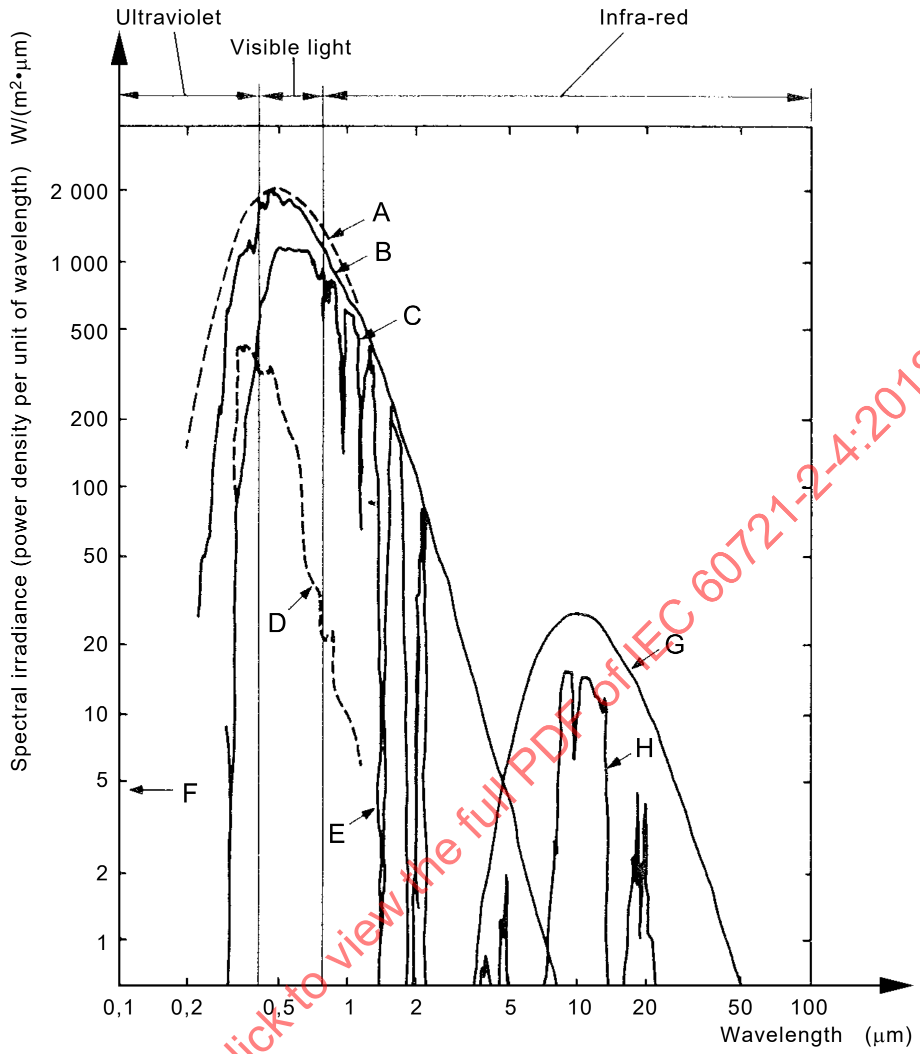
In practice, temperatures will be higher due to heat conduction, convection and water condensation.

As an example, it has been found that the surface of a horizontal disk thermally isolated from the ground and exposed to the night sky during a clear night can attain a temperature of −14 °C when the air temperature is 0 °C and the relative humidity is close to 100 %.

~~Figure 1 shows the atmospheric radiation from the night sky in clear air as a function of air temperature at a height of 2 m above the ground level.~~ The relative humidity is normally very high on clear nights.



~~**Figure 1 – Atmospheric radiation from a clear night sky**~~



A Radiation outside the atmosphere from the Sun represented as a black body at temperature 6 000 K (1,60 kW/m^2)

B Solar radiation outside the atmosphere (1,37 kW/m^2)

C Direct solar radiation at the surface of the Earth perpendicular to the direction of radiation (e.g. 0,9 kW/m^2)

D Diffuse solar radiation at the surface of the Earth (e.g. 0,10 kW/m^2)

E Absorption bands of water vapour and carbon dioxide

F Absorption by oxygen and ozone

G Radiation of a black body at 300 K (0,47 kW/m^2)

H Thermal radiation from the Earth (e.g. 0,07 kW/m^2)

Figure ~~2~~1 – Spectra of electromagnetic radiation from the Sun and the surface of the Earth

Annex A
(informative)

World distribution of daily global irradiation

Figures A.1, A.2 and A.3 are world maps showing isohels of relative global irradiation (June, December and annual mean values), derived from satellite measurements (see [1][1]). Relative global irradiation is defined as the ratio of global irradiation measured at the Earth's surface, divided by the extra-terrestrial global irradiation, which is the solar radiation on a plane perpendicular to the direction of the Sun just outside the atmosphere.

In order to obtain the mean daily value of global irradiation at the Earth's surface, the percentage value shown on the maps should be multiplied by the appropriate mean daily value of extra-terrestrial global irradiation, which is given as a function of geographical latitude in Table A.1.

NOTE The basis for determining the daily irradiation values in kWh/m^2 is the values of monthly and annual irradiation in MJ/m^2 divided by the number of days in June (30), in December (31), and in the year (365).

EXAMPLE:

Determination of the mean daily global irradiation to be expected in June at the southern point of the Californian peninsula.

From Figure A.1, the point (at an approximate geographical latitude of 23° N) is surrounded by an isohel of 60 %, and the percentage value for the point is estimated to be 62 %.

In Table A.1, interpolation for 23° N in the June column gives 11,16 kWh/m^2, which is multiplied by the percentage value above.

The mean daily global irradiation will thus be approximately 6,9 kWh/m^2.

1 Numbers in square brackets refer to the Bibliography.

Table A.1 – Mean daily extra-terrestrial global irradiation (kWh/m²)

Latitude	June	December	Annual
90 N	12,47	0,0	4,17
85 N	12,42	0,0	4,20
80 N	12,28	0,0	4,30
75 N	12,05	0,0	4,49
70 N	11,72	0,0	4,76
65 N	11,40	0,11	5,16
60 N	11,40	0,65	5,71
55 N	11,48	1,36	6,29
50 N	11,56	2,16	6,87
45 N	11,61	3,00	7,42
40 N	11,61	3,85	7,93
35 N	11,56	4,72	8,40
30 N	11,44	5,57	8,82
25 N	11,26	6,40	9,19
20 N	11,00	7,20	9,49
15 N	10,68	7,96	9,73
10 N	10,30	8,68	9,90
5 N	9,84	9,34	10,01
0	9,33	9,95	10,04
5 S	8,76	10,50	10,01
10 S	8,13	10,98	9,90
15 S	7,46	11,39	9,73
20 S	6,74	11,73	9,49
25 S	5,99	12,00	9,19
30 S	5,21	12,19	8,82
35 S	4,41	12,32	8,40
40 S	3,60	12,37	7,93
45 S	2,79	12,37	7,41
50 S	2,01	12,31	6,86
55 S	1,27	12,22	6,29
60 S	0,60	12,13	5,71
65 S	0,10	12,12	5,16
70 S	0,0	12,45	4,75
75 S	0,0	12,80	4,48
80 S	0,0	13,05	4,30
85 S	0,0	13,20	4,20
90 S	0,0	13,25	4,16

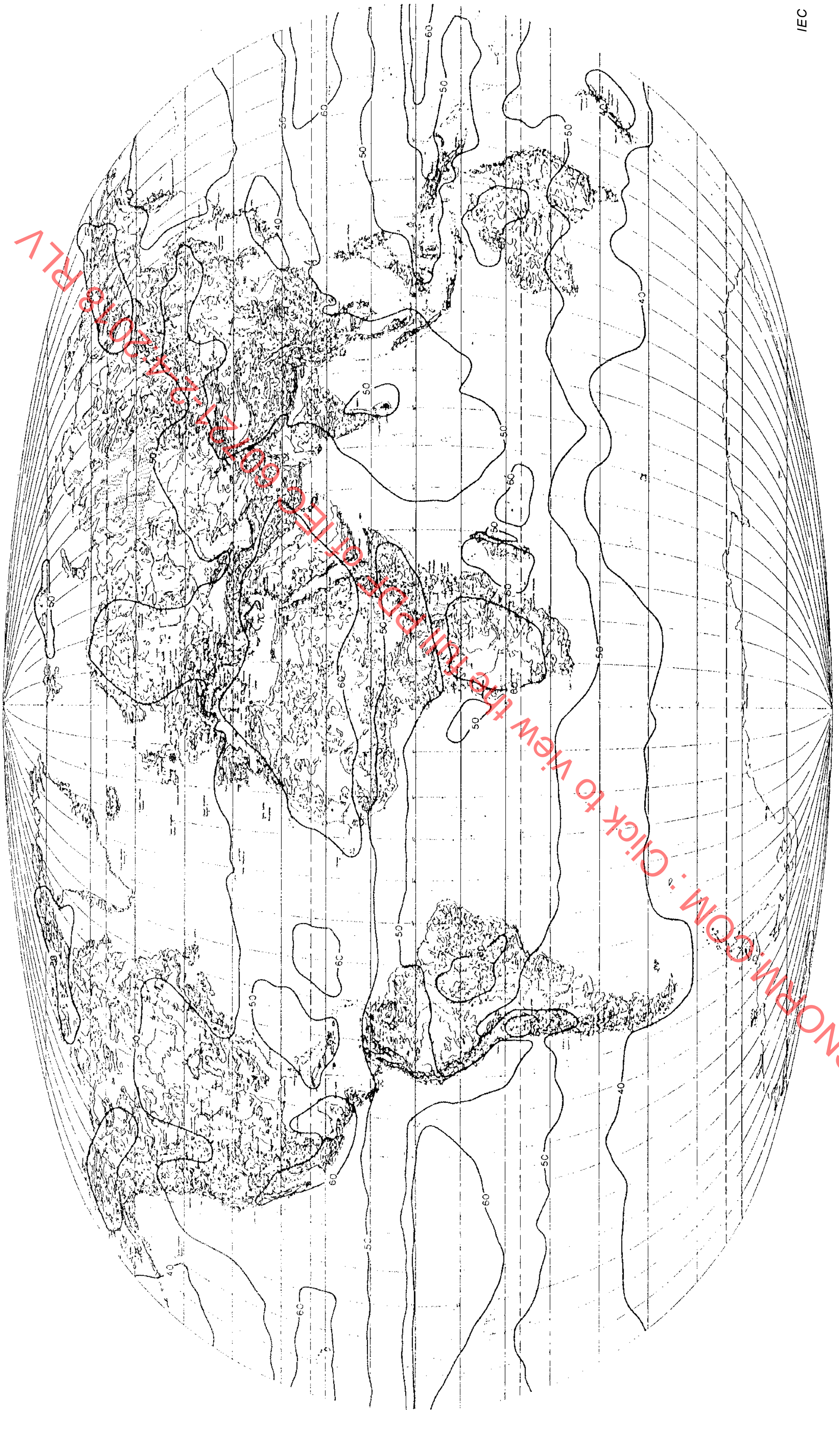


Figure A.1 – Mean relative global irradiation for the month of June (in %)

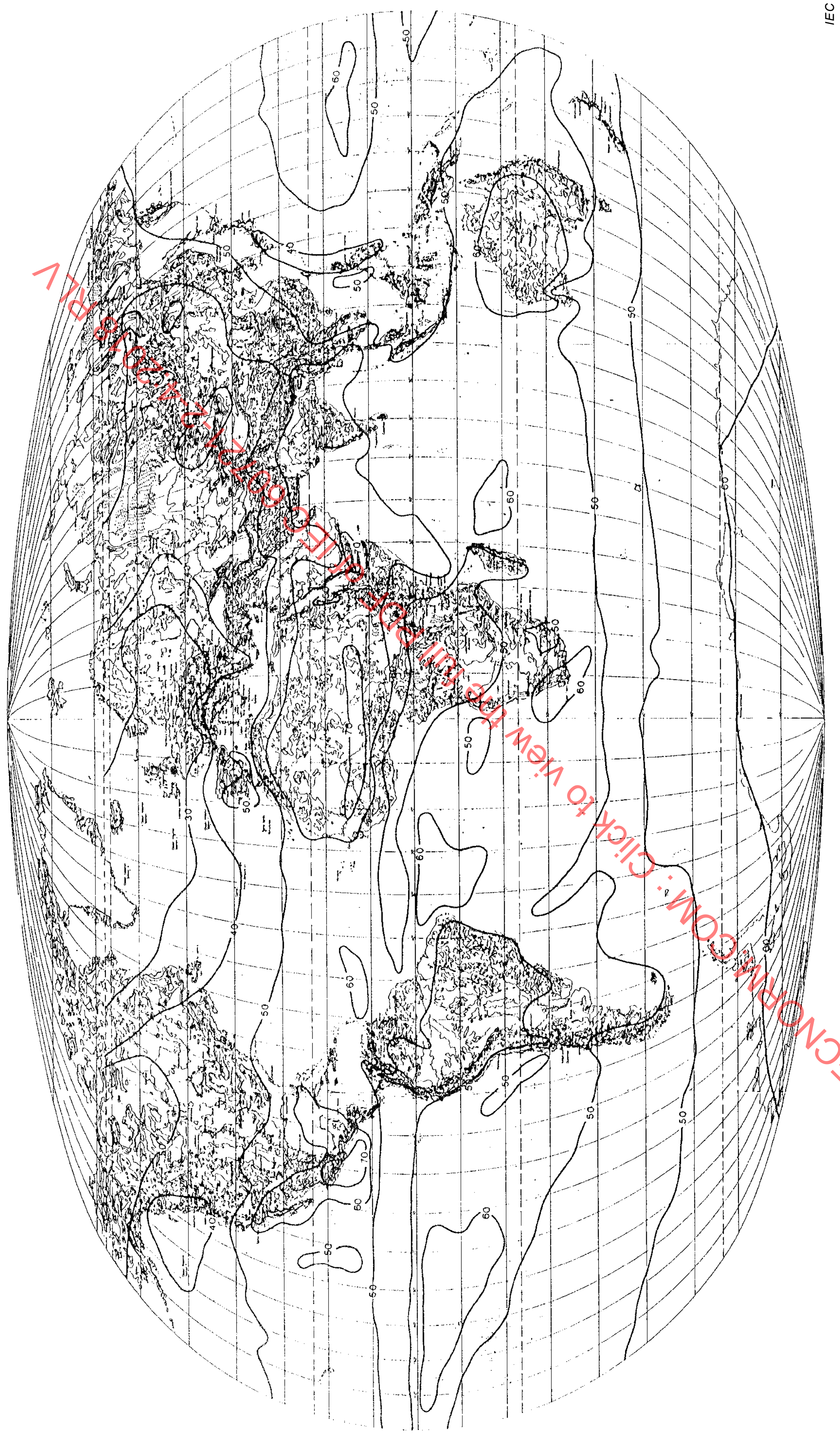


Figure A.2 – Mean relative global irradiation for the month of December (in %)

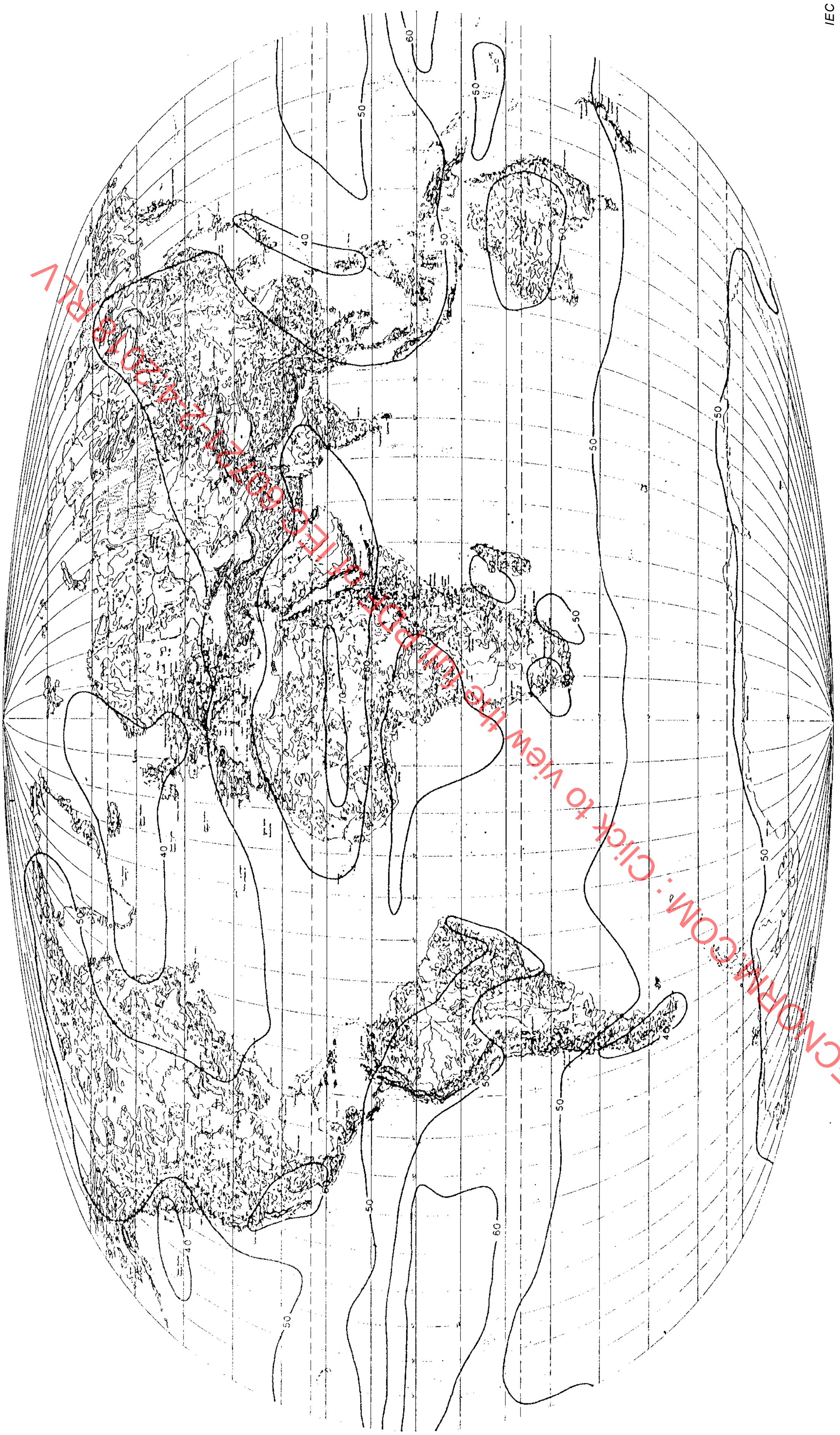


Figure A.3 – Mean relative global irradiation for the year (in %)

Bibliography

[1] G. Major et al., *World maps of relative global radiation*

[2] World Meteorological Organization, *Technical Note No. 172, Annex. WMO-No. 557*, Geneva (1981)

[3] Haarto, Antti, 2001, *Estimation methods for sky radiance distribution from multipyranometer observations*, Annales Universitatis Turkuensis Ser A1, vol 265, Turku, University of Turku, 121 p. ISBN 951-29-1889-7

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INTERNATIONAL STANDARD

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Classification of environmental conditions –
Part 2-4: Environmental conditions appearing in nature – Solar radiation and temperature

Classification des conditions d'environnement –
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IEC 60721-2-4:2018-06(en-fr)

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Approximately 99 % of the energy of the Sun is emitted at wavelengths below 4 µm. Most of the energy below 0,3 µm is absorbed by the atmosphere and does not reach the surface of the Earth. Further absorption and scattering of the radiation takes place, due to particles and gases, during passage through the atmosphere. The scattering of the direct solar radiation in the atmosphere results in diffuse radiation from the sky. Thus, the energy received at a certain place on Earth is the sum of the direct solar radiation and the diffuse solar radiation, which is referred to as "global radiation". From the point of view of heating effects, this sum is of interest and the levels given in this document are therefore related to global radiation.

6 Levels of global radiation

6.1 Maximum levels

The maximum level of global radiation on a clear day occurs at noon. The highest value of the power achieved on a cloudless day at noon at a surface perpendicular to the direction of the Sun depends on the content of aerosol particles, ozone and water vapour in the air. It varies considerably with geographical latitude and type of climate.

The global radiation on a surface perpendicular to the direction of the Sun can reach a value of 1 120 W/m^2 in a range of 280 nm to 3 000 nm at noon on a cloudless day with approximately 1 cm of water vapour content, 2 mm of ozone and aerosols of β = 0,05, where β is the Ångström turbidity coefficient. The value 1 120 W/m^2 is typical for flat land far away from industrial areas and from large cities at solar elevations exceeding 60°.

NOTE 1 The water vapour content of a vertical column of the atmosphere is measured as the height, in centimetres, of the corresponding precipitated water. Analogously, the ozone content of a vertical column of the atmosphere is measured as the height of the corresponding ozone column at normal temperature and pressure. The scattering and absorption by aerosol particles is expressed by the Ångström turbidity coefficient, which is the optical depth of the atmosphere with respect to extinction of monochromatic radiation of wavelength λ = 1 µm.

NOTE 2 During partly clouded days the global solar irradiation can increase up to 1 300 W/m^2 for a few minutes. This short-term phenomenon occurs when the Sun comes out behind the clouds and the radiation is reflected from the edges of the clouds.

The direct solar radiation decreases with increasing turbidity. Turbidity is high in subtropical climates and in deserts where the concentration of particles in the air is high. It is also high in large cities and low in mountainous areas.

The levels in Table 1 are recommended for application as peak values of global irradiance at noon, experienced by a surface perpendicular to the direction of the Sun in a cloudless sky. The level varies only by a few per cent within the hours nearest to noon and can therefore be assumed to be representative for a few hours at a time.

Table 1 – Typical peak values of global irradiance (in W/m^2 from a cloudless sky)

Area	Large cities	Flat land	Mountainous areas
Subtropical climates and deserts	700	750	1 180
Other areas	1 050	1 120	1 180

6.2 Mean monthly and annual global solar radiation

Whilst the maximum heating effect of solar radiation on a surface is normally dependent on short-term irradiance around noon, the photochemical effects are related to radiation, integrated over time, i.e. irradiation. For the purpose of comparison, daily global irradiation is the most convenient and commonly used value.

In December, the monthly mean average of daily irradiation reaches approximately 10,8 kWh/m^2 close to the South Pole, because of the duration of daylight. Outside the Antarctic area, daily levels reach approximately 8,4 kWh/m^2.

The highest annual mean averages of daily global irradiation, up to 6,6 kWh/m^2, are found mainly in desert areas.

6.3 Simultaneous values of maximum air temperatures and solar radiation

The lowest values of the turbidity coefficient β are found in cold air masses. Therefore, the levels in Table 1 do not occur at the highest values of air temperature.

6.4 World distribution of daily global irradiation

For the distribution of daily global irradiation, see Annex A.

7 Minimum levels of atmospheric radiation at night

In cloudless nights when the atmospheric radiation is very low, objects exposed to the night sky will attain surface temperatures below the surrounding air temperature.

The theoretical temperature T_0, in kelvins, of an object in equilibrium with the atmospheric radiation is given by Boltzmann's law:

$$T_0 = \left(\frac{A}{\sigma}\right)^{1/4}$$

where

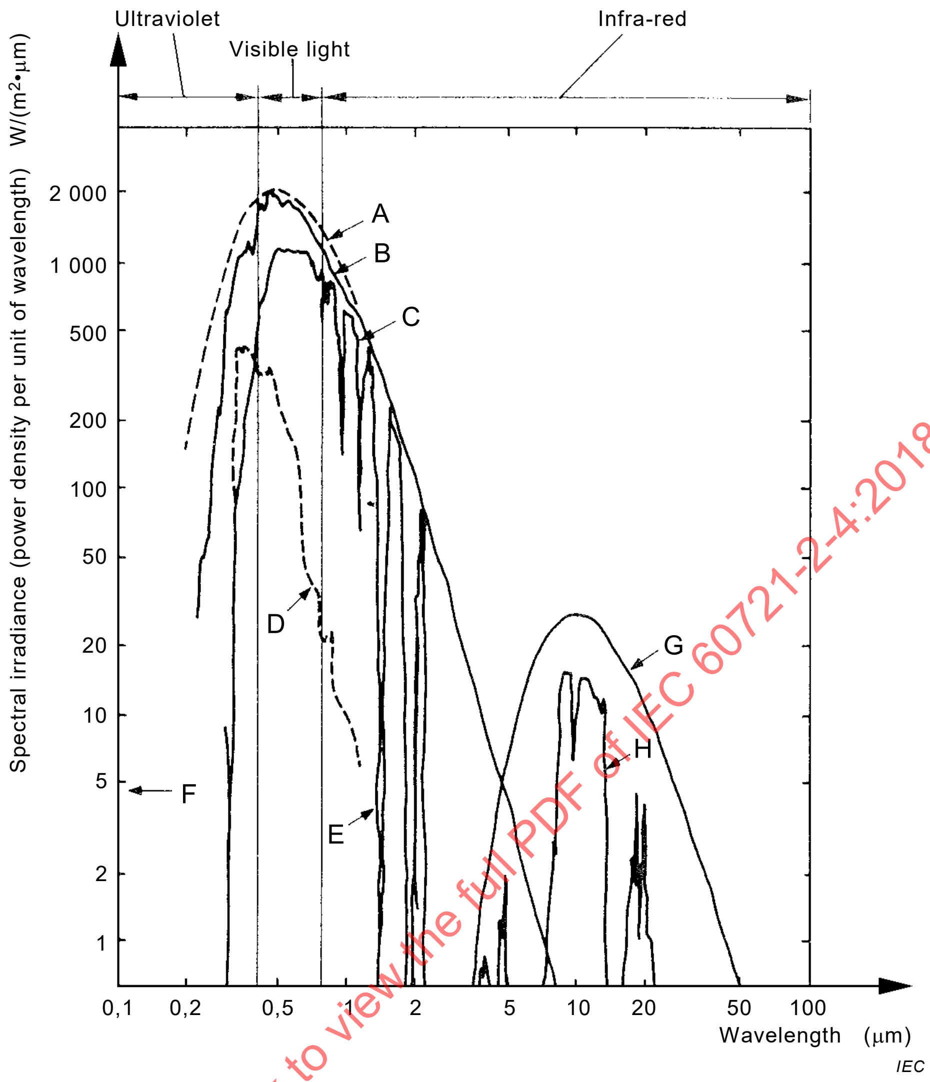
σ is Stefan-Boltzmann's constant, 5,67 · 10^{-8} W/(m^2 · K^4);

A is the atmospheric radiation in W/m^2.

In practice, temperatures will be higher due to heat conduction, convection and water condensation.

As an example, it has been found that the surface of a horizontal disk thermally isolated from the ground and exposed to the night sky during a clear night can attain a temperature of −14 °C when the air temperature is 0 °C and the relative humidity is close to 100 %.

The relative humidity is normally very high on clear nights.



A	Radiation outside the atmosphere from the Sun represented as a black body at temperature 6 000 K (1,60 kW/m^2)	E	Absorption bands of water vapour and carbon dioxide
B	Solar radiation outside the atmosphere (1,37 kW/m^2)	F	Absorption by oxygen and ozone
C	Direct solar radiation at the surface of the Earth perpendicular to the direction of radiation (e.g. 0,9 kW/m^2)	G	Radiation of a black body at 300 K (0,47 kW/m^2)
D	Diffuse solar radiation at the surface of the Earth (e.g. 0,10 kW/m^2)	H	Thermal radiation from the Earth (e.g. 0,07 kW/m^2)

Figure 1 – Spectra of electromagnetic radiation from the Sun and the surface of the Earth

Annex A
(informative)

World distribution of daily global irradiation

Figures A.1, A.2 and A.3 are world maps showing isohels of relative global irradiation (June, December and annual mean values), derived from satellite measurements (see [1][1]). Relative global irradiation is defined as the ratio of global irradiation measured at the Earth's surface, divided by the extra-terrestrial global irradiation, which is the solar radiation on a plane perpendicular to the direction of the Sun just outside the atmosphere.

In order to obtain the mean daily value of global irradiation at the Earth's surface, the percentage value shown on the maps should be multiplied by the appropriate mean daily value of extra-terrestrial global irradiation, which is given as a function of geographical latitude in Table A.1.

NOTE The basis for determining the daily irradiation values in kWh/m^2 is the values of monthly and annual irradiation in MJ/m^2 divided by the number of days in June (30), in December (31), and in the year (365).

EXAMPLE:

Determination of the mean daily global irradiation to be expected in June at the southern point of the Californian peninsula.

From Figure A.1, the point (at an approximate geographical latitude of 23° N) is surrounded by an isohel of 60 %, and the percentage value for the point is estimated to be 62 %.

In Table A.1, interpolation for 23° N in the June column gives 11,16 kWh/m^2, which is multiplied by the percentage value above.

The mean daily global irradiation will thus be approximately 6,9 kWh/m^2.

[1] Numbers in square brackets refer to the Bibliography.

Table A.1 – Mean daily extra-terrestrial global irradiation (kWh/m²)

Latitude	June	December	Annual
90 N	12,47	0,0	4,17
85 N	12,42	0,0	4,20
80 N	12,28	0,0	4,30
75 N	12,05	0,0	4,49
70 N	11,72	0,0	4,76
65 N	11,40	0,11	5,16
60 N	11,40	0,65	5,71
55 N	11,48	1,36	6,29
50 N	11,56	2,16	6,87
45 N	11,61	3,00	7,42
40 N	11,61	3,85	7,93
35 N	11,56	4,72	8,40
30 N	11,44	5,57	8,82
25 N	11,26	6,40	9,19
20 N	11,00	7,20	9,49
15 N	10,68	7,96	9,73
10 N	10,30	8,68	9,90
5 N	9,84	9,34	10,01
0	9,33	9,95	10,04
5 S	8,76	10,50	10,01
10 S	8,13	10,98	9,90
15 S	7,46	11,39	9,73
20 S	6,74	11,73	9,49
25 S	5,99	12,00	9,19
30 S	5,21	12,19	8,82
35 S	4,41	12,32	8,40
40 S	3,60	12,37	7,93
45 S	2,79	12,37	7,41
50 S	2,01	12,31	6,86
55 S	1,27	12,22	6,29
60 S	0,60	12,13	5,71
65 S	0,10	12,12	5,16
70 S	0,0	12,45	4,75
75 S	0,0	12,80	4,48
80 S	0,0	13,05	4,30
85 S	0,0	13,20	4,20
90 S	0,0	13,25	4,16

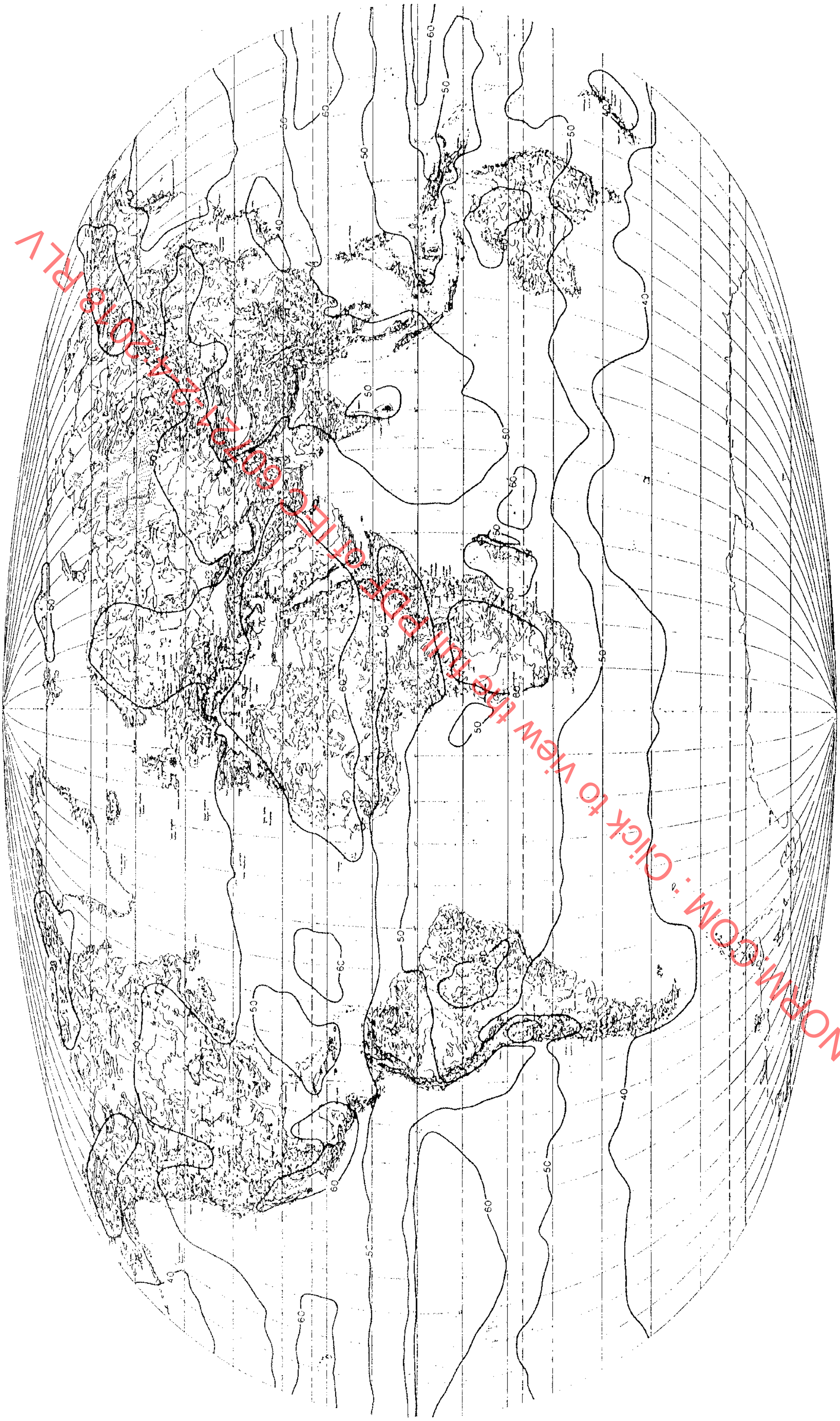


Figure A.1 – Mean relative global irradiation for the month of June (in %)

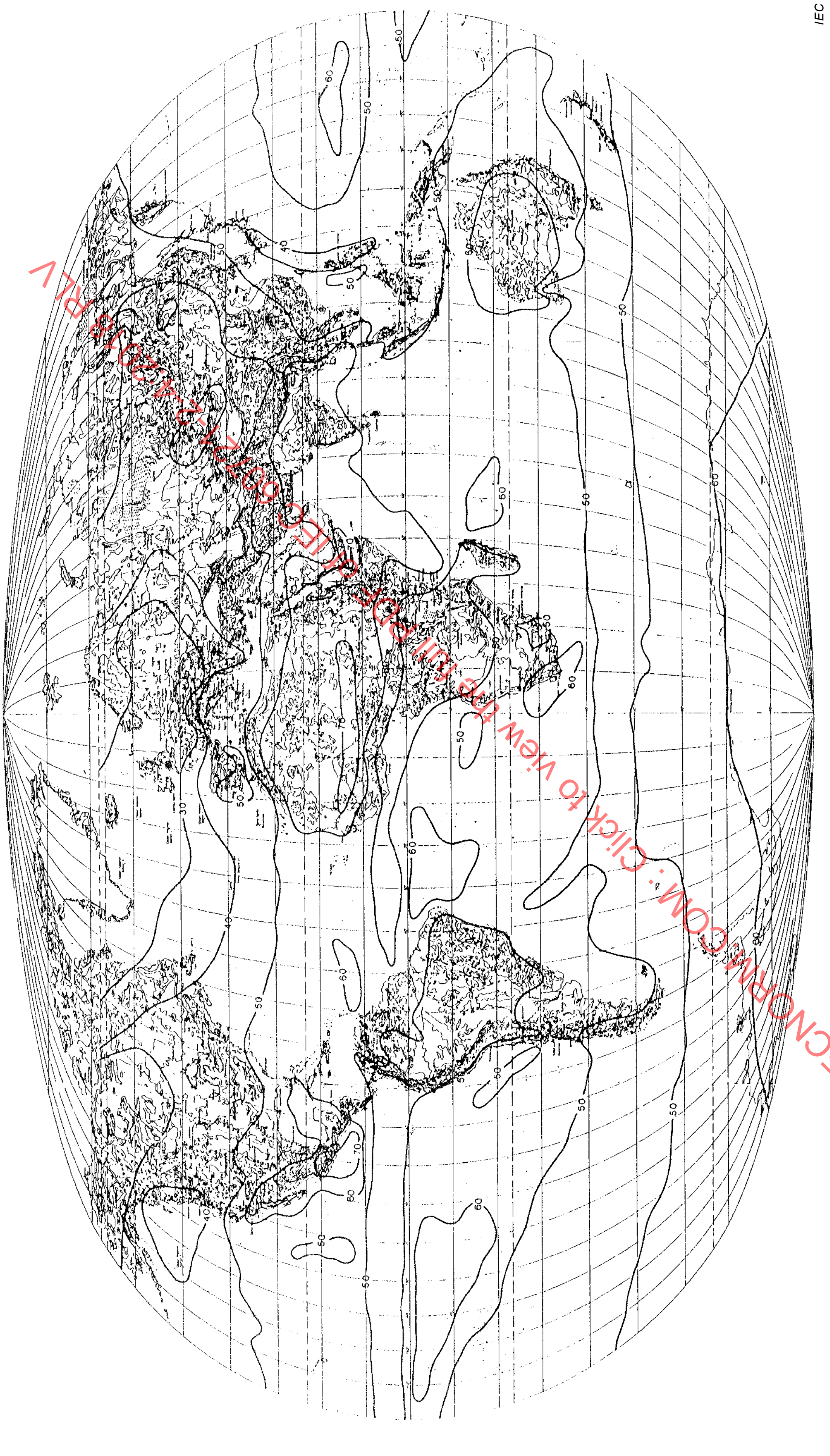


Figure A.2 – Mean relative global irradiation for the month of December (in %)

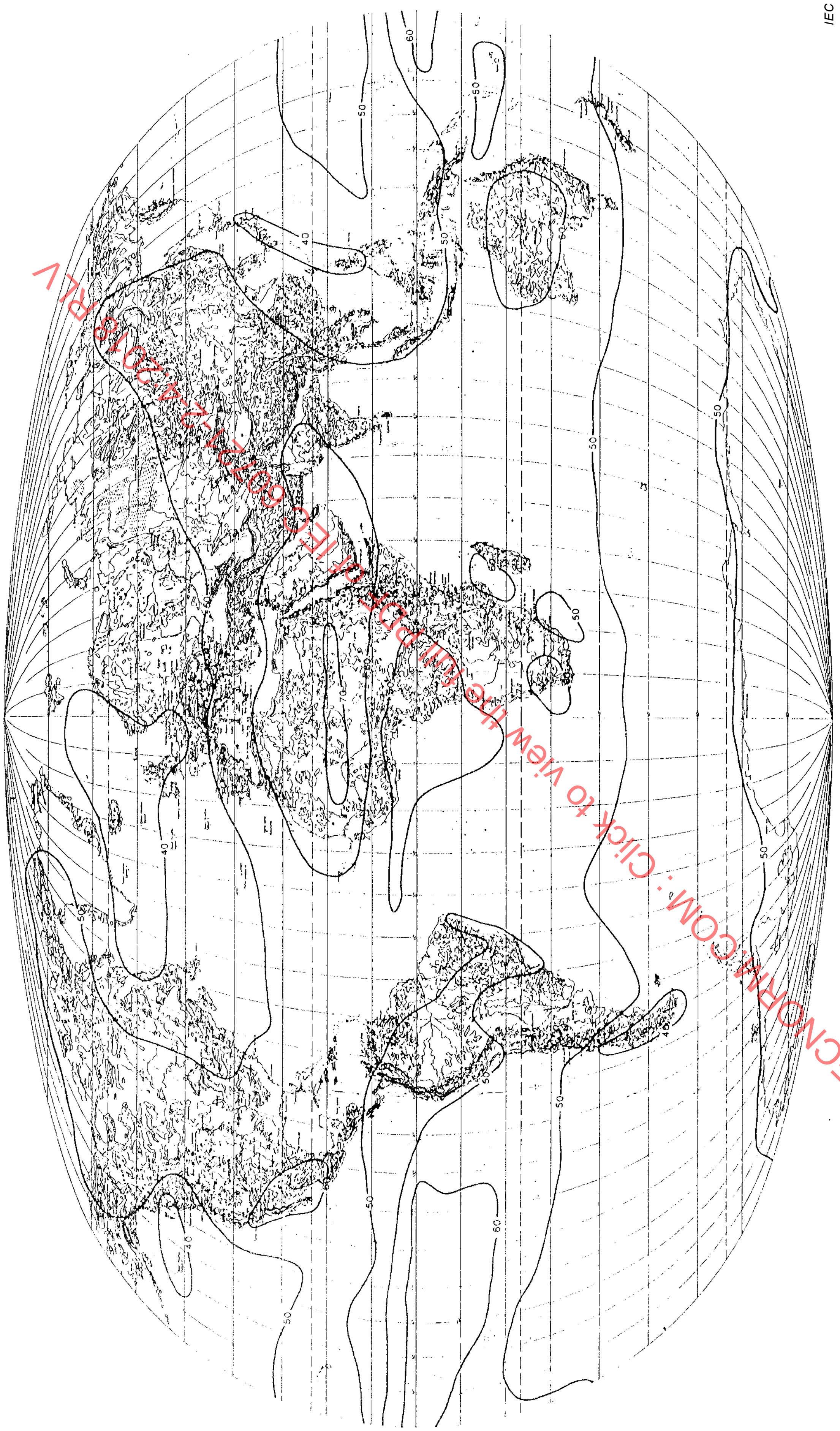


Figure A.3 – Mean relative global irradiation for the year (in %)

Bibliography

[1] G. Major et al., *World maps of relative global radiation*

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[3] Haarto, Antti, 2001, *Estimation methods for sky radiance distribution from multipyranometer observations*, Annales Universitatis Turkuensis Ser A1, vol 265, Turku, University of Turku, 121 p. ISBN 951-29-1889-7

SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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CLASSIFICATION DES CONDITIONS D'ENVIRONNEMENT –

Partie 2-4: Conditions d'environnement présentes dans la nature – Rayonnement solaire et température

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La Norme internationale IEC 60721-2-4 a été établie par le comité d'études 104 de l'IEC: Conditions, classification et essais d'environnement.

Cette deuxième édition annule et remplace la première édition parue en 1987 et l'Amendement 1:1988. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

a) Mise à jour des figures incluant l'ajout d'informations sur l'exposition énergétique globale,
b) Mise à jour du format.

Le texte de cette Norme internationale est issu des documents suivants:

FDIS	Rapport de vote
104/800/FDIS	104/803/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de cette Norme internationale.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2.

Une liste de toutes les parties de la série IEC 60721, publiées sous le titre général *Classification des conditions d'environnement*, peut être consultée sur le site web de l'IEC.

Le comité a décidé que le contenu de ce document ne sera pas modifié avant la date de stabilité indiquée sur le site web de l'IEC sous "http://webstore.iec.ch" dans les données relatives au document recherché. A cette date, le document sera

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- supprimé,
- remplacé par une édition révisée, ou
- amendé.

CLASSIFICATION DES CONDITIONS D'ENVIRONNEMENT –

Partie 2-4: Conditions d'environnement présentes dans la nature – Rayonnement solaire et température

1 Domaine d'application

Cette partie de l'IEC 60721 présente une large division en types de zones de rayonnement solaire. Elle est destinée à faire partie de la documentation de base pour choisir des sévérités appropriées de rayonnement solaire pour l'application aux produits.

Tous les types de zones géographiques sont couverts, sauf les zones situées à plus de 5 000 m d'altitude.

Le présent document sert également à définir les sévérités limites du rayonnement solaire auquel les produits sont susceptibles d'être exposés durant le transport, le stockage et la mise en œuvre.

2 Références normatives

Le présent document ne contient aucune référence normative.

3 Termes et définitions

Aucun terme n'est défini dans le présent document.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse http://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse http://www.iso.org/obp

4 Généralités

Le rayonnement solaire peut affecter les produits essentiellement par l'échauffement des matériaux et de leur environnement, ou par dégradation photochimique des matériaux.

Le rayonnement solaire, en particulier la part d'ultraviolets qui le constitue, est la cause d'une dégradation photochimique de la plupart des matériaux organiques. L'élasticité et la plasticité de certains composés de caoutchouc ou de matières plastiques sont affectées. Le verre optique peut devenir opaque.

Le rayonnement solaire décolore les peintures, les textiles, le papier, etc. Cela peut avoir une importance, par exemple, pour les couleurs codées des composants.

L'échauffement des matériaux est une conséquence de l'exposition au rayonnement solaire. La présentation des sévérités du rayonnement solaire est pour cette raison liée à la puissance surfacique rayonnée – ou éclairement énergétique – exprimée en W/m^2.

Un objet soumis au rayonnement solaire atteint une température dépendant essentiellement de la température de l'air environnant, de l'énergie rayonnée par le Soleil et de l'angle d'incidence du rayonnement sur l'objet. D'autres facteurs, par exemple le vent, la transmission de la chaleur aux structures, peuvent avoir de l'importance. De plus, le facteur d'absorption α_s du spectre solaire par la surface est important.

Une température conventionnelle t_s de l'air peut être définie, qui, dans des conditions stables, a pour résultat une température de surface d'un objet égale à la combinaison de la température réelle t_u de l'air, et du rayonnement solaire de l'éclairement énergétique E.

Une valeur approximative peut être obtenue au moyen de l'équation suivante:

$$t_s = t_u + \frac{\alpha_s \cdot E}{h_y}$$

Le coefficient h_y est le coefficient global de transmission thermique pour la surface, en W/(m^2 · °C). Il comprend le rayonnement thermique vers l'entourage, la conduction de la chaleur du matériau de surface et la convection due au vent.

Le facteur d'absorption α_s, dépend de la couleur thermique et des facteurs de réflexion et de transmission de la surface.

Les valeurs typiques par ciel clair pour des matériaux courants sont:

α_s = 0,7

h_y = 20 W/(m^2 · °C)

E = 900 W/m^2

Elles ont pour effet une température excessive, due au rayonnement solaire, d'environ 30 °C. On peut constater qu'une erreur de 10 % dans l'estimation de l'intensité du rayonnement solaire aura une influence de moins de 5 °C sur la température concernée. Aussi n'est-il nullement besoin, dans cette classification, d'une grande précision pour les sévérités de rayonnement solaire, si bien que les facteurs mineurs affectant la chaleur rayonnée ont été ici négligés.

L'effet d'échauffement est causé principalement par un rayonnement de courte durée et de haute intensité, c'est-à-dire le rayonnement solaire aux environs de midi, les jours sans nuages. Ces valeurs sont présentées dans le Tableau 1.

Il peut aussi être intéressant d'identifier la plus faible valeur de rayonnement atmosphérique par nuit claire afin de déterminer la «sous-température» des produits exposés au ciel nocturne.

5 Physique héliothermique

Le rayonnement électromagnétique en provenance du Soleil vers la Terre couvre le spectre de l'ultraviolet au proche infrarouge. La plus grande partie de l'énergie atteignant la surface de la Terre se situe dans la bande de longueur d'onde de 0,3 µm à 4 µm, avec une valeur maximale dans la bande visible autour de 0,5 µm. Des spectres typiques sont indiqués à la Figure 1.

La quantité d'énergie rayonnée par le Soleil qui tombe sur la surface unitaire d'un plan perpendiculaire aux rayons solaires, juste à l'extérieur de l'atmosphère, à la distance moyenne Soleil-Terre est appelée «constante solaire». Sa valeur est de 1 367 W/m^2.

La distance Soleil-Terre varie au cours de l'année et, par suite, le rayonnement varie.

Près de 99 % de l'énergie du Soleil est émise à des longueurs d'onde inférieures à 4 µm. La plus grande partie de l'énergie émise à moins de 0,3 µm est absorbée par l'atmosphère et n'atteint pas la surface de la Terre. Une absorption supplémentaire et une dispersion du rayonnement surviennent en raison de la présence de particules et de gaz pendant la traversée de l'atmosphère. La dispersion du rayonnement solaire direct dans l'atmosphère a pour résultat un rayonnement diffus du ciel. Ainsi, l'énergie reçue en un certain point de la surface terrestre est la somme du rayonnement solaire direct et du rayonnement solaire diffus, appelée «rayonnement global». Du point de vue des effets d'échauffement, c'est cette somme qui présente de l'intérêt, et les niveaux donnés dans le présent document sont, pour cette raison, relatifs au rayonnement global.

6 Niveaux de rayonnement global

6.1 Niveaux maximaux

Le niveau maximal de rayonnement global se constate à midi, par temps clair. La plus haute valeur de la puissance obtenue par un jour sans nuages, à midi, sur une surface perpendiculaire à la direction du Soleil dépend de la teneur de l'air en aérosols, ozone et vapeur d'eau. Elle varie considérablement avec la latitude géographique et le type de climat.

Le rayonnement global sur une surface perpendiculaire à la direction du Soleil peut atteindre une valeur de 1 120 W/m^2 dans une gamme de 280 nm à 3 000 nm à midi, par un jour sans nuages, avec environ 1 cm de vapeur d'eau contenue, 2 mm d'ozone et des aérosols de β = 0,05, où β est le coefficient de turbidité d'Ångström. La valeur 1 120 W/m^2 est typique pour un pays de plaines, à l'écart des industries et des grandes villes, et pour une hauteur du Soleil supérieure à 60°.

NOTE 1 La vapeur d'eau contenue dans une colonne verticale de l'atmosphère est mesurée comme la hauteur, en centimètres, de l'eau précipitée correspondante. De façon analogue, l'ozone contenu dans une colonne verticale de l'atmosphère est mesuré comme la hauteur de la colonne d'ozone correspondante à température et pression normales. La diffraction et l'absorption par les aérosols sont exprimées par le coefficient de turbidité d'Ångström, qui est la profondeur optique de l'atmosphère, au regard de l'extinction du rayonnement monochromatique de longueur d'onde λ = 1 µm.

NOTE 2 De jour avec une couverture nuageuse partielles, l'exposition au rayonnement solaire global peut augmenter jusqu'à 1 300 W/m^2 pendant quelques minutes. Ce phénomène de courte durée survient lorsque le Soleil apparaît derrière les nuages et que le rayonnement est reflété par les contours des nuages.

Le rayonnement solaire direct décroît en raison inverse de la turbidité. Celle-ci est grande dans les climats subtropicaux et dans les déserts où la concentration de particules dans l'air est élevée. Elle est grande aussi dans les régions urbaines et faible dans les zones montagneuses.

Les niveaux du Tableau 1 sont recommandés pour être appliqués comme des valeurs maximales de l'éclairement énergétique global à midi, reçu sur une surface perpendiculaire à la direction du Soleil dans un ciel sans nuage. Le niveau varie seulement de quelques pourcents dans les heures proches de midi et peut, pour cette raison, être considéré comme représentatif d'une durée de quelques heures.

Tableau 1 – Valeurs typiques maximales de l'éclairement énergétique global (en W/m^2 dans un ciel sans nuage)

Zone	Grandes villes	Plaines	Zones montagneuses
Climats subtropicaux et déserts	700	750	1 180
Autres régions	1 050	1 120	1 180

6.2 Rayonnement solaire global moyen, mensuel et annuel

Alors que l'effet maximal d'échauffement du rayonnement solaire sur une surface est dû normalement à un éclairement énergétique de courte durée aux environs de midi, les effets photochimiques sont liés à l'intégration dans le temps du rayonnement, appelée «exposition énergétique». Pour les besoins de comparaison, l'exposition énergétique globale journalière est la valeur la plus commode et la plus souvent utilisée.

En décembre, aux environs du pôle Sud, la moyenne mensuelle d'exposition énergétique journalière atteint environ 10,8 kWh/m^2, du fait de la durée du jour. Les niveaux journaliers hors des zones antarctiques atteignent environ 8,4 kWh/m^2.

Les plus hautes moyennes annuelles d'exposition énergétique journalière globale, qui peuvent atteindre 6,6 kWh/m^2, sont relevées principalement dans les zones désertiques.

6.3 Valeurs simultanées des températures maximales de l'air et du rayonnement solaire

On trouve les plus faibles valeurs du coefficient de turbidité β dans les masses d'air froid. C'est pourquoi les niveaux figurant dans le Tableau 1 ne sont pas rencontrés quand la température de l'air atteint ses valeurs les plus élevées.

6.4 Distribution mondiale de l'exposition énergétique globale journalière

Pour la distribution de l'exposition énergétique globale journalière, voir l'Annexe A.

7 Niveaux minimaux de rayonnement atmosphérique nocturne

Lors des nuits sans nuages, quand le rayonnement atmosphérique est très faible, les objets exposés au ciel nocturne prennent une température de surface inférieure à celle de l'air environnant.

La température théorique T_0, en kelvins, d'un objet en équilibre avec le rayonnement atmosphérique est donnée par la loi de Boltzmann:

$$T_0 = \left(\frac{A}{\sigma}\right)^{1/4}$$

où

σ est la constante de Stefan-Boltzmann, soit 5,67 · 10^{-8} W/(m^2 · K^4);

A est le rayonnement atmosphérique en W/m^2.

En pratique, les températures seront supérieures en raison de la conduction thermique, de la convection et de la condensation d'eau.

A titre d'exemple, on constate que la surface d'un disque horizontal, isolé thermiquement du sol et exposé au ciel nocturne pendant une nuit claire, peut atteindre une température de –14 °C lorsque la température de l'air est de 0 °C et que l'humidité relative est proche de 100 %.

L'humidité relative est normalement très élevée par nuit claire.