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Hygrothermal performance of buildings — Calculation and presentation of climatic data —

Part 1: Monthly means of single meteorological elements

Performance hygrothermique des bâtiments — Calcul et présentation des données climatiques —

Partie 1: Moyennes mensuelles des éléments météorologiques simples

Reference number
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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 15927-1 was prepared by the European Committee for Standardization (CEN) in collaboration with Technical Committee ISO/TC 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 2, *Calculation methods*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

Throughout the text of this document, read "...this European Standard..." to mean "...this International Standard...".

ISO 15927 consists of the following parts, under the general title *Hygrothermal performance of buildings — Calculation and presentation of climatic data:*

— *Part 1: Monthly means of single meteorological elements*

— *Part 4: Data for assessing the annual energy demand for cooling and heating systems*

— *Part 5: Winter external design air temperatures and related data*

Further parts are in preparation.

Contents

Foreword

This document (EN ISO 15927-1:2003) has been prepared by Technical Committee CEN/TC 89, "*Thermal performance of buildings and building components*", the secretariat of which is held by SIS, in collaboration with Technical Committee ISO/TC 163, *"Thermal performance and energy use in the built environment"*, Subcommittee SC 2 "*Calculation methods"*.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by April 2004, and conflicting national standards shall be withdrawn at the latest by April 2004.

This standard is one of a series of standards on calculation methods for the design and evaluation of the thermal and moisture performance of buildings. EN ISO 15927, *Hygrothermal performance of buildings – Calculation and presentation of climatic data,* consists of six parts:

Part 1: *Monthly means of single meteorological elements*;
Part 2: *Data for design cooling loads and risk of overheating*;
Part 3: *Calculation of a driving rain index for vertical surfaces from hourly wind and rain data*;
Part 4: *Data for assessing the annual energy for heating and cooling*;
Part 5: *Winter external design air temperatures and related wind data*;
Part 6: *Accumulated temperature differences for assessing energy use in space heating*.

Annexes A and B are informative.

This document includes a Bibliography.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom.

1 Scope

This European Standard specifies procedures for calculating and presenting the monthly means of those parameters of climatic data needed to assess some aspects of the thermal and moisture performance of buildings. Numerical values should be obtained from the meteorological service in the relevant country.

This European Standard covers the following single climate variables:

- air temperature;
- atmospheric humidity;
- wind speed;
- precipitation;
- solar radiation;
- longwave radiation.

Meteorological instrumentation and methods of observation are not covered; these are specified by the World Meteorological Organisation (WMO).

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text, and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

World Meteorological Organisation: *Guide to meteorological instruments and methods of observation.* 6th Edition WMO - No.8 1996.

3 Terms, definitions, symbols and units

3.1 Terms and definitions

For the purposes of this European Standard, the following terms and definitions apply.

3.1.1
mixing ratio
ratio of the mass of water vapour to the mass of dry air with which the water vapour is associated

3.1.2
water vapour pressure
part of the total atmospheric pressure exerted by water vapour

3.1.3
saturated vapour pressure over water
vapour pressure of moist air in equilibrium with a plane liquid water surface

3.1.4
relative humidity
ratio of the vapour pressure of moist air to the vapour pressure it would have if it were saturated

3.1.5
reference wind speed
wind speed measured at a height of 10 m above ground level in open country without nearby obstacles

3.1.6
gust speed
greatest instantaneous wind speed observed during the period over which the mean is calculated

3.1.7
solar irradiance
radiation power per area generated by the reception of solar radiation on a plane of any tilt and orientation

The following special quantities can be distinguished according to the conditions of reception:

3.1.7.1
global solar irradiance
irradiance generated by reception of solar radiation from the full hemisphere

NOTE According to the following definitions it is equal to the reception of direct solar and diffuse solar radiation on a horizontal plane. In the case of tilted planes a portion of the ground reflected global solar radiation is also received.

3.1.7.2
direct solar irradiance
irradiance generated by the reception of solar radiation from a conical angle which surrounds concentrically the apparent solar disk

NOTE 1 Also referred to as "beam solar radiation".

NOTE 2 The horizontal component of the direct solar irradiance is a part of the global solar irradiance.

NOTE 3 Any component of the direct solar irradiance is generated nearly exclusively from unscattered solar radiation.

NOTE 4 The diameter of the apparent solar disk corresponds to about 0,5 degrees; for technical reasons the available radiometers receive the direct solar irradiance from solid angles around the solar disk which correspond mostly to field-of-view angles between 3° and 6°.

3.1.7.3
diffuse solar irradiance
irradiance generated by the reception of scattered solar radiation from the full sky hemisphere , with the exception of that solid angle which is used to measure the direct solar irradiance

NOTE 1 Practical measurement requires a sun following disk, which permanently shades the receiver of the radiometer with a 'field of shade' angle which equals the field of view angle used for measuring direct solar irradiance. This allows the global irradiance to be calculated as the sum of diffuse solar and the horizontal component of the direct solar irradiance.

NOTE 2 The use of a ring to shade the sun along its daily path instead of a disk requires an equation to correct for the corresponding losses of diffuse solar irradiance.

3.1.7.4
reflected solar irradiance
irradiance generated by reception of the rising reflected global radiation on a downward looking plane

NOTE 1 The ratio of reflected solar and global solar irradiance is called albedo.

NOTE 2 Part of the reflected global solar radiation is received on any tilted plane.

3.1.8
solar irradiation
radiant energy per area received from the sun on a plane of defined inclination and orientation during a given period of time

NOTE The same components as indicated in 3.1.7 for irradiance can be distinguished.

3.1.9
longwave (terrestrial) radiation
radiation with wavelength greater than 3 μm from surfaces at the ground and from the atmosphere

NOTE The exchange of longwave radiation occurs permanently between buildings, the ground and the atmosphere at temperatures between 240 K and 340 K.

3.1.10
thermometer screen
white painted, wooden, plastic, or aluminium louvered enclosure, which allows a free flow of air over thermometers while shielding them from solar radiation, longwave radiation and precipitation

3.2 Symbols and units

Symbol	Quantity	Unit
C_{R}	roughness coefficient	-
C_{T}	topography coefficient	-
D	wind direction from North	°
d_m	number of days in a month	-
d_y	number of days in a year	-
$G_{\mathrm{l,a}}$	longwave irradiancefrom the atmosphere on a horizontal plane	°W/m^2
G_{s}	solar irradiance	W/m^2
$G_{\mathrm{s,b}}$	direct (beam) solar irradiance	W/m^2
$G_{\mathrm{s,d}}$	diffuse solar irradiance	W/m^2
$G_{\mathrm{s,g}}$	global solar irradiance	W/m^2
$G_{\mathrm{s,r}}$	reflected global solar irradiance	W·m^2
H	effective height of topographic feature	m
H_{s}	solar irradiation	MJ/m^2
h_m	number of hours in a month	-
K_{R}	terrain factor	-
L_{d}	actual length of downwind slope	m
L_{e}	effective length of upwind slope	m
L_{u}	actual length of upwind slope	m
R	rainfall total (or equivalent amount of melted solid precipitation)	mm
P	total atmospheric pressure	hPa
p	water vapour pressure	hPa
$p_{\mathrm{sat}}\ (\theta)$	saturated vapour pressure over water at temperature θ	hPa
s	scale factor for topography coefficient	-
T	temperature	K
v	wind speed	m/s
$\hat{v}$	gust wind speed	m/s

Symbol	Quantity	Unit
$\bar{v}_r$	reference mean wind speed	m/s
$\bar{v}_s$	mean wind speed at a site	m/s
x	mixing ratio	g/kg
$x_{sat}(\theta)$	saturated mixing ratio with respect to liquid water at temperature θ	g/kg
y	horizontal distance of site from crest of topographic feature	m
z	height above ground	m
z_{min}	minimum height	m
z_0	roughness height	m
ε	ratio of gas constant of dry air to gas constant of water vapour (ε = 0,62198)	-
θ	air temperature	°C
Φ	upwind slope of topographic feature	-
φ	relative humidity	-

3.2.1 Subscripts

Subscript	Meaning
a	atmosphere
dm	mean over a day
dx	maximum over a day
dn	minimum over a day
h	values representative of an hour (either instantaneous measurements or the mean of many readings in the hour)
ic	inclination of a surface
mm	mean over a month
N	values representative of a number of hours N (e.g. 3 h, 6 h or 12 h but less than 24 h) (either instantaneous measurements or the mean of many readings in the period)
l	longwave
pq	value exceeded for q % of the time
s	solar
sd	standard deviation

4 Periods over which parameters are calculated

The methods specified in clauses 5 to 9 can be used to calculate monthly means or totals from either individual months (e.g. a January from a specified year) or from all the corresponding months from many years (e.g. all the Januarys from a 30 year data set).

Calculations of the standard deviation of daily means or totals about the monthly or annual means or totals (see 5.3 and 5.4) shall refer to a specified month or year.

The specified year or the multi-year period over which all parameters are calculated shall be quoted with the values of the parameters.

5 Air temperature

5.1 Sources of data

The dry-bulb air temperature data used to calculate monthly means shall come from observations from a thermometer screen fitted with louvers to allow a free flow of air.

5.2 Calculation of the monthly mean

5.2.1 From hourly data

The hourly temperature may be either: a) the mean of continuous measurements recorded during that hour or b) measurements recorded at a particular moment within the hour (e.g. on the hour).

The monthly means shall be calculated as:

$$\theta_{m\mathrm{m}} = \frac{\sum_{h=1}^{h_m} \theta_h}{h_m} \tag{1}$$

where

θ_h is the hourly temperature, in °C;

h_m is the number of hours in the month under consideration.

5.2.2 From data measured at intervals of 3 h or 6 h

If dry-bulb outdoor air temperature data are available at intervals of 3 h or 6 h (each value may be either the mean of continuous measurements during the interval or an instantaneous measurement taken on the interval), the monthly mean is calculated from:

$$\theta_{m\mathrm{m}} = \frac{\sum_{N=1}^{n_m} \theta_N}{n_m} \tag{2}$$

where

n_m = 8 d_m for data at three-hour intervals;

= 4 d_m for data at six-hour intervals;

d_m is the number of days in the month under consideration.

5.2.3 From daily maximum and minimum data

If the only dry-bulb outdoor air temperatures available are the daily maximum and minimum for each day of the month, the daily mean for each day is calculated as:

$$\theta_{\mathrm{dm}} = \frac{\theta_{\mathrm{dn}} + \theta_{\mathrm{dx}}}{2} \tag{3}$$

and the monthly means obtained as:

$$\theta_{m\mathrm{m}} = \frac{\sum_{d=1}^{d_m} \theta_{d\mathrm{m}}}{d_m} \tag{4}$$

where

d_m is the number of days in the month under consideration.

NOTE Daily means calculated from the daily maximum and minimum temperature will, in general, be different from those calculated from hourly values. Most (95 %) of the differences lie between ± 1,0 °C but they can range up to ± 2,0 °C. Monthly means calculated from daily maximum and minimum values will also differ from those calculated from hourly values, but in this case 95 % of the differences lie between ± 0,2 °C and the maximum difference lies between ± 0,25 °C.

5.2.4 From instantaneous data at 07:30, 14:30 and 21:30 or at other similar times

If dry-bulb outdoor air temperature data are available only at 07:30, 14:30 and 21:30, or at other similar times, the daily mean for each day is calculated using Equation (5), or the equivalent equation for the appropriate times.

$$\theta_{d\mathrm{m}} = \frac{\theta_{07:30} + \theta_{14:30} + 2\theta_{21:30}}{4} \tag{5}$$

and the monthly mean obtained from Equation (4).

5.3 Calculation of the standard deviation of daily means about the monthly mean

If not defined in 5.2.2, 5.2.3 or 5.2.4, the daily mean temperatures for each day in the month are calculated from data measured at one, three or six hourly intervals using:

$$\theta_{d\mathrm{m}} = \frac{\sum_{N=1}^{n_d} \theta_N}{n_d} \tag{6}$$

where

n_d = 24 for data at one-hour intervals;

= 8 for data at three-hour intervals;

= 4 for data at six-hour intervals;

or from daily maximum and minimum data using Equation (3) or at 07:30, 14:30 and 21:30 or similar times using Equation (5).

Then the standard deviation of the daily means from the monthly mean is given by:

$$\theta_{\mathrm{sd}m} = \sqrt{\frac{d_m \sum_{d=1}^{d_m} \theta_{d\mathrm{m}}^2 - \left(\sum_{d=1}^{d_m} \theta_{d\mathrm{m}}\right)^2}{d_m(d_m - 1)}} \tag{7}$$

5.4 Calculation of the annual mean and standard deviation

The annual mean temperature shall be calculated from the daily means using:

$$\theta_{y\mathrm{m}} = \frac{\sum_{d=1}^{d_y} \theta_{d\mathrm{m}}}{d_y} \qquad (8)$$

The standard deviation of the daily means from the annual mean shall be calculated by:

$$\theta_{\mathrm{sd}\,y} = \sqrt{\frac{d_y \sum_{d=1}^{dy} \theta_{d\mathrm{m}}^2 - \left(\sum_{d=1}^{d_y} \theta_{d\mathrm{m}} \right)^2}{d_y (d_y - 1)}} \qquad (9)$$

5.5 Expression of results

Monthly mean values of the dry-bulb outdoor temperature shall be expressed to the nearest 0,1 °C and the type of data (i.e. hourly, daily, etc.) used for the monthly mean calculation shall be specified.

The following parameters shall be reported for each month:

a) the measurement dates from which the parameters are calculated;

b) the monthly means of the dry-bulb outdoor temperature;

c) the standard deviation of the daily mean dry-bulb temperature about the monthly mean;

and, when available:

d) the maximum value of the hourly dry-bulb outdoor temperatures;

e) the minimum value of the hourly dry bulb outdoor temperatures;

f) the values of the hourly dry-bulb outdoor temperature at the 1 %, 5 %, 10 %, 90 %, 95 % and 99 % percentiles.

NOTE If four or more values of the dry-bulb outdoor temperature per day are available, provided that these values are reasonably spread through the day, it is possible to estimate hourly values by linear or other interpolation of the raw data and then calculate the statistical values specified in f).

These parameters summarised in b) to f) shall be presented in tabular form similar to the example shown in Table 1.

Table 1 — Sample table of monthly and annual mean temperatures

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
θ_{mm}	5,7	5,4	6,2	8,1	10,4	13,1	14,1	14,7	13,0	10,9	8,1	6,2	9,7
θ_{Sdm}	3,0	3,0	2,7	2,8	2,6	2,3	2,0	2,3	1,7	2,3	2,2	2,9	4,2
θ_{min}	-4,0	-1,7	-3,5	1,7	5,5	7,8	9,0	9,3	6,6	4,2	1,1	-0,8	-4,0
θ_{p1}	-2,4	-1,1	-1,4	2,0	6,0	8,8	9,5	10,2	7,9	5,8	2,2	-0,6	-0,1
θ_{p5}	0,6	-0,1	2,0	3,5	7,0	9,8	10,6	11,6	10,5	7,2	3,9	0,4	2,5
θ_{p10}	1,4	0,5	3,4	4,2	7,6	10,2	11,5	12,3	11,0	8,2	5,0	1,9	4,3
θ_{p90}	9,4	9,0	9,2	11,3	13,7	16,1	16,7	17,1	15,3	13,9	10,6	9,5	15,0
θ_{p95}	10,1	9,4	11,0	12,4	15,9	17,2	17,3	19,3	15,9	14,9	11,1	10,2	16,0
θ_{p99}	10,9	9,9	15,8	15,0	18,7	20,3	18,7	23,4	16,7	16,3	12,2	11,5	18,4
θ_{max}	11,1	10,3	18,9	16,5	23,0	21,6	19,7	25,6	17,5	16,8	13,9	11,8	25,6

6 Atmospheric humidity

6.1 Sources of data

All humidity data used to calculate monthly means shall come from either

a) observations with mechanically ventilated wet and dry bulb thermometers; or

b) a chilled mirror dewpoint meter; or

c) a capacitance hygrometer; or

d) hair hygrometer.

Data derived from wet and dry bulb temperatures measured in a thermometer screen without mechanical ventilation, as is the practice in many climatological stations, or from hair or similar hygrometers, are too imprecise to be usable when calculating monthly means.

6.2 Relationships between temperature and humidity parameters

6.2.1 Saturated vapour pressure and temperature

The saturated vapour pressure is given as a function of temperature in Table 2.

Table 2 — Saturated vapour pressure in hPa as a function of temperature $\theta + \Delta T$

θ °C	ΔT °C									
	+0	**+1**	**+2**	**+3**	**+4**	**+5**	**+6**	**+7**	**+8**	**+9**
-20	1,03	1,13	1,24	1,37	1,50	1,65	1,81	1,98	2,17	2,37
-10	2,59	2,83	3,09	3,38	3,68	4,01	4,37	4,75	5,17	5,62
0	6,11	6,56	7,05	7,57	8,13	8,72	9,35	10,01	10,72	11,47
10	12,27	13,12	14,02	14,97	15,98	17,04	18,17	19,37	20,63	21,96
20	23,37	24,86	26,42	28,08	29,82	31,66	33,59	35,63	37,78	40,03
30	42,41	44,90	47,52	50,27	53,16	56,19	59,37	62,71	66,21	69,87

Intermediate values may be found by linear interpolation.

NOTE Saturated vapour pressure can also be calculated using the empirical equations:

$$p_{\text{sat}}(\theta) = 6{,}105 \exp\left(\frac{17{,}269\,\theta}{237{,}3 + \theta}\right) \quad \text{for } \theta \geq 0 \qquad (10)$$

$$p_{\text{sat}}(\theta) = 6{,}105 \exp\left(\frac{21{,}875\,\theta}{265{,}5 + \theta}\right) \quad \text{for } \theta < 0 \qquad (11)$$

6.2.2 Mixing ratio and vapour pressure

Vapour pressure is calculated from mixing ratio using

$$p = \frac{xP}{\varepsilon + x} \qquad (12)$$

where P is the total atmospheric pressure measured at the site, in hPa.

6.2.3 Relative humidity

Relative humidity is calculated from dry-bulb temperature and vapour pressure using

$$\varphi = \frac{p}{p_{\text{sat}}(\theta)} \qquad (13)$$

where the saturated vapour pressure is derived from temperature as specified in 6.2.1.

NOTE 1 Relative humidity is commonly expressed as a percentage.

NOTE 2 Relative humidity can also be measured directly.

6.3 Calculation of monthly mean

6.3.1 From hourly data

If hourly values (either as hourly means or values measured at a set time during the hour) of temperature and vapour pressure (or mixing ratio) are available, the monthly mean temperature shall be calculated as specified in 5.2.1, and the monthly mean vapour pressure shall be calculated from:

$$p_{m\mathrm{m}} = \frac{\sum_{h=1}^{h_m} p_h}{h_m} \qquad (14)$$

and the mean mixing ratio from:

$$x_{m\mathrm{m}} = \frac{\sum_{h=1}^{h_m} x_h}{h_m} \qquad (15)$$

where h_m is the number of hours in the month under consideration.

The hourly saturated vapour pressure shall be obtained from Table 2 or calculated from the hourly temperatures using Equation (10) or (11) as appropriate.

The monthly mean relative humidity shall then be calculated from the monthly mean vapour pressure and saturated vapour pressure using Equation (13). Equation (12) may be used to convert from the monthly mean mixing ratio to the monthly mean vapour pressure, if necessary.

If hourly values of temperature and relative humidity are available, the hourly vapour pressure shall be calculated from

$$p_h = p_{\mathrm{sat}}(\theta)\, \varphi_h \qquad (16)$$

and then used to calculate the monthly means as specified above.

Due to the non-linear relationship between saturated vapour pressure and temperature, calculating the monthly mean vapour pressure from the mean relative humidity and temperature will lead to significant errors, especially in warm climates. Monthly mean vapour pressures should be calculated from the highest frequency vapour pressure data available.

6.3.2 Data measured at intervals of three, four or six hours

If temperature and vapour pressure data are available at intervals of three, four or six hours, these shall be averaged over the month and the mean relative humidity calculated as in 6.3.1.

6.3.3 From instantaneous data measured at 7:30, 14:30 and 21:30 or at other similar times

If the relative humidity is available only at 7:30, 14:30 and 21:30, or at other similar times, the daily mean for each day is calculated using Equation (17) or the equivalent equation for the appropriate times.

$$\varphi_{d\,\mathrm{m}} = \frac{\varphi_{07:30} + \varphi_{14:30} + 2\,\varphi_{21:30}}{4} \qquad (17)$$

and the monthly means are obtained using Equation (18):

$$\varphi_{m\mathrm{m}} = \frac{\sum_{N=1}^{d_m} \varphi_{d\mathrm{m}}}{d_m} \quad (18)$$

6.3.4 Calculation of the annual means

The annual mean temperature shall be calculated using Equation (7) and the annual mean water vapour pressure calculated from:

$$p_{y\mathrm{m}} = \frac{\sum_{d=1}^{d_y} p_{d\mathrm{m}}}{d_y} \quad (19)$$

and the mean mixing ratio from:

$$x_{y\mathrm{m}} = \frac{\sum_{d=1}^{d_y} x_{d\mathrm{m}}}{d_y} \quad (20)$$

and the mean relative humidity calculated using Equation (13).

6.4 Expression of results

Mean values shall be expressed to the precision shown in Table 3.

Table 3 — Precision to which monthly and annual means shall be expressed

Parameter	Precision	Unit
Temperature	0,1	°C
Water vapour pressure	0,1	hPa
Mixing ratio	0,1	g/kg
Relative humidity	0,01	-

The following parameters shall be reported for each month and the year:

a) the measurement dates from which the parameters are calculated;

b) the mean temperature, water vapour pressure (or mixing ratio) and relative humidity;

c) when hourly data are available, the 1 %, 5 %, 10 %, 90 %, 95 % and 99 % percentiles and the absolute maximum and minimum of the water vapour pressure, mixing ratio or relative humidity.

These parameters shall be presented in tabular form similar to the examples shown in Tables 4 and 5.

Table 4 — Sample table of monthly and annual means (with distribution of water vapour pressure)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
θ_{mm}	5,7	5,4	6,2	8,1	10,4	13,1	14,1	14,7	13,0	10,9	8,1	6,2	9,7
P_{mm}	8,2	7,7	7,9	8,9	10,0	12,6	13,3	13,9	13,0	11,2	9,4	8,5	10,4
φ_{mm}	0,89	0,85	0,83	0,83	0,79	0,84	0,83	0,83	0,87	0,86	0,87	0,89	0,86
P_{min}	3,7	3,5	4,0	4,7	5,6	8,6	9,4	10,4	8,9	7,1	5,3	4,0	3,5
P_{p1}	4,0	4,1	4,4	4,9	6,3	9,2	9,9	11,1	9,4	7,6	5,7	4,5	4,5
P_{p5}	4,6	4,4	5,5	5,6	7,5	9,8	10,5	11,6	10,4	8,0	6,5	5,0	5,5
P_{p10}	5,3	4,7	5,9	6,3	8,2	10,3	10,8	12,1	10,7	8,3	7,1	5,3	6,5
P_{p90}	11,3	10,7	9,4	11,2	12,3	14,7	15,8	16,8	15,7	14,6	12,0	11,3	14,3
P_{p95}	11,9	11,4	10,3	11,6	12,9	15,4	16,3	17,2	16,3	15,5	12,5	12,1	15,4
P_{p99}	12,5	12,0	11,5	12,4	13,6	17,7	17,6	18,1	17,5	17,2	13,5	13,2	17,2
P_{max}	12,7	12,1	11,9	13,0	14,4	20,1	19,8	19,2	18,4	17,6	14,2	13,6	20,1

Table 5 — Sample table of monthly and annual means (with distribution of relative humidity)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
θ_{mm}	5,7	5,4	6,2	8,1	10,4	13,1	14,1	14,7	13,0	10,9	8,1	6,2	9,7
P_{mm}	8,2	7,7	7,9	8,9	10,0	12,6	13,3	13,9	13,0	11,2	9,4	8,5	10,4
φ_{mm}	0,89	0,85	0,83	0,83	0,79	0,84	0,83	0,83	0,87	0,86	0,87	0,89	0,86
φ_{min}	0,34	0,34	0,36	0,16	0,16	0,29	0,28	0,28	0,36	0,46	0,43	0,52	0,16
φ_{p1}	0,63	0,54	0,49	0,40	0,38	0,43	0,45	0,46	0,52	0,58	0,62	0,67	0,46
φ_{p5}	0,72	0,64	0,59	0,50	0,47	0,52	0,55	0,55	0,61	0,67	0,71	0,74	0,57
φ_{p10}	0,76	0,70	0,65	0,56	0,53	0,57	0,60	0,61	0,66	0,72	0,75	0,78	0,64
φ_{p90}	0,97	0,96	0,95	0,94	0,93	0,94	0,94	0,95	0,96	0,96	0,97	0,98	0,96
φ_{p95}	1,00	0,98	0,97	0,96	0,95	0,96	0,96	0,97	0,98	0,98	0,99	1,00	0,98
φ_{p99}	1,00	1,00	1,00	0,99	0,98	0,99	0,98	1,00	1,00	1,00	1,00	1,00	1,00
φ_{max}	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00

7 Wind speed and direction

7.1 Methods of measurement

Wind speed is measured with an anemometer and wind direction with a vane. The reference mean wind speed $\bar{v}_r$ is calculated over a time period ranging from 10 min to 1 h.

NOTE 1 The instantaneous speed is in fact a mean speed over approximately 2 s depending on the nature of the measuring instrument used.

NOTE 2 In reference conditions with a mean time period of 10 min the gust speed $\hat{v} \approx 1{,}54\,\bar{v}_{\mathrm{r}}$, and for a mean time period of 1 hour $\hat{v} \approx 1{,}65\,\bar{v}_{\mathrm{r}}$.

NOTE 3 Wind speed data are sometimes expressed in knots (1 knot = 0,514 m/s).

Mean wind direction D, calculated over the same period as wind speed, is the up wind direction generally given by sectors of 10 degrees from north. For example, sector 90 means east wind and is noted 09, west wind (270) is noted 27 and north wind 36. Calm is denoted 00 and, if the wind direction is variable, 99 is reported.

7.2 Environmental influence on mean wind speed

7.2.1 General

The mean wind speed is a function of the local environment (topography, ground roughness and nearby obstacles). Mean wind speeds, observed at two different sites of similar altitude within about 10 km, do not differ significantly if both sites have a similar local environment. Conversely, to obtain the reference regional wind $\bar{v}_{\mathrm{r}}$ from observations over a site $\bar{v}_{\mathrm{s}}$, or to have an estimation of wind conditions over a site from the reference wind, the mean wind speed shall be corrected following the relationship (assuming that there are no nearby obstacles):

$$\bar{v}_{\mathrm{s}} = \bar{v}_{\mathrm{r}}\ C_{\mathrm{R}}\ C_{\mathrm{T}} \tag{21}$$

where

C_{R} is the roughness coefficient;

C_{T} is the topography coefficient.

7.2.2 Roughness coefficient

The roughness coefficient accounts for the variability of mean wind speed at the site due to:

- the height above the ground;
- the roughness of the terrain depending on the direction from which the wind is coming.

The roughness coefficient at height z is given by:

$$C_{\mathrm{R}}(z) = K_{\mathrm{R}} \ln(z/z_0) \qquad \text{for } z \geq z_{\min}$$

$$C_{\mathrm{R}}(z) = K_{\mathrm{R}} \ln(z_{\min}/z_0) \qquad \text{for } z < z_{\min} \tag{22}$$

where

K_{R} is the terrain factor;

z_0 is the roughness height;

$z_{\min}$ is the minimum height

These parameters depend on the terrain category as given in Table 6.

Table 6 — Terrain categories and related parameters

Terrain category	K_R	z_0	z_{min}
I Rough open sea; lake shore with at least 5 km fetch up wind and smooth flat country without obstacles	0,17	0,01	2
II Farm land with boundary hedges, occasional small farm structures, houses or trees	0,19	0,05	4
III Suburban or industrial areas and permanent forests	0,22	0,3	8
IV Urban areas in which at least 15 % of the surface is covered with buildings of average height exceeding 15 m	0,24	1	16

If there is a change of roughness upwind of a site within a kilometre, the smoothest terrain category in the upwind direction shall be used.

7.2.3 Topography coefficient

The topography coefficient accounts for the increase in mean wind speed over isolated hills and escarpments (not undulating nor mountainous regions) and is related to the wind velocity upwind to the hill. It shall be considered for locations:

— more than half way up the slope of a hill

— within 1,5 times the height of the cliff from the base of a cliff.

It is defined by:

$$C_T = 1 \quad \text{for } \Phi < 0{,}05$$
$$C_T = 1 + 2s\Phi \quad \text{for } 0{,}05 \le \Phi < 0{,}3 \qquad (23)$$
$$C_T = 1 + 0{,}6s \quad \text{for } \Phi > 0{,}3$$

where

s is a factor to be obtained from Figures 2 and 3 scaled to the length of the upwind, L_u, or downwind L_d slopes as shown in the figures;

Φ is the upwind slope H/L_e in the wind direction;

L_u is the actual length of the upwind slope in the wind direction;

L_d is the actual length of the downwind slope;

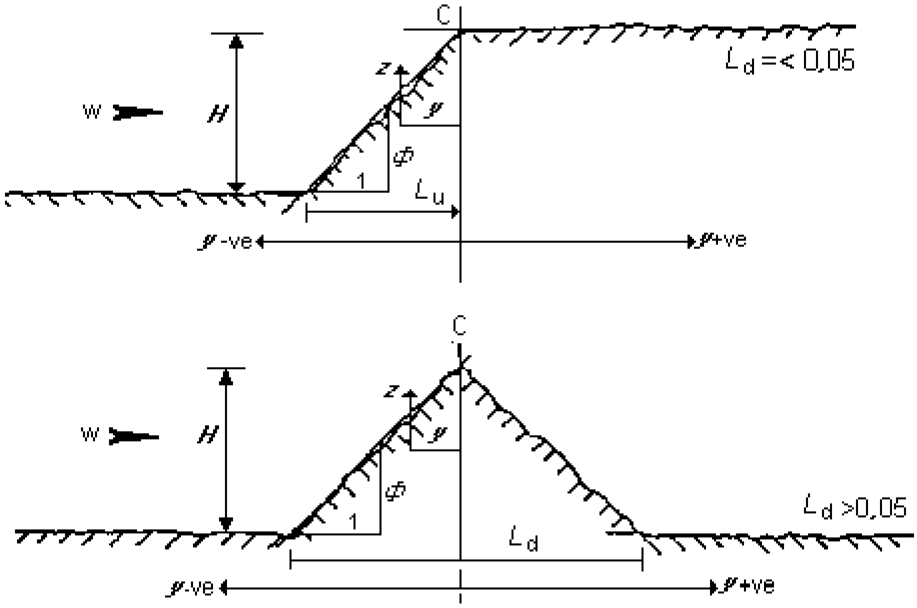
L_e is the effective length of the upwind slope defined in Table 7;

H is the effective height of the feature;

y is the horizontal distance of the site from the top of the crest;

z is the vertical distance from the ground level of the site.

See Figure 1 for clarification of these quantities.

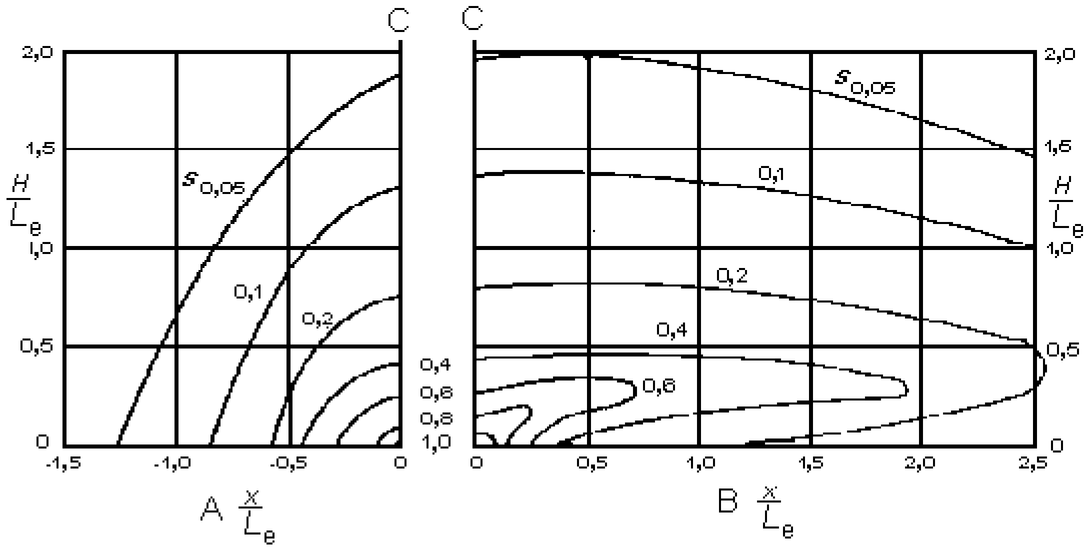


Key
C crest of hill
w wind direction

Figure 1 — Definition of factors determining topography coefficient

Table 7 — Values of L_e

Slope ($\Phi = H/L$)	
Shallow ($0,05 < \Phi \leq 0,3$)	Steep ($\Phi > 0,3$)
$L_e = L_u$	$L_e = H/0,3$



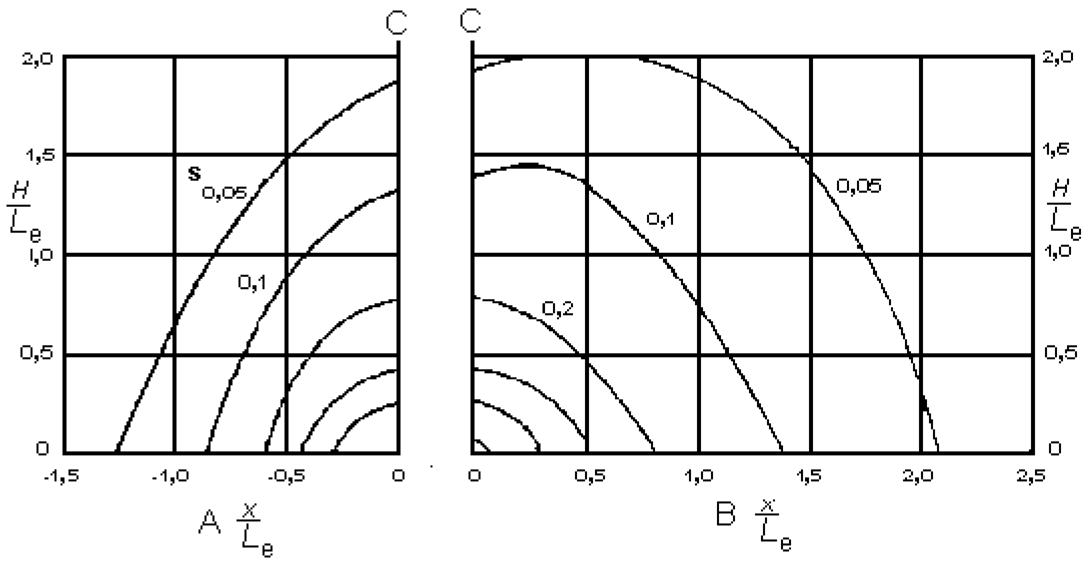
Key

A upwind

B downwind

C crest of hill

Figure 2 — Factor *s* for cliffs and escarpments



Key

A upwind

B downwind

C crest of hill

Figure 3 — Factor *s* for hills and ridges

7.3 Statistical elements

7.3.1 General

The monthly or annual mean wind speed may be calculated from data measured either continuously or at intervals not exceeding 3 h.

7.3.2 Monthly mean wind speed

The monthly mean wind speed shall be calculated by:

$$v_{m\mathrm{m}} = \frac{\sum_{N=1}^{n_m} v_N}{n_m} \tag{24}$$

where

n_m is the number of wind speed readings in the month in question.

7.3.3 Annual mean wind speed

The annual mean wind speed shall be calculated by

$$v_{y\mathrm{m}} = \frac{\sum_{N=1}^{n_y} v_N}{n_y} \tag{25}$$

where

n_y is the number of wind speed readings in the year.

7.3.4 Cumulative frequency distribution of wind speeds

The cumulative frequency distribution of winds not exceeding a given speed is the proportion of a month or a year when the mean wind speed measured has not exceeded this speed. It can be deduced in terms of a cumulative distribution function, a probability of exceeding a value of wind speed $\overline{v}$ denoted 1-P, where P is the probability that the wind is below any given value. The "parent" wind speed distribution, $P_{\overline{v}}$, irrespective of direction, is well represented by the Weibull distribution:

$$P_{\overline{v}} = 1 - \mathrm{e}^{-(\overline{v}/c)^k} \tag{26}$$

where

c is a scale parameter;

k is a shape parameter.

NOTE 1 The scale parameter, c, and the shape parameter, k, are determined from the wind data.

NOTE 2 It is also possible to define a Weibull distribution for each direction.

7.3.5 Wind direction

The statistical distribution of frequencies of mean wind by ranges of direction and speed shall be given as tables, by month and for the whole year, as shown in Table 8. The presence of any local obstructions likely to distort the distribution of wind direction should be recorded.

Table 8 — Sample table of monthly or annual frequency of wind by speed and direction

Speed m/s	Direction												All directions
	345 to 15	15 to 45	45 to 75	75 to 105	105 to 135	135 to 165	165 to 195	195 to 225	225 to 255	255 to 285	285 to 315	315 to 345	
>14	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,00	0,02
12 to 14	0,01	0,00	0,00	0,02	0,00	0,00	0,01	0,08	0,02	0,01	0,00	0,00	0,14
10 to 12	0,03	0,07	0,07	0,10	0,00	0,01	0,11	0,34	0,15	0,06	0,03	0,01	0,97
8 to 10	0,14	0,26	0,39	0,31	0,02	0,05	0,46	1,53	0,75	0,24	0,16	0,10	4,43
6 to 8	0,66	1,13	1,01	0,82	0,08	0,27	0,96	3,20	2,17	0,94	0,52	0,49	12,25
4 to 6	1,82	3,26	1,84	2,13	0,68	0,86	2,02	5,37	5,08	2,25	1,46	1,63	28,41
2 to 4	1,97	2,81	1,41	2,24	1,27	1,09	2,43	4,67	4,55	2,31	1,99	2,05	28,79
0 to 2	3,10	1,63	1,38	1,97	1,47	1,12	2,32	3,55	2,68	2,37	1,83	1,58	24,99
All speeds	7,74	9,16	6,10	7,60	3,52	3,40	8,31	18,75	15,41	8,17	5,99	5,86	100,00
	N			**E**			**S**			**W**			

These statistics may also be represented by a graph called a “wind rose”: the length of symbols in any direction are proportional to the cumulative frequencies of wind speed in that direction lower than several speed thresholds.

7.4 Expression of results

The following parameters shall be reported for each month or year :

a) the measurement dates from which the parameters are calculated;

b) the location of the anemometer from which the measurements are taken, including any local features that shelter it in particular directions;

c) the frequency of the original data used to calculate means and distributions.

d) the monthly or annual mean speed;

e) a cumulative frequency distribution of wind speed for each month or year, or the parameters of the corresponding Weibull distribution;

f) if required, a table of the frequency distribution of speed by direction over the month or year.

8 Precipitation

8.1 Sources of data

Rainfall shall be measured by a rain gauge with design and siting complying with WMO Guidelines No. 8 1996. The depth of newly fallen snow and other solid precipitation on level ground adjacent to the rain gauge shall be measured to the nearest centimetre. The solid precipitation in the rain gauge shall be melted, by a method which minimises evaporation, and the liquid volume measured. The days when the ground is covered with snow shall be noted.

8.2 Calculation of monthly total

8.2.1 From hourly data

The hourly values of precipitation and melted solid precipitation shall be totalled to give the monthly precipitation.

$$R_m = \sum_{h=1}^{N_m} R_h \tag{27}$$

8.2.2 From daily data

The daily totals of precipitation and melted solid precipitation shall be totalled to give the monthly precipitation:

$$R_m = \sum_{d=1}^{d_m} R_d \tag{28}$$

8.3 Expression of results

The following data shall be reported:

a) the measurement dates from which the parameters are calculated;

b) frequency with which the original precipitation data were recorded and, if the data originated from daily measurements, the time of day at which they were recorded;

c) monthly total precipitation to the nearest 1 mm;

d) number of days in the month when the precipitation is 0,1 mm or more;

e) maximum fall in one day during the month to the nearest 1 mm;

f) if the data are derived from hourly measurements, the maximum fall in one hour during the month to the nearest 0,1 mm;

g) if the data are derived from hourly measurements, the number of hours in the month in which the precipitation exceeded 0,1 mm;

h) total depth of newly fallen snow or other solid precipitation;

i) number of days on which the ground is covered with snow.

9 Solar radiation

9.1 Sources of data

Solar irradiance and solar irradiation are measured in accordance with the WMO Guidelines No. 8 1996. Of particular interest are the irradiances on a horizontal plane and those on the four vertical planes of orientation

South, East, North, and West. Frequently only global horizontal irradiance is measured, the other components can be estimated from auxiliary data. Useful parametres are hourly, daily, monthly and annual total solar irradiation.

9.2 Calculation of monthly total solar irradiation

9.2.1 General

Usually daily, monthly and annual data are expressed in energy rather than in mean power.

9.2.2 From irradiance or hourly irradiation measurements on any plane

From the mean solar irradiances, $\overline{G}_{\mathrm{s},ic,i}$, measured on a surface of any inclination, ic, during a time interval Δt (usually 1 h or 3 h) at time i, the monthly total global, direct and diffuse irradiation are given by:

$$H_{\mathrm{s,g},ic} = \sum_{i=1}^{Nm} \overline{G}_{\mathrm{s,g},ic,i} \Delta t \quad (29)$$

$$H_{\mathrm{s,d},ic} = \sum_{i=1}^{Nm} \overline{G}_{\mathrm{s,d},ic,i} \Delta t \quad (30)$$

$$H_{\mathrm{s,b},ic} = \sum_{i=1}^{Nm} \overline{G}_{\mathrm{s,b},ic,i} \Delta t \quad (31)$$

where

N_m is the number of measurements in the month;

and the subscripts denote

g global radiation;

d diffuse radiation;

b direct radiation;

ic a surface of any inclination.

This assumes that the planes on which the measurement and for which the calculation of the mean take place are identical in orientation. Furthermore, it is essential that the intervals Δt are constant and cover all the hours of the month without overlapping.

In the case that already hourly irradiation data are available for all days of the month, the monthly solar irradiation can be calculated simply by additions according to the type of formulae [32] to [34].

9.2.3 From daily total irradiation

From the daily total irradiation $H_{\mathrm{s,j}}$ of the day d, on a surface of inclination ic, the monthly total global, direct and diffuse irradiation are given in turn by:

$$H_{\mathrm{s,g},ic} = \sum_{d=1}^{dm} H_{\mathrm{s,g},ic,d} \quad (32)$$

$$H_{\mathrm{s,d},ic} = \sum_{d=1}^{dm} H_{\mathrm{s,d},ic,d} \quad (33)$$

$$H_{\mathrm{s,b},ic} = \sum_{d=1}^{dm} H_{\mathrm{s,b},ic,d} \quad (34)$$

The same remarks on the inclination of the plane apply as in 9.2.2.

9.3 Expression of results

The following parameters shall be reported for each component of the radiation for each month:

a) the measurement period from which the parameters were recorded;

b) the interval at which the radiation is recorded;

c) the monthly total solar irradiation.

When the monthly totals are based on hourly values, the following additional statistics shall be reported: the minimum, 10 percentile, the median, the 90 percentile and the maximum irradiance.

9.4 Estimating irradiances that are not measured

The methods of 9.2.2 and 9.2.3 can only be applied if a series of measurements of the quantity required is available. This will hardly ever be the case when irradiation on a vertical plane, or diffuse or direct irradiation are required.

Established methods to compute the required data exist. Thus for practical cases, knowledge of a series of measurements of global irradiance on a horizontal plane, together with air temperature and humidity, solar constant, albedo and solar time, or cloud amount and cloud type, are the only data needed to reconstruct diffuse, global and direct irradiance of any inclination and orientation. However measured data, if available, are always to be preferred to computed data.

NOTE Annex A gives recommended methods for the computation of non measured radiation parameters.

10 Longwave radiation

10.1 General

Longwave radiation, with wavelengths longer than 3 μ, is emitted at temperatures between 240 K and 340 K by the atmosphere and from the ground and buildings. As shown in annex B, the effect of radiation from the sky can be expressed in terms of an equivalent sky temperature for use in thermal calculations.

10.2 Sources of data

Longwave, or terrestrial, radiation is measured in accordance with the WMO Guidelines No. 8 1996. Either the mean longwave irradiance or the irradiation over a period of time, usually an hour or a day, is measured.

NOTE Measured data are obtainable from climate archives of national weather services cooperating with WMO, or from the World Radiation Data Center (WRCD) of WMO in St. Petersburg.

10.3 Calculation of monthly total longwave irradiation from the atmosphere (sky)

10.3.1 From irradiance measurements

From the mean longwave irradiance $\overline{G}_{\mathrm{l,a},i}$ measured during a time interval Δt (usually 1 h or 3 h) at time i, the monthly total longwave irradiation is given by:

$$H_{\mathrm{l,a},m} = \sum_{i=1}^{Nm} G_{\mathrm{l},i}\ \Delta t \qquad (35)$$

10.3.2 From daily total irradiation measurements

From the daily total irradiation $H_{\mathrm{l,j}}$ of the day d, the monthly total longwave irradiation is given by:

$$H_{\mathrm{l,a},m} = \sum_{d=1}^{dm} H_{\mathrm{l},d} \qquad (36)$$

10.4 Expression of results

The following parameters shall be reported for each month:

a) the period from which the parameters were recorded;

b) the interval at which the radiation is recorded;

c) the monthly total longwave irradiation;

and, when the monthly totals are based on hourly values, the following statistics shall be reported: the minimum, 10 percentile, the median, the 90 percentile and the maximum irradiance.

Annex A
(informative)
Methods for splitting global solar irradiance into the direct and diffuse parts

A.1 General

A number of models, based on statistical analysis of measured data, have been developed in different climates to enable global solar irradiance to be split into the direct and diffuse parts. The models described below have proved to be the most effective in mid-latitude climates; other models might be more suitable for tropical climates. The European Solar Radiation Atlas (3rd edition) [6], contains a complete description of methods for analysing solar data. The European Solar Radiation Atlas (4th edition of 2000, ESRA 4) [5] contains on a CD-Rom not only a data base but also 10 algorithmic chains for deriving modified quantities.

A.2 On a horizontal plane

Global irradiance measured on a horizontal plane can be split into the approximate direct and diffuse fractions by calculating the diffuse fraction according to the statistical results in Erbs [7]. The direct irradiance fraction is then calculated as the difference of global irradiance and diffuse irradiance. The formulae for the calculation of the diffuse fraction are as follows:

$k_T \le 0{,}22$: $G_{s,d}/G_{s,g} = 1{,}0 - 0{,}09\, k_T$

$0{,}22 < k_T \le 0{,}80$: $G_{s,d}/G_{s,g} = 0{,}9511 - 0{,}1604\, k_T + 4{,}388\, k_T^2 - 16{,}638\, k_T^3 + 12{,}336\, k_T^4$ (A.1)

$k_T > 0{,}80$: $G_{s,d}/G_{s,g} = 0{,}165$

where

k_T is the clearness index of the atmosphere related to extraterrestrial global irradiance;

$G_{s,d}$ is the diffuse fraction of global irradiance, in W/m^2;

$G_{s,g}$ is the global irradiance on a horizontal plane, in W/m^2.

The clearness index of the atmosphere, k_T, is the ratio of the extraterrestrial global irradiance on the ground to the measured global irradiance

$$k_T = \frac{G_{s,g}(\text{ground})}{G_{s,g}(\text{extra terrestrial})} \qquad \text{(A.2)}$$

The extraterrestrial irradiance can be calculated from astronomical data (distance to sun, incidence angle, etc.) using the methods specified in, for example, [5, 13].

A.3 On tilted planes

If the plane is tilted, radiation reflected from ground can also reach the plane. Also, as the plane is not open to the whole sky hemisphere, the diffuse irradiance cannot be calculated as an integrated value; the angle dependent components should be calculated separately. Details of how to derive the three components of diffuse irradiance (circumsolar fraction around the sun, horizon ribbon and the isotropic fraction) can be found in the papers [5, 8, 9,10, 11, 14] in the Bibliography.

Annex B
(informative)
Methods for estimating the longwave atmospheric irradiances (longwave sky irradiances)and the sky temperature

The irradiance generated on a horizontal plan by the reception of longwave radiation from the atmosphere can be described with the Stefan-Boltzmann law using a special atmosphere emittance $\varepsilon_a < 1$

$$G_{l,a} = \varepsilon_a \sigma T^4 \quad (B.1)$$

where

$G_{l,a}$ is the atmospheric longwave irradiance, in W/m^2;

ε_a is the atmospheric emittance;

σ is the hemispherical Stefan-Bolzmann constant = $5,6697 \times 10^{-8}$, in $W/(m^2 \cdot K^4)$;

T is the air temperature measured at 2 m height in a screen, in K.

Reference [13,14] give information on the calculation of sky emissivity for cloudy and cloudless skies.

If measured dewpoint temperatures, θ_{dp}, and observations of the cloud cover, c, are available, Equations (B.2) and (B.3) should be used (from Unsworth [12]).

$$\varepsilon_a = \varepsilon_0 (1 - D c) + D c \quad (B.2)$$

with $$\varepsilon_0 = A + B\theta_{dp} \quad (B.3)$$

where

ε_0 is the emissivity for clear sky conditions;

c is the cloud cover fraction $(0 \leq c \leq 1)$;

θ_{dp} is the dew point temperature measured at 2 m height in a screen, in °C;

A, D are fitted parameters from measurements;

B is a fitted parameter from measurements, in $°C^{-1}$.

If no measured data are available, the following values can be used:

$A = 0,745$ $B = 0,0056\ °C^{-1}$ $D = 0,84$

If the air temperature, T, is measured and the cloud cover observations for low n_L, middle n_M or high cloud n_H, Equations (B.4) and (B.5) should be used [13].

$$\varepsilon_0 = 9,9 \times 10^{-6}\ T^2 \quad (B.4)$$

$$\varepsilon_a = \varepsilon_0\ [1 + a_L\, n_L^{PL} + a_M\, (1 - n_L)\, n_M^{PM}\, a_H\, (1 - n_L)\, (1 - n_{nM})\, n_H^{PH}] \quad (B.5)$$

According to [13, 14] the following values should be used:

$P_L = P_M = P_H = 2,5$

$a_L = 2,30 - 7,37 \times 10^{-3}\ T$;

$a_M = 2,48 - 8,23 \times 10^{-3}\ T$;

$a_H = 2,89 - 1,00 \times 10^{-2}\ T$.

Assuming that the sky behaves as an ideal black body radiator (emissivity equals 1), a corresponding sky temperature T_a can be calculated:

$$T_a = \sqrt[4]{\frac{G_{l,a}}{\sigma}} \qquad \text{(B.6)}$$

Bibliography

[1] SMITHSONIAN INSTITUTION, *Smithsonian Meteorological Tables.* Washington, 1958.

[2] CIBSE, Guide Volume C*, Reference Data*. Chartered Institute of Building Services Engineers, London, 1986.

[3] LINKE and BAUR (1970), *Meteorlogisches Taschenbuch,* Neue Ausgabe, Band II, zweite Auflage. Leipzig: Akademische Verlagsgesellschaft Geest & Portig K.-G, 1970.

[4] DEUTSCHER WETTERDIENST, *Aspirations-Psychrometer-tafeln.* Vierte, erweiterte Auflage. Verlag Friedrich Vieweg & Sohn, Braunschweig, 1963.

[5] EC: GREIF, J. and SCHARMER, K, *The European Solar Radiation Atlas 2000 (ESRA 4)*. Distributed by: Ecole des Mines de Paris, 2000; 60, Boulevard Saint-Michel, 75272 Paris Cedex 06.

[6] PALZ, W. and GREIF, J., *European Solar Radiation Atlas: Solar Radiation on Horizontal and Inclined Surfaces*. 3rd Edition: Springer, 1996.

[7] ERBS, D.G., *Estimation of the diffuse radiation fraction for hourly, daily and monthly average global irradiation*. Solar Energy Vol. 28/4, 1982.

[8] PEREZ, R. et al., *An anisotropic hourly diffuse radiation model for sloping surfaces – Description, performance validation, site dependency evaluation*. Solar Energy 36, p 6, 1986.

[9] PEREZ, R. et al., *Variations of luminous efficacy of global radiation and zenith illuminance with weather conditions, description of a potential method to generate key daylight availability data from existing solar radiation data bases*. Solar Energy 38, 1, pp 33-44, 1987.

[10] PEREZ, R. et al, *A new simplified version of the Perez diffuse irradiance model for tilted surfaces*. Solar Energy 39, 3, pp 221-231, 1987.

[11] PEREZ, R. et al, *Modelling daylight availability and irradiance components from direct and solar irradiance.* Solar Energy 44,5, pp 271-289, 1990.

[12] UNSWORTH, M.H. et al., *Longwave radiance at the ground*. Quarterly Journal of the Royal Meteorological Society, 1975.

[13] CZEPLAK, G., and KASTEN, F., *Parameterisierung der atmosphärischen Wärmestrahlung bei bewölktem Himmel*. Meteorologische Rundschau 6, l987.

[14] VDI 3789, Blatt 2, *Umweltmeteorologie – Wechselwirkungen zwischen Atmosphäre und Oberflächen-Berechnung der kurz- und langwelligen Strahlung*, (Part 2, *Environmental Meteorology, Interaction between Atmosphere and Surfaces, Calculation of shortwave and longwave Radiation)*. Verein Deutscher Ingenieure, Oct. 1994.

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