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# IEC TS 62862-1-2

Edition 1.0 2017-11

# TECHNICAL SPECIFICATION

colour inside

## Solar thermal electric plants –
## Part 1-2: General – Creation of annual solar radiation data set for solar thermal electric (STE) plant simulation



IEC TS 62862-1-2:2017-11(en)

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Technical Specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 62862-1-2, which is a Technical Specification, has been prepared by IEC technical committee 117: Solar thermal electric plants.

The text of this Technical Specification is based on the following documents:

| Enquiry draft | Report on voting |
|---|---|
| 117/67/DTS | 117/77/RVDTS |

Full information on the voting for the approval of this Technical Specification can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62862 series, published under the general title *Solar thermal electric plants*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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# INTRODUCTION

During the various stages of planning, design and start-up of a solar thermal electricity (STE) plant, engineering and economic studies often require the simulation of plant power production, and an analysis of the response of its various components and systems. All these simulation studies use precise, organized and standardized information of the solar resource and other meteorological variables.

As a one-year period includes the most important meteorological cycle, the response of a power plant is simulated for a complete year, and attempts to achieve results that can be extrapolated to the long term. The need therefore arises for a complete year of data for the meteorological variables that influence plant operation and provide a response to solar thermal power plant simulation studies. This standard year of data, which is known as the typical meteorological year (TMY), serves for both annual plant electricity production studies and engineering studies associated with a solar thermal power plant project, except for studies on extreme events.

The meteorological information for a specific place, especially knowledge of the solar resource, is always subject to uncertainty. Furthermore, this information comes from quite different sources and its availability is very irregular. Therefore, in order to generate a typical meteorological year, a standard, characteristic methodology is used which ensures its operability in the framework of solar thermal power plant projects, and offers adequate support for decision-making in this type of project.

This functional typical meteorological year as defined by this document is hereinafter called the annual solar radiation (ASR) data set.

Precise knowledge of the solar resource available is important for the design and development of any system that intends to make use of the energy from the sun. The large non-determining component of solar radiation[1] and the need to simulate the response of a solar system in the long term have led to the development of a methodology for generating a reference year that includes information on diurnal and seasonal variations in the meteorological variables involved as well as their long-term averages.

The typical meteorological year that has made this name best known was developed at Sandia National Laboratories [4], and employed part of the SOLMET/ERSATZ (1951-1976) database [5] made up of 248 stations of which 26 provide solar radiation measurements and the rest estimated data, for the US and adjacent territories. This TMY was built up from the concatenation of typical months to form a year with 8 760 hourly records. Each month was selected by evaluating nine variables: the mean, maximum and minimum temperature and dew point temperature, maximum and mean wind speed and global horizontal radiation. A weighted sum of the Filkenstein-Schafer statistic [5] [6] was used, resulting in the selection of five months. The final choice of the typical month considered the long-term persistence of climate patterns.

Although various authors have proposed slight variations in the Sandia methodology, in essence it remains practically unaltered in the generation known as TMY2 and TMY3 [5] [7].

TMY version 2 employs data from the National Solar Radiation Database (NSRDB) from 1961 to 1990, with 93 % of the data estimated by models and 7 % from data measured for 239 locations. The records include measurements of associated meteorological variables

1 In this document, the term solar radiation is used as a generic reference to the "radiation emitted by the Sun" (as is defined in ISO 9488:1999, 3.13), and irradiance and irradiation are used as the physical magnitudes defined in ISO 9488:1999, 3.4 and 3.5 respectively]. On the other hand, these references notwithstanding, in this document, it has been agreed to express irradiance in W/m$^2$ and irradiation in Wh/m$^2$.

such as temperature, humidity, cloud cover and visibility. The solar radiation measurement is present at 52 NSRDB stations, but the measurement period is short.

The TMY version 3 was produced using hourly solar radiation data and meteorological data from 1 454 stations, from NSRDB database time series (1961-1990) and its update, consisting of NSRDB station time series (1 %) and a dataset estimated using the State University of New York (SUNY) model based on geostationary operational environmental satellite (GOES) images for an eight-year recording period (1998-2005).

Finally, it should be mentioned that there are other methodological proposals that differ somewhat more from the National Renewable Energy Laboratory (NREL) TMYs, involving other variables, with a variety of statistics and even proposing the collection of typical meteorological data for only a few days a month instead of a whole year.

As the data necessary for generating the TMYs mentioned above are not available in the locations of most STE plant projects, a procedure is defined for the creation of an annual solar radiation data set for the plant simulation that standardizes the procedures currently used for this.

In this document, a set of procedures are presented. Only the minimal requirements of these procedures are described even when there may be additional considerations that will be more than welcome during the application of the procedures, but there may be times that they will not be available and the inclusion in this document will block the option of following it.

It is important that all the proposed methodologies use a measurement campaign with well-defined quality characteristics during a whole year and at least containing direct solar irradiance ($G_b$) measurements in the expected location.

Two options are proposed to generate the annual solar radiation data set depending on the data availability. One only uses measurements of $G_b$ but in addition uses high quality $G_b$ estimations during more than 10 years. This methodology is very similar to the classic TMY but with a preliminary assessment of coherence with the local measurements. In this methodology, the ASR could be formed by the estimations selected in the process, by $G_b$ measurements or by simultaneous measurements of GHI and $G_b$.

The other option uses $G_b$ measurements as well as global horizontal irradiance (GHI); and uses a methodology for GHI long-term estimation based on additional sources of information (aimed low quality GHI estimations). In this second methodology, the ASR will always be formed by simultaneous measurements of GHI and $G_b$.

Recent works, such as the creation of multiple annual solar radiation (MASR) data sets for the simulation of a STE plant, are out of the scope of this document even when their use could be better than the use of a unique annual data set of data for the prefeasibility assessment of a STE plant project. At the moment of the elaboration of this document, there is not a consensus or a relation of procedures for MASR creation.

MASR creation as well as annual solar radiation data sets referred to an annual percentile (commonly the 10th percentile 10 of the estimated annual values distribution) could be covered in future projects.

This document is related to works developed in the context of the International Energy Agency SolarPACES and Solar Heating and Cooling agreements as a liaison organization of experts in solar radiation for energy applications. Coordination with subcommittee 1 of ISO technical committee 180 is also considered.

# SOLAR THERMAL ELECTRIC PLANTS –

## Part 1-2: General – Creation of annual solar radiation data set for solar thermal electric (STE) plant simulation

## 1 Scope

This part of IEC 62862 defines the procedures for the creation of annual solar radiation data sets (ASR) for solar thermal electricity (STE) plant simulation.

In addition to the definition of procedures needed for the ASR construction, its components and parameters will be also described.

The scope of application of this document refers to the needs associated with solar thermal power plant projects and mainly related to the simulation of an annual period with a solar radiation sum close to a normal annual value (from among an estimation of all possible annual values).

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9488:1999, *Solar energy – Vocabulary*

## 3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

**3.1**
**annual solar radiation data set**
**ASR**
complete standardized set of solar irradiance data, which may be accompanied by other meteorological variables considered of interest, and which attempts to establish a reference for radiometric evolution in a specific place during the year

Note 1 to entry: This data set shall have a solar radiation sum close to a normal annual value (among an estimation of all possible annual values).

**3.2**
**direct measurement**
value of a certain variable found with a measurement instrument on the surface at the specific site

Note 1 to entry: Direct measurement data shall be considered to be any statistic derived from values of the same variable that meet the above definition for a given period of time. For example, those found by the arithmetic mean of values recorded by the corresponding measurement instrument (sensor and data acquisition system) for a given period of time are direct measurements.

**3.3**
**indirect measurement**
value of one variable found by combining direct measurements of other variables

EXAMPLE The measurement of direct solar irradiance with a pyrheliometer directed at the sun is a direct measurement process. On the other hand, its determination from the direct measurement of global solar irradiance and diffuse solar irradiance is an indirect measurement involving two previous direct measurements.

Note 1 to entry: Finding direct solar irradiance from a numerical model, for example, a regression equation, may not be considered either direct or indirect measurement.

**3.4**
**derived data**
data found from a statistical function that relates to a set of simultaneous data for different variables at the same place

EXAMPLE Data found from regression models, such as some models for calculating direct solar irradiance from global horizontal irradiance, are derived data.

**3.5**
**synthetic data**
<synthetic generation of a series> interpolated data of the same variable recorded in another space and/or time frequency

EXAMPLE All data found from spatial or temporal interpolation are synthetic data.

**3.6**
**satellite data**
data found from information collected by a measurement instrument on board a satellite

Note 1 to entry: This document distinguishes between high and low quality satellite data. High quality satellite data refers to satellite data with a temporal resolution of one hour or less, and a maximum spatial resolution of 20 km [8]. ASR data sets could be formed by high quality satellite data.

**3.7**
**meteorological model data**
**NWP**
data found from models that include a numerical solution of differential equations defining the behaviour of the atmosphere based on given initial conditions

Note 1 to entry: This document distinguishes between high and low quality data from meteorological models. High quality data from a meteorological model refers to data from a meteorological model with a temporal resolution of one hour or less, and a maximum spatial resolution of 20 km [8]. ASR data sets could be formed by high quality data from meteorological models.



# 4 Elements forming the ASR data set

## 4.1 Geographic and time identification

### 4.1.1 Geographic identification

The WGS 84 world geodetic system standard is taken as the reference ellipsoid to define the geographical location on lambertian coordinates.

The geographic identification of the place to which the data set refers to is determined by:

- the geodetic latitude and longitude coordinates;
- the elevation above mean sea level.

#### 4.1.2 Time reference

For each individual data point in the ASR, two timestamps should be given. One timestamp should indicate the time of the value within the ASR (functional date). The other timestamp corresponds to the time to which the original data value belongs (original date). The time in the ASR cannot be completely defined without stating the year. In order to avoid errors and ambiguities, the year of the ASR data set should be set to 2015. This way, the solar position can be calculated in the same way by all users and it is clear that the ASR is no leap year.

The record date shall follow the time reference established in this document, that is, they shall correspond to the UTC referencing system (see Annex A).

#### 4.1.3 Time frequency

ASR data set frequency has to be hourly or higher (higher frequency corresponds to a shorter time period). The value corresponding to the time period (one hour, ten minutes, five minutes, etc.) may come from a high sampling frequency, which has to be an exact divider of one hour. The corresponding record is assigned an average, maximum, minimum, or instantaneous value for that period, depending on the variable observed. In the case of direct solar irradiance, ASR shall at least be the average.

### 4.2 Variables

#### 4.2.1 General

The ASR data set shall contain the number of records corresponding to a whole year at the frequency of direct solar irradiance and in all available variables. There shall be records corresponding to twelve different months from January to December, not necessarily consecutive nor do they have to be from the same year.

#### 4.2.2 Mandatory variable

The unit for direct solar irradiance is $Wm^{-2}$, expressed in integer numbers. In this document, direct solar irradiance is understood as the value of the magnitude as defined in ISO 9488, i.e. direct solar irradiance is the radiant flux received on a flat surface from a small solid angle centered on the solar disk, and the area of this surface, which is perpendicular to the axis of the solid angle.

The detailed definitions of direct solar irradiance given in IEC TS 62862-1-1[2] should be taken into account.

In the framework of this document, we refer to a small solid angle that corresponds to the recommendations for new pyrheliometers from the WMO [20].

The recommended nomenclature for direct solar irradiance is $G_b$ (ISO 9488), although other nomenclatures commonly used for this variable are: DNI (from Direct Normal Irradiance), B (from the term beam radiation) and $I_b$ [9].

#### 4.2.3 Other variables

The direct solar irradiance series may be accompanied by other variables, such as:

- global horizontal irradiance;
- diffuse horizontal irradiance;
- ambient temperature;

2 Under preparation. Stage at the time of publication: IEC BPUB 62862-1-1:2017.

- relative humidity;
- wind speed;
- wind direction;
- atmospheric pressure.

These variables have to be reported for the same period of time and shall be in the same time frequency (frequency as described in 4.1.3) as the direct solar irradiance and be physically and dynamically coherent with it. That is, if ten-minute direct solar irradiance is supplied, the rest of the meteorological variables shall also be ten-minute, and at the same time have to be coherent with it in absolute values (physically) as well as its sequence (dynamically).

Ambient temperature, relative humidity and atmospheric pressure measurement have to be measured with instruments not exposed to sudden changes in temperature and from vibration and dust. Ambient temperature and relative humidity values should correspond to a height of between 1,2 m and 2,0 m above ground level as defined in [20].

Wind surface measurements, such as wind speed and wind direction, will be referenced "at a standard height of 10 m above open flat ground" for the exposure of wind instruments as defined in Chapter 5, Part I, of [20].

### 4.3 Format

The annual series should be formatted according to IEC TS 62862-1-3.

A label showing where data are from is a parameter which gives information on the origin or type of data of the minimum variable (direct solar irradiance) and should be included in the data set. Depending on the origin, values would be from 2 to 7 (corresponding to definitions 3.2 to 3.7), reserving 1 for "unknown". Possible label values are summarized in Table 1. Two label columns should be provided for each record, one associated with the original date ("label_orig") and the other associated with the functional date ("label_func").

Any data on the label associated with the functional date that are not for the annual instant to which it corresponds (where the original date and the functional date are not identical – except for the year) are considered synthetic, whatever the origin they are from.



**Table 1 – Direct solar irradiance place label values**

| Data from | Label |
|---|---|
| Direct measurement data | 1 |
| Indirect measurement data | 2 |
| Derived (modelled) data | 3 |
| Synthetic data | 4 |
| Satellite data | 5 |
| Meteorological model data (NWP) | 6 |

## 5 Procedures and methodology for ASR generation

### 5.1 General

The ASR generation procedure is divided into three sections (see Figure 1):

- measurement campaign;
- study of the representative long-term value;
- creation of the representative series.

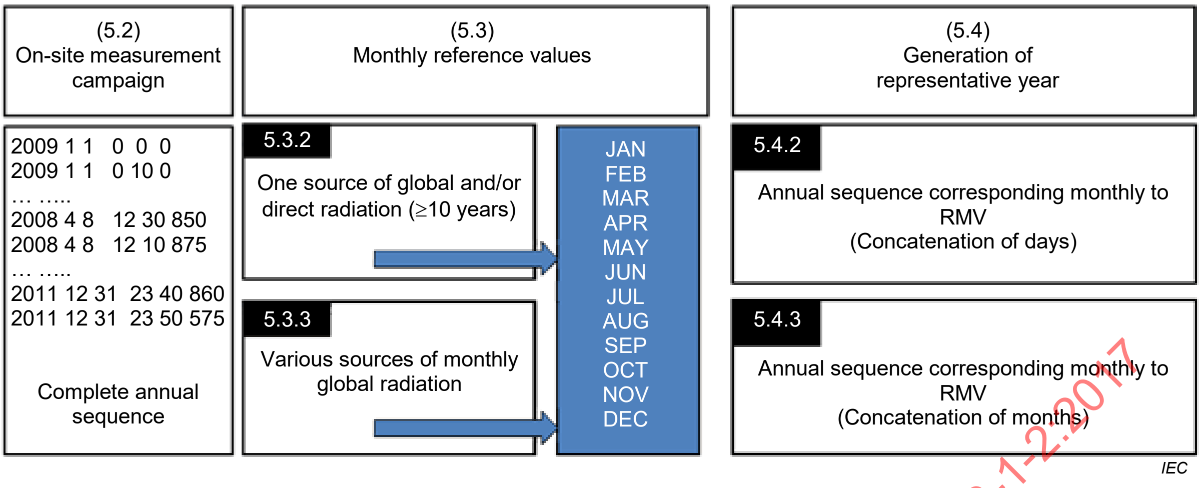


**Figure 1 – Sections of ASR generation procedure**

## 5.2 Measurement campaign

### 5.2.1 General

Data have to come from an on-site ground measurement station (or an equivalent site according to Annex C). Annex B gives a series of recommendations for measurement stations.

Data shall be comprised of on-site direct or indirect (as defined in 3.2 and 3.3) direct solar irradiance measurements. Additional global horizontal radiation measurements are recommended.

Measurement campaign records shall be subjected to two consecutive processes: quality control and validation. The duration of the measurement campaign will depend on the results of these processes. The measurement campaign should overlap one complete year with long term datasets, allowing a total of 30 days of gaps during this period. The determination of valid data uses the validation procedure explained below.

### 5.2.2 Quality control

First, data recorded at the measurement station will have to be subjected to quality control filter using the methods described in Annex D, and those data which do not pass quality control are considered erroneous and are not used for the ASR.

### 5.2.3 Validation and gap filling

The measured data that pass quality control filter are subjected to validation and gap filling.

A complete valid year is one comprised of 12 different valid months (from January to December), not necessarily in consecutive order, that is, not necessarily from the same year.

Valid months are considered to be those in which, if there are days that are not valid, these do not exceed four (4) days [10]. Note that many more days without valid measurement data might still be acceptable for site adaptation of satellite or meteorological model data with measurements. To find the monthly value corresponding to a month with anomalous days, the values of the hourly irradiation and other meteorological variables on these days will be substituted by the values of another day. This day will be within a range of no more than ±5 days from the substituted day and its irradiance value shall be the closest to the mean value of these months. Hence, a similar methodology as the World Radiation Data Centre (WRDC) is adopted [10], although in this case, measured data will be employed instead of a statistical mean of the available data.

Days considered valid are those on which, if there are anomalies in the direct solar irradiance measurement (values that have not passed the quality control in Annex D), these cumulative anomalies do not exceed the overall period of one (1) hour. For example, in the case of hourly data, only one anomaly per day would be accepted, and for ten-minute data, six errors per day. This anomaly has to be corrected coherently (for example by using linear interpolation) before proceeding to monthly validation.

## 5.3 Study of the representative long-term value

### 5.3.1 General

Climatological studies have found that a series of at least 30 years is necessary to define the period or number of years to be used to study the representative long-term value at a given site [11]. Nevertheless, other studies suggest shorter periods of 5 to 15 years for only the solar radiation variable [12] [13]. In the context of this document, information for the study of the representative long-term value shall be based on a minimum span of 10 consecutive years. Due to some recent changes of solar resources in the past decades, the averaging interval for the calculation of the long term average should be as recent as possible [19].

As for the variables to be used for characterizing the long-term performance of direct normal irradiation, this document admits the use of either this variable (applying the procedure in 5.3.3) or global horizontal irradiation for the long-term study (applying the procedures in 5.3.2 or 5.3.3).

The representative annual long-term value is determined using 12 representative monthly values, which can be for direct normal irradiation or global horizontal irradiation, together with the standard deviation associated with each. One of the two methodologies described below shall be applied to find these values.

### 5.3.2 One source

Subclause 5.3.2 describes a procedure by which representative long-term monthly means (RMV) and their associated standard deviation ($\sigma$) are estimated based on a single data solar radiation data source (whether direct normal, global horizontal irradiance or both) for an overall period of 10 years.

In addition to the types of data described in 3.2 to 3.7, in 5.3.2, it is also possible to use a source with data measured at a station located at a distance of up to 50 km providing that the climatic characteristics of both sites are similar.

The data source, which can be hourly or daily, has to be subjected to quality control and validation as described in 5.2.2 and 5.2.3. A valid daily series will then be available for the 10 year period (minimum time necessary to be able to apply this procedure).

The duration of the measurement campaign and its overlap with the long-term datasets have to fulfill the requirements of 5.2, and local adaptation on hourly value estimations have to be performed. The data source has to have a minimal overlap of one complete year with the measurement campaign period, so local adaptation on hourly value estimates is allowed. This adaptation will be applied for each one of the radiation variables that are going to be used, taking into account only the original measured data.

The adaptation resulting from the overlapping year analysis will be applied to the whole series, and with these daily values a table such as Table 2 will be filled in for each of the radiation variables used (normal direct, global horizontal or both).

**Table 2 – Table format for the estimation of a representative long-term value based on one data source**

| Day | Year 1 | Year 2 | Year 3 | ... | Year 10 |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |
| .... | | | | | |
| 365 | | | | | |

The representative long-term monthly value (RMV) for each variable is the sum of the daily values in a specific month from the years available. The selection of that specific month is made using the Sandia National Laboratories Method [4], in which the weighted mean (WM) is evaluated using the Finkelstein-Schafer statistic (FS) for each month available in the data source [6].

This statistic considers the distance between the distribution functions (CDF or cumulative density function) of the daily data for each variable ($x$) in a specific month ($j$) and the CDF for daily data in that month in all the years available. The distances are weighted (Equation (2)) using a relative weight for each variable ($\delta_x$), and the sum of all the relative weights is equal to one ($\sum \delta_x = 1$).

$$FS^x_{jk} = \sum_{r=1}^{n_r} \left| CDF^x_j(r) - CDF^x_{jk}(r) \right| \quad (1)$$

$$WM_{jk} = \sum_x \delta_x \times FS^x_{jk} \quad (2)$$

where

$r$ are the values of each of the ranges (abscissas) in which the daily values of variable are distributed, where the distribution function is evaluated;

$n_r$ is the number of ranges (abscissas) in the distribution functions;

$CDF_{jk}(r)$ is the value of the distribution function of the daily data for variable $x$ evaluated in range $r$, in the daily data sample in month $j$ and year $k$;

$CDF_j(r)$ is the value of the distribution function of daily data for variable $x$ evaluated in range $r$, in the daily data sample in month $j$ of all the years;

$\delta_x$ is the relative weight for each variable.

The following special considerations are made on the use of this method in the context of this document.

- At least a 10-year database is required.
- The meteorological variables involved in this case are exclusively direct solar irradiance and/or global horizontal irradiance. If only one variable is involved, its relative weight is equal to 1 ($\delta_x$ = 1), and if two are involved, the relative weight of each is 0,5 ($\delta_x$ = 0,5).

The FS statistic (Equation (1)) and the corresponding weighted mean (Equation (2)) are calculated from the data in Table 2 for each month ($j$) and year ($k$).

The specific month for determining the representative monthly value is selected according to the following procedure. First, the five months with the lowest FS statistic value will be chosen. Second, from these five months, the one with the most similar value to the whole data set long term monthly mean will be chosen.

The representative long-term monthly value (RMV) can therefore be determined for the variables that have been used in the process (direct solar irradiance and/or global horizontal irradiance) as well as the sum of the daily values in the month chosen.

Once the representative long-term monthly value has been determined, the standard deviation for this value is found by analysing all the monthly values available.

### 5.3.3 Several sources

Subclause 5.3.3 describes a procedure for estimating the monthly means representative of long-term performance, representative long-term monthly value (RMV), and their associated standard deviation ($\sigma$) based on several different sources of global horizontal irradiation.

Exceptionally, in 5.3.3, it is possible to use different data sources for the data described in 3.2 to 3.7, but in that case, these sources may not be used for the final ASR. Therefore, sources of information on global horizontal irradiation may be included to determine monthly values (or hourly or daily), whether from specific years or from a previous long-term estimate, and not necessarily according to the procedures described here. If possible, it is recommended that data from such sources be subjected to the quality control and validation processes described in 5.2.2 and 5.2.3.

Therefore, some sources available may have been well checked and others less so, but this and other characteristics of each source are duly considered in processing.

All sources together should span a minimum period of 10 consecutive years, and it is recommended that the year corresponding to the different sources be distributed as uniformly as possible over the 10 years, attempting to avoid any specific year having excessive influence of a unique source.

Each source has to provide (or allow the calculation of) monthly values from complete years (whether or not those monthly values belong to the same year or consecutive years) within the overall 10-year period considered in the paragraph above. It shall be possible to complete a table such as the one shown in Table 3 with this information. If the need for a correction is recognized or can be calculated from a certain database, this correction has to be made before using the monthly values in the methodology.

**Table 3 – Table format for estimating the representative long-term value from several different data sources**

| Month | Source 1 | Source 2 | Source 3 | ... | Source No. |
|---|---|---|---|---|---|
| January | | | | | |
| February | | | | | |
| March | | | | | |
| April | | | | | |
| May | | | | | |
| June | | | | | |
| July | | | | | |
| August | | | | | |
| September | | | | | |
| October | | | | | |
| November | | | | | |
| December | | | | | |



Each of the sources is assigned a weight ($P_i$) calculated using Equation (3):

$$P_i = \frac{T_i}{C_i \times D_i} \tag{3}$$

where

$i$ is each database;

$T_i$ is the time indicator (unit: number of years). Takes integer numbers from 1 to 10 maximum (lower values are not allowed, higher values are cut off at 10), where the time period of the database is expressed in years, or in other words, the number of years it comes from or represents.

$D_i$ is the distance indicator (unit: km). Takes integer numbers from 10 to 100 maximum (lower values start at 10, higher values are not allowed). This value is a distance or resolution, depending on whether it deals with a measurement or estimation source. Measurements are assigned a value for the distance from the source location to the site under evaluation. Estimates are assigned the estimate resolution. Therefore, data from measurement stations at distances over 100 km or databases supplying an estimate for an area of over 10 000 km$^2$ (or 1°) cannot be included.

$C_i$ indicates the origin of data (unit: source importance index without units), not necessarily according to the restrictions in 3.2 to 3.7. It takes values of 1, 2 or 3. It is assigned a value of 1 for a data source with direct or indirect on-site (or equivalent according to Annex C) measurements. It is assigned a value of 2 if the source supplies estimated data, typical years or known valid measurements. A value of 3 is assigned if they are from estimates of typical or representative years for a long period of unchecked sources (such as from scientific articles or information to which there is no direct access).

This methodology is only applicable if at least one of the following conditions is met:

- the number of data sources is equal to or greater than four;
- the sum of $P_i$ supplies a value equal to or greater than 1.

When the weights of each source are available, $P_i$ will have to be normalized to a sum equal to 1, and go on to be called $P_{in}$. This normalization can be done with an intermediate step in which a different relative weight is given measurements and estimates (for example, if possible, it is recommended that a relative weight of 0,6 be assigned to measurements and 0,4 to estimates).

The representative long-term monthly value (RMV) for each specific month (January to December) is found using Equation (4).

$$RMV_j = \sum_i P_{in} \times MV_{ji} \tag{4}$$

where,

– $i$ is each database;
– $j$ is each month (1 to 12);
– $P_{in}$ is the normalized weight of each database $i$;
– $MV_{ji}$ is the monthly value of month $j$ and database $i$

The standard deviation of the RMV is calculated by extending the definition of variance to the weighted case [15].

$$\sigma_j = \sqrt{\sum_i P_{in} \left(MV_{ji} - RMV_j\right)^2} \tag{5}$$



### 5.4 Generation of the representative series

#### 5.4.1 General

The generation of the ASR requires the generation of a sequence of hourly or higher frequency data which span the complete period of one year. Generation is based on the selection of 12 valid months from a given source (January to December), including all the corresponding records (meteorological variables, date of origin and origin label parameters) which are concatenated and processed to form the ASR. This source has to meet all the requirements included in 4.1 on geographic and time identification.

In principle, ASR construction is based on the measurement campaign (with direct solar irradiance values of the type described in 3.2 or 3.3), but estimates of direct solar irradiance of the type described in 3.6 or 3.7 may also be used. If the series of estimated values has already been used to determine the RMV (see 5.3.2 or 5.3.3), these data have already been subjected to quality control and validation, but if not, they have to do so now.

The ASR can be generated by either of the two methodologies described below.

#### 5.4.2 Procedure based on estimates

Subclause 5.4.2 shows a procedure for constructing the ASR file from direct solar irradiance estimates. This procedure is based on the concatenation of the months selected following the instructions given in 5.3.

The result shall be a concatenation of 365 valid and complete days that include all the simultaneous variables.

The final file, containing all the data, will be elaborated following all the instructions detailed in 4.3.

#### 5.4.3 Procedure based on measurement campaign

In this methodology, the generation of the ASR is carried out based on the selection of months in the measurement campaign.

The starting point is the measured, validated and previously qualified series for each specific month. The 12 monthly values for the qualified months are again compared with the RMV monthly irradiation (in the variable that directs the process: direct normal or global horizontal) found in 5.3.

For the selected data, the difference between monthly irradiance in the measurement campaign (for each month) and the corresponding RMV shall be checked. The resulting difference shall not be higher than 2 % of the twelfth part of the annual representative value according to Equation (6):

$$RMV_j - MV_{jk} < \frac{2\,\%ARV}{12} \tag{6}$$

where

$ARV$ is the annual representative irradiance value of the ASR obtained in 5.3.

If the selected months fulfill this equation, then they will be considered the ASR of the selected placement. For months that do not fulfill the equation, the incomplete days of these months (with all their associated variables) will be substituted by complete days from the original dataset until the equation is fulfilled. The complete data set shall be carried out with the minimum number of substitutions possible.



The following criteria shall be applied to the substitutions.

- Substitute an incomplete day for the same day in another year. This is strongly recommended as the first option as it does not add errors to the solar geometry of the missing.
- Substitute that day for another day from the same month within a range of ±5 days from the missing date (for example if the missing day is the 20$^{th}$ of January this day could be substituted by days between the 15$^{th}$ and the 25$^{th}$ of January). This restriction tries to minimize the solar geometry error to a quantity below 10 min for latitudes where thermo-solar power plants are usually located.
- A generated dataset shall not appear the same day (from the original dataset) more than four times
- A generated dataset shall not contain more than a 25 % substituted dates per month.
- The result has to be an annual dataset found by concatenation of 365 days of complete valid days, which includes all the simultaneous variables, where their monthly radiation fulfill Equation (6). With these data, a file can finally be made following each and every one of the instructions in 4.3.

## 6 Report

Following the generation of ASR, a report will have to be written giving the results of the steps in the process and which includes the following compulsory sections.

- Identification
  - author identification (company or organization and authors);
  - creation date;
  - description of the site.
- Introduction
  - time interval;
  - variables included in the ASR.
- Measurement campaign

  - characteristics of the measurement station;
    i) geographic location;
    ii) technical report of the station;
    iii) sensor quality certificate;
  - quality control (description and results);
  - validation;
    i) description (including the number of valid days, annual and monthly bases);
    ii) results.
- Study of the representative long-term value
  - methodology;
    i) description of the data sources;
    ii) in case of estimations, indicate results of the local adaptation;
  - results.
- Generation of the representative series
  - methodology;
  - results.
- Summary of monthly values
  - monthly values from the measurement campaign;
  - monthly values from the representative long-term value study;
  - monthly values from the ASR in all meteorological variables it contains.

# Annex A
(informative)

## Expression and relationships between formats of types of time

**Solar mean time (SMT)**, also called civil time, is the expression of time that considers the time span between consecutive passages of the mean sun (a fictitious sun which moves at a constant rate throughout the year) at the local meridian.

**Greenwich mean time (GMT):** is the solar mean time at the Royal Observatory in Greenwich (England) which by convention is at 0° longitude. The International Astronomical Union decided to replace it as reference with what is called Universal Time (UT) in 1928.

**Universal time (UT):** is a measure of time based on the position of astronomical references other than the sun, which leads to greater precision than the GMT reference. In any case, it is still a non-uniform time scale since it is based on the Earth's rotation.

**Coordinated universal time (UTC):** is an atomic time scale that is similar to UT. It is currently the international standard on which Official Time is based.

**Official time (OT):** also called the "official hour" is the time reference adopted by a particular country by the appropriate legislation. In the Canary Islands, it corresponds to the WET reference (Western European Time – UTC+0 in winter, UTC+1 in summer) and in the rest of Spain, it is CET (Central European Time – UTC+1 in winter, UTC+2 in summer). It is the time on a conventional clock.

**Official correction: ($C_{\text{official}}$):** change in the time twice a year in most countries (beginning of autumn and spring) in coordinated universal time to set the Official Time (Equation (A.1)).

$$OT = UTC + C_{\text{official}} \tag{A.1}$$

Data acquisition systems rarely consider it due to the inadvisability of having to consider the real time when it was applied, which does not always coincide with its official implementation.

**Standard time (ST):** also called "legal time", the standard time is the reference time corresponding to all locations within the same "time zone", a function of the "time zone convention" by which the Earth is divided into 24 zones by equidistant meridians called "time zones" with a width of 15º longitude at the equator. The meridian that divides each zone in two equal parts is called the reference time meridian and its identification is indispensable to correctly set the standard time (Equation (A.2)).

$$OT = UTC + C_{\text{official}} = ST + C'_{\text{official}} \tag{A.2}$$

where $C_{\text{official}}$ is a correction analogous to the official correction (as defined above) referring in this case to standard time; this correction in hours would be expressed in the following manner (using the negative longitude sign convention west of the Greenwich meridian):

$$C'_{\text{official}} = C_{\text{official}} + lon_{\text{ref}} / 15 \tag{A.3}$$

where

$lon_{\text{ref}}$ is the corresponding longitude of the reference time meridian (in degrees).

**True solar time (TST):** is the time given by the daily movement of the sun in the sky. It is based on the solar day which is the interval of time between consecutive passages of the sun at the local meridian. It is the time shown by a sun dial at a specific site and corresponds to the hourly angle of the sun at a specific instant. The relationship between true solar time and legal time is shown in Equation (A.4) (in hours).

$$TST = ST + C_{\text{long}} + E_{\text{t}} / 60 = OT - C_{\text{official}} + C_{\text{long}} + E_{\text{t}} / 60 \qquad \text{(A.4)}$$

where

$$C_{\text{long}} = (lon_{\text{site}} - lon_{\text{ref}})/15 \qquad \text{(A.5)}$$

**Time equation** ($E_{\text{t}}$): is the difference between true solar time and solar mean time at a site at a given instant. The time equation in minutes is calculated using Fourier series representations [16].

# Annex B
(informative)

## General recommendations for measurement stations

There has to be a meteorological station at the study site for measuring the available solar resource over an extended period to generate an ASR (described in the body of the standard as a function of quality of measurements collected).

This station shall be at a well-exposed site that is representative of the area around it. Be careful that instrument measurements are not affected by buildings or terrain, or by other instruments at the same station.

The station should have a remote connection between electronic units and IT media (software) for management, storage and transfer of data collected for later filtering and analysis.

There should be a station-component-maintenance programme to avoid, insofar as possible, collecting erroneous data or their loss due to malfunction or chance events that could affect the sensors.

The data acquisition system should have a remote synchronization mechanism, preferably by connection to a network time protocol.

The following parameters should be measured:

- global horizontal irradiance;
- diffuse horizontal irradiance;
- temperature;
- relative humidity;
- atmospheric pressure;
- wind speed;
- wind direction.

# Annex C
(informative)

## Equivalence of measurement station locations

A meteorological station equivalent to one located on site is any that is located within a 10 km radius.