METEONORM Version 6.0

Handbook part I: Software

METEOTEST

Imprint

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1 Short Review

What is *METEONORM*?

METEONORM is a comprehensive climatological database for solar energy applications:

- a meteorological **database** containing comprehensive climatological data for solar engineering applications at every location of the globe.
- a **computer program** for climatological calculations.
- a **data source for engineering design programs** in the passive, active and photovoltaic application of solar energy with comprehensive data interfaces.
- a **standardization tool** permitting developers and users of engineering design programs access to a comprehensive, uniform data basis.
- **meteorological reference** for environmental research, agriculture, forestry and anyone else interested in meteorology and solar energy.

What is it based on?

METEONORM's orderly facade conceals not only numerous **databases** from all parts of the world but also a large number of computational models developed in international research programs.

***METEONORM* is primarily a method for the calculation of solar radiation on arbitrarily orientated surfaces at any desired location**. The method is based on databases and algorithms coupled according to a predetermined scheme. It commences with the user specifying a particular location for which meteorological data are required, and terminates with the delivery of data of the desired structure and in the required format.

Depending on user requirements, the calculation procedure employs between one and four computation models (Tab. 1.1):

Tab. 1.1: The table shows the sequence in which the computational models are coupled in generating hourly radiation data on an arbitrarily orientated surface at a site for which no measurements are available.

Interpolation with monthly average value model G_h, Ta	Space dependent interpolation of horizontal radiation and temperature based on weather data taking altitude, topography, region, etc. into account
Hourly value generator G_h, Ta	Stochastic generation of time dependent global horizontal radiation and temperature data having a quasi-natural distribution and an average monthly value equal to the average value over 10 years
Radiation resolution $G_h \rightarrow D_h$, B_n	Resolution of global radiation into diffuse and direct components
Radiation on inclined surface with skyline effect, hourly value model G_k	Calculation of hemispherical radiation on arbitrarily orientated surfaces taking the reduction due to skyline profile into account

In addition to the monthly values, *METEONORM* provides maximum radiation values under clear sky conditions. For Switzerland, standardized data (design reference years) for building simulation purposes are available for a number of locations.

Which data for what problem?

Depending on his/her specific requirements, the user must choose the most suitable method from among the numerous procedures available in *METEONORM*. To provide the user with the best possible service, a whole series of dependent parameters in addition to the measured data are available. In choosing the data, the quality and relevance of the basis data sets must be considered. The following criteria should be applied:

- **Measured and interpolated monthly values** are of similar precision. Although measured data reflect the specific characteristics of a local site, they are always subject to measurement errors, and these tend to be compensated by the interpolation process. Interpolated data should therefore be used at sites with no weather station in the vicinity (approx. 20 km distance).
- **Dependent parameters** such as diffuse radiation, celestial radiation, dew point temperature, etc., which are determined from calculated as opposed to measured data, are subject to greater inaccuracy owing to error propagation.
- **Design reference year** – DRY – data (for Switzerland only) should preferably be used in situations for which they were generated and tested, i.e. for building simulations. This is because, like generated data, they are produced from original data via a data transformation procedure.

What has changed since the last edition?

The new version 6.0 includes **more data** and many **additional features**:

- Database:
  - Two time periods are now selectable for temperature, humidity, precipitation and wind seed: periods 1961-90 and 1996-2005; for radiation parameters 1961-90 and 1981-2000.
  - Enhanced use of satellite data for areas with low density of weather stations.
  - Inclusion of climate change forecast (Hadley CM3 model, business as usual scenario)
- Models:
  - Minute time resolution for radiation parameters.
  - Enhanced calculation of radiation for inclined surfaces with updated models (several models are available optionally)
  - Enhanced temperature and humidity generation for building simulation (including extreme events).
- Software:
  - Total redesign of software and graphical user interface: (e.g. possibility to save different user defined output formats).
  - All information fields (boxes, labels etc.) are colored khaki. All fields allowing input are white.
  - Four steps are needed to get the results. To go from one step to another click button *Continue*.
  - Enhanced import of user data (including current monthly data by internet).
  - Effects of high horizon considered in radiation calculations. High horizon calculated automatically for the most important mountain regions.
  - 7 new output formats: Humidity, Science, Standard optimisation, Climate change, Dynbil and PHPP.
  - Latitude and longitude are now given consequently in degrees and decimal values of degrees.
  - The sign of time zone has been changed to fit the most common definition.

How precise is *METEONORM*?

Owing to the comprehensive framework chosen for the present edition, certain inconsistencies could not be avoided. However, it is always possible to establish which data basis and algorithms were used. Differences between the various data bases and algorithms may be summarized as follows:

- **Quality of basis data:**
  The radiation data was subjected to extensive tests. The error in interpolating the monthly radiation values was 9%, and for temperature 1.5°C.

- **Climatic variations:**
  The ***METEONORM*** radiation data base is based on 20-year measurement periods, the other parameters mainly on 1961-90 and 1996-2005 means. Comparisons with longer term measurements show that the discrepancy in average total radiation due to choice of time period is less than 2% for all weather stations.

- **Computational models:**
  The models used in *METEONORM* are designed to calculate radiation on inclined surfaces and additional parameters. One or more models are used depending on data basis. If the results are to be passed on for further processing, the data basis and models used should be specified to ensure that the results are correctly interpreted.

- In general, the **hourly model** tends to overestimate slightly the total radiation on inclined surfaces by 0-3% (depending on model). The discrepancy compared to measured values is ±10% for individual months and ±6% for yearly sums.

It is important for users of *METEONORM* to be aware that the data basis and computational models only approximate the real situation. Notwithstanding this, the variation in measured total radiation between one year and another is greater than the inaccuracy in the models.

2 Computer Program

2.1 Installation

The program is installed using the CD-ROM supplied. The installation program is started automatically and the installation procedure given in easy-to-follow instructions. The procedure is quite simple: insert the CD-ROM and start the installed **setup.exe** program in the subdirectory run via the File Manager.

To install and run the program, a personal computer (IBM compatible) with Windows 2000/XP/Vista is required. 700 MB of storage space are required on the hard disk. At least 512 MB RAM are needed.

The license conditions (Chap. 2.5) should be read prior to installation.

The program is by default installed to the C:\programs\Meteotest\MN_60 directory. If required, the directory can be changed.

The MN_60 directory contains the three sub-directories Data, Import and Output. Certain files are copied to the Windows directory. The MN_60.exe file and several files are contained in the MN_60 directory. The program may be started with the MN_60.exe file or with an entry in the start list provided by the installation program. The Data directory contains the databases, the weather data, the skyline profiles and control files (most of them in binary form). The Import directory is provided for imported files (monthly or hourly values) and is initially empty. The Output directory contains the output files and is likewise initially empty.

The operating language of the program is English (default), but this can be changed during program operation. Help is only available in English.

2.2 Standard results

2.2.1 An introductory example

METEONORM supplies meteorological data at any desired location in the world as monthly, daily, hourly or minute values in a range of alternate output formats. The following simple example provides an initial introduction to the main features of the program.

Example: For a design project in San Diego (CA, USA), hourly values of global radiation on a south-facing surface inclined at 45° and the temperature are required. The user has no data of his/her own. You will need to follow the instructions below:

1. Choose the language and press button ***Continue***.
2. Choose type of site *Cities*, to select one of the 3'200 cities with more than 100’000 habitants in the world (UN list). The coordinates and altitude of the city centre are given for each city. Select the continent (here: North America) and confirm with *OK*. Type *San Diego* (or part of the name) in the empty space (above *Search site*), and click button “Search site” or press *Enter*. The names of the city or cities corresponding to the characters typed appear in the box below. If you like to reset all labels and text boxes, click on *Reset* button. Choose the city by clicking the name. The basic geographical data then appear at the top (box *Site*). Press the *Continue* button to confirm the chosen site. The *Continue* button will be disabled as long as no site has been chosen.
3. In the **data form** different models, time periods, and additional settings can be chosen and own data can imported. In this example default settings can be used. Click *Continue*.
4. In the **format form**, choose output format *Standard* and select the plane orientation. Type 45° in the inclination box, and leave the azimuth at 0° (due south). Click *Continue* to run the calculations.
5. The calculation takes about 2 to 10 seconds. The monthly values are first interpolated, then the hourly global horizontal radiation values and the temperature are calculated, and finally the radiation on the inclined surface. The results are shown in the display. The monthly average values of the resulting parameters can be displayed with the *Preview* button.
6. By pressing the Save button you can store the *Monthly values, Daily values* and/or the *Hourly values* depending on which option is chosen. The so-called standard output file contains the global radiation, diffuse radiation, global radiation inclined, diffuse radiation inclined, direct normal radiation and air temperature.

The principle city and surface data are shown in the status section at the top.

2.2.2 Program overview

2.2.2.1 Introduction

The software of version 6.0 has been redesigned totally. Now four steps are needed to get the results. These steps have to be passed each time:

1. Define the **site**
2. Choose **data** model and additional settings
3. Choose the output **format**
4. Save and preview the **results**.

The most important information of the 4 steps is shown in the status bar at the top of the window. With the arrows you can switch from one form to another. The language can be selected in the intro form.

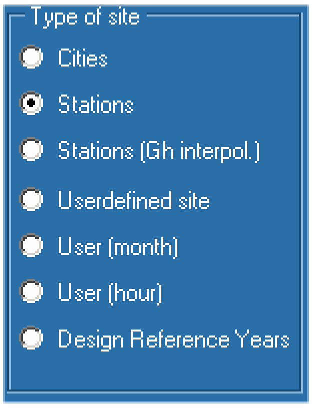
2.2.2.2 Site

To have *METEONORM* calculate meteorological data, the question of which data basis to use arises. Do you have your own data, or should one of *METEONORM's* custom databases be used? The site for the calculations must be chosen according to the data basis used, since the **sites and the databases are intimately coupled**.

If your project is near a weather station, this station can be selected. The distance from the nearest station should not be greater than 20 km, and the altitudes should not differ by more than 100 m. When weather stations are selected, their data is used in the calculations. If your project lies far from a specified city or weather station, it is advisable to define a separate site (form *Site* - button *Enter / edit*).

Basically, there are 7 different site types to choose from: cities, weather stations, design reference years (DRY's), user-defined sites, sites with imported monthly values (*User (month)*), sites with imported hourly values (*User (hour)*) and stations (Gh interpol.) – that means no measured global radiation is available at those sites and that the radiation is interpolated. The cities and weather stations are subdivided according to continent. For Switzerland, all 3'020 municipalities are included under cities. You will find more information on design reference years in the 1995 edition of *METEONORM* (SFOE, 1995).

Thus the choice of data basis is dependent on the choice of site type. The data for cities, weather stations and DRY stations are contained in a database, and may not be altered. A second database contains the imported sites and those defined by the user. These alone can be accessed (e.g. enter, change, delete) with Button *Enter / Edit*. You can modify a given site and place it in the modifiable database.



The fixed database in *METEONORM* contains 3'200 cities, 7'750 weather stations, 22 DRY sites in Switzerland (based on 1981-1990 data), and approx. 3'020 municipalities. For weather stations, monthly average values are stored. Should you require hourly values, these are generated accordingly. For cities, the monthly average values (long term averages) are interpolated and then the hourly values generated. For other sites, the monthly values are likewise interpolated and hourly values generated. If you choose a DRY site, the DRY data (hourly values) will automatically be read in and used in the calculations.

If your project site is not in the vicinity of a predefined city or weather station, it is advisable to specify a new site. To specify a new site, the following parameters must be available: name of site, altitude and coordinates. Specification of time zone, terrain, site abbreviation and time reference are optional. The default value for the time zone is that of the corresponding longitude relative to Universal Time (UTC). For Central European Time (MEZ), it is 1. The sign of the time zone has been changed for version 6.0 to match the general standards. Sites of type *Userdefined site* and either *User (month)* or *User (hour)* can be specified.

Situation

The default value for terrain is *open*. In the section *Situation*, this can, however, be changed. The specification of terrain is central to the interpolation and generation procedure, and must be very carefully considered. There are 14 types of terrain from which to choose (Tab. 2.2.2). They are classified according to local topography as shown in Figure 2.2.1 below.

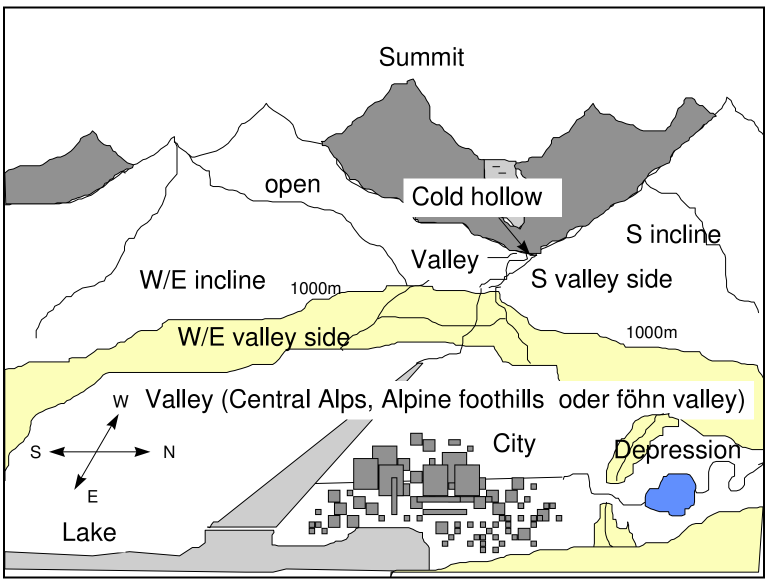
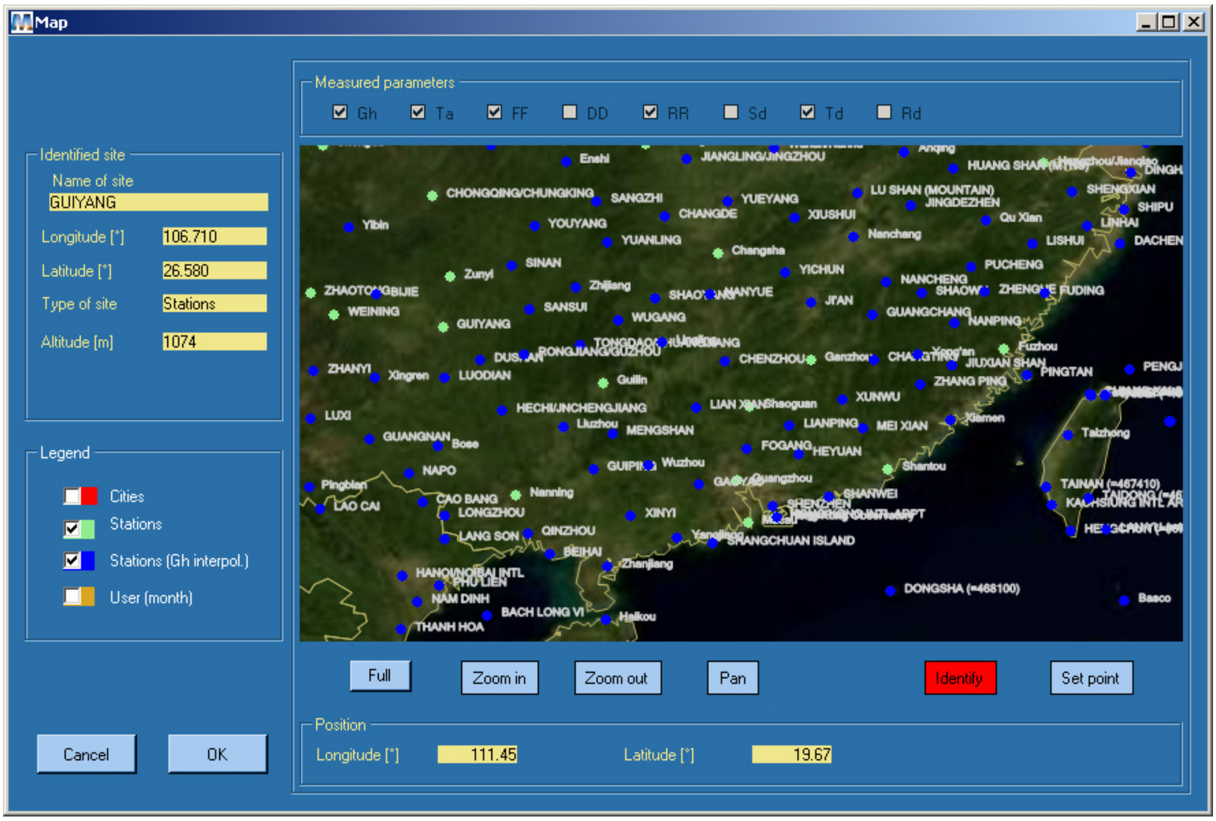


Fig. 2.2.1: Classification of the 14 types of terrain situations.

Tab. 2.2.2: Definition of terrain

Terrain	Features
Open	Open site, open terrain, north facing incline, no raised skyline. Applies to most sites.
Depression	Depression or very flat valley floor, in which cold air collects, particularly in the Jura and the Alps.
Cold hollow	Extensive cold hollows, e.g. in the valleys of Goms and Oberengadin.
Sea/lake	Shore of sea or larger lake (up to 1 km from the shore).
City	Centre of larger city (over 100'000 inhabitants).
S incline	South facing incline (above approx. 10° inclination) (incline facing between SE - S - SW). At least 200 m above valley floor.
W/E incline	West or east facing incline (exceeding approx. 10° inclination) (incline facing between SW - W - NW or. NE - E - SE). Minimum of 200 m above valley floor.
Valley	Valley floor in mountainous valley at higher altitudes. Valley floor inclined (flat valleys are often treated as depressions).
Valley Central Alps	Floor of large central Alpine valley (e.g. Alpine regions of Valais).
Föhn valley	Valley floor of föhn valley (regions with warm descending air currents).
Valley Alpine foothills	Valley floor in northern Alpine foothills.
S valley side	South facing incline (exceeding approx. 10° inclination) up to 200 m above valley (incline facing between SE - S - SW).
W/E valley side	West or east facing incline (exceeding approx. 10° inclination) up to 200 m above valley floor (incline facing between SW - W - NW or. NE - E - SE).
Summit	Open summit above 500 m. Overlooking surroundings in all directions.

In addition to the lists, all sites may also be chosen on a *Map*. This is accessed with the *Map* button. In this menu, sections of the map can be enlarged (*Zoom*) and displaced and zoomed at the same time (*Pan*), sites identified (*Identify*) and new sites set (*Set point*). Press the *Zoom* button to enlarge (see Fig. below). Sites are shown are shown only when zommed in enough (otherwise they are disabled). In Version 6.0 also user defined sites can be displayed (only when zoomed in).



The site abbreviation consists of 1–4 letters and/or numbers. In the standard case, the first 4 letters of the name are used. For the main centres, the number of the municipality according to the Swiss Federal Office of Statistics is used as site abbreviation. The output file names also begin with this abbreviation. The time reference in minutes specifies the difference between the centre of the interval and the full hour. The default value is -30. This means that the current full hour designates the end of the interval. For example, 14.00 hours designates the time interval 13.00–14.00 hours (see Chap. 4.).

2.2.2.3 Data

The next important question concerns the time step. Do you need minute, hourly or monthly values? Most of the output formats need hourly values. However, if you choose finer time resolutions the data can be stored later in courser resolution. In data form you can also import data, choose different models and make additional settings. These are intended for more experienced users.

Radiation model

- Default (hour). The new chain of algorithms is used.
- Version 5 (hour): The daily and hourly stochastic generation model for global radiation of version 5.0 is used. The rest of the calculation is made with the default models.
- Minute. The own minute generation model is used. For minute data only a special output format "Minute" will be available in the form *Format*. Only radiation paramaters are available.
- Clear sky radiation Calculation of maximum global radiation and corresponding diffuse radiation for clear days (cloudless sky) at hourly intervals. Generation of a clear day temperature (warmest possible temperature). The choice of clear sky radiation also narrows the list of possible output formats.

Temperature model

- Default. The default model for hourly temperature values produces hourly extremes, which correspond to mean extreme values.
- 10 year extreme (hour): This model for hourly temperature values produces hourly extremes, which correspond to 10 year extreme values. It's suited for simulations, where also extreme hot or cold periods should be included (e.g. for building simulation).

Tilt radiation model

Perez model is the default model. 3 further models are optionally available for calculation of radiation on tilted planes.

- Hay's model (1979)
- Skartveit and Olset model (1986)
- Gueymard's model (1987)
- minute time resolution model (Skartveit and Olseth, 1986)

Hay's model gives the most robust and best results for generated time series. See chapter 6.7.2 for test results.

Time period

The time periods can be defined for radiation parameters (radiation) an all other parameters together (temperature). Two periods are available for both groups:

- Temperature (and all other parameters but radiation): 1961-90 and 1996-2005
- Radiation: 1981-90, 1981-2000

The 1961-90 period for temperature and the 1981-90 period for radiation define only the most often used periods. At some stations, the periods can be different. If you choose weather stations, the measured periods are shown. For sites of type *Cities* or *Userdefined* the period of radiation can't be chosen. The radiation values are interpolated for these sites. For this interpolation a database including global radiation measurements of all time periods is used.

Additional settings

- Atmospheric turbidity: The used interpolated Linke turbidity is shown. Optionally the turbidity of the nearest ground site of Aeronet can be chosen (the site and its distance is shown).
- 10 y. extreme monthly values: The 10 year minimum and maximum monthly conditions can be chosen for global radiation as well as for temperature. The extreme values are calculated using the standard deviation of the nearest site with such measurements. For the maximum values the standard deviations, multiplied by the factor 1.28, are added to the mean, for the minimum values the standard deviations are subtracted. The annual mean resulting this way does not correspond to any realistic value, because 12 ten year extreme months are not probable to follow each other. As a new feature in version 6.0 the extremes can be selected for half years (summer/winter) or for the whole year.
- 1. random seed: 5 different first random numbers of the generation algorithm of hourly radiation can be chosen. In changing this number, different time series of all meteorological parameters are generated.

The chosen model is displayed on the main form and specified in the printout, if extreme values or not standard random seeds are chosen.

The chosen model is displayed on the main form and specified in the printout, if extreme values or not standard random seeds are chosen.

Import

If you wish to use your own data, this can be read in using the import function. A detailed description of the import function is given in Chap. 2.4 (Import of Data). There are only two formats available for data import. Monthly data can be read in automatically or manually and hourly data are read in using a fixed format. Hourly import can only be made at sites of the userdefined type *User (hour).*

Current monthly data can be imported automatically. By pressing the button *Current data*, the period can be entered (1–12 months) and the data (radiation and temperature, for Switzerland also temperature distributions) is downloaded automatically from a ***METEOTEST*** internet server. Data is always interpolated. The data exists from 1998 onwards. Data will be available approx. 2 weeks after the end of each month.

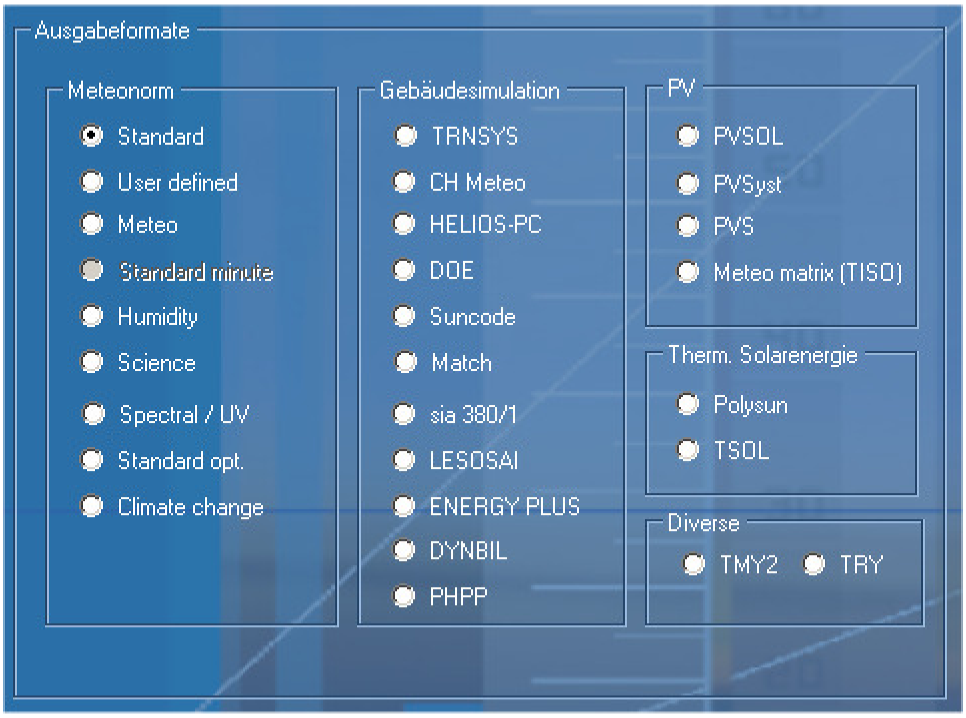
The quality of the data is specified in 4 steps:

- High: Near station with current data available or interpolation within Switzerland (from 2001 onwards). In Switzerland, data with corrections for horizon and location influences are available since 2001.
- Middle: More than 3 stations available for interpolation (normally nearer than 500 km). Satellite data available (from October 2002 onwards).
- Low: Less than or equal to 3 stations for interpolation.
- Not available: No station nearer than 2000 km, no other data source.

2.2.2.4 Format

If you choose the standard or user-defined output, you are free to choose any desired surface orientation. If you select a fixed format for a particular applications program, the surface orientation and also the units may be disabled, if the format does not include radiation on inclined planes.

With the user-defined output format you can specify the sequence of parameters at will. The format specified is stored. In version 6.0 you even can save addiotionally different own output formats.



Tab. 2.2.1: Definition of hourly output formats: Number and sequence of parameters. Symbols: y: year, m: month, dm: day in month, dy: day in year, h: hour, hy: hour in year. The remaining symbols are defined in Chap. 7.

Format	Header lines	Parameters	Separator	Units
Standard	-	m, dm, h, hy, G_{Gh}, G_{Dh}, G_{Gk}, G_{Dk}, G_{Bn}, Ta	Tab.	[W/m^2], [°C]
User defined	4 / -	Selection from: Nr, y, dm, dy, h, hy, Ta, Td, Tp, Ts, RH, RR, Rd, DD, FF, p, N. G_{Gh}, G_{Dh}, G_{Gk}, G_{Dk}, G_{Bn}, G_{Lin}, G_{Lv}, G_{Lup}, G_R or H_{Gh}, H_{Dh}, H_{Gk}, H_{Dk}, H_{Bn}, H_{Lin}, H_{Lv}, H_{Lup}, H_R., L_G, L_D, hs, γ_s. Sequence optional	Various	various
Standard minute	-	m, dm, h, hy, min, G_{Gh}, hs, G_{ex}, G_{Gh} (hour), G_{Dh}, G_{Gk}, G_{Bn}	Tab.	[W/m^2]
Humidity	-	m, dm, h, hy, G_{Gh}, Ta, Td, RH, Tp, mx, PP, Enthalpy, RR	Blank	[W/m^2], [°C], [hPa], [mm]
Science	-	m, dm, h, hy, Ta, G_{Gh}, Td, RH, G_{Dh}, FF, DD, G_{Lin}, RR, Sd, N, hs, TL, G_{Bn}, G_{cs}, G_{Dh}, I_{ex}, G_{Gh} profile	Blank	[W/m^2], [°C], [%], [m/s]
Spectral	-	G_{Gh}, G_{Dh}, Ta, UVA_c, UVB_c, ERY_c, UVA, UVB, ERY, UVA_{diff}, UVA_{incl}	Blank	[W/m^2], [°C]
Climate change	-	m, dm, h, hy, G_{Gh}, G_{Dh}, G_{Gk}, G_{Dk}, G_{Bn}, Ta [for 2071-2100]] Monthly file also with difference between 1996-2005 and 1961-90 means and monthly values for 2016-45.	Blank	[W/m^2], [°C], [m/s], [cm], [h], [hPa]
TRNSYS	2	dm, m, h, G_{Bh}, G_{Dh}, Ta, FF, RH	Blank	[W/m^2], [°C], [m/s]
CH-METEO	-	Nr, y, dy, h, FFE, FFN, Ta, RH, p, RR, G_{Gh}, Sd, FF, Td, Tp, N	Blank	[W/m^2], [°C], [m/s], [cm], [h], [hPa]
HELIOS-PC	-	y, dy, dm, m, h, G_{Gh}, G_{GvE}, G_{GvS}, G_{GvW}, G_{GvN}, G_{Dh}, G_{Lin}, G_{Lv}, Ta, RH, FF, FFaS, FFaW, FFaN, FFaE, G_{Bn}	Blank	[W/m^2], [°C], [%], [m/s]

Tab. 2.2.1f: Definition of hourly output formats: Number and sequence of parameters. Symbols: y: year, m: month, dm: day in month, dy: day in year, h: hour, hy: hour in year. The remaining symbols are defined in Chap. 7.

DOE	-	Nr, Ta, Tp, Td, DD, FF, p, Wc, N, N1a, N1, G_{Gh}, G_{Bn}, G_{Dh}, y, m, dm, h	Blank	[btu/ft^2 h], [F], [1/100 inch Hg]
SUNCODE	-	G_{Bn}, G_{Gh}, Ta, Td, FF	Blank	[kJ/m^2 h], [1/10 °C], [1/10 m/s]
MATCH	-	Ta, Td, G_{Gh}, G_{Dh}, G_{Bn}, N, FF	Comma	[W/m^2], [1/10 °C], [kt]
ENERGY PLUS**	1	m, d, h, G_{Go}, I_{ex}, G_{Gh}, G_{Bn}, G_{Dh}, L_G, L_D, L_Z, N, N1, Ta, Td, RH, p, DD, FF, Vis, Hc, Wc, w, Ad, Sn, Ds**	Blank	[W/m^2], [°C], [m/s], [cm], [h], [hPa]
DYNBIL	11	m, d, h, min, Ta, RH, Ts, FF, DD, G_{Lin}, G_{Dk}, G_{DirX}, G_{DirY}, G_{DirZ}	Blank	[°C], [W/m^2], [m/s]
T/PVSOL	4	G_{Gh}, Ta, RH, FF	Tab.	[W/m^2], [°C], [%]], [m/s]
PVSYST	6	G_{Gh}, G_{Dh}, Ta, FF	Blank	[W/m^2], [°C], [m/s]
PVS	6	G_{Gh}	Blank	[W/m^2]
Meteo Matrix	1	G_{Gh}, Ta (classified in form of matrix)	Tab	[W/m^2], [°C]
POLYSUN	-	hy, G_{Gh}, G_{Dh}, Ta, FF	Tab.	[W/m^2], [°C], [m/s]
TMY2	1	m, d, h, G_{Go}, I_{ex}, G_{Gh}, G_{Bn}, G_{Dh}, L_G, L_D, L_Z, N, N1, Ta, Td, RH, p, DD, FF, Vis, Hc, Wc, w, Ad, Sn, Ds**	Blank	[W/m^2], [°C], [m/s], [cm], [h], [hPa]
TRY	24	Nr, dm, m, h, DD, FF, FFv, Wc, RR, p, Ta, RH, Bh, Dh, L_G, G_{Lin}, G_{Lup}	Blank	[°], [m/s], [mm], [hPa] [°C], [%], [W/m^2], [lux]

*: For a horizontal surface, H_{Gk}, H_{Dk} and H_{Bk} are replaced by H_{Bh}, and G_{Gk}, G_{Dk}, G_{Bk} by G_{Bh}. ** Special parameters for TMY2 and Energy Plus (not calculated): L_Z: Zenith Luminance; N1: opaque sky cover; Vis: Visibility, Hc: Ceiling Height; Wc: Current Weather; Ad: Aerosol Optical Depth, Sn: Snow Depth; Ds: Days since last snowfall

Tab. 2.2.2: Definition of monthly output formats: Number and sequence of parameters.

Monthly values:				
Meteo	5	Ta, Ta_{min}, Ta_{dmin}, Ta_{dmax}, Ta_{max}, RH, G_{Gh}, SD, SD_{astr}, RR, RD, FF	Blank	[°C], [%], [W/m^2], [h/day], [mm], [days], [m/s]
Standard/opt.	-	H_{Gh}, H_{Gk} (optimum inclination), Ta	Blank	[W/m^2], [°C]
sia 380/1	-	Ta, H_{GvS}, H_{GvE}, H_{GvW}, H_{GvN}, HD_{10}, $HDD_{18/10}$, HD_{12}, $HDD_{20/12}$, HD_{14}, $HDD_{22/14}$	Blank	[MJ/m^2], [°C]
LESOSAI	-	Ta, H_{GvS}, H_{GvE}, H_{GvW}, H_{GvN}, HD_{10}, $HDD_{18/10}$, HD_{12}, $HDD_{20/12}$, HD_{14}, $HDD_{22/14}$, FF, RH	Blank	[MJ/m^2], [°C], [m/s], [%]
PHPP	2	Ta, H_{GvN}, H_{GvE}, H_{GvS}, H_{GvW}, H_{Gh}, Td, Tsky	Blank	

A total of **28 formats** are available for the calculation of hourly values for the different simulation programs. In Table 2.2.1 the parameters and units calculated for the respective formats are given. In user-defined format, you can choose the parameters which are to appear in the output file, and also their sequence. For DOE format, an additional file for ground temperatures is written. The additional DOE file has the same name as the output file, but with the extension *.DOE. If desired, the binary files are directly packed.

Format Meteo gives a first overview of all meteorological parameters of a site.

In user-defined format, you can specify the desired units. The default units for radiation are [kWh/m^2] for monthly values, and [W/m^2] for hourly values. The default temperature is in [°C]. On altering the default values, user-defined output format is set automatically. If you subsequently select a fixed output format, the units will revert to their fixed values.

In user-defined format, a header with 4 lines can be specified. The first line contains the name of the site, the second line the latitude and longitude, height above sea level, time zone and elevation and azimuth of the plane (if elevation is greater than 0°). The third line is blank, and the fourth line contains the parameter headings.

In this form, the skyline profile can be chosen (*Horizon*), or, if this is not available, it can be entered. Following these steps, the calculation is begun, and the necessary parameters are calculated.

Plane orientation

Here the surface inclination and orientation may be defined in cases where no fixed format has been chosen. In the default case, a horizontal surface is assumed.

The inclination is the angle between the surface and the horizontal plane, and can take values between 0° and 90°. The azimuth is the angle between the horizontal projection of the normal to the surface and due south. It takes values between -180° and 180°. A south facing surface has an azimuth of 0°. East facing surfaces have negative azimuths, and west facing surfaces positive azimuths. An east facing vertical surface thus has an inclination of 90° and an azimuth of -90°.

The albedo can be set user defined. The albedo is the part of the shortwave radiation that is reflected by the ground. It normally lies between 0.1 and 0.8 (mean values of grass are 0.15 - 0.2). Using user defined albedo walls that are built in front of bright horizontal planes can be modelled more exactly, for example. If the albedo is not set by hand, it is calculated using a temperature dependent model (see Theory 2). This model takes the snow coverage into account.

Horizon

In *METEONORM*, the influence of skyline profile on the monthly and hourly values is taken into account. Should the skyline in the interval NE through S to NW be raised above 10°, a noticeable reduction in average monthly radiation occurs (for the Northern Hemisphere). For hourly values, a relatively small elevation of the skyline may have a strong influence on individual values. For these reasons it is important to consider the effects of a raised skyline.

To include the skyline, 2 menus are available. The first contains data from previously stored profiles, while the second enables profiles to be entered in tabular and graphical form. The input menu consists of a graphical input section and a tabular section. The skyline can be entered in 1° units. One single profile point may be entered per degree of azimuth. In the graphical section, the points can be set and displaced using the left mouse button and deleted using the right button. Previously stored skyline profiles can be displayed and modified.

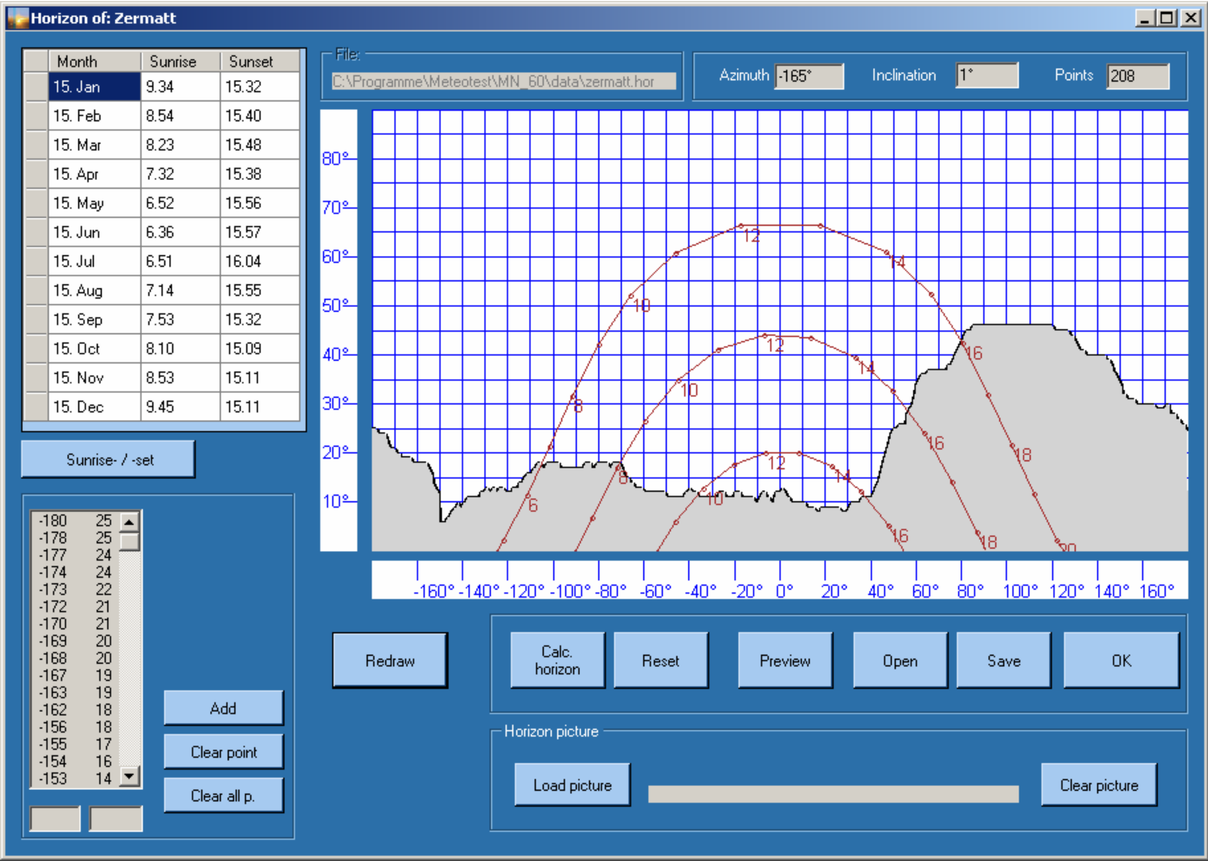
After choosing the skyline profile, the times of sunrise and sunset are calculated for each day and the middle of the month and displayed. Multiple sunrises or sunsets due to obstructions in the horizon (e.g. trees, towers) are also calculated. You may store the daily times of sunrise and sunset. The output file is stored in the output directory and contains the number of the day, and number of sunrises and sunsets and their times.

For fixed hourly output formats (DOE, TMY2, TRY etc.), the global radiation is corrected for skyline profile (e.g. the selected raised skyline is included in the calculation) and written to the output. For standard and user-defined output formats, Gk and Dk are corrected for skyline profile, but not Gh and Dh. Gh and Dh are calculated with an astronomical skyline and written unmodified to the output.

The skyline profile can be input using Meteotest's Horicatcher, Mützenberg system, geological compass, theodolite or fish-eye camera. As a new feature in version 6 the horizon can be calculated for all most important mountain regions of the world using a 90 m digital terrain model. This normally gives quite a good approximation of the horizon line. If horizon is very near (e.g. the site is on a slope) the horizon is shown as blocks. Use the redraw button to repaint the horizon rectangle, if some parts or the whole area is blank.

If the area of the digital terrain model, used for calculation of the horizon line, is not available on the PC, the software searches for the horizon line served by an internet horizon server of Meteotest.

Pictures of the horizon can be imported in jpg- or png-format. The format of the pictures must stretch from N over W, S, E to N again (azimuth from +180° to -180°) and from 0° to 90° elevation. As an example the horizon picture dscn0025_hc.jpg is available in data directory (made with Meteotest's horizon camera system called Horicatcher). As a further help the sun paths of December 21, March 21 / September 21 and June 21 are shown.



2.2.2.5 Results

The radiation data may be displayed either in time-integrated form in terms of energy per unit area (irradiation, e.g. [kWh/m^2]), or as average radiation intensity (irradiance, e.g. [W/m^2]). Time-integrated radiation is designed as „H", and average radiation intensity as „G". The type of radiation (i.e. global, diffuse, etc.) is designated using a suffix preceded by an underscore (e.g. H_Gh for integral radiation integral of global radiation).

Finally, the dependent parameters are calculated and written to the output file according to the units and format specified. The standard calculations are divided into 3 parts: calculation of diffuse radiation and global radiation, beam, and, where necessary, the radiation on inclined surfaces with or without raised skyline. For hourly values, additional parameters (humidity, wind speed, longwave radiation, etc.) are calculated when required by the output format.

The hourly files may contain very different parameters depending on output format. The parameters are shown in Tab. 2.2.1. All files consist of 8'760 lines. Each line contains the values for one hour. A heading can be provided at the beginning of the file. For user-defined output format, the separator, i.e. comma, tabulator, or space, can be specified.

The new preview tool enables to save the monthly values in form of pdf files or Excel (and other). As a new feature 6 figures are shown in the result window (monthly and daily values of radiation, temperature, precipitation and sunshine duration).

2.2.3 Examples

Two examples of program operation are given here in detail.

Example 1: Set a user defined site

For a project in Offenburg, Germany, the monthly values of global horizontal radiation and on an inclined surface (45°, south) (in [kWh/m^2]), temperature (in [°C]) are required:

1. Selection of site: Offenburg is not included in the list of predefined cities. The simplest procedure is to select a nearby city using the graphical selection menu (*Map*). Using this menu you may zoom and move sections of the map, and identify sites. First zoom and pan to Europe and then to south-west Germany. Then click on the type of site you want to select. Identify (button identify) the station nearest to Offenburg, i.e. Strasbourg (F). Select the station by pressing *OK*.
   Modification of the site: On returning to the site form, the selected site is seen displayed. Alter this using *Enter /Edit*. The program displays the Edit menu in which the data may be modified. Correct the name, the abbreviation, the altitude (200 m) and the coordinates (48.467/-7.933) of the site and store the changes (*Save* or *OK*). Following this operation, the site is directly chosen in the site form. You can also get directly from the main page to this form via the pull button *Enter /Edit*. Click *Continue*.
2. Choose default values (button *Default values*). Click *Continue*.
3. Choice of output format: The standard format contains the needed information (click on it, if another format is chosen). Click *Continue*.
4. Specification of the surface (*Plane orient.*): azimuth: 0°, inclination: 45°. Click *Continue.*
5. View file with Button *Preview*. Data storage with Button *Save* with option [mon] in the form results.
6. Click *Continue* and Exit the program.

Example 2: Site with a high horizon

For a project in Zermatt, Switzerland, hourly values are required. The following parameters are to be calculated: G_{Gh}, G_{Dh} and G_{Gk} (45°, S), Ta, Td and G_{Lv} in [W/m^2], or [°C]. A header is required. The skyline in Zermatt is very high (Matterhorn!) and must be considered. Month, day of month and hour are to be specified in the output. The tabulator is to be used as separator.

1. Selection of site: Zermatt has its own weather station. Select *Station* as type of site and *Switzerland* for part of the world. Enter *Zermatt* or part of the name in the white field *search site*. Click on Zermatt in the list. Click *Continue*.
   In the case of Zermatt, as the measured values of monthly average radiation are strongly reduced owing to the skyline (approx. 10–15%), the program requires a user response as to whether the measured values (which are also subject to a skyline effect) are to be replaced by interpolated values corrected for skyline. If, as in this example, the data are to be used as starting point for hourly data generation, it is advisable to use the interpolated radiation data corrected for skyline profile. The specific horizon of the site can be entered afterwards.
2. Choose default values in data form and Click *Continue*.
3. Selection of output format: click on user-defined and a form will appear. In the user-defined menu, the parameters selected in the last calculation are displayed. The parameters not selected are listed in the various boxes. To select and display a parameter, double click the respective box. By double clicking the selected parameter a second time, the selection is cancelled. The sequence of selected parameters can be altered using the (⮟, ⮝) arrows. Click OK if parameters have been selected.
4. Surface orientation (*Plane orient.*): azimuth: 0° (S), inclination: 45°.

5. Selection of skyline profile by clicking *Horizon button.* Click on *calc. horizon* to start the automatic calculation of the horizon based on the 90 m SRTM digital elevation model. The elevation data are either read from the harddisk (if available) or the horizon line is accessed from an xml server of Meteotest. This service is available for all most important mountain chains in the world. Save the horizon (optionally) and Click *OK* to select it.
6. Click *Continue* to start the calculation. Calculation of the hourly values of radiation taking raised skyline into account, and of temperature and dependent parameters (without raised skyline).
7. Writing to output file in user-defined format and units using *Save* [h]. In the output file, the effect of raised skyline is only considered with G_{Gk} and not with G_{Gh} and G_{Dh}.

2.3 Data interfaces

METEONORM is conceived as a meteo module, and supplies the basic meteorological data. The interfaces have been carefully designed to be compatible with the other modules. **All interfaces are defined on the basis of ASCII files**.

METEONORM has two types of interface: (1) Interfaces for the import of hourly and monthly values (see Chap. 2.4); and (2) interfaces for output files designed to be compatible with well known solar design programs. A total of 15 output formats is available (Tab. 2.2.1). In user-defined format, parameters may be chosen as required.

2.4 Import of data

In *METEONORM,* the user may provide his/her own monthly and hourly data. This allows the user to apply *METEONORM* to externally supplied data. Values can be imported by specifying sites of type *User (Hour)* or *User (Month)*. To avoid excessive complexity in data input, the input parameters and their sequence are fixed.

2.4.1 Monthly values

Monthly data for global and diffuse radiation, temperature and humidity (*Format / Import / Monthly values*) can be input manually or automated. For data containing missing values, these values are interpolated (with long term means). Externally supplied monthly values are saved automatically in a file, when closing the import form with *OK*. This can then be reimported when needed using *Import file*. Imported data stored with version 5 (like in version 4) are written in a special file. The data is defined in this file by the code of the station and the key number of the database (stnuser2005.mdb).

Tab. 2.4.1: Parameters for data import. Parameters designated with Yes must be available and those designated with opt. are optional. The sequence shown must be adhered to.

Parameter		Symbol	Month	Hour	Units
Time	Month	m	No	Yes	
	Day (of year or month)	dy	No	Yes	
	Hour (day)	h	No	Yes	[h] (1,...,24)
Radiation type	Global radiation	Gh	opt.	Yes	[W/m^2], [kJ/m^2 h], [btu/ft^2 h], [kWh/m^2], [MJ/m^2]
	Diffuse radiation	Dh	opt.	opt.	
	Direct normal radiation	Bn	No	opt.	
Temperature	Air temperature	Ta	opt.	opt.	[°C], [1/10 °C], [F]
	Dew point temperature	Td	No	opt.	
Humidity	Relative humidity	RH	opt.	No	[%]
Precipitation	Precipitation	RR	opt.	No	[mm]
	Days with prec. >0.9mm	RD	opt.	No	[days]

Imported and saved monthly data of version 3 can still be read. Data can be imported for any type of site. The files of version 3.0x are stored with headers. In versions 6 all data are stored in the same ASCII file, named MonImp6.bin in the data directory.

Using imported data for interpolation

Imported monthly data can be used for interpolation for userdefined sites of type *User (month)*. After the data is entered, it has to be selected whether these data are used for interpolation or not. If selected, the data will be used when data is interpolated for a user defined site or a city nearer than 300 km. Own networks can be entered. The selection for or against using for interpolation can be changed by importing the same data again. The selection of imported data for interpolation has to be made carefully. Especially the period of measurements should be of the same scale in one region (the METEONORM database contains at least 10 year means). If imported data are selected to be used for interpolation the type of site is changed to import (month) ip.

2.4.2 Hourly values

Hourly values can only be imported for sites of type User (hour). So first define such a type to be able to import data.

Hourly data must be read in according to a predefined procedure (Form *Format / Import hourly values*). The parameters to be supplied are specified in Table 2.4.1 (Fig. 2.4.1). Missing values are permitted and are to be coded as **-999**. Data series covering less than a full year are also permitted.

The order of the imported parameters must be in all cases: m, dy or dm, h, Gh, Bn, Dh, Td and Ta (Td before Ta!). Bn, Dh, Td and Ta are optional.

For hourly output formats and sites of type *User (hours)*, there is only the „Standard"-output format available if there is no import of temperature (Ta). The units can, however, be specified. A comma or tabs are used as separator.

1	1	1	0
1	1	2	0
1	1	3	0
1	1	4	0
1	1	5	0
1	1	6	79
1	1	7	212
1	1	8	373
1	1	9	572
1	1	10	787

Fig. 2.4.1: The figure shows the first 10 lines of the input file *sydnhimp.dat* (Example 4). The first column contains the number of the month, the 2nd column the day of the year, the third column the hour of the day and the fourth column the global radiation. The values must be separated by commas or tabs.

The time definition used in the measurement have to be used in the definition of the site. The time is defined with the two parameters timezone and time reference (see chapter 6.1 in mn6_theory.pdf).

If the definitions don't match, it's possible, that the data can't be imported. If too many hours with global radiation at negative sun elevations or no global radiation with positive sun elevations occur, the import is stopped. 40 hours are allowed in Version 6.0. However, if more than 10 hours occur, the software shows the user, that the time zone might be too high or too low.

The easiest way to examine the time definition of the measured values is to save standard output values for the same site (change the type to "Userdefined site") for clear sky radiation with different time zones and time references and compare them to the measured time series e.g. in Excel.

2.4.3 Examples

Example 3:

For a project on the Zugspitze, Germany, external data for global horizontal radiation and temperature are available for all months. The measured values are: Radiation (Jan. – Dec.) 67, 126, 176, 235, 268, 263, 233, 204, 188, 142, 101, 60 W/m^2. The global radiation (in [kWh/m^2]) on a surface inclined at 60° and monthly values of temperature (in [°C]) are required. The results are required in printed form. Because more projects around the Zugspitze are known to come and the fix database of *METEONORM* does not contain Zugspitze, the data should be used for interpolation in future.

1. Selection of site: The Zugspitze is defined as a type station Gh interpol., where temperature data, but no radiation data is available. Choose this station. Click *Continue*.
2. Import of monthly values: This is done in the data form by pushing the button *Import monthly values*. Not all values have to be filled (column Gh - global radiation – must be filled). The missing ones are interpolated and all values are saved automatically when leaving the form by the OK button. Choose to use the data for interpolation. Click *Continue*.
3. Selection of output format: The needed parameters (Ta, Gk) are included in the Standard format.
4. Specification of surface: azimuth: 0°, inclination: 60°. The skyline of the Zugspitze is practically horizontal. Click *Continue*.
5. Storage of results with *Save* with option *[mon]*.
6. Printing of monthly values with *Preview.*
7. Define a new station around the Zugspitze (e.g. 47.21 N / -10.51 E / 2421 m). Check the difference of interpolation when the Zugspitze data are selected for interpolation or not.

Example 4:

For a project in Sidney, Australia, hourly values for a complete year are to be imported. The measured data are from the Sydney weather station and were stored with normal time reference (Chap. 4.2.1), i.e. the IZRM = -30, and the time refers to the end of the measurement interval. Using the measured global radiation data in [W/m^2], the radiation on a vertical, north facing (!) surface is to be calculated.

1. Selection of site: The simplest method is to select the city of Sydney (*Cities, Australia / Oceania*) and then change this with *Enter / Edit*. The program then displays the Edit menu for the respective database. Correct the site type to (*User / (Hour)*) and store the changes (*Save*) and press OK. Click *Continue*.
2. Importing hourly values: Push *Import hourly values* (file *sydnhimp.dat*, actually a generated file). This file must correspond exactly to the format defined in Table 2.4.1. Click *OK* and then *Continue*.
3. Selection of output format: If only radiation parameters are imported only a special format is available. If also temperature is imported all output formats can be chosen. In this case the standard format is good.
4. Specification of surface: azimuth: -180°, inclination: 90°. Click *Continue*.
5. File storage by pushing *Save* button with option [h].

2.5 Delivery, license agreement

The *METEONORM* program is supplied complete with data on CD-ROM or can be downloaded at www.meteonorm.com. The purchaser is entitled to use the software and data supplied for his/her own purposes. The licensing conditions to be adhered to are printed on the package of the digital storage medium and are displayed when *METEONORM* is installed:

Carefully read all the terms and conditions of this Agreement prior to installing.

1. **General remarks**: All rights remain with *METEOTEST*. By installing, you automatically accept the license conditions.
2. **License:** You have the non-exclusive right to use the program. The software and data may be used on one single PC only.
3. **Limited Warranty:** Neither the data producers, nor *METEOTEST* are liable for incorrect information or subsequent damages of any kind. The program is provided "as is" without warranty of any kind.
4. **Copyright:** You may not copy the program, data or its documentation except for back-up purposes and in order to load the program into the computer as part of executing the program. All other copying is in violation of this Agreement.
5. **Data:** Some of the included climatological databases may not be forwarded to any other user. They may only be used in connection with this software. Further use must be regulated with the owners of the data directly:
   - Worldwide radiation Data: Institute for Atmosphere and Climate Science, Swiss Federal Institute of Technology, Zurich Switzerland
   - Swiss Climatological Data: Swiss Meteorological Institute, Zurich, Switzerland
   - Design Reference Years (DRY), Eidgenössische Materialprüfungs Anstalt EMPA - Bauphysik, Dübendorf, Switzerland
6. **Algorithms & internal databases:** *METEONORM* version 6.0 contains modules developed in the EU IST project SODA (FP5).
   Co-authors of UV algorithms: UMIST, Department of physics, Manchester UK.
   Co-authors of temperature model: ENTPE, Lyon F.
7. **Registration:** The software has to be registered for each installation at *METEOTEST*. This can be done with an on-line form, by e-mail or by telephone. The password will generally be delivered within 4 hours during working hours.
8. **Governing Law:** This license agreement shall be governed by the laws of Berne, Switzerland.

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3 Data Basis

In this Chapter the data basis of *METEONORM* is presented, the sites to which the models were adapted and validated are listed, and the climatic classification system used for the generation of hourly values are defined.

3.1 Climatological Databases

3.1.1 Ground stations

In simulating solar energy systems, data from all parts of the world are required. In this work, several databases that had already been thoroughly checked to ensure reliability were coupled to form a single comprehensive database permitting worldwide simulation of solar energy systems. The new database contains all necessary parameters for further processing (global radiation, temperature, wind, humidity and precipitation).

In the present version, the Swiss database used in the 1995 version 2 has been retained partly. This was compiled by the MeteoSwiss and contains 10-year mean data for Gh, Ta, FF, DD and Sd for 64 weather stations for the period 1983–1992. These values can be accessed for these sites for radiation parameters.

For worldwide applications, several different international databases have been added. Global radiation data was taken from the GEBA Global Energy Balance Archive (WMO World Climate Program - Water) (Gilgen et al., 1998). The data was quality controlled using 6 separate procedures (checking of physical probability, time series analysis, comparison of cloud data). Temperature, humidity, wind data, sunshine duration and days with rain was taken from WMO Climatological Normals 1961–90 (WMO, 1998). To replace missing data and ensure a homogeneous distribution of weather stations, other databases such as the data summary of international weather stations compiled by the National Climatic Data Center, USA (NCDC, 1995) were added. For some stations in the USA, monthly mean values 1961–90 of global radiation of the National Renewable Energy Laboratory (NREL) database “The Solar Radiation Data Manual For Buildings” were used.

For version 6.0 two sources have been updated:

- Globalsod data (NCDC, 2007): Parameters temperature, wind speed and precipitation. Parameters have been processed to 1996-2005 means.
- GEBA: The main period have been extended to 1981-2000. For some regions like China a lot of stations have been added.

The monthly average radiation values were calculated for periods of at least 10 years. Although the 10-year periods differ, a uniform period was used for each continent (Tab. 3.1.1). For some stations the data was extended with data from neighbouring stations using a differential procedure. The database contains **a total of 7'756 stations**. Table 3.1.1 gives an oversight of the distribution and type of stations.

For most primary stations outside the USA, average values of temperature, humidity, wind and rainfall are available for the measurement period 1961–90. In the USA, average values of these parameters are available for most weather stations for the period 1961–90. All stations of type Gh Interpol. have now average values of the period 1996-2005 (in version: 1961-90).

Tab. 3.1.1: Distribution and number of available stations.

Available parameters	global radiation and temperature	temperature, additional parameters	only temperature or radiation	total
Europe	348	1'095	39	1'482
North America	303	2'183	63	2'549
South/Central America	85	556	17	658
Asia (with Russia)	278	1'469	40	1'787
Australia / Pacific	45	641	17	703
Africa	129	437	11	577
World	1'188	6'381	187	7'756

In addition to the monthly data, design reference years for 22 Swiss weather stations are included. The hourly data were obtained from EMPA files. Further information on the DRY's may be obtained from the 1995 edition of *METEONORM* (BEW, 1995) and from Skartveit et al. (1992).

3.1.2 Satellite data

In version 6.0 satellite data is used for radiation interpolation in remote areas. Where no radiation measurement is nearer than 300 km satellite information is used (Fig. 3.1.1). If the nearest site is more than 50 km away, a mixture of ground and satellite information is used.

The used method is a approximation of methods like Heliosat II (Lefèvre et al., 2002).

The 3 hourly pictures of the visible channel of the 5 geostationary satellites have been used (period 2003-2005). The satellite pictures are processed to daily means and summed up to monthly values. These monthly values are interpolated with mean ground measurements (mainly GEBA data). The difference between the ground measurements and satellite information is interpolated spatially with the inverse distance method (see Chapter 6.2.1). This gives a result which includes the values at the ground stations and the variation of the satellite pictures.

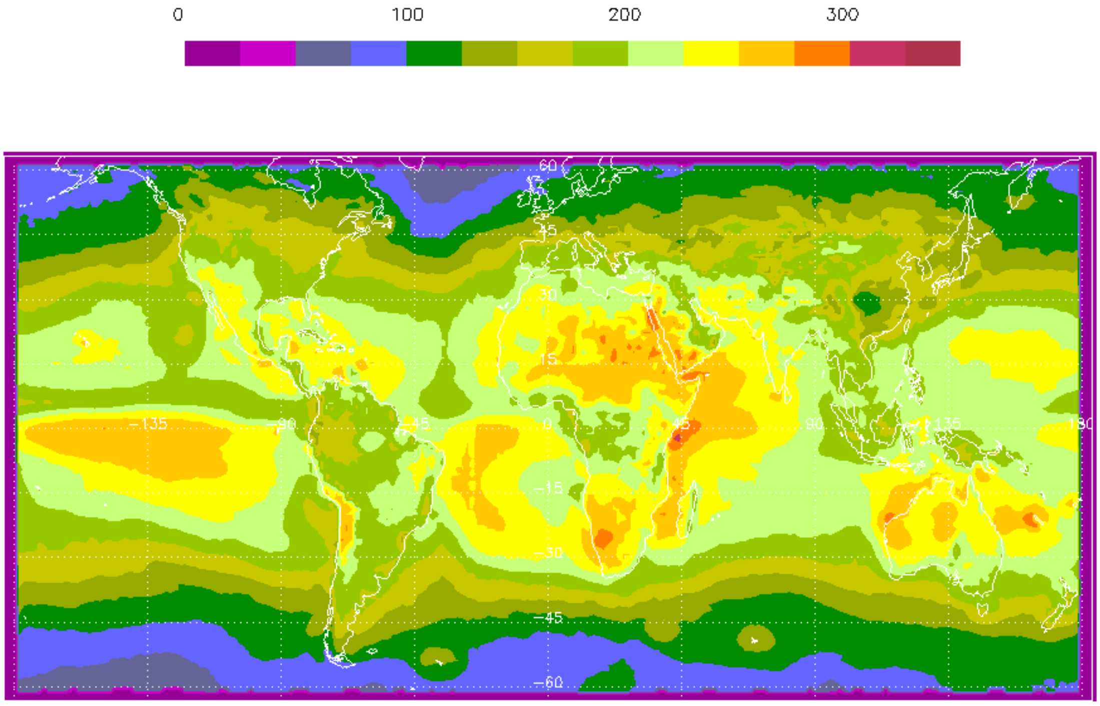

Fig. 3.1.1: Global irradiance map for January in W/m^2 based on satellite and ground information. Means adopted mainly to 1981–2000.

3.2 Climate change data

For the output format the data of Hadley CM3 model were included (UK Met. Office, 2007). The experiments assume that future emissions of greenhouse gases will follow the IS92a scenario, in which the atmospheric concentration of carbon dioxide more than doubles over the course of the 21st century. This is a 'business as usual' scenario, which assumes mid-range economic growth but no measures to reduce greenhouse-gas emissions.

It is important to be aware that predictions from climate models are always subject to uncertainty because of limitations on our knowledge of how the climate system works and on the computing resources available. Different climate models can give different predictions.

3.3 Climatic zones

In table 3.3.1 the climatic zones defined by Troll and Paffen (1980) are listed.

Tab. 3.3.1a: The climatic zones defined by Troll and Paffen (1980).

I	Polar and subpolar zones	
	I, 1	High polar ice climates: polar ice deserts
	I, 2	Polar climates with low summer temperatures (< 6°C)
	I, 3	Subarctic tundra climates with cool summers
	I, 4	Subpolar maritime climates
II	Cold temperate boreal zone	
	II, 1	Maritime boreal climates
	II, 2	Continental boreal climates
	II, 3	High continental boreal climates with severe winters (< -25°C)
III	Cool temperate zones	
	Wooded climates:	
	III, 1	Elevated maritime climates with very mild winters
	III, 2	Maritime climates with mild winters
	III, 3	Submaritime climates
	III, 4	Subcontinental climates
	III, 5	Continental climates
	III, 6	Elevated continental climates
	III, 7	Warm summer, and humid summer and winter climates
	III, 8	Warm and humid summer climates
	Steppe climates:	
	III, 9	Humid steppe climates with cold or mild winters
	III, 0	Steppe climates with cold or mild winters and dry summers
	III, 1	Steppe climates with cold and dry winters and humid summers
	III, 2	Desert or semi-arid climates with cold or mild winters
IV	Warm temperate zones	Subtropical climates
	IV, 1	Mediterranean climates with humid winters and dry summers
	IV, 2	Humid winter and very dry summer climates
	IV, 3	Short humid winter and dry winter climates
	IV, 4	Long humid summer and dry winter climates
	IV, 5	Desert and semi-arid climates without severe winters but with frost
	IV, 6	Perpetually humid grassland climates in southern hemisphere
	IV, 7	Perpetually humid hot summer climates
V	Tropical zones	
	IV, 1	Tropical rain climates
	IV, 2	Tropical humid summer climates
	IV, 3	Tropical humid winter climates
	IV, 4	Tropical dry climates
	IV, 5	Tropical desert or semi-arid climates

4 Abbreviations and Symbols

Tab. 4.1: Alphabetic index of abbreviations and symbols

Group	Abbreviation/Symbol	Description
General	Anetz	**A**utomatic **Net**work of the SMA
	SFOE	**S**wiss **F**ederal **O**ffice of **E**nergy
	DRY	**D**esign **R**eference **Y**ear
	DWD	**D**eutscher **W**etter**d**ienst
	EMPA	**E**idgenössische **M**aterial**p**rüfungs- und Forschungs**a**nstalt
	gen	**Gen**erated
	mbe	**m**ean **b**iased **e**rror
	MN	**M**eteo**n**orm
	NABEL	**Na**tionales **Be**obachtungsnetz für **L**uftfremdstoffe
	PV	**P**hoto**v**oltaics
	rmse	**r**oot **m**ean **s**quare **e**rror
	WMO	**W**orld **M**eteorological **O**rganisation
	SMI	**S**wiss **M**eteorological **I**nstitute, MeteoSwiss
Parameter	B_h	Direct radiation on horizontal surface
	B_k	Direct radiation on inclined surface
	B_n	Direct normal radiation (beam)
	DD	Wind direction
	D_h	Diffuse radiation (horizontal)
	$D_{h\ hor}$	Diffuse radiation (horizontal) with raised horizon
	$D_{h\ min}$	Diffuse radiation on clear days
	D_k	Diffuse radiation on inclined surface
	ε_h	Emissivity horizontal
	ε_v	Emissivity vertical
	FF	Wind speed
	FFE	Wind speed in E direction
	FFN	Wind speed in N direction
	FFaE, N, W, S	Wind fraction E, N, W, S (in %)
	<G>	Average radiation intensity
	G_h	Global radiation (horizontal)
	$G_{h\ hor}$	global radiation (horizontal) with raised horizon
	$G_{h\ max}$	Maximum global radiation (on clear days) (horizontal)
	G_k	Hemispherical radiation on inclined surface
	GvE, N, W, S	Hemispherical radiation on vertical surface in E, N, W, and S directions
	H	Radiation time integral (radiation energy)
	$HDD_{12/20}$	Heating degree days
	Lin	Longwave horizontal radiation impinging (longwave incoming)
	Lup	Longwave horizontal radiation emitted (longwave outgoing)
	Lv	Longwave radiation on vertical surface
	L_G	Global illuminance
	L_D	Diffuse illuminance
	mx	Mixing ratio
	N	Total cloud cover
	p	Atmospheric pressure

Group	Abbreviation/Symbol	Description
	ρ	Albedo, reflection coefficient
	R	Radiation balance
	Rb	Ratio of direct radiation integral on inclined and horizontal surfaces
	RD	Days with precipitation > 0.1 mm
	R-Faktor	Ratio of global radiation integral on inclined and horizontal surfaces
	RH	Relative humidity
	RR	Precipitation
	Ta	Air temperature
	Td	Dew point temperature
	Tp	Wet-bulb temperature (psychrometer temperature)
	Ts	Surface temperature
	w	Water content of Atmosphere (precipitable water)
Earth	φ	Latitude
	φ'	Latitude of equivalent horizontal area
	λ	Longitude
Surface	β	Surface inclination
	γ	Surface azimuth (orientation of surface)
	Θ	Incident angle of radiation on inclined surface
	r_D	Isotropic diffuse view factor
	r_R	Isotropic reflex view factor
Sun	m_a	Optical air mass
	δ	Declination
	γ_s	Solar azimuth
	hs	Solar altitude
	I_0	Solar constant
	I_{ex}	Radiation at the upper edge of the atmosphere (Solar constant adjusted to distance earth-sun)
	G_0	Extraterrestrial solar radiation (horizontal)
	$\overline{K}_t$	Clearness index (month)
	K_t	Clearness index (day)
	k_t	Clearness index (hour)
	S_o	Astronomical day (sunshine duration)
	Sd	Effective sunshine duration
	ω_s	Hourly (solar) angle
	ω_{ss}	Hourly angles at sunrise and sunset
Time	dm	Day of month (1..28/29/30/31)
	dy	Day of year (1..365/366)
	ET	Time equation
	GMT	**G**reenwich **m**ean **t**ime (=UTC)
	h	Hour of day
	hy	Hour of year
	IZRM	Internal reference time in min
	m	Month
	CET (MEZ)	Central European Time
	ST	True solar time
	t	Local time (time of day)
	t_s	Time difference between local time and zonal time
	t_z	Time difference between zonal time and universal time
	UTC	**U**niversal **t**ime **c**oordinated

5 Parameters and Units

5.1 Definition of Parameters

Tab. 5.1: Definition of parameters

Parameter	Description	Basic unit	Further units
DD	Wind direction	[°]	-
FF	Wind speed	[m/s]	[1/10 m/s], [kt], [km/h]
G	Average hourly radiation intensity: (H/Δt) (Index refers to radiation type)	[W/m^2]	[btu/ft^2 h], [kJ/m^2 h]
<G>	Average radiation intensity: (H/Δt) (Index refers to radiation type). For daily, monthly and yearly averages	[W/m^2]	[btu/ft^2 h], [kJ/m^2 h]
H	Time integrated radiation (Index refers to radiation type)	[kWh/m^2]	[MJ/m^2]
hs	Solar altitude, i.e. the angle between the line joining the center of the sun with the site and the horizontal plane at the site.	[rad]	[°]
KT_m, Kt_d k_t	Clearness index: Ratio of global radiation on earth's surface and extraterrestrial radiation (Gh / Go). KT refers to monthly values, Kt to daily values and kt to hourly values.	[ ]	-
mx	Mixing ratio: quantity of water vapor per kg of dry air	[g/kg]	-
N	Cloud cover	[octal units]	-
L_G	Global illumance	[lux]	-
L_D	Diffuse illuminance	[lux]	-
p	Atmospheric pressure	[hPa]	[1/100 inch Hg]
RD	Days with Precipitation > 0.1 mm	[mm]	-
RH	Relative humidity	[%]	-
RR	Precipitation	[mm]	-
Sd	Effective sunshine duration	[h]	-
Ta	Air temperature (ambient temperature)	[°C]	[1/10 °C], [F]
Td	Dew point temperature	[°C]	[1/10 °C], [F]
Tp	Wet-bulb temperature (psychrometer temperature)	[°C]	[1/10 °C], [F]
Ts	Surface temperature	[°C]	[1/10 °C], [F]
w	Precipitable water	[g]	-

Tab. 5.2: Definition of radiation types

Parameter	Description
B_h	Direct radiation horizontal, i.e. shortwave radiation ($\lambda < 3$ µm) arising from a narrow solid angle (6° aperture) centered around the sun's disk impinging on a horizontal surface
B_k	Direct radiation inclined, i.e. shortwave radiation ($\lambda < 3$ µm) arising from a narrow solid angle centered around the sun's disk (6° aperture) and impinging on an inclined surface
B_n	Beam, i.e. direct normal radiation. Shortwave radiation ($\lambda < 3$ µm) arising from a narrow solid angle (6° aperture) centered around the sun's disk and impinging on a surface normal to the direct of radiation
D_h	Diffuse radiation horizontal, i.e. shortwave isotropic radiation ($\lambda < 3$ µm) arising from the upper hemisphere reduced by the direct solar radiation from the sun's disk and its surroundings (6° aperture)
$D_{h\ hor}$	Diffuse radiation horizontal with raised horizon, i.e. shortwave isotropic radiation ($\lambda <$ 3 µm) arising from the upper hemisphere reduced by the direct solar radiation from the sun's disk and its surroundings (6° aperture) taking raised horizon into account
$D_{h\ min}$	Diffuse radiation, horizontal, minimum: Minimum diffuse radiation on horizontal surface on clear, cloudless days (clear sky conditions)
D_k	Diffuse radiation inclined, i.e. shortwave isotropic radiation ($\lambda < 3$ µm) arising from the upper hemisphere reduced by the direct solar radiation from the sun's disk and its surroundings (6° aperture) on inclined surface
G_h	Global radiation, horizontal, i.e. shortwave radiation ($\lambda < 3$ µm), received by a horizontal surface from the solid angle 2π
$G_{h\ hor}$	Global radiation horizontal with raised horizon, i.e. shortwave radiation ($\lambda < 3$ µm) received by a horizontal surface from the solid angle 2π, taking raised horizon into account
$G_{h\ max}$	Global radiation, horizontal, maximum, i.e. maximum global radiation on horizontal surface on clear, cloudless days (clear sky conditions)
G_k	Hemispherical radiation, inclined, i.e. shortwave radiation ($\lambda < 3$ µm), received by an inclined surface from the solid angle 2π
G_0	Extraterrestrial radiation, horizontal, i.e. shortwave radiation ($\lambda < 3$ µm) arising from the sky (upper hemisphere) on a horizontal surface at the upper edge of the atmosphere
L_{in}	Longwave (thermal) radiation on horizontal surface arising from the sky (upper hemisphere) (longwave incoming), wavelength > 3 µm
L_{up}	Longwave (thermal) radiation on horizontal surface emitted from the earth's surface (longwave outgoing) wavelength > 3 µm
L_v	Longwave thermal radiation on vertical surface, wavelength > 3 µm
R	Radiation balance , i.e. balance of total incident and emitted radiation (short and longwave)

Note: As most computer programs do not provide for subscripts, there are two modes of representation for each variable. In the *METEONORM* program and most of the figures, the subscripts are represented by a suffix preceded by an underscore.

Example of variable representation:

G_Gh : Designates average hourly radiation intensity for global horizontal radiation.
H_Gh : Designates time integral of horizontal global radiation.

5.2 Conversion Factors

The conversion factors used for converting the units are given in Table 5.3.

Tab. 5.3: Conversion factors for conversion of units (Krist, 1976).

	Parameter	Basic unit (1)	Required unit (2)	Formula
Radiation	H	[kWh/m^2]	[MJ/m^2]	(2) = 3.6*(1)
	<G>	[W/m^2]	[kJ/m^2 h]	(2) = 3.6*(1)
			[btu/ft^2 h]	(2) = 0.317*(1)
			[MJ/m^2 h]	(2) = 0.0036*(1)
			[MJ/m^2 mon]	Month with 28 days: (2) = 2.42*(1) 30 days: (2) = 2.59*(1) 31 days: (2) = 2.68*(1) Year: (2) = 31.54*(1)
			[kWh/m^2 h]	(2) = 0.001*(1)
			[kWh/m^2 day]	(2) = 0.024*(1)
			[kWh/m^2 mon]	Month with 28 days: (2) = 0.67*(1) 30 days: (2) = 0.72*(1) 31 days: (2) = 0.74*(1) Year: (2) = 8.76*(1)
Temperature	Ta, Td, Tp	[°C]	[°F]	(2) = 1.8*(1)+32
Wind	FF	[m/s]	[kn]	(2) = 1.94*(1)
			[km/h]	(2) = 3.6*(1)
Pressure	p	[hPa] = [100 N/m^2]	[1/100 inch Hg]	(2) = 2.95*(1)

[btu]: British thermal unit