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Andersen, Elsa; Johansen, Jakob Berg; Furbo, Simon; Perers, Bengt; Andersen, Lars Kokholm; Dragsted, Janne; Dannemand, Mark

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Elsa Andersen
Jakob Berg Johansen
Simon Furbo
Bengt Perers
Lars Kokholm
Janne Dragsted
Mark Dannemand

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DTU Civil Engineering
Department of Civil Engineering

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Preface

In the period 2016-2017 the project “Availability of high quality weather data measurements” is carried out at Department of Civil Engineering at the Technical University of Denmark. The aim of the project is to establish measured high quality weather data which will be easily available for the building energy branch and the solar energy branch in their efforts to achieve energy savings and for researchers and students carrying out projects where measured high quality weather data are needed.

The project is financed by the Bjarne Saxhof foundation.

Background and objective of the project

At the Climate station, detailed measurements of global, beam and diffuse irradiance are performed. Also other meteorological parameters, i.e. temperature, rain, wind etc. are measured at the climate station.

The detailed measurements of solar irradiance and other meteorological parameters have been performed at the climate station since 1989, [1]. The climate station was upgraded and extended in in the period 2013-2014 in a project financed by Bjarne Saxhofs Foundation, [2].

The global solar irradiance is also measured in many other locations in Denmark, mainly by the Danish Meteorological Institute but the highly desired additional measurements of beam and diffuse irradiance, measured at the climate station are rare.

The weather determines the heat demand of buildings and the energy production of renewables. The outdoor temperature and the solar irradiance both the direct irradiance from the sun disc and the diffuse irradiance from the sky dome play important roles. Detailed information of the weather data is needed in order to evaluate if the heat demand of buildings is as low as expected and if solar energy systems used to reduce the energy consumption are as efficient as expected. The energy production of renewable energy systems is dependent on the weather conditions and the context of which the individual energy systems are included in the overall energy system. Some applications utilize only the beam irradiance coming directly from the sun disc, e.g. concentrating solar thermal plants while other applications, e.g. applications with evacuated tubular solar collectors also utilize diffuse irradiance coming from other parts of the sky.

Historical measurements and currently obtained measurements are also useful for studying the trends in the weather conditions.

The detailed measurements of solar irradiance and other weather parameters from the climate station are frequently used in research and student projects and it is expected that the measured climate data will form the basis for many future research and student projects at DTU. Further, very often experts from the building energy and solar energy branches ask for detailed climate data.

Hence it is considered of great value to give the many users easy access to the measured climate data via a homepage.

This report describes the climate station, the quality assurance of the measurements, the gap filling procedure for missing or false data and the homepage from where users can download complete detailed climate data with high quality and high time resolution.

The Climate station

The Climate station is located at Department of Civil Engineering, Technical University of Denmark at the roof of building 119. The latitude and longitude of the climate station are 55.8 N and 12.5 E respectively.

Figure 1 shows a picture of the horizon seen from the climate station. Figure 2 shows a schematic illustration of the top view of the climate station showing the location of the tracker and the cardinal directions (left) and a photo of the climate station taken from south (right).

Figure 1: 360° view of the horizon seen from the Climate station.

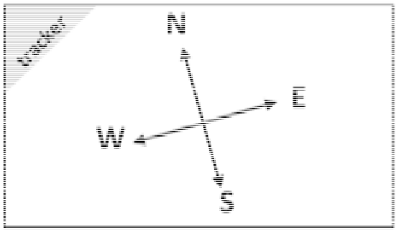

Figure 2: Left: Top view of the climate station. Right: Photo of the climate station taken from south.

The picture in Figure 1 shows a 360° view from the climate station. The sun can be seen in south. The solar radiation measurement instruments are mounted on the tracker in the North-West corner and have a clear view to the horizon without any shading.

The measurement equipment

The solar radiation measurement instruments are from the Dutch company Kipp and Zonen B.V. and comprise two pyranometers for measuring shortwave solar irradiance, one pyrheliometer for measuring shortwave direct normal irradiance and a pyrgeometer for measuring longwave downwelling radiation.

The solar radiation measurement instruments for measuring the shortwave direct normal radiation (pyrheliometer) and the shortwave horizontal diffuse radiation (pyranometer) are mounted on a tracker from Kipp and Zonen, type SOLYS 2. A shading ball assembly is used to screen of the beam irradiance when measuring the shortwave horizontal diffuse irradiance. A sun sensor mounted on the tracker fine tunes the tracking of the sun.

The pyranometer used to measure the shortwave horizontal diffuse radiation is mounted on the top plate on the tracker. The shading ball screens of the shortwave direct normal radiation and the pyranometer measures only the shortwave horizontal diffuse radiation. The pyrheliometer that measures the shortwave direct normal radiation is mounted on the left side of the tracker. The view angle from the pyrheliometer to the sky is 5° and the view angle from the pyranometer to the shadow ball is 5°. In this way, the pyrheliometer measures exactly the amount of solar irradiance that is screened of by the shadow ball, see figure 2.

Figure 3: The SOLYS 2 tracker. On the top mounting plate, the solar radiation measurement instruments can be seen. On the left side of the tracker, the solar sensor and the pyrheliometer that measured the shortwave beam normal irradiance can be seen.

The refraction is taken into consideration by the tracker when the geometric solar altitude is between 0°-25° by means of Michalsky algoritmen [3]. In this way, the tracker follows the visible sun when the geometric solar altitude is between 0°-25°.

The other meteorological parameters are measured by a weather transmitter, type WXT520 is from the Finnish company Vaisala Oyj, see figure 4.

Figure 4: Weather station, type Vaisala WTX520. The weather station is mounted 6 meter above the roof of building 119.

Table 1 shows the irradiance measurement instruments used at the climate station while Table 2 shows the other meteorological parameters from WXT520 used at the climate station. For wind measurements, scalar averaging is used for both wind speed and direction.

Table 1: Solar radiation measurement equipment.

Measurement	Sensor type	Resolution	Accuracy
Global shortwave solar irradiance	CMP 11	0.1 W/m^2	1.4 %
Short wave horizontal solar irradiance	CMP 11	0.1 W/m^2	1.4 %

Short wave direct normal solar irradiance	CHP 1	0.1 W/m^2	1 %
Downwelling horizontal longwave irradiance	CGR 4	0.1 W/m^2	1 %

Table 2: Other meteorological parameters.

	Range	Resolution	Accuracy
Wind direction minimum [°]	0 - 360° (The direction from where the wind blows. 0°=North, 90°=East, 180°=South, 270°=Vest)	1°	3°
Wind direction average [°]			
Wind direction maximum [°]			
Wind speed minimum [m/s]	0 – 60 m/s	0.1 m/s	The greater of 0.3 m/s or 3% of the measurement range 0…35 m/s 5% for the measurement range of 36…60 m/s
Wind speed average [m/s]			
Wind speed maximum [m/s]			
Air temperature [°C]	-52 – 60 °C	0.1 °C	0.2 K at ambient temperature of -50 °C – 0 °C 0.3 K at ambient temperature of 20 °C. 0.4 K at ambient temperature of 40 °C 0.7 K at ambient temperature of 60 °C
Relative humidity [%]	0 – 100 %RH	0.1 %RH	3 %RH at 0…90 %RH 5 %RH at 90…100 %RH
Air pressure [hPa]	600 – 1100 hPa	0.1 hPa	1 hPa at ambient temperature range -52…+60 °C
Rain fall [mm]	Collecting area: 60 cm^2	0.01 mm	Cumulative accumulation after latest auto reset. < 5 %, weather dependent. Due to the nature of the phenomenon, deviations caused by spatial variations may exist in precipitation readings, especially in short time scale. The accuracy specification does not include possible wind induced error.
Rain duration [s]		10 s	Counting each 10-second increment whenever droplets detected.

Rain intensity [mm/h]	0 – 200 mm/h		Running one minute average in 10-second steps.
Hail [hits/cm^2]		0.1 hits/cm^2	Cumulative amount of hits against collecting surface.
Hail duration [s]		10 s	Counting each 10-second increment whenever hailstone detected.
Hail intensity [hits/m^2/h]		10 hits/cm^2/h	One-minute running average in 10-second steps.

Data acquisition system

The hardware is from the company National Instruments and comprises a real-time controller, type cRIO 9067 with analog input/output modules of the types NI 9214 and NI 9217 for measuring voltage and temperature respectively. Further, the controller has built in an RS232 channel which is used by the weather transmitter, measuring other weather parameters.

The measurement accuracy of NI 9214 is about 8 μV corresponding to an accuracy of around 1 W/m^2 for solar radiation measurements.

The measurement accuracy of NI 9217 is about 0.15 K for temperature measurements.

The data acquisition system is placed in an electromagnetic compatibility (EMC) cabinet and all connections are carried out with shielded plugs. Further, the cables between measurement instruments and data acquisition system are twisted pairs with 80% braid coverage. In this way noise from electrical sources in the surroundings are eliminated.

Quality control and gap filling of the measured climate data

In order to ensure the data quality of the measured climate data, the measurement instruments are cleaned and calibrated on a regular basis. The measurements are filtered for physical impossible values and possible gaps are filled before the data is distributed.

The measured climate data are distributed as:

- filtered data where data gaps are filled (BSRN filtered data – gaps filled)
- filtered data (BSRN filtered data – no gaps filled)
- raw measured data where data gaps are filled (Non filtered data – gaps filled)
- raw measured data (Non filtered data – no gaps filled)

Filtering the data to eliminate physical impossible data

The filtering to detect physical impossible data is done by applying a filter in accordance with the Baseline Surface Radiation Network (BSRN) standard. Physical impossible data are deleted from the filtered files and replaced in a gap filling procedure, described in the next section.

BSRN is a network under the World Climate Research Program (WCRP) [4] aiming to provide the climate community with accurate and highly resolved irradiances for climate research purposes. This global network measures surface radiative fluxes at the highest possible accuracy with well calibrated state-of-the-art instrumentation at selected sites in major climate zones, [5].

The filters for physically possible intervals on horizontal are listed in table 3. S_0 is the solar constant adjusted for Earth-Sun distance, μ is the cosine of the solar zenith angle, GLOB is the global irradiance, SWDIFF is the shortwave horizontal diffuse irradiance, SWDIR is the shortwave direct normal irradiance, LWDOWN is the downwelling longwave irradiance. Irradiance values that fall outside the physically possible irradiance intervals are deleted and the gap is filled by the gap filling procedure described in the next section.

Table 3: Upper and lower limits for the physically possible irradiance intervals on horizontal, [5].

Parameter	Lower limit	Upper limit
GLOB	-4 W/m^2	$1.5 \cdot S_0 \cdot \mu^{1.2}$+100 W/m^2
SWDIFF	-4 W/m^2	$0.95 \cdot S_0 \cdot \mu^{1.2}$+100 W/m^2
SWDIR	-4 W/m^2	$S_0 \cdot \mu^{1.2}$
LWDOWN	40 W/m^2	700 W/m^2

The solar constant adjusted for Earth-Sun distance S_0 is calculated by the approximation (1)

$$S_0 = 1367\ W/m^2 \cdot (1+0.033 \cdot \cos(360 \cdot n/365)) \qquad (1)$$

The cosine of the solar zenith angle, μ is calculated by equation (2)

$$\mu = \cos(SZA) \qquad (2)$$

Where

n = the day number. January 1 is day number 1.

SZA= solar zenith angle, the angle between the vertical and the line to the sun [°]

The calculation of the zenith angle, SZA is explained in [6].

Gap filling procedure

Data gaps caused by missing or false data are filled by the method described by [7] and [8].

The solar radiation gaps are filled either by using equation relation of the three solar radiation components, modeled values, linear interpolation of clearness indices or by replacing data from neighboring days.

The relationship between the three solar radiation components i.e. global horizontal irradiance (GHI), shortwave horizontal diffuse irradiance (DHI) and direct normal irradiance (DNI) is described by equation (3). The modeled values are the clearness index (k) and the diffuse fraction (d) and the values are calculated by means of the Skartveit Model, [8]. The relationship between the modeled values and the solar radiation components are described by the equations (4) and (5).

$$GHI = DHI + DNI \cdot \mu \qquad (3)$$
$$k=GHI/(S_0 \cdot \mu) \qquad (4)$$
$$d=DHI/GHI \qquad (5)$$

The gap filling procedure distinguishes between missing solar radiation data and missing other meteorological data. For solar radiation data, the procedure distinguishes between:

- The availability of three components of solar radiation being i.e. GHI, DHI and DNI
- The length of the gap i.e. gaps less than 3 hours and gaps greater than 3 hours and gaps greater than 24 hours.

This leads to three cases:

Case 1: One component is missing.

- The missing component is found by equation (3)

Case 2: Both DHI and DNI are missing.

- GHI is used as input to the Skartveit Model, [8] to calculate clearness index, k and diffuse fraction, d. Finally, the missing DHI and DNI values are calculated by (5) and (3) respectively.

Case 3: All three solar irradiance components are missing.

- If the data gap is less than 3 hours, the clearness indices are calculated for GHI and DNI for all the time steps where GHI and DNI are available on both sides of the gap. The clearness indices, k for the gap are then calculated by linear interpolation and used as input to the Skartveit Model, [8] to calculate the diffuse fraction, d. Finally, GHI and DHI values are calculated by (4) and (5) respectively and DNI values are calculated by (3).
- If the data gap is larger than 3 hours, the gap is filled with data from neighboring days if data is available. The gap filling procedure can fill data gaps up to 10 days if data before and after the gap are available. The first 5 days will be replaced by data from the day before the gap and the last 5 days with data from the day after end of the gap. The limit of 10 days is set due to the fact that in atmospheric science it is assumed that weather stays constant for a period of 5 days. Further, since the sun position does not deviate significantly for a period of 5 days, this procedure is applied to solar radiation data so that the data matches with sunrise and sunset times and also with sun elevation and azimuth angles, [7].

The gap filling procedure for other meteorological data follows the method described in case 3. Instead of linear interpolation of the clearness indices, the values of the parameters are directly linear interpolated.

Data resolution

The data resolution can be selected to 1 minute, 30 minutes, 1 hour or 24 hours.

Data resolution of 1 minute contains the mean value of the measurement in the previous minute. For rain and hail, the measurements contain the sum measured in the previous minute. Maximum and minimum values are the maximum and minimum values measured in the previous minute.

For data resolution of 30 minutes, 1 hour and 24 hours, the average value or the sum of the previous time span is used. In this way, the time 30 minutes contains the average value or the sum from the time span 0 minutes to 30 minutes, and so on.

Home page

The homepage can be accessed by: http://climatestationdata.byg.dtu.dk/

Figure 5 shows a picture of the front page.

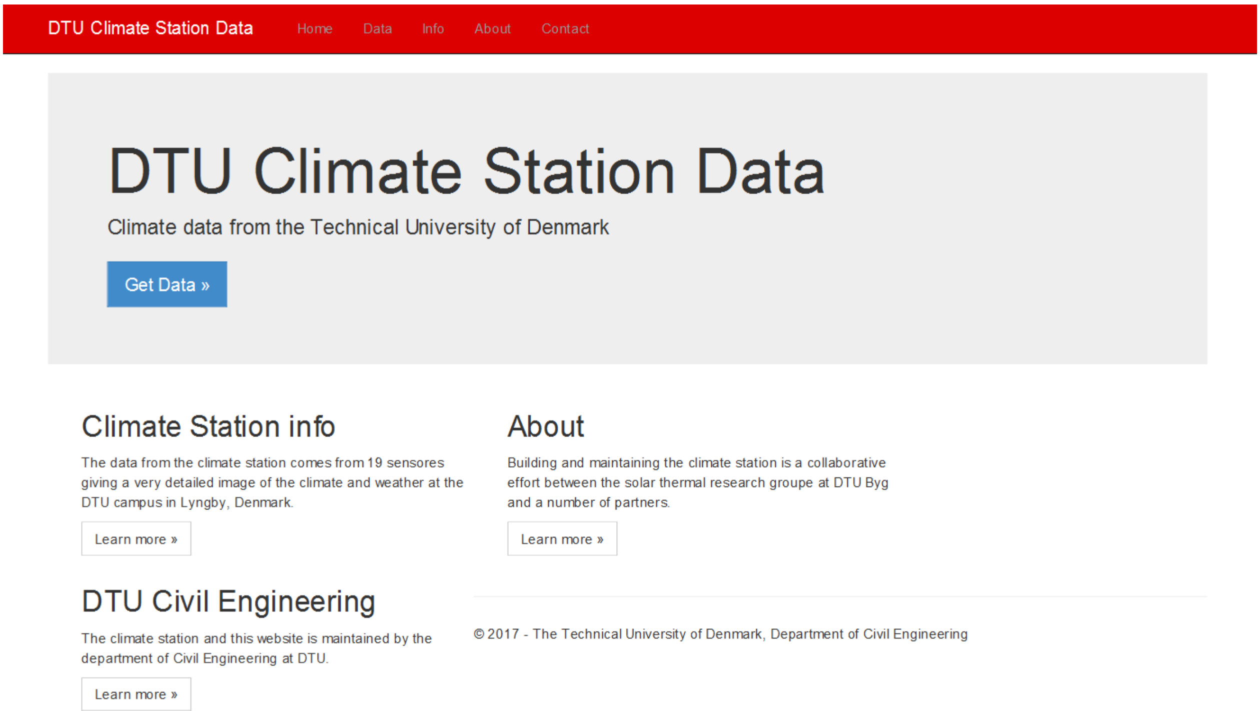

Figure 5: Front page.

From the front page, the measured weather data can be downloaded by choosing ‘Get Data’. The page shown in figure 6 will appear. It is now possible to choose the data period ‘From’ and ‘To’, the time step in the file and the type of data ‘Select time step’ and which data the file should contain ‘Select data type (advanced users only)’. The default value for the time step is ‘one minute’ and the default value for the data file is ‘BSRN filtered – gaps filled’. All users must state their affiliation and the purpose of downloading data from the climate station. This information is automatically stored in a file and gives a good overview of the number of users and how the data is used. Finally, the users are requested to make a reference to the climate station in any publication in which the climate data are used.

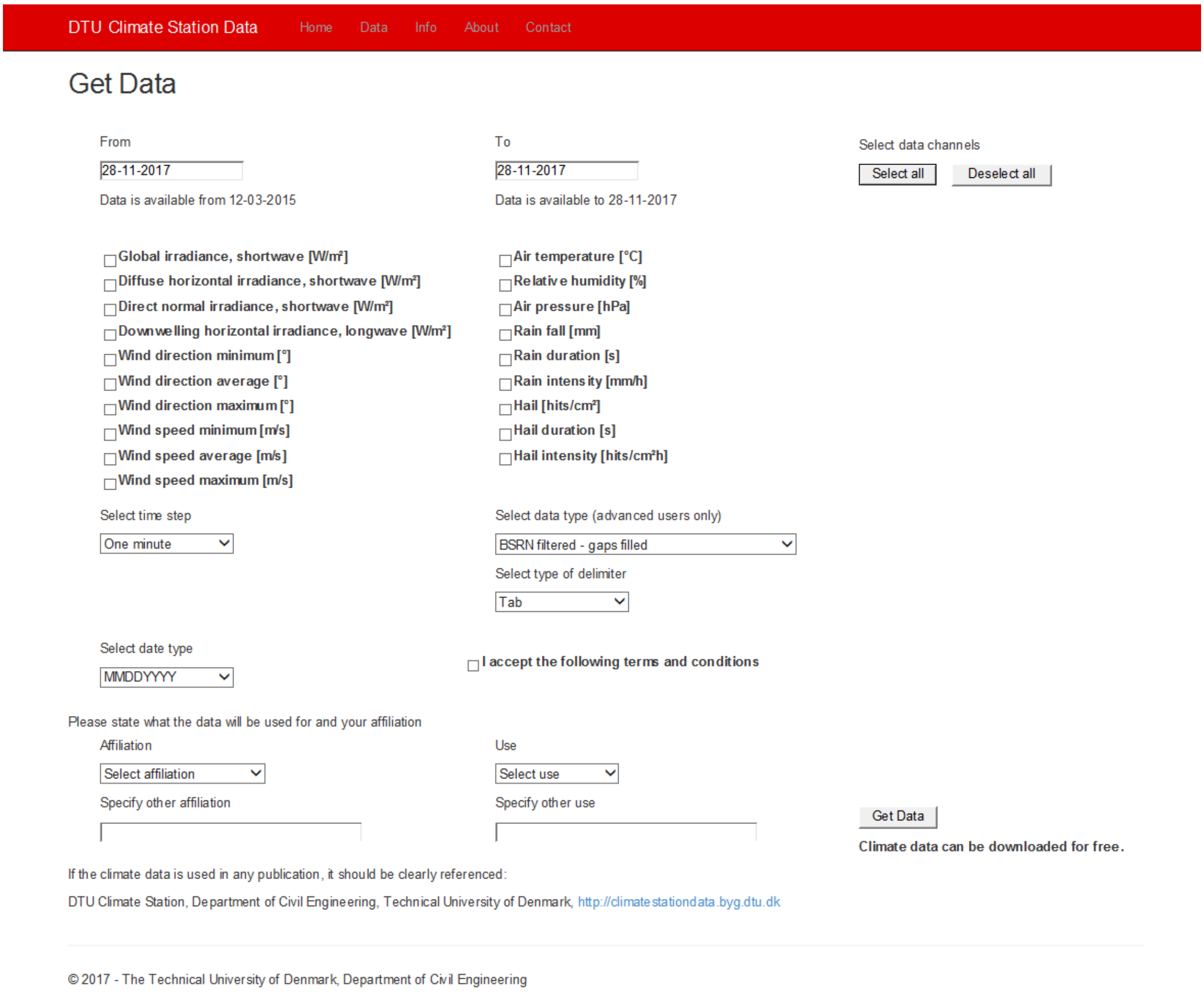

Figure 6: ‘Get data’ page.

From the front page, also information about the climate station can be accessed.

Symbols and abbreviations

Symbols:

S_0	Solar constant adjusted for Earth-Sun distance [W/m^2]
μ	Cosine of the solar zenith angle [°]
k	Clearness index [-]
d	Diffuse fraction [-]
n	Day number [-]

Abbreviations:

SZA	Solar zenith angle [°]
GLOB, GHI	Shortwave global horizontal irradiance [W/m^2]
SWDIFF, DHI	Shortwave diffuse horizontal irradiance [W/m^2]
SWDIR	Shortwave direct horizontal irradiance [W/m^2]
DNI	Shortwave direct normal irradiance [W/m^2]
LWDOWN	Downwelling horizontal longwave irradiance [W/m^2]

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DTU Civil Engineering
Technical University of Denmark

Brovej, Bygning 118
2800 Kgs. Lyngby
Tlf.   45 25 17 00

www.byg.dtu.dk

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