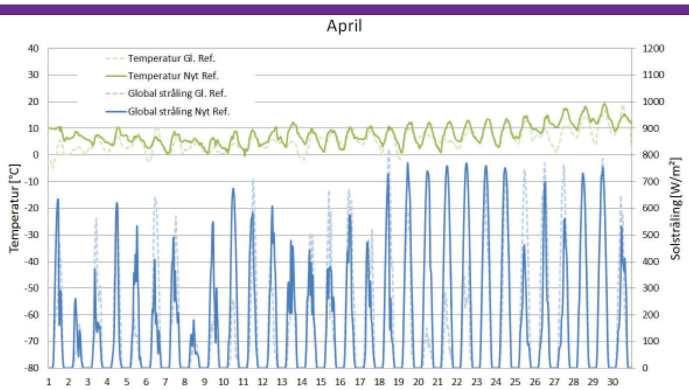
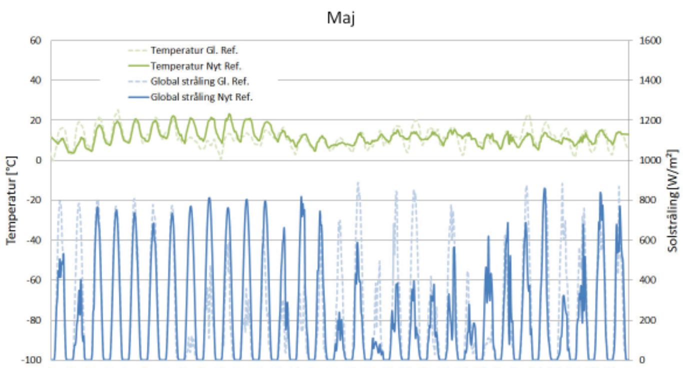
New Weather Data for Thermal Building Simulation





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Report

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2015

DTU Civil Engineering-Report SR 15-07 (UK)
November 2015

DTU Civil Engineering
Department of Civil Engineering

New weather data for thermal building simulation

Byg Sagsrapport SR 15-07

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Preface

This report describes the work carried out in the project 'New weather data for thermal building simulation' (Nye vejrdata til termisk bygningssimulering) funded by the Bjarne Saxhofs foundation. The aim of the project is to analyse weather data from 1996 to 2010, and select the most representative months for a new reference year for Denmark.

Acknowledgment

To the Danish Meteorological Institute for providing weather data from the stations Jægersborg and Kastrup.

Content

1 Introduction

The existing weather data set consists of data from 1975 to 1989. Therefor it has been a wish from the professional engineering industry in Denmark to have an upgraded version of the weather data set to be used in building simulation.

The weather data is used as climate data for computer simulation of the performance of solar energy systems and assessment of building energy consumption as well as indoor climate and comfort.

The new data set for the reference year is based on data from 1996 to 2010, measured at three different stations in close proximity of each other.

2 Measured data

The measured data in the new reference year is derived from 3 different locations; DTU–Lyngby, DMI-Jægersborg and DMI-Kastrup. This has been necessary in order to obtain the required parameters for the reference year. Table 1 gives an overview of the data in the new weather data set and from which station it is derived.

Table 1 Parameters in the weather data set.

	DMI Jægersborg	DMI Kastrup	DTU Lyngby
Dry bulb temperature	X		
Dew point temperature	X		
Global irradiance			X
Diffuse irradiance on horizontal			X
Direct normal irradiance			X
Wind direction	X		
Wind speed	X		
Barometric pressure	X		
Precipitation		X	
Cloud cover		X	

The data from DMI and DTU is described with more detail in the following:

Dry bulb temperature [°] : Measured 2 m above ground at DMI station Jægersborg, Denmark. Validated and adjusted according to the description in [1].

Dew point temperature [°] **:** Measured 2 m above ground at DMI station Jægersborg, Denmark. Not adjusted.

Global irradiance [W/m²] **:** Measured at the climate station at DTU in Lyngby, Denmark. The measurements are validated and adjusted according to the description in [1].

Diffuse irradiance on horizontal [W/m²] : Measured at the climate station at DTU in Lyngby, Denmark. The measurements are either collected with a tracking disc blocking out the sun or when the tracker has been positioned wrong with the shadow band. The correction for the shadowband is carried out as described in [2]. The measurements are validated and adjusted.

Direct normal irradiance [W/m²] : Measured at the climate station at DTU in Lyngby, Denmark. The measurements have been collected with a tracker. When the tracker has been positioned wrong, the direct normal irradiance is calculated based on the diffuse radiation measured with the shadowband. The measurements are validated and adjusted.

Wind direction [°] : Measured 10 m above ground, as mean from 10 minute values from the DMI station in Jægersborg. Not adjusted.

Wind speed [m/s] : Measured 10 m above ground at the DMI station in Jægersborg. Not adjusted.

Barometric pressure [hPA] : Measured 2 m above ground at the DMI station Jægersborg, Denmark. Not adjusted.

Precipitation [mm] : The precipitation is accumulated every 3 hours and measured at the DMI station Kastrup, Denmark. Not adjusted.

Cloud Cover [-] : Is recorded in oktas at the DMI station Kastrup, Denmark. Not adjusted.

2.1 Validation of data

The data received by DMI is checked and validated against current standards.

The DTU data is not checked and validated automatically and must therefore undergo a series of checks. The data is collected with a timestamp of 2 minutes, and based on these, hour data is generated.

Check of the DTU data

The first check of the DTU data is registering missing data. The check is carried out on the 2 min measurements, where missing data for less than an hour is generated by interpolation. Missing data for over an hour registered and left missing.

The second check is regarding faulty measurement. To eliminate this, a limit regarding the solar altitude is introduced, where data collected with a solar altitude angle below 3 degrees is then disregarded. This is because the inaccuracy of the pyranometers is increasing with decreasing the solar altitude angle.

The third check is concerning the diffuse radiation, which is measured with both a disc and a shadowband. In order to assess whether the measurement with the disc is accurate, it is compared with the measurement from the shadowband. On Figure 1 this correlation is shown. The blue dots show when the relationship between the two measurement with the disc and the shadowband falls outside the interval from 0.8 to 1.2 which is chosen as a secure interval for the measurement. The data that falls outside the interval is then manually checked and if the tracker has been positioned wrong the diffuse radiation measured with the shadowband is used instead and the direct radiation is then calculated based on this measurement.

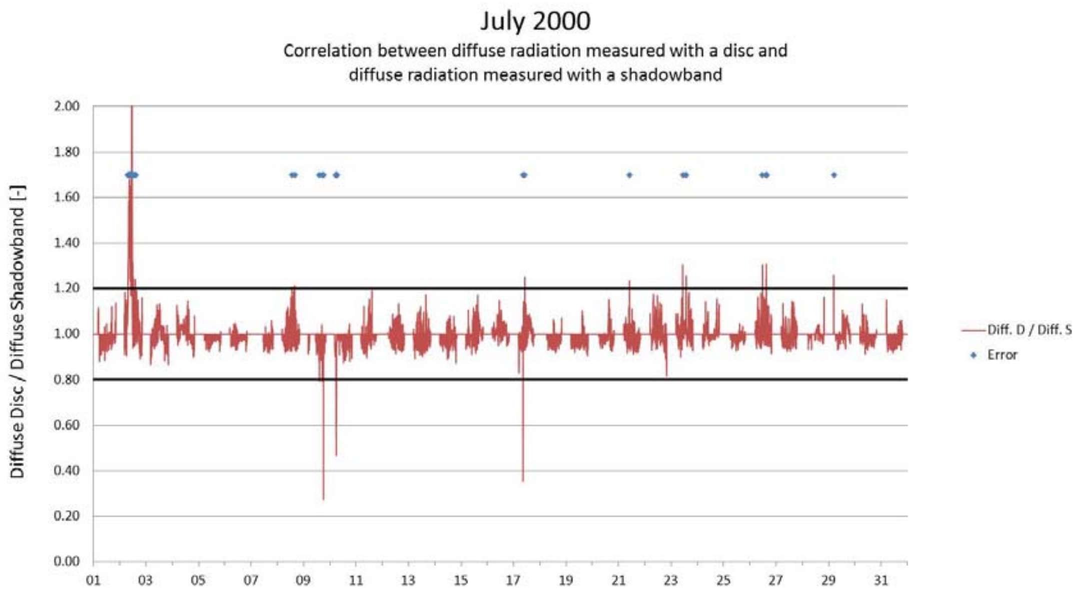


Figure 1 Correlation between the diffuse radiation measured with the disc and the shadowband from July 2000.

All the 15 years of data is also visually checked, where for instance unusually high values are evaluated. If there is uncertainty with the measurements it is disregarded.

All changes to the measurements are registered and documented.

The checked 2 minute measurements from DTU are used to generate hour data. This is done by collected the measurements from the previous hour and averaging them. This means that data with the hour timestamp 12:00 is generated based on the data collected from 11:00 to 12:00.

The data from the 3 station is then combined into one file

2.2 Available data

Because of missing data, both from the DMI stations and the data from DTU, several months where disregarded and not used during the selection. Figure 2 shows available data, where the available months are green and the month mark with red are disregarded.

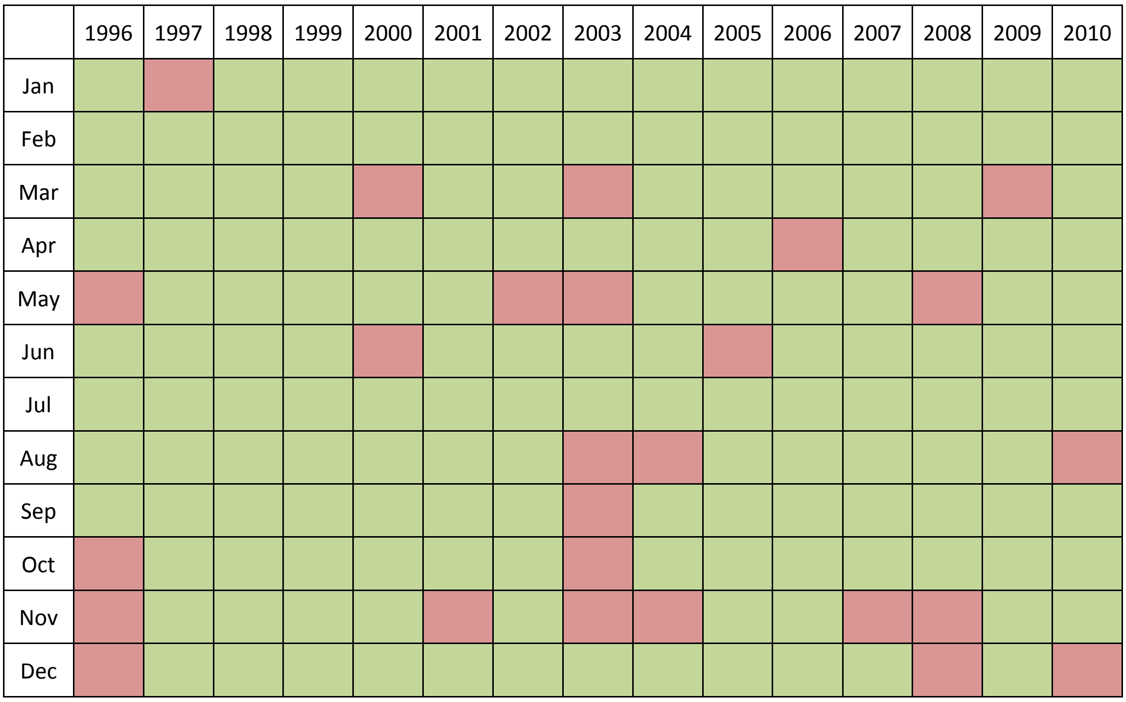


Figure 2 The available data from the period 1996 to 2010.

Figure 3 and Figure 4 along with table 2, 3,Table 4 and Table 5, show the global irradiance and dry bulb temperature from the period 1996 to 2010. The gaps seen in the figures are the months that have been disregarded because of missing data.

Global radiation

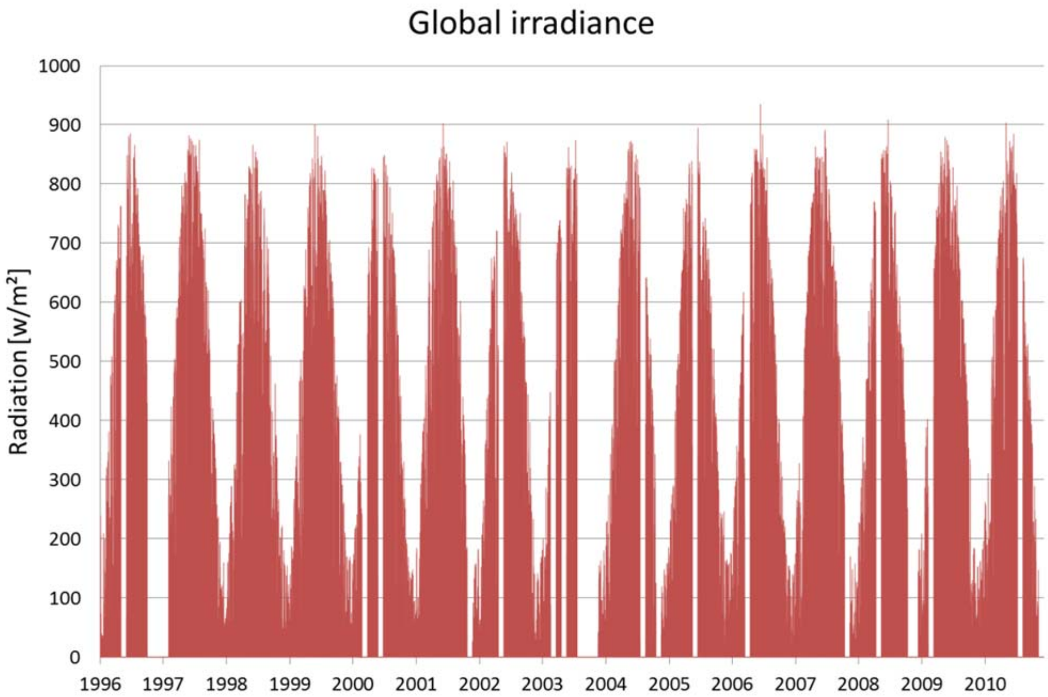


Figure 3 Global irradiance from 1996 to 2010.

Table 2 Monthly global radiation from 1996 to 2010.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	9.8	24.7	63.2	130.2		151.1	156.9	147.3	95.0			
1997		31.8	78.9	115.1	140.4	167.3	181.5	155.3	86.1	45.8	16.3	7.3
1998	17.4	23.4	75.7	82.8	165.5	138.4	130.6	117.8	67.4	35.8	15.4	9.6
1999	11.7	29.1	52.8	110.6	152.9	161.1	173.6	129.9	99.1	46.6	18.3	10.4
2000	15.3	28.9		117.7	169.9		134.6	121.2	85.0	39.5	15.9	8.5
2001	10.5	35.8	70.3	94.0	169.8	168.2	177.4	123.6	68.3	36.4		8.6
2002	12.0	30.7	85.1	98.2		180.5	155.8	147.6	106.7	44.4	14.7	7.4
2003	14.1	31.3		128.6		162.3	160.6					8.6
2004	15.6	30.0	72.4	132.9	162.0	138.2	136.5		95.7	41.8		8.3
2005	17.9	29.1	84.9	134.3	153.5		156.6	126.3	86.9	56.4	19.4	10.7
2006	14.5	26.8	72.5		155.7	174.7	191.8	121.1	98.4	40.2	17.5	9.6
2007	13.2	19.9	83.5	140.6	153.1	149.0	133.0	124.7	81.7	50.7		7.0
2008	10.1	28.2	67.9	121.8		181.9	177.9	113.4	84.9	48.4		
2009	12.2	28.8		157.5	168.4	191.4	160.3	145.4	92.0	45.4	10.9	9.2
2010	15.0	21.9	68.5	118.9	116.2	161.0	174.8		84.8	51.1	15.5	

Ambient temperature

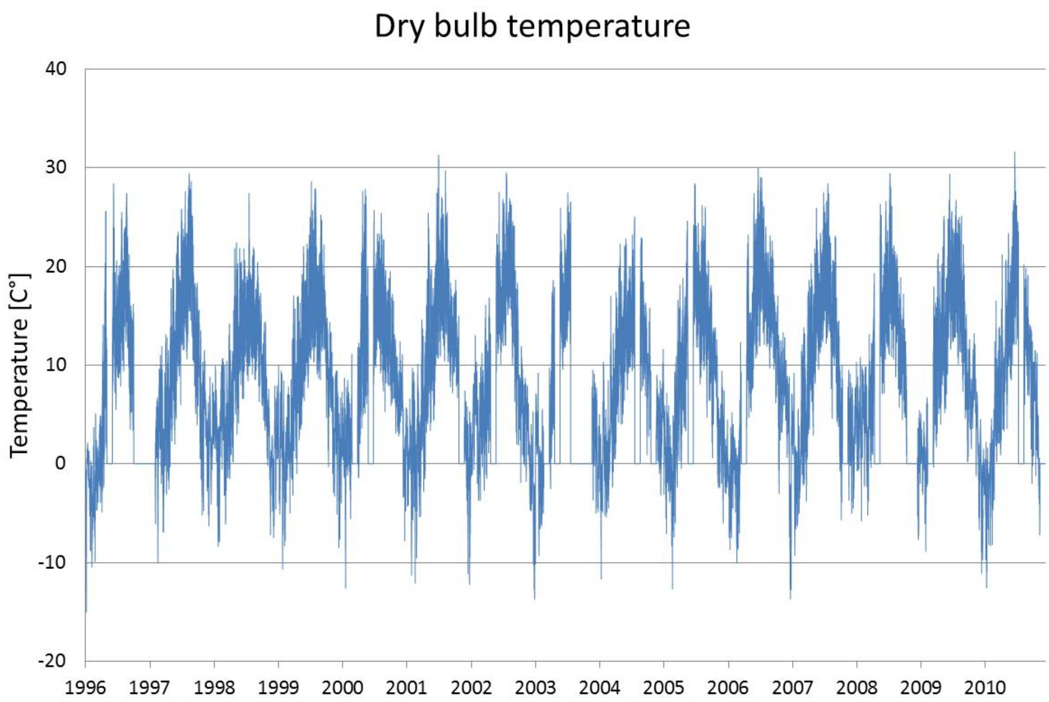


Figure 4 Dry bulb temperature from 1996 to 2010.

Table 3 Average ambient temperature from 1996 to 2010.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	-1.9	-3.2	-0.3	7.1		14.2	15.3	18.0	11.4			
1997		2.6	3.6	5.5	9.9	15.4	18.1	20.8	13.5	7.4	4.4	2.2
1998	2.0	4.8	3.1	6.8	12.2	14.2	14.6	14.9	13.2	8.4	1.6	1.2
1999	1.7	0.4	3.2	8.1	10.5	14.3	17.9	16.5	16.0	9.4	5.4	1.7
2000	1.9	3.0		8.9	14.1		15.7	15.8	13.0	11.0	7.1	3.6
2001	1.5	0.4	1.3	6.1	12.7	14.1	19.1	17.8	12.9	12.1		0.5
2002	2.4	4.1	4.6	7.5		15.6	18.3	20.3	14.6	7.2	4.5	0
2003	0.0	-1.5		7.2		16.2	18.6					3.9
2004	-0.9	1.7	3.7	8.1	11.8	14.0	15.5		14.0	9.8		3.6
2005	3.2	0.1	1.2	7.9	11.7		18.4	16.2	14.9	11.0	5.9	2.3
2006	-1.0	0.1	-0.4		11.7	16.5	21.0	17.8	16.3	12.3	7.6	6.6
2007	0-1	-1-5	3.6	6.9	12.4	16.4	18.6	18.1	14.3	6.3		3.9
2008	3.9	4.6	3.7	7.7		15.3	18.3	17.1	13.5	9.7		
2009	0.9	0.3		10.0	12.2	14.7	18.7	18.3	15.0	7.9	7.4	1.3
2010	-2.9	-1.6	2.9	7.5	10.2	15.1	20.1		13.1	8.4	3.5	

Tabel 4 and 5 give the max and min ambient temperature from the period 1996 to 2010.

Table 4 Max ambient temperature from 1996 to 2010.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	2.1	5.1	4.9	25.6		28.4	25.5	27.8	21.2			
1997		9.6	12.1	13.9	19.7	25.8	27.6	29.4	24.1	16.6	11.5	8.8
1998	9.9	10.7	14.2	21.8	22.4	21.8	27.4	21.9	20.4	14.4	7.6	7.9
1999	10.0	8.4	14.2	17.0	22.0	23.2	28.6	27.9	25.2	15.9	13.3	9.4
2000	8.7	11.1		27.6	27.8		25.6	25.4	19.6	19.5	12.6	11.1
2001	6.6	9.7	10.1	16.0	25.4	27.4	31.3	29.7	19.8	18.6		7.4
2002	9.2	13.0	14.8	16.8		27.5	29.5	28.6	24.6	18.1	8.7	6.1
2003	9.2	5.5		18.6		25.9	27.4					9.5
2004	5.0	10.3	17.0	17.4	22.3	22.8	25.0		22.9	16.3		9.0
2005	11.6	5.9	10.9	18.1	24.6		28.4	26.2	26.0	18.1	13.8	9.4
2006	4.5	5.2	12.3		23.2	27.4	30.0	26.1	23.1	18.4	13.3	12.8
2007	9.2	5.5	13.8	18.6	21.8	25.9	27.4	28.4	23.1	14.5		9.5
2008	10.3	10.8	13.1	19.3		26.3	29.4	28.0	21.2	17.2		
2009	5.4	6.7		21.3	24.8	26.3	29.3	26.7	25.1	15.1	13.2	7.3
2010	2.2	4.6	16.5	21.2	20.6	25.6	31.6		20.1	14.1	11.5	

Table 5 Min ambient temperature from 1996 to 2010.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	-15.0	-10.5	-4.7	-4.9		5.5	7.9	9.4	3.4			
1997		-10.1	-6.9	-3.1	2.0	4.7	11.3	10.6	4.0	-5.2	-4.8	-6.3
1998	-8.4	-7.9	-6.1	-1.5	3.0	6.6	8.4	8.5	6.3	3.2	-7.2	-7.5
1999	-10.7	-8.3	-5.0	-1.0	2.4	6.4	10.3	8.7	8.5	-0.3	-3.3	-8.5
2000	-12.6	-5.6		-1.4	5.0		8.1	7.4	5.3	5.9	2.8	-7.8
2001	-4.8	-12.1	-9.5	-2.8	3.4	4.4	10.7	10.3	7.2	6.7		-12.2
2002	-9.5	-3.7	-3.7	-1.5		9.3	11.4	13.9	2.0	-1.9	-1.8	10.2
2003	13.7	-9.3		-2.5		9.6	11.8					-5.0
2004	-11.7	-5.4	4.5	0.5	4.0	6.5	9.4		7.4	0.9		-3.2
2005	-7.1	-8.3	-12.7	-2.3	3.3		11.8	8.1	4.7	0.6	-2.4	-6.0
2006	-8.7	-7.5	-10.0		3.7	7.5	11.1	11.9	9.7	3.6	-3.0	0.6
2007	-13.7	-9.3	-3.2	-3.8	2.9	9.6	11.8	7.6	4.3	-5.7		-5.0
2008	-3.5	-5.8	-5.2	-0.4		7.1	10.6	8.8	5.7	0.9		
2009	-7.7	-8.9		-0.3	4.0	5.2	11.6	10.1	5.5	0.2	1.5	-7.2
2010	-12.5	-10.8	-8.2	0.9	3.3	8.5	12.1		6.0	-2.0	-7.2	

3 Selection method of the months in the reference year

The selection of the most representative month for the new reference year are based on standard ISO 15927-4 Hygrothermal performance of buildings – Calculation and presentation of climatic data, Part 4 Hourly data for assessing the annual energy use for heating and cooling [3].

3.1 Principle

The requirements of a reference year is that it must corresponds to an average year, both regarding monthly and seasonal mean values.

Further requirements are:

- True frequencies
- True sequences
- True correlation between different parameters

3.2 Procedure

The procedure for determining the best months for the new reference year is by ranking the different months by the Frankelstein-Schafer statistic.

The Frankelstein-Schafer statistic is given by:

$$F_S = (p, y, m) = \sum_{i=1}^{n} |F(p, y, m, i) - \phi(p, m, i)|$$

Where

$\phi(p, m, i)$ is the Cumulative distribution function of the daily means of all years in the data set .

$F(p, y, m, i)$ is the Cumulative distribution function of the daily means within each calendar.

Cumulative distribution function of the daily means of all years in the data set is given by:

$$\phi(p, m, i) = \frac{K(i)}{N + 1}$$

Where

K(i)	is the ranking order of the i^{th} value of the daily means within that calendar month in the whole data set.
N	is the number of days in any calendar month in the whole data set

And

Cumulative distribution function of the daily means within each calendar is given by:

$$F(p, y, m, i) = \frac{J(i)}{n + 1}$$

Where

J(i) is the ranking order of the ith value of the daily means within that month and that year.

3.3 Adjustment between the chosen months

It is necessary to adjust the transition from one month to the next to ensure a smooth transition. This adjustment is done by interpolation between the last eight hours of a month along with the first eight hours of the following month.

4 The new weather data set

Based on the calculations the weight of the global radiation and the ambient temperature of each month from the period 1996 to 2010 was evaluated.

The selection of the new weather data set is based equally on the global radiation and ambient temperature. The selection can be seen in Table 6.

Table 6 The months that form the new weather data set.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Year	2009	2009	2010	2008	2006	2010	2002	2006	2004	1999	1999	2004

In the following the new weather data set is presented and compared the values from the old weather data set from 1975 to 1989.

4.1 Global, beam and diffuse radiation

The global, beam and diffuse radiation is seen in Figure 5 along with the monthly values in Table 7 for the new weather data set.

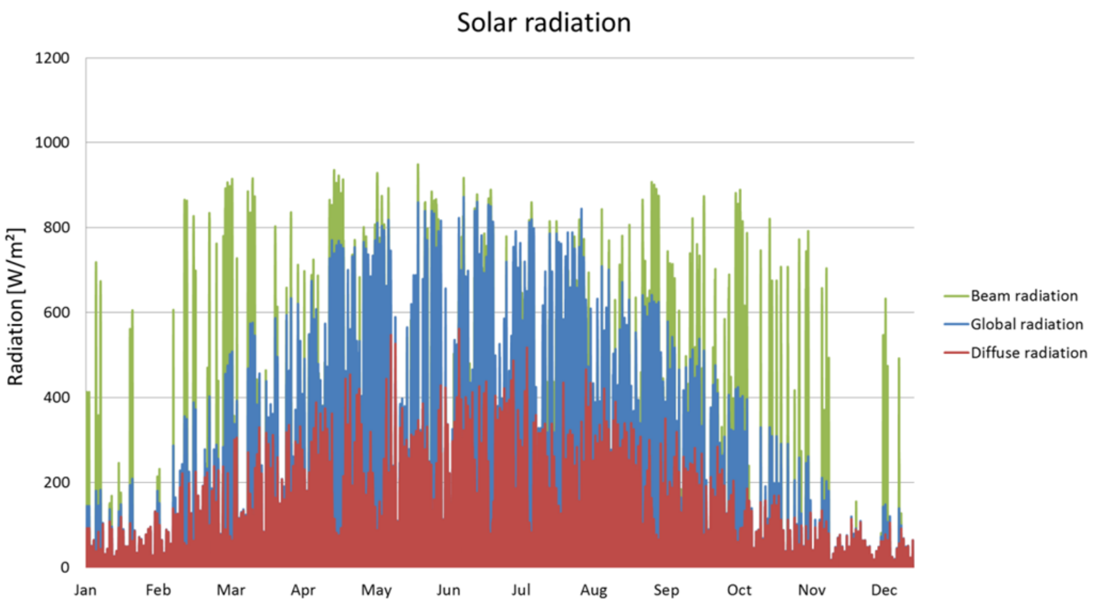


Figure 5 Global, beam and diffuse radiation for the new weather data set.

Table 7 Monthly values for the global, beam and diffuse radiation for the new weather data set.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Global radiation [kWh]	12	29	68	122	156	161	156	121	97	47	18	8	995
Diffuse radiation [kWh]	9	19	38	58	73	73	79	67	44	26	11	7	504
Beam radiation [kWh]	17	33	75	120	143	149	123	97	116	64	32	8	976

In Figure 6 and Figure 7 a comparison of the solar radiation form the old and new weather data set is seen. The figures show the yearly solar radiation is slightly lower in the new weather data set.

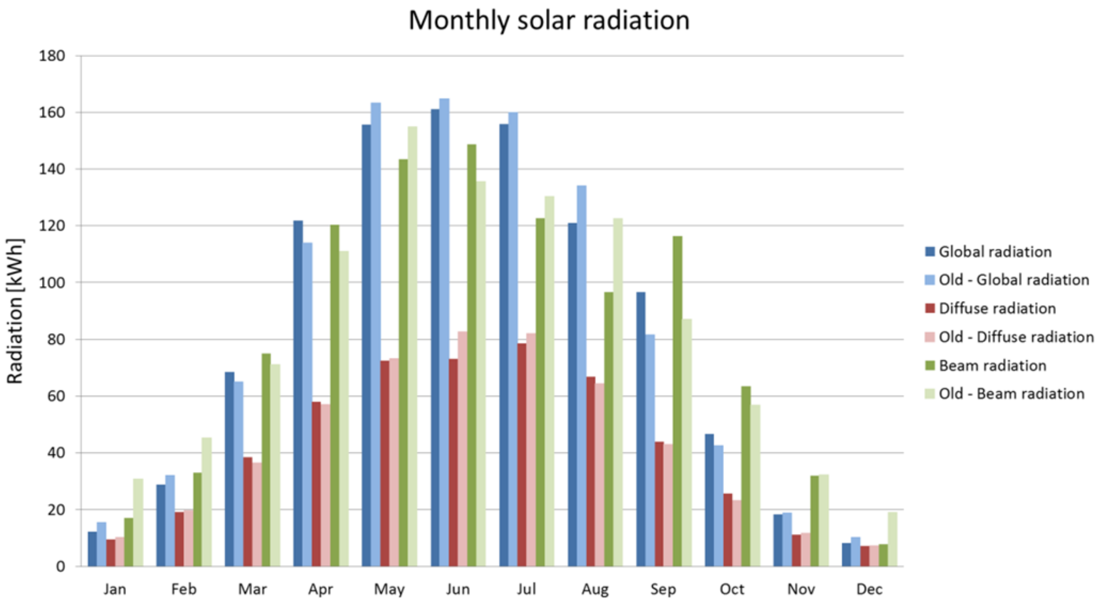


Figure 6 A comparison of the monthly solar radiation from the new and old weather data set.

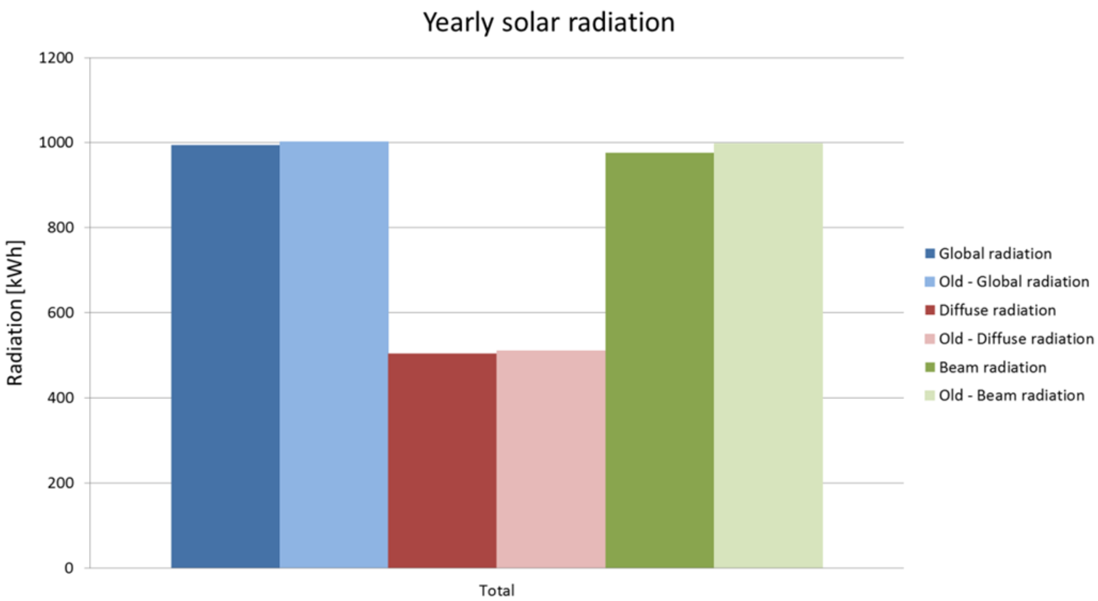


Figure 7 A comparison of the yearly solar radiation from the new and old weather data set.

4.2 Ambient Temperature

The ambient temperature is seen in Figure 8 and the max, min and average values for each month is show in Table 8 for the new weather data set.

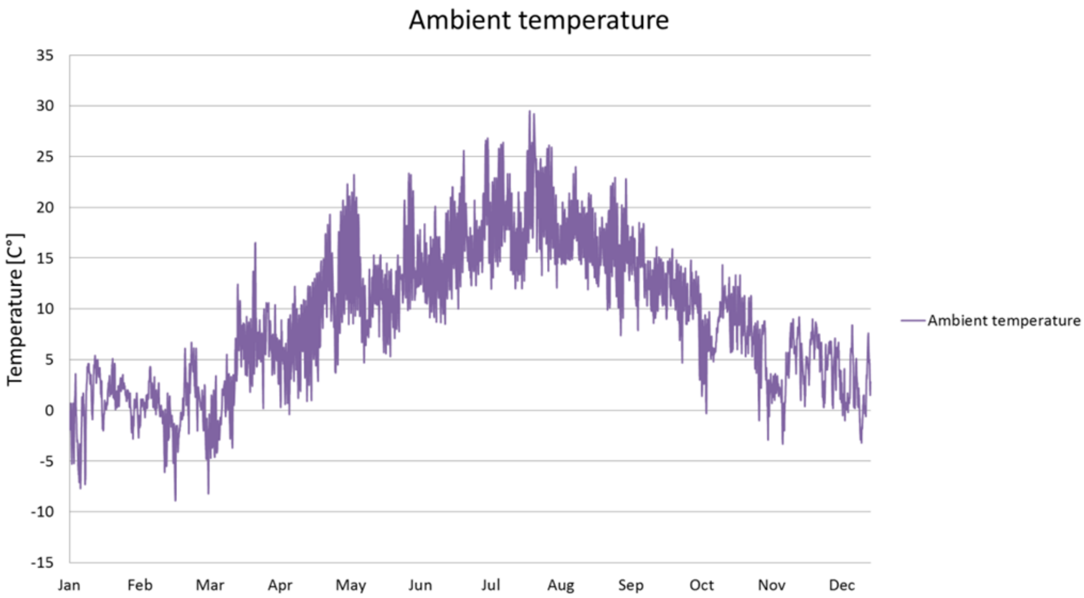


Figure 8 The ambient temperature in the new weather data set.

Table 8 The max, min and average values for each month in the new weather data set.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maks [°C]	5.4	6.7	16.3	19.3	23.2	25.6	29.5	26.1	22.9	15.9	13.3	9.0
Min [°C]	-7.7	-8.9	-8.2	-0.4	3.7	8.5	12.0	11.9	7.4	-0.3	-3.3	-3.2
Average [°C]	0.9	0.3	3.0	7.8	11.8	15.1	18.4	17.9	14.1	9.4	5.3	3.6

Figure 9 show a comparison between the new and old ambient temperature.

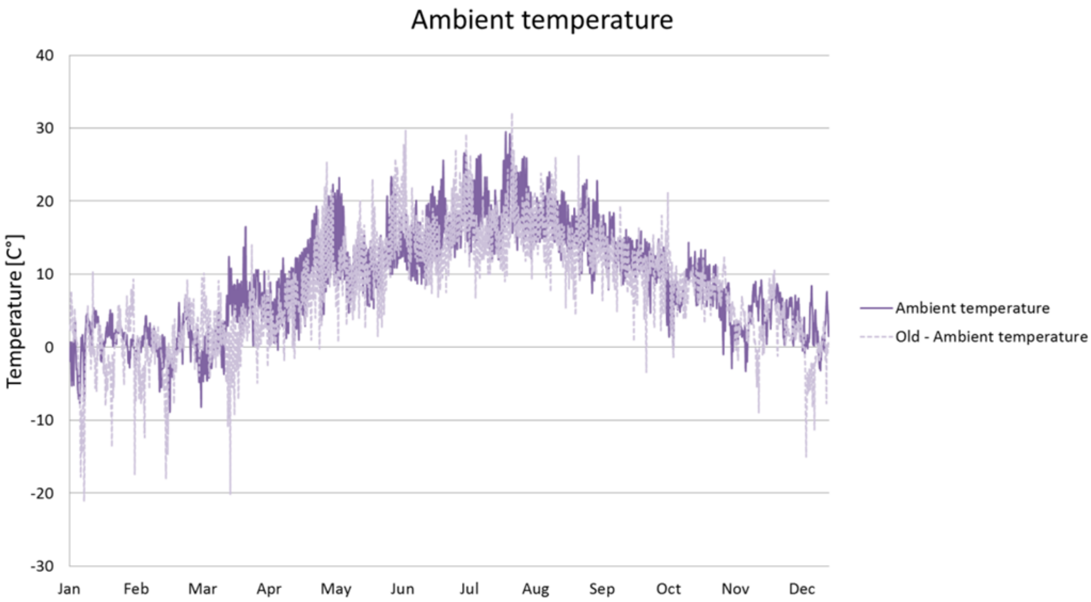


Figure 9 A comparison between the new and old ambient temperature.

4.3 Dew point temperature

The dew temperature is seen in Figure 10 and a comparison between the old and new dew point temperature is seen in Figure 11.

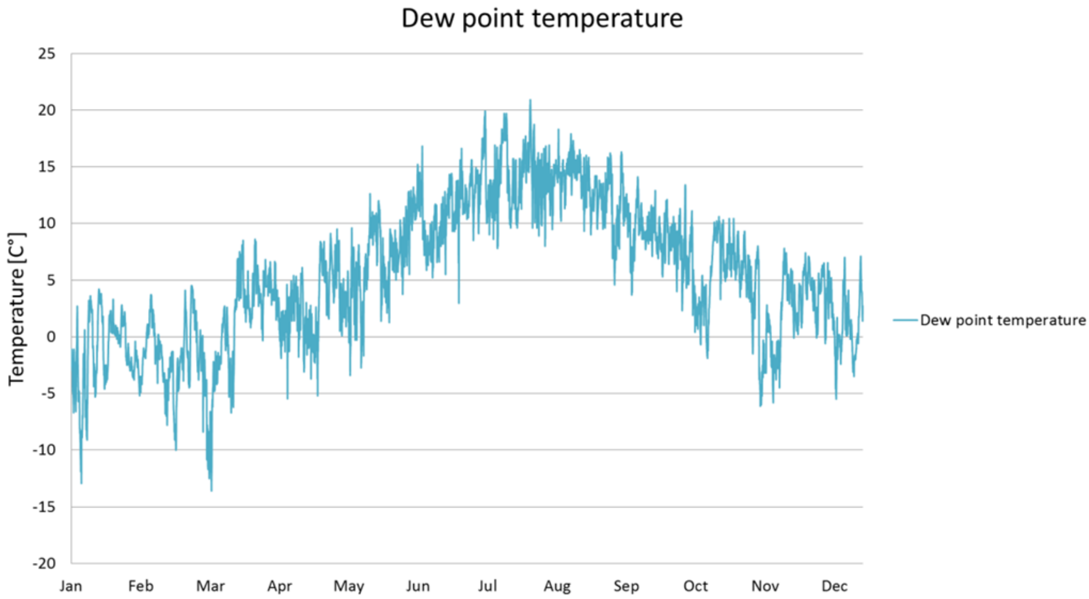


Figure 10 The dew point temperature in the new weather data set.

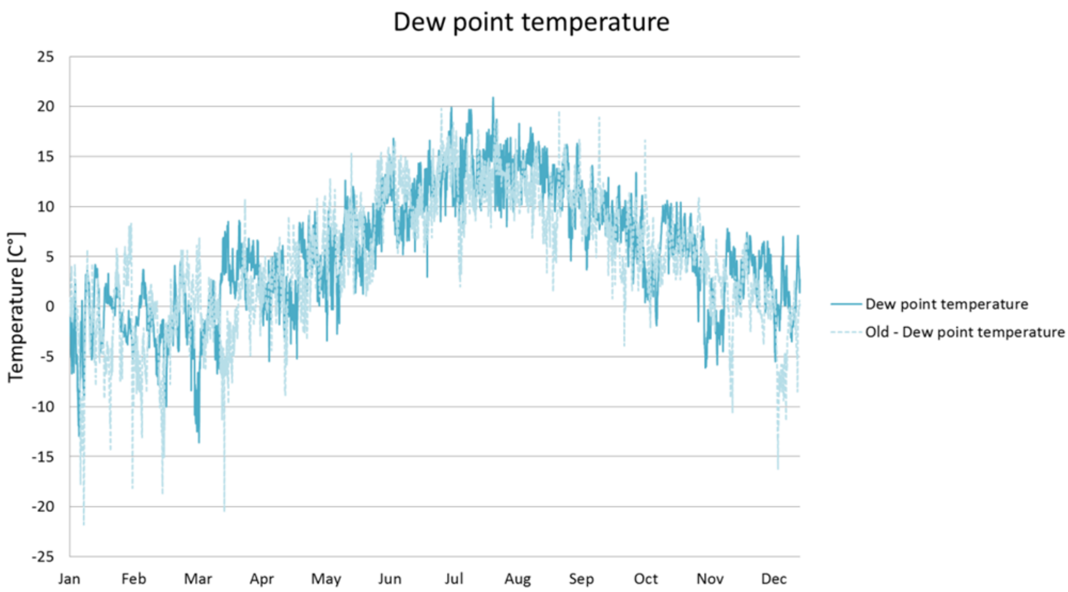


Figure 11 A comparison between the new and old dew temperature.

4.4 Wind and wind gust

Figure 12 shows the wind and wind gust in the new weather data set.

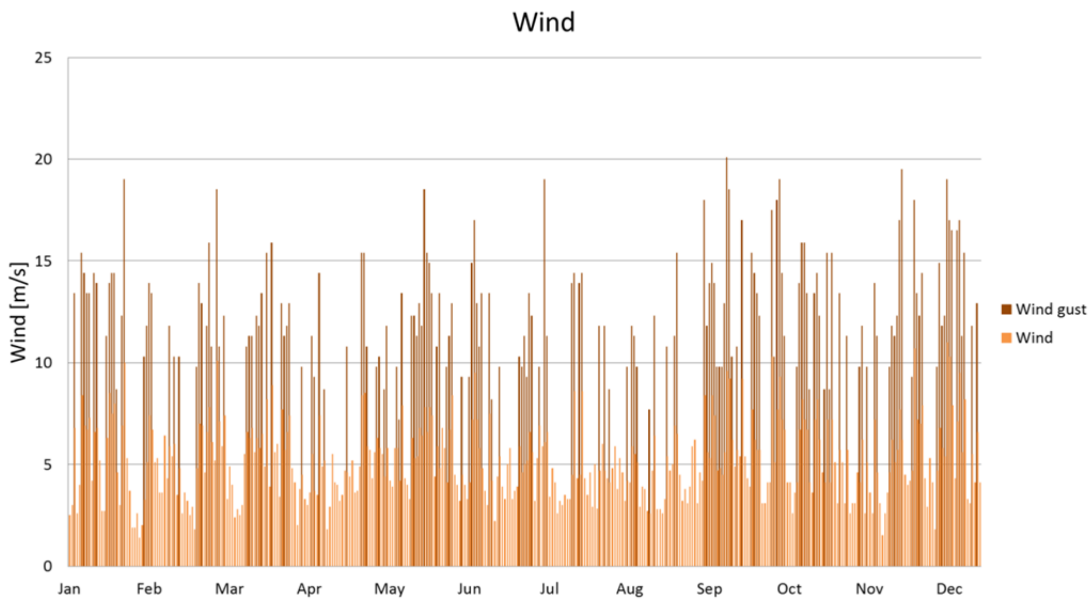


Figure 12 The wind and wind gust in the new weather data set.

4.5 Precipitation

Figure 13 shows the precipitation in the new weather data set.

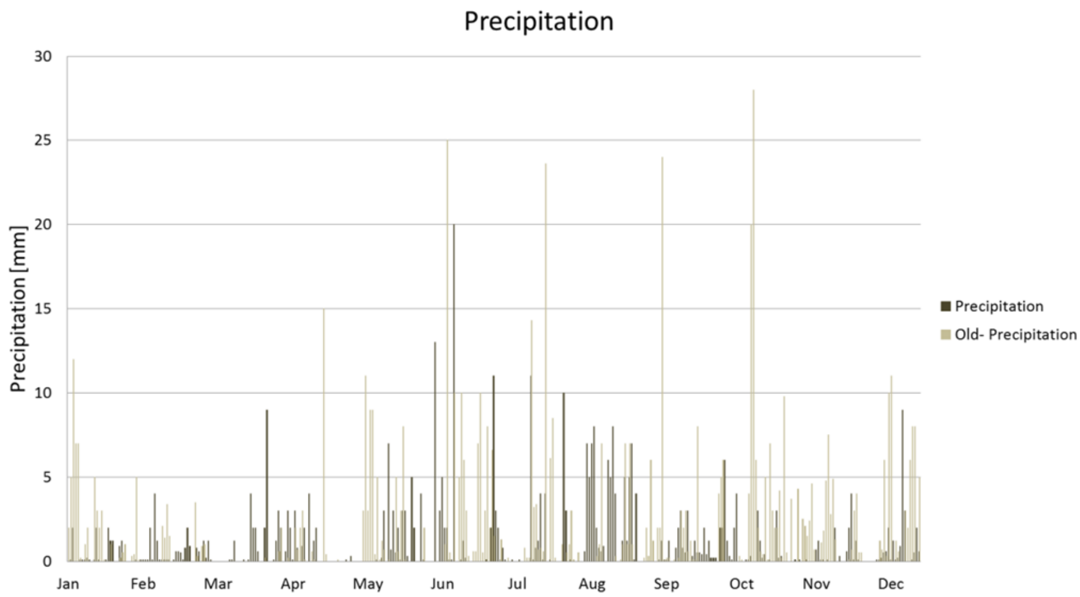
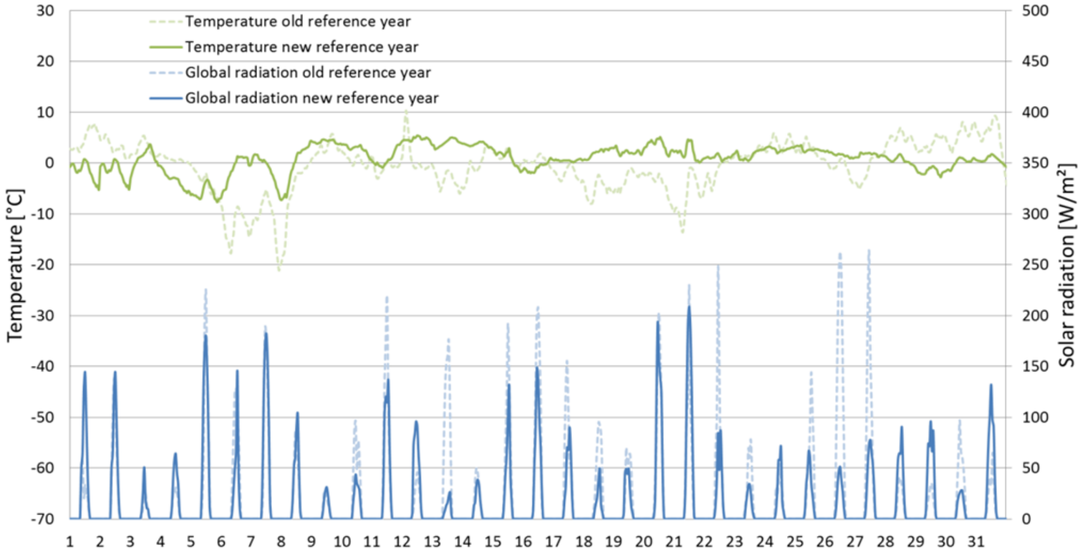


Figure 13 The precipitation in the new weather data set.

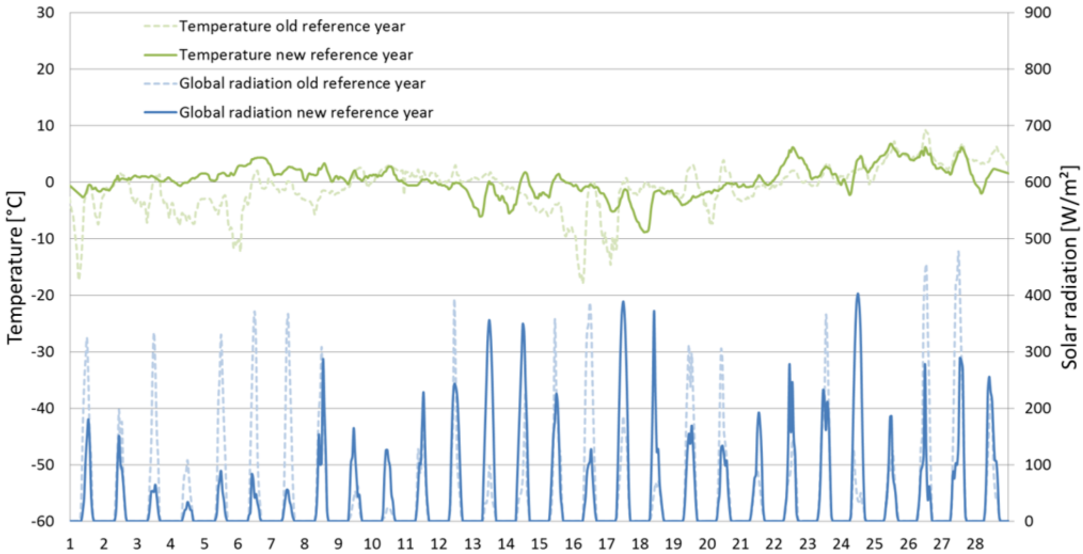
5 Presentation of each month in the new weather data set

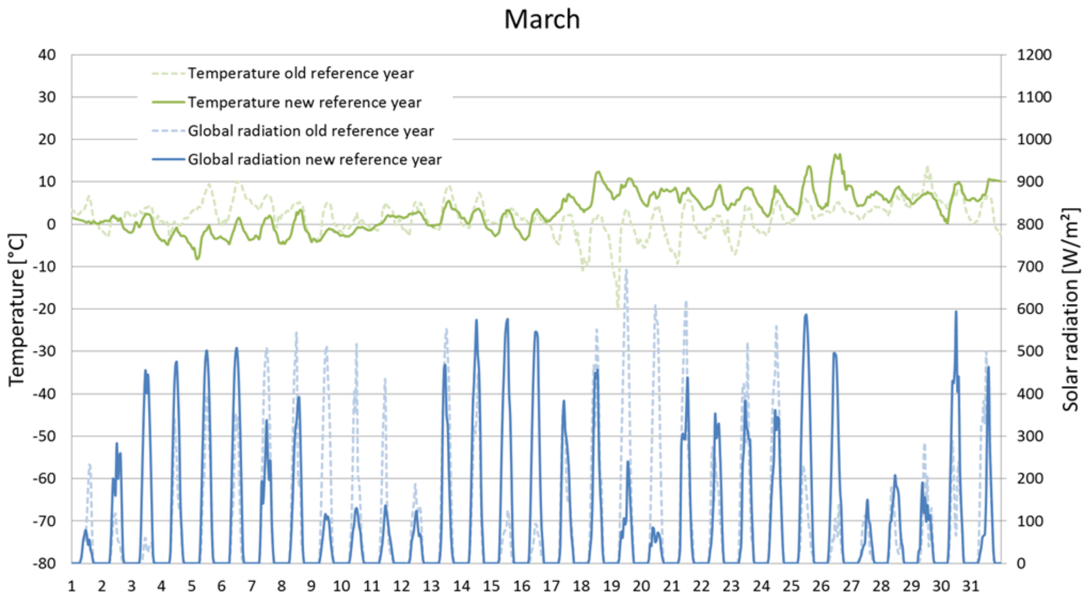
In the following each month is shown with the global radiation and ambient temperature both for the new weather data set and the old weather data set.

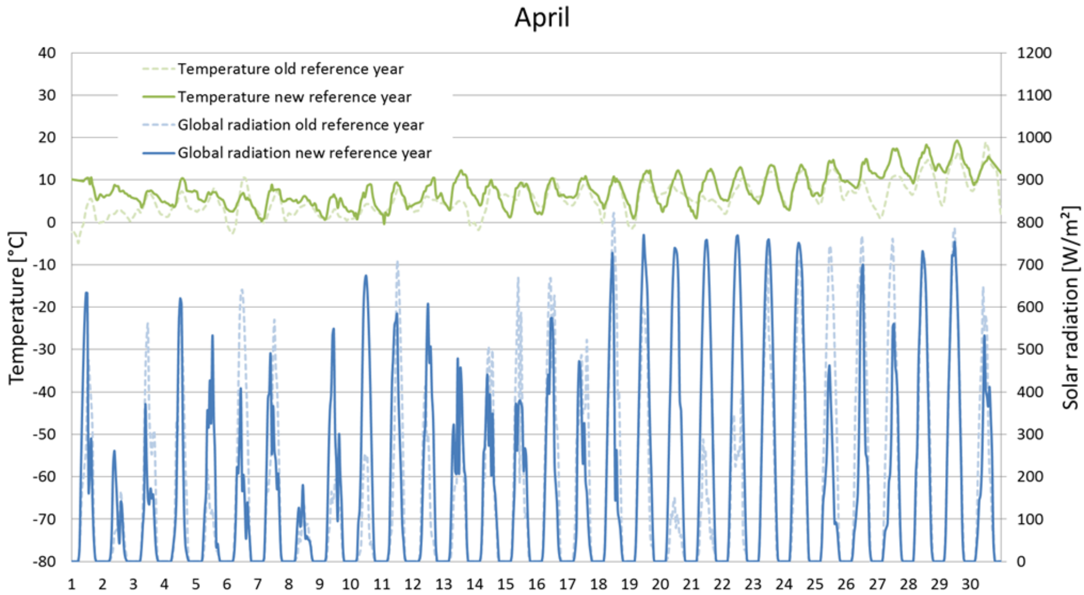
January

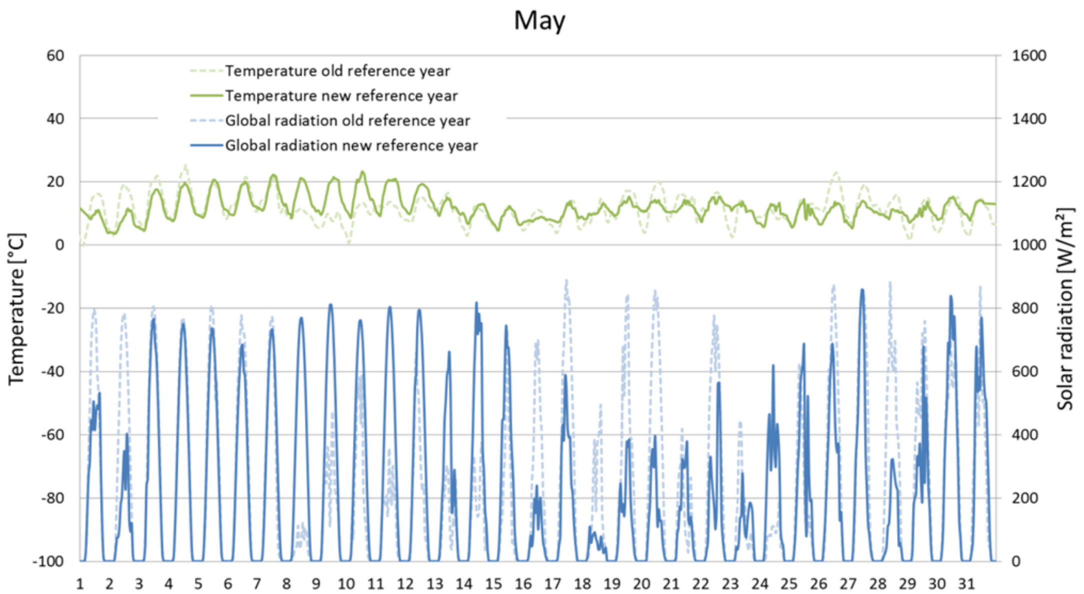


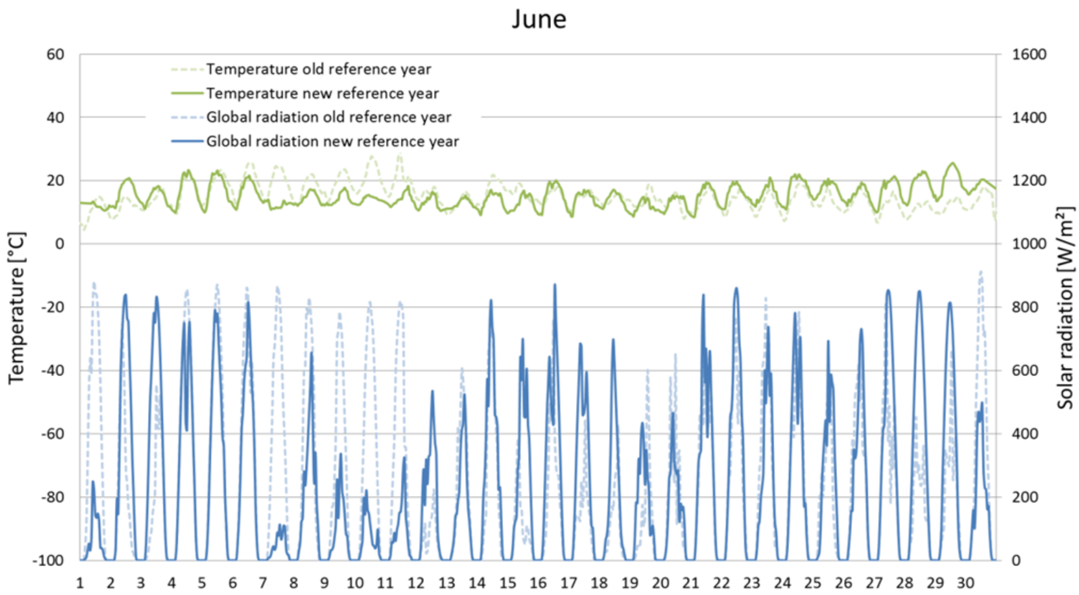
February

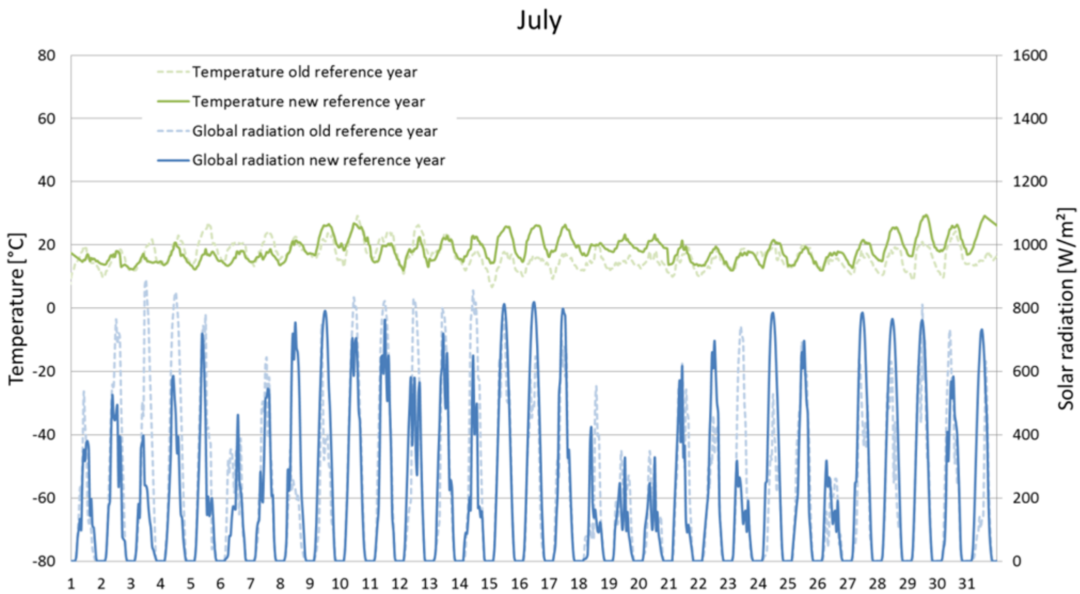


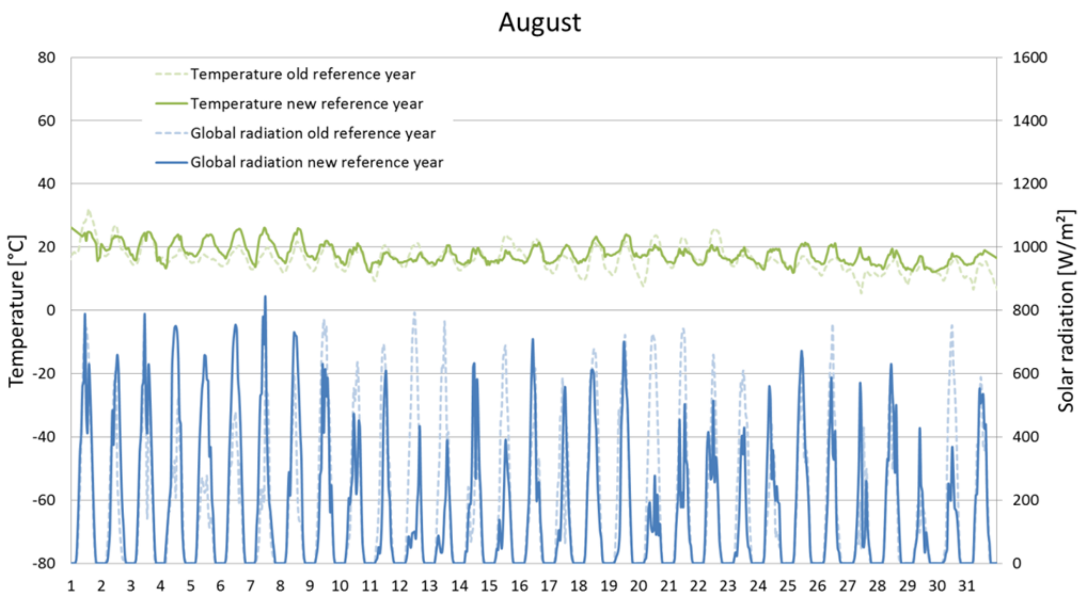

March
Temperature old reference year
Temperature new reference year
Global radiation old reference year
Global radiation new reference year
Temperature [°C]
Solar radiation [W/m²]

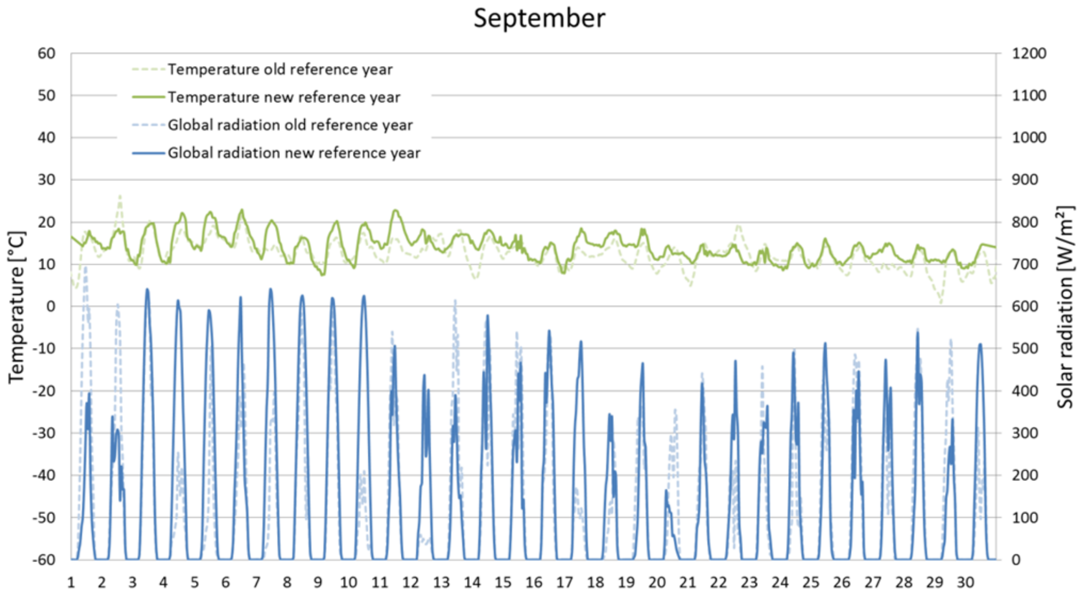

April
Temperature old reference year
Temperature new reference year
Global radiation old reference year
Global radiation new reference year
Temperature [°C]
Solar radiation [W/m²]

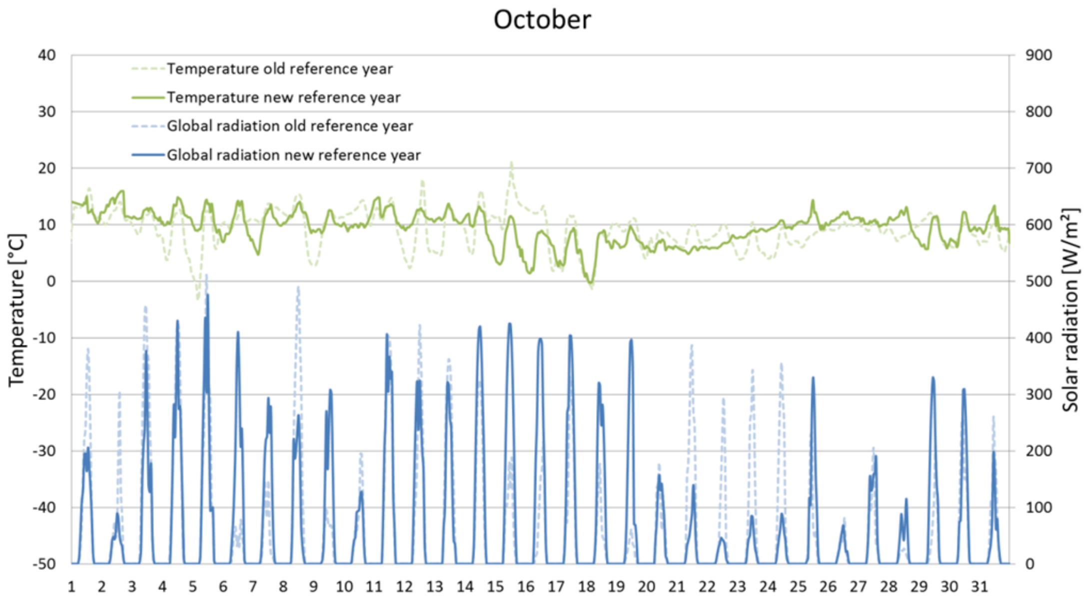

May
Temperature old reference year
Temperature new reference year
Global radiation old reference year
Global radiation new reference year
Temperature [°C]
Solar radiation [W/m²]

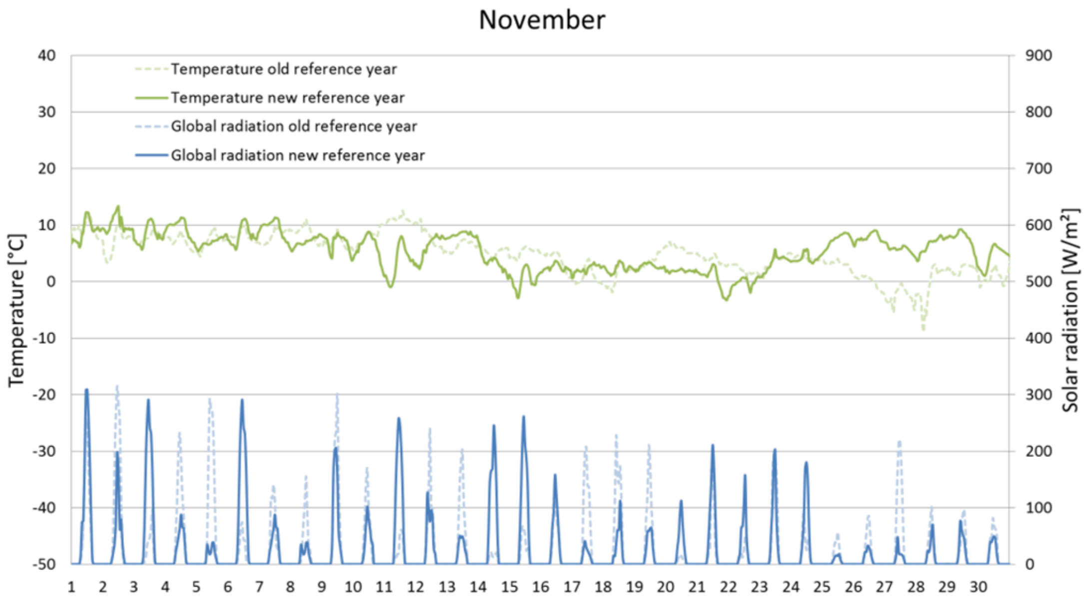

June
Temperature old reference year
Temperature new reference year
Global radiation old reference year
Global radiation new reference year
Temperature [°C]
Solar radiation [W/m²]

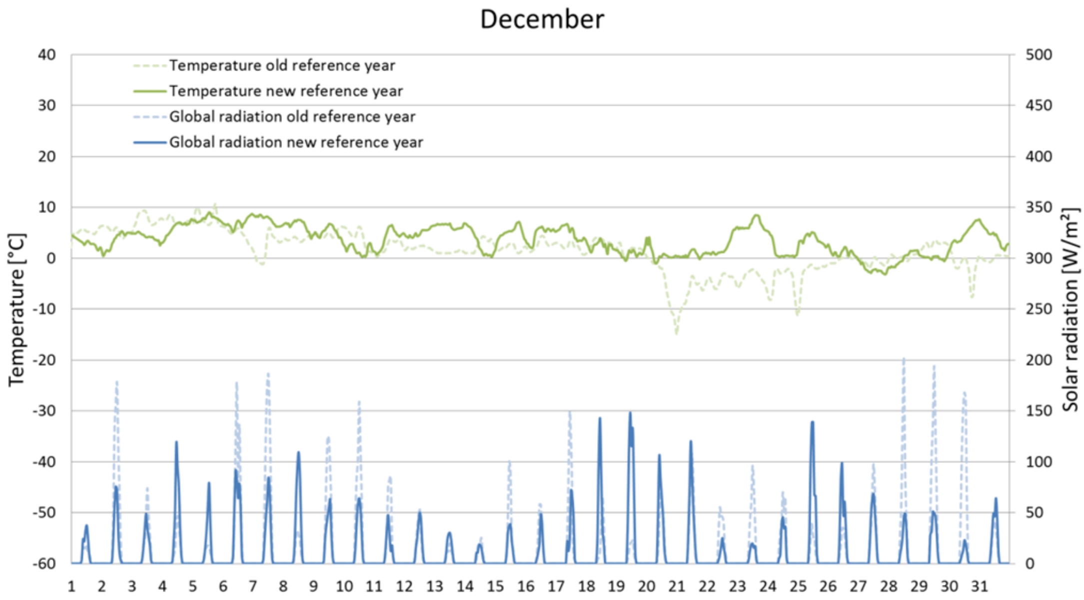

July
Temperature old reference year
Temperature new reference year
Global radiation old reference year
Global radiation new reference year
Temperature [°C]
Solar radiation [W/m²]


August
Temperature old reference year
Temperature new reference year
Global radiation old reference year
Global radiation new reference year
Temperature [°C]
Solar radiation [W/m²]


September
Temperature old reference year
Temperature new reference year
Global radiation old reference year
Global radiation new reference year
Temperature [°C]
Solar radiation [W/m²]


October
Temperature old reference year
Temperature new reference year
Global radiation old reference year
Global radiation new reference year
Temperature [°C]
Solar radiation [W/m²]


November
Temperature old reference year
Temperature new reference year
Global radiation old reference year
Global radiation new reference year
Temperature [°C]
Solar radiation [W/m²]



6 Conclusion and recommendation

A new set of data has been selected as a new reference year for Denmark.

It is recommended that when using this new data set, that the results are compared with the results obtained by the old reference year.

7 Referencer

[1] Lund, H. “The Design Reference Year Users Manual” IEA Report of Task 9: Solar Radition and Pyranometer Studies, 1995.

[2] “An introduction to meteorological measurements and data handling for solar energy applications” IEA Report of Task 4 – Development of Insolation Handbook and Instrument Package, 1980.

[3] ISO 15927-4. “Hygrothermal performance of buildings – Calculation and presentation of climatic data, Part 4 Hourly data for assessing the annual energy use for heating and cooling”, 2005.

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ISBN 9788778773968
ISSN 1601-2917