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Calculated thermal performance of solar collectors based on measured weather data from 2001-2010

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Abstract

This paper presents an investigation of the differences in modeled thermal performance of solar collectors when meteorological reference years are used as input and when mulit-year weather data is used as input.

The investigation has shown that using the Danish reference year based on the period 1975-1990 will result in deviations of up to 39 % compared with thermal performance calculated with multi-year the measured weather data. For the newer local reference years based on the period 2001-2010 the maximum deviation becomes 25 %.

The investigation further showed an increase in utilization with an increase in global radiation. This means that besides increasing the thermal performance with increasing the solar radiation, the utilization of the solar radiation also becomes better.

Peer-review by the scientific conference committee of SHC 2014 under responsibility of PSE AG.

Keywords: Thermal performance, reference year, weather data

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1. Introduction

In 2012 19 new design reference years for solar utilization were developed for different locations in Denmark based on measured weather data from the period 2001 to 2010 from different weather stations [1]. The reference years included measurements of global radiation, outdoor 2-meter temperature, 10-meter wind velocity and 2-meter air humidity and calculations of the diffuse radiation on horizontal irradiance. These reference years were then used

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to calculate the thermal performance of solar collectors at different locations in Denmark. When using the reference years untypical monthly weather data are removed and their effects on the performance are therefore not seen. Calculations of the thermal performance of solar collectors were also carried out with the measured data for the different years. Therefore the thermal performance of the collectors in the different years can be compared.

Nomenclature

a_1	first order heat loss coefficient, (W m^{-2} K^{-1})
a_2	second order heat loss coefficient, (W m^{-2} K^{-2})
G	global radiation, (W/m²)
I_b	beam radiation on horizontal, (W/m²)
I_d	diffuse radiation on horizontal, (W/m²)
$K_{\theta(60°)}$	incidence angle modifier for diffuse radiation, (-)
p	incidence angle coefficient in the equation $K_{diff}=1-\tan(\theta/2)^p$
T_a	ambient temperature, (°C)
T_m	solar collector fluid mean temperature, (°C)
η_0	zero-loss efficiency, (-)
η	efficiency of solar collector (-)
θ	incidence angle, (°)

2. Weather data

The weather data used in this investigation is measured global radiation and ambient temperature from 6 different weather stations in Denmark as shown in Fig. 1. These measured weather data sets were used to create new local reference years for solar energy utilization in order to improve the accuracy of predicted thermal performances and in order to optimize new solar collector fields [2]. The measured weather data is from the period 2001-2010, although 2001 is not used in this investigation since it is an incomplete data set.

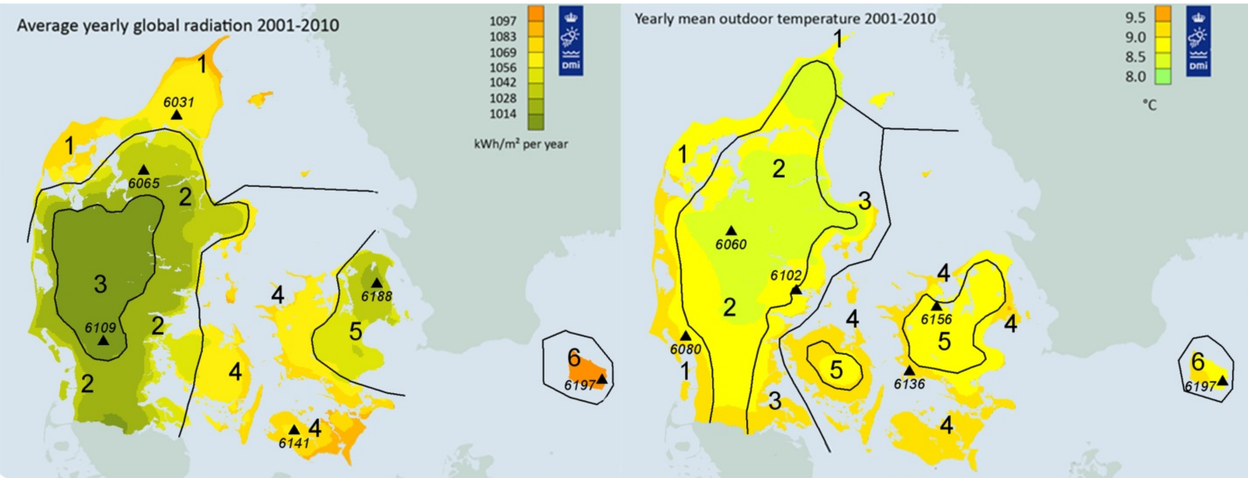

Fig. 1(a) Weather stations chosen for global radiation data. (b) Weather stations chosen for the ambient 2-meter temperature data. The four digit number are the official WMO station numbers.

The measured yearly global radiations are seen in Fig. 2 where also the yearly global radiation for the new local reference years are shown along with the global radiation for the old Danish reference year based on data from 1975-1990 [3]. There is a good agreement between the average measured data from 2002-2010 from each of the stations and the new local reference years. It is also seen that the new local reference years have more solar radiation compared to the old Danish reference year. The figure shows that for some of the stations there is a large variation in the solar radiation from year to year. The station measuring for ‘Eastern Zealand’ (B) has a max. yearly global radiation of 1108 kWh/m² per year and a min. of 918 kWh/m² per year measured in the time period, where the yearly global radiation in the new local reference year for ‘Eastern Zealand’ is 1038 kWh/m² per year. This is a variation of -12 % to +7 % compared to the new local reference years. Stations such as ‘Bornholm’ (A) and ‘Central Jutland’ (D) have much lower variations of -7 % to +2 % for ‘Bornholm and’ -3 % to +6 % for ‘Central Jutland’.

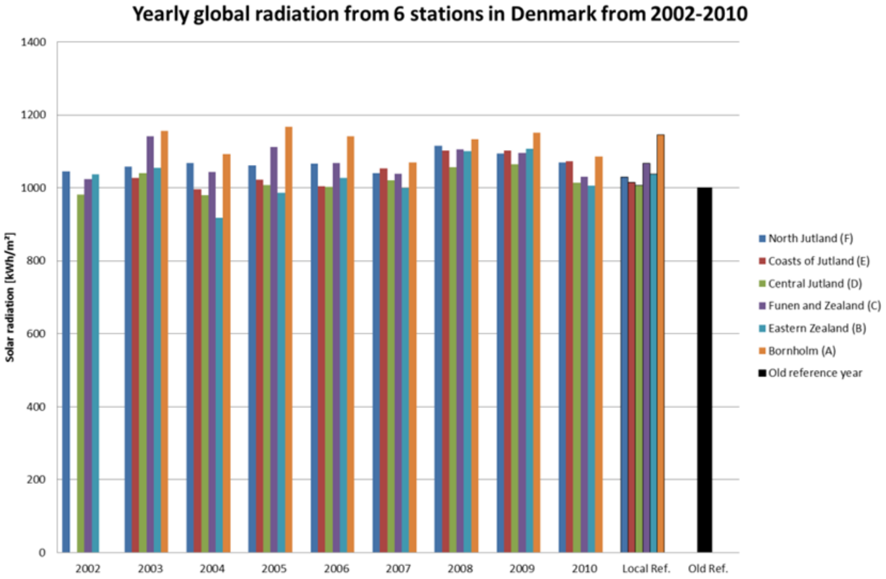

Fig. 2 Yearly global radiation from 6 weather stations in Denmark from the time period 2002-2010.

The beam and diffuse radiation is calculated using the model ‘Skartveit and Olseth’ [4] for determining the diffuse horizontal irradiance and the beam normal irradiance Fig. 3 shows the variation in diffuse horizontal irradiance over the time period and the new local reference years and the old Danish reference year.

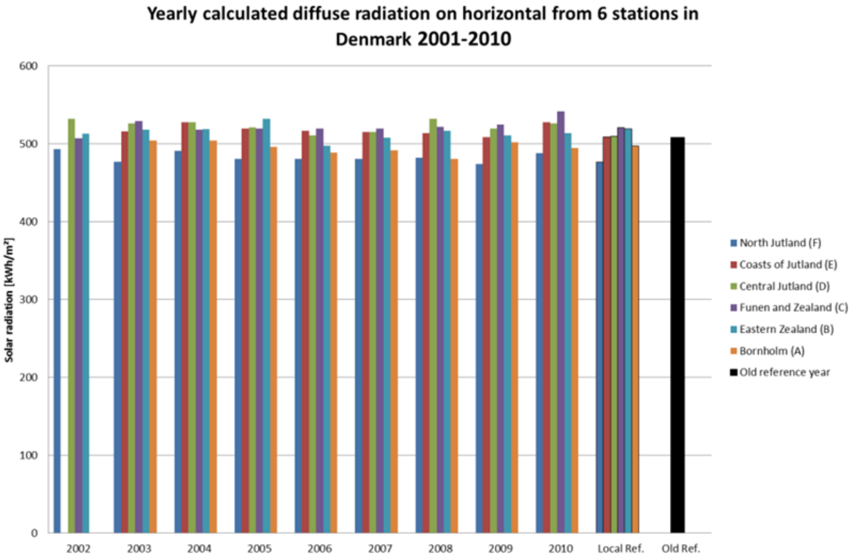

Fig. 3 Yearly calculated diffuse horizontal irradiancefor 6 weather stations in Denmark from the time period 2002-2010.

The figure shows that there is less diffuse irradiance in ‘North Jutland’ and ‘Bornholm’ compared to the old Danish reference year and more in ‘Eastern Zealand’ and ‘Funen and Zealand’. This means that there is more beam normal irradiance in ‘North Jutland’ and ‘Bornholm’ and less in ‘Eastern Zealand’ and ‘Funen and Zealand’, which has a great impact on predicting the thermal performance of solar collectors for these locations.

3. Solar collector and calculations

The calculation of the thermal performance is carried out with a collector that has the efficiency expression of:

$$\eta = K_\theta \cdot 0.846 - 3.5\frac{T_m - T_a}{G} - 0 \cdot \frac{(T_m - T_a)^2}{G}$$

The characteristics of the solar collector parameters can be seen in Table 1.

Table 1. Solar collector characteristics.

Solar collector characteristics			
First order heat loss coefficient	a_1	3.5	W/m²K
Second order heat loss coefficient	a_2	0	W/m²K²
Incidence angle modifier for diffuse radiation	$K_{\theta(60°)}$	0.846	-
Incidence angle coefficient in the equation $K_{diff}=1-\tan(\theta/2)^p$	p	3.4	-
Solar collector fluid mean temperature	T_m	40/60/80	°C
zero-loss efficiency	η_0	0.81	-

The solar collectors are assumed to be tilted 40° and oriented due south. The reflected irradiance is calculated using the reflection coefficient of 0.2 of the ground. No shadows are assumed.

4. Results

The thermal performance is calculated with a mean solar collector fluid of 40°C, 60°C and 80°C. The results of the yearly thermal performances for all the years are shown as a function of the yearly global radiation for different mean solar collector fluid temperatures in Fig. 4 to Fig. 6.

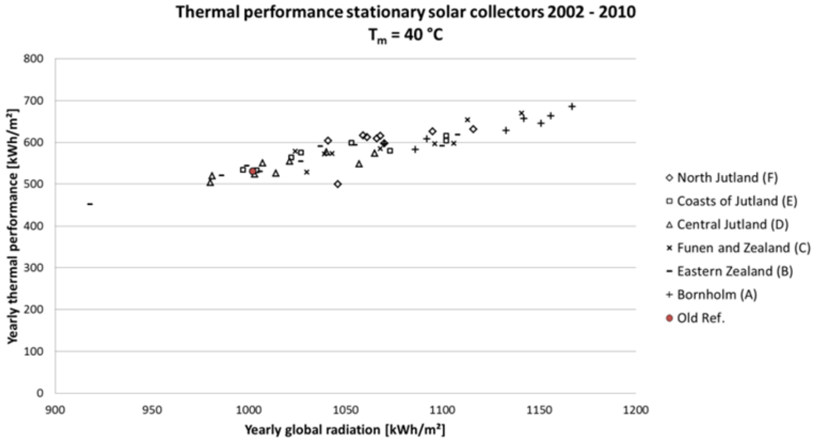

Fig. 4 The thermal performance as a function of the yearly global radiation with a mean solar collector fluid temperature T_m=40°C.

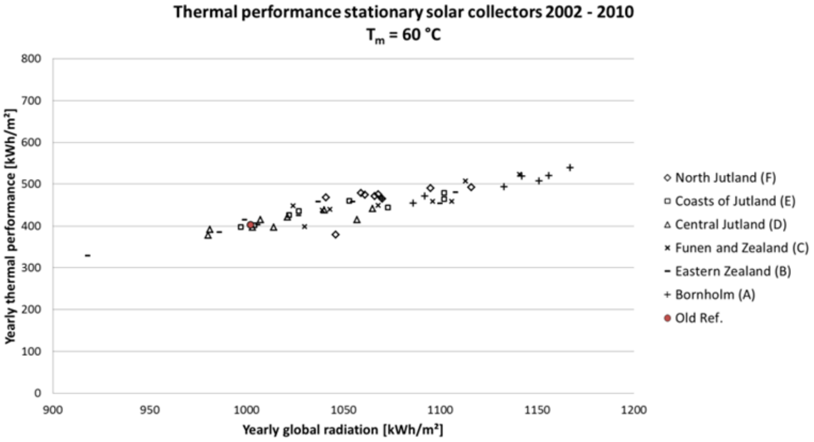

Fig. 5 The thermal performance as a function of the yearly global radiation with a mean solar collector fluid temperature T_m=60°C.

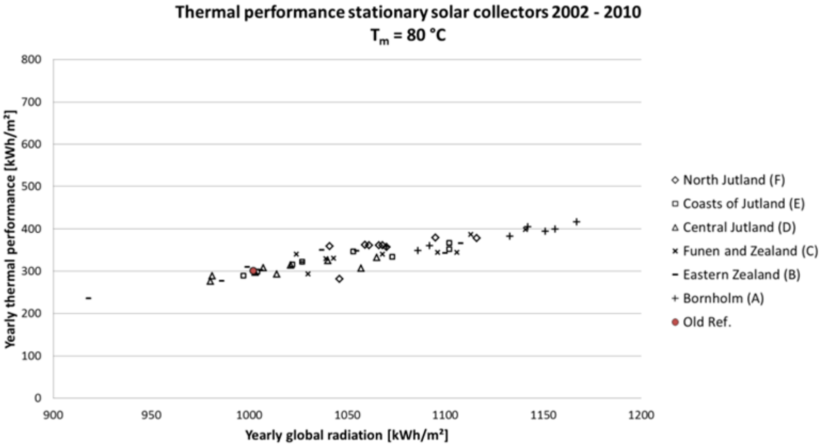

Fig. 6 The thermal performance as a function of the yearly global radiation with a mean solar collector fluid temperature T_m=80°C.

Despite the difference in location, the figures show linear correlations between the yearly thermal performances and the yearly global radiations regardless of the mean solar collector fluid temperature.

The figures also show the effects of the mean solar collector fluid temperature, where an increase in temperature naturally will result in lower thermal performance.

Table 2. Variation of yearly thermal performance in 2002-2010 for each location compared to old Danish reference year.

	Mean solar collector fluid temperature		
Location	T_m = 40°C	T_m = 60°C	T_m = 80°C
North Jutland	-7% to 19%	-8% to 22%	-9% to 26%
Coasts of Jutland	0% to 16%	-1% to 19%	-4% to 22%
Central Jutland	-11% to 9%	-13% to 10%	-16% to 11%
Fuenen and Zealand	0% to 26%	-1% to 30%	-2% to 33%
Eastern Zealand	-15% to 16%	-18% to 19%	-22% to 22%
Bornholm	10% to 29%	13% to 34%	16% to 39%

The variations in yearly thermal performance for each of the different stations compared to the old Danish reference year are seen in Table 2. The largest variations are seen for ‘Bornholm’ and ‘Eastern Zealand’. The large variation in thermal performances in ‘Bornholm’ is because of the big difference in global radiation for this location compared to the old Danish reference year, which was based on data from Eastern Zealand. For ‘Eastern Zealand’ the difference is mostly due to the low measured global radiation in 2004 for this location, see Fig. 2. For all locations the variations becomes larger with an increasing mean solar collector fluid temperature.

The comparisons between the new local reference years and the measured data from 2002 to 2010 are seen in Table 3. Here the variations are smallest for ‘Bornholm’ and ‘Central Jutland’, which is because these locations have the least variation in the measured yearly global radiation in the period from 2002-2012, see Fig. 2.

Table 3. Variation of yearly thermal performance in 2002-2010 for each location compared to the new local reference years.

	Mean solar collector fluid temperature		
Location	$T_m = 40°C$	$T_m = 60°C$	$T_m = 80°C$
North Jutland	-11% to 12%	-12% to 15%	-13% to 17%
Coasts of Jutland	-1% to 14%	-2% to 18%	-4% to 22%
Central Jutland	-6% to 7%	-8% to 8%	-9% to 10%
Fuenen and Zealand	-10% to 15%	-11% to 17%	-13% to 18%
Eastern Zealand	-19% to 11%	-22% to 14%	-25% to 17%
Bornholm	-10% to 6%	-11% to 6%	-12% to 5%

The yearly utilization of solar radiation is shown on Fig. 7 for varying mean solar collector fluid temperatures. The figure shows a linear increase in utilization with an increase in yearly global radiation. There is a slightly greater increase in the utilization of solar irradiance for the mean solar collector fluid temperature of 80°C compared to the lower temperatures.

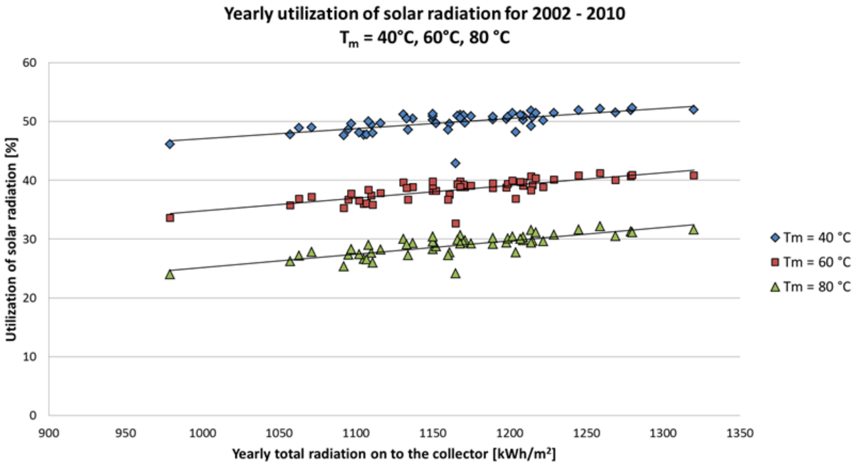

Fig. 7 Yearly utilization of solar radiation for 2002-2010 for a mean solar collector fluid temperature T_m=40°C, 60°C, 80°C.

4. Conclusions

The thermal performances of solar collectors using the new local reference years are higher than the thermal performances of solar collectors using the old Danish reference year. This is due to the increased solar radiation.

The investigation has also shown that using both the old Danish reference year and the new local reference years will leave out the effects of untypical meteorological months on the thermal performance of solar collectors. The comparison of the calculated thermal performance with the old Danish reference year and the thermal performance based on the measured weather data revealed a deviation of up to 39 % for a mean solar collector fluid temperature of 80 °C. The deviation is mostly due to the large difference in solar irradiance at different locations in Denmark, but also due to overall solar brightening during the recent decades.

Using the new local reference years the deviation decreases to 25 %, and has revealed the true effect of the untypical meteorological months on the thermal performance of the solar collectors are revealed. The variation in yearly thermal performance from year to year is strongly depending on the location, even in Denmark, which is a small country.

The investigation has also shown an increase in utilization with an increase in global radiation. This means that besides increasing the thermal performance with increasing of solar radiation, the utilization of the solar radiation also becomes better.

Acknowledgements

The weather data used in this investigation has been provided by Danish Meteorological Institute.

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