Thermal advantage of tracking solar collectors for different Danish weather conditions

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Abstract

Theoretical investigations have been carried out with the aim to elucidate the thermal advantage of tracking solar collectors for different weather conditions in Kgs. Lyngby, Denmark (55.8°N), and for the weather conditions in Sisimiut, Greenland (66.9°N), just north of the arctic circle. The investigations are based on calculations with a newly developed program. Measured weather data from a solar radiation measurement station at Technical University of Denmark in Kgs. Lyngby Denmark in the period 1990 to 2002 and the Danish Design Reference Year, DRY data file are used in the investigations. The weather data used for Sisimiut are based on a Test Reference Year, TRY weather data file.

The thermal advantages of different tracking strategies is investigated for two flat plate solar collectors with different efficiencies, operated at different temperature levels.

The investigations show that the advantage of full tracking is in the range 40% – 90% depending on the solar collector and the operation conditions. The advantage is higher for a low efficient solar collector than for a high efficient solar collector and higher for high solar collector temperatures than for low solar collector temperatures. Further, design reference years are not suitable to elucidate the advantage by tracking.

1. Introduction

Recently solar trackers have been applied in PV systems. Maybe it is also attractive to mount solar collectors on solar trackers in order to increase the thermal performance of solar collectors. Theoretical investigations are carried out with the aim to elucidate the thermal advantages of using solar trackers for solar collectors.

The investigations are based on calculations with a newly developed program [5] that makes use of hourly weather data. The weather data used for the investigations are from the Danish Design Reference Year, DRY data file, derived from measured weather data from the period 1975 to 1989 [1], from the Greenlandic Test Reference Year for Sisimiut, TRY data file, derived from measured weather data from the period 1992 to 2005 [2] and measured weather data from the solar radiation measurement station at the Technical University of Denmark, DTU in Kgs. Lyngby from the period 1990-2002 [3].

In [3], it is shown how the thermal performances of different stationary mounted solar collectors are generally influenced by weather variations and that there are large variations in the yearly solar radiation from year to year and that the monthly solar radiation can vary much in years with the same yearly solar radiation.

In [4] the advantage of azimuth tracking (horizontal tracking) and full tracking (horizontal and vertical tracking) for different latitudes in the range from 26°N to 75°N is found to increase for increasing latitudes. Also it is found that trackers do not significantly raise solar energy collected during winter at mid to high latitudes.

The Greenlandic climate is interesting in connection with tracking, especially due to reflections from snow. Measurements carried out show that the albedo coefficient varies throughout the year and is strongly influenced by snow. During summer where there is no snow, the albedo coefficient is 0.2 while it reaches 0.7 during winter when the ground is covered with snow [6,7].

Although the results in this study are based on measured Danish weather data, the results are not considered specific for Danish conditions.

2. Tracking strategies

Three different tracking strategies are applied. The strategies are:

- Full tracking, comprising vertical and horizontal tracking at the same time. In this case, the incidence angle is always 0°.
- Azimuth tracking, which is horizontal tracking with a constant tilt angle of the solar collector. In this case, the incidence angle is always $90°-\alpha_s-\beta$.
- Vertical tracking, where the tilt of the solar collector is always $90°-\alpha_s$. In case the sun is behind the solar collector, the solar collector is turned 180° in order to always have the sun on the front side of the solar collector.

3. Weather data

Figure 1 shows the measured yearly global solar radiation, the calculated yearly solar radiation on a 45°-tilted south facing solar collector and on a full tracking solar collector and the ratio between solar radiation on a full tracking collector and on a 45°-tilted south facing solar collector for the years 1990-2002, the Danish DRY and the Greenlandic TRY for Sisimiut. It can be seen that the solar radiation varies from one year to another and that the average global solar radiation from 1990-2002 is similar to the global solar radiation in DRY data file and that the global solar radiation in Sisimiut is lower than the global solar radiation in Denmark due to the higher latitude of Sisimiut. The average solar radiation from 1990-2002 on a south facing 45°-tilted collector and on a full tracking collector is lower than the solar radiation in DRY data file on the same collector while the solar radiation ratio between full tracking and south 45° is higher with the average solar radiation from 1990-2002 than with the solar radiation in DRY data file.

Figure 2 shows the yearly solar radiation on a differently tilted azimuth tracking solar collector and on a differently oriented vertically tracking solar collector for the years 1990-2002, the Danish DRY and the Greenlandic TRY for Sisimiut.

It can be seen that the optimal tilt of a azimuth tracking solar collector is between 45° and 60° for Denmark and surprisingly enough also for Sisimuit in Greenland. One would expect that the optimal tilt of an azimuth tracking solar collector would be higher in Greenland than in Denmark because of the higher latitude which results in a lower solar altitude. Most likely it is due to cloudy weather in Sisimiut where it is more important to receive diffuse radiation from the sky dome than beam radiation from the sun. Regarding vertically tracking, it can be seen that the highest solar radiation in Denmark is reached for the solar collector oriented east or west while the solar collector situated in Sisimiut should be oriented south or north in order to gain most from the vertically tracking strategy.

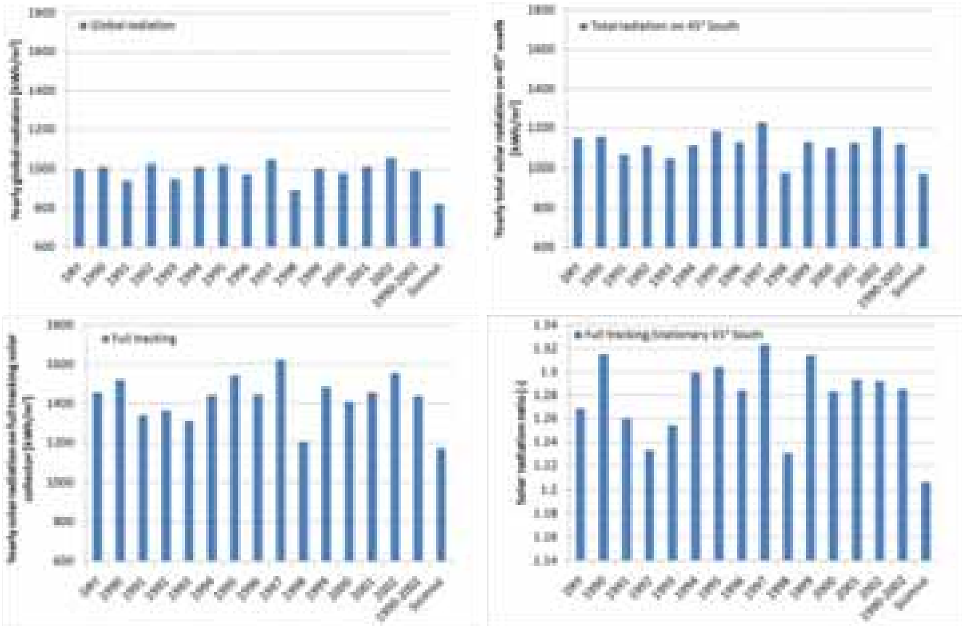

Fig. 1. Yearly solar radiation on stationary and tracking solar collector and solar radiation ratio for different weather conditions.

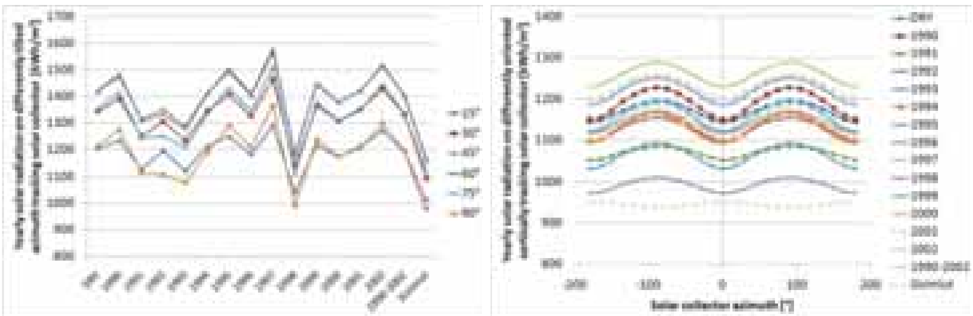

Fig. 2. Left: Yearly solar radiation on differently tilted horizontally tracking solar collector for different weather conditions. Right: Yearly solar radiation on differently oriented vertically tracking solar collector for different weather conditions.

4. Investigations

Two solar collectors are used for the investigations. Table 1 show the data of the solar collectors.

The solar collector coefficients for the flat plate collectors given in Table 1 are used to describe the solar collector efficiency η for all incidence angles with the equation:

$$\eta = k_{\Theta}\eta_0 - a_1 \frac{(T_m - T_a)}{G_t} - a_2 \frac{(T_m - T_a)^2}{G_t} \qquad (1)$$

Where k_{Θ} is the incidence angle modifier given by:

$$k_{\Theta} = 1 - tg^p \left(\Theta / 2 \right) \qquad (2)$$

The power produced by each m^2 of the solar collector is calculated with a correction term for diffuse radiation [10]:

$$P = \eta_0 \cdot k_{\Theta}(\Theta) \cdot G_b + \eta_0 \cdot k_{\Theta}(60^{\circ}) \cdot G_d - a_1 \cdot (T_m - T_a) - a_2 \cdot (T_m - T_a)^2 \qquad (3)$$

The isotropic solar radiation processing model is used to calculate the diffuse solar radiation on the solar collector [11]. The diffuse solar radiation comprise the diffuse solar radiation from the part of the sky that is visible to the solar collector and the diffuse reflected solar radiation from the surroundings that are visible to the solar collector. For the calculations with the Danish weather data, an albedo of 0.2 is used. For the calculations with the Greenlandic weather data from Sisimiut, variable albedo coefficients are used. The ground reflection coefficients are high during the winter when the ground is covered with snow and low during the summer without snow. The used ground reflection coefficients are shown in Table 2 [7].

Table 1. Data of the solar collectors [8,9].

Solar collector	HT-SA 28/10	BA 22
Manufacturer	Arcon Solvarme A/S, Denmark	BATEC A/S, Denmark
Start efficiency	0.817	0.767
Heat loss coefficient, a_1 [W/m^{2}K]	2.205	3.867
Heat loss coefficient, a_2 [W/m^{2}K^2]	0.0135	0.01
Incidence angle modifier coefficient, p	3.0	3.4

Table 2. Albedo coefficient used to calculate the diffuse radiation on the solar collector. x is the difference between the solar azimuth (γ_s) and the surface azimuth (γ).

Month	Albedo = Equations	Month	Albedo = Equations
Jan	$\rho(x) = -9 \cdot 10^{-6} \cdot x^2 - 5 \cdot 10^{-5} \cdot x + 0.5204$	Jul	$\rho(x) = 1 \cdot 10^{-7} \cdot x^2 - 1 \cdot 10^{-5} \cdot x + 0.133$
Feb	$\rho(x) = -1 \cdot 10^{-6} \cdot x^2 - 5 \cdot 10^{-5} \cdot x + 0.7031$	Aug	$\rho(x) = 1 \cdot 10^{-7} \cdot x^2 + 1 \cdot 10^{-5} \cdot x + 0.1324$
Mar	$\rho(x) = -7 \cdot 10^{-6} \cdot x^2 - 0.0001 \cdot x + 0.6031$	Sep	$\rho(x) = -1 \cdot 10^{-7} \cdot x^2 - 1 \cdot 10^{-5} \cdot x + 0.1776$
Apr	$\rho(x) = -5 \cdot 10^{-6} \cdot x^2 - 0.0002 \cdot x + 0.6083$	Oct	$\rho(x) = -2 \cdot 10^{-6} \cdot x^2 - 3 \cdot 10^{-5} \cdot x + 0.2276$
May	$\rho(x) = -1 \cdot 10^{-6} \cdot x^2 - 5 \cdot 10^{-5} \cdot x + 0.2392$	Nov	$\rho(x) = -6 \cdot 10^{-6} \cdot x^2 - 4 \cdot 10^{-5} \cdot x + 0.4653$
Jun	$\rho(x) = 6 \cdot 10^{-8} \cdot x^2 - 1 \cdot 10^{-5} \cdot x + 0.1294$	Dec	$\rho(x) = -3 \cdot 10^{-6} \cdot x^2 - 3 \cdot 10^{-5} \cdot x + 0.3051$

The calculations are carried out with constant operation temperatures of 20°C, 40°C, 60°C, 80°C and 100°C throughout the year and the solar collector azimuth is varied between south and north.

4.1. Simulation results

The thermal performance Q and the performance ratio PR are defined as:

Q = Energy produced by the solar collector assuming constant operation temperature (4)

$$PR = \frac{Q}{Q_{REF}}$$, Q_{REF} is the thermal performance of a south facing 45°-tilted collector (5)

Figure 3 – Figure 6 show the performance ratio for the two investigated solar collectors for the three different tracking strategies. For vertical tracking, the results are shown both for vertical tracking on a south-north axis and on an east-west axis. The figures show the average performance ratio in the period 1990-2002, the performance ratio with DRY data file and with TRY data file for Sisimiut. The figures also show the maximum and the minimum performance ratio in the period 1990-2002.

If full tracking is applied, Figure 3 shows that the average performance ratio in the period 1990-2002 is in the range 1.4 – 1.9 depending on the solar collector and the operation conditions. With DRY the range is 1.4 – 1.8 and with TRY Sisimiut the range is 1.4 – 1.7. The higher the temperature level, the higher the thermal advantage of the tracking will be. The thermal advantage of tracking is higher for a low efficient collector than for a high efficient collector.

If azimuth tracking is applied, Figure 4 shows that the average performance ratio in the period 1990-2002 is in the range 1.4 – 1.7 depending on the solar collector and the operation conditions. With DRY the range is 1.3 – 1.7 and with TRY Sisimiut the range is 1.3 – 1.6.

If vertical tracking on a south-north axis is applied, Figure 5 shows that the advantage of tracking is in the range 0% - 5% for the period 1990-2002 and DRY, while there is no advantage with weather data from TRY Sisimiut.

If vertical tracking on an east-west axis is applied, Figure 6 shows that the advantage of tracking is in the range 6% - 15% for the period 1990-2002 and in the range 4% - 7% with DRY data file. There is absolutely no advantage with TRY data file for Sisimiut.

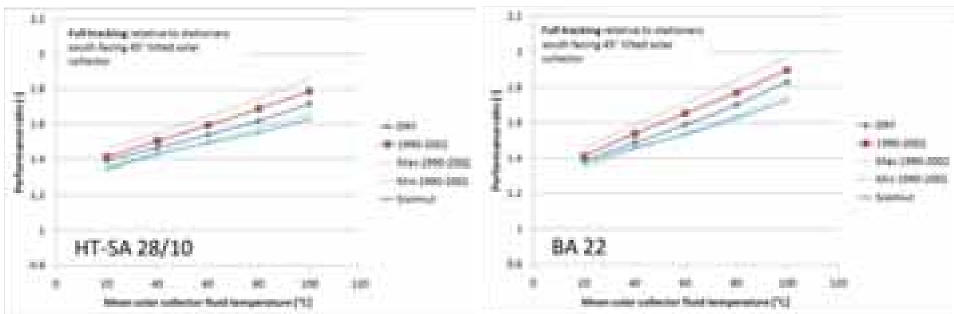

Fig. 3. Performance ratio for full tracking solar collectors as function of the mean solar collector fluid temperature.

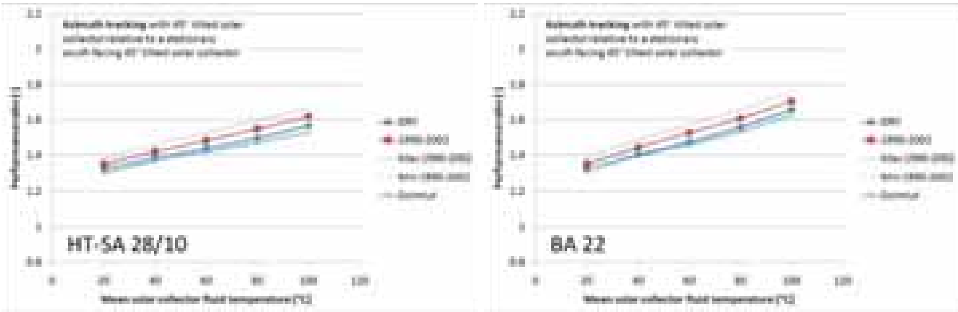

Fig. 4. Performance ratio for azimuth tracking 45°-tilted solar collectors as function of the mean solar collector fluid temperature.

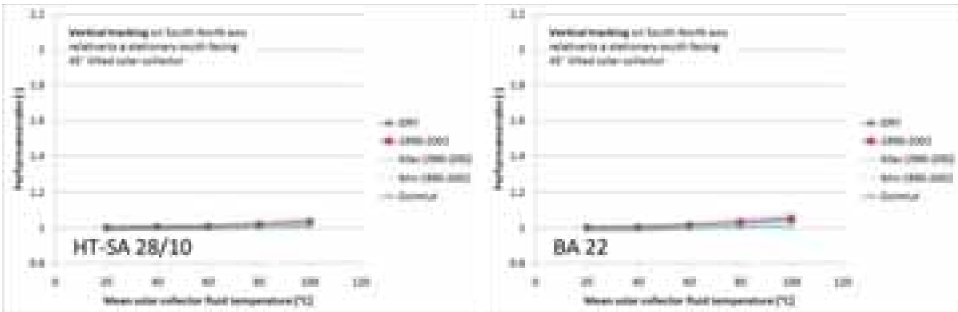

Fig. 5. Performance ratio for vertical tracking on south-north axis solar collectors as function of the mean solar collector fluid temperature.

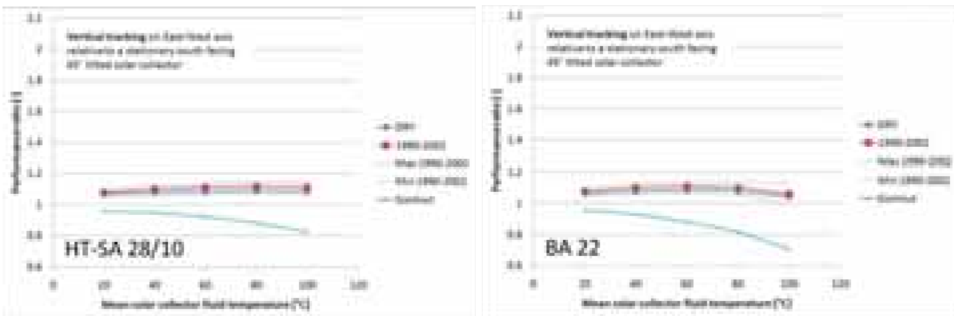

Fig. 6. Performance ratio for vertical tracking on east-west axis solar collectors as function of the mean solar collector fluid temperature.

5. Discussion and conclusion

The thermal performance advantage of applying different tracking strategies to solar collectors is theoretically investigated. The investigations show that the advantage of tracking is mainly due to the extra thermal performance during summer time. The advantage of a tracking collector compared to a stationary collector is much lower with DRY data file than with the individual measured years.

Figure 7 shows the monthly total solar radiation on a south facing 45°-tilted solar collector with DRY data file and with the average weather data from the years 1990-2002. The figure also shows the weather data from the individual years and the difference between the monthly total solar radiation on a full tracking solar collector and on a south facing 45°-tilted solar collector with weather data from the individual years. It can be observed that the difference between DRY data file and the individual years is the yearly solar radiation and the monthly distribution of solar radiation. The monthly total solar radiation difference on a full tracking and on a stationary solar collector for the individual years is lower or higher than with DRY data file. With DRY data file, there are no high monthly peaks, while the individual years almost all contain monthly peaks resulting from very sunny periods, mainly during summer. DRY data file is designed with a smooth solar radiation profile without such very sunny periods. Hence it can be concluded that the smoothened designed reference years are not suitable to elucidate the thermal advantage of tracking.

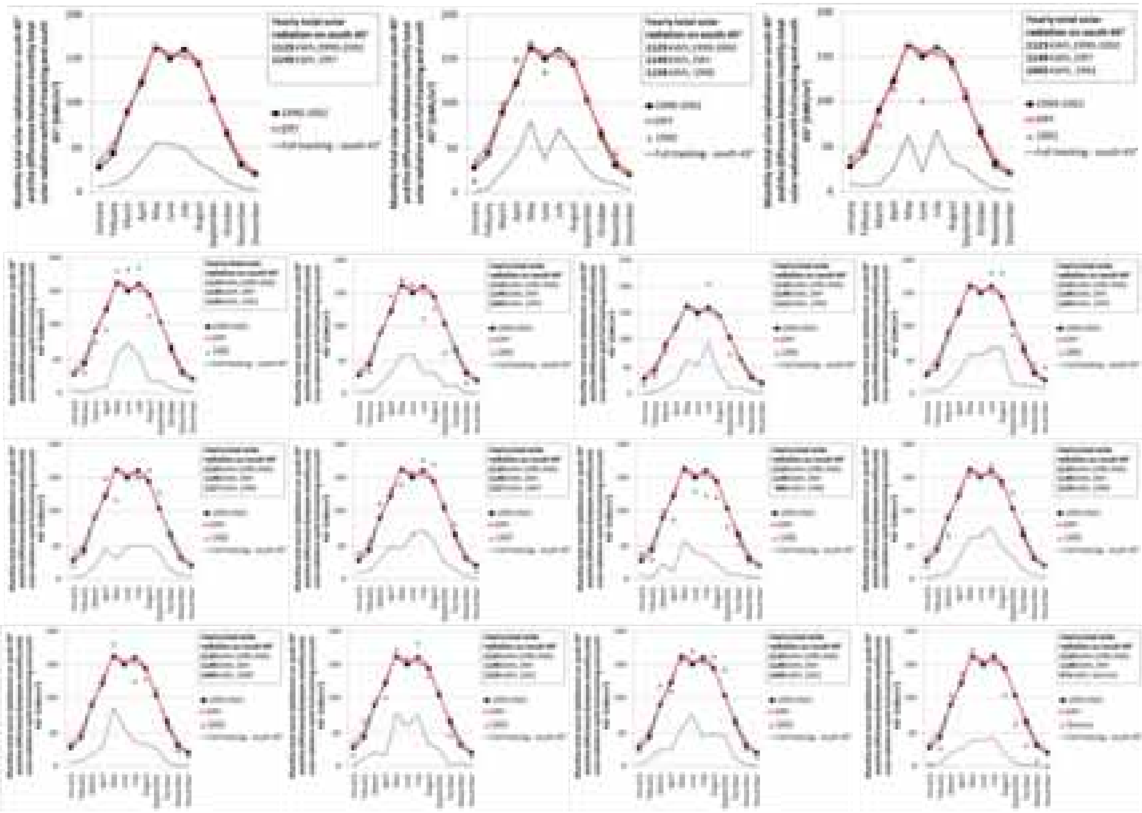

Fig. 7. Monthly total solar radiation on a south facing 45°-tilted collector with weather data from 1990-2002, DRY data file, and from the individual years. The difference between the monthly total solar radiation with full tracking and a south facing 45°-tilted collector are shown with weather data from the individual years. In the top left figure the difference is based on DRY data file.

Nomenclature

γ_s	Azimuth angle of the sun, (°)	k_Θ	Incidence angle modifier, (-)
γ	Azimuth angle of the solar collector, (°)	Θ	Incidence angle, (°)

η	Solar collector efficiency, (-)	p	Incidence angle modifier coefficient, (-)
η_0	Optical efficiency of incident radiation, (-)	x	Difference in solar azimuth angle and solar collector azimuth angle, (°)
a_1	Solar collector heat loss coefficient, (W/m^{2}K)	T_m	Mean temperature in the solar collector, (°C)
a_2	Solar collector heat loss coefficient, (W/m^{2}K^2)	T_a	Ambient temperature, (°C)
α_s	Altitude angle of the sun (°)	P	Usefull solar collector power output, (W/m^2)
β	Tilt angle of solar collector (°)	Q	Useful solar collector energy output, (kWh/m^2)
G_b,	Beam irradiance, (W/m^2)	G_d	Diffuse irradiance, (W/m^2)
G_t	Total irradiance, (W/m^2)	Q_{REF}	Useful solar collector energy output of reference solar collector, (kWh/m^2)
PR	Performance ratio, (-)	$\rho(x)$	Albedo, (-)

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