STUDY ON A TRACKING SOLAR COLLECTOR

Ziqian Chen, Simon Furbo, Jianhua Fan, Elsa Andersen and Bengt Perers

Department of Civil Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark

1. Introduction

Tracking solar collectors have been investigated by many researchers. Based on the weather data file of the Danish Design Reference Year, the weather data measured at Technical University of Denmark in the period 1990 to 2002, the weather data for Sisimiut and TRNSYS weather data file, the efficiencies and incidence angle modifiers (IAM) of solar collectors from Arcon Solvarme A/S, Denmark and BATEC A/S, Denmark, the performance for azimuth tracking solar collectors and the ratio of the performance between a azimuth tracking solar collector and a stationary solar collector were theoretically studied by Andersen et al. (2010). One-axis sun tracking and two-axis sun tracking systems have been discussed by Kalogirou (1996) and Bakos (2006). Investigations on the principle of a sun tracking system for maximizing the solar heating system performance have been carried out by Hossein et al. (2009).

In this paper, the efficiency and IAM of two solar collectors are determined. One of the collectors is installed in a stationary test facility, the other collector is installed in an azimuth tracking test facility. The thermal performances of the stationary and the tracking solar collectors are measured for a long period. The measured and calculated daily thermal performances are compared both for the stationary and the tracking solar collectors. The simulation models for calculating the thermal performances of the stationary and the tracking solar collectors are validated. Further, the yearly thermal performances of the stationary and the tracking solar collectors are determined with the validated models. In this way, the benefits by the tracking collector on the yearly thermal performance of the solar collector are determined. The results are compared with the results from Andersen et al. (2010).

2. Experimental setup

The thermal performance and efficiencies of two 13.88 m^2 solar collectors from SUNMARK A/S are investigated at the Technical University of Denmark, latitude: 55.29°N and longitude: 12.53°E. One collector faces south and has a collector tilt of 45°. Another collector is installed on a tracker from N.N. Energi ApS with a collector tilt of 45°. The solar orientation of the tracking solar collector is changed approximately 6 times per hour. The difference between the solar azimuth and collector azimuth is always around 15°. A photo of the setup is shown in Fig.1. The solar collector fluid used in the setup is a 40% of propylene glycol/water mixture.

Fig.1: Photo of the collectors in the experimental setup.

3. Measurement results

3.1. Measured efficiencies for solar collectors

The efficiencies of both the stationary collector and the tracking collector were measured at the same flow rate. The flow rates for the efficiency measurements are 20 l/min and 10 l/min. The incidence angle modifiers for the stationary collector at flow rates of 20 l/min and 10 l/min were measured as well. The measuring points and collector efficiency for the stationary solar collector at small incidence angles determined by regression analyses based on the measuring points at a flow rate of 20 l/min are shown in Fig.2. Fig.3 shows the measuring points and incidence angle modifier for the stationary solar collector at a flow rate of 20 l/min. Eq.1 and Eq.2 are the efficiency and incidence angle modifier expressions for the stationary collector at a flow rate of 20 l/min.

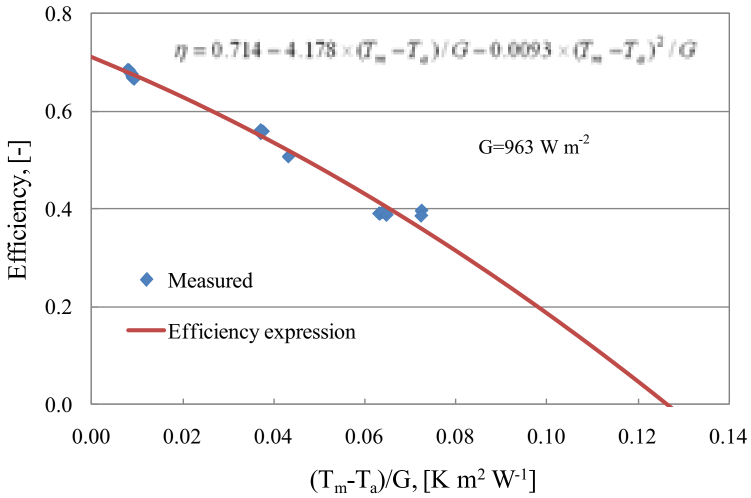

Fig.2: Measuring points and collector efficiency for the stationary collector at small incidence angles at a flow rate of 20 l/min and at a solar irradiance of 963 W m⁻².

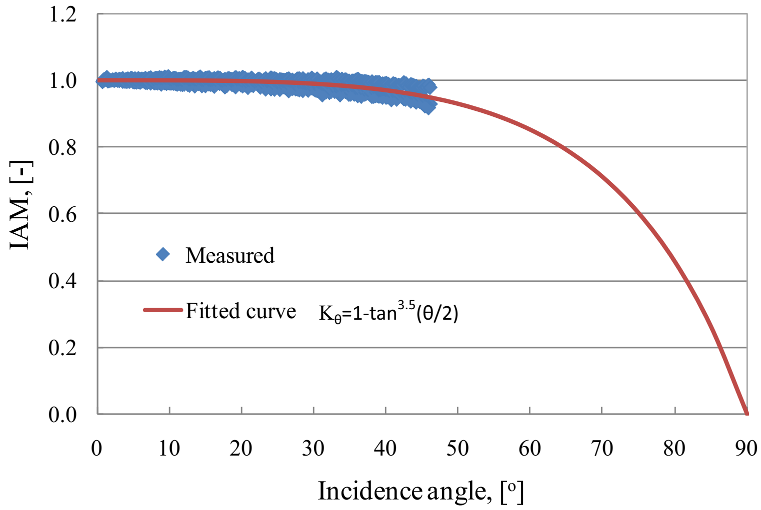

Fig.3: Measuring points and approximate tangent expression of the incidence angle modifier for the stationary collector at a flow rate of 20 l/min.

$$\eta = 0.714 - 4.178 \times \frac{(T_m\text{-}T_a)}{G} - 0.0093 \times \frac{(T_m\text{-}T_a)^2}{G} \quad \text{(Eq.1)}$$

$$K_\theta = 1 - \tan^{3.5}(\theta/2) \quad \text{(Eq.2)}$$

where η is the efficiency of a solar collector.

T_m is the average temperature of solar collector fluid (°C).

T_a is ambient temperature (°C).

ϑ is the incidence angle of beam solar irradiance on a solar collector (°).

K_ϑ is an incidence angle modifier (-).

Further, the regression efficiency and incidence angle modifier for the stationary collector determined by the measuring points at a flow rate of 10 l/min are expressed by Eq.3 and Eq.4:

$$\eta = 0.710 - 4.818 \times \frac{(T_m\text{-}T_a)}{G} \qquad \text{(Eq.3)}$$

$$K_\theta = 1 - \tan^{3.6}(\theta/2) \qquad \text{(Eq.4)}$$

Eq.5 and Eq.6 are the efficiency expressions determined by the measurements for the tracking collector at the flow rates of 20 l/min and 10 l/min:

$$\eta = 0.754 - 4.794 \times \frac{(T_m\text{-}T_a)}{G} \qquad \text{(Eq.5)}$$

$$\eta = 0.741 - 4.788 \times \frac{(T_m\text{-}T_a)}{G} \qquad \text{(Eq.6)}$$

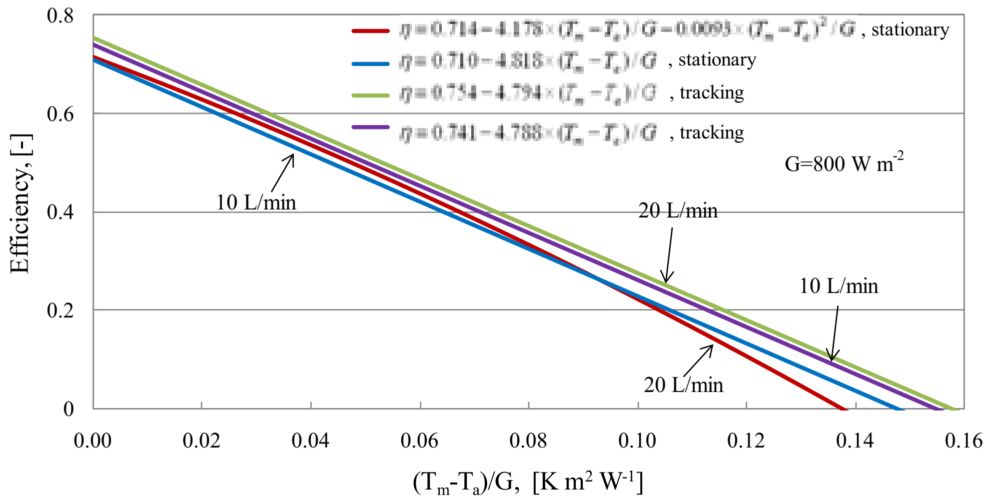

Fig.4: Efficiencies of the stationary and the tracking solar collectors at different flow rates for a solar irradiance of 800 Wm^{-2}.

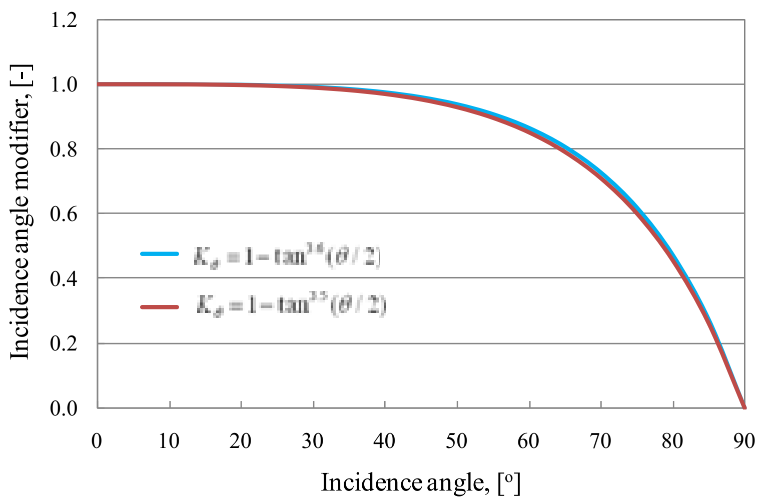

Fig.5: Incidence angle modifier of the stationary solar collector at different flow rates.

Fig.4 and Fig.5 show the comparison between the collector efficiencies expressed by Eq.1, Eq.3, Eq.5 and Eq.6 and the comparison between incidence angle modifiers for the stationary solar collector at different flow rates.

3.2. Measured thermal performance for stationary and tracking solar collectors

The thermal performance of the stationary and the tracking solar collectors were carried out during the period March-July, 2011. The inlet temperature and the flow rate of the solar collector fluid for the two collectors were the same every single day. The inlet temperature for the two collectors changed between 17°C and 91°C and the flow rate through each collector was varied between 4 l/min and 21 l/min. It is estimated that the shadows from the surroundings and from the collectors in most of the test periods have no significant influence on the collector thermal performance. Therefore it is reasonable to compare the daily collector thermal performance apart from the performance in the period of the day when shadows affect the thermal performance. These measured daily thermal performances for the two solar collectors and the percentage of the daily extra thermal performance that is achieved by the tracking solar collector relative to the stationary solar collector are shown in Fig.6 and Fig.7.

The higher the average solar collector fluid temperature is, the higher the extra thermal performance of the tracking collector will be.

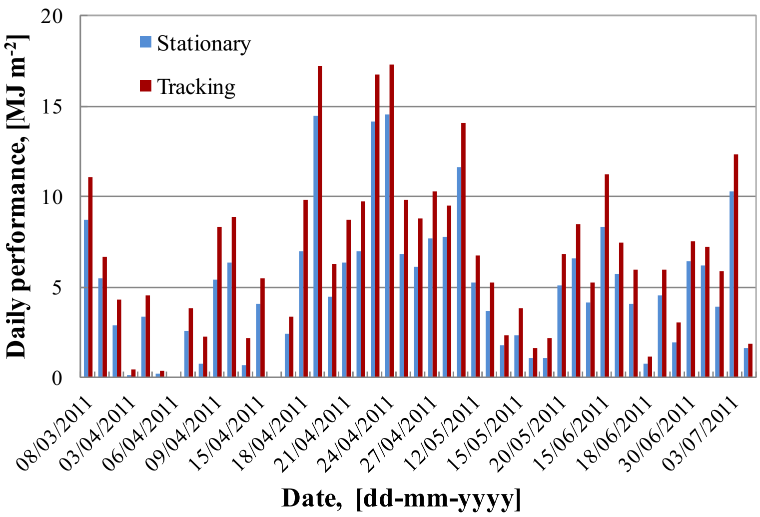

Fig.6: Measured daily thermal performance of the stationary and the tracking solar collector.

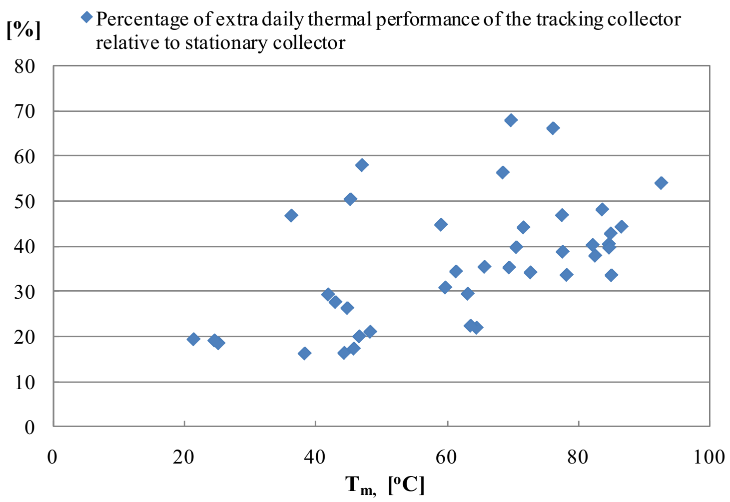

Fig.7: Measured extra daily thermal performance of the tracking solar collector relative to the stationary solar collector as a function of the average daily solar collector fluid temperature for the stationary collector.

4. Discussions

4.1. Measured and calculated solar irradiance on the tracking solar collector

The measured daily solar radiation on the tracking solar collector is compared with the daily solar radiation on the stationary solar collector, on the tracking solar collector in the period between March-July, 2011. The calculations are based on the measured solar irradiance on the stationary solar collector. It is shown in Fig.8. The average of the ratio between the measured and the calculated daily solar radiation in the test period is about 1.00. Fig.8 shows that the difference between the measured and calculated daily solar radiation is small. The measured and calculated solar irradiance on the tracking solar collector for the 5th of June 2011 is shown in Fig.9.

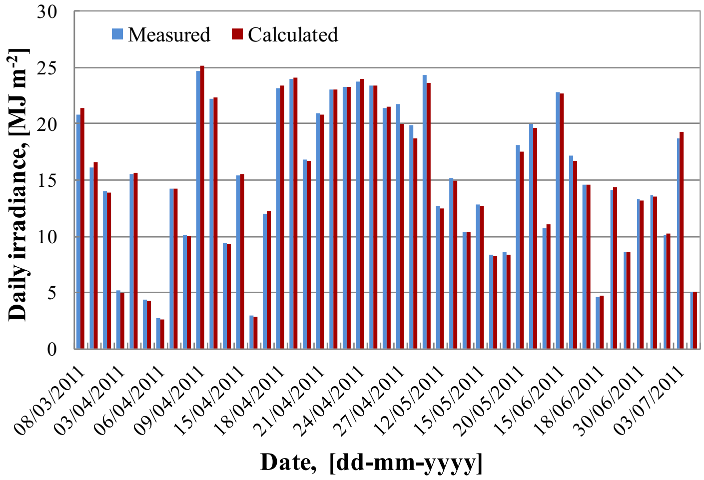

Fig.8: Measured and calculated daily solar radiation on the tracking solar collector.

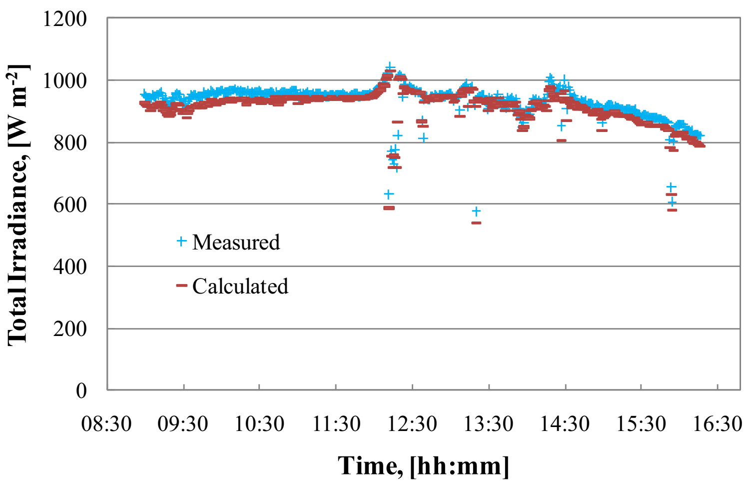

Fig.9: Measured and calculated solar irradiance on the tracking solar collector on June 5, 2011.

4.2. Comparisons of the calculated daily thermal performance with measured daily thermal performance for the stationary solar collector

Based on the measured efficiencies and incidence angle modifier for the stationary collector, the measured direct and diffuse solar irradiance on the stationary collector, the outdoor temperature, the inlet temperature of the collector and the flow rate through the collector, the instantaneous thermal performance for the stationary solar collector through the entire test period is calculated. The daily thermal performance is calculated for the part of the days where shadows have no influence on the thermal performance. The calculated daily thermal performance is compared with the measured results and shown in Fig.10. It is seen that there is a good agreement between measured and calculated daily thermal performance for the stationary collector. Calculated and measured thermal performance is compared for three days with different heating temperature in Figures 11, 12 and 13. It can be seen that there is a good agreement between the measured and calculated thermal performance.

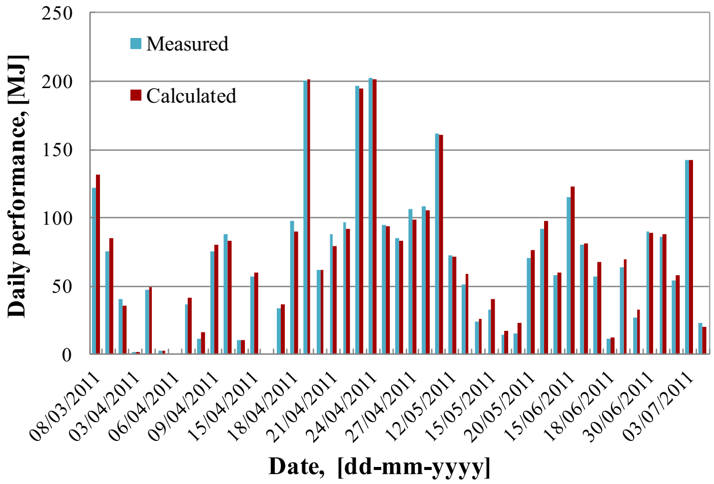

Fig.10: Measured and calculated daily thermal performance for the stationary solar collector.

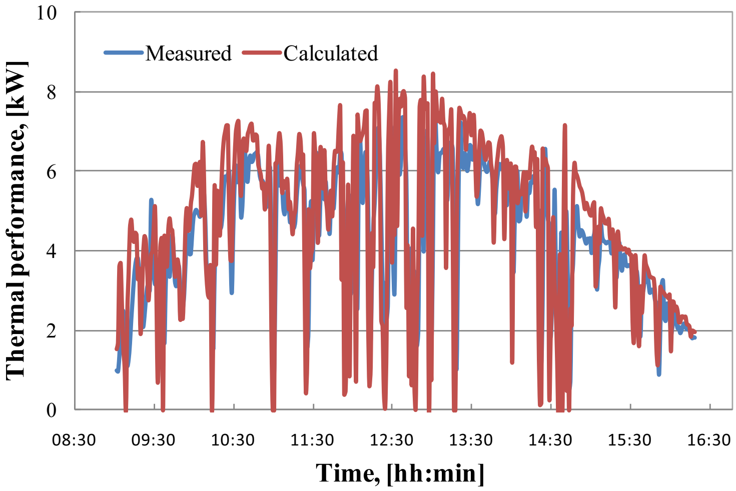

Fig.11: Measured and calculated thermal performance for the stationary solar collector on June 15, 2011 at a flow rate of 19.9 l/min and an inlet temperature of 63.1°C.

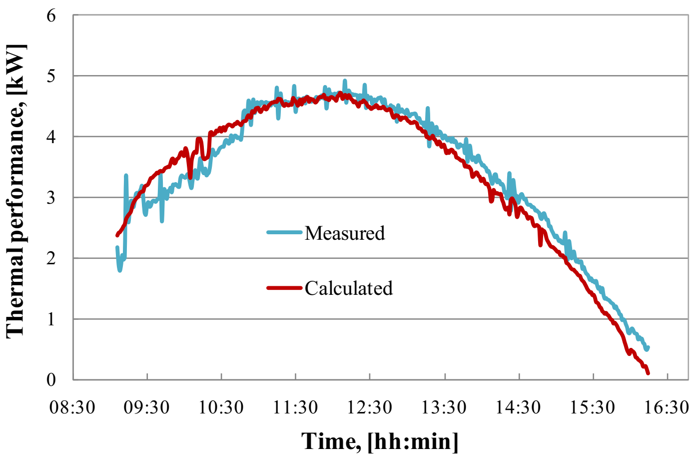

Fig.12: Measured and calculated thermal performance for the stationary solar collector on April 10, 2011 at a flow rate of 19.8 l/min and an inlet temperature of 82.6°C.

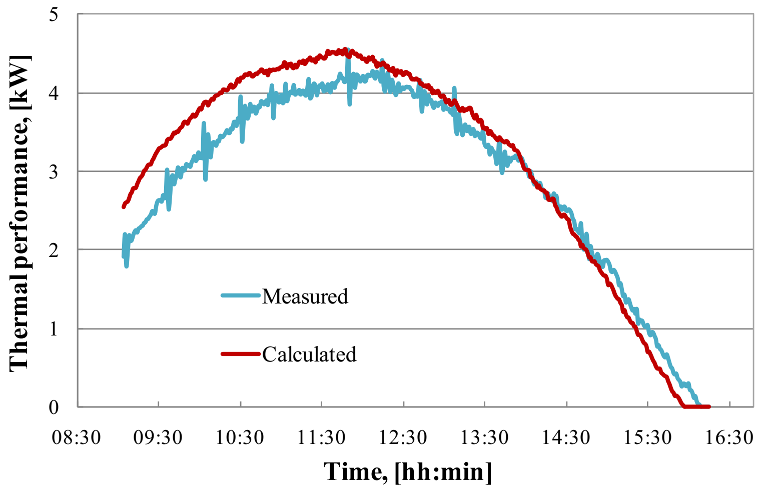

Fig.13: Measured and calculated thermal performance for the stationary solar collector on April 9, 2011 at a flow rate of 19.5 l/min and an inlet temperature of 91.1°C.

4.3. Comparisons of the calculated daily thermal performance with measured daily thermal performance for the tracking solar collector

Based on the measured efficiencies for the tracking collector, the incidence angle modifiers for stationary collector, the calculated direct and diffuse solar irradiance on the tracking collector, the outdoor temperature, the inlet temperature of the collector, the flow rate through the collector and the tracking collector's orientation, the instantaneous thermal performance for the tracking solar collector through the test period is calculated. The daily thermal performance is calculated for the part of the days where shadows have no influence on the thermal performance. The calculated daily thermal performance is compared with the measured results and shown in Fig.14. It is seen that there is a good agreement between measured and calculated daily thermal performance for the tracking collector. Calculated and measured thermal performance is compared for three days with different temperature levels in Figures 15, 16 and 17. It can be seen that there is a good agreement between the measured and calculated thermal performance.

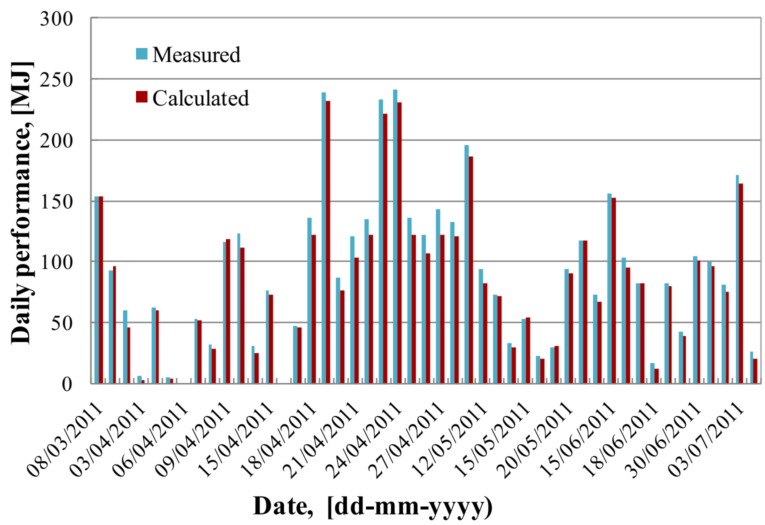

Fig.14: Measured and calculated daily thermal performance for the tracking solar collector.

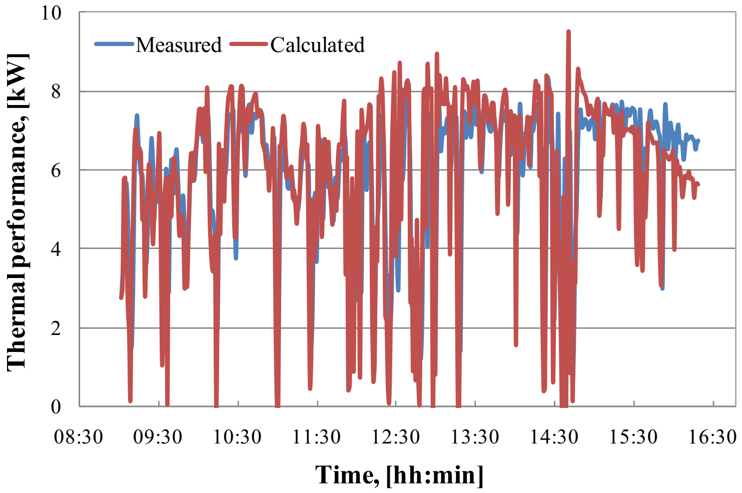

Fig.15: Measured and calculated thermal performance for the tracking solar collector on June 15, 2011 at a flow rate of 19.9 l/min and an inlet temperature of 63.1°C.

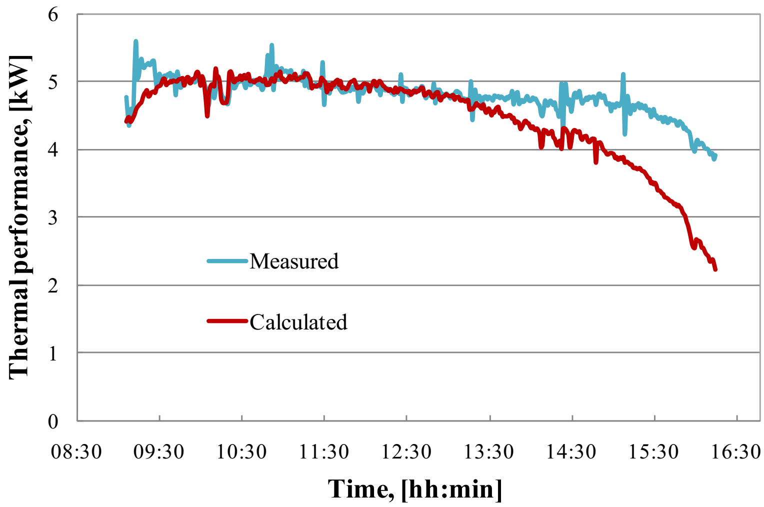

Fig.16: Measured and calculated thermal performance for the tracking solar collector on April 10, 2011 at a flow rate of 19.8 l/min and an inlet temperature of 82.6°C.

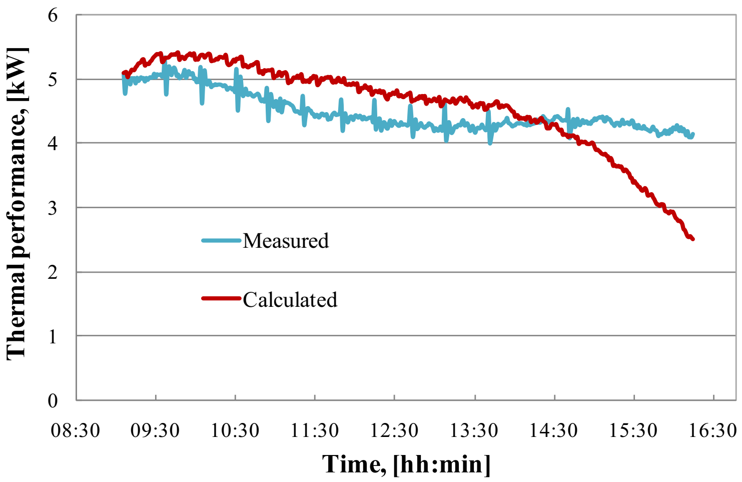

Fig.17: Measured and calculated thermal performance for the tracking solar collector on April 9, 2011 at a flow rate of 19.5 l/min and an inlet temperature of 91.1°C.

4.4. Yearly thermal performance of the solar collectors

The theoretically annual thermal performance in Denmark for a stationary and a tracking solar collector with constant solar collector fluid temperature at a flow rate of 20 l/min is shown in Fig.18and Fig.19. In Fig.18 the calculations are made with the measured collector efficiency for the stationary solar collector and the model used in Chapter 4. In Fig.19 the calculations are made with the measured collector efficiency for the tracking solar collector and the model used in Chapter 4. The stationary collector is assumed to face south and have a slope of 45°. The tracking collector has a tilt of 45° and turns constantly at the sun. The figures also show the relative annual performance of the tracking solar collector, defined as the ratio between the thermal performance of the tracking solar collector and the thermal performance of the stationary solar collector. The annual thermal performance of the tracking solar collector is higher than the thermal performance of the stationary solar collector. The higher the solar collector fluid temperature is, the higher the relative performance will be. At 40°C the relative performance is 1.42, at 60°C it is 1.51, and at 80°C it is 1.61 or 1.60.

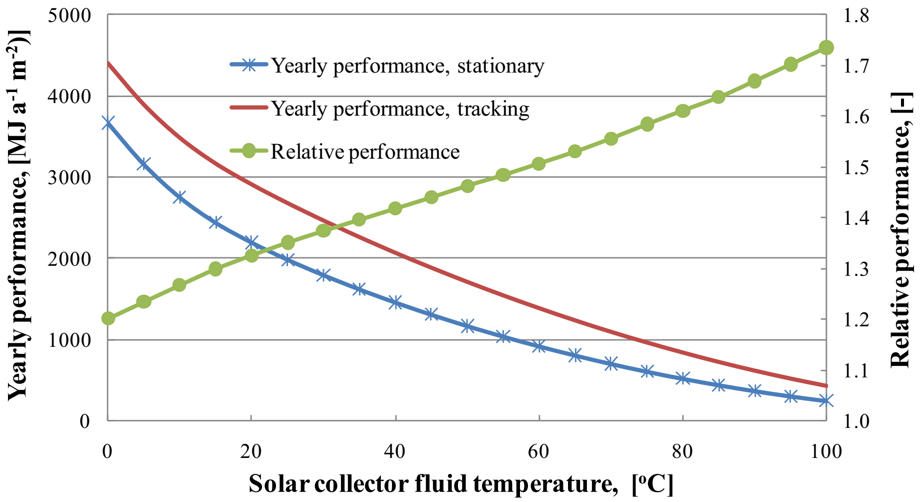

Fig.18: Calculated yearly thermal performance for a stationary and a tracking solar collector as a function of collector fluid temperature. The investigated stationary solar collector efficiency is used in the calculations.

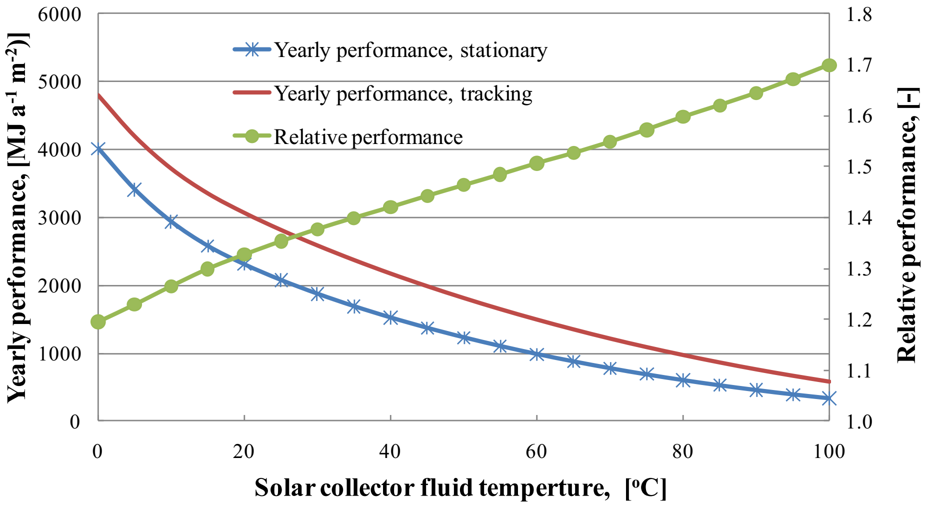

Fig.19: Calculated yearly thermal performance for a stationary and a tracking solar collector as a function of collector fluid temperature. The investigated tracking solar collector efficiency is used in the calculations.

The results are in good agreement with the theoretical results achieved by Andersen et al. (2010).

5. Conclusions

The thermal performances of two solar collectors from SUNMARK A/S have been studied experimentally and theoretically. One collector faces south and has a tilt of 45°. Another collector is placed on a tracker with a constant tilt of 45°. The tracking collector is always somewhat ahead of the sun's direction. So the difference between the tracking collector azimuth and solar azimuth is always around 15°.

The studies show that the yearly thermal performance of a tracking solar collector is higher than the thermal performance of a stationary collector. The higher the solar collector fluid temperature is, the greater the extra thermal performance of the tracking collector will be. At 40°C the yearly thermal performance increases approximately 42%, at 60°C approximately 51% and at 80°C approximately 60%.

6. NOMENCLATURE

Quantity	Symbol	Unit
Total irradiance	G	$W\ m^{-2}$
Incidence angle modifier	K_θ	-
Mean temperature of collector fluid	T_m	°C
Ambient temperature	T_a	°C
Efficiency of solar collector	η	-
Incidence angle	θ	°

7. References

Elsa Andersen, Janne Dragsted, Simon Furbo, Bengt Perers and Jianhua Fan. Thermal advantage of tracking solar collectors for different Danish weather conditions. Proceedings of Eurosun 2010, Graz, Austria

George C. Bakos. Design and construction of a two-axis Sun tracking system for parabolic trough collector (PTC) efficiency improvement. Renewable Energy, 2006, 31: 2411–2421

Hossein Mousazadeh, Alireza Keyhani, Arzhang Javadi, Hossein Mobli, Karen Abrinia, Ahmad Sharifi. A review of principle and sun-tracking methods for maximizing solar systems output. Renewable and Sustainable Energy Reviews, 2009, 13: 1800–1818

Kalogirou SA. Design and construction of a one-axis Sun-tracking system. Solar Energy 1996;57(6):465–9.