Conference Proceedings

EuroSun 2016
Palma de Mallorca (Spain), 11 - 14 October 2016

ANALYSIS OF MEASURED AND MODELED SOLAR RADIATION AT THE TÅRS SOLAR HEATING PLANT IN DENMARK

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Abstract

A novel combined solar heating plant with tracking parabolic trough collectors (PTC) and flat plate collectors (FPC) has been constructed and put into operation in Tårs, 30 km north of Aalborg, Denmark in August 2015. To assess the operation performance of the plant, detailed parameters, such as solar radiation, inlet and outlet temperature for the solar collector field, flow rate and pressure, ambient temperature, wind speed and wind direction were measured. Global horizontal radiation, direct normal irradiation (DNI) and total radiation on the tilted collector plane of the flat plate collector field have been measured in Tårs solar heating plant. To determine the accuracy of modeled and measured solar radiation in Tårs solar heating plant, monthly comparisons of measured and calculated radiation using 6 empirical models have been carried out. Comparisons of measured and modeled total radiation on the tilted surface with different methods were also studied. The results have shown that the DTU model could be used to calculate the diffuse radiation on horizontal surface and the anisotropic models (Perez 1988 model and Perez 1999 model) with only 1% and 2% disagreement with measured data respectively were the most accurate to be used for the calculation of total radiation on the tilted collector surface under Danish climate conditions only based on global horizontal radiation.

Keywords: Tårs solar heating plant, solar radiation, diffuse radiation, total radiation on tilted surfaces, measurements, calculations

1. Introduction

Solar radiation data are the best source of information for estimating thermal performance of solar thermal systems and necessary for design and assessment of solar thermal systems. However, a drawback, common for solar energy systems is the unpredictable nature and variability of solar radiation. Solar heating systems are strongly dependent on weather conditions. The accuracy of the solar radiation is valuable for design and evaluation of the solar energy systems. In the past, in most cases cheap and low accurate solar radiation meters were used to measure solar radiation in solar heating plants. Acquiring information about correct and typical solar irradiation available at potential plant sites is of high importance for controlling and planning of the solar heating plants to improve the thermal performance of the solar thermal systems.

Generally, climate stations only measure global radiation and only in rare cases DNI or diffuse solar radiation. Therefore, total tilted surface irradiation in most cases is calculated by using measured global horizontal irradiation by means of empirical models for general use.

A novel combined solar heating plant with a 4039 m^2 parabolic trough collector field and a 5960 m^2 flat plate collector field in Tårs has been put into operation in August 2015 (Aalbog CSP.2016). To evaluate the thermal performance of the plant and the accuracy of modeled solar radiation, detailed solar radiation, such as, DNI, global (total) horizontal radiation and total titled solar radiation are measured. In addition, a weather station was also constructed nearby the solar heating plant to make sure that the pyranometers in the plant have correct values to reduce systemic errors and to measure the direct normal irradiance. South facing flat

doi:10.18086/eurosun.2016.09.12 Available at http://proceedings.ises.org

plate collectors were installed with 50° tilt in the solar heating plant. Pyranometers were adhered to the flat plate collector with the same tilt to measure the total radiation on the tilted surface. Calibrated high class solar sensors were used.

Previous empirical models for conversion of global solar radiation may not be applicative under Danish climate conditions with high accuracy. A DTU model has been developed to calculate the diffuse radiation on horizontal surface under Danish climate conditions based on the global radiation (J. Dragsted,et al. 2012). DTU model was used to calculate the diffuse radiation on horizontal surface and 5 empirical models were used to investigate the total radiation on the tilted surface in this paper. The difference between measured solar radiation and modeled total radiation on the tilted surface estimated by the empirical formulas under Danish climate conditions were shown. Calculated total tilted radiation only based on the global horizontal radiation and based on both the global horizontal radiation and beam radiation were discussed, which could provide a new method to calculate total tilted radiation with less measurements under Danish climate conditions and maybe the proposed method can be extended to other Nordic area with similar weather conditions.

2. Monitoring equipments

As is shown in the figure 1, Denmark has 6 climate zones. The Tårs plant is located in the first climate zone, in the northern part of Denmark. Figure 2 illustrates the locations of the weather station and the pyranometers in the flat plate collector field in Tårs solar heating plant. The weather station is next to the solar heating plant. There are several pyranometers to measure the global solar radiation on horizontal surface and the tilted plane of the flat plate collectors in the middle of the flat plate collector field to reduce systematic errors (figure 3). The latitude of the plant is 57.39 °N and the longtitude is 10.11°E respectively.

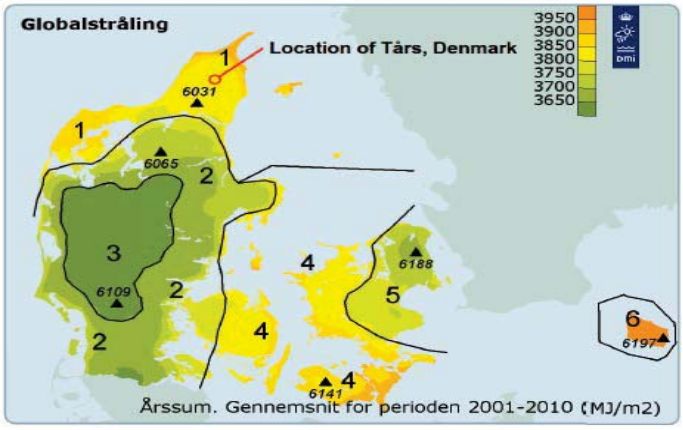

Fig.1. Location of Tårs in Denmark.

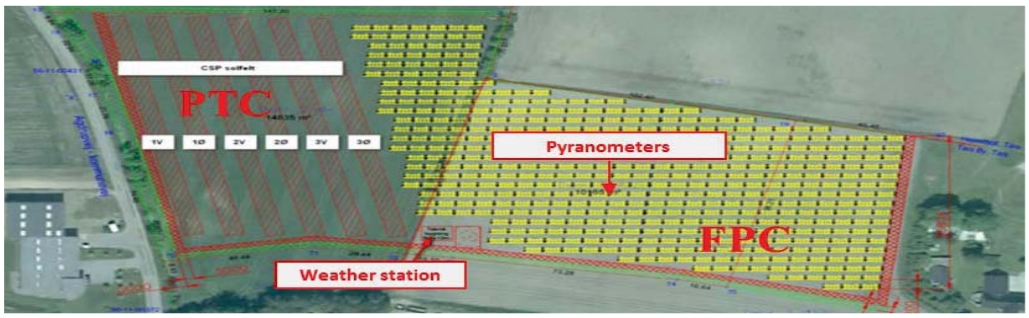

Fig.2. Location of the weather station and pyranometers

Fig.3. Pyranometers in the middle of flat plate collector field

As is shown in figure 2 and figure 3, five pyranometers with a tilt 50° were installed in the middle of the flat plate collector field. One is installed on a horizontal surface. Four pyranometers were installled on the tilted collector plate. Global solar radiation on the horizontal surface and solar radiation on the titled collector plane were measured with Kipp&Zonen SMP11. DNI was measured with a PMO6-CC pyrheliometer with the sun tracking platform Sunscanner SC1 in the weather station next to the solar heating plant, see Fig.2 and 4. Table 1 and 2 show the technical specifications of Kipp&Zonen SMP11 pyranometer and PMO6-CC pyrheliometer. It is estimated that that the uncertainty of the measured solar radiation is about 2%.

Fig.4. Weather station and pyrheliometer at Tårs solar heating plant

Table 1. Specifications of Kipp & Zonen SMP11 Pyranometer

Parameters	Values
Spectral range (50% points)	285 to 2800 nm
Response time (63%)	< 0.7 s
Response time (95%)	< 2 s
Zero offset A	< 7 W/m²
Zero offset B	< 2 W/m²
Directional response (up to 80° with 1000 W/m² beam)	< 10 W/m²
Temperature dependence of sensitivity (-20 ºC to +50 ºC)	< 1 %
Analogue output (-V version)	0 to 1 V
Analogue output (-A version)	4 to 20 mA

Table 2. Specifications of PMO6-CC pyrheliometer

Parameters	Values
Dimension	80 x 80 x 230 mm
Mass	2.15 kg
Field of view (full angle)	5°
Slope angle	1°
Range	up to 1400 W/m^2 (Or custom design available)
Traceability to WRR	< 0.1%
Operating temperature range	-25 °C to +50 °C

3. Models

Solar radiation, including DNI, global horizontal radiation and total solar radiation on a tilted south facing surface of 50° parallel to flat plate collectors have been measured with high time resolution: 2 minutes time steps. Hourly mean values are calculated based on the measurements. Six solar radiation models using the hourly mean data are used to calculate the diffuse radiation on horizontal surface and total solar radiation on the tilted surfaces. The DTU model was used to calculate diffuse radiation on the horizontal surface. And five empirical models for general use were used to calculate the total solar radiation on the tilted surface (Beckman W A.,et al. 1990-2012). Calculation methods of five empirical models were investigated (Beckman W A.,et al. 1990-2012). Ground reflectance was assumed to be 0 in the calculation of modeled solar radiation in the solar heating plant, which is the fair value when shadow between collectors is taken into consideration in the calculations.

4. Results and Discussions

Based on the measurements, total radiation on the tilted flat plate collectors has been investigated with different models. Further, accuracies of the different mentioned models on the calculation of total radiation on the tilted surface have been figured out. The TRNSYS platform was used to set up the mentioned models. Monthly comparisons of modeled and measured solar radiation on horizontal and tilted surface are presented.

4.1 Total radiation on 50° tilted surface facing south

To investigate the total radiation on the tiled surface and accuracy of the different empirical models, calculated total radiation on the tilted surface by the isotropic and anisotropic models based on measured total horizontal radiation and measured beam radiation are shown in figure 6. Because the tilt of the flat plate collectors is 50°, all the mentioned tilted surfaces are 50° tilt surfaces towards south.

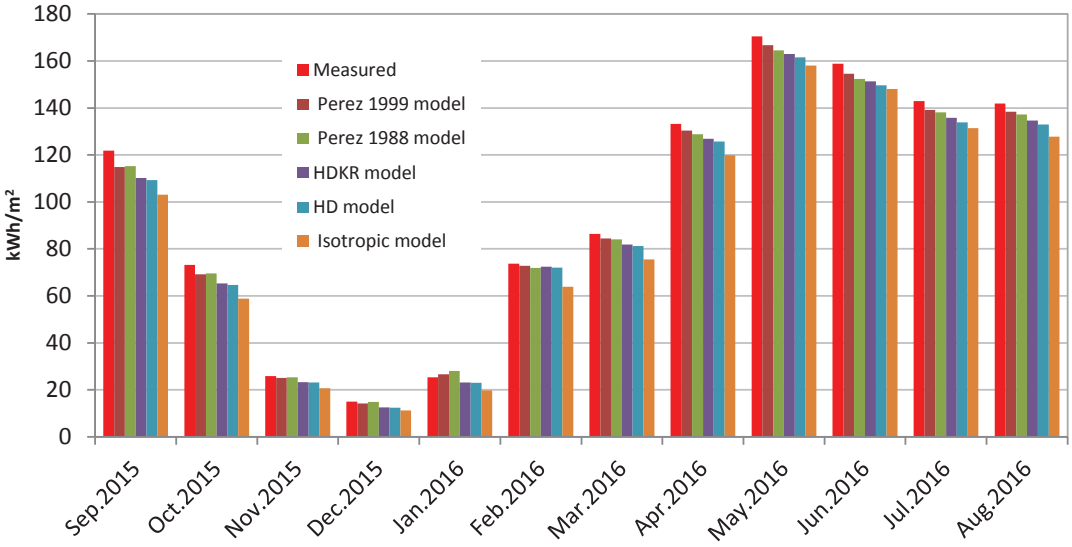

Fig.5. Modeled and measured monthly total radiations on 50° tilted surface facing south (Sep.2015 – Aug.2016)

Fig.5 illustrates measured and modeled total radiation on the tilted surface. The modeled total radiation by isotropic model is lower than the measured values obviously. For the four anisotropic models, the modeled total tilted radiations of the Perez 1999 model and Perez 1988 model are the closest to the measured values with only average -3% and -1% difference between the modeled and measured values, which is the same as reported by Andersen E., et al (Andersen E., et al,2004).

4.2 Measured and calculated total tilted radiation

Normally the total radiation on tilted surfaces is not measured in solar heating plants. Calculated total radiation on tilted surfaces only based on measured global radiation on horizontal surface is useful. By the DTU model, calculated diffuse radiation and beam radiation are obtained only based on measured global radiation on horizontal surface. Because the anisotropic models (Perez 1999 model and Perez 1988 model) are closest to measured value in section 4.1, the anisotropic models (Perez 1999 model and Perez 1988 model) were selected to calculate the total radiation on the tilted surface based on the calculated diffuse radiation and calculated beam radiation. The calculated total tilted radiation by the Perez 1988 model and Perez 1999 model are only 1% and 2% respectively larger than the measured one from Sep.2015 to Aug.2016, see figure 6. Calculated total tilted solar radiation by the Perez 1999 model mainly is a bit higher than measured values in the summer (Fig.6.b.). The Perez 1988 model has the best agreement with measurements of the investigated two empirical models. Compared to the calculated total tilted radiation based on the measured global radiation and measured beam radiation, the accuracy of calculated total tilted radiation only based on the measured global radiation also has high accuracy (the anisotropic model -Perez 1999 model and Perez 1988 model).

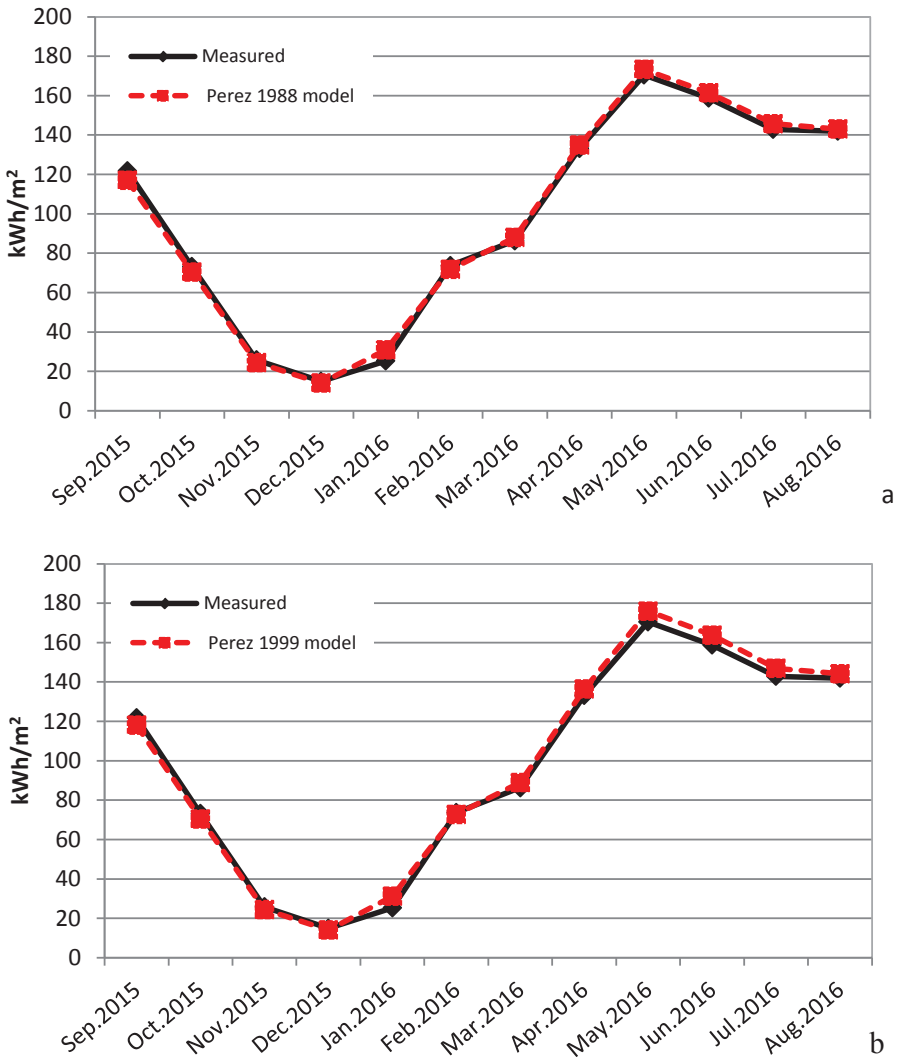

Fig.6. Measured and calculated monthly total radiation on 50° tilted south facing surface (Sep.2015 – Aug.2016: a-Perez 1988 model, b- Perez 1999 model.)

5. Conclusions

Measured and modeled solar radiation in a demonstration solar heating plant in Denmark were analyzed. The main purpose of this paper is to present a new calculation method to determine tilted total radiation on tilted flat plate collectors for large solar heating plants in Denmark. Calculated total tilted solar radiation only based on measured global horizontal radiation was investigated. Furthermore, an isotropic model and four anisotropic models for general use have been investigated for calculation of total radiation on tilted surfaces under Danish climate conditions.

It is suggested that the anisotropic model can be used to calculate total radiation on the tilted surface with better accuracy than the isotropic model under Danish climate conditions. The anisotropic models (Perez 1999 model and Perez 1988 model) are the most suitable empirical model for the calculation of total radiation on the tilted surface under Danish climate conditions. Calculated tilted solar radiation based on the anisotropic models and DTU model only based on the global horizontal radiation can be a new method to predict the total radiation on tilted surfaces accurately under Danish climate conditions.

6. Acknowledgements

Special thanks are expressed to Aalborg CSP for the information provided. The first author also really appreciated the financial support of China Scholarship Council for the PhD study at DTU (No.201506120074).

References

[1] AalborgCSP: http://www.aalborgcsp.com/
[2] J. Dragsted, S. Furbo. Solar radiation and thermal performance of solar collectors for Denmark. DTU Civil Engineering Report R-275 (UK) October 2012.
[3]. Klein S A, Beckman W A. Trnsys 17-a TRaNsient SYstem Simulation program. Programmer'Guide[J]. Solar Energy Laboratory, University of Wisconsin-Madison, 2012.
[4]. Reindl D T, Beckman W A, Duffie J A. Diffuse fraction correlations[J]. Solar energy, 1990, 45(1): 1-7.
[5]. Reindl D T, Beckman W A, Duffie J A. Evaluation of hourly tilted surface radiation models[J]. Solar energy, 1990, 45(1): 9-17.
[6]. Duffie Jone A, Beckman William A. Solar engineering of thermal process[J]. John Wiley& Sons Inc,2013.
[7]. PMO6-CC pyrheliometer. https://www.pmodwrc.ch/pmod.php?topic=pmo6
[8]. Kipp&Zonen SMP11. http://www.kippzonen.com/Product/202/SMP11Pyranometer#.V35QMvl95mM
[9]. Sunscanner SC1. http://www.black-photon.de/products/sunscanner-s
[10]. Andersen E, Lund H and Furbo S. The influence of the solar radiation model on the calculated solar radiation from a horizontal surface to a tilted surface, in proceedings of EuroSun 2004 Congress, Freiburg, Germany, 2004.