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Yearly thermal performances of solar heating plants in Denmark – Measured and calculated

Simon Furbo[a,*], Janne Dragsted[a], Bengt Perers[a], Elsa Andersen[a], Federico Bava[a], Kristian Pagh Nielsen[b]

[a] DTU Civil Engineering, Technical University of Denmark, Brovej, Building 118, 2800 Kgs. Lyngby, Denmark
[b] DMI, Lyngbyvej 100, 2100 Kbh Ø, Denmark

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ABSTRACT

The thermal performance of solar collector fields depends mainly on the mean solar collector fluid temperature of the collector field and on the solar radiation. For Danish solar collector fields for district heating the measured yearly thermal performances per collector area varied in the period 2012–2016 between 313 kWh/m^2 and 577 kWh/m^2, with averages between 411 kWh/m^2 and 463 kWh/m^2. The percentage difference between the highest and lowest measured yearly thermal performance is about 84%. Calculated yearly thermal performances of typically designed large solar collector fields at six different locations in Denmark with measured weather data for the years 2002–2010 vary between 405 kWh/m^2 collector and 566 kWh/m^2 collector, if a mean solar collector fluid temperature of 60 °C is assumed. This corresponds to a percentage difference between the highest and lowest calculated yearly thermal performance of about 40%. This variation is caused by different weather conditions from year to year and from location to location. Approximately half of the variations of yearly thermal performances can be related to variable weather conditions.

1. Introduction

The number of solar heating plants in Denmark for district heating has increased strongly in the last couples of years (Windeleff and Nielsen, 2014) and (Bava et al., 2017). Denmark is today frontrunner worldwide on large solar heating plants connected to district heating systems (Weiss et al., 2017). In 2016 about 500,000 m^2 solar collectors were installed in large scale solar heating plants. By the end of 2016, 110 solar heating plants with a total collector area of more than 1,300,000 m^2 were in operation. The solar collector fields are based on a high number of parallel connected rows of serial connected collectors mounted on the ground. In most of the solar heating plants flat plate solar collectors are used, see Fig. 1.

The solar collector fluids in the solar collector loops are propylene glycol/water mixtures. Flat plate heat exchangers are used to transfer the heat produced by the solar collectors from the solar collector fluid to water in the secondary loop. In order to achieve a good cost efficiency of the solar heating plants it is important that the thermal performances of the plants are as high as expected. The heat production of all the solar collector fields is measured.

This paper summarizes measured yearly thermal performances of Danish solar heating plants for the period 2012–2016 as well as theoretically calculated yearly thermal performances of a typical solar heating plant based on measured weather data for different locations in Denmark. The locations of the plants are in the paper indicated by region numbers according to Fig. 2, which shows six different regions for Demark as suggested by Wang et al. (2012). The yearly thermal performance vary from plant to plant and for one plant from year to year. This work elucidate how much of the variation are caused by different weather conditions from location to location and from year to year.

2. Measured Yearly thermal performances of solar collector fields

The thermal performances of all Danish solar heating plants are measured. The measurements of the thermal performance are carried out with conventional energy meters in the secondary loop with water as the heat transfer fluid. The solar radiations are typically measured with inexpensive pyranometers on the top of collectors inside the collector fields. Most of the measurements are available on the website www.solvarmedata.dk (2017). Information for most of the solar heating plants, such as collector manufacturer, collector area, ground area of the collector field, collector tilt, year of installation, etc. is also available. The solar collectors in all the solar heating plants face south and the solar collector tilts vary in the interval from 30° to 45°. Most of the

* Corresponding author.
E-mail address: sf@byg.dtu.dk (S. Furbo).

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Nomenclature

η	collector efficiency, –
θ	incidence angle, °
K_θ	incidence angle modifier, –
G	solar irradiance on the solar collector, W/m^2
Gb	direct radiation on horizontal, W/m^2
Rb	geometric factor, –
Tm	mean solar collector fluid temperature, °C
Ta	ambient temperature, °C

Fig. 1. Solar collector field with a high number of rows with flat plate collectors.

solar heating plants have collector tilts between 35° and 40°.

Table 1 lists 48 solar heating plants inclusive the region numbers of the locations with available measurements of the thermal performance for all months of 2012, 2013, 2014, 2015 and/or 2016. The solar heating plants were installed in the period 1996–2015. All the plants have flat plate collectors either from ARCON Solar A/S and/or from SUNMARK Solutions A/S. Arcon-Sunmark A/S was established in 2015 as the fusion of the two companies. The collector aperture areas of the solar heating plants are in the interval 2970–70,000 m^2. The average solar collector area for the 48 solar heating plants is 12,756 m^2. The table shows the measured yearly thermal performance, the measured yearly solar radiation on the solar collectors and the yearly utilization of the solar radiation for the solar heating plants for 2012, 2013, 2014, 2015 and/or 2016. The thermal performance and the solar radiation are given per m^2 solar collector aperture area. The utilization of the solar radiation is the ratio between the thermal performance of the solar collector field and the solar radiation on the collectors of the solar collector field. Measurements from 16, 21, 31, 36 and 41 plants are available for 2012, 2013, 2014, 2015 and 2016.

The measured yearly thermal performances of the solar heating plants per collector area ranged from 313 kWh/m^2 to 577 kWh/m^2 with averages for all plants of 411 kWh/m^2, 450 kWh/m^2, 463 kWh/m^2, 439 kWh/m^2 and 435 kWh/m^2 for 2012, 2013, 2014, 2015 and 2016, respectively. The measured yearly solar radiations on the solar collectors were in the interval 876 kWh/m^2 collector - 1474 kWh/m^2 collector with averages for all plants of 1102 kWh/m^2 collector, 1135 kWh/m^2 collector, 1114 kWh/m^2 collector, 1101 kWh/m^2 collector and 1153 kWh/m^2 collector for 2012, 2013, 2014, 2015 and 2016. The yearly utilizations of the solar radiation were in the interval 27.6–50.8%, with averages for all plants of 37.3%, 39.6%, 41.6%, 39.9% and 37.9% for 2012, 2013, 2014, 2015 and 2016. It is estimated that the measured thermal performances and utilizations of the solar radiation for all the plants are satisfactory high.

There are many reasons for the differences in thermal performances between the different solar heating plants. First of all, different weather conditions from location to location and from year to year will influence the yearly thermal performance. Adsten et al. (2001) and Andersen and Furbo (2009) have for Swedish and Danish locations shown that both the yearly thermal performance of solar collectors and the yearly utilization of solar radiation of solar collectors will increase for increasing yearly solar radiation. This also appear from Fig. 3, which for all plants in the different regions for all years shows the yearly

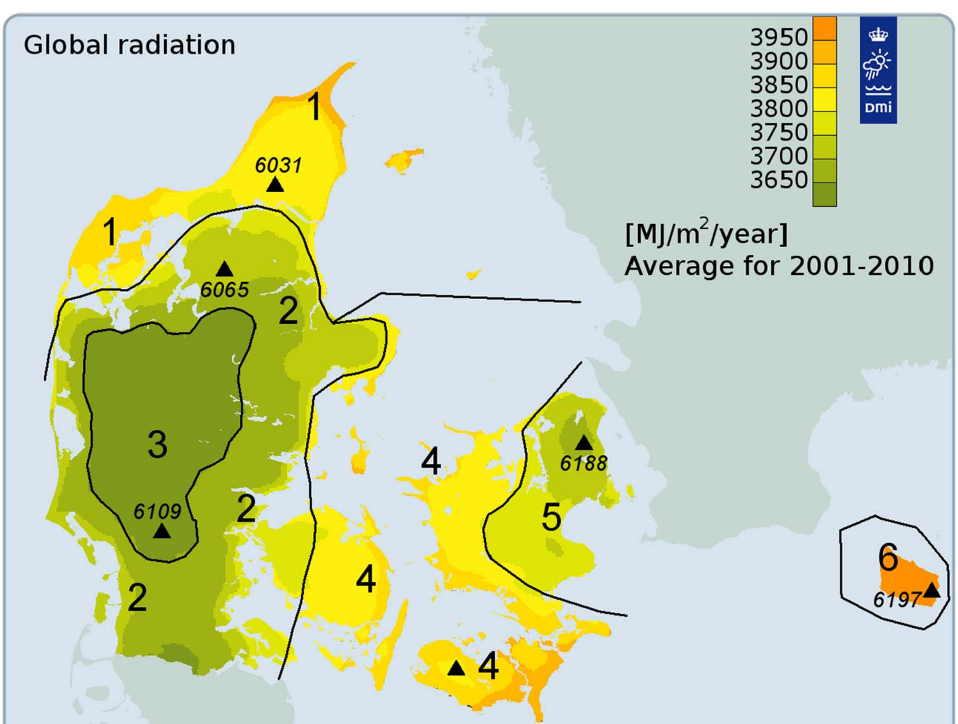

Fig. 2. Six Danish regions with different solar radiation.