C-D1. Simulation and design of collector array units within large systems

IEA SHC FACT SHEET 55.C.D.1.1.

Subject:	Long-term thermal performances of solar collector fields: Measured and calculated
Description:	Investigation of measured long-term field performance in relation to standardized collector test information and tools/models for annual performance prediction at different operating conditions and field designs.
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Download possible at:	http://task55.iea-shc.org/fact-sheets

Intro

This fact sheet summarizes measured yearly thermal performances of Danish solar heating plants for the period 2012-2018 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 yearly thermal performance vary from plant to plant and for one plant from year to year. The fact sheet elucidate how much of the variation is caused by different weather conditions from location to location and from year to year.

Measured yearly thermal performances of solar collector fields

The thermal performances of all Danish solar heating plants are measured. Most of the measurements are available on the website www.solvarmedata.dk [1]. 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 solar heating plants have collector tilts between 35° and 40°. The collector aperture areas of the solar heating plants are in the interval 2970 m² - 156694 m².

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.

Furbo et al. [2] reported measured thermal performances for the Danish solar heating plants for the period 2012-2016. Here the thermal performances are summarized for the 7 years period 2012-2018. The thermal performance and the solar radiation are given per m² 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, 41, 54 and 52 plants are available for 2012, 2013, 2014, 2015, 2016, 2017 and 2018, respectively.

The measured yearly thermal performances of the solar heating plants per collector area ranged from 313 kWh/m² to 602 kWh/m² with averages for all plants of 411kWh/m², 450 kWh/m², 463 kWh/m², 439 kWh/m², 435 kWh/m², 407 kWh/m² and 494 kWh/m² for 2012, 2013, 2014, 2015, 2016, 2017 and 2018, respectively. The measured yearly solar radiation on the solar collectors was in the interval 848 kWh/m² collector - 1491 kWh/m² collector with averages for all plants of 1102 kWh/m² collector, 1135 kWh/m² collector, 1114 kWh/m² collector, 1101 kWh/m² collector, 1153 kWh/m² collector, 1133 kWh/m² collector and 1246 kWh/m² collector for 2012, 2013, 2014, 2015, 2016, 2017 and 2018. The yearly utilizations of the solar radiation were in the interval 26% - 51%, with averages for all plants of 37%, 40%, 42%, 40%, 38%, 36% and 40% for 2012, 2013, 2014, 2015, 2016, 2017 and 2018. It is estimated that the measured thermal performances and utilizations of the solar radiation for all the plants are satisfactorily high.

There are many reasons for the differences in thermal performance 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 [3] and Andersen and Furbo [4] 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 appears from figure 1, which for all plants and years shows the yearly thermal performances as a function of the yearly solar radiation on the solar collectors. The location of the plants is indicated by the region number. Denmark is divided into six regions with different solar radiation as suggested by Wang et al. [5].

Further, there are different temperature levels in the different district heating systems. This will result in different temperature levels in the solar collector fields and therefore in different thermal performances. The lower the temperature level is, the higher the thermal performance.

Furthermore, the different solar collector types, the different designs of the solar collector fields, the different control strategies including the different flow rates and maybe the different uneven flow distributions in the solar collector fields will influence the thermal performance. For instance, Bava and Furbo [6] showed that the flow rate will influence the flow distribution and efficiency of solar collectors and Rohde and Knoll [7], Dorantes et al. [8] and Bava et al. [9] showed that the flow rate influences the flow distribution and thermal performance of a solar collector field.

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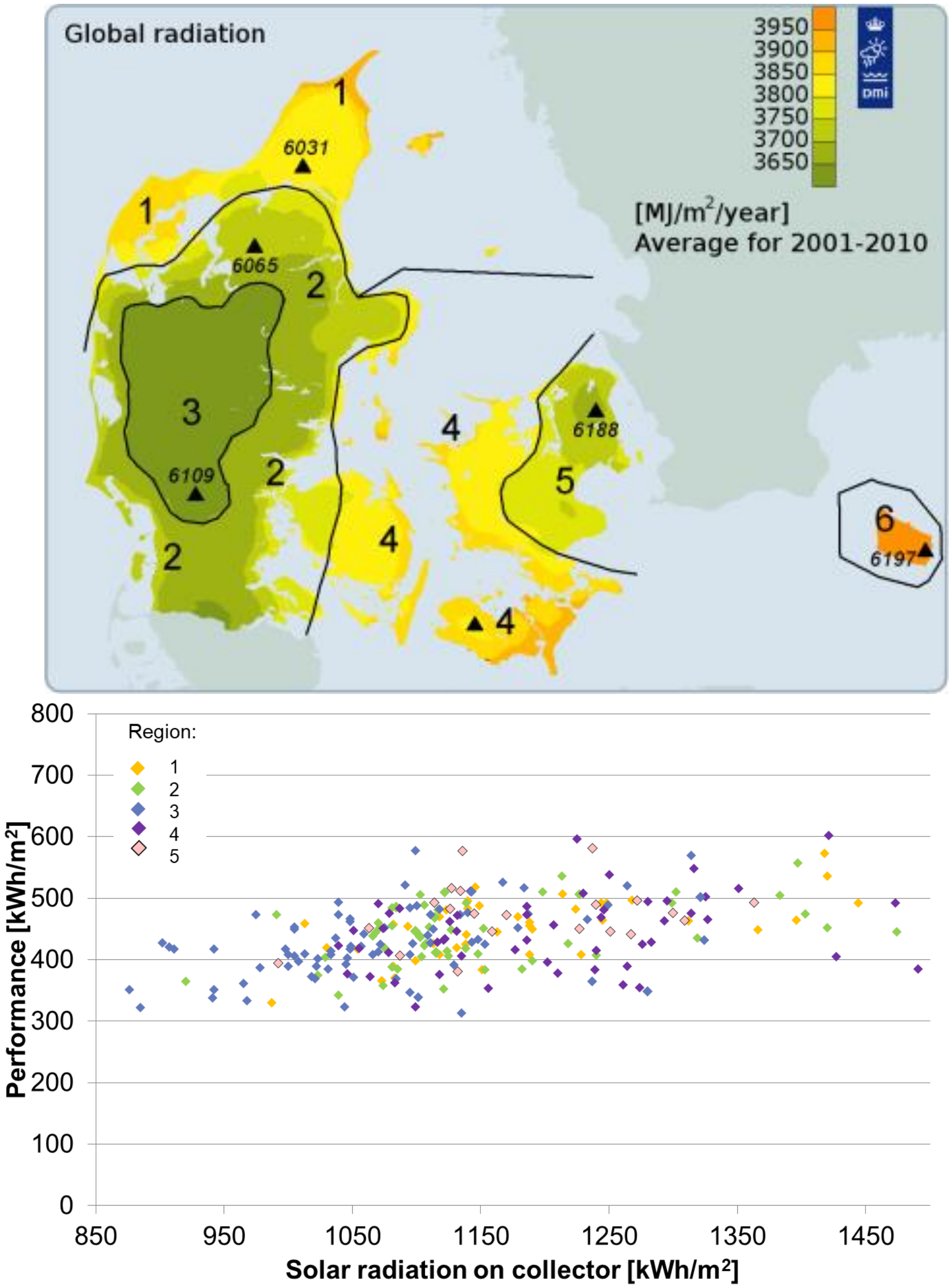

Figure 1. Yearly thermal performances as function of yearly solar radiation on solar collectors for all plants and years.

Additionally, the different heat losses from the pipes in the solar collector loops, the different collector tilts, the different shading conditions, the different moisture conditions inside the solar collectors, the different snow conditions, and the different dirt conditions on the glass covers of the solar collectors may influence the thermal performance. Finally, some plants have long term heat storages charged at high temperatures during summer resulting in a relatively lower thermal performance per m² collector.

Calculated yearly thermal performances of solar collector fields

Yearly thermal performances of a solar collector field have been calculated for six different Danish locations, see figure 1. The calculations have been done with a typical marketed solar collector from Arcon-Sunmark A/S, HTHEATstore 35/10 with the efficiency and incidence angle modifier based on the aperture area given by Månsson and Aronsson [10]:

$$\eta = K_\theta \cdot 0.802 - [2.226 \cdot (T_m - T_a)/G] - [0.010 \cdot (T_m - T_a)^2/G]$$

$$K_\theta = 1 - \tan^{3.1}(\theta/2)$$

- η collector efficiency, -
- θ incidence angle, °
- K_θ incidence angle modifier, -
- G solar irradiance on the solar collector, W/m²
- Rb geometric factor, -
- T_m mean solar collector fluid temperature, °C
- T_a ambient temperature, °C

The collector has a polymer foil between the absorber and the cover glass.

Calculations are carried out for each location and each year with measured weather data from the period 2002-2010. An hourly value for the global radiation on horizontal is measured for every hour of the years. The method described by Dragsted and Furbo [11] is used to calculate the hourly diffuse and direct radiation on horizontal Gb. The hourly direct radiation on the collector plane is determined by Rb·Gb. The direct radiation on the collectors is decreased by shadows from the collector row in front of the collector row in question. The reduction of direct radiation is proportional to the shaded area in relation to the total collector area of the row.

The diffuse radiation on horizontal is converted to tilted diffuse radiation using a classical isotropic model, and both diffuse radiation from the sky and from the ground are taken into account. Inside the collector field the diffuse radiation is reduced due to the shading from the collector row in front using view angles from the collector to the sky and to the ground from the middle height of the collector row. Solar angles in the middle of the hour in question are used in the calculations. The diffuse and direct radiation determined as described above as well as the incidence angle for direct radiation are used together with the collector efficiency to determine the hourly thermal performance of the solar collector field. It is estimated that the method will give reasonably accurate results.

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A solar collector field with 20 collector rows with 35° tilted collectors facing south is assumed. The row distance is 5.5 m and shadows from one row to the next are considered.

Figures 2, 3 and 4 show for region 1 the following for the nine years period 2002-2010: The measured yearly global radiation on horizontal, the calculated total yearly radiation on the collectors and the calculated yearly thermal performance of the collector field as a function of the mean solar collector fluid temperature, which is assumed constant during all operation periods. Further, the values for the design reference year for the region are included in the figures, Wang et al. [5]. The performance ratio included in figure 4 is defined as the ratio between the thermal performance of the solar collector field for the year in question and the thermal performance of the solar collector field for the reference year for the region.

Quantities similar to the quantities shown for region 1 are shown for region 2, 3, 4, 5 and 6 in figures 5-19. It should be mentioned that solar radiation measurements for 2004 for region 5 are not available and therefore omitted.

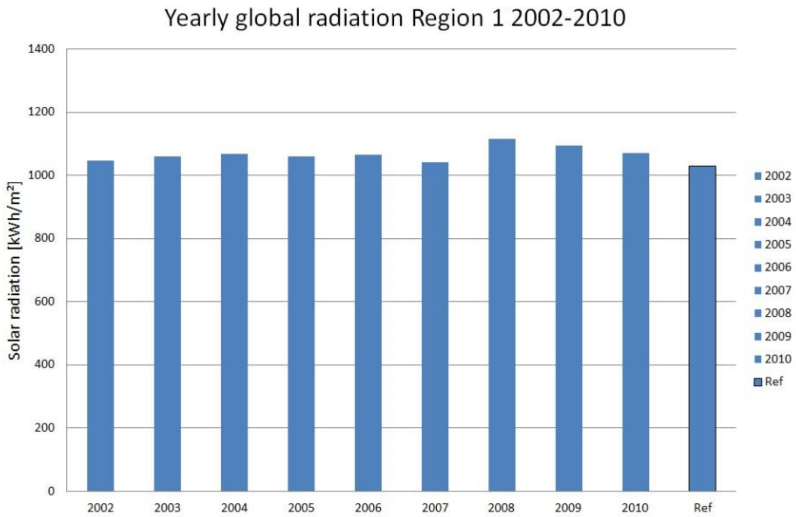

Figure 2. Measured yearly global radiation for region 1.

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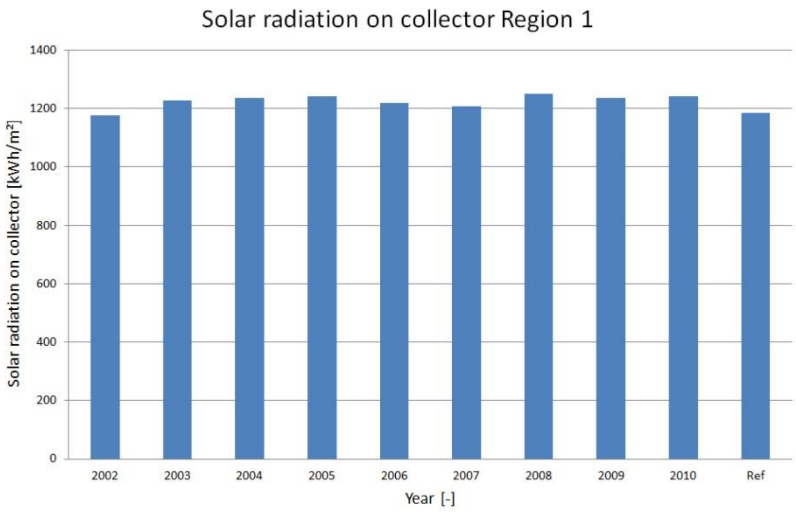

Figure 3. Calculated yearly solar radiation on collectors for region 1.

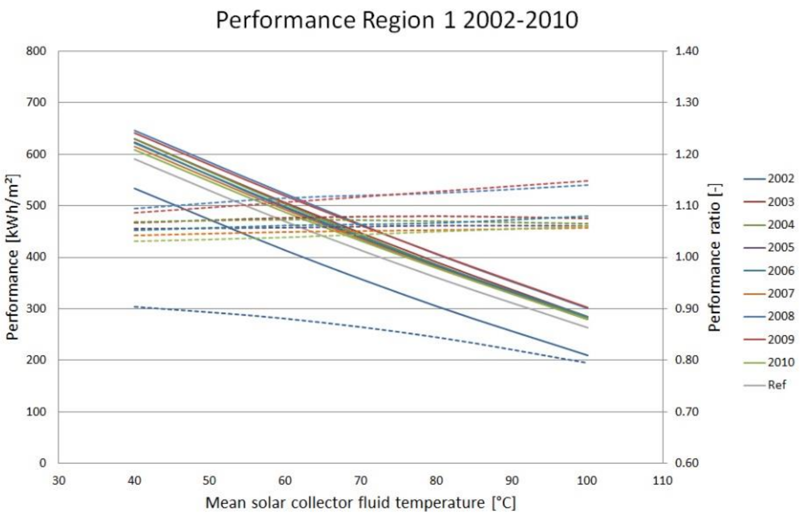

Figure 4. Calculated yearly thermal performance of a collector field as a function of the mean solar collector fluid temperature for region 1.

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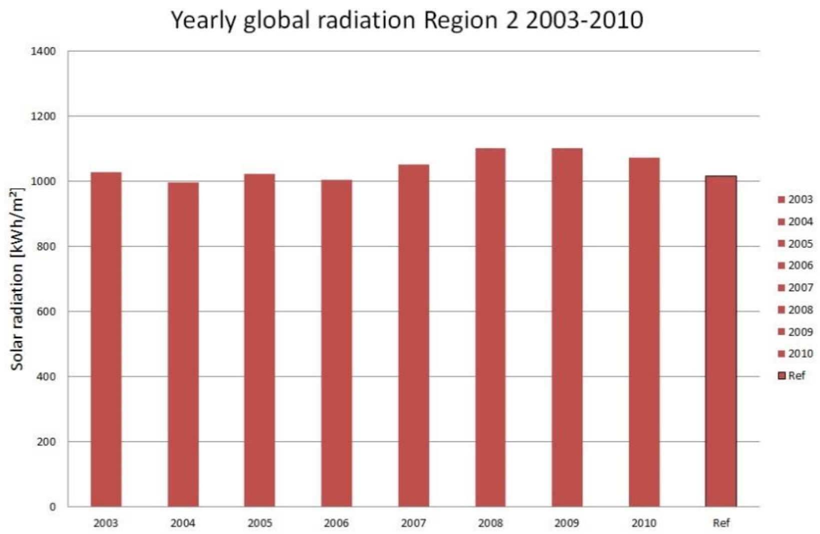

Figure 5. Measured yearly global radiation for region 2.

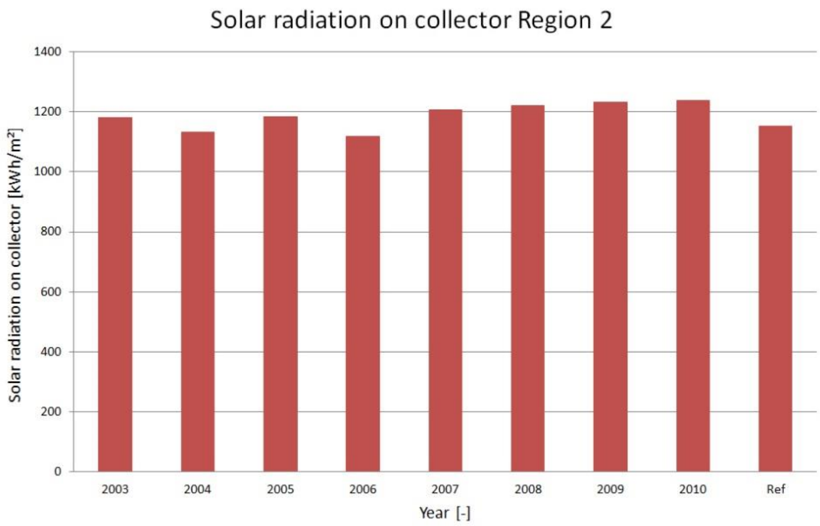

Figure 6. Calculated yearly solar radiation on collectors for region 2.

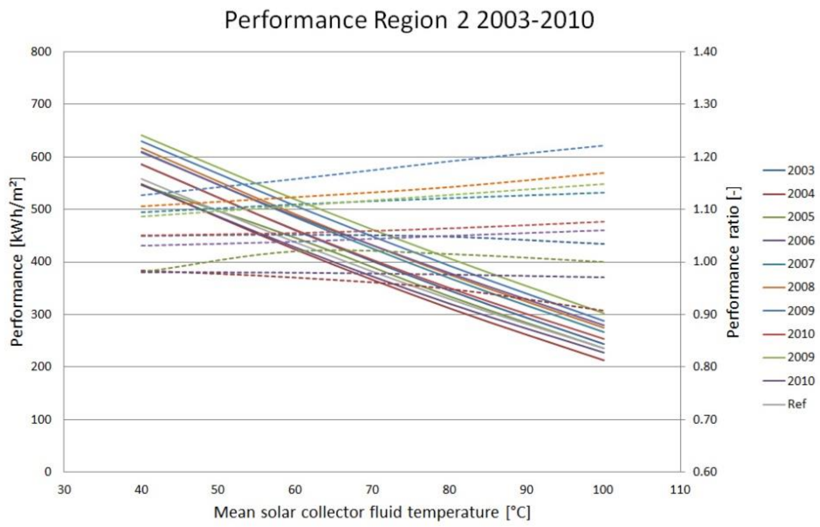

Figure 7. Calculated yearly thermal performance of a collector field as a function of the mean solar collector fluid temperature for region 2.

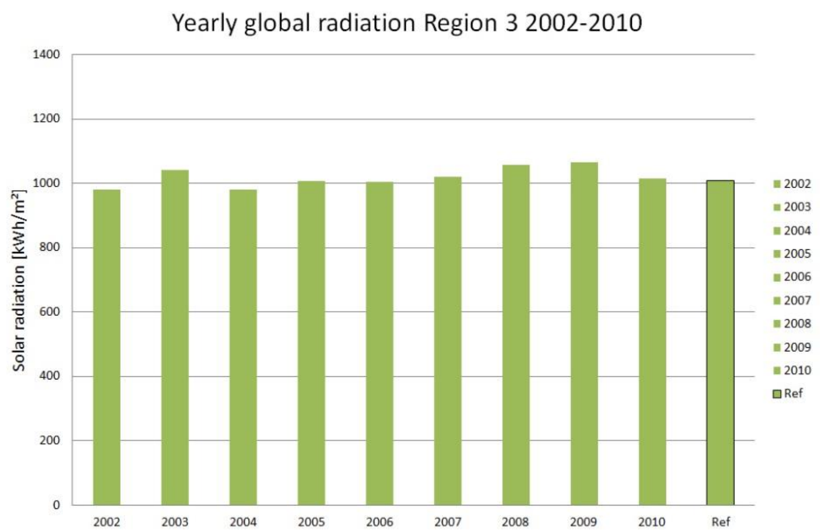

Figure 8. Measured yearly global radiation for region 3.

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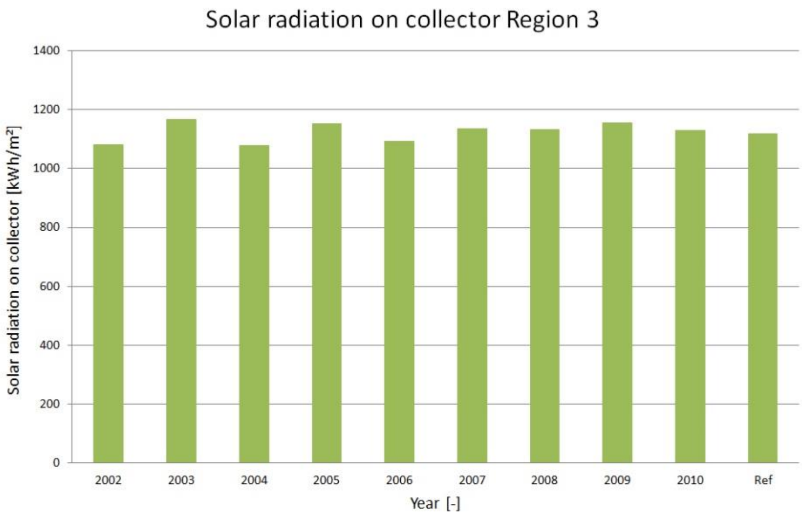

Figure 9. Calculated yearly solar radiation on collectors for region 3.

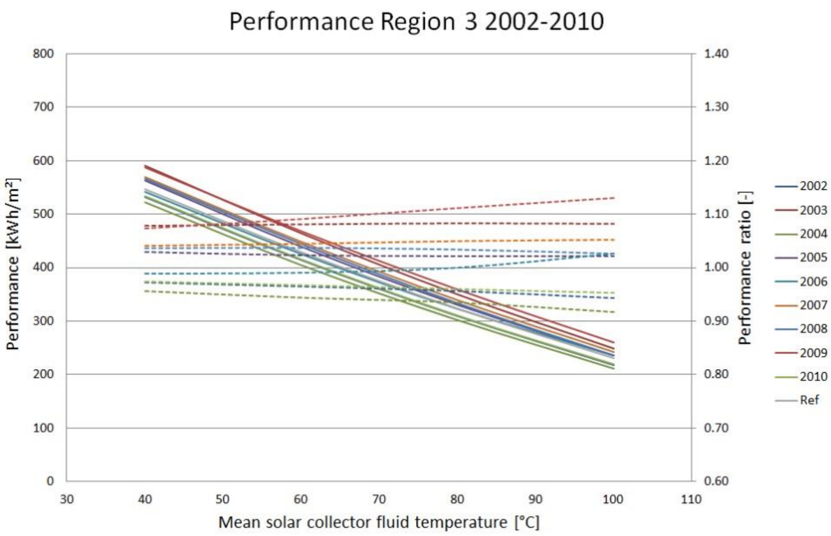

Figure 10. Calculated yearly thermal performance of a collector field as a function of the mean solar collector fluid temperature for region 3.

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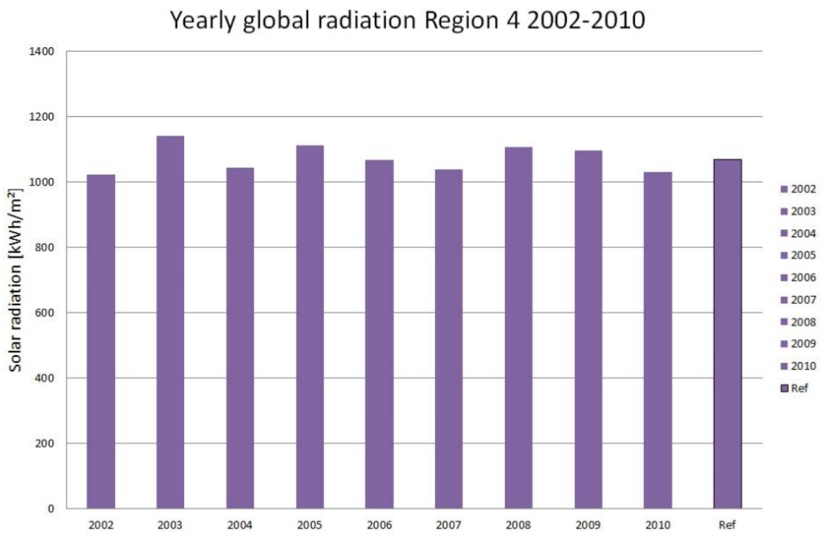

Figure 11. Measured yearly global radiation for region 4.

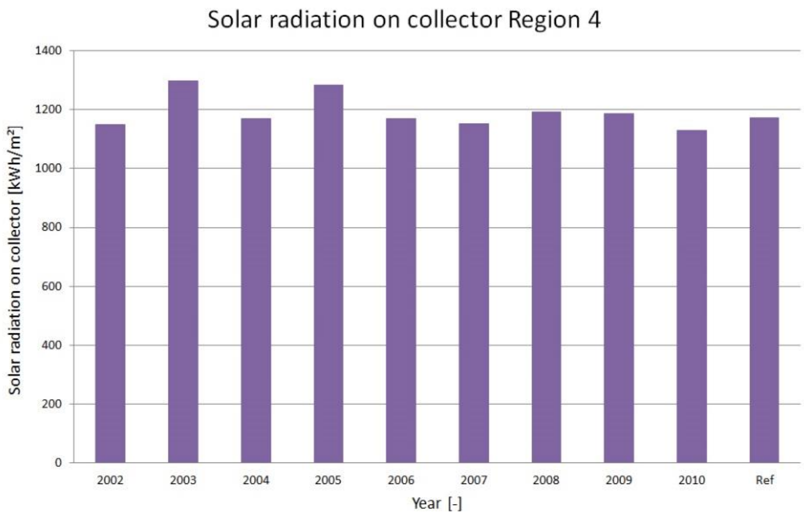

Figure 12. Calculated yearly solar radiation on collectors for region 4.

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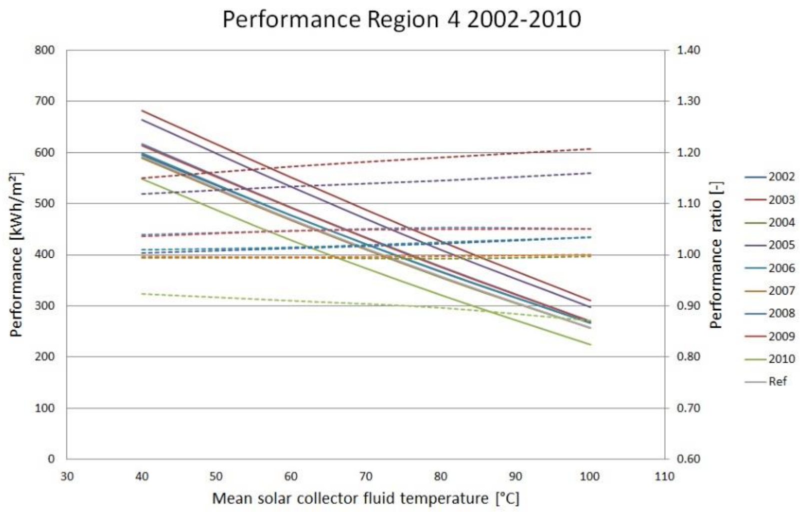

Figure 13. Calculated yearly thermal performance of a collector field as a function of the mean solar collector fluid temperature for region 4.

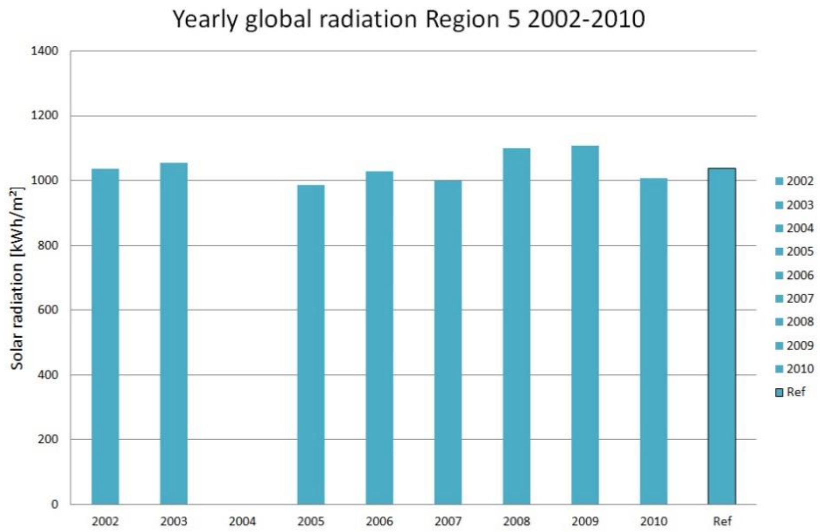

Figure 14. Measured yearly global radiation for region 5.

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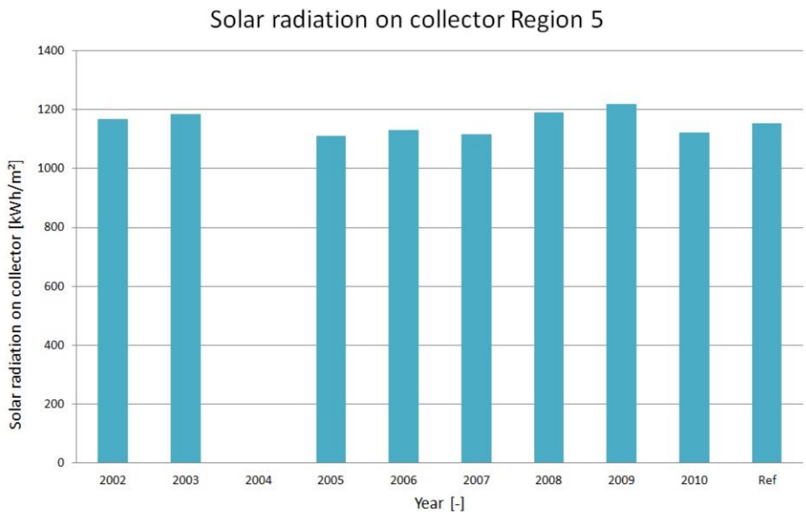

Figure 15. Calculated yearly solar radiation on collectors for region 5.

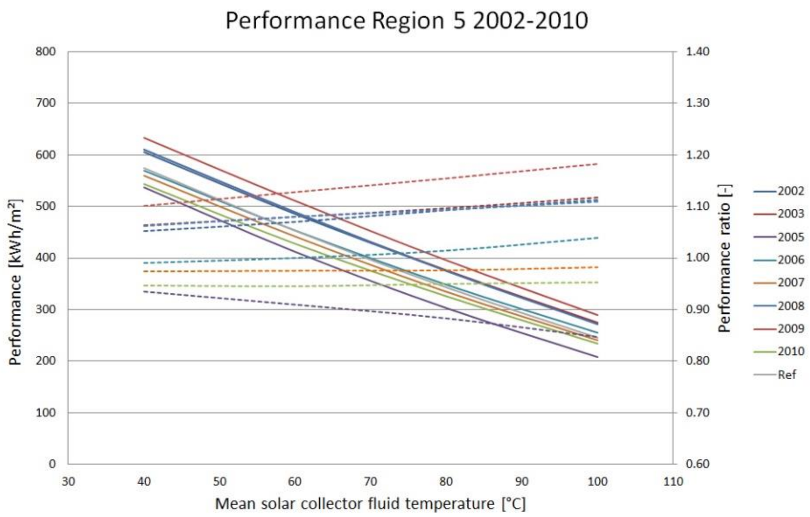

Figure 16. Calculated yearly thermal performance of a collector field as a function of the mean solar collector fluid temperature for region 5.

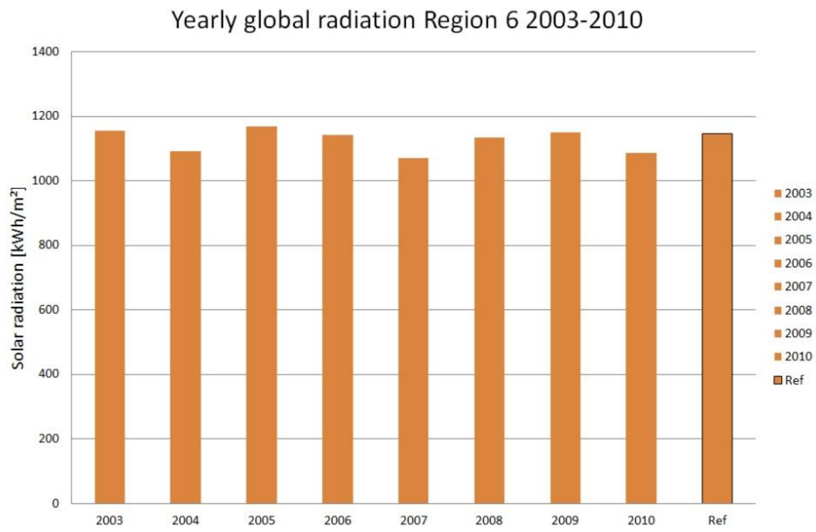

Figure 17. Measured yearly global radiation for region 6.

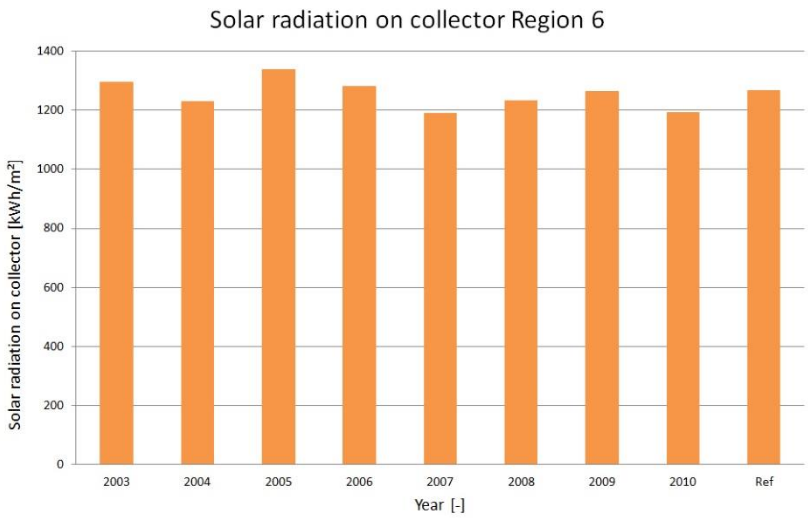

Figure 18. Calculated yearly solar radiation on collectors for region 6.

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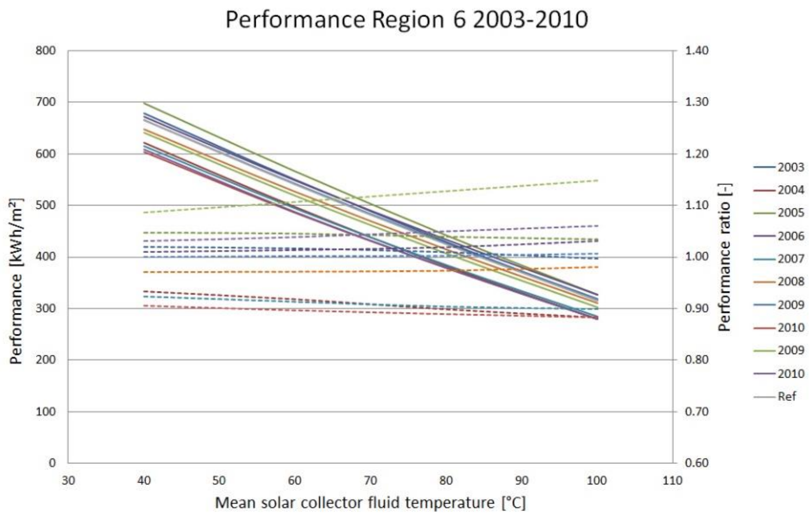

Figure 19. Calculated yearly thermal performance of a collector field as a function of the mean solar collector fluid temperature for region 6.

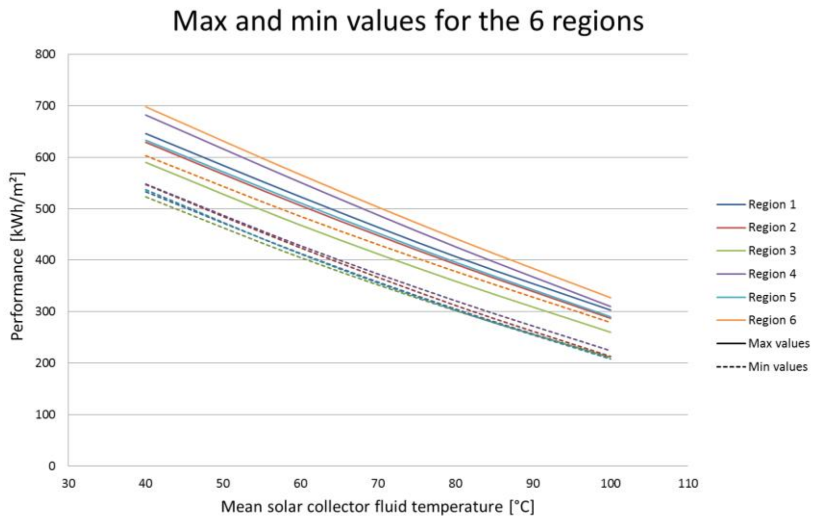

Figure 20. Calculated highest and lowest yearly thermal performance for the Danish regions as a function of the mean solar collector fluid temperature.

Figure 20 shows the highest and lowest yearly thermal performances for all six regions as a function of the mean solar collector fluid temperature.

The measured yearly global radiations on horizontal are in the interval 980 kWh/m² - 1150 kWh/m². The highest yearly global radiation is 17% higher than the lowest yearly global radiation. The highest yearly global radiation is measured in region 6, Bornholm for 2005. The lowest yearly global radiation is measured in region 3, the inner parts of Jutland for 2004.

Based on the hourly global radiation measurements, the hourly solar radiations on the collectors are calculated. Shadows from the row placed in front of the collectors are considered. The calculated yearly solar radiations on the collectors are in the interval 1077 kWh/m² - 1337 kWh/m². The highest yearly solar radiation on the collectors is 24% higher than the lowest yearly solar radiation on the collectors. Again, the highest yearly solar radiation on the collectors is for region 6, Bornholm for 2005 and the lowest yearly solar radiation on the collectors is for region 3, the inner parts of Jutland for 2004.

The yearly thermal performance is strongly influenced by the mean solar collector fluid temperature. For decreasing temperature, the yearly thermal performance is increasing and the percentage differences between the yearly thermal performances from year to year are decreasing.

It is seen that the yearly thermal performances of the solar collectors typically are highest in region 6, Bornholm followed by regions 1 and 4, the northern part of Jutland and Funen & the western part of Zealand, region 5, the eastern part of Zealand, region 2, parts of Jutland close to the coastline and last region 3, the inner parts of Jutland.

The highest and lowest yearly thermal performances for the solar collector field with a mean solar collector fluid temperature of 60°C are listed in table 1 for the six regions.

Table 1. Calculated highest and lowest yearly thermal performances of a solar collector field for the period 2002-2010 for six regions with a mean solar collector fluid temperature of 60°C.

Region	Highest thermal performance kWh/m² collector	Lowest thermal performance kWh/m² collector	Ratio between highest and lowest yearly thermal performance -
1	523	413	1.27
2	506	424	1.19
3	468	405	1.16
4	551	428	1.29
5	511	412	1.24
6	566	485	1.17

For a mean solar collector fluid temperature of 60°C the yearly thermal performance is in the interval 405 kWh/m² collector - 566 kWh/m² collector. The lowest thermal performance is calculated for 2004 for region 3, the inner parts of Jutland. The highest calculated thermal performance is for 2005 for region 6, Bornholm. The highest yearly thermal performance is 40% higher than the lowest yearly thermal performance.

The percentage differences between the highest and lowest yearly thermal performance of the collectors are lowest in region 3, the inner parts of Jutland, followed by region 6, Bornholm, region 2, parts of Jutland close to the coastline, region 5, the eastern part of Zealand, region 1, the northern part of Jutland, and last region 4, Funen & the western part of Zealand.

References

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