Performance of the 27000 m^2 parabolic trough collector field, combined with Biomass ORC Cogeneration of Electricity, in Brøndeslev Denmark

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SUMMARY

A new concentrating solar power (CSP) plant combined with biomass combined heating and power (CHP), using organic rankine cycle (ORC) technology has been taken into operation in Brønderslev, Denmark during spring 2018. The price for biomass is expected to increase with more and more use of this very limited energy source and then CSP will be cost effective in the long run, also in the Danish climate. Oil is used as heat transfer fluid in the high temperature PTC collectors in this application for district heating. Total efficiencies and costs, competitive to PV plants, are expected. The paper presents a performance analysis of the full scale CSP collector field of 27000 m^2 in the Danish climate during 2017.

key-words: concentrating solar power, combined heating and power, organic rankine cycle, TRNSYS

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1. Introduction

The potential for installing ORC-units in Danish district heating plants with wood chip boilers is calculated to 30 utilities with more than 20,000 MWh in yearly heat production [1]. The first Danish plant (4 MW heat and 0.75 MW electricity) was implemented in 2011-12 in Marstal.

Aalborg CSP A/S has developed a concentrating solar collector array design. It has been demonstrated in several pilot plants. In the Brønderslev plant a further improved large collector array layout and control for operation temperatures up to 312°C is demonstrated.

The Brønderslev district heating company, expects lack of biomass in the future, resulting in higher prices. Therefore they implemented a CSP-plant, to supply the ORC with hot oil in periods with enough DNI (Direct Normal Irradiance). The collector array area is 27000 m^2 and the nominal peak power is 16 MW, see figure 1 and 2.

The collector array consists of very large 700 m^2 PTC (Parabolic Trough) collectors units with just one tracker each. Four such units are connected in series in each loop to reach a high flow velocity in the absorber tubes. The heat transfer media is a special thermal oil.

DTU has previously developed solar radiation models to determine the DNI availability in Denmark, see figure 3. They also investigated the potential performance for good PTC collectors utilizing direct solar radiation with promising results, see figure 8. Also a normal flat plate collector needs some direct radiation to reach operating temperatures and deliver heat.

Figure 1. The Brønderslev ORC-CSP biomass combined heat and power plant. The collector area is 27000 m^2 and nominal thermal power 16 MW.

The collector absorber tubes are of vacuum type giving extremely low heat losses even at high temperatures. This means that the collectors can start at extremely low beam radiation levels and that the tubes keep the temperature like a thermos flask between the sunshine periods.

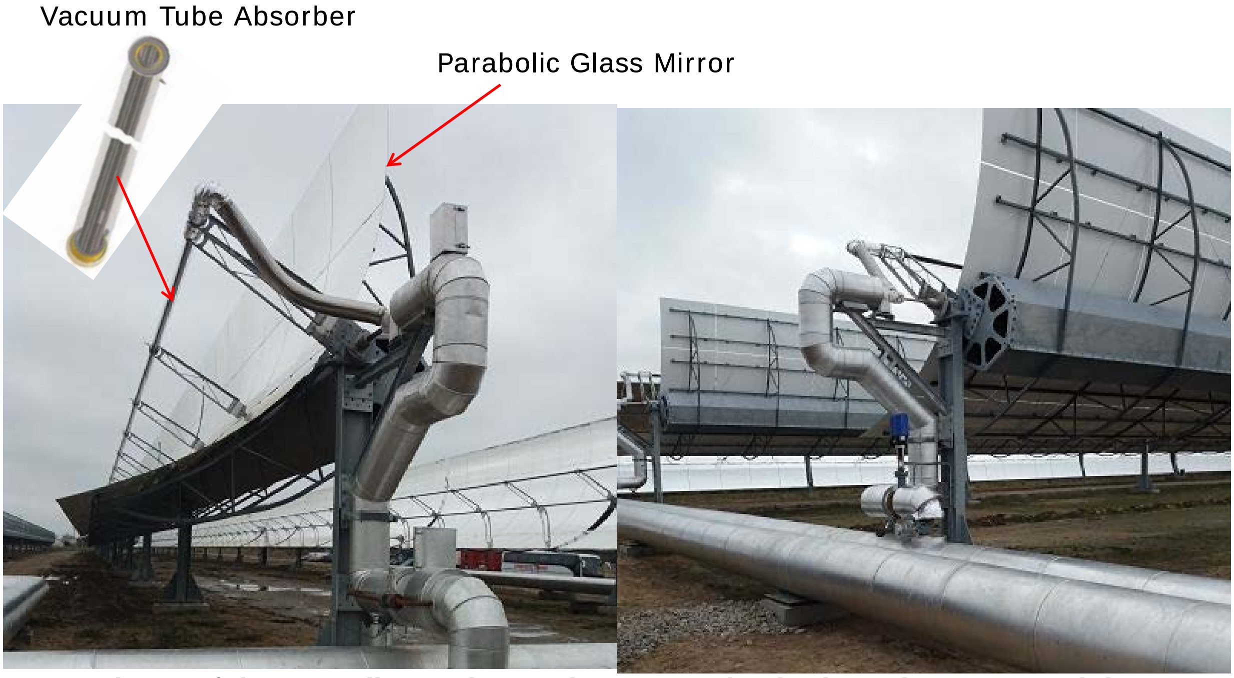

Figure 2. Closeup of the PTC collectors showing the vacuum tube absorbers, glass mirrors and the optimized mechanical trough metal structure. Only one tracker is needed for a 120 m long trough with almost 700 m^2 aperture area.

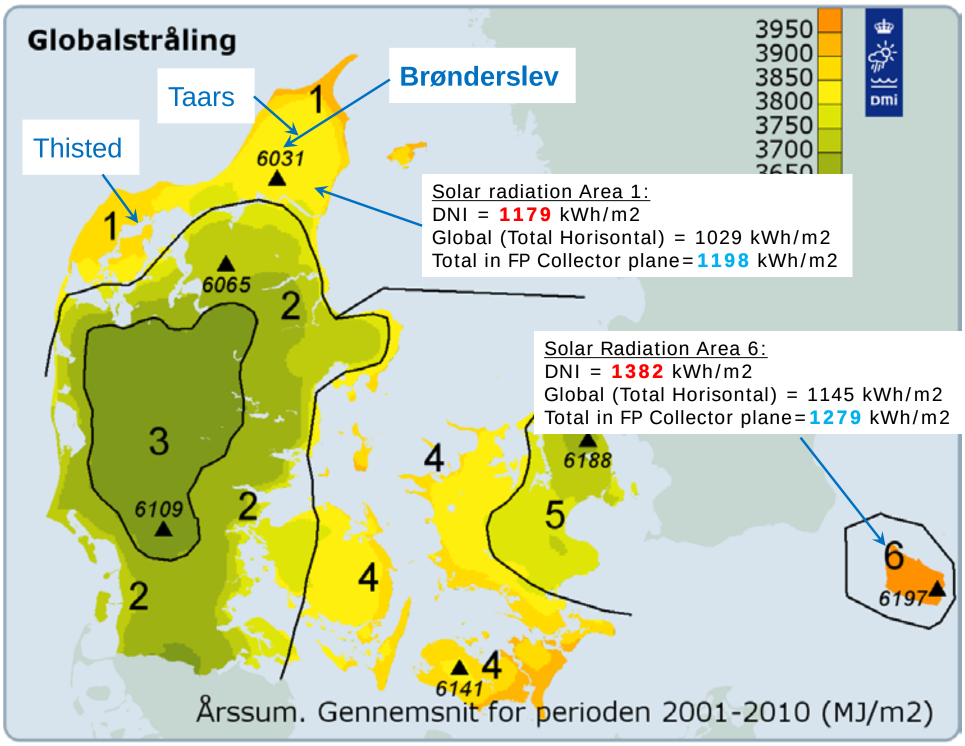

Figure 3. The Solar radiation distribution and availability in Denmark. Yearly Solar radiation for area 1:DNI=1179 kWh/m^2. Global (total Horisontal=1029 kWh/m^2. Total on Flat Plate Collectors=1198 kWh/m^2.Yearly Solar Radiation for area 6: DNI=1382 kWh/m^2. Global Radiaton=1145 kWh/m^2. Total on Flat Plate Collectors 1279 kWh/m^2.

2. The Plant Technology

The Italian Company Turboden has delivered the ORC unit. In the last 15 years Turboden has implemented ORC-units at about 300 places. Of these, approximately 250 plants are heated up with oil from biomass boilers and of these 250 plants, 170 are placed in Germany, Italy and Austria. One plant using CSP as heat source was implemented in Morocco in 2010 and three new plants are under implementation or planning in Italy. The technical efficiency when using solar as heat source is higher than 15%. CSP Solar power with ORC is thus as efficient as photovoltaic systems and on top of this the large fraction of ORC condenser heat, can be used for district heating in this plant design giving a favorable total efficiency. The ORC CSP principle is schematically shown in figure 4.

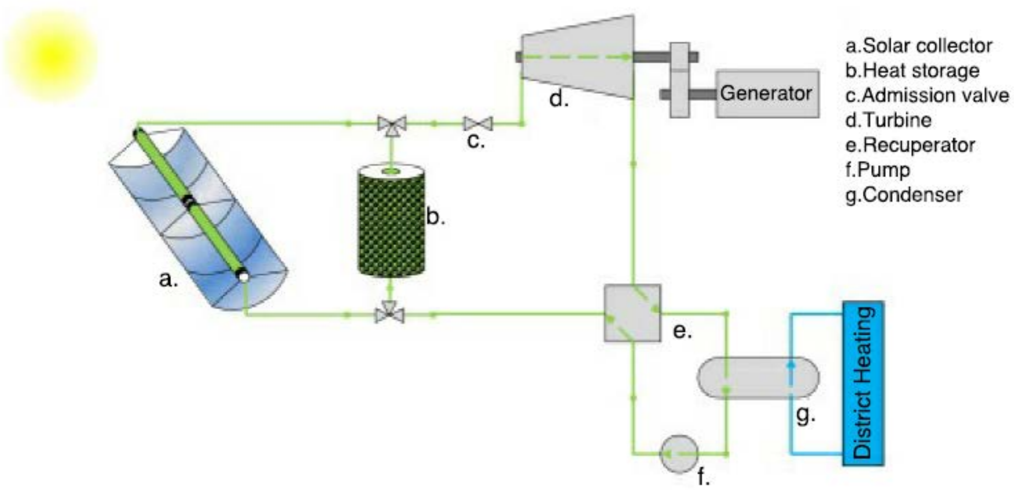

Figure 4. The ORC CSP principle. In this case the collector field is directly connected. In Brønderslev oil is used in the collector array.

The total Brønderslev system is shown in a simplified drawing in figure 5. The solar collector array can deliver heat both via the ORC machine or directly do district heating. The same for the biomass boiler, that also has a heat pump, to make use of waste heat from the biomass chimney and convert to district heating energy.

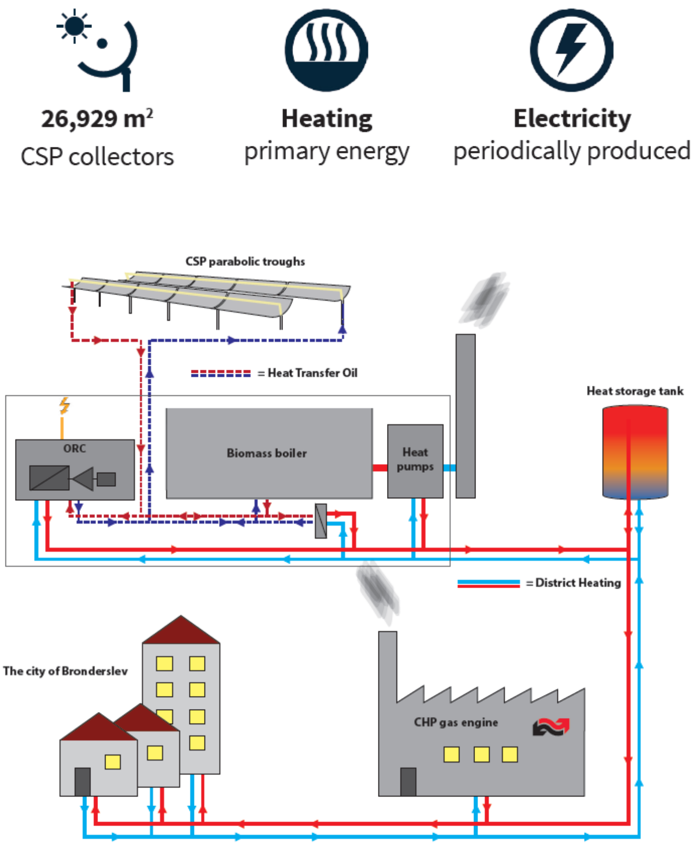

Fig.5. Flow sheet of biomass CHP-plant with ORC-power unit and feed-in of solar thermal energy both to the ORC and district heating network [3].

3. Measurements

To be able to analyze the collector field performance accurately the Brønderslev plant was instrumented carefully with advanced solar radiation equipment. Figure 6 shows the weather station and the DNI sensor measuring the direct or beam solar radiation coming from the sun disc. This sensor is very sensitive to dirt and is equipped with an air pressure cleaning device.

Figure 6. The weather station and DNI sensor for direct solar radiation measurements. Note the automatic air pressure cleaning system.

4. The 27000 m^2 CSP Collector field modelling

A detailed TRNSYS model has been developed for the full size collector field, so that control and performance can be investigated in detail.

Then effects of for example weather and operating conditions can be exactly taken into account and a true performance check can be made.

In figure 7 a comparison between modeled and measured power and temperatures is shown. The agreement is very good over the whole day. The thermal power delivered to the district heating network is also peaking close to the nominal 16 MW.

In figure 8 the solar radiation conditions with DNI (Direct Normal Incident radiation) and direct radiation in the tracking collector plane is shown for the same day. Also the incidence angle is given. This shows the effect of turning the tracking axis from exactly North South direction. The daily profile is then changed and may be adapted to the highest electricity price that at present often is in the mornings at around 8-10.

In figure 9 all relevant temperatures and the oil and water mass flow rates are shown. It can be seen that during this day the flow control is done only on the water side of the heat exchanger not on the oil side. The oil side shows very high temperatures compared to what is delivered to the district heating network. This control strategy can be optimized later when the plant is in full operation with ORC electricity production.

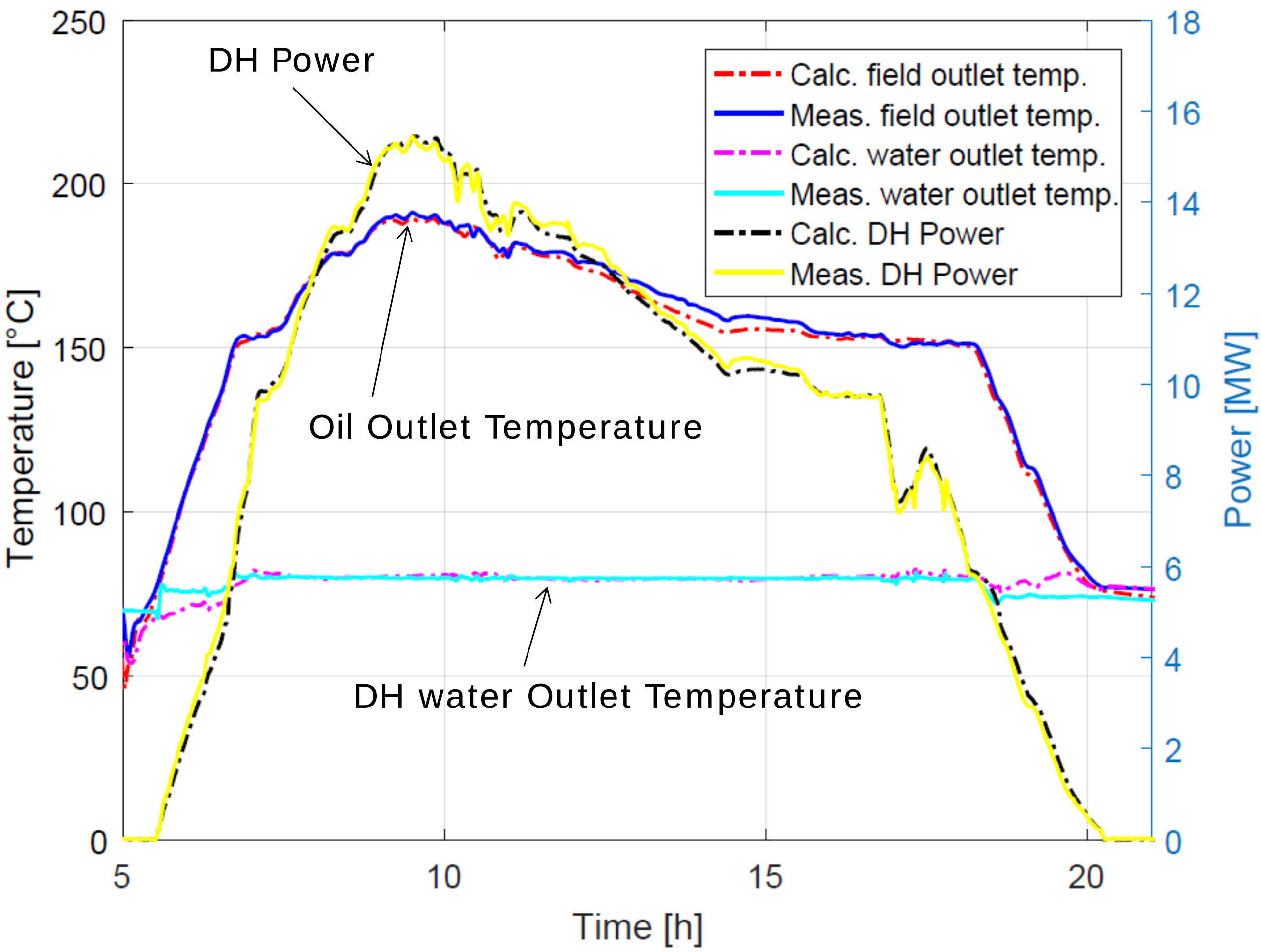

Figure 7. Detailed TRNSYS model validation for direct District heating operation. The match is very good concerning power but also temperature levels on water and oil side.

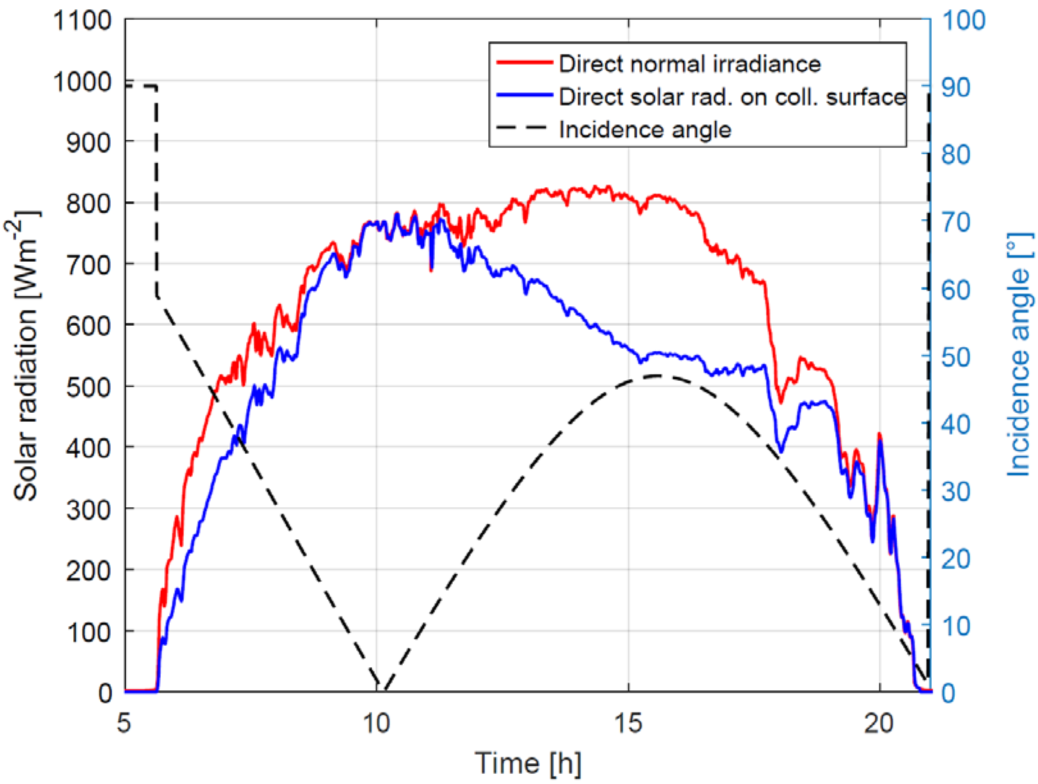

Figure 8. The solar radiation and incidence angles during the day shown for model validation in figure 7.

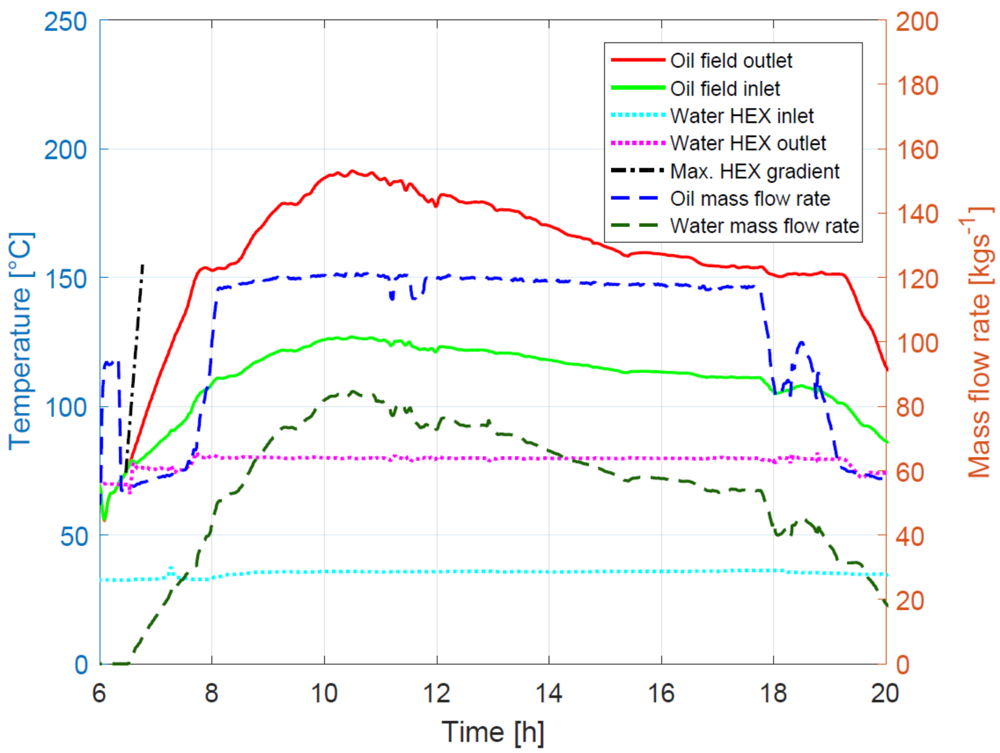

Figure 9. The most important temperatures and flows during the validation day in figure 7. The flow on the water side of the district heating heat exchanger is controlled to get a constant forward temperature to the district heating network.

Figure 10 shows the potential yearly thermal performance of a CSP solar collector field for different regions in Denmark determined with the validated model.

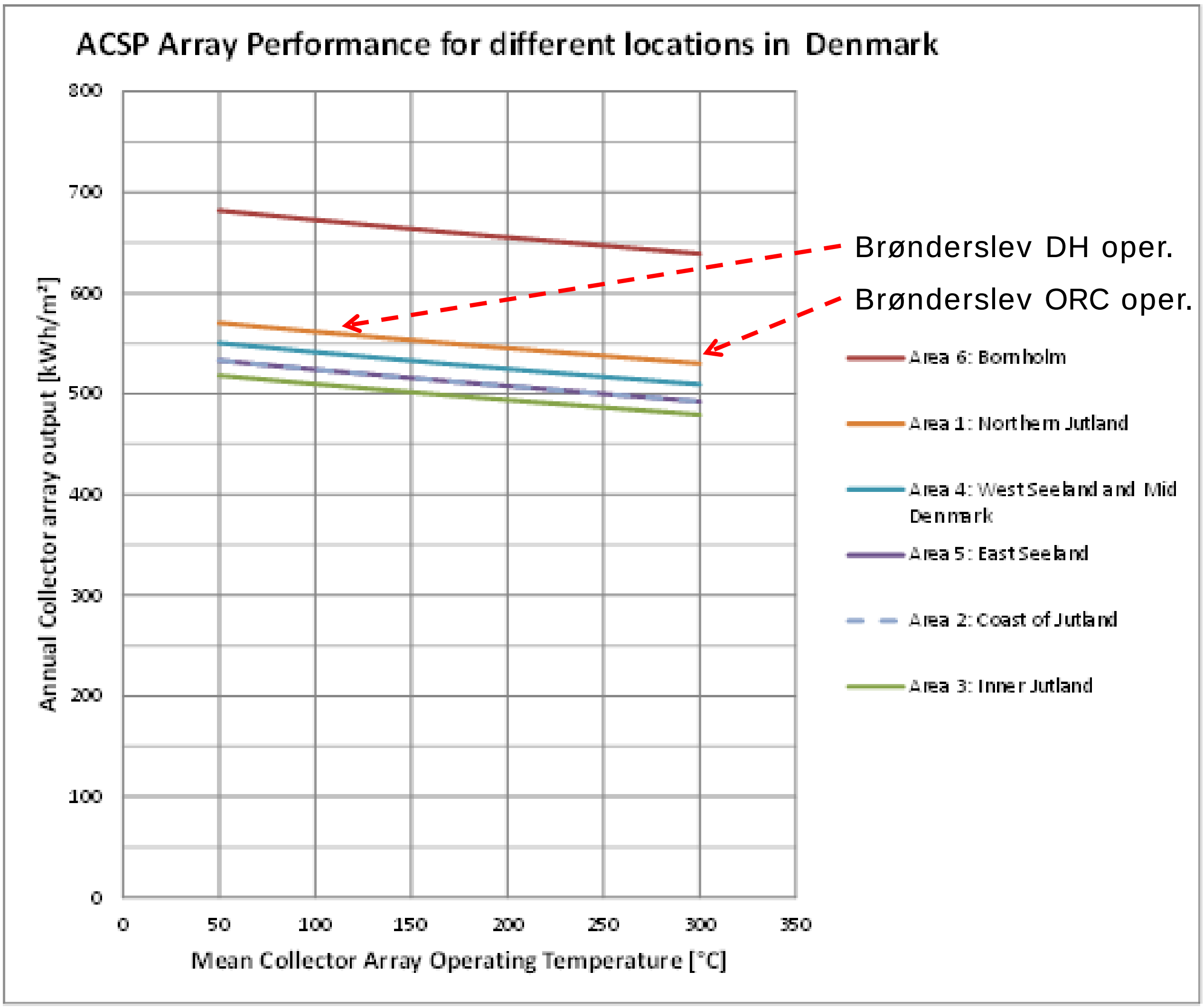

Figure 10. Potential CSP performance in different parts of Denmark at a wide temperature span. Bornholm has an extra favourable climate being and island. The difference between the other locations is surprisingly small. Danish reference year data and a validated collector model and parameters have been used.

5. Conclusions

The 27000 m^2 CSP array performance and control has been modelled in TRNSYS and a model validation is presented in this paper.

The first detailed results show a collector array performance close to the expectations.

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