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OPERATIONAL IMPROVEMENTS OF A LARGE SCALE SOLAR THERMAL PLANT USED FOR HEAT SUPPLY IN THE HAM PRODUCTION

Ilyes Ben Hassine[1], Mariela Cotrado S.[1], Robert Söll[2] and Dirk Pietruschka[1]

[1] zafh.net Research Center on Sustainable Energy Technology, Schellingstraße 24, 70174 Stuttgart (Germany)

[2] S.O.L.I.D. Solarinstallationen und Design GmbH, Puchstrasse 85, 8020 Graz (Austria)

Abstract

The company S.O.L.I.D. and Fleischwaren Berger in Austria are operating since the end of June 2013 a solar thermal plant including a 1.067m² large flat plate field and a 60m³ storage tank. The solar plant is used to preheat the feed water of a steam boiler operated with fuel oil and also to heat service water up to 70°C (Fig.1). The solar plant has been installed in the framework of the FP7 demonstration project InSun. The objective of the InSun project is the demonstration of reliability and quality of large scale solar thermal plants for the generation of heat used in three different industrial processes working at low and medium temperature ranges.

The first results of the system installed in Austria have already been published (Cotrado et al. (2013)). After the analysis of first monitoring data, some optimization potentials for the operation of the solar plant were identified. Using dynamic simulation tools, new operation parameters are set to enhance the system performance and to achieve higher solar yields (up to 2.4% more). The measures include sharing the gained heat between both processes and controlling the collector loop flow rate.

Coupling the operation of both primary and secondary side pumps increases the solar gains by approximately 2.3 MWh/a. A season dependent charging of the storage tank enables energy savings of around 650 kWh/a. Furthermore, several measures to damp the originally high fluctuating supply temperature in the solar loop are shown.These are the optimization of the PI control parameters, the placement of a temperature sensor and the use of a ΔT- instead of a supply temperature set point. This also helps to increase significantly the durability of the solar pumps.

Keywords: Solar heat; Industrial process heat; solar collectors; solar thermal plant, ham production, operational improvement.

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1. Plant description

Fleischwaren Berger GmbH is a company located in Sieghartskirchen, Lower Austria with about 380 employees. The Production is approximately 80-90 tons of meat and sausage products per day. In Fig.1 a general diagram of the layout is shown. For the processing of the delivered feed stock / raw material coming from the abattoirs, Berger installed together with S.O.L.I.D. a solar flat plate collector filed with an overall area of ca. 1,067 m². The system was originally planned as roof top type to primarily preheat feed water for the steam boiler. The surplus heat was supposed to increase the supply temperature within the heating water system up to 70 °C. The feed water (HE2) of the steam vessel shall be preheated from approx. 40 °C up to 95 °C. The steam is internally required for process heating – specifically for ham cooking. The hot water (HE3) is required for drying the air conditioning systems – specifically in the climatic chamber and the maturation room for production of long-lasting sausages.

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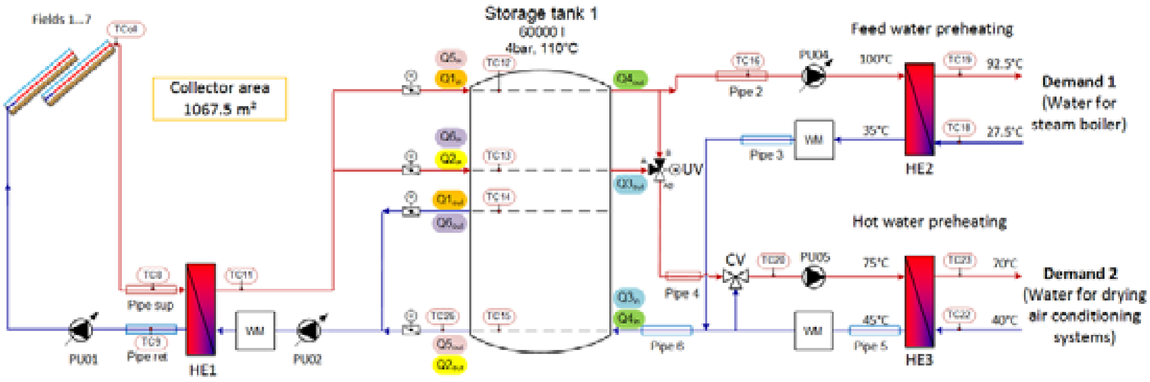

Fig. 1: General layout of the installation

1.1. System performance

Fig.2 shows the amount of solar irradiance (rad) on the collector plane, the collector useful heat (sol HX), the heat transferred through HE2 and HE3 during the current monitoring period. The collector utilization ratio ranges from 7 in the winter to 40% in autumn and spring months. The system utilization ratio varies between 6 and 37% respectively. Due to technical difficulties encountered while planning the roof top solar plant, the installation was shifted to the ground and the system size was limited to 1,067 m² with significant shadowing effects. Due to the temperature level reached on the top of the storage, the hot water sink (and not the boiler as expected) was predominantly assisted by the solar system. The Measurement data are currently being analyzed to find out how to augment the temperature level in the primary circuit.

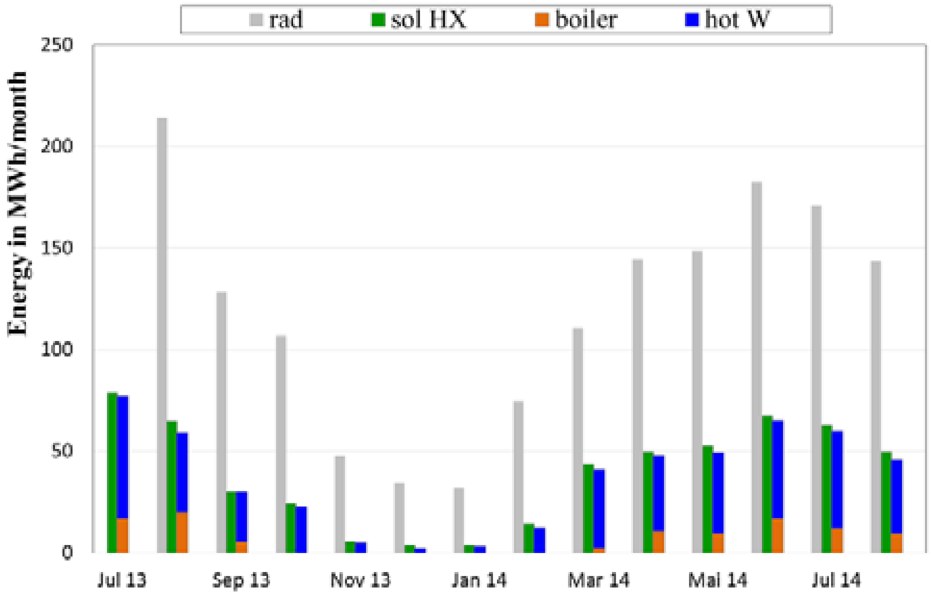

Fig. 2: Share of the collector useful heat

1.2. Solar field behaviour

Fig.3 shows a daily course of global irradiance, medium flow and supply temperature in the solar field. The supply temperature is considerably fluctuating within the medium flow (e.g. medium irradiance) range due to the fluctuating pump flow in the collector field. The applied controller is obviously unable to cope with the changing dynamic of the field within this range.

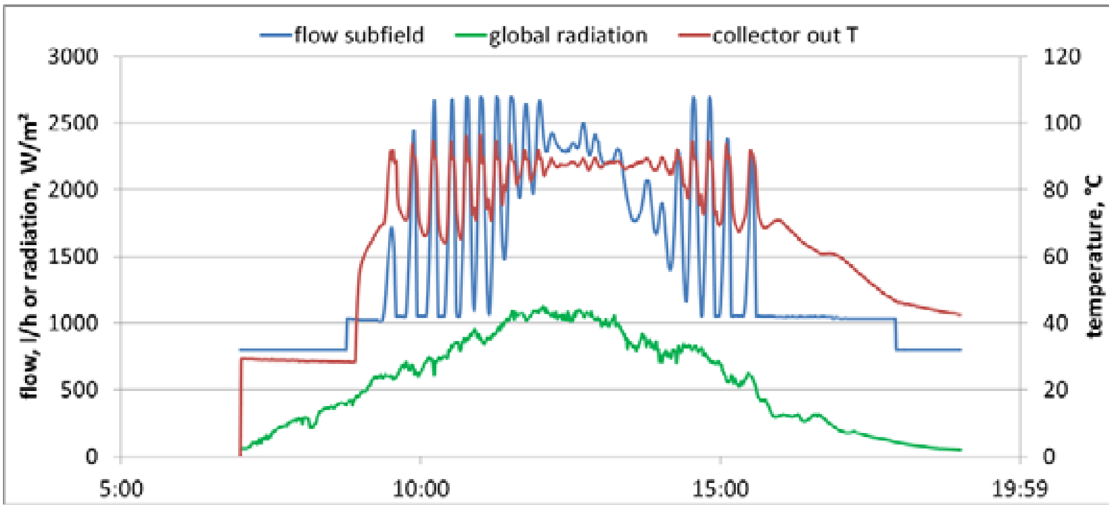

Fig. 3: Measurement data of the solar loop

In the following, the solar field behavior is addressed and some measures are presented to improve the temperature course.

2. Control of the solar field

The control logic of the whole system was described in (Cotrado et al. 2013). The control variable in the solar field is the supply temperature TC08 (see Fig.1). A PI- controller (with anti-windup) is applied to maintain a constant temperature level. The solar heat exchanger (HE1) has two sides: one source (primary) and one load (secondary/storage) side.

2.1. Modeling

In order to take the system dynamics and fast irradiance disturbances into account, the originally aggregated collector field model described in (Cotrado et al. 2013) was extended using the MATLAB Toolbox CARNOT to consider:

- 3 aggregated collector subfields instead of 1
- Several pipe diverters
- Heat capacity of pipe wall
- Dead time of pump
- Dead time of temperature sensors
- Weather data time resolution of 1 min

A PI controller was designed to regulate the solar side supply temperature around 95°C. The controller parameters were tuned for high flow conditions (>14 l/m²h) using the design rules of Reswick, Hrones and Chien (1952). The controller input is the temperature tracking error and its control signal is the percentage of pump speed. The parameters obtained are Kp = -0.087 %/K and Ti = 280 s. The load side pump was regulated to maintain a temperature difference of 5 K to the source side. The solar irradiation data at 23.08.2013 and the measured storage temperature at the load side were used as input values for a one day simulation. The flow and temperature courses of solar and load sides around the solar heat exchanger are presented below in Fig.4.

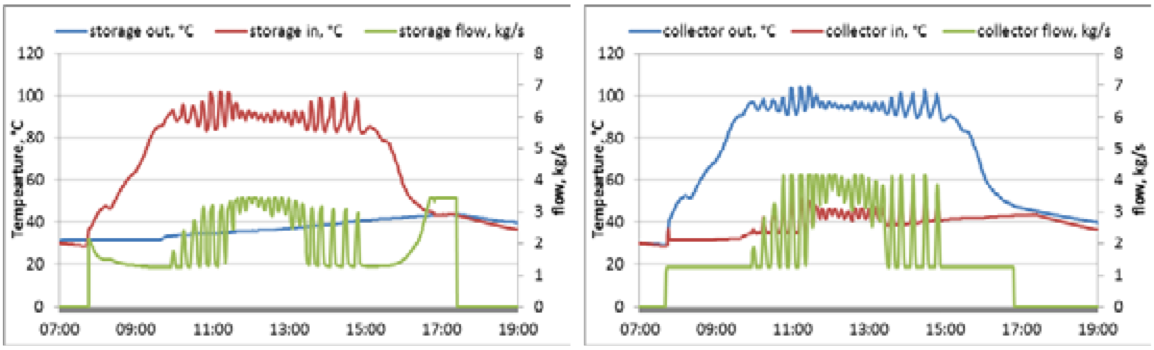

Fig. 4: Simulation data initial state

The figure shows a qualitatively similar behavior of temperature and flow as of measurement. The pump keeps oscillating between maximum and minimum frequency before the system reaches a certain settlement under high flow. On the load side the temperature oscillation amplitude reaches 20 °C.

2.2. Improvements

All improvements shown in this section were implemented upon the initial state model.

- T-sensor placement

The compensation time of the whole field was determined to be around 7min. One of the first measures to enhance the controllability of the system is to decrease the dead time by moving the temperature sensor TC08 closer to the field. Assuming the T-sensor to be maximally shifted by 37 m, which is the distance between the heat exchanger and the first mixer valve in the field, a better course in terms of temperature stability is obtained (Fig.5).

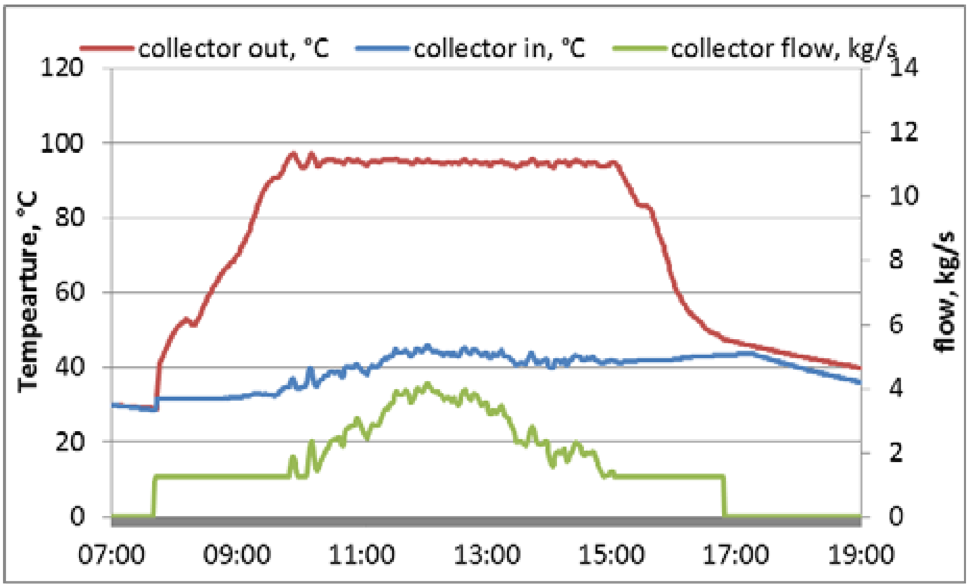

Fig. 5: Simulation data T sensor

The fluctuations in flow and temperature significantly decrease. Using the mean value of the output temperature of all subfields as input signal of the controller would similarly enhance the system controllability (lower dead and compensation time). This control layout was subsequently implemented by the operator.

- Optimized PI parameters

The PI controller was then tuned for medium flow conditions using the rules of Chien, Hrones und Reswick (1952). The parameters obtained are shown in the Fig.6 below (Kp = -0.042 %/K and Ti = 720s). The system gain at low flow is much higher, so that Kp should be half as much as for high flow.

Fig. 6: Empirically tuned PI parameters

The application of a medium-flow optimized PI controller leads to the course in the following Fig.7:

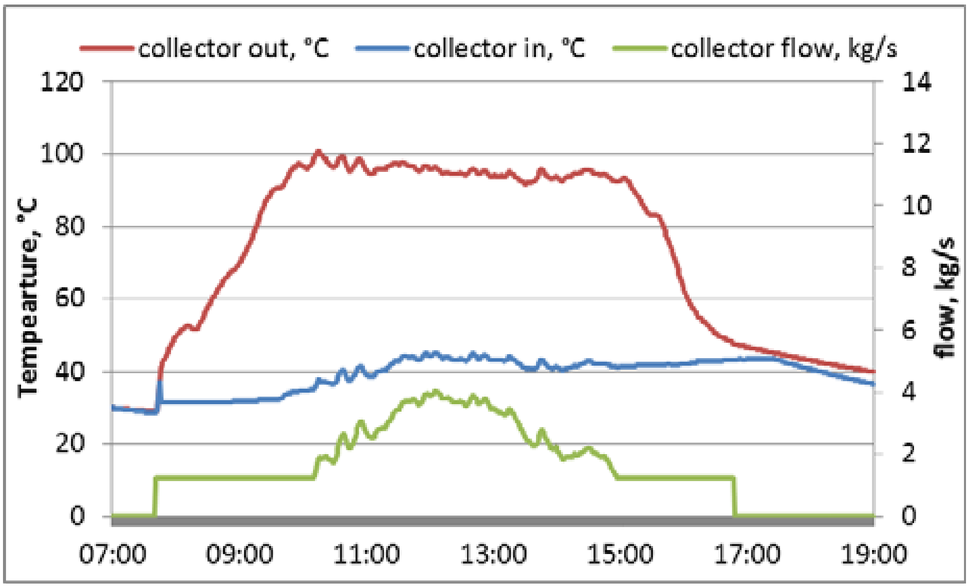

Fig. 7: Simulation data optimized PI

Some of the fluctuations calculated in the high flow range can be further decreased by applying an adaptive control scheme (switching between medium and high flow optimized parameters). The results obtained with an adaptive control structure are not presented.

- Control at constant ΔT

The variable speed control logic of pump 01 and 02 described in (Cotrado et al. 2013) was modified to the following:

Source pump PU01

- ON (max speed) if max. collector T > storage bottom T +hysteresis

- Speed control at constant ΔT between supply and return (between TC08 and TC09)

- Minimal speed 30%

Load pump PU02

- ON (max speed) if TC08 > storage bottom T +hysteresis

- Speed control at TC11=90°C

- Minimal speed 30%

Using ΔT instead of T as control variable reduces the influence of fluctuating return temperature and offsets the sensor dead time. The results of this improvement are presented in Fig.8.

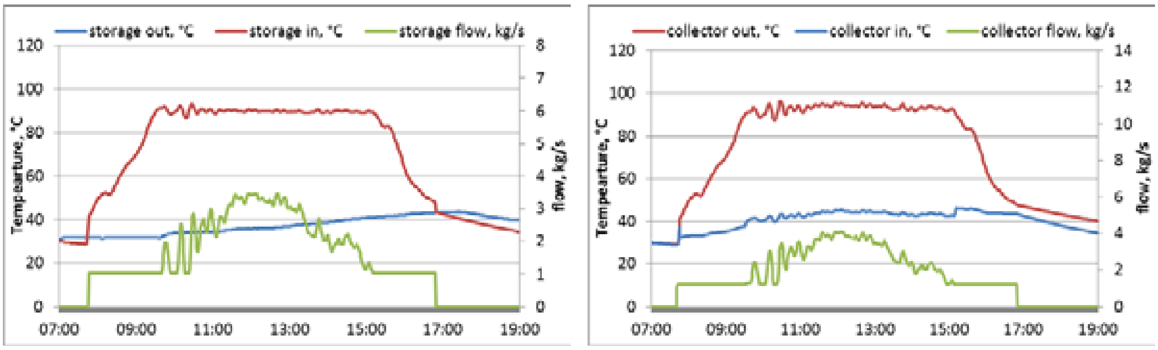

Fig. 8: Simulation data ΔT control

The three improvements shown in this section (in comparison in Fig.9, enhance the temperature course on both heat exchanger sides. The pump speed signal is significantly dumped, which would lead to higher durability of the pump components (bearings and other moving parts). The electricity consumption may also be reduced due to longer nominal operation time. The useful energy transferred to the load side was calculated for each case. Moving the temperature sensor (in the same magnitude as indicated above) will enable approx. 2.4% more solar heat gains with respect to the initial non-improved model.

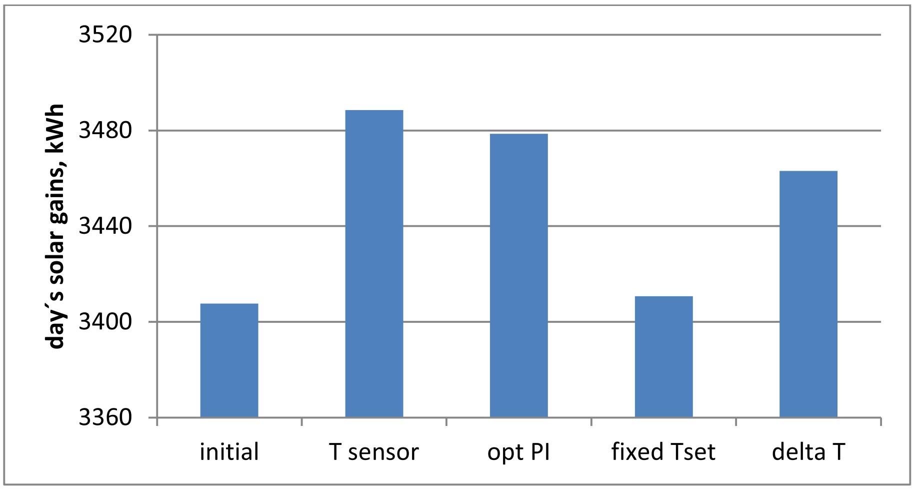

Fig. 9: Solar gains improvements for the 23rd of August

3. High level control of the whole system

The estimated solar gains in a SHIP plant depend on the required temperature at process level. Due to the fact that the solar heat in the case of Berger is supplied at different temperature levels depending on the heat sink, the heat share influences the amount of heat that can be transferred.

Using the plant model developed in TRNSYS the heat share between both sinks is varied in order to maximize the solar gains. The storage is charged depending on its mean temperature. The water flows to the solar heat exchanger from the middle or the bottom of the tank depending on TC14. A threshold value of 55 °C was initially applied to switch between both storage outlet nodes. Among all control parameters, it has been shown that this threshold has the greatest impact on the heat distribution to both processes.

The threshold is first changed from 40 to 85 °C as in Fig.10 in order to vary the mean storage temperature along the day.

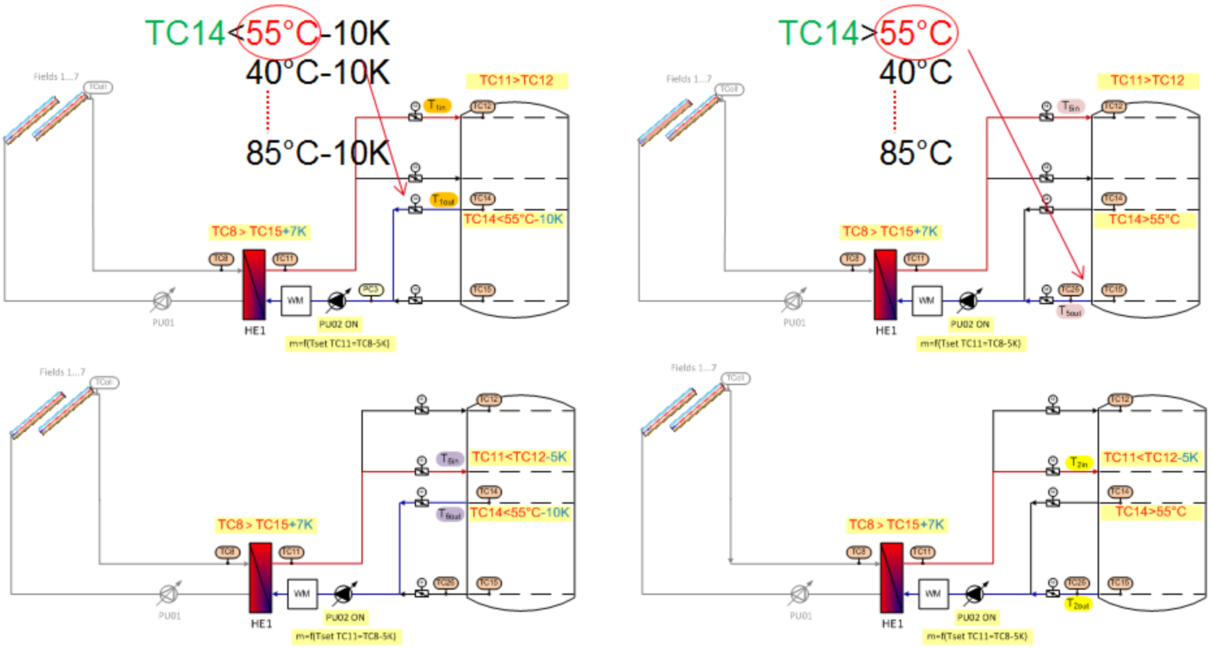

Fig. 10: Threshold variation

The yearly heat share varies depending on the applied threshold as shown in the figures below (11 to 13). With increasing threshold value, the feed water share rises and the hot water portion slightly decreases. The maximum solar heat gains can be reached with a 60 °C threshold. The transferred heat significantly decreases if the threshold is set to 85 °C because of higher stagnation hours.

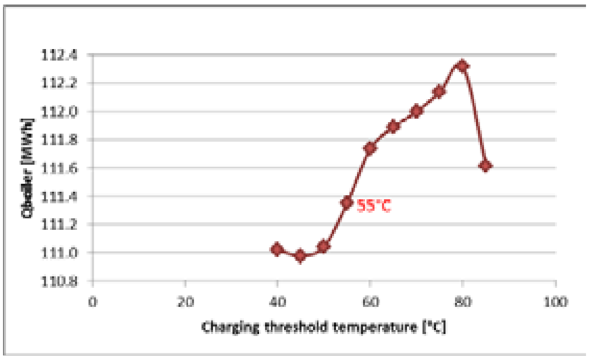

Fig. 11: Solar heat for feed water preheating

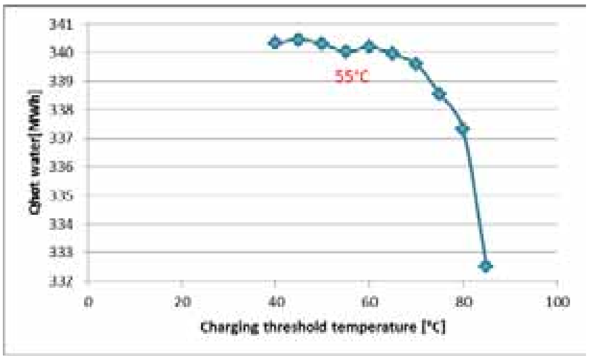

Fig. 12: Solar heat for hot water

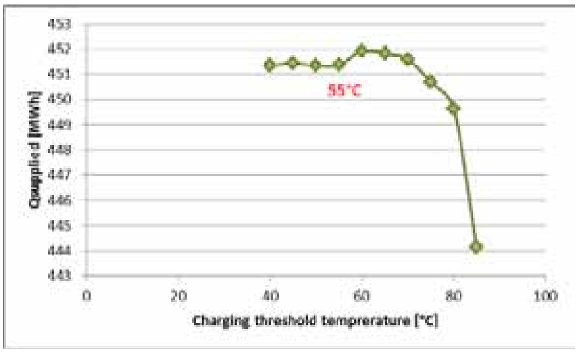

Fig. 13: Total solar gains

Second, a season dependent threshold value was applied. In a separate parametric study it has been demonstrated that the combination (60 °C for the summer and 50 °C for the winter) is the most favorable over the year. As shown in Fig.14 the solar heat gains slightly increase with season dependent storage charging.

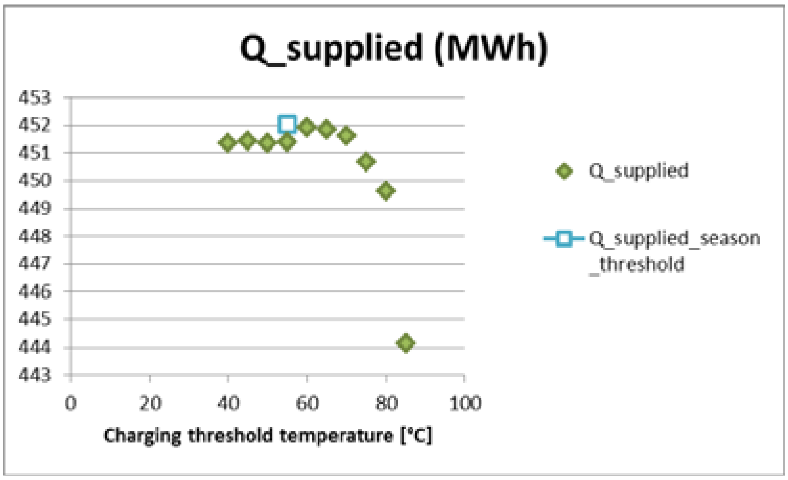

Fig. 14: Total solar gains with season dependent threshold

Finally dynamic storage charging was applied. The threshold value was changed according to the following daily schedule: 65 °C from 0 until 12AM and 55 °C later. The purpose of this measure is to quicker heat up the top side of the storage during the morning and to be able to supply the steam boiler tank. The improvement of the solar gains is highlighted in Fig.15.

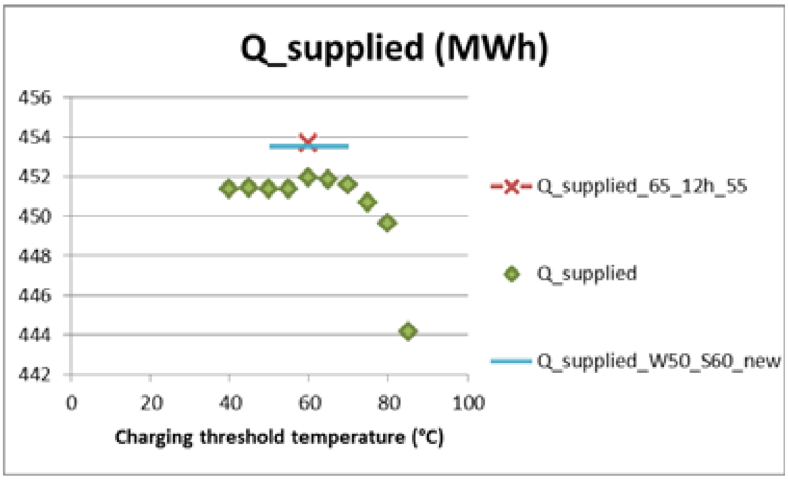

Fig. 15: Total solar gains with dynamic charging

Around 2.3 MWh more solar gains can be reached if dynamic storage charging is applied. The season dependent threshold variation leads to an improvement of 2.1 MWh

4. Conclusion

The Berger solar plant installed in the framework of the FP7 demonstration project InSun has been successfully commissioned in the summer 2013. The system is well equipped with different sensors and the monitoring data are automatically transferred to the project partners. The system utilization ratio reaches 37% in April 2014. Higher values are expected in the next operation period.

The analysis of the first monitoring data shows weaknesses of the collector loop controller. The system tends to oscillate in the medium flow range. This paper describes three measures to dump the temperature fluctuations and to enhance the pump life time. Furthermore, the threshold value for storage charging was varied to improve the solar gains by 2.3MWh/a. The calculated improvements are -compared to the solar heat gains- relative low. Further investigations of the heat streams through the whole system are still on going.

5. Acknowledgments

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6. References

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