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Solar District Heating – Fundamental Correlations regarding Energy and Economics

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Summary

Two solar district heating systems have been dynamically simulated: a central solar heating plant with tank thermal energy storage and a distributed solar district heating plant. The main parameters have been varied for each system. The analysis and assessment of the results from the over 200 000 simulations allow a good overview of the influence of different parameters on the performance and economics of the two systems, and therefore of the potential of solar district heating.

The SDH Online-Calculator (http://www.sdh-online.solites.de) developed by Solites is based on the simulations. It is available for market actors as user-friendly program for first system dimensioning and performance and economics calculations.

1. Introduction

Within the development of an online calculator, two different solar district heating systems have been dynamically simulated with TRNSYS [2] for numerous combinations of the main parameters: collector type, location, net operation temperature, collector aperture area, collector azimuth and slope for both systems. For the central solar heating plant with tank thermal energy storage the specific load has been varied in addition.

On the one hand, the resulting database has been analyzed in order to work out fundamental correlations between these parameters and the energetic performance of the two solar district heating systems. On the other hand, energetic results have been linked to an economical calculation. The influence of the boundary conditions i.e., technical parameters but also interest rate and collector costs, on the economical feasibility of the systems has been investigated.

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2. Hydraulic concepts

Two systems concepts have been considered in the simulations: a distributed solar district heating plant and a central solar heating plant with tank thermal energy storage.

Figure 1 shows the hydraulic concept of a distributed solar district heating system. The solar collector field is connected to the district heating net via a heat exchanger but without additional major components.

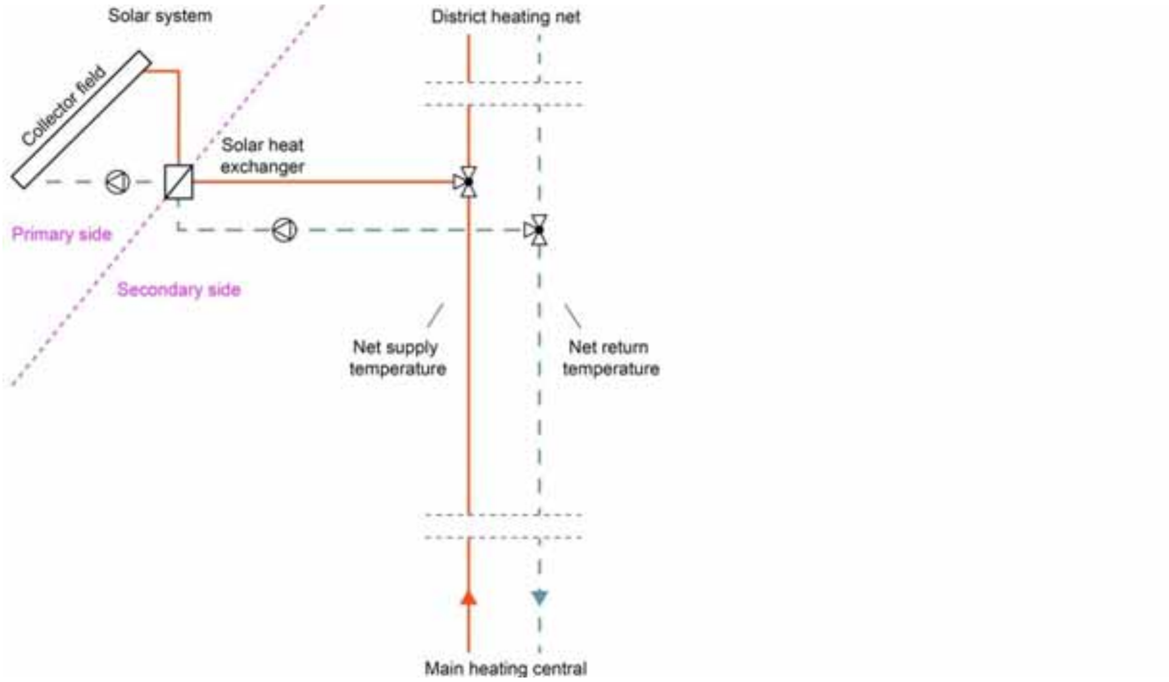

Fig. 1: hydraulic concept of the distributed solar district heating system

In the case of the distributed solar district heating system, it is assumed that the produced solar heat is always fed into a district heating net which can absorb the total solar heat produced at any time. Hence no self consumption is taken into account and the energy turnover in the district heating net is assumed to be always big compared to the amount of solar heat. The feed-in occurs from the nets return line into the forward line at user-defined forward temperatures between 70 °C for a low temperature distribution net and 110 °C for a high temperature net. To reach those feed-in supply temperatures as often as possible, both pumps around the solar heat exchanger are operated as matched-flow pumps.

The central solar district heating system with tank thermal energy storage is composed of a large collector field feeding into a tank thermal energy storage situated at the main heating central of the district heating system (see figure 2). The pumps on the primary side and on the secondary side of the solar heat exchanger are matched-flow controlled.

When the solar plant produces heat when there is no heat demand, it is fed into the storage. Depending on the temperature in the storage and the temperature coming from the collectors the solar heat can either be fed in at the top or in the middle of the storage. In time periods during which the solar plant produces heat and heat demand occurs at the same time, a direct pre-heating is possible i.e. the solar heat feeds directly into the main heating station and not in the storage. Also a simultaneous charging (in the middle) and discharging (from the top) of the storage is possible if e.g. the solar collectors deliver only low temperature heat due to bad weather conditions but at the same time the heat demand in the distribution network can be covered from the top part of the storage. An auxiliary heat source supplements the solar heating plant in order to cover the total heat demand.

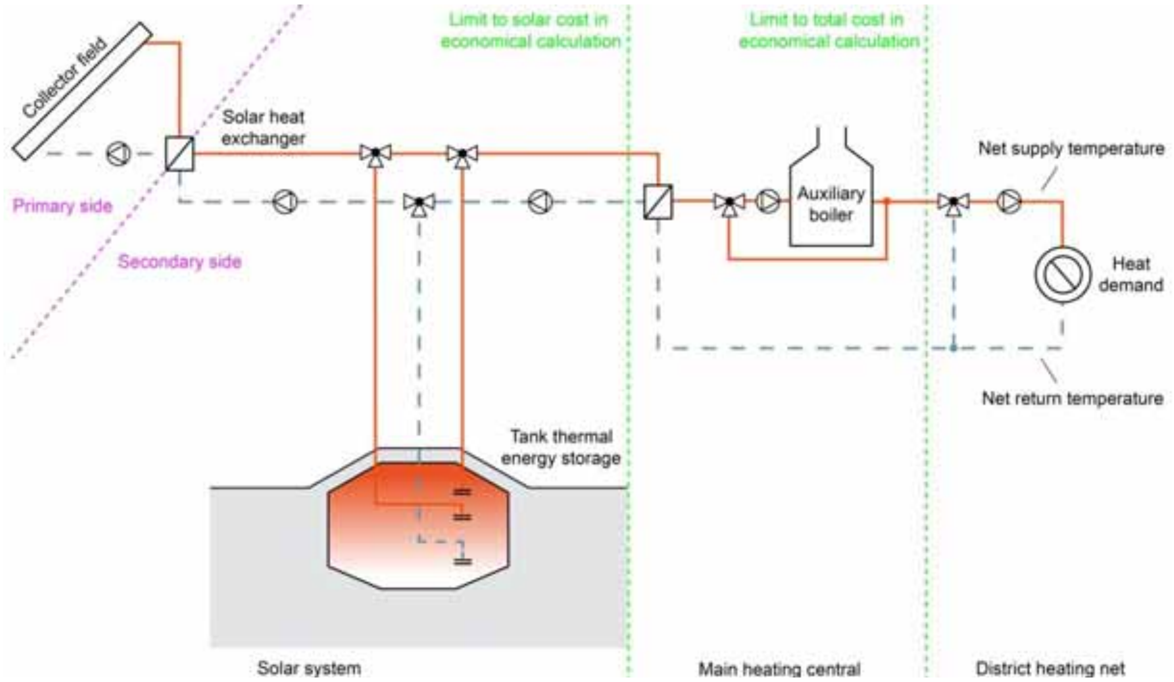

Fig. 2: hydraulic concept of the central solar district heating system with tank thermal energy storage

3. Performance of the systems

Figure 3 shows the solar net gain for a distributed system in different European locations with a collector slope of 45 °C and a collector azimuth of 0°, for different collector types and net temperatures. It can be observed that the evacuated tube collectors are more robust regarding high net operation temperatures. With the adequate collector type, between 300 and 500 MWh can be delivered to the net in mid and northern Europe and between 400 and 850 in the part of southern Europe where district heating systems are in operation.

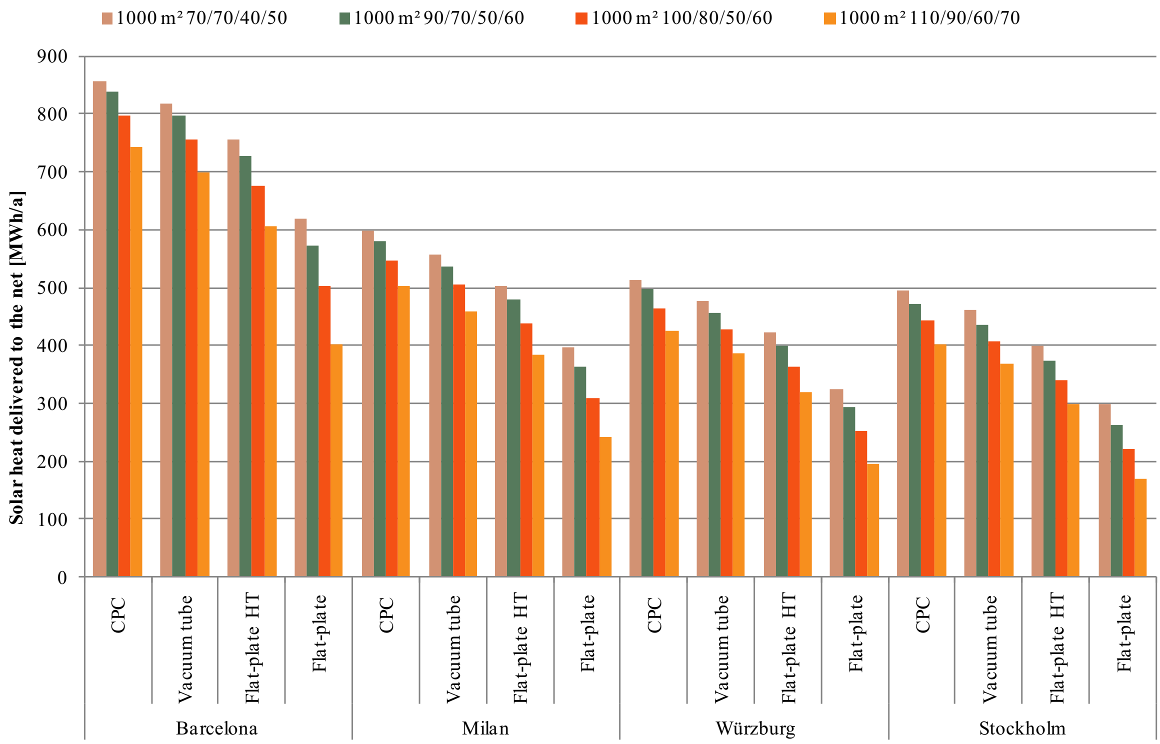

Fig.3: Solar heat gain for different collector types (CPC: evacuated-tube collectors with coumpound parabolic concentrator, flat-plate HT: high-temperature flat-plate collector) and net operation temperatures in °C (Supply winter / supply summer /

return winter / return summer) for the distributed system with 1000 m² collector area in Barcelona, Milan, Würzburg, Stockholm

Figure 4 presents the development of the solar fraction and efficiency of the solar plant with increasing specific collector area, for a central solar district heating system under the conditions given in table 1, in Stockholm and Barcelona. If the global yearly heat demand is the same for both, it has to be taken into account that the heat demand profile over the year varies according to the location.

Tab. 1: Conditions for the system analyzed in fig. 4

Collector type	Evacuated-tube collector with compound parabolic concentrator
Collector area	1200 m²
Collector azimuth	0°
Collector slope	45°
Specific storage volume	0,4 m³/m²

The solar fraction is defined as the fraction of heat delivered to the net produced by solar energy:

$$f_{sol} = \frac{Q_{load} - Q_{aux}}{Q_{load}} = 1 - \frac{Q_{aux}}{Q_{load}} \quad \text{(eq.1)}$$

Where:

f_{sol}: Solar fraction [%]

Q_{aux}: Heat produced by the auxiliary heater yearly [MWh]

Q_{load}: Heat delivered to the district heating net yearly [MWh]

The solar plant efficiency is defined as:

$$\eta_{sol} = \frac{Q_{sol}}{G_t} \quad \text{(eq.2)}$$

Where:

η_{sol}: Solar plant efficiency [%]

Q_{sol}: Heat produced by the solar plant at the solar heat exchanger yearly [MWh]

G_t: Global yearly radiation in the collector plane [MWh]

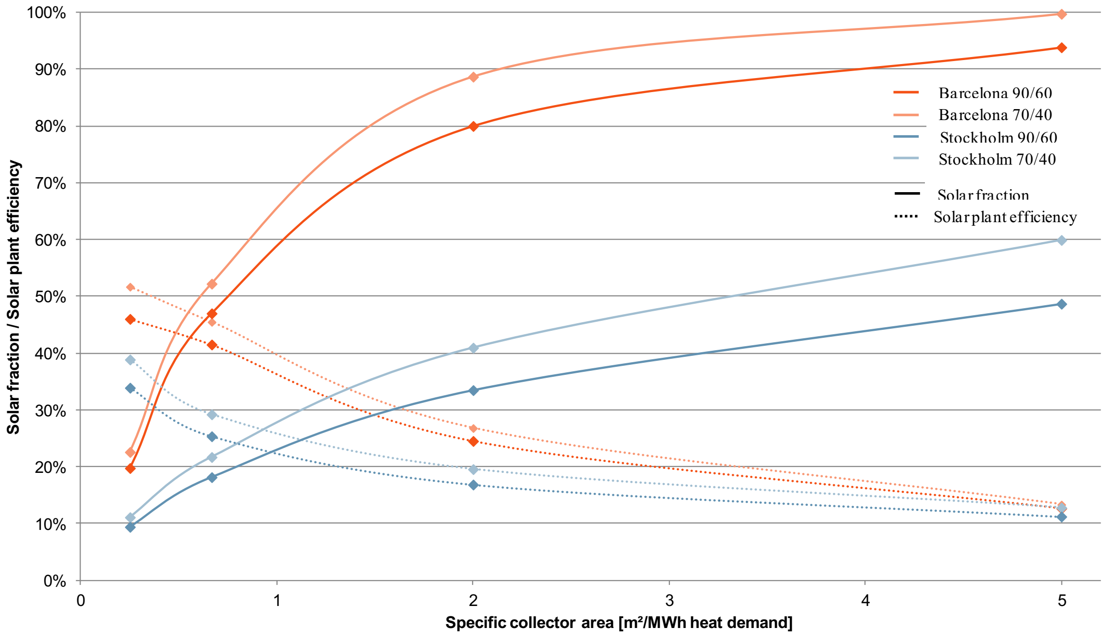

Fig.4: Evolution of the solar fraction and the solar plant efficiency related to increasing collector area per MWh yearly heat demand for the central system in two different locations and two net operation temperatures (Supply temperature / return temperature) for 1 200 m²

For high collector area to yearly heat demand ratios, the solar fraction of the system increases but the solar plant efficiency decreases. Hence, increasing the ratio over a certain value does not improve the solar fraction sufficiently to make the additional collector area profitable. This value depends on the system, the location and the dimensioning.

For Barcelona, increasing the collector area to yearly heat demand ratio brings more at first because even if the total yearly heat demand is the same for the two locations, the distribution of the load over the year is much more constant in Barcelona, meaning more heat demand in summer than in Stockholm where the winter/summer heat demand variation is more important.

4. Economics

In the following part, the economics of the systems are analysed as well as the influence of an often disregarded but important economical parameter: the interest rate. A simplified economical calculation according to VDI 2067 [1] has been coupled to the TRNSYS results.

In order to observe the influence of the interest rate on the economics of a system, an example of a central solar district heating plant with tank thermal energy storage has been selected. The parameter configuration for this reference central system is presented in Table 2.

Tab.2: Parameter configuration of the reference central system (CA: collector aperture area)

Parameter	Value	Unit
Collector area	1200	m²
Collector type	High-temperature flat-plate	-
District heating net operation temperature (supply / return)	70/40	°C
Collector slope	45	°
Collector azimuth	0	°
Specific storage volume	0.4	m^3/m^2_{CA}
Specific heat demand	4	MWh/m^2_{CA}

The district heating net operation temperatures given are indicative values, the operation temperatures of the district heating net over the year depend on the environment temperature.

Figure 5 shows the influence of the interest rate on the solar heat cost for the reference centralized system. The cost has been calculated considering 40% subsidy on the collector and storage cost. It can be seen that between Milan (IT) and Würzburg (DE) a difference of 2% of the interest rate can have more influence than the difference of solar irradiation between the two locations.

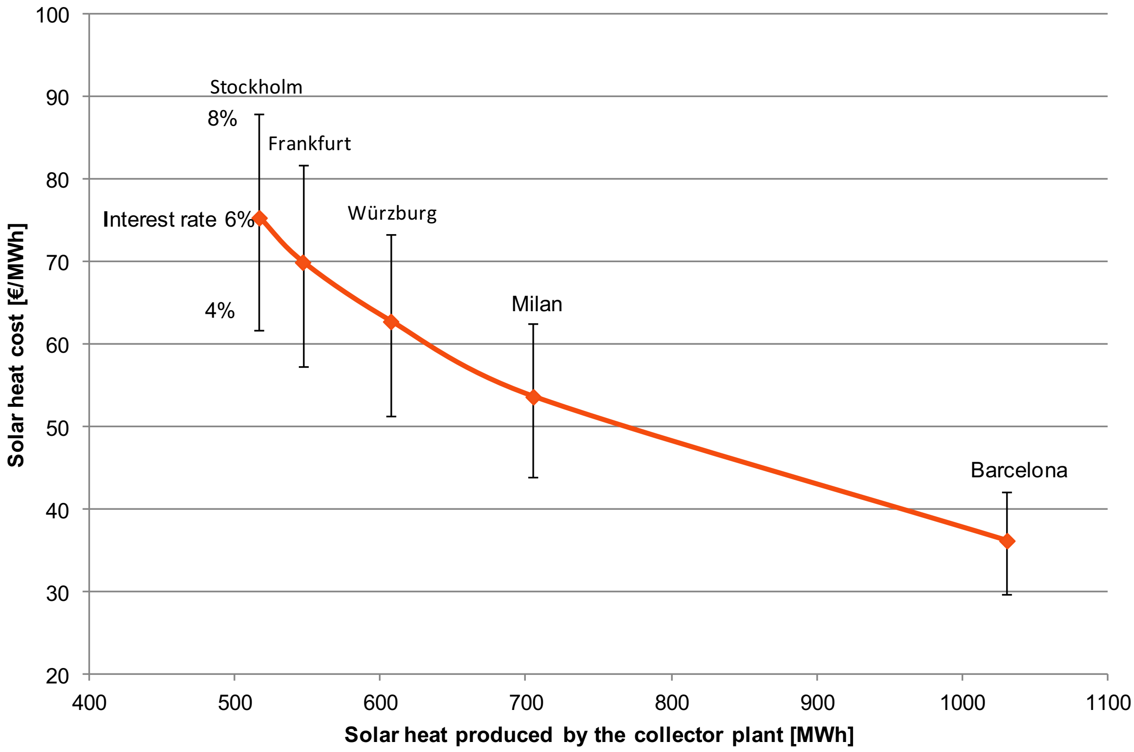

Fig.5: solar heat cost in €/MWh for the reference central system described in table 2 depending on the heat produced by the collector plant in MWh

Moreover, the technical and economical optimum has been analysed for a central solar district heating system with tank thermal energy storage with high-temperature flat-plate collectors and a yearly heat demand of 5000 MWh. Figure 6 presents the solar heat cost for this system, depending on the solar fraction for different specific storage volumes and collector areas. The economical calculation takes into account, like in Figure 5, 40 % incentives on collector cost and storage cost.

Unrealistic combinations of collector area and specific storage volume are not represented, for example a very large collector area with a very small specific storage volume.

The figure shows which dimensions of collector area and storage volume are most economical to reach a specific solar fraction. From a certain collector area on, increasing the specific storage volume reduces the stagnation periods of the collector plant and therefore increases the usability of the solar heat and improves the economics of the system. The curves for each specific storage volume show with increasing collector area a trend to the optimum storage dimensions with maximum use of the storage capacity. After reaching the optimum (bend in the curve), the stagnation periods of the solar system increase and the economics worsen.

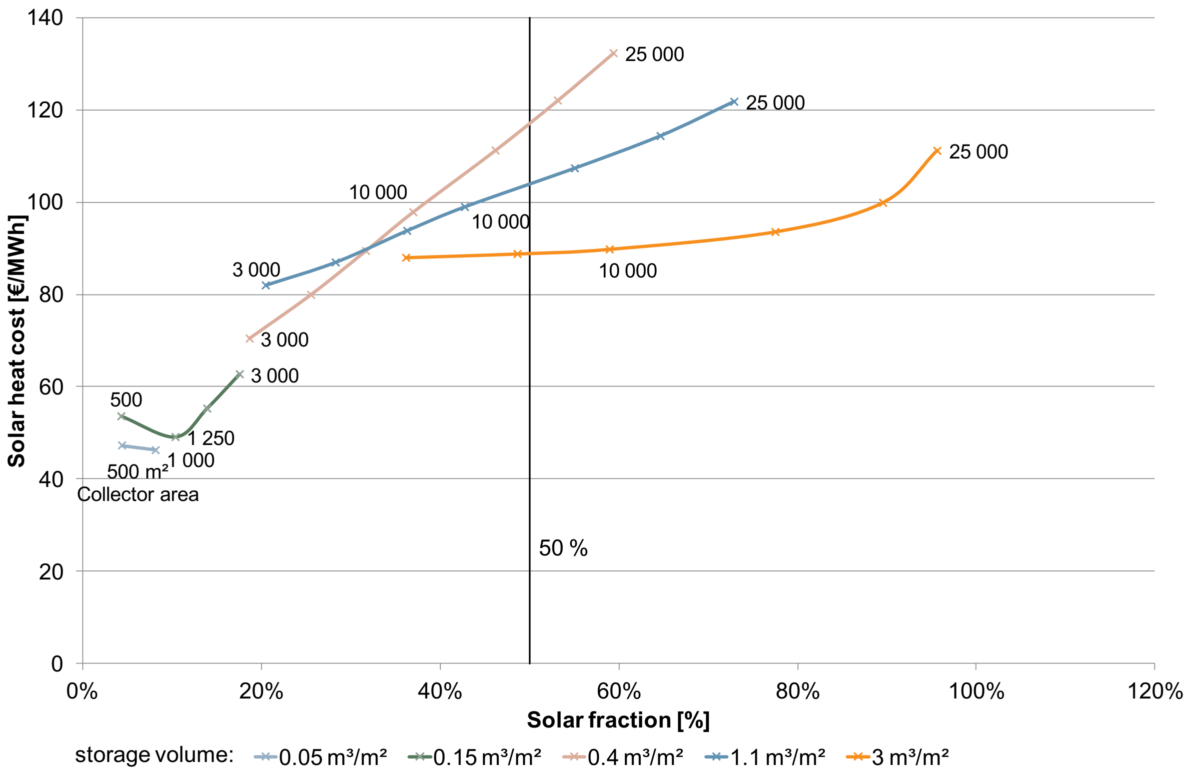

Fig. 6: Solar heat cost in €/MWh depending on the solar fraction in [%] for different specific storage volumes and collector areas for a central solar district heating system with tank thermal energy storage in Frankfurt with high-temperature flat-plate collectors, net supply temperature 70 °C, net return temperature 40 °C and a yearly heat demand of 5000 MWh

The same analysis has been done for a similar system with 30 000 MWh yearly heat demand instead of 5 000 MWh. It can be observed (Figure 7), that if much larger systems are needed to reach a specific solar fraction, the specific solar heat cost in €/MWh associated is also much lower. This is due to the scale effect: solar thermal collectors and especially tank thermal energy storages have decreasing specific cost with increasing size. Moreover, for the same system size, more solar heat can be produced if the yearly heat demand is higher.

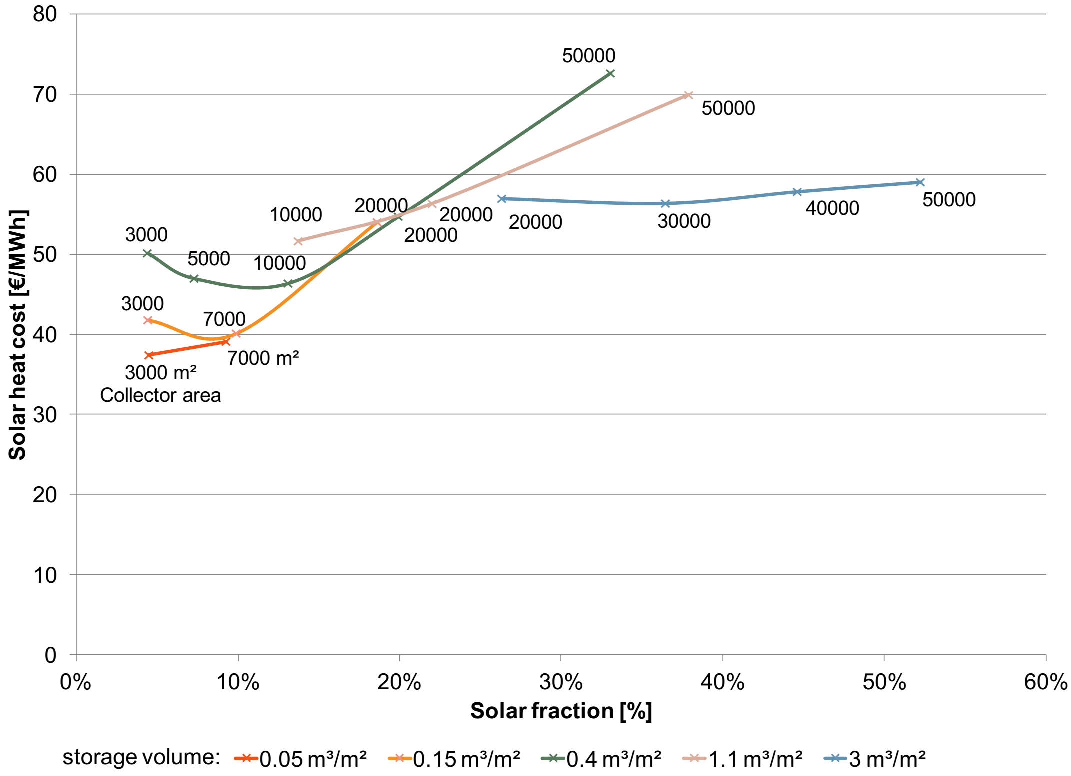

Fig. 7: Solar heat cost in €/MWh depending on the solar fraction in [%] for different specific storage volumes and collector areas for a central solar district heating system with tank thermal energy storage in Frankfurt with high-temperature flat-plate collectors, net supply temperature 70 °C, net return temperature 40 °C and a yearly heat demand of 30 000 MWh

5. Conclusion

Thanks to the analysis and assessment of the results of a large number of dynamic system simulations the potential of large scale solar thermal plants could be evaluated: 300 to 500 kWh/m².a solar gain in northern and mid-Europe, depending on the collector type and net operation temperatures. Furthermore, the importance of the assumed interest rate for the economical calculations was demonstrated.

This analysis shows that when dimensioning a solar district heating system, not only the collector area is important but also more system parameters must be considered in order to reach a technical and economical optimal configuration. The SDH Online-Calculator, available at www.sdh-online.solites.de can assist when doing first calculations in early project stages.

6. References

[1] Verein Deutscher Ingenieure – Fachbereich Technische Gebäudeausrüstung, 2011. Richtlinie VDI-2067 Blatt 1: Economic efficiency of buildings installations – Fundamentals and economic calculation.

[2] TRNSYS, A Transient System Simulation Program, Solar Energy Laboratory, University of Wisconsin, Madison, USA und Transsolar, Stuttgart, 2012