SCFW - SOLAR YIELD PREDICTION TOOL FOR SOLAR DISTRICT HEATING SYSTEMS BASED ON SCENOCALC

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Abstract – SCFW is an open-source calculation tool in MS Excel. The tool predicts the solar yield of solar thermal plants, which are integrated in district heating networks. It is based on international standards (Solar Keymark, ISO 9806) and comprises an entire solar thermal system including storage. The current version of the tool ‚ScenoCalc - Fernwärme' (SCFW 2.0) is available in German language.

1. INTRODUCTION

Large-scale solar thermal plants integrated in district heating systems are supplying renewable, zero-emission heat to residential and industrial areas. The technology can play an important role in the energy transition of the heating sector in Europe and beyond and the market is growing. However, one big challenge in developing solar district heating (SDH) systems remains in the yield prediction of solar thermal collectors. So far, there are different simulation tools for experts available, which are very detailed. A simple calculation tool, which is easy to use for everyone and gives a first impression of the expectable solar yield was missing.

Collector testing institutes use the Excel tool ScenoCalc (ESTIF, 2017) to calculate the annual collector output for Solar-Keymark certification (Solar Keymark, ISO 9806). Therefore it is limited to consider one single collector with constant average collector temperatures. In the project SCFW (Solites, 2017) an open-source calculation tool was developed in MS Excel, which is transparent in the calculation methods and based on ScenoCalc . SCFW enables the hourly calculation and comparison of different solar system designs with all components of a SDH system. The calculation result is the solar net gain at the point where it is fed into the district heating network. Another option is to calculate the solar gain of a single collector according to the solar Keymark certificate. Figure 1 shows the user interface of SCFW 2.0.

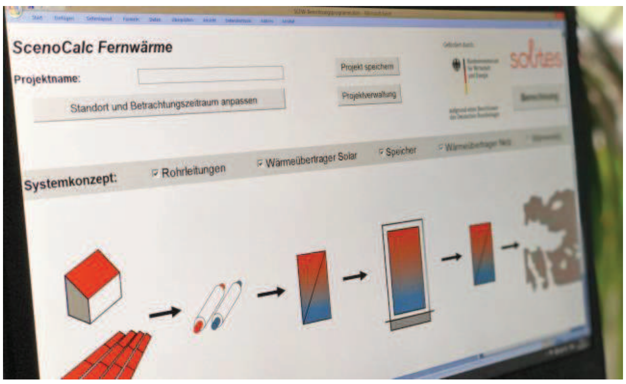

Figure 1: User interface of ScenoCalc Fernwärme SCFW 2.0

The calculation tool SCFW 2.0 was published in June 2017. It is free of charge and available online on www.scfw.de. The language of the tool is only German, however in case of growing interest it might be translated in English.

2. METHODS

As a first step for developing SCFW, the calculation and formulas of ScenoCalc were implemented in an MS Excel calculation sheet to get a transparent structure of calculation. To ensure the accuracy of this first version, the new tool was verified against ScenoCalc.

In a second step, the tool was developed further to calculate not just one collector but the solar net gain at the point where it is fed into the district heating network. The calculation follows strictly the formulas of ScenoCalc and ISO 9806 (DIN, 2014) on the one hand and considers relevant effects of the different solar system components on the other hand. To calculate these effects, the components collector field, pipes, heat exchanger in the solar circuit, buffer storage, heat exchanger in the net circuit and the load of the district heating network were integrated into the calculation model. The complete solar thermal system is shown in Figure 2. The broken grey line shows the system boundary for the solar system (left side of broken grey line). To separate the solar circuit and the net circuit hydraulically a heat exchanger is applied. Often a heat storage is integrated into the system to store the heat from the solar collectors before it is transported to the additional heater and then delivered at supply temperature to the district heating net. The district heating net itself is not considered in the calculation.

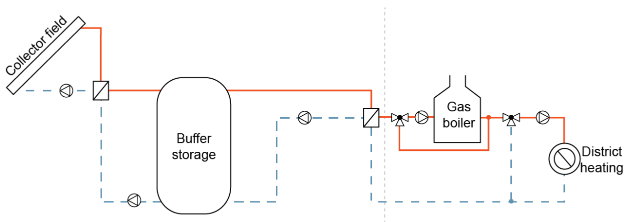

Figure 2: Schematic of a solar thermal plant for solar district heating

For each solar system component, the thermodynamic dependencies were analysed mathematically and transferred into formulas. For some cases a mathematical solution was found to solve the thermodynamical problems. However, if it was not possible to solve the single problem with a mathematical solution or this solution would have needed iterative calculation, an approximation was developed in an empirical approach. The use of iterations was avoided to keep the MS Excel calculations fast and reliable. The empirical solutions were developed by using simulation results of a Trnsys model, which was validated against measured data of real plants. The developed entire approximation formulas were validated against calculations with simple and constant system parameters, Trnsys simulations with broad changes of the most influencing parameters, and measurement data of real plants.

With the developed calculation methods, which are integrated in the published version SCFW 2.0, effects caused by the heat capacity of collectors, heat losses of pipes, fittings and optional storage, antifreeze protection and heat exchangers can be considered.

In addition, a high usability of the tool was developed by the following measures:

- In a graphical user interface in one sheet of the MS Excel workbook the system components can be chosen and its specific parameters can be set in separate user interfaces, which are opened by choosing the single component.
- A collector database containing the collector products for SDH systems available in the German market was integrated and can be expanded with further collector data.
- The calculation can be done for one year or shorter ranges in an hourly time step.
- Different profiles for the hourly supply and return temperatures and the load of the district heating network can be entered and saved.
- Climate data for Athens, Davos, Stockholm and Würzburg are included according to ScenoCalc. As it is a German tool, climate data for Frankfurt and Hamburg were added and data for other locations can be entered and saved. To consider not just one year, average climate data over 10 years from Meteotest is used (Meteotest, 2017).
- Whole calculation projects with all parameters can be saved in a project archive and loaded again.

The user interface is working with VBA macros (Visual Basic for Applications), which are separated from the calculation formulas, because the results needed to be calculated only based on formulas in MS Excel sheets to keep the calculation methods transparent.

In order to meet the market needs, the tool was discussed and tested in an early stage by companies producing and designing solarthermal systems for district heating. These companies are cooperating in the initiative IniSW, which was set up in 2015 and is chaired by Solites. In these discussions important new ideas were suggested and some of them are now implemented in the final version.

To prove the correctness of the calculations in the tool the hourly and yearly results were compared to Trnsys simulations. Some results are shown in Figure 3 with different supply and return temperatures for high temperature flat plate as well as vacuum tube collectors. For all other parameters the same values were used to compare the calculation methods. The results show just small differences between SCFW and Trnsys calculations.

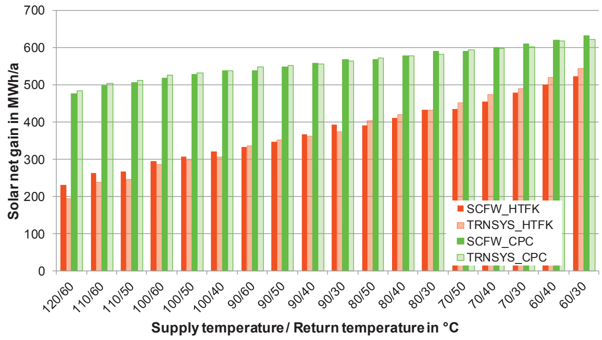

Figure 3: Comparison of yearly solar net gain calculated in SCFW and by Trnsys simulations – example for 1000 m² collector aperture area (HTFK: High temperature flat plate collector, CPC: Vacuum tube collector)

3. OPTIONS IN SCFW 2.0

With the tool SCFW solar thermal systems can be calculated, which are integrated in the heating central or directly in a district heating network.

The options of SCFW 2.0 are described in the following points:

- For the collector field the heat transfer fluid can be chosen between water and water-glycol. In case of water-glycol, a value for the energy loss by the reduced heat transfer can be set. In case of water, a parameter to consider the heat demand of the antifreeze protection can be set.
- Pipes in the collector field and for the connection to the buffer storage can be considered. The heat losses are calculated according to the given parameters and calculated in the energy balance. For the connecting pipes of the collector field to the district heating net it is possible to choose between pipes above ground, buried in the ground or with constant ambient temperature.
- The consideration of heat exchangers is possible between the collector field and the buffer storage and between the buffer storage and the district heating network by the implementation of a temperature

decrease. In case of heat exchangers, the increasing collector average temperature is more relevant than additional heat losses.

- A buffer storage can be calculated with a temperature filling level as a balance. This enables the calculation of charged and discharged heat, heat losses and surplus solar heat. In addition to that, an increase in the return temperature to the solar collectors can be calculated depending on the filling level to get realistical average collector temperatures.
- One important point is to consider the district heating network in which the solar thermal collectors are feeding. The district heating net is not calculated, but it represents the system boundary. The conditions at the point where the solar heat is fed into the district heating net are described by hourly data for thermal power in the district heating net and its supply and return temperatures. The hourly thermal power can be entered or chosen from pre-defined data, which can be scaled to the individual yearly heat demand. The supply and return temperature can be entered as well or calculated in a course of one year from two set points for summer and winter. The data can be saved to use it again.
- Two different operation modes are available: pre-heating or delivering the supply temperature. In the preheating mode the collectors can supply heat at a lower temperature level than needed in the district heating net. In case of the second operation mode, solar heat is produced only, if the irradiation is high enough to deliver the supply temperature.
- If the direct feed-in is chosen, it is assumed that the entire solar gain is used in the district heating net in each time step and the thermal power of the network is not considered.

In SCFW 2.0 the main parameters and monthly results are shown in a separate sheet and can be saved as a report in pdf format. Figure 4 shows the monthly results for irradiation on the collector (yellow), the heat demand (grey), the solar gain of the collector field (red), and the solar net gain at the point where it is fed into the district heating net (green).

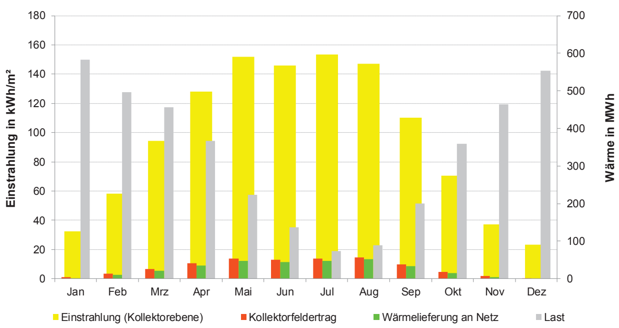

Figure 4: Diagram showing the calculation results in SCFW 2.0

4. CALCULATIONS WITH SCFW 2.0

In this chapter, some calculations done with SCFW 2.0 are described.

For a favorable performance of the solar thermal system, the overall system design is important. First of all the location of the solar thermal plant decides about the amount of solar irradiation the collectors receive. The solar thermal plant is able to heat its inlet temperature only if the irradiation is high enough. The following Figure 5 shows the differences between the global irradiation of two cities in Germany over ten years, whereas Würzburg is a location with very good solar irradiation conditions and Hamburg is a location with quite low solar irradiation. The solar irradiation in the years 2007 to 2016 fluctuates with +4 to -6 % of the average from the ten years for Würzburg (broken line). For Hamburg, the variation comprises the range of +7 to -5 % of the average level. There is a significant difference in the global solar irradiation of the two locations, which is very variable over the ten years.

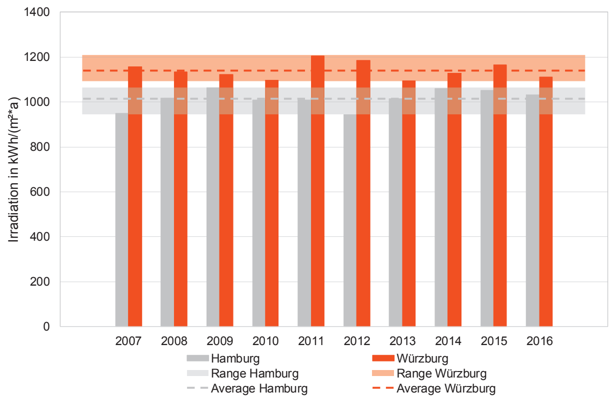

Figure 5: Yearly global solar irradiation in the years 2007 to 2016 for Würzburg and Hamburg (Deutscher Wetterdienst, 2017) on horizontal plane

Therefore, it is recommended to dimension a solar thermal plant using climate data of the location of the plant over a longer period, e.g. 10 years (like it is included in SCFW 2.0). By varying the solar irradiation in a sensitivity analysis within a system simulation program, its effect on the energy gain of the solar system can be analysed and valuated. If necessary, the solar thermal plant can be dimensioned with a safety factor to reach a needed solar heat gain even in years with poor irradiation.

In addition to that, the solar heat gain depends on the operation temperatures. The higher the average operation temperature of the collectors is, the lower the efficiency of the collectors gets because of higher heat losses of each collector. Therefore, the return temperature to the collector field and the needed supply temperature are decisive for the achievable solar heat gain.

This correlation is shown by calculations in SCFW 2.0 for high-temperature flat plate and vacuum tube collectors in the German market (Figure 6). The sample collector is a high-temperature flat plate collector with average specific values. The results are calculated with average climate data over 10 years (Meteotest, 2017) of the German city Frankfurt. The average net temperatures in the diagram are the yearly average for the arithmetic mean value of the supply and return temperatures of the regarded collector in each hour of the year.

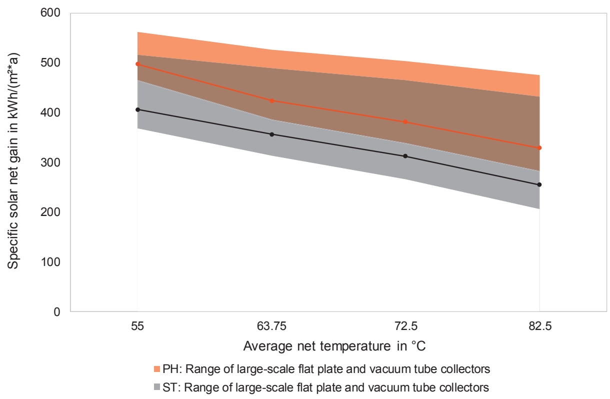

Figure 6: Usable solar heat of large-scale collectors in the German market with two different control strategies for the delivered temperature of the solar thermal plant: ST = heating up to the supply temperature, PH = preheating. The lines represent a sample collector (m²: brutto collector area)

In the preheating mode (PH, Figure 6), the solar thermal plant delivers heat at a lower temperature level than the supply temperature of the district heating net. Therefore, the solar thermal plant can produce heat even if the solar irradiation is low. The solar heat production in this mode mainly depends on the return temperature of the district heating net that should be heated by the solar thermal plant. This is visible by the strong reduction of the solar heat gain between the cases with 55 °C and 63.75 °C average temperature. The return temperature increases between these two cases from 40 to 50 °C in a yearly average.

A first idea of the performance of one single collector gives the Solar Keymark certificate (ESTIF, 2017). Each collector is tested and certified under standardized conditions with a constant average temperature in the collector. Neither the influence of the system integration nor the realistic supply and return temperatures are considered in the tests. In the certificate the performance indicators and yearly heat productions are declared for the climate data of four different locations in Europe.

As mentioned above, the solar irradiation influences the solar heat production of the collector field to a strong extend. This is shown in Figure 7 for the sample collector and with the application of the formerly mentioned climate data from Würzburg and Hamburg (see Figure 5).

The calculations of the solar heat production, whose results are shown in Figure 7, are based on a solar thermal system with a direct feed-in and without a heat storage. This system is operated to deliver always the supply temperature of the district heating net. The average net temperature is 63.75 °C, in summer the supply temperature amounts to 75 °C and the return temperature to 55 °C. The results show the direct dependency of the solar heat gain on the solar irradiation and the strong variation in single years from the average. The variation from the 10-years-average lies in a range of +10 to -15 % for Würzburg and +20 to -14 % for Hamburg.

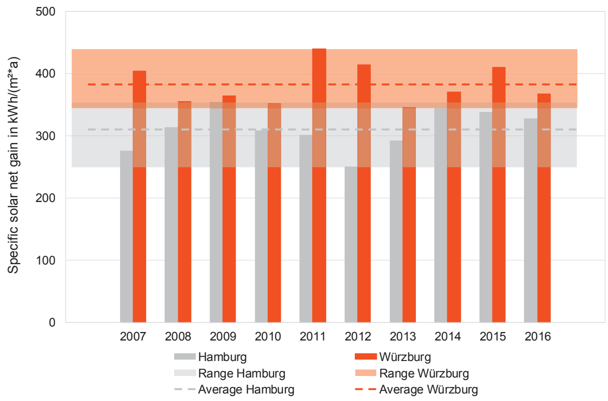

Figure 7: Calculated specific solar heat gain per m² brutto collector area of a sample collector with climatic data for the years 2007 to 2016 of the cities of Würzburg and Hamburg. The solar thermal plant is operated to always reach the supply temperature in a district heating network with 63.75 °C average temperature.

Such variations in the solar heat gain need to be considered in the dimensioning of a solar thermal plant. That is why the careful calculation of the solar heat gain with all available data and, in addition, based on realistic assumptions is essential for the feasibility of solar district heating systems. Compared to conventional heat producers, dynamic system behavior and the variations of the solar irradiation, the mass flow, and the temperatures of the district heating net need to be considered in detail.

If a solar thermal plant is dimensioned to deliver the entire heat demand of the district heating net during the summer time, in most cases a short-term heat storage is necessary to store the heat from day to night and for the case of some cloudy days. In Europe during summer, the heat demand of district heating systems usually is defined by tap water heating and the heat demand of industrial processes. The solar fraction of these solar thermal systems depends on the seasonal distribution of the yearly heat demand and is usually between 10 to 15 %. The higher the solar fraction, the more solar heat needs to be stored, not only for some days but for weeks. In case of high solar fractions in the range of more than 40 % of the yearly heat demand, a seasonal heat storage is necessary, because the solar heat gain from summer has to be used in winter. Due to the longer storage time of the solar heat, the heat losses increase and the specific net solar heat gain of the collectors decreases. **Fehler! Verweisquelle konnte nicht gefunden werden.** gives an example for the interrelations of the main parameters for such systems.

Therefore, it is assumed that the collector field comprises high temperature flat plate collectors of the sample type (see Figure 6), located in the city of Frankfurt in Germany. The collector field feeds in directly into a district heating net with a supply temperature of 78 °C in a yearly average and a yearly heat demand of 4 GWh/a. To increase the solar fraction of the yearly heat demand of the district heating net (see red line in **Fehler! Verweisquelle konnte nicht gefunden werden.**), the collector area has to be increased (see x-axis in **Fehler! Verweisquelle konnte nicht gefunden werden.**). The higher the solar fraction gets, the larger the heat storage volume has to be. The dashed grey line shows the specific storage volume in m³ water, related to the brutto collector area, which is necessary to reach the intended solar fraction. By mathematical variation, the specific storage volume was fitted to the respective collector area in a way that the storage volume is used completely and stagnation in the collector field is just avoided. For a solar collector area of 10,000 m² a solar fraction of 70 % of the yearly heat demand of the district heating net can be reached with a specific storage volume of 2.3 m³/(m² brutto collector area). In Figure 8, this specific storage volume is set to 100 % (see y-axis). The black broken line in Figure 8 gives the specific solar net gain of the entire solar thermal system (see Figure 2). The solar net gain is the usable solar thermal energy that is fed into the district heating net. Heat losses by the storage etc. are already subtracted. The maximum value of 313 kWh/(m² a), equals 100 %, is quite low and caused by the overall system layout that asks for a feed-in of the net solar heat gain always on the supply temperature of the district heating net of 78 °C in a yearly average. This specific net solar heat gain declines with the rising solar fraction due to rising heat losses of the necessary storage and rising average operation temperatures in the collector field.

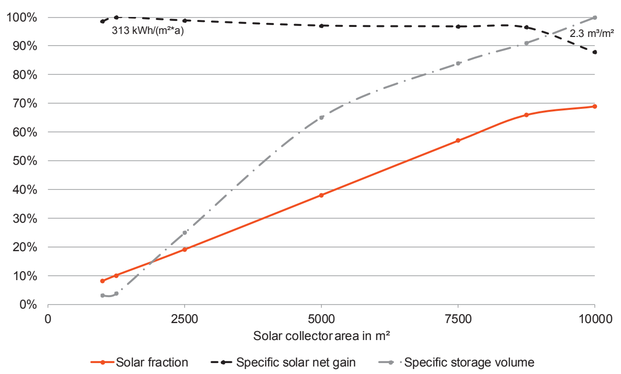

Figure 8: Correlation of solar collector area, specific heat storage volume, solar fraction of the yearly heat demand and solar heat gain for a solar thermal plant that feeds directly in a district heating net and always delivers the supply temperature of 78 °C in a yearly average (sample collector and weather data of the German city Frankfurt (see Figure 6))

For a real plant, possible next steps in the overall system design could be to change the system integration of the solar thermal system to a preheating mode (see Figure 6) or to integrate a heat pump into the solar system to unload the heat storage to lower temperatures. Both possibilities allow to reduce the operation temperatures of the solar collector field to reach higher specific solar net gains per year.

5. CONCLUSIONS

The examinations in chapter 4 show that SCFW 2.0 can be used for first assessments of SDH systems as well as for comparison of different system boundaries.

Since the publication of SCFW 2.0 in June 2017, there are about 330 downloads. Besides the calculation tool a handbook was published, which explains the use and the options of SCFW 2.0.

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The research project has been funded by the German Federal Ministry for Economic Affairs and Energy (BMWi, FKZ 0325554A and B) by reason of a decision of the German Parliament. The sole responsibility for the content of this publication lies with the authors. Neither the funding organization nor the authors are responsible for any use that may be made of the information contained therein.