DECENTRALISED INTEGRATION OF SOLAR THERMAL PLANTS INTO AN EXISTING DISTRICT HEATING SYSTEM

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Abstract – The research project *smartSOLgrid* aims at a decentralised integration of solar thermal plants into an existing district heating network. During the conceptual phase of the project, several studies of different retrofitting approaches were compared. This paper describes the solutions found by a simulation-based optimisation and the implementation of one of the developed plants. Three different ways of utilising the solar energy were selected for the retrofitting - a local domestic hot water production, a solely decentralised feed-in to the district heating network and a combined solution for local use and feed-in of excess heat. Annual solar yields of 280 kWh/m² up to 660 kWh/m² are reached for the different concepts. A comprehensive metrological investigation, which is conducted after the implementation, allows an assessment of the real plant performance and the energy balance of the complete district heating network.

1. INTRODUCTION

1.1 Research project

The research project *smartSOLgrid – Solar Smart Grid for the Heating Sector*, funded by the *Federal Ministry for Economic Affairs and Energy,* intends to retrofit a district heating system in the south of Germany, built in the 1970s (Figure 2). The object is typical for many urban residential areas and composed of several multi-storey buildings. Only a small amount of roof space has favourable orientations and inclinations for the installation of large, contiguous solar collector arrays. The available space inside and outside the buildings is limited. Therefore, the utilisation of large-scale seasonal storages and ground-mounted collector arrays is challenging. Due to the old age of the buildings and the high number of residents, the study site faces a high consumption of space heat and domestic hot water. The *Institute of new Energy Systems* of the *Technische Hochschule Ingolstadt* aims at a retrofitting concept, which provides low solar heat generation costs at a decent solar fraction. Partners of the project are the operator of the plant, *Gemeinnützige Wohnungsbau-Gesellschaft Ingolstadt GmbH (GWG)*, and the collector manufacturer *Citrin Solar Energie- und Umwelttechnik GmbH*. From the experience gained during the simulation study, the retrofitting and the monitoring phase, guidelines for the installation of solar thermal plants in similar district heating networks will be derived.

1.2 Motivation

The installation of large, central collector arrays was the most common approach for integrating solar thermal energy into district heating systems in Germany up to now. These collector arrays are usually located at the central heating station of the network or connected to the central heating station via an additional solar piping network. Several plants with decentralised integration are already set up in other countries, like Sweden, Denmark and Austria. Figure 1 shows the collector yield and collector area of a collection of decentralised plants in Sweden. It shows that the yields are, compared to typical plants for domestic hot water production, on a lower level. [1]

Nevertheless, for the retrofitting of large solar thermal plants in existing urban areas, this concept of the integration of collector arrays is of high relevance, due to the difficulties of installing large, central components. At the same time, housing associations, which want to use solar heat, would like to have an acquisition and documentation of the solar yield to assess the profitability of the investment. This paper describes the solutions found for the plant layout of a demonstration project in Ingolstadt and the metrological investigation, which is conducted after the implementation.

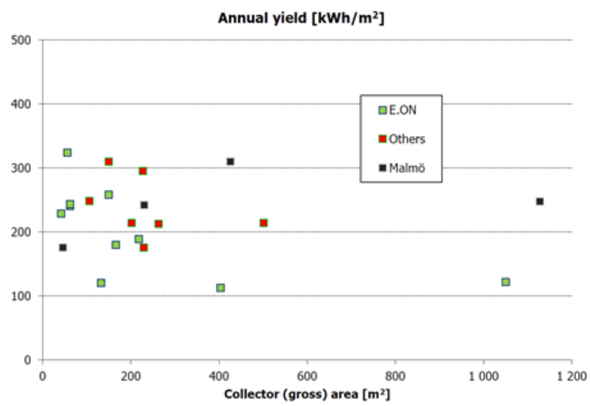

Figure 1: Solar yield of existing decentralised solar thermal plants in Sweden [1]

2. METHODOLOGY

Under the given boundary conditions (e.g. roof size, orientation and available space in the buildings) solutions for different ways of utilising the solar heat were

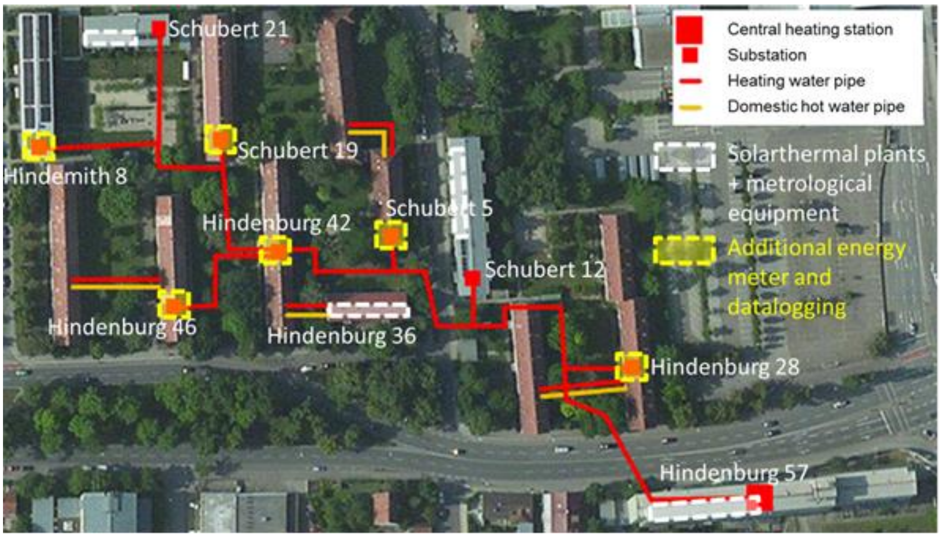

Figure 2: Plan of the retrofitting measures at the investigated district heating system

developed. A detailed data collection was the basis for modelling the district heating network in the Simulink-based CARNOT-toolbox [2]. A simulation study on different approaches of the integration of solar thermal plants was conducted performed to optimise the plant layouts and sizes. Furthermore, a detailed monitoring concept, based on cost effective metrological equipment, allows the assessment and the long-term monitoring of the plants.

3. PLANT CONCEPTS

3.1 Existing System

Finding a cost effective and easy-to-install solution for the retrofitting of existing urban district heating networks was the focus of the investigation. The given structure of the research site leads to a restriction of the possible locations of solar thermal plants. Taking into account the irradiation, the roofs of the buildings Hindenburgstraße 36, 57 as well as Schubertstraße 12 and 21 are preferable as there are a flat roof, a south-oriented roof with 40° and 10° inclination and a west-oriented roof with 10° inclination. An existing solar thermal plant and a large photovoltaic system already occupy the roof of Hindemithstraße 8. All other buildings have east/west roofs with 40° inclination, various installations and windows. Moreover, in these buildings the available space in the basement is limited. The installation of additional components for heating systems is therefore hardly possible. The central heating station of the network is installed in Hindenburgstraße 57. It is composed of three gas boilers with a combined thermal power of 1,945 kW. Table 1 shows the three years average heat consumption of the substations of the network.

A high heat demand is located in Hindenburgstraße 57. Schubertstraße 12 and 21 are newer buildings with less residential units. The domestic hot water demand and in particular the space heat demand are lower here. Hindenburgstraße 36 was, like the rest of the buildings, built in the 1970´s and doesn´t have an own substation.

Table 1: Yearly energy consumption of the substations connected to the investigated district heating network

Building	**Residential units**	**Space heat [MWh]**	**Domestic hot water [MWh]**	**Circulation [MWh]**
Hindenburgstraße 57	85	906	145	135
Hindenburgstraße 28	30	759	57	34
Hindenburgstraße 42	48	444	37	42
Hindenburgstraße 46	60	472	46	52
Hindemithstraße 8	24	78	38	23
Schubertstraße 5	36	240	42	39
Schubertstraße 12	24	69	39	25
Schubertstraße 19	24	281	19	23
Schubertstraße 21	12	34	22	14
Sum	343	3,282	447	387
Overall consumption				4,116

It is supplied by the neighbour building via a 4 pipe network (space heat flow and return, domestic hot water, circulation).

The basic opportunities for including solar thermal plants into a heating system are domestic hot water production, support of the space heating system and the feed-in to a district heating network. Due to past experiences with solar thermal systems, the *GWG* was highly interested in simple plant layouts. Therefore, the investigation of a ground-mounted plant for a solely feed-in to the district heating network north to Schubertstraße 12 was part of the design phase. The investigated concepts are described in the following section.

3.3 Solely feed-in to district heating

For the ground-mounted plant and Hindenburgstraße 36 a simple feed-in to the district heating return pipe was investigated, which is shown in Figure 3. As the *GWG* is the operator of the buildings as well as of the district heating network, the distribution of costs and income due to heat losses in the network and solar gains are, compared with the feed-in to a foreign network, not relevant. The return temperature is in the range of 60 to 70 °C. By using a solely return feed-in, this relatively high level for solar thermal plants can be partially compensated, as collector temperatures above 65 °C already lead to a solar energy production.

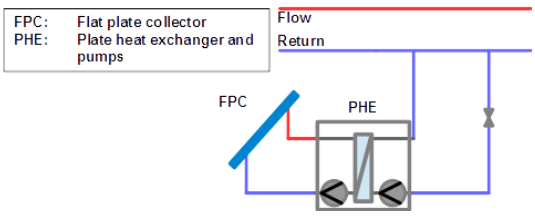

Figure 3: Plant scheme for feed-in to the district heating return pipe

3.4 Local domestic hot water supply

As Hindenburgstraße 57 is a nine-storeyed building and therefore has a relatively low roof size compared to the heat consumption, a pure domestic hot water plant was the focus of the investigation here. Like for the already existing plants of the housing association, the utilisation of a storage for preheating the tap hot water is an efficient solution for this approach. Compared to the existing plants, the use of a domestic hot water storage was discarded and a buffer storage with internal pipe heat exchanger was selected. This leads to a reduction of the efficiency decrease due to the daily thermal disinfection that has to be performed. The volume of the drinking water in the pipe heat exchangers is only 60 l and the dwell time in the storage is very short. Nevertheless, a circulation pump was installed to allow a controlled thermal disinfection for safety reasons and to provide the opportunity to shift energy from the buffer to the existing domestic hot water storage in case of a low consumption during sunny days (Figure 4).

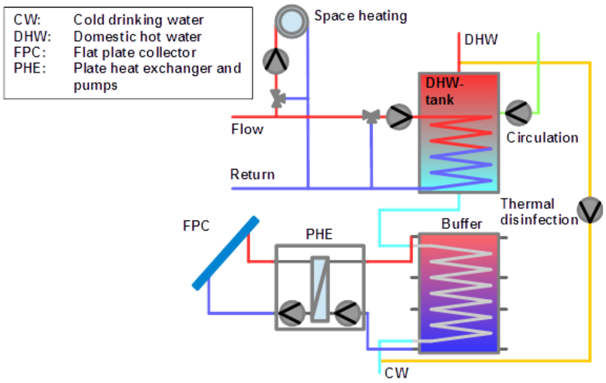

Figure 4: Plant scheme for local domestic hot water preheating

3.1 Local domestic hot water supply and feed-in of excess heat

Schubertstraße 12 and 21 are very similar buildings. The main differences is the number of residential units and the roof orientation. The two buildings have an existing solar thermal plant with a 750 l storage for domestic hot water preheating each. There are 21 m² of vacuum tube collectors on Schubertstraße 12 and 17 m² flat plate collectors on Schubertstraße 21. The buildings have a higher fraction of roof size to heat consumption compared to other buildings in the network. This leads, when utilising the complete available roof space, to a high production of excess heat during summer. The obvious solution was therefore to enlarge and optimise the existing solar thermal plants and to feed in excess heat to the district heating network similar to Hindenburgstraße 36. The hydraulic layout of this concept is shown in Figure 5. The buffer storage is unloaded to the return pipe by an additional pump, when the solar gains cannot be consumed locally. A stagnation of the plant is prevented by this approach.

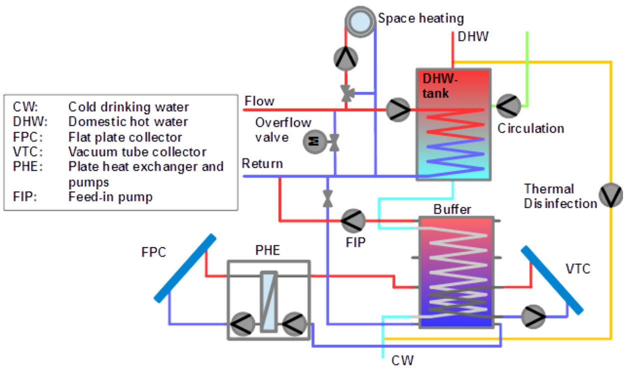

Figure 5: Plant scheme for local domestic hot water production and additional feed-in of excess heat

4. SIMULATION RESULTS

After determining the concepts, the plant sizes were optimised by implementing the buildings in a simulation model. The calculation of the space heating power is based on a year's simulation of the CARNOT single node building model. The buildings geometry is based on the real construction and the building envelope selected according to typical data for buildings of the same age. To fit the real consumption, slight modifications of the heat losses through the walls were performed by modifying the thermal conductivity of the building envelope.

The profile for hot water demand is composed by the measured consumption on a weekly basis, a seasonal superposition according to VDI 6002 [3] and the yearly consumption provided by the housing association. The sum of all generated load profiles was used in the network model to calculate the return temperature on each feed-in point. The optimisation of the single plants was done in submodels, only composed by the investigated plant components. The maximum size of the collector area, including the restrictions by shadowing and other constructions on the roof, like antennas and windows, was 150 m² on Hindenburgstraße 57 (HB57), 100 m² on the south roof of Hindenburgstraße 36 (HB36), 450 m² on Schubertstraße 12 (SB12) (east and west) and 100 m² on Schubertstraße 21 (SB21). A maximum size of 160 m² for the ground-mounted plant (GM) was determined. The maximum storage sizes were limited by the lack of space in the basements of the buildings from 2 to 4 m³.

Table 2 shows an overview of several variants for all investigated objects and the simulated specific solar yields. Due to the length of the pipes from the plant to the nearest feed-in point of the existing district heating network and the resulting heat losses, no sufficient efficiency can be reached for the ground-mounted plant. As a decent solar yield is challenging at the given network temperature level at all and the effort for installing the plant would be very high, the plans for this plant were rejected.

The plant in Hindenburgstraße 36 has the same hydraulic layout. Nevertheless, the primary return pipe of the network passes the building in a 5 m distance. Additional losses of the connection pipes are almost completely avoided and the specific yields are on a higher level. Changing the collector area has no considerable influence on the specific yield, as the return temperature is not influenced by this measure. To keep the plant design simple and the investment on a low level, the variant with 71 m² was chosen. This collector array size can be connected by standard pumps and plate heat exchangers of the project partner *Citrin Solar*.

The flat roof of Hindenburgstraße 57 provides a higher flexibility for designing the plant. It was found that 71 m² collector area and 2 m³ buffer volume enable a stagnation-free operation during summer. Due to that sizing, a high specific annual solar yield of 658 kWh/m² can be reached. The inclination of 40° instead of the standard 30° leads to a slightly higher yield without any additional costs. As this inclination additionally enables a direct comparison of the different plant concepts of Hindenburgstraße 36 and Schuberstraße 21 at identical sizing and orientation, this variant was chosen. Figure 6 shows the collector array on the flat roof of Hindenburgstraße 57. To avoid a shading of the second row, collectors of the type CS 550 are used, which are mounted laterally.

Table 2: Selection of plant sizes and specific solar yields

Variant	**Collector area [m²]**	**Inclination [°]**	**Storage volume [m³]**	**Specific annual yield [kWh/m]**
GM_01	142	30	0	188
GM_02	71	30	0	172
GM_03	71	40	0	180
HB36_01	95	40	0	274
HB36_02	**71**	**40**	**0**	**276**
HB57_01	114	30	4	587
HB57_02	114	30	2	506
HB57_03	71	30	4	694
HB57_03	71	30	2	649
HB57_03	**71**	**40**	**2**	**658**
SB12_01	114	10	2	338
SB12_02	71	10	2	388
SB12_03	71	10	1	373
SB12_04	**92**	**10**	**1**	**368**
SB21_01	95	40	2	371
SB21_02	95	10	2	306
SB21_03	71	40	2	393
SB21_04	**71**	**40**	**1**	**412**

Figure 6: Collector array on the roof of Hindenburgstraße 57

Schubertstraße 12 is a special case, as the roof is west-oriented with 10° inclination and has already vacuum tube collectors installed. Mounting collectors on the east side of the roof is less efficient, as in the morning, there are often misty weather conditions in Ingolstadt. The existing collectors are integrated to the new plant. Due to the small area of only 21 m², the vacuum tube collectors can be connected to the buffer storage via an internal pipe heat exchanger. As for the other plants, a size of 71 m² for the new collectors is a compromise of plant size and the utilisation of standard components. Therefore, the same dimension was chosen for this plant. Enlarging the collector area would lead to a higher fraction of feed-in to the network, which is, compared to the domestic hot water preheating, less efficient. The solar fraction of the complete network could be increased by this measure but it would not meet the requirements of the operator of having low cost and simple plants. Enlarging the buffer volume only leads to a minor increase of the yield, as the buffer volume plus the domestic hot water storage volume approximately meet the daily consumption of hot water.

The same concept is chosen for Schubertstraße 21. However, the existing collectors are not integrated. This was discussed but finally discarded, due to the bad conditions of the collectors, which suffer from fogging and mechanical damages. The domestic hot water consumption in this building is around 60 % of the consumption of Schubertstraße 12. Therefore, a buffer volume of 1 m³ is suitable as well. Additional storages would actually slightly reduce the specific yield due to higher heat losses.

Figure 7 shows the 4 designed plants in comparison with several existing large solar thermal plants (collector area > 100 m²). The solar fraction is calculated based on the complete heat consumption of the supplied object for the space heating plants and on the tap hot water and circulation consumption for the domestic hot water plants. It shows that Hindenburgstraße 57 has a high system efficiency and the two plants in Schubertstraße have a high solar fraction. The additional feed-in to the district heating network increases the yield of the plants compared to plants only for local domestic hot water production by approximately 60 %.

Hindenburgstraße 36 contributes only a small fraction to the heat demand of the complete network. Nevertheless, due to the simple plant design, the investigation of installation effort and reliability at operation is of interest. By increasing the number or the size of plants in the network, the shown efficiency of the plants would be decreased. The influence of a further extension will be investigated after the validation of the simulation models.

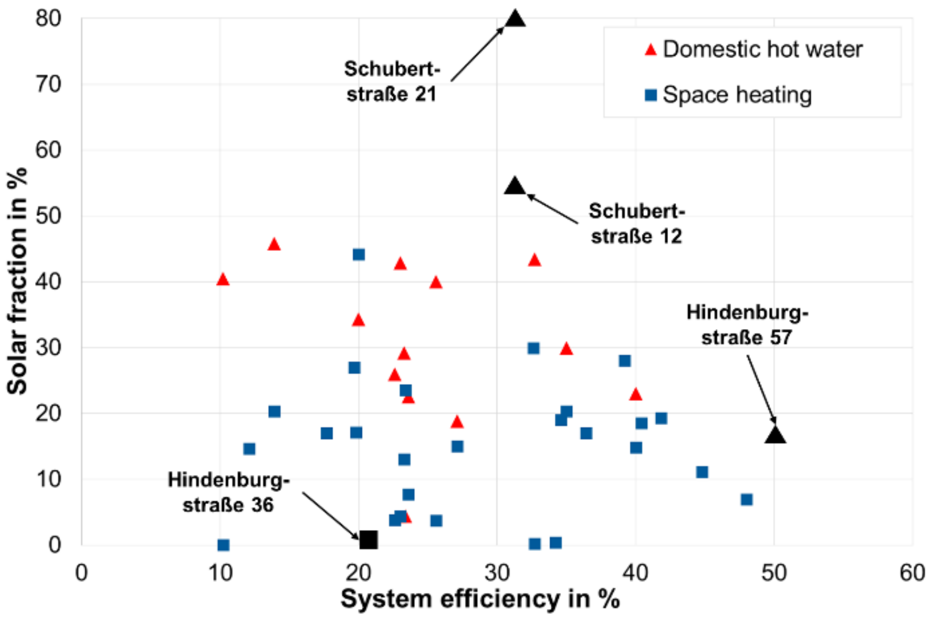

Figure 7: Comparison of solar fraction and system efficiency of the developed concepts with existing large solar thermal systems

5. METROLOGICAL CONCEPT

Goal of the metrological concept was to get results for the scientific investigation of the system at a detailed level as well as providing an easy-to-use long term monitoring for the operator. While the operator is primarily interested in the yields and ensuring a long lifetime of the plant, for validating the simulation model, additional data is are needed. This includes temperatures and flow rates in all relevant branches of the systems. Due to a lack of information on the design and current condition of the district heating piping, the simulated energy balance of the complete network suffers from some uncertainties. To get an exact model for further optimisation, a continuous logging of the transferred thermal power at all substations is conducted. This is done by installing clamp-on ultrasonic flow sensors and temperature sensors at the building´s substations. By choosing clamp-on sensors, an interfering with the running system is prevented. Besides that, the pipes of the network are too large in diameter for the most common stationary flow rate sensors. The data is logged by an impulse output of the sensor and the joining with the temperature sensor signals for flow and return pipe at a data logger. The data loggers store the information on SD-cards. As these values are only relevant for validating the model, a continuous monitoring is not necessary and reading the data from the cards at certain intervals is sufficient.

In the buildings, where the new solar thermal plants are installed, it was claimed to have a real time monitoring with online access. An internet connection via additional routers enables the monitoring on the online platform *vbus.net* by *RESOL*. The logged data include:

- All heat flows in the plants
  - Consumption/feed-in district heating network
  - Consumption space heat
  - Consumption domestic hot water
  - Circulation losses
  - Yield of the collector circuit
  - Yield of the solar system
- Electricity consumption of the pumps
- Irradiation at Schubertstraße 12 and 21 (10° west and 40° south)
- Temperature, global irradiation and wind speed at the weather station of THI
- Surveillance of the collector array on Schubertstraße 12 with webcam

A balancing of all heat flows in the buildings with a high sample rate is possible. To gather the data of the electricity that is necessary to run the solar thermal systems, additional energy meters are installed for the pumps, valves and controllers. The calculation of the system efficiency is enabled via the pyranometers installed parallel to the collector arrays on Hindenburgstraße 57 and Schubertstraße 12 (40° south and 10° west). Additionally, data from the weather station installed at THI is available, which is approximately 1.5 km away from the plants. To get a closer look on the fogging and ventilation behaviour of the collectors on Schubertstraße 12, which have a very low inclination angle, a webcam is used. This will lead to further knowledge on the utilisation of the collectors on such relatively flat roofs.

6. CONCLUSION

Three different approaches for the integration of decentralised solar thermal plants were selected, which either support the domestic hot water production for a single building, feed the solar gains into the district heating network or enable a combined solution with local use of the energy and the feed-in of excess heat into the return pipe of the district heating system. Some of the already existing collectors on the buildings' roofs were integrated to the new system.

The simulated annual yields of the systems is in the range of 280 kWh/m² for the solely feed-in, 390 to 410 kWh/m² for the combined solution and 660 kWh/m² for the preheating of domestic hot water. Further optimisations of the system operation are conducted during the implementation of the plants. One of the measures will be the reduction of the supply temperature and flow rate of the network to increase the feed-in of the solar thermal systems. A comprehensive concept for a metrological investigation of the complete district heating network was developed, allowing an assessment of the solar yield and the energy balance for the complete system. The planned measurement phase will enable a direct comparison of the different equally sized plants under the same weather conditions and allow an assessment of the concepts and the benefits of efficient retrofitting solutions over similar existing networks. First results show a good accordance to the simulation-based predictions. A detailed report on the metrological investigation will be published in future papers.

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