# Implementation of large solar thermal system into district heating network in Chemnitz (Germany)

**Nirendra Lal Shrestha[1], Thorsten Urbaneck[1], Thomas Oppelt[1], Bernd Platzer[1],**
**Thomas Göschel[2], Ulf Uhlig[2] and Holger Frey[2]**

[1] Chemnitz University of Technology, Department of Mechanical Engineering, Professorship
Technical Thermodynamics, 09107 Chemnitz (Germany)

[2] inetz GmbH, Augustusburger Straße 1, 09111 Chemnitz (Germany)

### Abstract

The interest on solar thermal systems in district heating networks has been growing all over the world for several years. The integration of solar heat into the district heating network along with the conventional combined heat and power plant requires special concepts. This contribution describes the recent implementation of a large-scale solar heating system into a low-temperature network in the city center of Chemnitz. The technical specification of different subsystems such as the solar collector fields, the two-zone thermal energy storage and the heat transfer substation for auxiliary heating is presented. Special features of this plant are e.g. the use of water in the complete system and the extraction of heat from the return line of the main district heating network. First monitoring results are presented for the period from May to September 2017. In general, the system works as expected and a solar fraction of 21 % could be reached in the observed period. A potential for optimization is identified e.g. related to the network return temperature.

*Keywords: large-scale solar heating system, district heating, low-temperature, network, two-zone storage, heat transfer substation, auxiliary heating system*

## 1. Introduction

In order to achieve the national and international energy and climate goals, the potential of solar energy should be exploited. A large-scale solar district heating is a sustainable and environmentally friendly solution for the supply of thermal energy in urban quarters. The AGFW, the German industry association for district heating and cooling, predicts that there will be an expansion of solar thermal systems with 800,000 m$^2$ of collector field area in the district heating systems until 2020 in Germany (IKZ, 2017). The integration of solar thermal energy in a district heating system along with the existing cogeneration plant enables many advantages such as the reduction of non-renewable primary energy consumptions, of the $CO_2$ emissions and of the operating costs of the system.

This paper is intended to describe the implemented solution in Chemnitz, Germany. Chemnitz is a typical East German industrial city with a large-scale district heating system. This hot water system was planned as a municipal heating system in 1928 and had grown steadily until 1990. The heat generation in this system is based on a very high share on combined heat and power (CHP), which is produced by large lignite blocks. For ecological and energy policy reasons, it is very important to find solutions for the cities which are currently supplied by such conventional district heating systems. A favorable situation was present in Chemnitz from 2009 to 2011. It was recognized that the Brühl quarter (part of the northern city centre of Chemnitz) had to be renovated completely including the infrastructure due to the condition of the buildings (Municipality of Chemnitz, 2017). A brief description of the urban design situation is available online (Staedtebaufoerderung, 2017). The main problem was the very high vacancy rate of residential and commercial units which exceeded 50 %. Hence, several major steps were taken to preserve the quarter and to fundamentally improve the social conditions. The authors (Urbaneck et al., 2015) got involved for a complete restructuring of the heat supply, in particular to increase the share of renewable energies. First, the building structure and the heat consumers

doi:10.18086/swc.2017.06.08 Available at http://proceedings.ises.org

as well as possible renewable energy sources were analyzed. A preliminary study (2011-2012) lead to the design of the heat supply concept with measures to increase energy efficiency and the use of solar thermal energy showing the best results (Urbaneck et al., 2015). The concept has been implemented as proposed except a few technical modification. In summer 2016, the plant was put into operation. The pilot plant consists of a heat transfer substation with two solar collector fields, a two-zone storage, a district heating connection as well as a low temperature network for the quarter with the house connection stations (Fig. 1). The monitoring and analysis are carried out as part of the project "Solar district heating for the Brühl district in Chemnitz – accompanying research (SolFW)" which is located in the 6th energy research program of the German federal government. Further objectives and tasks can be found online (Urbaneck, 2017).

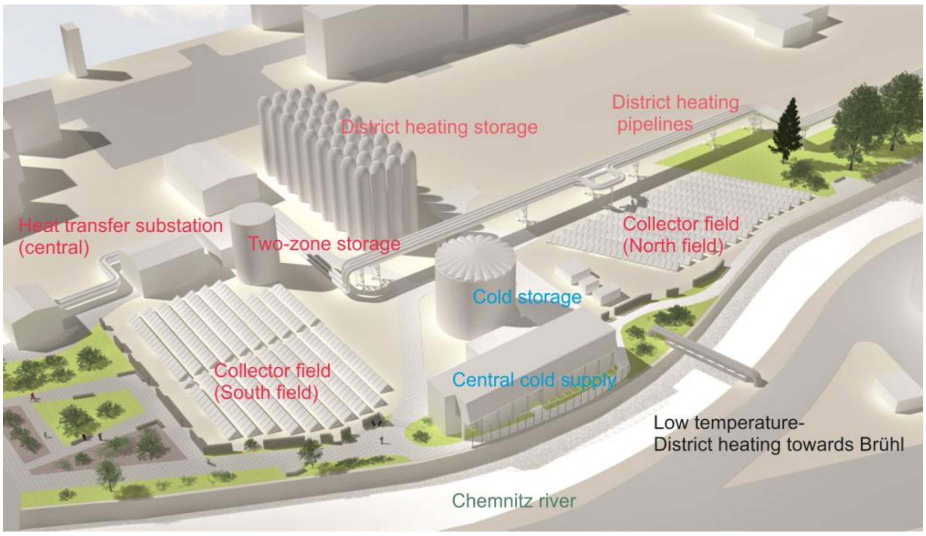

**Fig. 1: Scheme of the supply station at the Georgstrasse, Chemnitz, Source: inetz 2016.**

## 2. Solar heating system concept

The quarter (Hertelt et al., 2012) covers an area of more than 10,000 m$^2$ and includes mainly apartment buildings with around 1300 residential units. About 25 % of the buildings are subjected to preservation order. A low-temperature network with a supply and return temperature of 70 and 40 °C, respectively (design-supply temperature of 70 °C at an ambient temperature above 0 °C, linear rise to 80 °C at -14 °C ambient temperature) was built. Moreover, heat exchangers (pre-heating and post-heating stage, Fig. 2) decouple the quarter hydraulically from the existing main district heating network. The temperature reduction in the network enables the efficient use of solar thermal energy. That means, a "low-temperature island" is created in the city and in the district heating area. Additionally, in order to achieve low return temperatures, special heat transfer stations for the apartment residential units were chosen which are based on a solution by Mahler (Mahler, 2004). The construction of a supply station (transfer station between the existing district heating system (primary line) and the low-temperature network) with relatively large collector fields and a relatively large storage brings several advantages in the present urban situation:

- using existing brownfield areas close to the quarter,
- effective realization of construction measures outside the residential area,
- the reduction of specific investment costs due to large units,
- a central operation and
- no problems related to buildings being subject of a preservation order.

The structure of the transfer station is shown in Fig. 2. The main components of this supply station are described in the following sections.

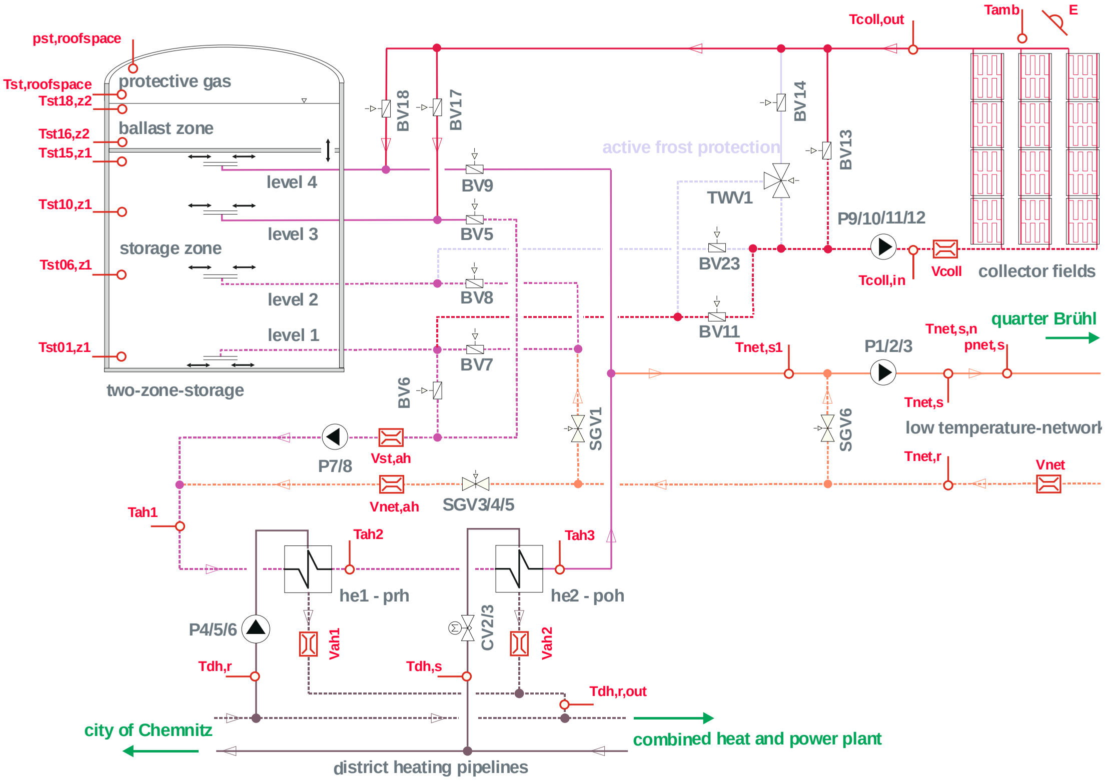

**Fig. 2: Structure of the transfer station (supply center).**

## 2.1 Solar thermal field

The large flat plate solar collectors were installed in two fields (north and south) based on the model of systems in Denmark (Holm, 2000) and cover a collector aperture area of 2093 $m^2$ (Fig. 3). The collectors were mounted on the ground with a tilt angle of 35° and field azimuths of 0° and -30° (south and north field, respectively). Two sizes of solar collectors provided by Wagner Solar GmbH, were installed for charging the storage and for supplying hot water directly to the network (Tab. 1).

**Tab. 1: Parameters of the collector fields.**

| | Collector field south | Collector field north |
|---|---|---|
| Aperture area | 1007 $m^2$ | 1086 $m^2$ |
| Collector type | Wagner WGK133AR,<br>Wagner WGK80AR | Wagner WGK133AR,<br>Wagner WGK80AR |
| Number of rows | 10 | 17 |
| No. of WGK133AR | 79 | 86 |
| No. of WGK80AR | 4 | 3 |

The special feature of the Chemnitz solar system is that water is used as heat transfer medium in the two solar fields. Additionally, there is no hydraulic separation between the solar fields, the storage and the customer's heating surface (e.g. radiator, floor heating). This reduces the heat and temperature losses along the supply path and increases the collector efficiency. Furthermore, a faster availability and the reduction of auxiliary energy requirements are achieved. In the collector, the heat transfer is improved due to the thermo-physical properties of water. From a practical point of view, deaeration is facilitated leading to simple and efficient operation. Cost reduction can be achieved by eliminating large heat exchangers, avoiding water-glycol mixtures, omission of pumps and valves on the secondary side, etc. However, in minus temperatures during winter the collectors must be heated with low heat amounts from the network in order to keep them frost-free. In the SolFW project, this active frost protection (Fig. 2) which was previously practiced only with compound parabolic concentrators (CPC) by Paradigma (Paradigma, 2016) is to be investigated in detail.

The solar fields are operated with matched flow. The specific volume flow rate is 15 l/($m^2 \cdot h$) at maximum and controlled between 30 % and 100 %. The aim is for each string to reach the desired supply temperature of ca. 70 °C. This is performed by the setting of regulating valves being located at the outlet of each collector row. These valves are adjusted in such a way that the desired flow distribution is reached in nominal operating conditions. The control strategy (on the system side) ensures supply temperatures of 70 °C – 80 °C (possibly higher). In case of stagnation, the solar fields are separated from the system.

**Fig. 3: South solar collector field and two-zone storage (left) and north collector field (right) in the Brühl system, Chemnitz.**

## 2.2 Storage

For buffering short-term solar surpluses and as short-term storage for the CHP plants, a welded flat bottom tank was installed above the ground close to the south field (Fig. 3). It is constructed as two-zone storage according to a patent application by Thümmler (Thümmler, 2014) with a thermal useful volume of 1000 $m^3$ (storage zone) and a volume in the ballast zone of approx. 500 $m^3$. It is possible to store hot water with a charging temperature of up to 108 °C in the tank with stratification. The high temperature is possible due to the hydrostatic load of the upper zone (ballast zone) which increases the pressure in the lower storage zone and thus influences the boiling temperature of the water to be stored. The increased temperature leads to a higher storage capacity. The two zones (Fig. 2) are separated by a rigid and tightly sealed intermediate ceiling with insulation. For pressure balance, both zones are interlinked by a pipe system. Thus, the static pressure in the storage zone is always above the boiling pressure and evaporation or cavitation are prevented reliably. Additionally, this design helps in absorbing the volume difference due to expansion of water in the storage tank or the entire distribution system.

The total height of the storage is 20 m and the two zones are separated at the height of 13.4 m. The inner diameter of the storage is approx. 10 m. and it is insulated with mineral wool being 0.50 m thick. The outer surface of the insulation was covered by aluminum trapezoidal profiles. Furthermore, in order to charge and discharge the storage at different temperatures, four radial diffusors with diameters of 1.4 m are arranged in different levels.

This new construction of the storage is one of the first of its type being built in a solar district heating system. To avoid a contact of the water surface in the storage with air, nitrogen is injected in the roof space inside the tank.

## 2.3 Heat transfer substation

Since the solar energy yield can only cover the demand on favorable summer days, auxiliary heat for charging the storage and direct supply of the low-temperature network is provided by the existing district heating system. For this purpose, a two-stage system was installed in the heat transfer substation. The first group of heat exchangers (pre-heating stage, Tab. 2) contains two parallel plate heat exchangers for transferring heat from the main district heating return line. Depending on the return temperature from the low-temperature network or the storage (Tah1 in Fig. 3) and the current temperature of the main return line (Tdh,r), pre-heating can be conducted. Then the water with the temperature Tah2 flows to the post-heating stage where two parallel shell and tube heat exchangers supply heat from the main supply line in order to reach the desired supply temperature.

**Tab. 2 Technical parameters of the heat transfer substation (Source: Requirements specification for Brühl district heating, AIC Ingenieurgesellschaft für Bauplanung Chemnitz GmbH, 2015).**

| **plate heat exchangers (pre-heating)** | | **shell and tube heat exchangers (post-heating)** | |
|---|---|---|---|
| capacity | 2.7 MW | capacity | 3.3 MW |
| *primary side:* | | *primary side:* | |
| allowable operating over pressure | 25 bar | design pressure | 25 bar |
| max. allowable operating temperature | 140 °C | design temperature | 160 °C |
| inlet- / outlet temperature | 60/50 °C | inlet- / outlet temperature | 120..130/63..65 °C |
| max. pressure loss | 0.20 bar | max. pressure loss | 0.25 bar |
| *secondary side:* | | *secondary side:* | |
| allowable operating over pressure | 16 bar | design pressure | 16 bar |
| max. allowable operating temperature | 140 °C | design temperature | 160 °C |
| inlet- / outlet temperature | 45/57 °C | inlet- / outlet temperature | 60/80..108 °C |
| max. pressure loss | 0.25 bar | max. pressure loss | 0.25 bar |

### 2.4 Network

A buried two-pipe network connects the buiding’s heat transfer substations to the supply center and distributes heat with constant/annually varying supply temperature. Most of the pre-insulated pipes with sizes from DN25 to DN250 have been newly laid since 2014. So far, the owners of 198 out of 259 buildings (76 %) have taken up the connection offer by the utility inetz. The current load of the connected buildings amounts to 12.6 MW. This is about 200 % of the load expected for the first stage of network construction which was assumed for designing the solar plant (Urbaneck et al., 2015).

## 3. Monitoring results

Although the operation of the solar plant started from August 2016, the recording of all the required parameters has been only available since May 2017 onwards. Therefore, at first the thermal behavior of the system from May to September 2017 is shown and evaluated:

- The continuous supply of the low-temperature network is depicted in Fig. 4. The supply temperature is slightly above 70 °C, which is due to the safety reasons. The return temperature is in the range of 52…63 °C. Several factors are responsible of this higher return temperature, e.g. the supply being used only for domestic hot water systems during the summer period, maintaining the network temperature in the low-temperature circuit and fluctuations in the charging cycles of the transfer station.
- The daily sums for the output of collector field (sum of north and south field), auxiliary heating demand and demand of the low-temperature network are shown in Fig. 5. The solar thermal system has been designed for the first stage of network construction (Urbaneck et al., 2015). As the interest of building owners exceeded the expectations, the number of connections and thus the load values (Fig. 5) already correspond to the second stage of construction. Therefore, the output of the collector fields can be seen below the network demand. Even during summer, auxiliary heating is necessary. No off-peak periods (e.g. vacation) can be detected in the analyzed period. The base daily demand is 10…15 MWh/day.
- The relatively high return temperatures in the low-temperature network (Fig. 4) have an effect on the auxiliary heating system (Fig. 6). A fluctuating temperature profile can be seen (mainly because of the control behavior of the pre-heating stage). The increase of the temperature to the desired value is mainly performed in the post-heating stage because the return temperature of the low-temperature network is close to the temperature of the main return line being used as heat source in the pre-heating stage.
- The daily sums of thermal energy transferred by the auxiliary heating system (stages 1 and 2) are depicted in Fig. 7. The pre-heating stage covers ca. 15 % of the total auxiliary heat demand. It is expected that during the heating season from autumn to spring, the return temperature in the network

will be lower which leads to an increasing contribution of the pre-heating stage to the total auxiliary heat supply.

- The desired supply temperature is hold ready in the upper level of the storage zone (Fig. 8). However, fluctuations between 65 and 82 °C can be observed due to the operation of the collector fields and the auxiliary heating system.
- The high return temperature of the network has an effect on the operation of the collector fields. During the day, the outlet temperature of the solar collector in the south field is between 70 °C and 80 °C (Fig. 9) and sometimes it exceeds 80 °C for a few hours. The inlet temperature is in the range of 50…60 °C (Fig. 10). The design temperature difference between the inlet and outlet of the collector field with nominal operation is 30 K. However, the observed temperature differences are often lower (ca. 20 K, Fig. 11) due to high return temperatures in the network.
- Fig. 12 and Fig. 13 show a regular behavior with respect to the solar collector yield. There are a few outliers which indicate temporary malfunction. Generally, the fluctuation range is relatively narrow and confirms continuous operation of the solar plant.

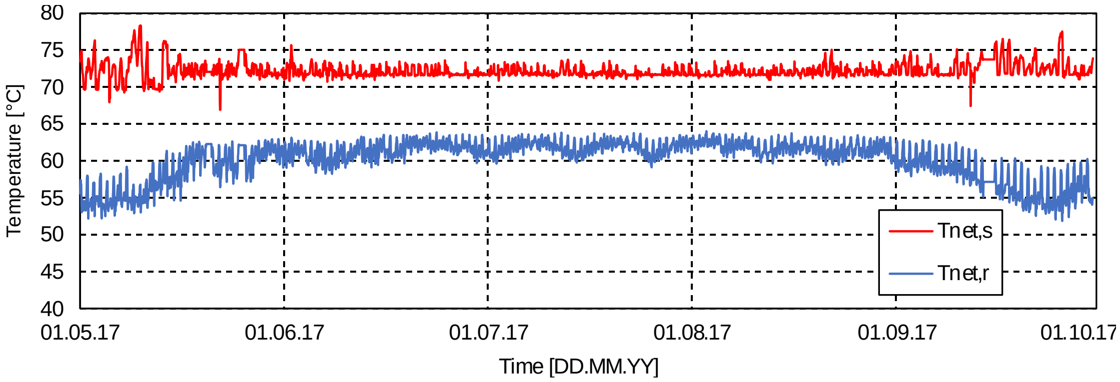

**Fig. 4: Temperatures in the course of time, supply and return of low-temperature network (hourly mean values).**

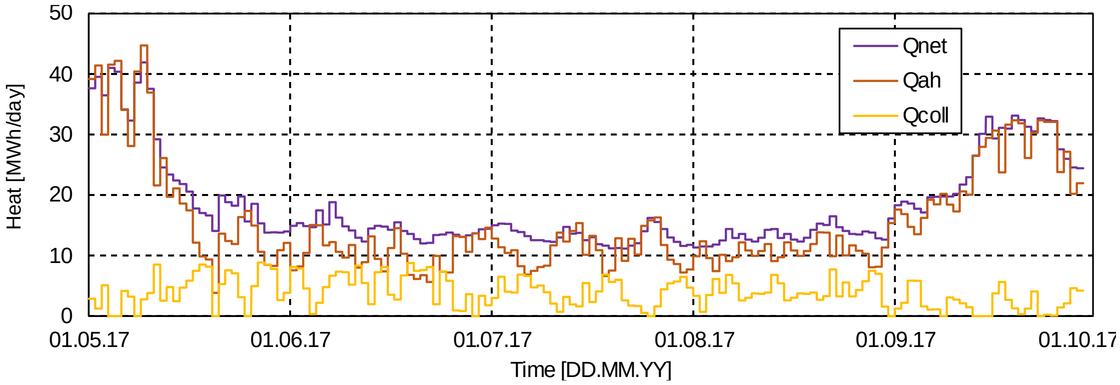

**Fig. 5: Daily heat sum, output of collector field, auxiliary heating demand, demand of low-temperature network.**

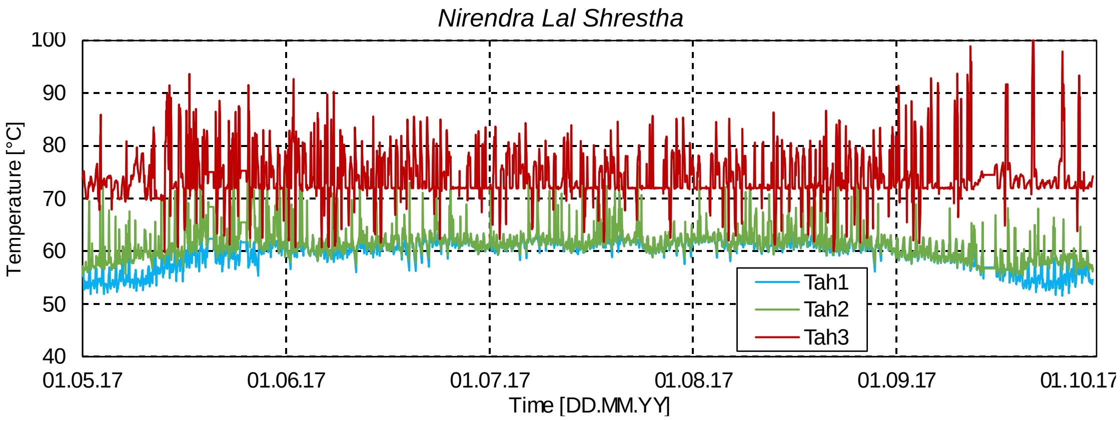

**Fig. 6: Temperatures in the course of time, auxiliary heating circuit (hourly mean values).**

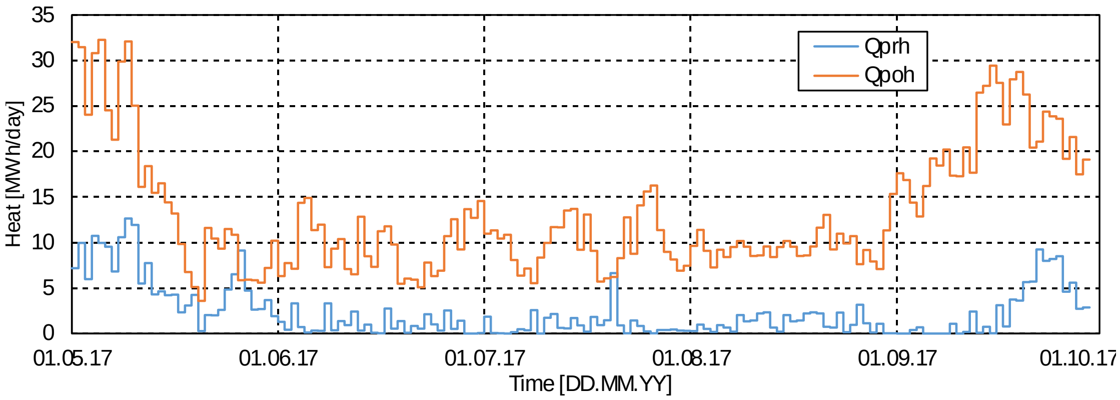

**Fig. 7: Daily heat sum, auxiliary heating stages 1 and 2.**

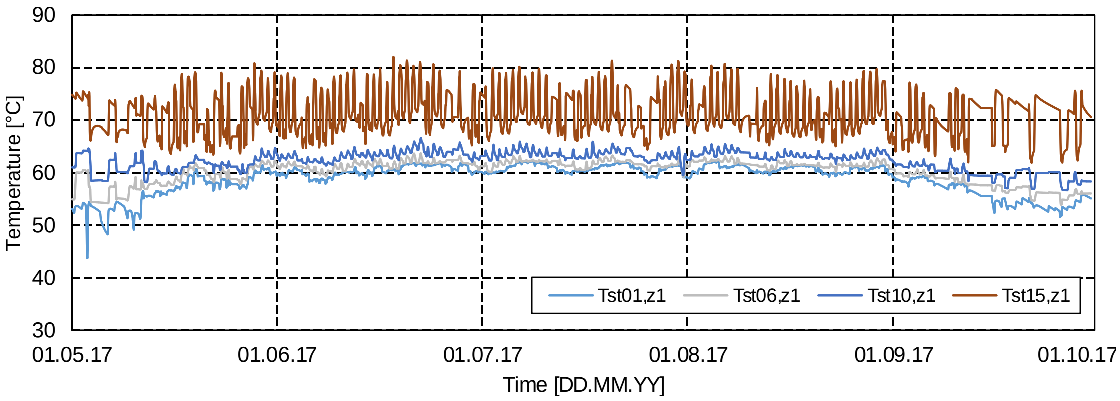

**Fig. 8: Temperatures in the course of time, two-zone storage (hourly mean values).**

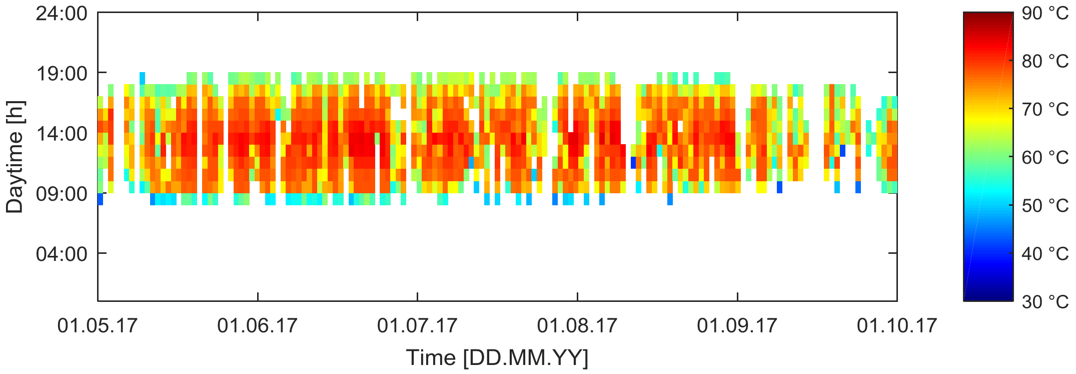

**Fig. 9: Temperatures in the course of time, outlet temperature of the south collector field (hourly mean values during matched flow operation).**

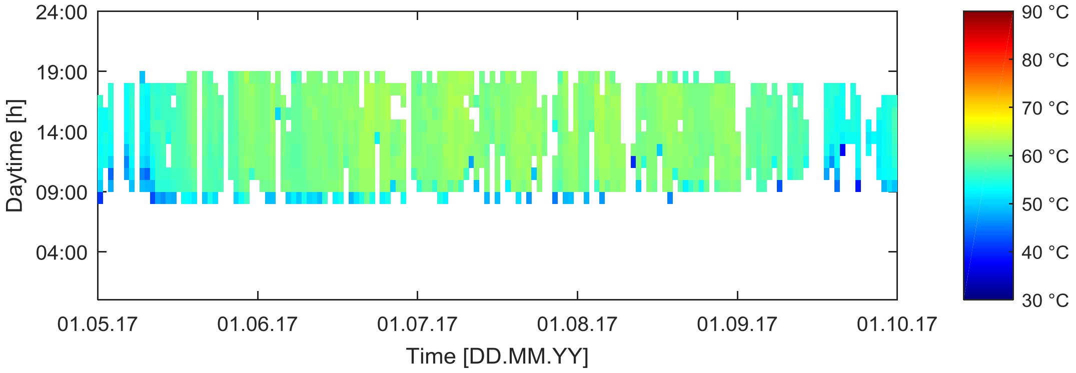

**Fig. 10: Temperatures in the course of time, inlet temperature of the south collector field (hourly mean values during matched flow operation).**

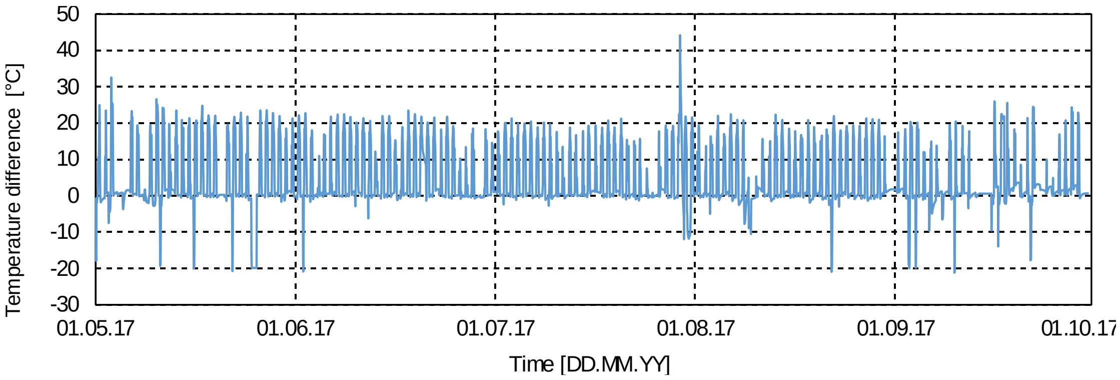

**Fig. 11: Temperature differences of the south collector field in the course of time (hourly mean values).**

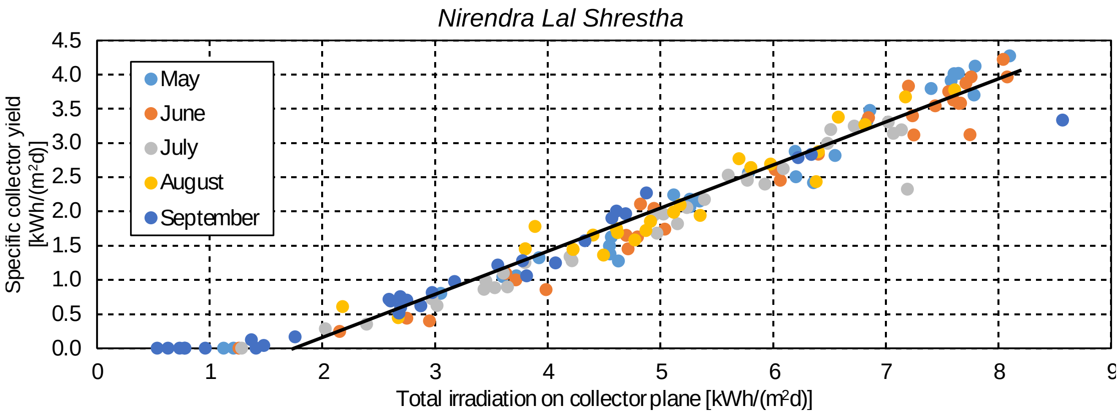

Fig. 12: Solar collector yield depending on the total irradiance on the collector surface in south field, 2017.

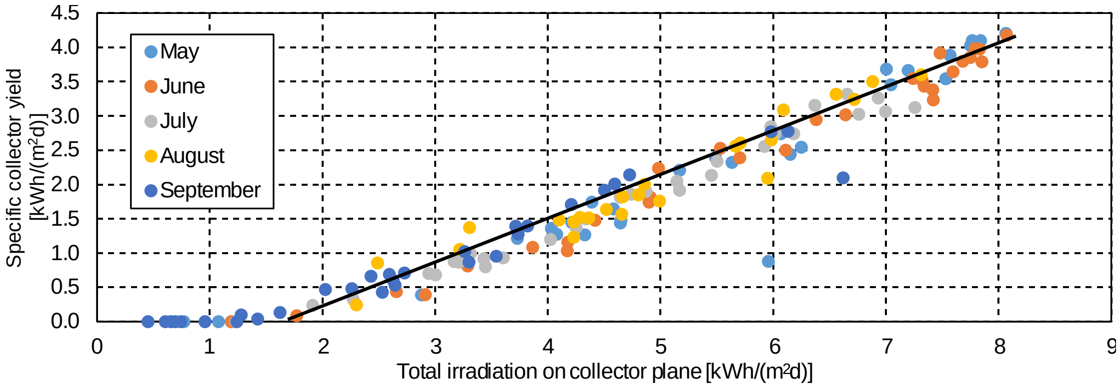

Fig. 13: Solar collector yield depending on the total irradiance on the collector surface in north field, 2017.

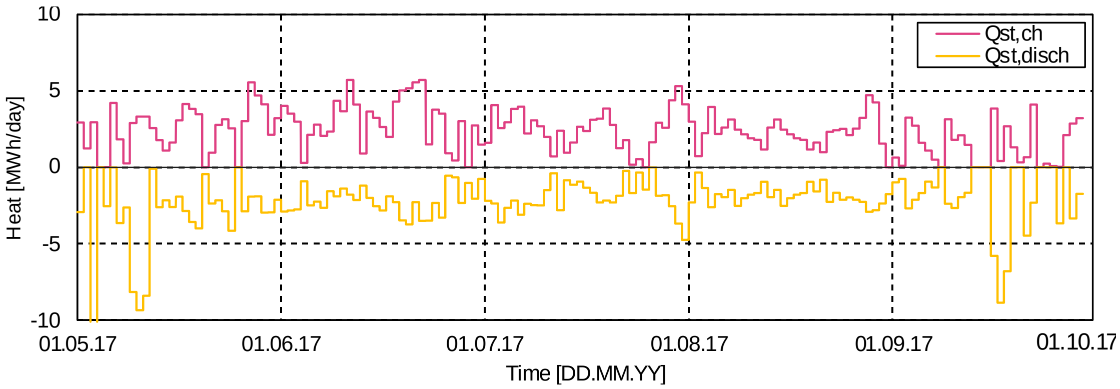

Fig. 14: Daily heat sum, charging and discharging of the storage.

On the basis of the monitoring data from May to September 2017, the heat quantities were calculated and are listed in Tab. 3. Furthermore, the key figures were listed which facilitate the evaluation:

- The summed yield of the solar collector fields is 599 MWh from May to September. In the design phase, a specific collector yield of about 402 kWh/(m$^2$·a) was simulated for a net collector area of 1800 m$^2$ (Urbaneck et al., 2015). Thus, 71 % of the predicted yield was achieved so far. The solar fraction for the analyzed summer period amounts to 21 %, which is quite small because the solar collector field has been designed for the first stage of network construction. However, the second stage of construction has been reached faster than expected.

- The difference in yield between the south field with ideal south orientation and the north field with an azimuth of -30° (east) is quite small with about 4 %. The azimuth of -30° was chosen for avoiding shading by the main district heating pipes (Fig. 1).
- The high return temperature of the network during the analyzed period lead to a relatively low share of the pre-heating stage in the total auxiliary heat supply.

**Tab. 3: Heat quantities and key figures.**

| **Heat** | | **Key figures** | |
|---|---|---|---|
| *Generation:* | | specific collector yield (north field) [kWh/m$^2$] | 281 |
| yield from collector field (north field) [MWh] | 305 | specific collector yield (south field) [kWh/m$^2$] | 292 |
| yield from collector field (south field) [MWh] | 294 | solar fraction [%] | 21 |
| auxiliary heating (stage 1) [MWh] | 356 | share of stage 1 in auxiliary heating [%] | 15 |
| auxiliary heating (stage 2) [MWh] | 2037 | share of stage 2 in auxiliary heating [%] | 85 |
| *Consumption:* | | collector field efficiency (south) [%] | 39.9 |
| supply to low-temperature network [MWh] | 2808 | collector field efficiency (north) [%] | 39.6 |
| losses [MWh] | 184 | | |

## 4. Conclusions

In this paper, the implementation of large flat plate solar collectors into a low-temperature district heating network is presented. First monitoring results for the period from May to September 2017 show that the system in general operates as expected. The return temperature of the network has a very high influence which has been known since the 1990s. Optimization measures are planned here. Further work will be conducted for improving e.g. control of the auxiliary heating system. It is possible to transfer this concept to other urban quarters. Moreover, with the scale-up of collector area and storage capacity, higher solar fraction can be achieved. Therefore, this concept is one useful technical solution for large-scale heating systems.

## 5. Acknowledgements

The project underlying this report is funded by the German Federal Ministry for Economic Affairs and Energy under the code 0325871 following a decision by the German parliament. Special thanks also go to the Project Management Jülich for supporting the project. The sole responsibility for the report’s contents lies with the authors.

## 6. References

Hertelt, J., Heller, M., Dilger, M., 2012. Städtebauliche Planungsstudie zur Entwicklung des Gebietes “Brühl-Boulevard” in Chemnitz [Urban design study for the development of the area “Brühl-Boulevard“in Chemnitz, in German]. Albert Speer & Partner GmbH, C&E Consulting and Engineering GmbH.

Holm, L., 2000. Experiences and results from Marstal district heating plant. In: Frankovic, B. (Editor): International Congress Energy and the Environment 2000 – 17th Scientific Conference on Energy and Environment. Opatija (Croatia), Proceedings, Vol. 1, p. 157-164. - ISBN 953-6866-00-6.

IKZ. http://www.ikz.de/detail/news/detail/vorhersagbarer-waermeertrag/, (accessed on 25.02.2017).

Mahler, B., 2004. Ganzheitliche Optimierung von solaren Nahwärmenetzen mit Langzeit-Wärmespeicher

[Holistic optimization of solar district heating networks with long-term heat storage, in German], PhD thesis. VDI-Verlag, Düsseldorf.

Municipality of Chemnitz. http://www.chemnitz.de/chemnitz/de/die-stadt-chemnitz/stadtentwicklung/entwicklung-bruehl/index.html., (accessed on 02.08.2017).

Paradigma. http://www.paradigma.de, (accessed on 15.05.2016).

Staedtebaufoerderung - Federal Institute for Research on Building, Urban Affairs and Spatial Development within the Federal Office for Building and Regional. http://www.staedtebaufoerderung.info/StBauF/DE/Programm/AktiveStadtUndOrtsteilzentren/Praxis/Massnahmen/Chemnitz/Chemnitz_node.html. Internet-Plattform zum Städtebauförderprogramm Aktive Stadt- und Ortsteilzentren (in German), (accessed on 25.08.2017).

Thümmler, E., 2014. DE102013111543 A1.

Urbaneck, T.; Oppelt, T.; Platzer, B.; Frey, H.; Uhlig, U.; Göschel, T.; Zimmermann, D.; Rabe, D., 2015. Solar District Heating in East Germany – Transformation in a Cogeneration Dominated City. Energy Procedia, Vol. 70, pp. 587–594. - doi: 10.1016/j.egypro.2015.02.090.

Urbaneck, T. www.solfw.de. Project website, (accessed on 27.07.2017).

## 7. Nomenclature

| | | | |
|---|---|---|---|
| ah | auxiliary heating | P | pump |
| amb | ambient | poh | post-heating |
| BV | butterfly valve | prh | pre-heating |
| ch | charging | Q | heat |
| coll | collector(-field) | r | return |
| CV | control valve | s | supply |
| dh | district heating | SGV | sliding gate valve |
| disch | discharging | st | storage |
| E | solar radiation (measurement) | T | temperature (measurement) |
| he | heat exchanger | TWV | Three-way valve |
| net | network | V | volume flow rate (measurement) |
| p | pressure (measurement) | z | zone |