Conference Proceedings

EuroSun 2014
Aix-les-Bains (France), 16 - 19 September 2014

DECENTRALIZED SOLAR DISTRICT HEATING SYSTEMS

Axel Oliva[1], Mehmet Elci[1], Wolfgang Kramer[1], Sebastian Herkel[1], Alexander Ripka[2]

[1] Fraunhofer Institute for Solar Energy Systems ISE, Freiburg im Breisgau (Germany)

[2] badenova Wärmeplus GmbH & Co. KG, Freiburg im Breisgau (Germany)

Abstract

The role of solar thermal technology in urban areas is investigated for future energy scenarios. The combination of a Combined Heat and Power (CHP) district heating system and decentralized solar thermal systems, located at each building connection unit (BCU) is focused in this context. Different technology options for domestic hot water (DHW) preparation are taken into account. These affect the efficiency of the solar thermal system, thus leading to a potential reduction of dimensioning. Hence, cost for the solar thermal system can be reduced, hence, resulting in lower cost for the complete system depending on the chosen DHW preparation system. Furthermore the robustness of solar thermal supply regarding varying environmental conditions represented by 19 years of monitored historical weather data at the location of Freiburg im Breisgau is demonstrated.

1. Introduction

The new development area “Gutleutmatten”, with 500 households, 40000 m^2 living area and a heat demand of approximately 2600 MWh per year, will be constructed in Freiburg im Breisgau between 2015 and 2017 within the framework of the inner-city development. A decentralized solar thermal system will be integrated into a heat supply system based on a Combined Heat and Power (CHP) district heating system. The operation of the CHP will be optimized aiming at the best possible interaction with the electricity network and aiming to minimize the distribution losses of the local heating network. The hypothesis of the conducted project “EnWisol” is that such a concept will be beneficial for this and similar urban areas on the long term due to an optimum support of load management of electric networks and the maximum use of renewable energies. The central topics of this project are to implement and to test the concept and operational management, and to deduce overall rules for the long-term perspective of solar thermal heating in similar urban districts. The main objective is to present an innovative integration of solar thermal systems in the local heating network in a way that is economically beneficial for the system operator, the investor and the end user.

2. Building area Gutleutmatten

The building area named Gutleutmatten is located in Haslach, a city district close to the city center of Freiburg. Figure 1 shows the building area, West-Gutleutmatten and East-Gutleutmatten. In the western part, approximately 280 households and a daycare center will be built. The number of stories in each building varies between four and six, except for one building with nine stories in the northern entrance of the district. In the eastern part, approximately 230 households, a daycare center, and a commercial area will be built. The number of stories in each building varies between three and five. In the southern area of this side, terraced houses with three stories will be erected. The maximum floor area in Gutleutmatten will measure 57000 m^2, where 40000 m^2 will be heated. The territory is divided into 45 individual plots of land. All the buildings will be built following the standard “KfW-Effizienzhaus 55”. The heat demand of the urban district is 1400 MWh per year for space heating and 1200 MWh per year for domestic hot water (DHW) preparation.

The heat supply concept includes a district heating system, decentralized solar thermal systems and

doi:10.18086/eurosun.2014.19.10 Available at http://proceedings.ises.org

decentralized heat storages. The heat network in Gutleutmatten (see Figure 2) will be connected to the already existing heat network Haslach/Staudinger School. The design of the heat network is carried out/optimized with the software STEFaN [2]. The maximum operating pressure of the system is 6 bar.

Figure 1: Three-dimensional view of the development area Gutleutmatten in Freiburg i. Br.

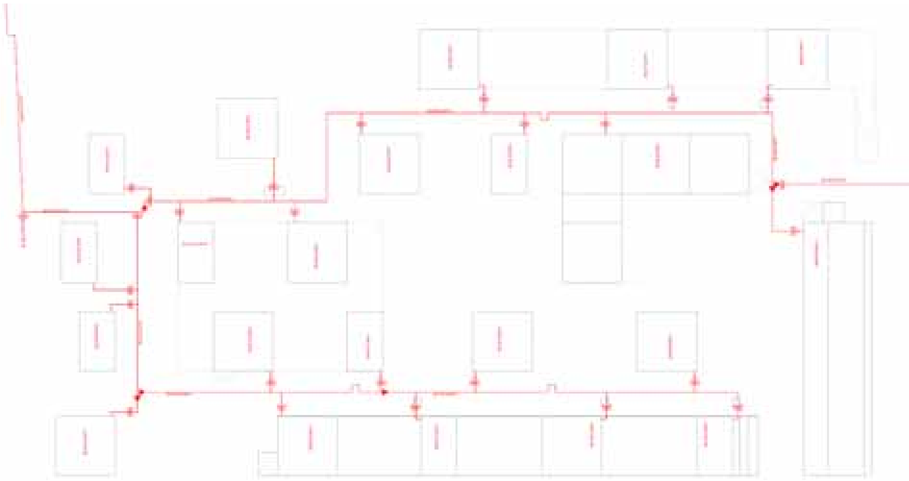

Figure 2: Plan of the heat network in West-Gutleutmatten

The heat network is fed by a heat station located in the utility room of Staudinger School. The station consists of a biogas CHP and four natural gas boilers. The CHP has a capacity rating of 750 kW_{th}/600 kW_{el} and the boilers have a capacity rating of 1000 kW each. The operation temperatures are 75/90°C (summer/winter).

3. Status of concept design of heat supply

As already stated, each building supply connection will be equipped with a solar thermal system. In a **first step** the maximum installable collector area on the flat roof area is determined. Its impact on the interaction between electricity production and solar thermal supply is investigated. **Second,** the robustness regarding varying weather conditions will be checked by simulation with 19 years of historical weather data of the site. In the **third step** different variants for DHW preparation concepts are investigated concerning their impact on energy efficiency and economics.

Usually, collector arrays are set in a way that shading of irradiation is as low as possible. The so-called shading angle is defined as the lowest elevation angle of the sun, which does not produce shading. Normally, this angle is set to about 10° to 20° in locations of Central Europe. Applying this value allows for maximum solar yield during a complete annual period.

However, in the case of the energy supply concept of Gutleutmatten, the goal is to especially avoid operation of the CHP system when economically not reasonable. In future electricity supply scenarios it is very likely that during summertime with a surplus of photovoltaic electricity production CHP systems cannot be run economically. Therefore, the solar thermal system has to be designed in order to replace heat from the CHP system especially during summertime. Thus, the solar thermal system design aims at partial self-sufficient heat supply. This means in a first approach, that at least 3 months of accumulated "self-sufficient days" in summer time have to be reached.

This shift of focus from a maximum annual yield to a minimum level of self-sufficient heat supply in summer time leads to the result, that in cases of limited available roof area collectors have to be moved closer together. Shading angles increase correspondingly. Although this reduces the specific solar annual yield, the yield in summertime with steep irradiation angles of the sun is increased due to an increased surface area. An optimum shading angle has to be determined. Figure 3 shows the impact of the shading angle onto the loss of annual solar yield.

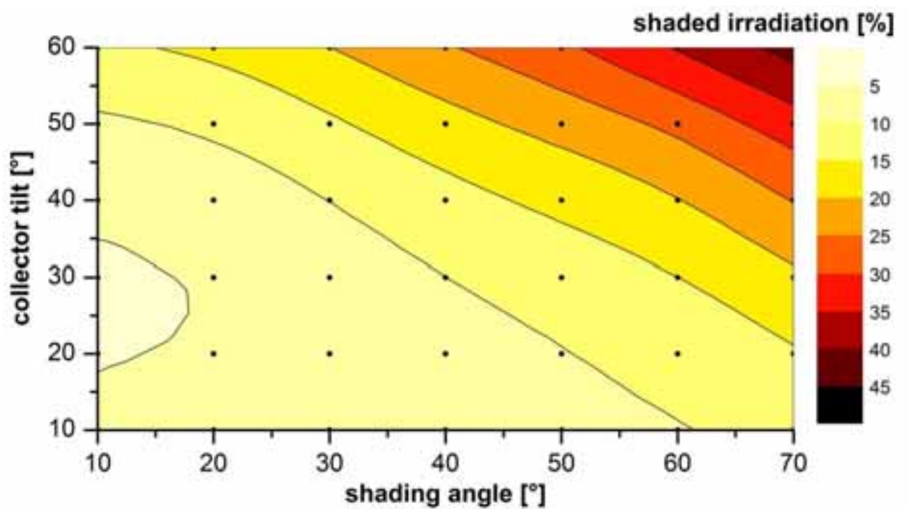

Figure 3: Shaded annual irradiation depending on the shading angle and the collector tilt for one typical roof area in the western part of "Freiburg-Gutleutmatten".

In a first approach, a shading angle of up to 40° seems to be acceptable. In this case, when installing the collectors with a tilt of not more than 30° the annual shaded irradiation would be about 10%. Figure 4 shows the potential collector area resulting from 40° of shading angle as a specific value per person for each building supply connection system.

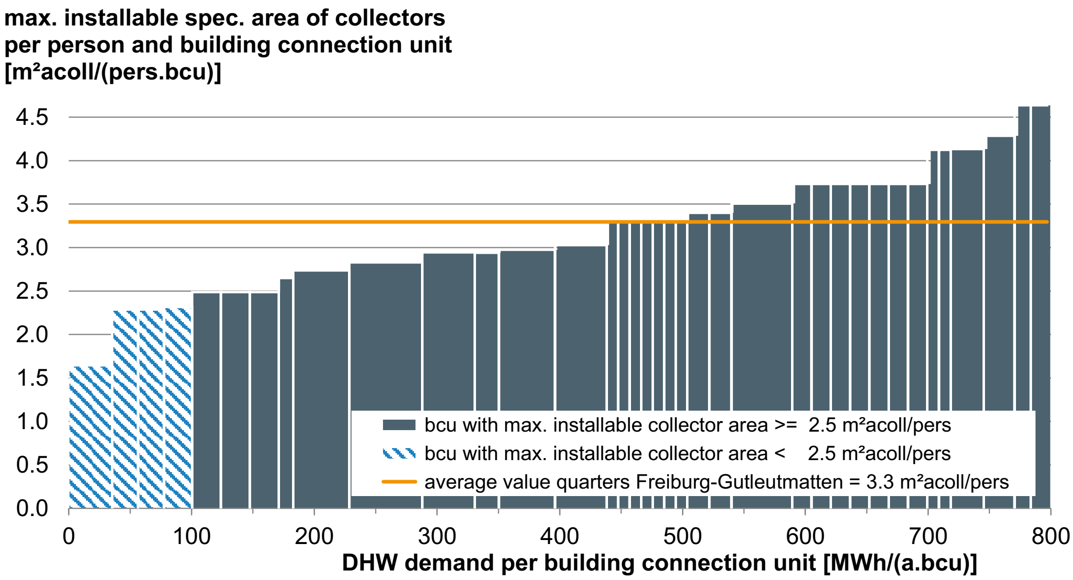

Figure 4: Energy demand for domestic hot water preparation related to each building connection unit (BCU) accumulated on the axis of abscissa. The corresponding maximum installable collector area is shown on the ordinate.

The first calculations were performed with an area of 1.5 m² of collector area per person. This value is based on the land development plan where the building base area and the maximum high of the structure are stated. It was assumed, that 70% of the total floor area is heated. Furthermore it is assumed that 30 m² floor area is occupied per person. The results shown below indicate that this collector area is sufficient in order to allow for a total of 3 months of self-sufficient heat supply of the decentralized solar thermal system. However, since the available area might shrink due to surface demand of other devices like elevators and other equipment, it is assumed, that for save dimensioning 2.5 m² of available collector area should be aimed at. Thus, the 4 buildings with collector areas below 2.5m² might be critical.

Systems considered for DHW preparation

The technology applied for DHW preparation is one key parameter in the concept of "Freiburg-Gutleutmatten". Three types of technology have been evaluated more in detail until now.

The **stand-by- tank charging technology** is the oldest and most widespread type of technology. It is based on keeping a stand-by volume of heated drinking water ready for supply. Its principle hydraulic scheme is shown in Figure 5. High peaks of demand are covered by the storage volume of hot water. The charging unit consists of a heat exchanger and a pump. Common volumetric design allows charging of the entire tank within 30 minutes at maximum. Due to the German regulation of DVGW [3] the outlet temperature of the tank has always to be above 60°C. Furthermore the temperature in the DHW distributing network has to be at 55°C at the lowest. High heat losses are one result of this type of technology. Furthermore the fresh-water content is quite high so that a hygienic thermal treatment is considered as energetically disadvantageous.

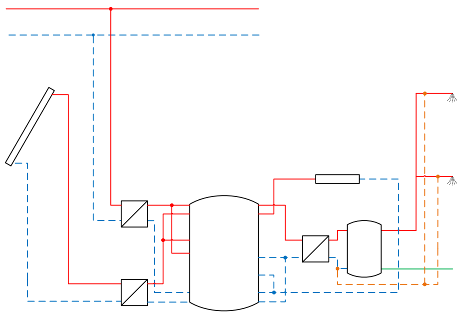

Figure 5: Stand-by tank charging technology for DHW preparation

The technology of **central flow-through** for DHW preparation does not include any stand-by volume of heated fresh water. The fresh water flows through a heat exchanger unit and is heated by the flow-through principle. The fresh water content of the system is much lower. A typical scheme for this kind of technology is shown in Figure 6. The regulations of the German DVGW do also demand the same temperatures to be guaranteed as stated above for the stand-by tank system. It is obvious that avoiding the stand-by tank reduces heat losses.

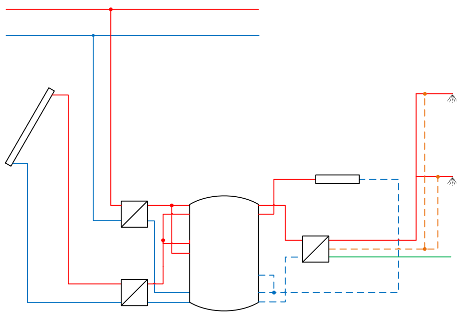

Figure 6: Central flow-through technology for DHW preparation

Energy efficiency can be maximized applying the technology of **decentralized flow-through**. System temperatures can be decreased regarding the DVGW regulations when the volume of the fresh-water hydraulic distributing system is below 3 liters. The integration of each decentralized system is realized by two pipes (one flow and one return for both space heating and DHW preparation) instead of four in the case of the previously mentioned systems (one flow space heating and one flow DHW and one return for each). The hydraulic integration is shown in Figure 7.

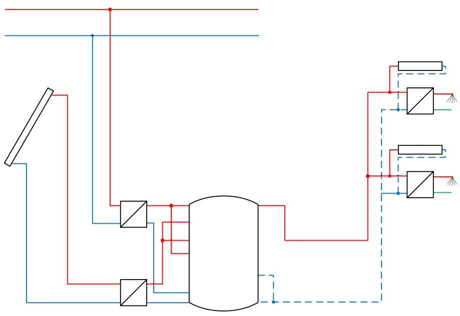

Figure 7: Decentralized flow-through technology for DHW-preparation. The integration of space heating is also realized in a decentralized manner.

Using this technology, flow temperatures of about 50°C to 55°C at the inlet of the heat exchanger are sufficient to meet the consumer comfort criteria. This leads to a significant reduction of heat losses for distribution and circulation.

4. Results of building equipment simulations

Dynamic simulations have been performed evaluating the performance for typical building supply connections in "Freiburg-Gutleutmatten". The program used for this approach was TRNSYS 17.

Model set up

In the first step the performance of the heating network has been considered as an instant energy source with full effective power. The flow temperature is set to 3K above the maximum temperature in the system needed for DHW preparation. A hot water stand-by zone is defined in the storage of at least 200 liters or 5% of the storage volume. Both, the heating circuit and the hot water circuit are connected with corresponding hydraulic connections to the storage volume. The annual hot water demand is set to 20 kWh/m^{-2} and the circulation losses are set to 10 kWh/m^{-2} per year.

Robustness regarding varying weather data

The solar thermal systems performance has been calculated considering different boundary conditions concerning local weather variations. The system used is the one with central flow-through technology for

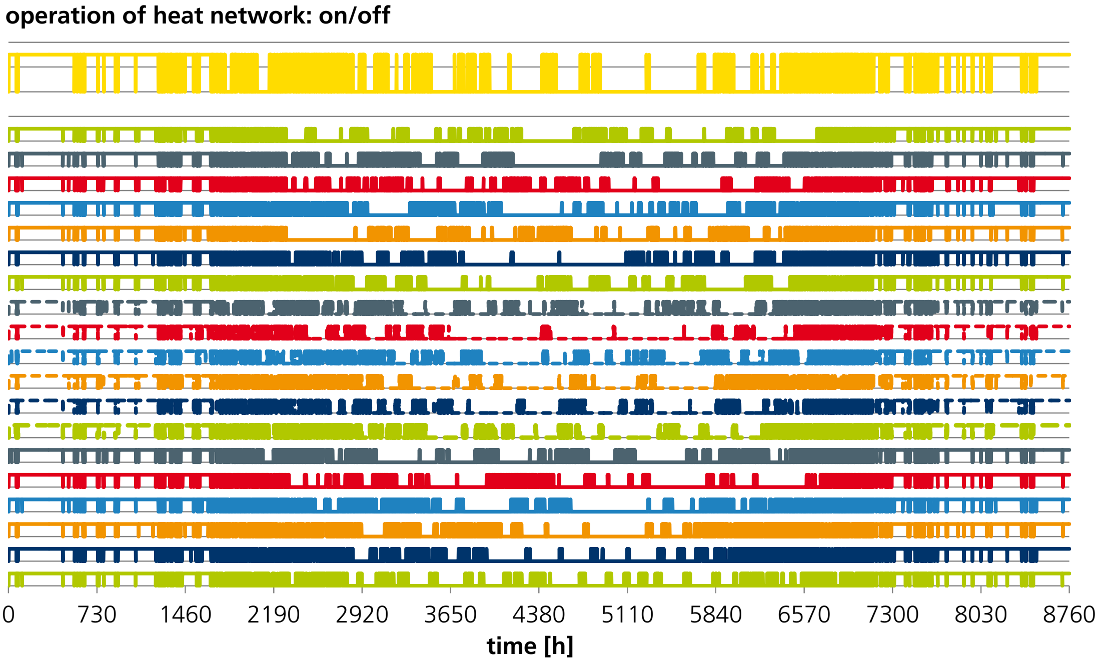

Figure 8: Requirement for auxiliary heat for one typical building simulated with 19 years of historical weather data and compared with the reference climate [1] (graph on top)

DHW preparation with an available flat plate solar collector surface area of 1,5m² per person. 19 years of historical weather data have been applied to the model and compared to the results obtained with reference data by Meteonorm [1]. The requirement for auxiliary heat by means of switching on the CHP system is indicated in Figure 8 in each graph as a high line. If there is no auxiliary heat for at least one hour the graph shows a low line. The simulated result, applying the reference weather data to the model, is plotted in the topmost yellow line. The years 1993 till 2012 are plotted for the lines beneath. An accumulated sum of approximately 3 months of self-sufficient heat supply time is reached in every year.

Impact of different technologies for DHW preparation on required collector area

The mentioned three different systems for DHW preparation have been simulated. The dimensioning of the solar thermal system, including the remaining parts of the supply system like the size of the store, piping dimensioning etc. is equal. Results are shown again for one typical building (i.e. 1.5m² of flat plate collector area per person) for the summer period of April to September. Figure 9 indicates the operation of the heat network. The most efficient DHW concept of decentral flow through allows for much more shut-off hours than the others.

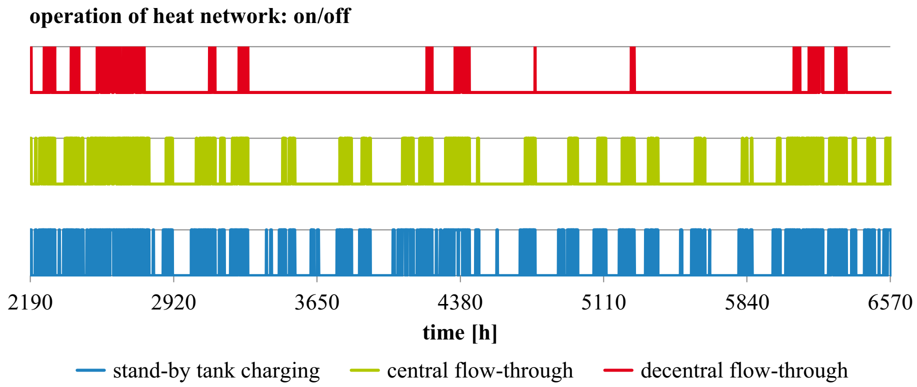

Figure 9: Operation of heat network for different DHW preparation concepts during summer time.

This advantage of the flow-through technology can also be used to reduce the collector area and the supply system dimensions for those systems. The result is shown in Figure 10. The operation periods of the heat network are now equal for all applied technologies. Due to reduced heat losses, the central flow through and decentral flow-through concept can be build smaller in size.

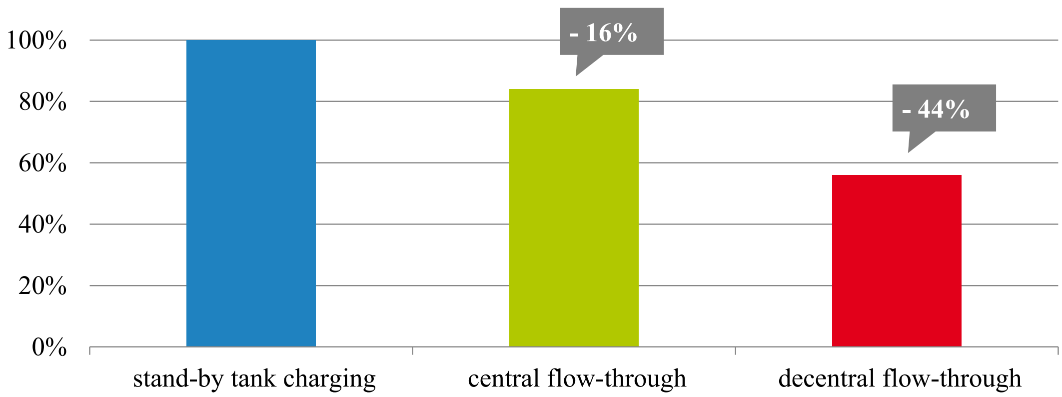

Figure 10: Operation of heat network of the considered technologies for DHW preparation during summer time. The dimensioning of the solar thermal sytem combined with central flow-through technology and decentralized flwo-through are fitted to meet the operation of the heat network of the stand-by tank charging system.

By applying the different technologies, the solar thermal system size can be reduced by 16% for the central flow-through technology and by 44% by the decentralized flow-through technology when compared to stand-by tank charging option.

Cost comparison of considered technologies

For the following consideration the same reference building is taken into account, as already mentioned before. Maximum heat load for space heating is larger than heat load for drinking hot water. (Therefore, the BCU cost of 6300 € do not depend on the applied technology of DHW preparation.) The storage tank is taken into account including installation with 1150 € per m³ of volume. The collector array including its substructure is supposed to cost 300 € per m² of collector area. Furthermore the piping and mounting of the solar and collector circuit are supposed to cost 150 € per m² of collector area. This means that the reference solar thermal system including collector, storage tank of 100 liter per m² collector area and mounting is summed up to 522 € per m² of collector area.

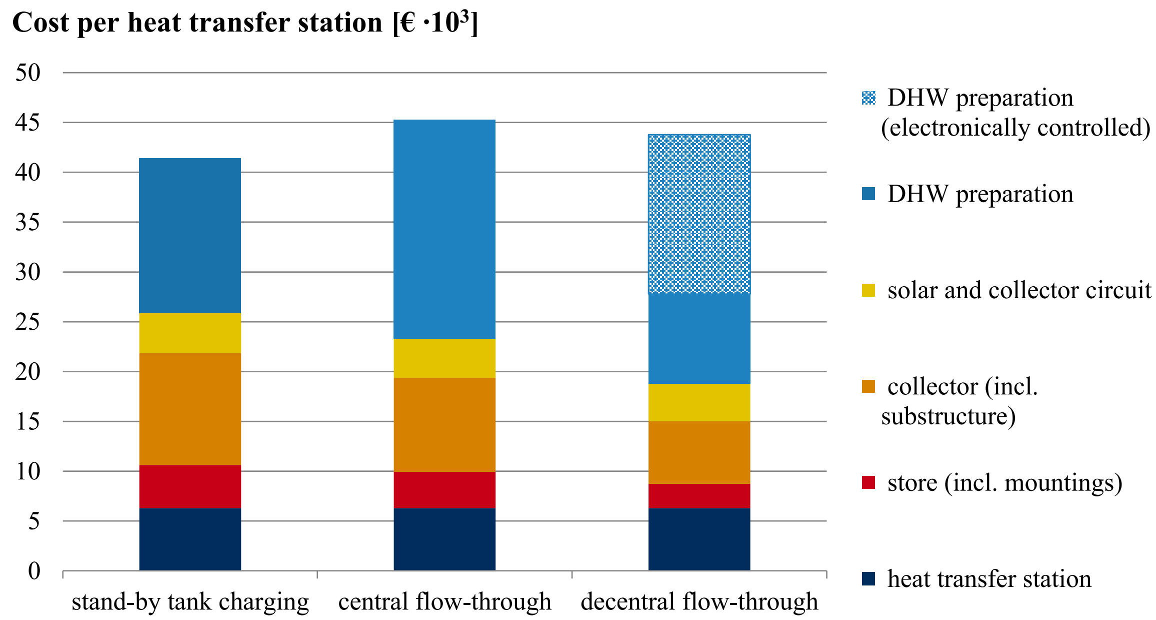

Figure 11: Composition of net costs for the considered systems of DHW preparation including cost reduction for the remaining supply system

The above demonstrated reduction of the dimensioning of the solar thermal system leads to a cost reduction of 13% considering the central flow-through technology and to 36% for the decentralized variant. The shown cost reduction is faced on the other side by the cost of the different applied technologies for DHW preparation. The composition of net cost for the main parts of the entire supply system including installation cost are shown in Figure 11.

The central flow-through technology shows lower cost of the solar thermal system due to smaller collector field and storage volume. However, DHW installation is more expensive. Over all, the complete system is slightly more expensive than the reference stand-by tank charging technology.

Looking at the decentralized flow-through technology, lower cost for the DHW preparation system can be stated accompanied by also lower cost for the solar thermal system. The most efficient technology for DHW preparation allows a significant reduction in the dimensioning for the solar thermal system and is also most cost efficient. The decentralized unit is assumed to cost 900 € readily installed including connection and control for the integration of the space heating loop. However, the range of cost for that kind of technology is quite large. It can reach 2500 € for an electronically controlled unit. In this case, the complete system cost reach the same order of magnitude as the before discussed systems.

5. Conclusions

The goal of 3 months of accumulated stand-alone operation of decentralized solar thermal in case of the Gutleutmatten project during summertime seems feasible. However, 4 critical buildings concerning sufficient roof top area are identified.

Considering 19 years of historical weather data of the location, it has been shown that the concept of decentralized solar thermal systems is quite robust regarding variations of weather conditions.

The investigated technologies for DHW preparation have a significant influence on the performance of the solar thermal system and hence on the time of solar thermal stand-alone heat supply. By applying more efficient technologies for DHW preparation the stand alone supply by the solar thermal system is increased. It is shown, that the dimensioning of the solar thermal system can be reduced by applying these efficient technologies for DHW preparation. Cost as one main point in all considerations can be reduced on the side of the solar thermal system by choosing the appropriate DHW preparation concept. On the other hand, cost for the applied technologies for DHW preparation rise particularly for the central flow-through concept. This compensates completely the savings on the solar thermal side in the shown case.

However, the decentralized flow-through concept has the potential of lowering cost significantly. Currently, market prices for such systems vary a lot, depending on the technology applied (i.e. mechanically or electronically controlled). At least the mechanically controlled systems allow for substantial savings. Future standardization will increase these savings even more.

6. Outlook

For a deeper understanding of the general potentials of integration of solar thermal in CHP heat networks a dynamic coupled system simulation of the heat network and the heat supply system for each building will be set up. To assure the same level of stand-alone heat supply by solar thermal also in the critical buildings more efficient technologies for solar thermal collectors (i.e. vacuum tube), will be taken into account. Another point of investigation will be the intelligent use of the network for the solar thermal heat distribution. In order to cover heat load peaks, electricity based heating systems might be another opportunity to reduce cost and overall CO_2 emissions of the district in buildings with small roof area especially in combination with intelligent control algorithms. The operation of the pilot scheme “Freiburg-Gutleutmatten” will be optimized using monitored data and implementing advanced control algorithm that will be derived from the dynamic system simulation studies. The goal is, to optimize cost, technology and system-design in general for comparable districts using the combination of decentralized solar thermal and a CHP under the boundary conditions of a floating price signal for electricity in future energy system scenarios.

Acknowledgements

The project “EnWiSol” is funded under the support code 0325544A regarding to a decision of the Lower House of German Parliament by the German Federal Ministry for Economic Affairs and Energy (Bundesministerium für Wirtschaft und Energie BMWi). The authors are thankful for the support and take full responsibility for the content of this publication.

References

[1] Meteonorm 7, METEOTEST-Genossenschaft,V7.0.22.8, Bern, Schweiz, 2012

[2] Rühling, K., et al., "LowEx-Fernwärme - Absenkung der Netztemperatur zur Verbesserung der Einsatzchancen regenerativer Energien," presented at: 20. Symposium Thermische Solarenergie, Bad Staffelstein, 2010.

[3] DVGW, Arbeitsblatt W 551-2004-04: Trinkwassererwärmungs- und Trinkwasserleitungsanlagen; Technische Maßnahmen zur Verminderung des Legionellenwachstums; Planung, Errichtung, Betrieb und Sanierung von Trinkwasser-Installationen, 2004