SOLAR THERMAL PLANTS FOR DISTRICT HEATING

Annex to D.T2.2. Planning Guidelines for Small District Heating

Version 1

05 2021

Content

1. Introduction

This document is an annex to the Planning Guidelines for Small District Heating (deliverable D.T2.2. of the ENTRAIN project) and comprises information regarding the integration of solar thermal plants into renewable energy sources district heating (DH) systems.

The integration of large-scale solar thermal plants into a district heating system requires the consideration of different points for planning and design. From the actual heat generation, depending on the solar irradiation, the collector type and its characteristics as well as the application area to the actual installation on a suitable surface. When integrating the system into district heating, a well-designed dimensioning and detailed calculations play an important role as well as the integration into the overall system depending on the heating network, its temperatures, load requirements and possible heat storage.

For potential operators and investors, in addition to the technical background, economic efficiency and reasonable heat generation costs also play an important role.

2. Heat generation with solar thermal systems

2.1. Global radiation

An important factor for the successful operation of a solar thermal plant is the usable global radiation at the intended location. In Germany, the global radiation averages between 950 and 1.200 kWh/m², tending to increase in a southerly direction. In other countries the global radiation deviates and must be determined individually. Fluctuations in global radiation must also be taken into account. Besides fluctuations during individual years, also over a longer period of time, seasonal as well as diurnal fluctuations occur.

Basically, the irradiation is higher in the summer months, whereas the heat demand of the district heating peaks in the winter months. The temporally staggered supply and demand must be taken into account in the planning and represents a further challenge. Usually, corresponding weather services (in Germany, for example, the “Deutscher Wetterdienst” DWD) provide climate and radiation data for different locations. Figure 1 shows an example of the radiation pattern and the heat demand of a typical district heating network over one year.

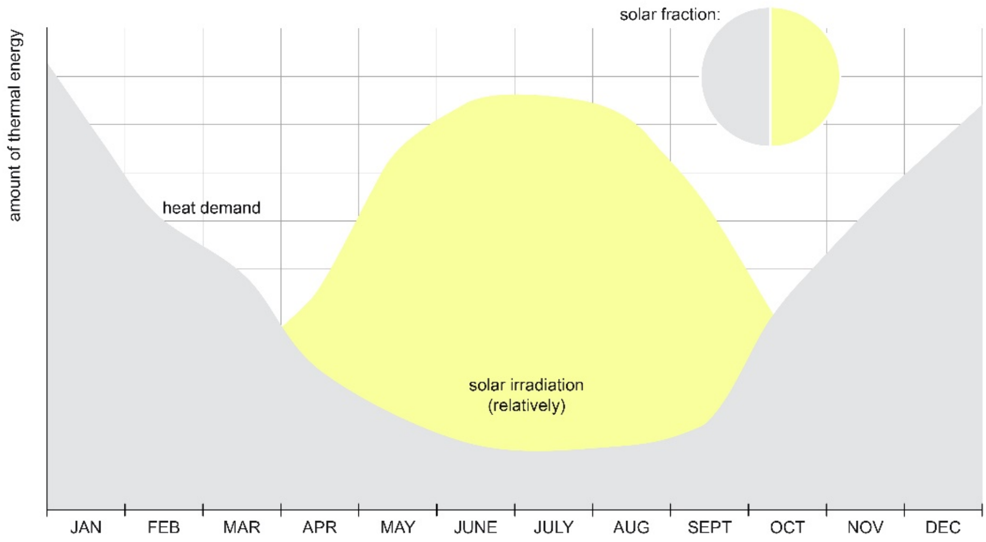

Figure 1: Example of the radiation pattern and the heat demand of a typical DH network over one year (source: Solites)

2.2. Collector technology

Two different basic collector types are available for heat generation with ground-mounted systems: high-temperature (HT) flat plate collectors and vacuum tube collectors. The mode of operation is similar: the irradiation heats a heat transfer medium flowing inside a copper or aluminium tube (absorber) and the heat gained is transported into the district heating system. However, the collector design is different and both types of collectors have advantages and disadvantages.

A high-temperature flat plate collector consists of a casing with temperature-resistant thermal insulation, a liquid-flow absorber and a highly transparent special glass cover. Due to the better thermal insulation on the back, HT flat plate collectors have low heat and radiation losses even at higher temperatures. With possible average collector temperatures of > 60 °C as well as application temperatures of approx. 100 °C, this collector type is well suited for district heating applications.

The vacuum tube collector has a slightly different design: here the absorber is located in an evacuated glass tube, which reduces heat losses to a minimum. The compound parabolic concentrator vacuum tube collector is available as a special form. The efficiency of the collector is increased by a structurally attached reflection mirror. With operating temperatures of up to 120 °C, also this type is very well suited for district heating applications. Figure 2 shows the design of the two collector types in cross-sectional view.

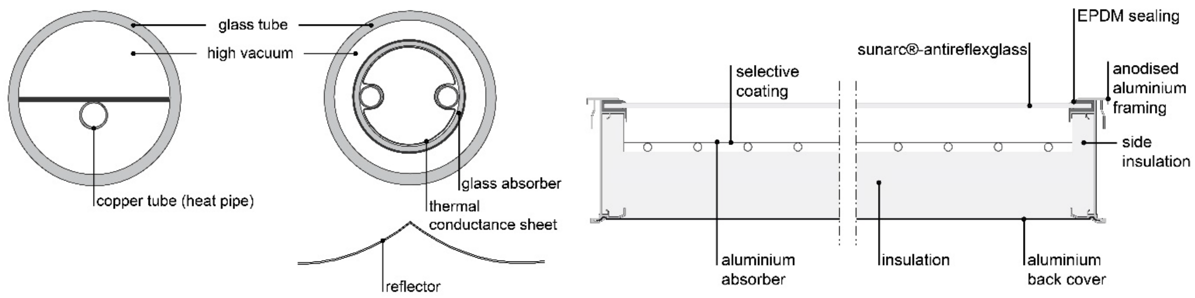

Figure 1: Design structure of the two typical solar thermal collectors: vacuum tube collector (left) and high-temperature flat plate collector (right) [source: Solites; Wagner Solar]

For large collector fields, specialized manufacturers offer large modules with a collector area of up to 20 m^2. This reduces the amount of piping required and makes it relatively easy to set up and interconnect large collector fields with several rows of collectors. Thanks to simple and adaptable mounting systems, the large modules can be installed cost-effectively. Here, a proven pile-driving method (coming from the photovoltaic sector) is used, whereby the installation time and the associated costs as well as the encroachment on the usable area can be significantly reduced. [1]

In addition to the collector design and the usable system temperatures, also the efficiency curves have different characteristics. The decisive factor here is the average system temperature of the district heating network. Depending on the outside air temperature, the collector efficiency decreases with increasing mean temperature of the heating network. Figure 3 shows typical efficiency curves for the two collector types. Depending on the area of application and the temperature levels of the heating network, the respective collector type has advantages in terms of efficiency.

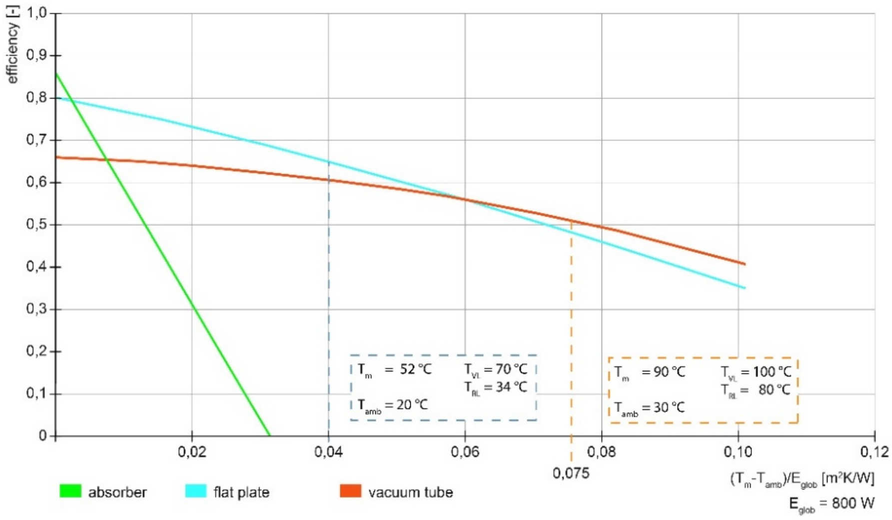

Figure 2: Typical efficiency curves of the collector types depending on the mean heating network temperature and the outside air temperature [source: Solites]

2.3. Open space availability for large-scale solar thermal systems

Techno-economic, legal, ecological and acceptance-related criteria play a major role for the suitability of an area for the installation of a solar thermal system. Particularly important for solar thermal plants is the location proximity to the heating center or to the district heating network. In contrast to electricity, heat can only be transported over longer distances with considerable heat losses and high specific costs.

Furthermore, also the hydraulic requirements at the intended location for the integration into the district heating system must be met. [1]

In the past, conversion areas, areas along traffic routes (noise barriers), landfills, slag heaps or green or agricultural areas have proven to be well suited. It must be checked in advance whether the corresponding area is available for development. In addition, there are criteria for the general orientation of the area (horizontal, southeast to southwest orientation, unshaded) to be considered. Additional space required for peripheral equipment and possible storage areas must also be taken into account. [1]

From an ecological point of view, ground-mounted solar thermal systems are very well suited to enhance the biodiversity and ecology in the affected area. For this purpose, a corresponding eco-concept can be developed and, if necessary, supervised by local (nature conservation) associations.

3. Integration into district heating systems

3.1. Centralized and decentralized integration

In principle, a distinction is made between two different types when integrating a solar thermal system into district heating systems: centralized and decentralized integration. In the case of central integration, the solar thermal system is integrated at the location of the heating plant (see Figure 4 left). For more distant plants, the integration is done via a separate solar network up to the heating plant. Central integration is used for most large-scale systems because of its simpler technical handling.

In the case of the decentralized variant, the integration takes place directly into the district heating network at a suitable location (see Figure 4 right). The prerequisite for this is that the solar heat generated can be fed into the district heating system at any time, because the solar system is operated without a separate heat storage tank.

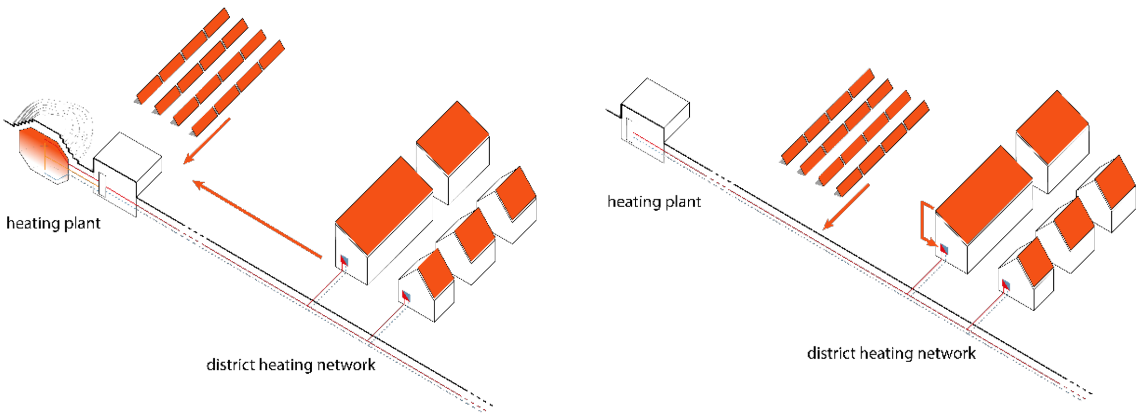

Figure 3: Schematic representation of the centralized (left) and decentralized (right) integration of a solar thermal system in a heating network

3.2. Heat storage

Due to the fluctuating heat generation and the opposing heat demand, a heat storage is necessary in most plant configurations. The heat storage stores the heat that is generated but not required and can feed it into the district heating system at a later time. This increases the degree of utilization of the system and the solar fraction (see chapter 4.2 for explanation).

There are two types of heat storages. With a buffer storage (up to approx. 1.000 m³), daily fluctuations can be balanced out and operation stagnation of the system can be avoided. Normally, this type of storage is designed as an above-ground storage tank.

From a storage size of 1.000 m³, it is called a seasonal or long-term heat storage. This allows heat to be stored for several weeks and months. The storage tank is usually charged during the summer months and discharged during the heating period. In addition to tank thermal energy storages, other types of seasonal storages applied are pit thermal energy storages, borehole thermal energy storages or aquifer thermal energy storages (see Figure 5).

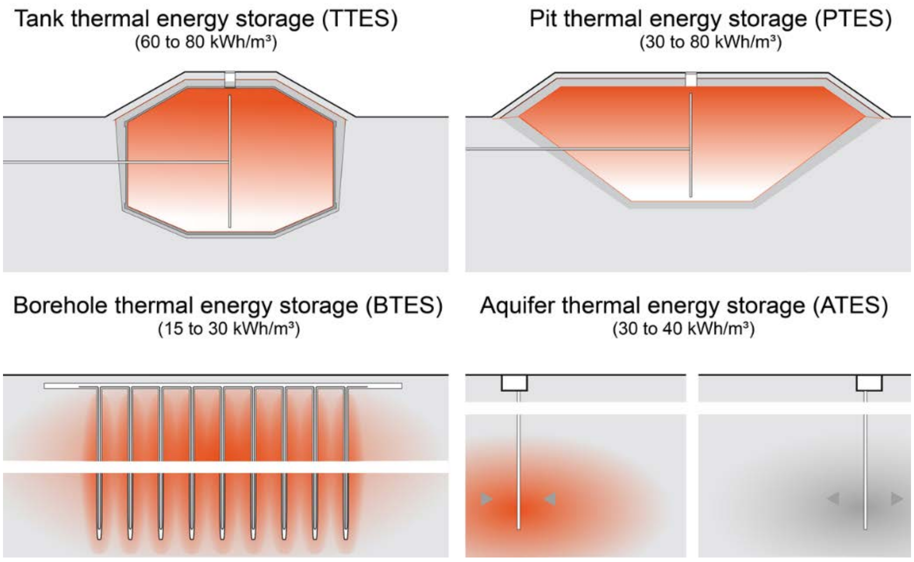

Figure 4: Schematic representation of different storage types for long-term heat storage [source: Solites]

Besides conventional storage operation, seasonal heat storages can be used in combination with heat pumps. In this case, the heat pump increases the utilization rate of the storage tank. The current trend is towards multifunctional heat storage systems, into which different heat generators feed in (see following chapter), making it possible to realise a completely renewable and sustainable heat supply concept.

Investment costs related to the storage are depending on the storage type applied, increase with storage size and considerably affect the profitability of the whole system.

3.3. Combination with other heat generators

In general, solar thermal energy can only cover a part of the heat demand of a DH system. Usually, solar fractions of the total heat production of less than 20 percent are realized (see chapter 4.3). Therefore, additional heat generators are required in any case in order to cover the whole heat demand. Furthermore, a peak load or redundant heat generator (which usually only has a very small coverage share) is required as well, in order to ensure security of supply. Combinations with all kinds of renewable heat sources (see Figure 6) are possible in principle but have to be evaluated regarding technological and economic feasibility.

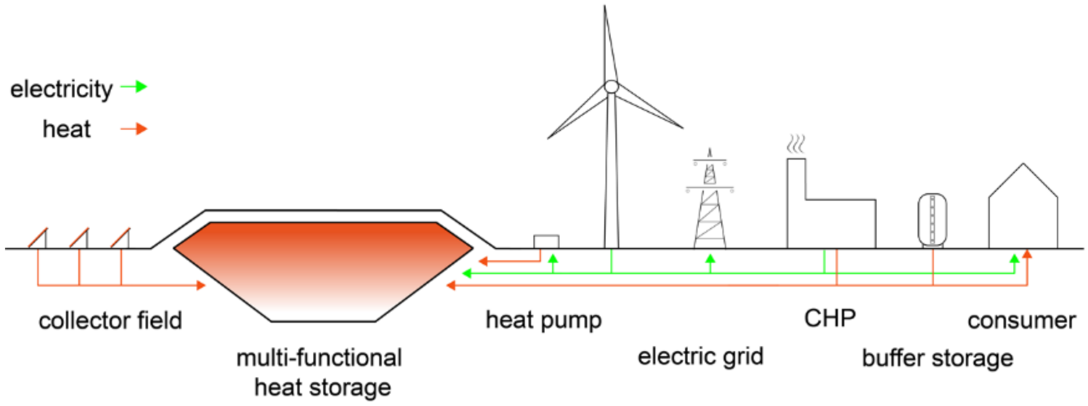

Figure 5: Solar thermal systems are well suited for combination with other heat generation systems [source: Solites]

In smaller, regional district heating networks in Germany, a combination of solar thermal plants with biomass (wood chips or wood pellets) boiler has proven to be well suited. In principle, solar thermal energy can be combined with all other types of (preferably renewable) heat generation. For example, a solar thermal system can also be combined with CHP (combined heat and power production), large-scale heat pumps, industrial waste heat, power-to-heat, or waste combustion.

The appropriate combination depends on different local factors and must always be assessed on a project-specific level according to ecological and economic aspects.

4. Dimensioning and profitability

4.1. Dimensioning of a solar thermal system for district heating

Taking into account the boundary conditions mentioned above, a suitable design and dimensioning of the solar thermal system can be carried out. Depending on the irradiation on site, the district heating temperatures and the heat demand, the solar thermal system in combination with the corresponding heat storage tank is designed according to demand. The potentially available (free) area for the installation of the solar thermal collectors, desired/targeted solar fractions and the solar heat surplus (stagnation days)[1] must be taken into account.

Depending on the collector type, average heating network temperature and hydraulic control integration (preheating mode or network flow temperature), the specific collector yield is between 300 and 550 kWh/(m^2collector area*a).

[1] Solar heat surplus (also stagnation) occurs on days when solar heat cannot be absorbed by the heat network or heat storage and it remains unused

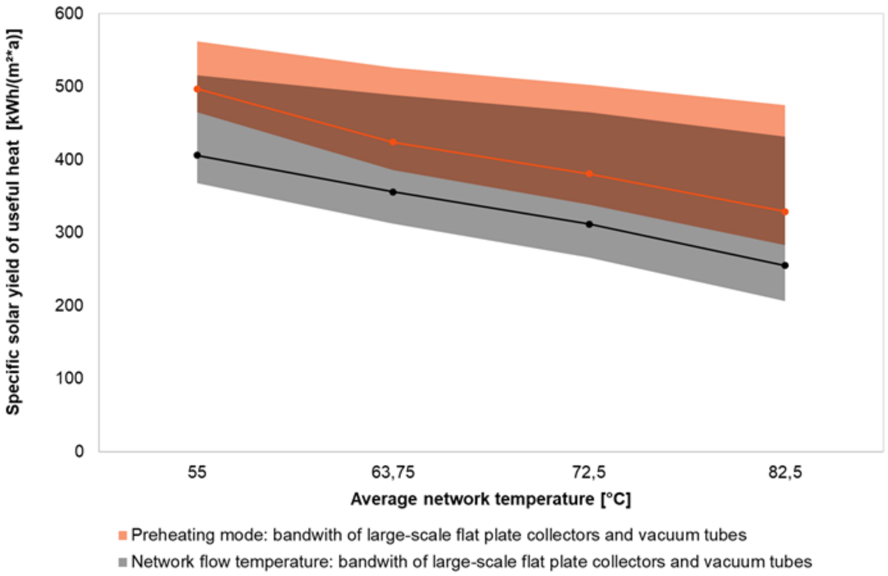

Figure 6: Specific solar yield of useful heat from different collector types depending on the average heating network temperature and the hydraulic control integration [Quelle: Solites]

With an average land to collector area ratio of 2 – 2.5, the annual heat output of a solar thermal system is 1.500 – 2.500 MWh per hectare of land area.

4.2. Utilization rate and solar fraction

Important criteria's for evaluating the efficiency of the system are the solar fraction, the system utilization rate and the solar utilization rate. The solar fraction describes the proportion of solar heat used in relation to the heat demand in the grid. The system and solar utilization rate show the efficiency of the solar heat used in relation to the collector field output and the total irradiation on the collector field, respectively.

With optimal design, the storage volume and also the solar fraction usually increase with increasing collector area. On the one hand, larger storage tanks allow the heat generated to be used more efficiently; on the other hand, this increases the heat losses through the storage tank. Due to this, the system efficiency and thus the economic efficiency decreases with increasing collector area (Figure 8). The aim of the design and dimensioning is to find the energetic, ecological and economic optimum of the system configuration.

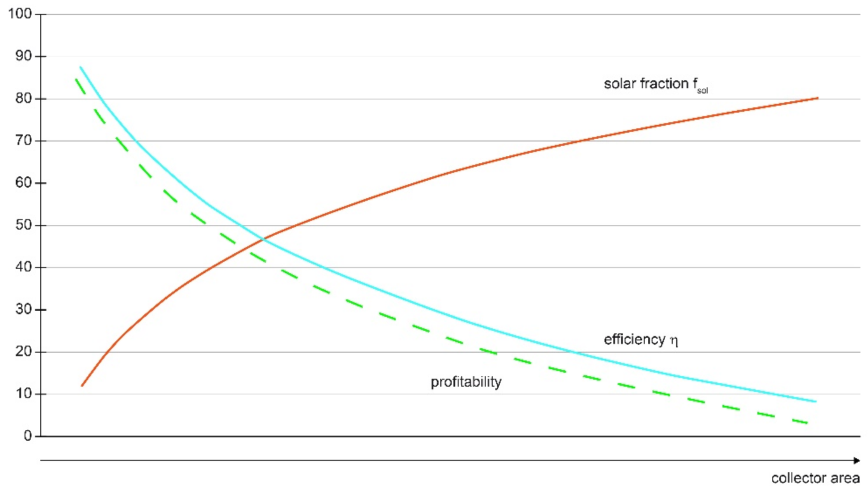

Figure 7: Exemplary representation of the dependence of solar fraction, utilization rate and economic efficiency on the collector area [source: Solites]

The overall efficiency and suitability of a collector for a specific application is usually determined and evaluated with a simulation program. This involves generating a yield forecast on at least an hourly basis with weather and load data for an operating year. The selection of a suitable collector type should always be project-specific and not only based on efficiency data.

For initial estimates, the ScenoCalc Fernwärme (SCFW, www.scfw.de)[2] calculation program can be used. ScenoCalc Fernwärme can be used to calculate the useful solar heat yield of solar thermal systems integrated into heating networks. In addition, other components of a system such as pipelines, heat exchangers, and heat storage tanks are taken into account, enabling the calculation of the solar useful heat yield at the point of feed-in to a district heating. The load profile of the district heating is also taken into account.

4.3. Profitability

Solar thermal plants are capital-intensive projects: primarily, the investment costs consist of the components collector field, heat storage, other system components and buildings, measurement and control technology, as well as planning and approval costs. In addition, there are costs for the required land area.[1]

However, the independence from fluctuating and accruing fuel costs as well as low maintenance and operating costs have a positive effect on the heat production costs in the long term. Over the entire project duration, depending on the plant configuration, there are known and constant specific heat costs of approx. 40 - 60 €/MWh.

If funding for the use of solar thermal systems, storage tanks, and more is added, the specific heating costs are further reduced. Since funding is mostly available on a country-specific national level, the possible conditions and requirements for each project must be checked individually.

Like any heat generation system, a solar thermal system must hold its own economically against other generation sources, while also taking into account the increase in efficiency of the overall combined heat generation system.

[2] SCFW requires solar thermal system knowledge. The calculation results serve for first estimations and do not represent a system design or final dimensioning. The tool is only available in German language.

The main requirements for low heat production costs are a sufficient plant size (greater than 1 MWth), simple plant technology (ground-mounted installation), moderate solar fractions of the total heat production (less than 20 percent), and suitable, medium heat network temperatures. [1]

The following example calculation shows a possible configuration and profitability calculation for a typical system configuration in rural areas.

Collector field (2.600 m²)	638.606 €
Storage (350 m²)	227.500 €
Connection pipe	60.000 €
Plant- and MSR-technology, buildings	162.611 €
Planning	54.435 €
Investment without funding	**1.143.152 €**
Annual cost of capital (interest rate 3 %, 25 a)	68.780 €/a
Maintenance and operation	11.405 €/a
Total annual costs	**80.185 €/a**
Heat production costs without funding	**63,4 €/MWh**
Heat production costs with funding (according to KfW: 471.294 €)	**38,5 €/MWh**

(Annual production 1.265 MWh/a; net costs, solar coverage 16,7 %)

Literature

[1] Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg, Freiflächensolaranlagen – Handlungsleitfaden, 2019, Stuttgart, Deutschland