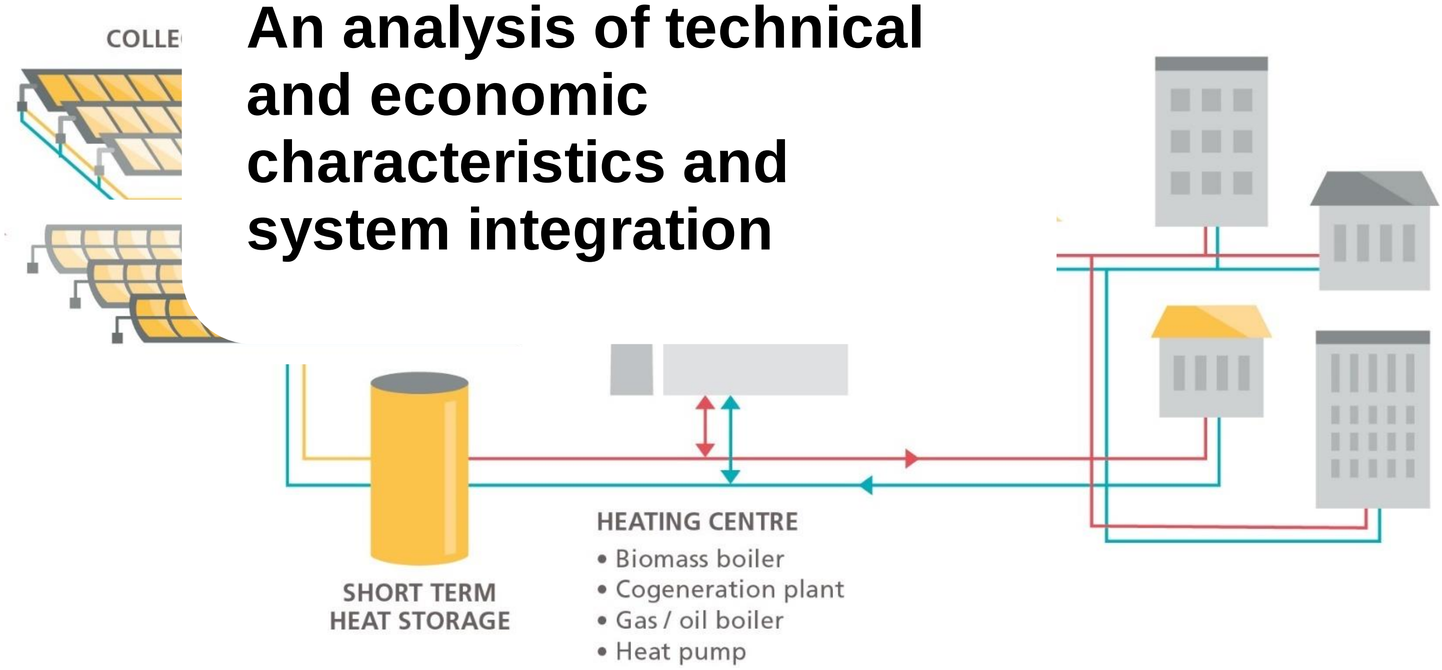
Solar Collector Technologies for District Heating

An analysis of technical and economic characteristics and system integration



IEA SHC TASK 68 | Efficient Solar District Heating Systems – Considering higher temperatures and digitalization measures

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Solar Collector Technologies for District Heating

This is a report from SHC Task 68: Efficient Solar District Heating Systems and work performed in Subtask A: Concepts for Efficiently Providing Solar Heat at Medium-High Temperature Level

Editors: Silas Tamm, Magdalena Berberich (Solites)

Authors: Stefan Albrecht, Dominik Bestenlehner, Luuk Beurskens, Andreas Bohren, Lukas Feierl, Dirk Krüger, Klaus Lichtenegger, Alex Mellor, Yuvaraj Pandian, Dimitris Papageorgiou, Pedro Rubio, Sebastian Schramm, Luis M. Serra, Marcel Wagner, Johannes Werner, Michael Zellinger

24.05.2024

Report RA.1, DOI: 10.18777/ieashc-task68-2024-0002

Title graphic from IEA SHC Task 55

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1 Executive Summary

Existing district heating networks in Europe often supply heat in a temperature range of 80 °C to 120 °C. To decarbonise these systems, solar thermal has a great potential. Up to now, high-performance flat-plate collectors and evacuated tube collectors are state of the art for the integration of solar heat into district heating (DH) networks and are well developed and described. However, other collector technologies, such as parabolic troughs and linear Fresnel collectors, can provide heat in a wider temperature range and might offer higher efficiency and advantages over the state of the art, like tracking and the possibility to control the heat yield.

In this report, we analyse and compare different solar thermal collector technologies and products with the focus on how they can be implemented in DH systems.

After the introduction and information about system integration, different supply temperatures of the technologies are compared. This is followed by an overview of the geometric characteristics of all participating collector products. The technologies with associated products are listed separately and their functionality and special features are explained, each with advantages and typical applications, as well as collector efficiencies. Four different technologies are then compared according to Solar Keymark certificates. Solar Keymark is a quality label for solar thermal products based on European norms. In addition to the standard temperatures of the certificates, yields with collector temperatures of 100 °C are also examined. The next step is a comparison of investment cost by the temperature ranges of the collectors. The diagrams created are mainly based on manufacturer information, which was requested as part of Task 68, Subtask A. In addition, standardized Solar Keymark certificates were used and own research was done to obtain further information on the collector products examined. Finally, there is a conclusion and an outlook on the potential of the various collectors for DH systems.

For a favourable performance of the solar thermal system, the overall system design is important. First of all, the location of the solar thermal plant decides about the amount of solar irradiation that the collectors receive. A study about the differences between the global irradiation of two cities in Germany over ten years shows variations in the range of +7 to -6 % of the average level. There is a significant difference in the global solar irradiation of the two locations, which is very variable over the ten years. Therefore, it is recommended to dimension a solar thermal plant using climate data of the location of the plant over a sufficiently long period of time, with at least ten years recommended. In addition to that, the solar heat yield depends on the operation temperatures. The higher the average operation temperature of the collectors is, the lower the efficiency of the collectors gets because of higher heat losses of every collector. Therefore, the return temperature to the collector field and the needed supply temperature, which shall be produced by the collectors, are decisive for the achievable solar energy yield.

If a solar thermal plant is dimensioned to deliver the entire heat demand of the district heating net during the summer time, in most cases a short-term heat storage is necessary to store the heat from day to night and for the case of some cloudy days. In Europe, the heat demand during summer usually is defined by tap water heating and the heat demand of industrial processes. The solar fraction of these solar thermal systems depends on the seasonal distribution of the yearly heat demand and is usually between 5 and 20 %. In case of high solar fractions of more than 30 % of the yearly heat demand, usually a seasonal heat storage may be necessary, because the heat from summer has to be used in winter.

The collector performance parameters measured under standard conditions of Solar Keymark, just consider the single collector without any influences of the system, where it is integrated in. However, these performance parameters give an overview for the comparison of the efficiencies and heat yield of the different technologies. There is a variety of collector technologies that can be used in DH systems with supply temperatures of 80 to 120 °C. Flat plate collectors are inexpensive and easy to install and are well suited to lower supply temperature (up to 80 °C) applications. Evacuated tube collectors use vacuum technology, which minimizes heat loss and increases efficiency. They are well suited to applications where higher supply temperatures (up to 150 °C) are required. Evacuated tubes with CPC (Compound Parabolic Concentrator) collectors use concentrating mirrors to direct the incoming sunlight onto the absorber, resulting in higher yields. They are efficient and well suited to medium-high supply temperature applications. Parabolic trough collectors and linear Fresnel collectors use mirrors to focus direct radiation onto an absorber along the focal line. They can reach very high supply temperatures (up to 400 °C) and are therefore interesting for industrial processes with high heat requirements, but also for heating networks with medium-high supply temperatures. Fresnel lenses use special types of lenses instead of mirrors to concentrate the sunlight. They can reach high supply temperatures and are well suited for specialized applications. Due to their compact design, they use 2-axis tracking, which increases solar irradiation and allows high temperatures to be delivered efficiently.

By comparing the annual yield calculated by Solar Keymark data, it can be seen that at a mean collector temperature of 25 °C, the flat-plate collector delivers the highest specific yields at the reference locations. As the collector temperature increases, the yields fall more sharply than with the CPC and the small parabolic trough. The large parabolic trough ensures relatively constant specific yields over a broad range of collector temperatures. Especially at average collector temperatures of more than 75 °C, there is an advantage over evacuated tubes with CPC. These results are directly connected to the efficiency curves shown in the sections of the collector technologies. In general, the yield is higher at lower collector temperatures because thermal losses are lower with a smaller temperature difference to the ambient. This is particularly important for the system integration of solar collectors to optimise the solar thermal output, the system efficiency and therefore the levelised cost of heat.

The economic analysis is based on a limited data basis with information provided by eight manufacturers. The investment costs refer to a collector field of 10 000 m² gross area and show a range of 320 to 700 EUR/m².

Each of the regarded collector technologies have its own advantages and disadvantages and is suitable for certain areas of application. The choice depends on various factors, such as the specific temperature requirements, the economic calculation of the overall system and the local conditions.

2 Introduction

The expansion of decarbonised heating networks is a key factor for a sustainable heat supply for buildings. Solar thermal energy has a large potential alongside large heat pumps and geothermal energy, as it has a high area efficiency with a factor three to four above that of photovoltaics (though the exergy output is similar) and a factor 30 to 100 above that of energy crop cultivation (Solar District Heating, 2018). However, the produced energy in a combination of photovoltaics with a heat pump may be comparable to solar thermal energy. This needs to be investigated individually.

However, care must be taken to choose a suitable collector for any district heating application, as the efficiency of solar thermal collector types varies depending on their operating temperatures. For district heating networks, the temperature is often in a range of 80 °C and 120 °C.

To reduce heat losses and enable low-temperature energy sources, the district heating sector must and will reduce the operating temperatures in the DH systems in addition to increasing the heat generated with renewable energies. While the network return temperature of certain countries is determined by the domestic hot water hygiene regulations (e.g. in Germany min. 55 °C in the circulation pipe), the supply flow currently offers potential for lowering the temperature to 70 to 75 °C during summer. Lower supply flow temperatures are only possible with special systems for domestic hot water heating. However, it is not easy to achieve low supply temperatures of 70 to 75 °C in summer in some areas of networks and also in the overall networks of many municipal utilities.

In the case of existing DH networks, the necessary transport capacities are limited by the existing pipe cross-sections of the heating network and cannot be achieved, if the temperature difference between the supply and return flow is reduced too much. This means that in some large district heating networks it will not be possible to reduce the temperature significantly, even in the long term. In addition, in existing heating networks with lower supply temperatures, it may make sense to increase the temperature difference between the network supply and return flow in order to increase the transport capacity of the heat quantities. Achieving high transport capacities in the existing pipelines is essential for increasing the flexibility of heating networks with new and decentralised heat sources. This is also demonstrated by the "Heat Hub Hennigsdorf", a lighthouse project in Germany (Stadtwerke Hennigsdorf, 2021). In some heating networks, connected industrial companies and major customers require high temperatures of 90 to over 110 °C for their processes (Aalborg University, 2019). This also applies to purely industrial grids, where the high temperatures are also necessary for the operation of industrial processes in the long term. In many cases, it will not even be possible to lower the grid temperatures. Hence, the integration of solar thermal systems into district heating networks therefore requires collector products that can supply heat economically at temperatures of 80 to 120 °C or even higher.

Up to now, high-performance flat-plate collectors and evacuated tube collectors are state of the art for the integration of solar heat into DH networks and are described e.g. in the AGFW's 'Solar thermal practice guide' (AGFW, 2021) (Task 68, 11.2021). However, other collector technologies, such as parabolic troughs and linear Fresnel collectors, can provide heat in a wider temperature range and might offer higher efficiency at different temperature levels and other advantages over the state of the art, like tracking and the possibility to control the heat yield.

Subtask A "Concepts for Efficiently Providing Solar Heat at Medium-High Temperature Level" provides information for the development of concepts, models and performance measures to enhance the efficiency of solar district heating (SDH). The focus is on medium-high temperature heat, which is defined within SHC Task 68 as 80 to 120 °C supply temperature.

In this report, solar thermal collectors are evaluated and compared to make them more accessible to the professional public in order to decarbonise SDH in the medium and long term. The aim is to list advantages and differences in terms of location requirements, achievable temperatures or economic aspects (Task 68, 11.2021). The collectors and data used in this report were determined via a survey among about 50 collector manufacturers, see section 12.4.

3 System integration

Combined with large seasonal heat storages, the solar thermal plant can contribute to more than 50 % of the yearly heat demand of a district heating system. The main market for SDH consists of plants with a solar fraction of up to 20 % of the yearly heat demand, including the application of a short-term heat storage or even without any heat storage. The market shows a variety of technical concepts and operating strategies. More information can be found e.g. here IEA SHC Task 55, www.solardistrictheating.eu.

3.1 Basic systems for solar thermal integration

A solar thermal plant can be connected to the district heating system by means of central feed-in or decentralized as shown in Figure 1. Central feed-in means the solar heat is integrated in the main heating centre where the heat storage is located. The schematic in Figure 1 shows a seasonal heat storage; it depends on the size of the collector area and the performance of the additional heat productions in relation to the fluctuating heat demand if a smaller short-term heat storage can be sufficient or even neglected.

In the case of decentral feed-in of solar thermal heat, the solar collectors are placed at suitable locations and are connected directly to the district heating circuit. In several large solar thermal plants in Sweden, Austria and in a few first plants in Germany, a decentral feed-in of solar heat into district heating systems has been realized.

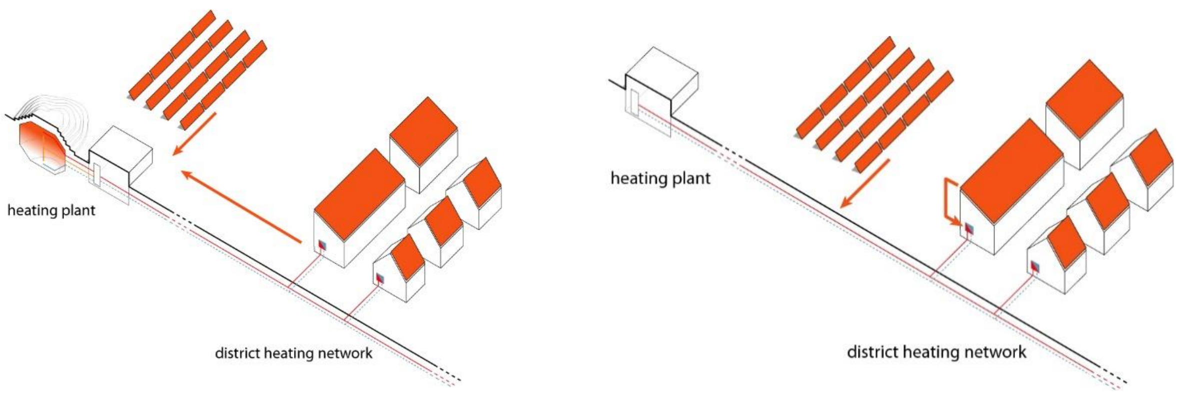

Figure 1 Schematic of central (left) and decentral (right) feed-in of solar thermal heat (Solites)

For both, central and decentral feed-in of solar thermal heat in a district heating net, the solar thermal plant can be operated to produce the supply temperature or to preheat the fluid in the return flow. Figure 2 shows a basic schematic of a solar thermal plant for district heating. Usually, it is applied for a solar thermal integration in the central heating plant. To separate the solar circuit and the net circuit hydraulically a heat exchanger is applied between the solar thermal field and the heat storage. Often a heat storage is integrated into the system to store the heat from the solar collectors before it is transported to the additional heater and then delivered with the supply temperature to the district heating net.

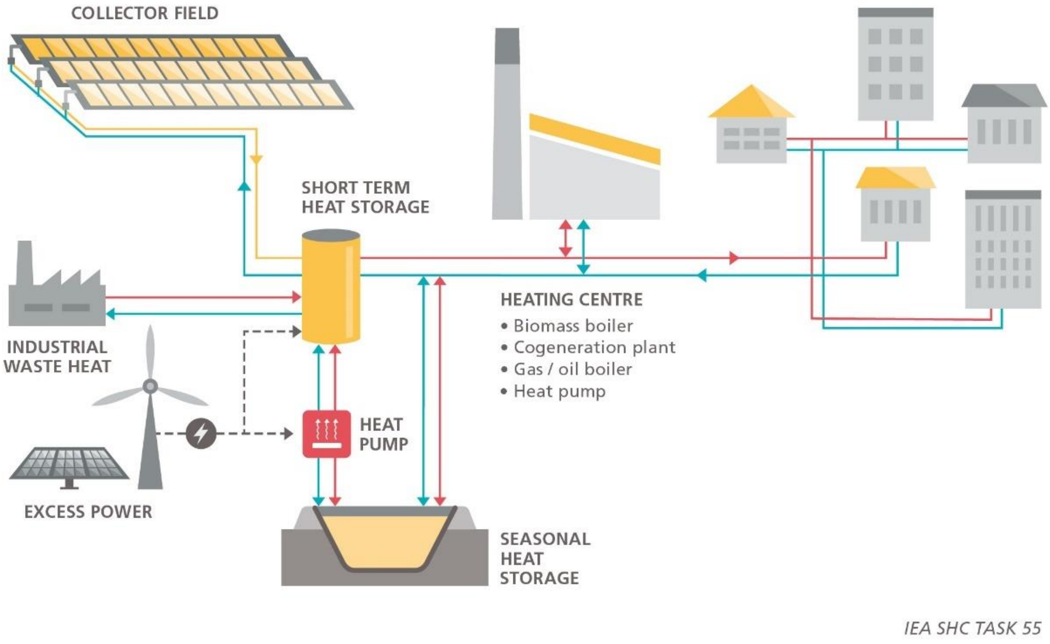

Figure 2 Schematic of central system integration of a solar thermal plant into a district heating system

The solar collectors only can produce heat if the solar irradiation is high enough. Either the solar collectors need to deliver the supply temperature of the heating network or they preheat the return flow. In the case of preheating the return flow, the solar collectors heat up the return flow with a minimum temperature difference or more. For supplying the heat to the district heating net the fluid is heated up to the supply temperature by an additional heater in the heating centre. The variation of the solar irradiation can be balanced by a volume-flow control of the pumps in the solar circuit to keep the temperature of the preheated flow from the collector field to the buffer storage within the predesigned range.

The sizing of the buffer storage depends on several parameters like the intended solar fraction, the operation characteristics of the collector field and the dynamics of the heat demand in the district heating net and in the unload circuit of the buffer storage etc. The larger the intended solar fraction and the higher the complexity of the hydraulic system concept are, the more a dynamic simulation of the overall system is recommended.

3.2 System design

For a favourable performance of the solar thermal system, the overall system design is important. First of all, the location of the solar thermal plant decides about the amount of solar irradiation that the collectors receive. The solar thermal plant is able to heat its inlet temperature only if the irradiation is high enough for that. A study about the differences between the global irradiation of two cities in Germany over ten years shows variations in the range of +7 to -6 % of the average level of the ten years. There is a significant difference in the global solar irradiation of the two locations, which is very variable over the ten years (M. Berberich, D. Mangold, 2017).

Therefore, it is recommended to dimension a solar thermal plant using climate data of the location of the plant over a sufficiently long period of time, with at least ten years recommended. By varying the solar irradiation in a sensitivity analysis within a system simulation program, its effect on the energy yield of the solar system can be analysed and valuated. If necessary, the solar thermal plant can be dimensioned with a safety factor to reach the needed solar heat yield even in years with poor irradiation.

In addition to that, the solar heat yield depends on the operation temperatures. The higher the average operation temperature of the collectors is, the lower the efficiency of the collectors gets because of higher heat losses of every collector. Therefore, the return temperature to the collector field and the needed supply temperature, which shall be produced by the collectors, are decisive for the achievable solar energy yield.

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

If a solar thermal plant is dimensioned to deliver the entire heat demand of the district heating net during the summer time, in most cases a short-term heat storage is necessary to store the heat from day to night and for the case of some cloudy days. In Europe the heat demand during summer usually is defined by tap water heating and the heat demand of industrial processes. The solar fraction of these solar thermal systems depends on the seasonal distribution of the yearly heat demand and is usually between 5 to 20 %. The higher the solar fraction, the more solar heat needs to be stored, not only for some days but for weeks. In case of high solar fractions of solar heat in the region of more than 30 % of the yearly heat demand, a seasonal heat storage is necessary, because the heat from summer has to be used in winter. Due to the longer storage time of the solar heat, the heat losses increase and the specific net solar heat yield of the collectors decreases. An illustration of the solar fraction depending on the heat storage is shown in Figure 3.

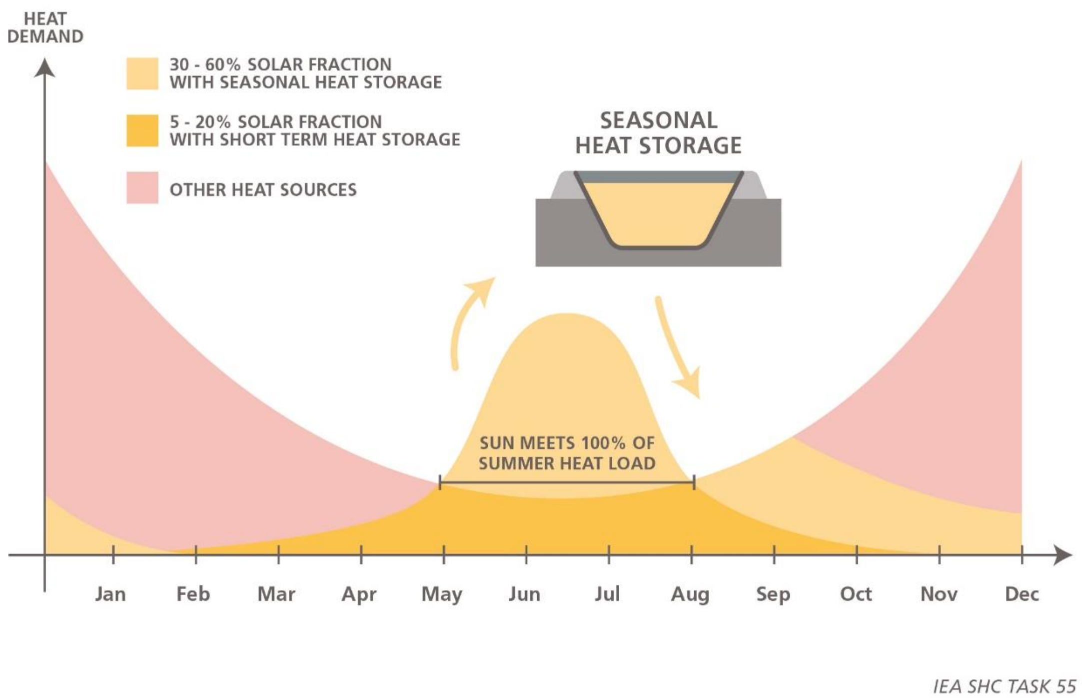

Figure 3 Exemplary illustration of the connection of solar fraction and heat storage volume for central Europe

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

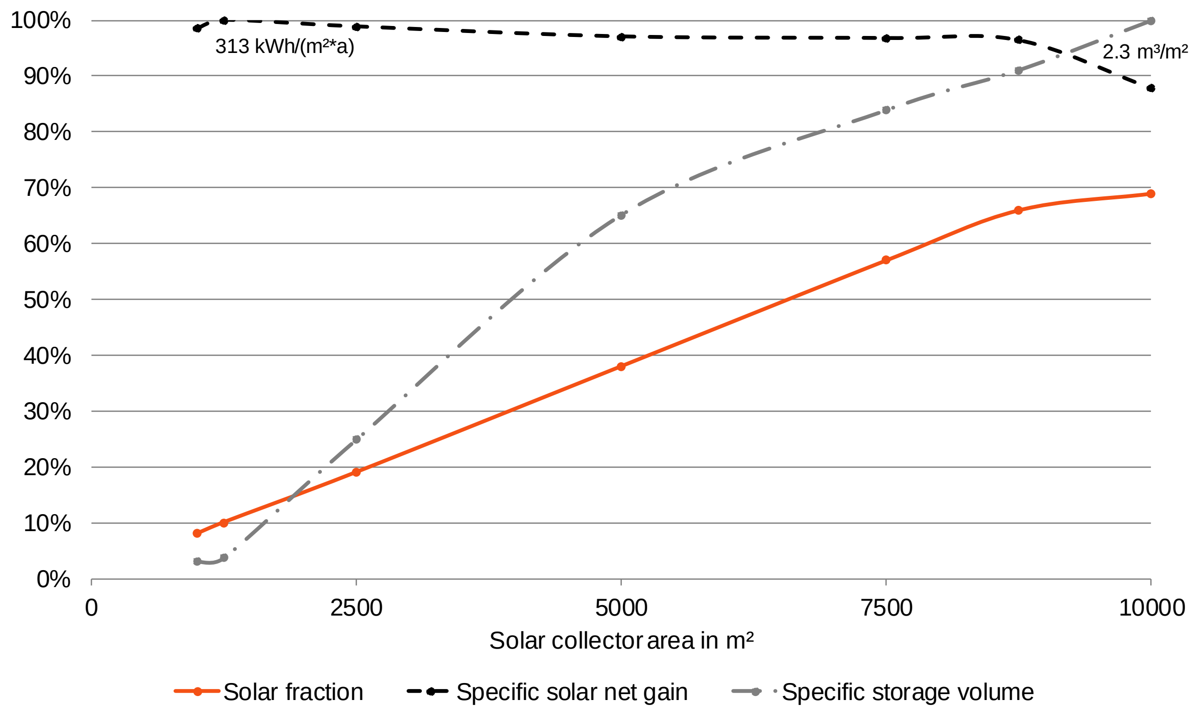

Figure 4 Example of a correlation of solar collector area, specific heat storage volume, solar fraction of the yearly heat demand and solar heat yield for a solar thermal plant that feed in decentrally in a district heating net and always delivers the supply temperature of 78 °C in a yearly average (sample collector and weather data of the German city Frankfurt) (M. Berberich, D. Mangold, 2017)

Even though the calculations were carried out for flat-plate collectors, the tendencies of the results apply to all collector technologies that are integrated into heating networks. The results in the diagram are calculated with the Excel-calculation program SCFW ("ScenoCalc Fernwärme", in German: "ScenoCalc for solar district heating systems") which is free of charge and can be used for first assessments of SDH systems (M. Berberich, D. Mangold, 2017)

For a real plant, possible next steps in the overall system design would be to change the system integration of the solar thermal system to a preheating mode or to integrate a heat pump into the solar system to unload the heat storage to lower temperatures. Both possibilities allow to reduce the operation temperatures of the solar collector field to reach higher specific solar net yields per year (M. Berberich, D. Mangold, 2017).

3.3 Land requirements

The land requirement is another relevant aspect of solar thermal plants. Around two to three times as much land as the collector area is needed to install the collectors on the ground. The design of the collector area on the available land area is an economic optimization with different parameters like the costs for the collectors and the system integration, the needed supply temperatures, the shading of the collector rows and the resulting heat output of the whole solar field.

Because large solar thermal systems are dependent on a direct connection to a heating network, the land requirement is probably one of the biggest challenges. Unlike electricity, heat cannot be transported over long distances, as this would lead to high energy losses and costs. Solar thermal systems must be installed close to consumers and their heat demand. The following figures show some concepts, how collectors can be installed on available areas.

Without regarding the cost for the ground, to mount the collectors on simple subconstructions directly on the ground offers the possibility to achieve the lowest cost for the realization of a solar collector area, see Figure 5. With ram profiles made from steel, collectors can be mounted very fast.

In order to use the ground area efficiently and to reach the needed supply temperatures, there are concepts combining different collector technologies in one system. Figure 6 shows the combination of flat plate collectors (supplying up to 70 °C) and parabolic trough collectors (here operated at 95 °C) in Taars, Denmark.

The availability of ground is restricted especially in urban areas. Thus, it might be also applicable to integrate the collectors on a roof. As the costs for installation on roofs are higher than for large ground-mounted systems this solution is only suitable as an alternative to a limited extent. As a result, the costs for the heat produced are also higher. Figure 7 shows a so called “solar roof” that was realized within an energetic retrofitting of an old army building. The “solar roof” replaces the roof tiles and integrates roof windows, gutter, snow guard etc.

Another possibility is to mount a collector field on a flat roof as shown in Figure 8. In this case, achieving low cost for the subconstruction can be a challenge due to the static requirements to carry especially the wind loads.

The search for suitable areas for such systems requires early and careful planning and consideration of various factors. It is crucial that local authorities proactively search for and identify suitable energy production areas and then reserve them for the use of solar heat. In this context, municipal heat planning can be used as an instrument for planning and designating areas for energy production (P. Ratz, 2023).

Figure 5: Ground mounted evacuated tube collectors in Büsingen, Germany (Solites)

Figure 6: Combination of flat plate collectors and parabolic trough collectors in Taars, Denmark (Aalborg CSP)

Figure 7: Roof integrated solar thermal collectors on “solar@home”-building in Crailsheim, Germany (Solites)

Figure 8: Demo system of Sun Oyster on a flat roof in Zhangjiakou, China (sunoyster.com)

Solar thermal collectors do not seal the ground area, therefore instead of competition for land, joint use can also be a solution. With multi-coding, the land area fulfils another function in addition to solar thermal use. Contaminated areas such as old landfill sites are often unsuitable for building or agricultural use. If solar thermal systems are installed there, the land costs are comparatively low and the system is also more likely to be accepted in urban residential areas. If the recultivation layer above closed landfills is thick, the collector modules can be installed using standard steel profiles. If the surface sealing layer is thinner, the collectors are mounted on concrete foundations.

Unused infrastructure and roof surfaces and areas along traffic routes or on noise barriers often cannot be used in any other way and are suitable for solar thermal systems if facing to the sun. Parking areas can be roofed over with solar collectors and the area can thus be used several times and also shaded. However, the higher installation costs due to the necessary elevation are a challenge for these systems.

If nature conservation aspects are taken into account when planning solar thermal systems, these areas can be ecologically enhanced and become biotopes. Especially if an area was formerly used for agriculture, the construction of a ground-mounted solar thermal system can have a positive effect on the ecosystem. Flora and fauna benefit if the input of fertilizers and pesticides is reduced. The concept has already been implemented in many solar thermal systems in Germany, see Figure 9. If sheep are allowed to graze on the area, mowing is much gentler than with machines and the naturally growing meadow under the collectors benefits the sheep. The principle is already widely practiced in Denmark, see Figure 10 (Infoblatt Solare Wärmenetze Nr. 9, 2020).

Figure 9: Flowering meadow as biotope in Randegg, Germany (Photo: Bröer)

Figure 10: Grazing sheep between the collectors in Marstal, Denmark (Photo: Erik Christensen)

4 Supply temperatures of different collector technologies

Figure 11 shows typical supply temperatures of the different collector technologies. Concentrating collectors and evacuated collectors generally are able to deliver higher temperatures due to lower thermal losses. In the case of concentrating collectors, such as large parabolic troughs, Fresnel lenses and linear Fresnel, the concentration of direct radiation also results in higher supply temperatures. In general, the possible supply temperatures always depend on the overall system design and how the solar thermal field is integrated in the system.

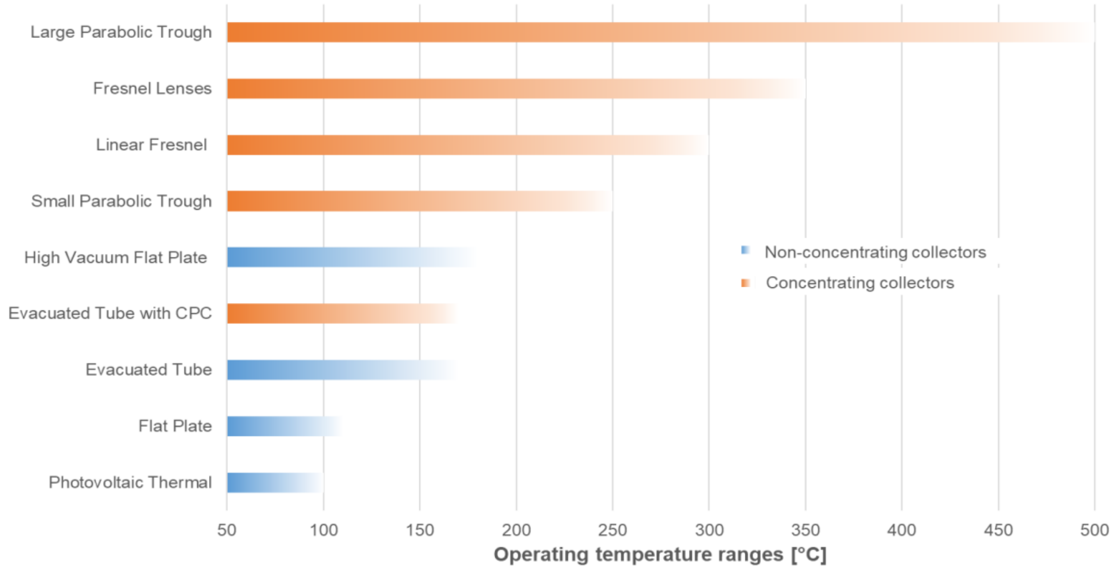

Figure 11 Operating supply temperatures ranges of collector technologies (manufacturer information) Since there is no strict upper limit for temperatures, the bars are faded out (figure: Solites)

5 Geometrical features of collector products

In this section, the geometric characteristics of the single collectors are shown, see Table 1. There are major differences depending on the technology. Collectors with a large aperture area are particularly interesting for large collector fields as they are quicker to install. On the other hand, collectors with a smaller size can be installed easier e.g. on roofs or areas which have special geometries or are interrupted.

Table 1 Geometrical features of different solar thermal collectors (manufacturer information)

Manufacturer, Product	**Technology**	**Collector width [m]**	**Collector length [m]**	**Gross area [m²]**	**Aperture area [m²]**
Abora, aH72SK	Glazed photovoltaic thermal (PVT)– Flat Plate	0.995	1.97	1.96	1.88
Ensol, DIS 150	Flat Plate double glazed	6.606	2.35	15.5	14.2
Gasokol, powerSol 136	Flat Plate double glazed	2.166	6.275	13.59	12.50

GREENoneTEC, GK 3133 GK 3133-S GK HT13,6	Flat Plate double glazed single glazed single glazed	5.92 5.92 5.97	2.22 2.22 2.28	13.17 13.17 16.61	12.35 12.35 12.56
Meriaura, Savo 16S	Flat Plate single glazed	6.158	2.591	15.96	14.81
TVP Solar, MT-Power v4	High-Vacuum Flat Plate (HVFP)	0.975	2.014	1.96	1.84
Akotec, MEGA-Kollektor	Evacuated Tube	2.18	5.95	12.99	11.6
Ritter XL Solar, XL 19/49	Evacuated Tube with CPC	2.432	2.033	4.94	4.50
Absolicon, T160	Small Parabolic Trough	5.514	1.095	6.04	5.51
Protarget, PT950	Large Parabolic Trough	3	12	36	34.83
Solarlite / Azteq, HYT6000	Large Parabolic trough	5.77	150	831	831
Soliterm group, PTC 1800	Small Parabolic Trough	1.80	5.07	9.13	9.08
Sun Oyster GmbH, Sun Oyster 16 HEAT	Small Parabolic Trough	3.865	3.986	15.41	15.31
ELLO (SUNCNIM), Ello module	Linear Fresnel	18	67	1206	898.8
Heliac, Hørsholm SP	Fresnel Lenses	1.4	1.7	2.4	18.5

6 Collector technologies

The collector technologies listed in Table 1 have different properties and special features. Besides the non-concentrating collectors, there are concentrating collectors that focus the direct radiation of the sun on a secondary absorber element, which significantly increases the solar yield at high temperatures. Examples of this are evacuated tubes with CPC, parabolic troughs and Fresnel collectors. While flat plate collectors, evacuated tube collectors or evacuated tubes with CPC generally have a fixed collector slope angle, there are other collectors with tracking systems. The solar yield can be increased by tracking of the collectors. The collectors track the sun to keep the angle of incidence as low as possible and thus maintain a high amount of irradiation at the collector plane. A differentiation can be made between single-axis and 2-axis tracking. To prevent form damage by overheating, the collector can be turned away from the sun and the thermal yield can be better regulated (Stahlhut, Ackermann, & Urbaneck, 1-2/2022).

Large parabolic trough collectors, for example, are tracked with a single axis, while compact collectors such as ‘Sun Oyster 16 HEAT’ or Fresnel lenses from the manufacturer Heliac are tracked with two axes. The main advantage of tracking systems is the increased and controllable solar yield. However, additional electrical energy is required and the row spacing may need to be increased in order to minimize energy losses due to shading (Stahlhut, Ackermann, & Urbaneck, 1-2/2022).

Different heat transfer fluids are used inside the solar collector depending on the technology and application. These are usually specified by the manufacturer. The most common fluids are water, water-propylenglycol mixtures, thermal oil and steam. If water is used, the associated costs are low and the transfer from the solar circle to a secondary circuit is not necessarily required. However, a concept to prevent freezing under all circumstances is required. The operating temperature range can be up to about 200 °C with water. In case of operating temperatures above 95 °C, the water-filled system must be pressurized, which causes costs.

If, on the other hand, water-propylenglycol is used, freezing can be avoided. Water-glycol fluids are available for up to about 170 °C operating temperatures for short periods and up to 120 °C for long periods (TYFOROP Chemie GmbH, 2015).

Thermal oils can be used for temperatures up to 400 °C, however some of these high temperature oils tend to have very high viscosity at low temperatures. This can lead to problems when starting a cold system. Furthermore, the environmental impact of such high temperature oils must not be neglected (Therminol, 2022).

Certificates are required for most collector funding programs. The most commonly used certificate in the European market is the Solar Keymark certificate (https://solarkeymark.eu/). This certificate is also used and accepted in many countries outside Europe. It was developed by Solar Heat Europe/ESTIF and CEN (European Committee for Standardization). Collectors are tested by accredited test laboratories in accordance with the EN 12975 and EN ISO 9806 standards. In addition, the certification scheme requires periodic surveillance of the manufacturing process and of the product itself. Very large parabolic trough collectors are difficult to test in laboratories due to the large space requirements. In-Situ testing is however a valid option in the Solar Keymark certification scheme.

In the North American market, certificates are mainly provided by ICC-SRCC (Solar Keymark, 2024). The testing standards and the general procedures are very similar to the Solar Keymark, so that collectors have to be tested only once.

A large number of the collectors investigated in this report are concentrating technologies. Mirrors or lenses are used to focus the solar radiation onto the absorber. An important parameter is the concentration factor, which results from the quotient of the aperture and absorber surface. Diffuse radiation cannot be deflected directly onto the absorber. It therefore has little influence on the solar yield, as the absorber area of concentrating collectors is comparatively small (Stahlhut, Ackermann, & Urbaneck, 1-2/2022), (W. Weiss, M. Rommel, 2008). This implies however also that highly concentrating collectors have significantly higher energy gains if used in regions with low diffuse radiation contributions.

For the thermal output of the concentrating collectors the choice of components plays a major role. Glas silver reflectors have a significantly higher reflectance than aluminium coil with highly pure aluminium as a reflector. Aluminium coil material may have a silver reflector surface, which improves the reflectivity, but should be covered against ambient influences. The absorber pipes are mostly surrounded by a glass envelope. Receivers which are used for power plants with 70 mm absorber diameter usually have an anti-reflex coating and a vacuum between glass envelope and absorber pipe. These components are difficult to use or purchase for smaller collectors. Therefore, not all of the collectors have these characteristics. Cleaning during operation is of importance: The effect of soiling on the mirror surface is higher than on the glass cover of flat plate collectors. Other parameters to consider include the expected risk of natural hazards such as wind, snow and hail, where there are significant differences between products. Other factors may include the space available (roof, green field, parking area, …), accessibility for maintenance, possibilities for dual use (collector field and agriculture), the fluid to be used in the system, visual aspects, etc.

6.1 Flat plate and PVT collectors

Flat plate collectors are generally used for applications with low and medium temperatures. The structure of a flat plate collector is shown in Figure 12. Diffuse radiation has a major influence on the heat yield due to the large absorber surface of the collector. The flat plate collector can therefore also be used in cloudy, dusty or humid environments. The collector is usually constructed with a glass cover, copper tubes, absorber plates, thermal insulation and aluminium casing. The production of the collector is therefore comparatively inexpensive (Shamsul Azha, Hussin, Nasif, Hussain, 2020). Anti-reflective glass is also used to increase performance by most of the manufacturers of high-performance collectors. A distinction can be made between single and double glazing for flat plate collectors.. At higher temperatures, the performance of a double glazed flat plate is better than of a single glazed collector, as the additional glass reduces heat losses to the environment. However, they are more expensive to produce and heavier in weight than single glazed collectors. Double-glazed large-scale collectors are often used for district heating applications.

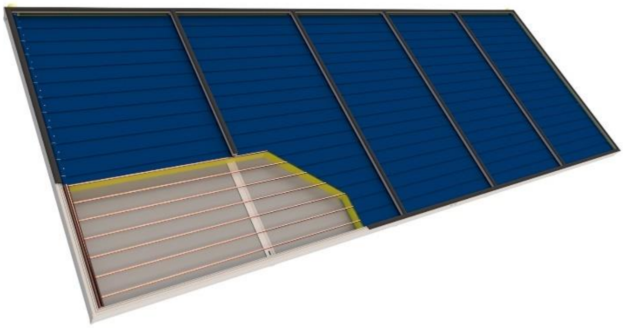

Figure 12 Structure of a flat plate collector for district heating (GREENoneTEC)

In this report, a PVT (photovoltaic thermal) collector from Abora is also included in the investigations. This is visually similar to a flat-plate collector and is therefore explained in this section. As the name suggests, both electricity and heat are generated in one collector. The upper part of the collector contains photovoltaic modules on which the solar radiation is converted into electrical energy and the heat absorber is located underneath. The overall efficiency of the collector is comparatively high, as the incident radiation is converted into electricity and heat. However, the operating temperatures are comparatively low, as the electrical components in the module are temperature-sensitive and the PV modules result in a lower heat transfer to the absorber element.

The following Table 2 provides an overview of the flat plate and PVT collectors that took part in the investigation.

Table 2 Overview of analysed flat plate and PVT collectors

Manufacturer **Country** **Website**	**Product**	**Picture of an example system** **Project name, location** **source**
ABORA Spain https://abora-solar.com	aH72SK Glazed PVT – Flat Plate	 Club de Natacio, Barcelone Spain picture: Universidad de Zaragoza
Ensol Poland www.ensol.pl	DIS 150 double glazed	 Mürzzuschlag, Austria picture: SOLID (KKB, Ensol & Gasokol collectors)

GASOKOL GmbH Austria www.gasokol.at	powerSol 136 double glazed	 Nahwärme St. Ruprecht, Austria picture: Gasokol
GREENoneTEC Solarindustrie GmbH Austria www.greenonetec.com	GK 3133 double glazed GK 3133-S single glazed GK HT13,6 single glazed	 SolarHeatGrid, Ludwigsburg Germany picture: GREENoneTEC
Meriaura Energy (Savosolar) Finland www.meriauraenergy.com	Savo 16S single glazed	 Malt plant of Issoudun, France picture: kyotherm.com

6.1.1 Advantages and applications

Within the last years, high temperature flat plate collectors as well as evacuated tube collectors became a state-of-the-art heating technology in DH systems of utilities, energy companies, cooperatives etc. The developments differed due to different boundary conditions in different European countries. All developments comprise specialized collectors for district heating application. They cover up to about 16 m² of collector area per collector, which makes installation very fast. Their internal hydraulic scheme is optimized to facilitate the realization of long collector rows by a simple connection of the collectors and to run these rows with low flow. This saves installation costs as well as electricity consumption of the solar circuit pumps.

As already mentioned, the flat-plate collector is inexpensive and available on large scale. There are numerous manufacturers and production facilities in Europe available offering turnkey systems. In addition, there are many years of established experience with flat plate collectors in large scale applications. The efficiency is comparatively high at medium collector temperatures and recycling is also possible due to the simple design (Ostschweizer Fachhochschule).

6.1.2 Collector efficiency

This section shows the efficiency curves of the flat plate collectors listed above, see Figure 13. The data is based on information provided by the manufacturers and certificates under steady state or quasi dynamic conditions and relates to the gross area in each case for a global radiation of 1000 W/m². The global radiation refers to the collector gross area, according to the Solar Keymark certification. Efficiency curves are obtained depending on the difference between the ambient temperature and the mean temperature of the collector. Basic and general information on the efficiency of collectors is explained in the appendix, see chapter 12.1.

Higher collector temperatures result in greater temperature differences to the ambient air. This leads to higher heat losses and therefore to lower efficiencies. Therefore, all curves decrease as the temperature difference increases. The PVT collector from Abora has the largest drop, as it is temperature-sensitive due to the hybrid technology. It can be seen that flat plate collectors have a high degradation of efficiency. On the other hand, they have a comparatively high efficiency at lower temperature differences. The reason for this is the high optical efficiency η_0 of flat-plate collectors. Due to the design and the relatively large absorber surface, flat-plate collectors are able to absorb a lot of solar radiation.

In general, the efficiency at higher temperature differences of a double-glazed flat plate is better than of a single glazed collector, as the additional glass reduces heat losses to the environment. This is visible for example in the comparison of the two products GK3133 and GK3133-S. Both products have the same geometry. Due to the single glazing, GK3133-S has a higher optical efficiency and poorer efficiency at higher temperature differences than GK3133 double glazed collector. The double glazed DIS 150 flat plate collector from Ensol has the highest efficiency at larger temperature differences.

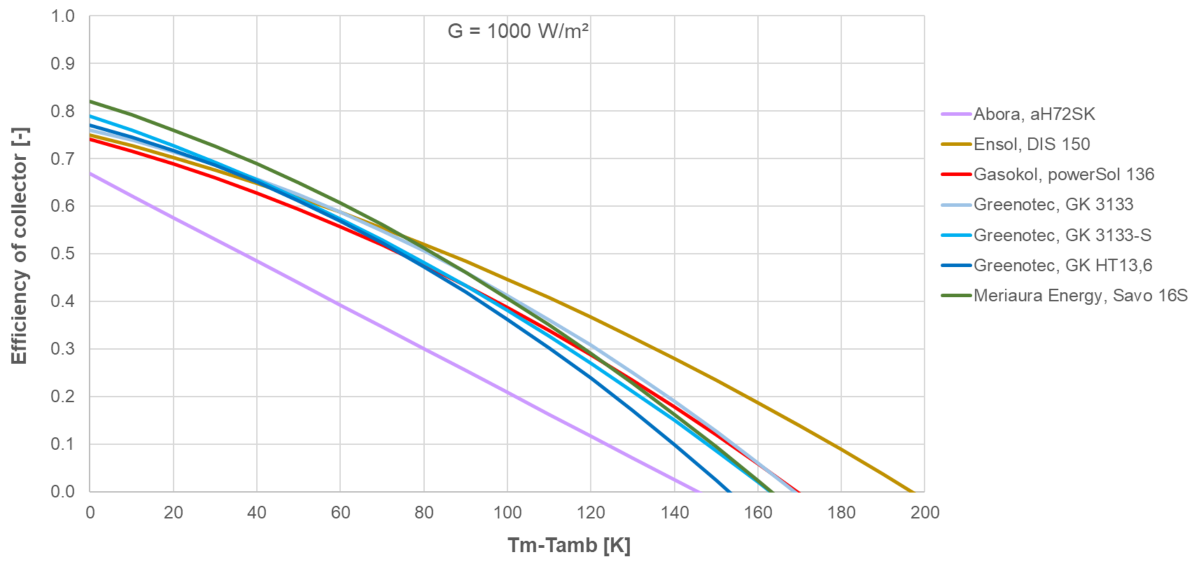

Figure 13 Efficiency curves of flat plate and PVT collectors (Solar Keymark) (figure: Solites)

6.2 HVFP collectors

One flat plate collector with a special construction is the High Vacuum Flat Plate (HVFP) collector from the manufacturer TVP Solar SA, see Figure 14. A vacuum below 0.1 Pa is created and maintained in the area of the absorber using patented technologies (the company provides a 20-year guarantee). The vacuum substantially reduces heat loss and increases the efficiency of the collector. Due to its high-vacuum insulation and ultra-transparent glass, it can efficiently deliver high temperatures of up to 180 °C without tracking (datasheet MT-Power v4, TVP Solar) (manufacturer information) (Buonomano, Calise, d'Accadia, Ferruzzi, Frascogna, Palombo, Russo, Scarpellino, 2016). Like other flat plate collectors, this one can be used under dirty, dusty, humid or cloudy weather conditions and absorbs both direct, as well as diffuse radiation.

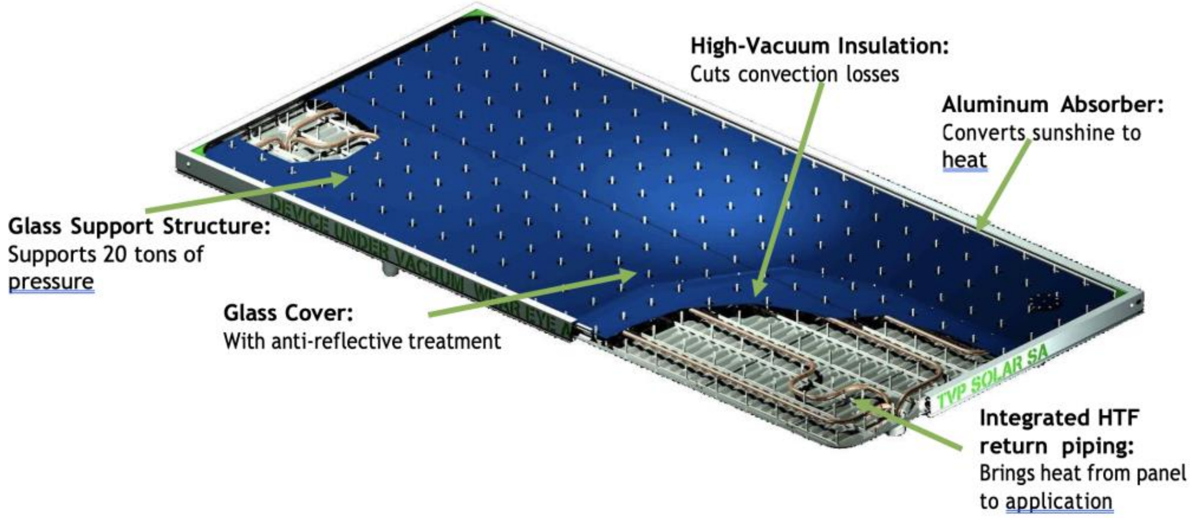

Figure 14 Main components of MT-Power v4 HVFP collector (TVP Solar SA) (Spirit-Heat, 23 Feb. 2024)

The MT-Power v4 collector product is shown below with an example system, see Table 3.

Table 3 Overview of analysed HVFP collector

Manufacturer **Country** **Website**	**Product**	**Picture of an example system** **Project name, location** **source**
TVP Solar SA Switzerland www.tvpsolar.com	MT-Power v4	 Rooftop solar district heating plant, Geneva Switzerland picture: solarheateurope.eu

6.2.1 Advantages and applications

Conduction and convection losses are low in the HVFP collector due to the vacuum. In addition, comparatively higher collector temperatures can be achieved and the direct and diffuse radiation has a significant influence on heat generation (Ostschweizer Fachhochschule). This collector is Solar Keymark certified for operation up to 200 °C and has been specifically designed for large-scale applications of industrial heat and district heating. As of December 2023, MT-Power-based solar thermal systems have been deployed in twelve countries across Europe, Middle East and Americas. There are empirical values from example systems for this collector. However, these are not as extensive as for other technologies. Because of the small size of the single collector, a substructure is required on which several collectors can be installed.

6.2.2 Collector efficiency

The efficiency of the HVFP collector is shown below, see Figure 15. The efficiency decreases more slowly at higher temperatures than with flat plate collectors. This is due to the low thermal losses resulting from the vacuum method.

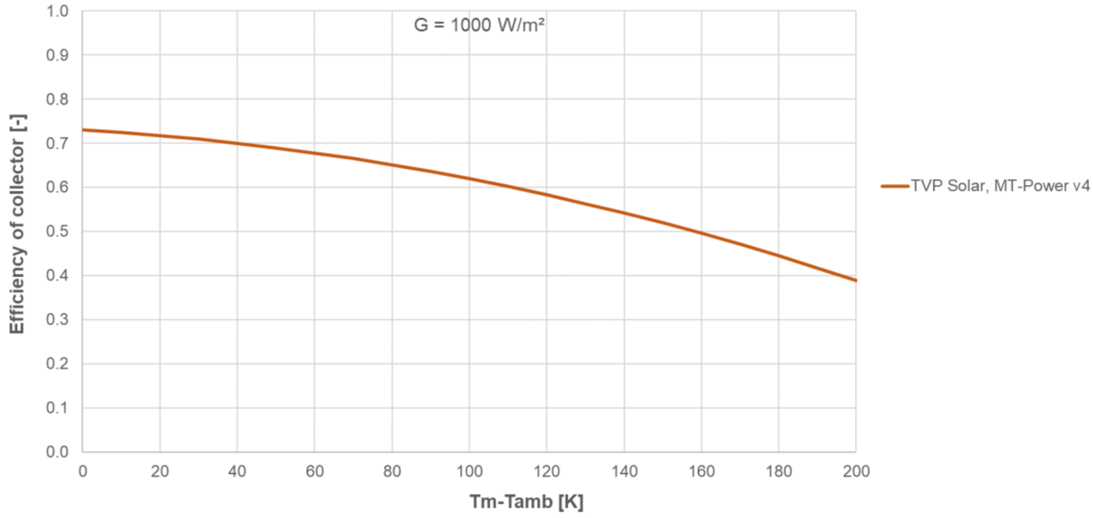

Figure 15 Efficiency curve of HVFP collector (Solar Keymark) (figure: Solites)

6.3 Evacuated tube collectors without and with CPC

There are two basic types of evacuated tube collectors (ETC): The so called Sydney tube collectors and the single glass tube collectors. The Sydney tube collectors consist of double glass tubes where the inner absorber tube is coated with a selective material. The space between the two tubes is evacuated. The single glass tube collectors are made of one evacuated tube with a conventional metallic absorber inside the tube.

The vacuum insulation reduces heat loss and this increases performance at higher temperatures.

The MEGA collector from AKOTEC serves as an example of an evacuated tube collector with heat pipes. Instead of a CPC (compound parabolic concentrator) reflector plate, a trapezoidal plate with a good reflection factor is used. The radiation is mainly reflected onto the vacuum tube as diffuse radiation. For example see Figure 16.

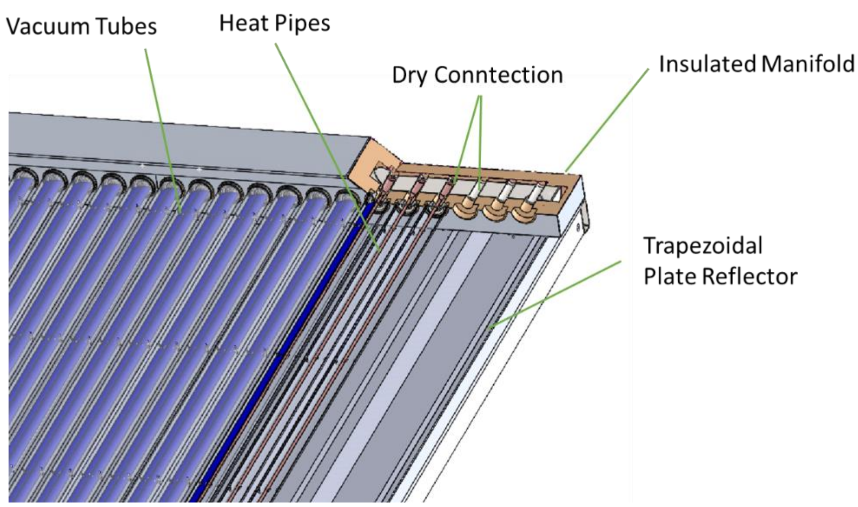

Figure 16 Main components of AKOTEC MEGA Collector (AKOTEC)

The evacuated tube with CPC (also called CPC collectors) is a special design of an evacuated tube collector. CPC collectors have a parabolic mirror on the backside of the absorber tube. Due to the geometry of the parabolic mirror, it reflects the direct radiation onto the absorber tube at any angle of incidence, see Figure 17. Therefore, no tracking is necessary and a small row spacing can be used, as the shading without tracking and the flat geometry is comparatively low. Due to its design, it is very area-efficient and able to generate high temperatures economically (manufacturer information).

Figure 17 Main components of a Ritter XL CPC collector, sectional view (Ritter Energie- und Umwelttechnik GmbH & Co. KG)

There is one collector model each of the evacuated tube and CPC collectors for which data was given for the analysis, see Table 4.

Table 4 Overview of analysed evacuated tube and CPC collector

Manufacturer **Country** **Website**	**Product**	**Picture of an example system** **Project name, location** **source**
AKOTEC Produktionsgesellschaft mbH Germany www.akotec.eu	MEGA-Kollektor (ETC)	 MEGA Leipzig, Leipzig picture: Akotec
Ritter XL Solar Germany www.ritter-xl-solar.de	XL 19/49 (CPC)	 Greifswald, Greifswald Germany picture: Ritter XL Solar

6.3.1 Advantages and applications

Within the last years, evacuated tube collectors without and with CPC as well as high temperature flat plate collectors became a state-of-the-art heating technology in DH systems of utilities, energy companies, cooperatives etc. The manufacturers offer turnkey solutions and installation on land area is standardised. All developments comprise specialized collectors for district heating application. Their internal hydraulic scheme is optimized to facilitate the realization of long collector rows by a simple connection of the collectors and to run these rows with low flow. This saves installation costs as well as electricity consumption of the solar circuit pumps.

Heat losses are also comparatively low with these collector technologies due to the vacuum and comparatively higher collector temperatures are achievable. In addition to direct radiation, diffuse radiation is also converted into heat. Even at flat angles of incidence, the efficiency is still comparatively high. With some products horizontal installation is also possible on a flat surface (Ostschweizer Fachhochschule). Evacuated tube collectors are already being used in a number of large-scale SDH systems, like the CPC collector from Ritter XL Solar like in Greifswald Germany.

6.3.2 Collector efficiency

The efficiency of the two collectors is compared in Figure 18. Due to the concentration of direct radiation on the absorber, the CPC collector has a higher efficiency than the evacuated tube collector at the temperature differences shown. However, this collector technology is also more complex to construct. Both technologies have comparatively constant efficiencies over the temperature differences. This is due to the relatively small absorber surface which results in a low optical efficiency η_0 and the vacuum, which protects the collectors from heat losses at higher temperatures.

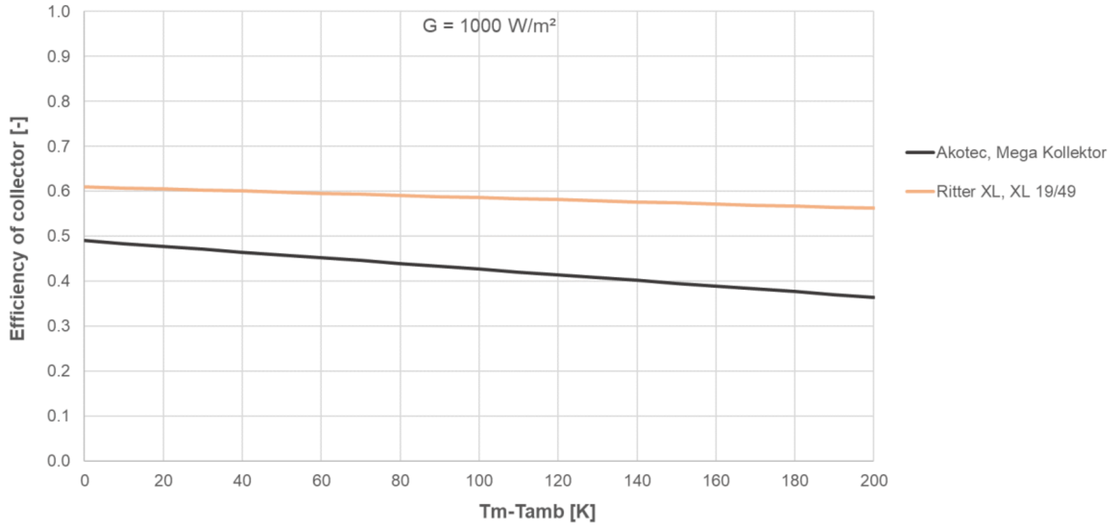

Figure 18 Efficiency curves of evacuated tube and CPC collector (Solar Keymark) (figure: Solites)

6.4 Parabolic trough collectors

The main feature of this technology is a large, curved mirror that is focussing the incoming radiation onto the absorber tube, see Figure 19. Due to the relatively large construction, these collectors can usually be tracked on a single axis. A major advantage of this technology is the low heat loss due to the small surface area of the absorber tube. As a result, high temperatures of over 400 °C can be achieved efficiently, also due to the concentration of the direct irradiation. Parabolic trough collectors are usually not stagnation safe, meaning that overheating protection is mandatory. In general stagnation is avoided by turning the collector out of the sun. Most of the absorber tubes are protected by a surrounding glass tube. Most of the receiver tubes have a vacuum which, may be re-evacuated during maintenance work. Due to its design, in some cases it does not require revacuuming (W. Weiss, M. Rommel, 2008).

Figure 19 shows the schematic structure of a large parabolic trough collector and defines the most important components and geometric parameters. The focal length indicates the distance between the main plane of the convex mirror and the focal point. The absorber is positioned so that it is at the focal point of the mirror. For parabolic troughs, the focal length is therefore the distance between the mirror and the absorber.

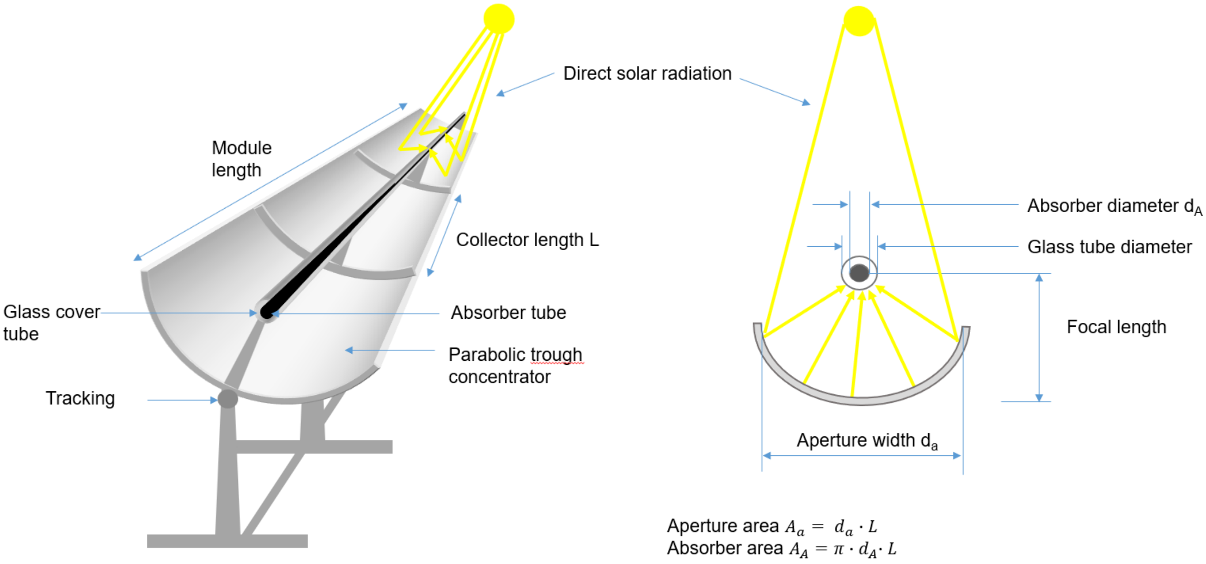

Figure 19 Large parabolic trough collector, perspective view and cross-sectional view (figure: Solites)

One special construction of a small parabolic trough is shown in Figure 20. Here the mirror is covered with a glass pane, while the receiver pipe has no additional glass cover tube.

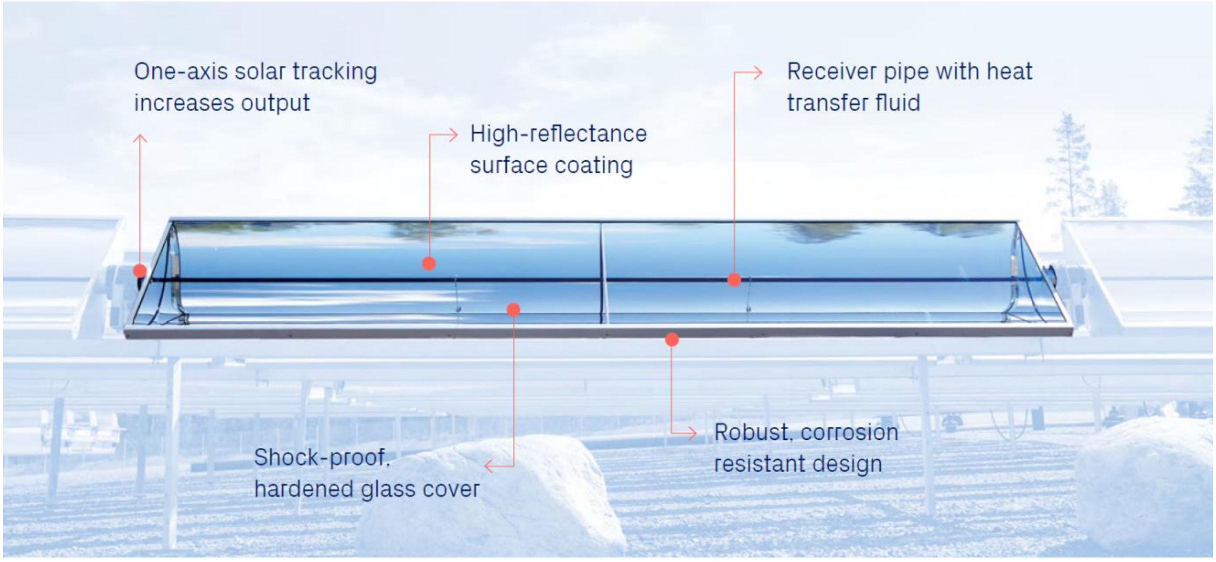

Figure 20 Photo of small parabolic trough T160, Absolicon (manufacturer information) (datasheet)

Another special form of parabolic trough is the SunOyster collector. The collector has a receiver that is protected by a borosilicate glass tube. The mirror concentrates the solar radiation onto the focal line of the glass tube, where special glass lenses ensure further concentration. The collector is a two-axis tracking system with a special substructure. Depending on the design of the collector, the liquid for thermal use can reach temperatures of 110 °C (with upstream electricity generation) and 170 °C (purely thermal application).

A total of five manufacturers of parabolic troughs took part in the evaluation, see Table 5. Depending on the gross area, a distinction can be made between large and small parabolic troughs. As shown in Figure 11, they differ in typical operating temperatures.

Table 5 Overview of analysed parabolic trough collectors

Manufacturer **Country** **Website**	**Product**	**Picture of an example system** **Project name, location** **source**
Absolicon Sweden www.absolicon.com	T160 Small Parabolic Trough	 Högslätten, Härnösand Sweden picture: absolicon.com
Protarget Germany www.protarget-ag.com	PT950 Large Parabolic Trough	 B&O Group, Bad Aibling, Germany picture: Protarget AG
Solarlite / Azteq Germany / Belgium www.solarlite.de / www.azteq.be	HYT6000 Large Parabolic Trough	 Avery Dennison CST project, Turnhout Belgium picture: azteq.be

Soliterm group Germany www.solitermgroup.com	PTC 1800 Small Parabolic Trough	 Mayr-Melnhof Graphia, Izmir Turkey picture: solitermgroup.com
Sun Oyster GmbH Germany www.sunoyster.com	Sun Oyster 16 HEAT Small Parabolic Trough	 Demo system, Zhangjiakou China picture: sunoyster.com

6.4.1 Advantages and applications

In parabolic trough collectors high supply temperatures can be achieved. This technology is therefore widely used for electricity production in sunny regions and often for solar industrial heat or steam production. However, first installations show the potential for the use in DH networks as well. The solar heat supply can be regulated by tracking, which can be very interesting for DH operators. On sunny days, the solar yield is also distributed relatively consistently throughout the day, which makes system control easier (Ostschweizer Fachhochschule).

Small parabolic trough collectors can be installed on roof areas or on the ground, whereas large parabolic troughs need a suitable land area for the installation. For example, the SunOyster collector is modelled on a shell that closes when the wind is too strong. By reducing the wind load, the SunOyster can therefore also be installed on roofs.

6.4.2 Collector efficiency

The efficiency of parabolic trough collectors is shown in Figure 21. These collector technologies show almost flat curves of efficiency over the temperature differences. Due to the relatively small absorber tube diameter, the heat-emitting surface of concentrating collectors is smaller than that of flat plate or evacuated tube collector technologies. This results in lower thermal losses and therefore higher efficiency at higher collector temperatures. Larger parabolic troughs as the PT950 and HYT6000 are the most efficient, because they are equipped with glass/silver mirrors and vacuum receivers (the two curves are overlaying in the diagram). They have almost no drop in efficiency in the shown temperature range. The data of the HYT6000 are taken from publications on the HelioTrough collector, which is equal. A Solar Keymark certification is planned for 2024. The collector from Sun Oyster has a higher drop in efficiency.

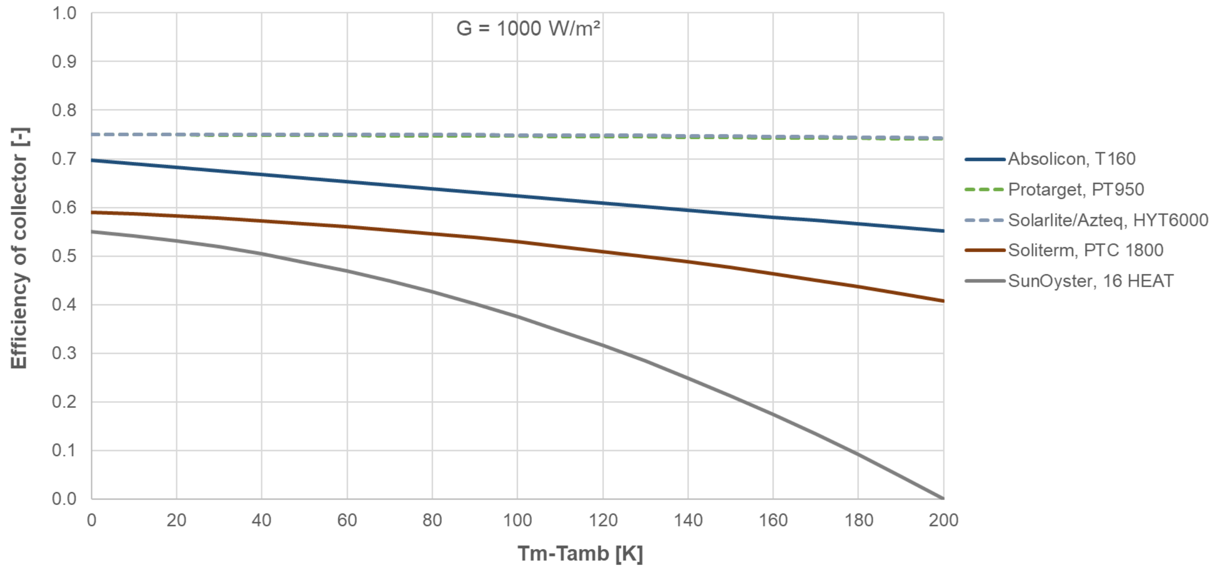

Figure 21 Efficiency curves of parabolic trough collectors (solid lines: Solar Keymark, dotted lines: manufacturer information) (figure: Solites)

6.5 Linear Fresnel collectors

Linear Fresnel collectors consist of many mirror surfaces that are tracked separately in a single axis and reflect the direct radiation onto the absorber tube, see Figure 22. To reduce optical losses, a secondary reflector is mounted on top of the absorber tube. Due to the simple geometry of the mirrors, they are cleaned by robots at night. This ensures radiation conditions on the mirrors, while the upper side of the receiver can be difficult to clean (manufacturer information).

Figure 22 Photo of linear Fresnel collectors Ello Module, Ello (manufacturer information)

The linear Fresnel collector from Ello (ex Suncnim) is analysed in this report, see Table 6.

Table 6 Overview of analysed linear Fresnel collector

Manufacturer **Country** **Website**	**Product**	**Picture of an example system** **Project name, location** **source**
ELLO (SUNCNIM) France www.suncnim.com	ELLO module	 Ello Solar Power Plant, Llo France picture: suncnim.com

6.5.1 Advantages and applications

The advantages of linear Fresnels are almost identical to parabolic troughs due to their similar functionality. These collectors can also deliver comparatively high temperatures efficiently. Due to tracking, the solar yield is constant throughout the day and the mirrors can be tracked away if there is a risk of stagnation. The use of linear Fresnel collectors also makes sense in sunny locations due to the high influence of direct radiation on the solar yield. The solar heat supply can be regulated by tracking of the single mirrors, which can be very interesting for DH operators. On sunny days, the solar yield is also distributed relatively consistently throughout the day, which makes system control easier. The ELLO module collector from the manufacturer of the same name delivers temperatures of up to 300 °C and can therefore be used for heat, steam or electricity generation as well as for industrial and heating or cooling applications. Due to the large dimensions of the single collectors, the installation of collector fields need a suitable ground area.

6.5.2 Collector efficiency

For the linear fresnel collector shown here, the optical efficiency η_0 is just under 70 %, see Figure 23. With a temperature difference of 200 K between the ambient and mean collector temperature, the collector efficiency is just under 40 %. This collector is not tested under Solar Keymark conditions and therefore the data is based on manufacturer information.

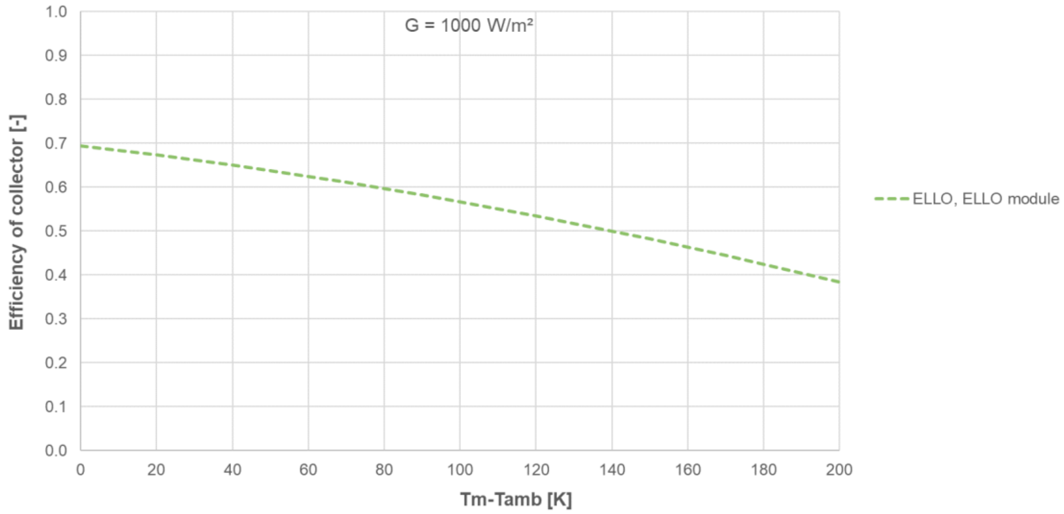

Figure 23 Efficiency curve of linear Fresnel collector (manufacturer information) (figure: Solites)

6.6 Fresnel lenses collectors

The Fresnel lenses collector from the Danish manufacturer Heliac is an innovative, concentrating collector technology. The direct radiation is focused onto the absorber surface behind the lenses, see Figure 24. The eight lenses of one module are made of plastic and focus the light like a magnifying glass. Due to its compact design, it can be tracked on two axes, which significantly increases the solar yield. There is no risk of glare, as the collector always reflects towards the sun due to the 2-axis tracking (datasheet, manufacturer information).

Figure 24 Photo of Fresnel lenses, Heliac in Denmark (Jensen, Sifnaios, Caringal, Furbo, Dragsted, 2022)

The Fresnel lenses from Heliac are examined in this report, see Table 7.

Table 7 Overview of analysed Fresnel lens

Manufacturer **Country** **Website**	**Product**	**Picture of an example system** **Project name, location** **source**
Heliac Denmark www.heliac.dk	Hørsholm SP	 Hørsholm, Denmark picture: heliac.dk

6.6.1 Advantages and applications

In addition to the efficient supply of high temperatures, the compact design is a major advantage. As a result of the used materials and the design, the construction has a comparatively low weight and a small impact on the ground area. The base of each module requires a screw foundation. Due to the 2-axis tracking, the angle of incidence in the collector plane is optimised during the day and the operator can regulate the collector output.

As with conventional collector technologies, the temperature level can be controlled by regulating the flow rate of the heat transfer fluid. The heat is then transferred to the end consumer via a standard heat exchanger. The first pilot plant has been in operation for E.On Denmark in Mön since 2019. Another plant was commissioned in Hørsholm in Denmark in 2022.

6.6.2 Collector efficiency

The efficiency of the Heliac Fresnel lenses decreases comparatively slowly with increasing temperature differences, see Figure 25. It starts at 60 % and reduces to 55 % at a temperature difference of 200 K. This collector is not tested under Solar Keymark conditions and theefore the data is based on manufacturer information (manufacturer information).

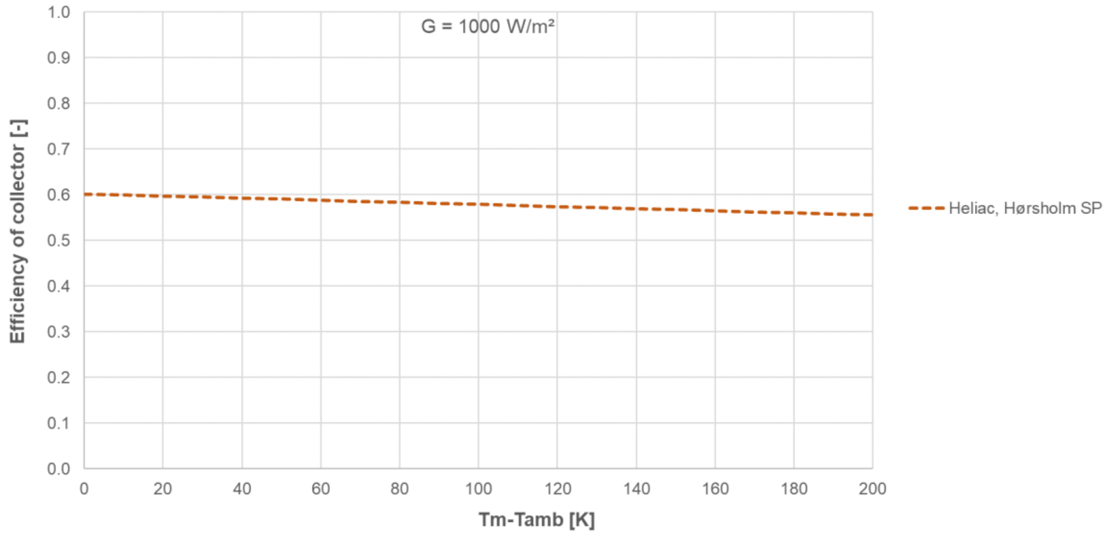

Figure 25 Efficiency curve of Fresnel lenses collector (dotted line: manufacturer information) (figure: Solites)

7 Comparison of collector technologies by Solar Keymark results

This section describes how to compare the performance of different collectors. To compute the output of a collector under specific climatic and operating conditions, it is necessary to know the thermal performance parameters and incidence angle modifiers, which can be obtained from the Solar Keymark or ICC-SRCC database. These parameters are measured by accredited testing laboratories according to ISO 9806 for a single collector under standardised testing conditions. This simplifies calculations and make collectors easily comparable. However, it is not reasonable to compare collector performance based solely on the individual thermal performance parameters indicted there. In a realised solar collector field, different categories of heat losses need to be taken into account before the collector field output can be used in the connected DH system. These aspects include shading of the collector rows or other buildings trees etc., not optimal irradiation, reflections, heat capacities, thermal losses in the field piping, daily start of operation of the collector field and soiling of the mirrors and the absorber area. Concerning the connected DH system, additional factors are important, like the characteristics of the heat demand, the supply and return temperatures, the operation of other system components, the size of the heat storage etc. These system aspects are more described in chapter 3.

For a fair and comprehensive comparison, the gross yield concept was introduced in the Solar Keymark certification scheme and the European EN 12975 standard many years ago. This concept will also be integrated into the new ISO 9806, set to be published in 2024/2025. A similar calculation method is used in ICC-SRCC. The gross thermal yield (GTY) is a measure of collector performance when operated at a fixed temperature and orientation throughout the year in a given climate. Solar Keymark indicates GTY values for operating temperatures of 25 °C, 50 °C, and 75 °C at reference locations in Athens, Davos, Stockholm, and Würzburg. Other locations and temperatures can be calculated using the free ScenoCalc tool (https://solarkeymark.eu/calculation-tools/).

The following diagrams (Figure 26 to Figure 29) show the annual yield of the technologies double glazed standard flat plate collector, evacuated tube with CPC, small parabolic trough and large parabolic trough. In addition to the standard temperatures of 25 °C, 50 °C and 75 °C, a further operating temperature of 100 °C was calculated using the ScenoCalc tool. According to Solar Keymark, the reference locations are Athens, Davos, Stockholm and Würzburg.

It can be seen that the flat-plate collector delivers the highest specific yields at the reference locations at a mean collector temperature of 25 °C. As the collector temperature increases, the yields fall more sharply than with the CPC and the small parabolic trough. The large parabolic trough ensures relatively constant specific yields over the shown collector temperatures. Especially at average collector temperatures of more than 75 °C, there is an advantage over CPC collectors. These results are directly connected to the efficiency curves shown in the sections of the technologies above. In general, the yield is higher at lower collector temperatures because thermal losses are lower with a smaller temperature difference to the ambient. This can also be seen in the efficiency curves shown above, where efficiency levels are comparatively high at lower temperature differences. This is particularly important for the system integration of solar collectors to optimise the solar thermal output, the system efficiency and therefore the levelised cost of heat.

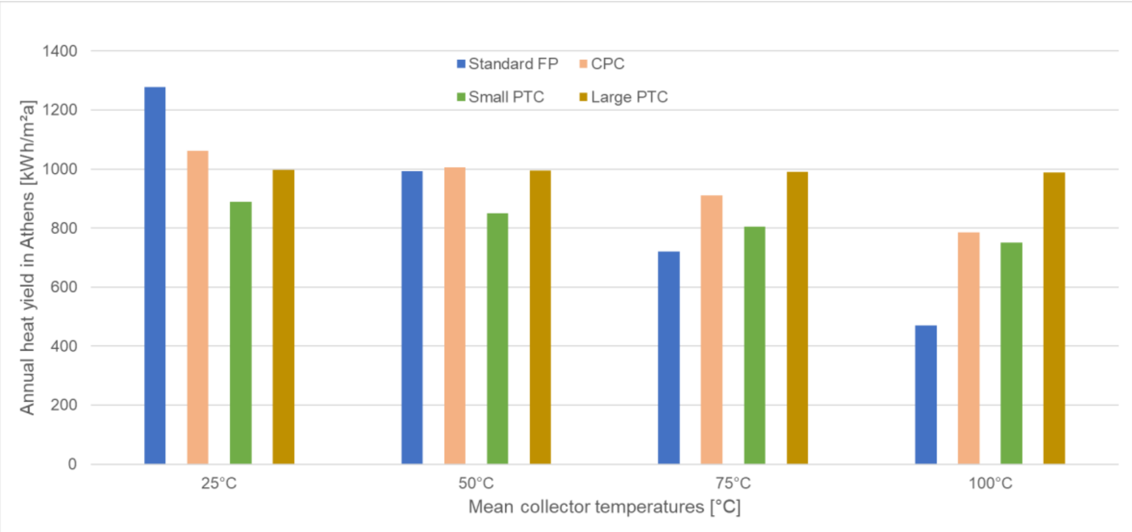

Figure 26 Comparison of gross thermal yield in Athens for different operating temperatures (Solar Keymark) (ScenoCalc)

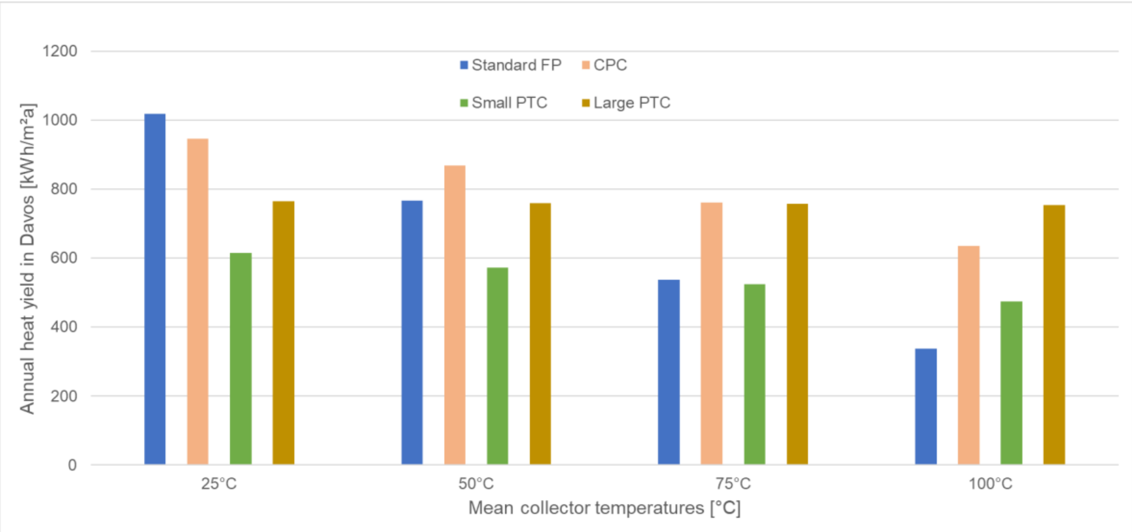

Figure 27 Comparison of gross thermal yield in Davos for different operating temperatures (Solar Keymark) (ScenoCalc)

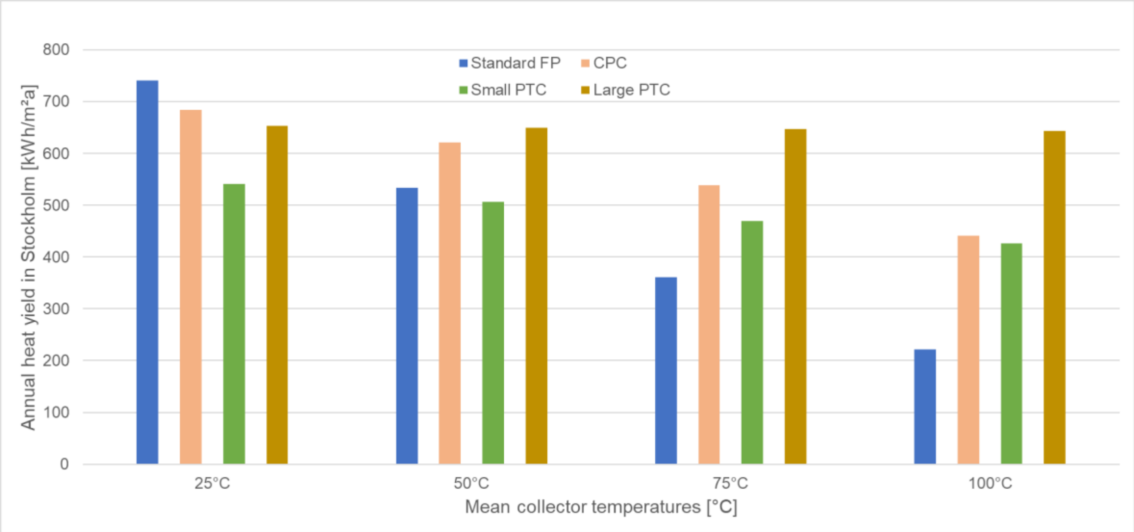

Figure 28 Comparison of gross thermal yield in Stockholm for different operating temperatures (Solar Keymark) (ScenoCalc)

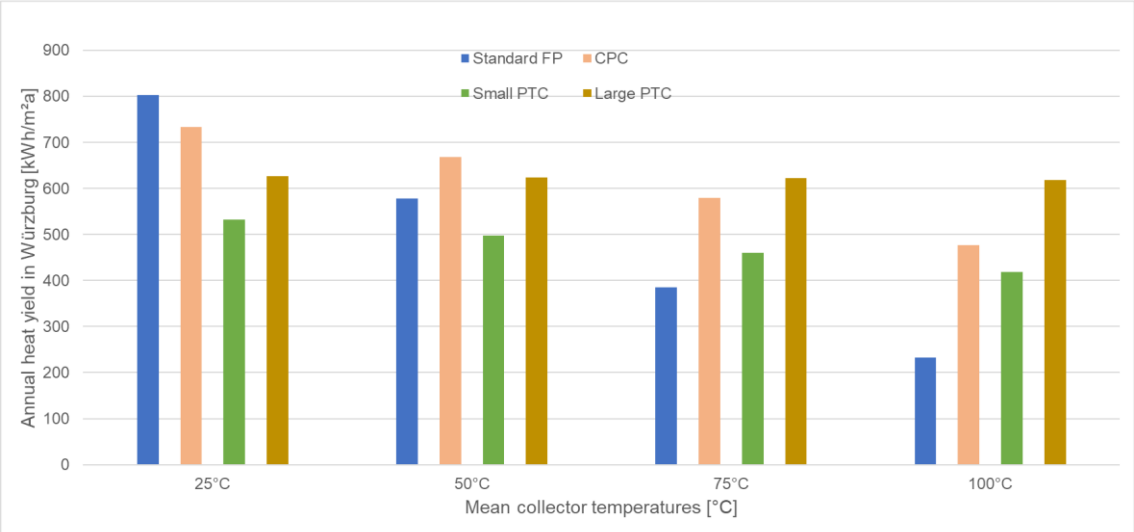

Figure 29 Comparison of gross thermal yield in Würzburg for different operating temperatures (Solar Keymark) (ScenoCalc)

The GTY figures are not intended to be used for planning a system, but rather to compare collectors based on their annual thermal output in a generalized way. Depending on other parameters such as user profiles or available space, the effective output can deviate considerably from the GTY. For large systems, it can be assumed that the generated solar energy is almost completely absorbed by the system. Therefore, the GTY parameters are good approximations of the effective annual yield.

The GTY is calculated for all certified collectors, but only for a maximum temperature of 75 °C. For collectors that are to be used at higher temperatures, the GTY must be calculated for higher temperatures. Although the GTY is a very reliable indicator, it is important to use it correctly. The GTY is expressed in kWh/m² where the reference area is the gross collector area.

Of course, the thermal yield at a given temperature is a relevant factor when designing a system. Collectors can be compared using the GTY concept and this must then be linked to the cost per collector quoted and the installation cost.

8 Investment costs of different technologies

The last sections show that the specific products of the collector manufacturers vary in performance and construction. To find the best suitable collector for a specific project it is recommended to invite offers from the solar companies and to decide according to the specific heat price. The solar heat price is calculated from the overall costs of the solar thermal plant in relation to the usable solar heat. To compare different offers, this usable solar heat should be calculated for all offers with the same simulation program, using the characteristic figures for every offered collector product according to test certificates like “Solar Keymark”, that is valid all over Europe.

The following economic analysis is not very detailed due to the limited data basis. Information on costs was provided by eight manufacturers. In order to ensure an anonymous consideration of the costs, these are shown in Figure 30 depending on the operating supply temperature range. The costs also refer to a collector field of 10 000 m² gross area and are shown specific per m². Furthermore, the figures are highly dependent on the location in which these costs occur.

Products with supply temperatures below 110 °C are in a small range of total investment costs. Conventional collectors, which are already widely available on the market, mainly operate in this temperature range. Therefore, due to competition, there are only minor deviations in the total investment.

The products with a delivery temperature of up to 250 °C are in a wide range. This is since different technologies are able of generating up to this supply temperature. The manufacturing costs can vary significantly, depending on the technology.

However, it should be noted that the figures are of restricted reliability due to the limited data.

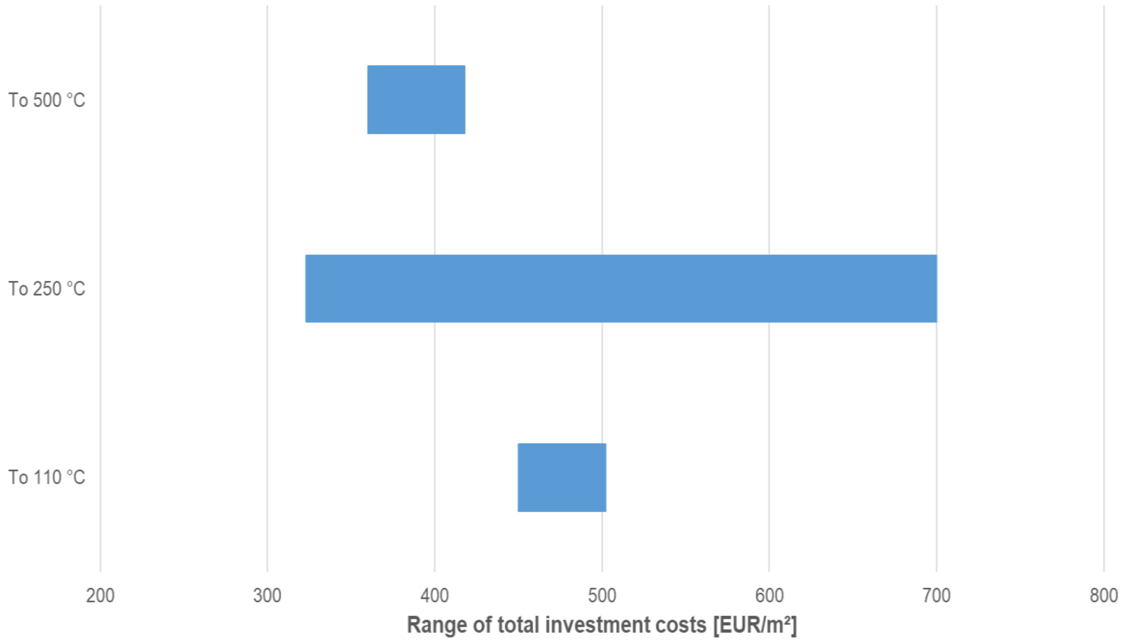

Figure 30 Range of total investment costs depending on maximum supply temperature of the collector. It is based on a 10 000 m² gross area collector field (manufacturer information) (figure: Solites)

The total investment costs are made up of several cost positions, which are listed and explained below. The development costs include administration, consultancy, project management, site preparation and approvals by authorities. The hardware investment costs of the collectors include piping, insulation, foundation, connection to balance of plant (heat centre) in 50 m distance. The hardware investment costs for balance of plant include infrastructure and connection costs, i.e. electricity, fuel and water connections inside the premises of a plant as well as measurement, control and regulation equipment. The hardware investment costs for diurnal heat storage used for solar heat include costs for heat storage for storing approximately the daily solar heat yield. The installation costs include engineering, civil works, buildings, grid connection and installation and commissioning of equipment.

In addition to the total investment costs listed above, there are also variable and fixed O&M (operation and maintenance) costs. As they can fluctuate each year, they refer to the average of the entire lifetime. The variable O&M costs include consumption of auxiliary materials, spare parts and output related repair and maintenance. Costs for auxiliary energy are not included. The fixed O&M costs include heat transfer fluids, as well as all costs that are independent of the term, such as administration, operational staff, payments for O&M service agreements, network or system charges, property tax, and insurance. Land rent or lease will be calculated separately and is not included here. Any necessary reinvestments to keep the plant operating within the technical lifetime are also included, whereas reinvestments to extend the life are excluded. Planned and unplanned maintenance costs may fall under fixed costs (e.g. scheduled yearly maintenance works) or variable costs (e.g. works depending on actual operating time) and are split accordingly. Costs were requested for the temperature levels. The technical lifetime was also queried.

9 Conclusion

The analysis shows that there are numerous technologies with individual characteristics and strengths. Every real medium-high temperature DH system is diverse and every application can be different. The analyses carried out that a broad variety of existing collector products can be used and are able to cover individual heat generation requirements.

Concentrating collectors are mainly of interest for higher supply temperatures, while flat plate collectors are typically more suitable for lower supply temperatures. However, there are certain non-concentrating collector technologies that serve higher supply temperatures. Highly efficient flat plate collectors and evacuated tubes with CPC collectors are a proven technology in the DH sector. Other concepts are emerging: Vacuum flat plate collectors have been installed in several plants. Parabolic trough collectors have been implemented in process heat installations and some years ago in Denmark in combination with DH. Comparison of their annual yield shows that they are well suited for DH.

The location of an example system is very important for the solar yield. The annual solar yield at a location in Spain is approximately three times higher on the same area than the solar yield in Sweden, although the technology is similar. Unfortunately, the cost analysis is relatively vague as less information was provided. Costs can also deviate from reality and vary depending on the application.

The integration of these technologies into DH systems requires careful consideration of various factors, including geographical characteristics, local climate and specific energy requirements. While concentrating collectors are suitable for applications requiring higher temperatures when using solar energy, flat plate collectors remain a promising option, especially in applications where lower flow temperatures are sufficient. However, in addition to technological considerations, the economic feasibility of these technologies must also be thoroughly assessed, taking into account potential cost variations and uncertainties associated with real applications.

10 Outlook

In the future, innovative collector technologies will become increasingly important for the use in district heating and better known to the professional public. Adapted laboratory conditions will make it easier to carry out Solar Keymark certifications in the future. This will provide several empirical values. This report should make it easier for DH system operators to get an overview of the available collector technologies which can be integrated in DH systems.

In subtask A1, questions were asked that can be used for later work in IEA SHC Task 68. One subtask deals with real example systems, another with simulation tools for SDH systems. In addition, a detailed analysis of economic efficiency of collector technologies will be done. For this reason, this report represents basic preliminary studies.

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12 Appendix

12.1 Basics on the efficiency of collectors

Efficiencies were shown in the previous sections according to the respective technology. Collector efficiencies can be generalized. The achievable thermal output of solar collectors is limited by the optical and thermal losses. While the optical losses are independent of the temperature, the thermal losses can be modelled as a parabolic curve depending on the temperature difference between the average collector temperature and the ambient temperature $\Delta T = T_m - T_a$, as shown in Figure 31. A temperature difference of 60 K occurs, for example, at an average collector temperature of 70 °C ((80+60)/2) and an outside temperature of 10 °C. The higher the average collector temperature and thus the temperature difference, the lower the achievable efficiency and yield of the collectors. The efficiency curve of a collector can be determined according to the EN ISO 9806:2017 standard using individual measured parameters. The most important collector parameters, such as the optical efficiency η_0 and the heat loss coefficients a1 and a2, are determined in the certification of solar collectors under standard conditions and specified in the certificate.

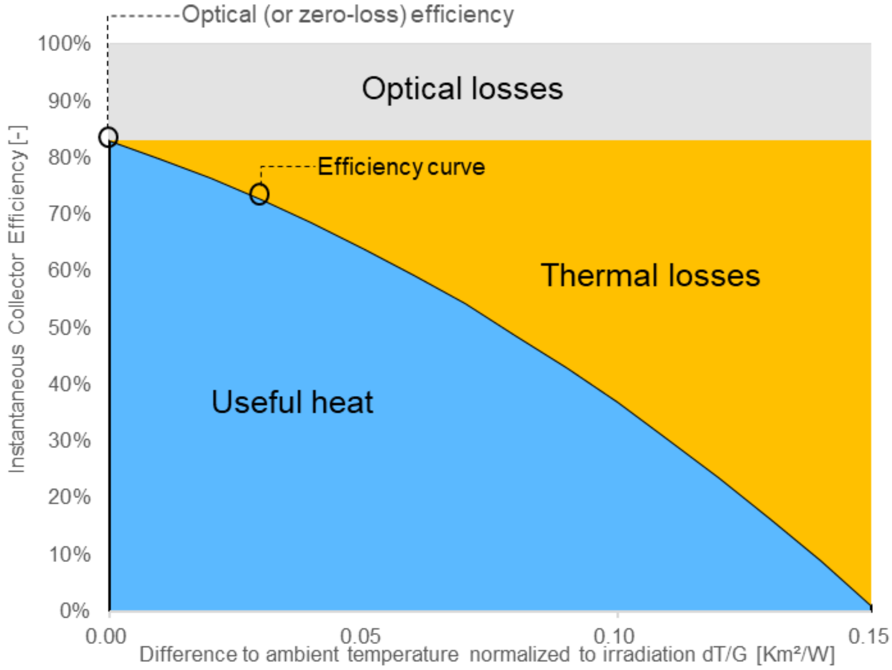

Figure 31 Solar collector efficiency curve (Horta, 2016)

12.2 Comparison of collector products by Solar Keymark results

For the sake of completeness, in this section the thermal yield of all collectors with a valid Solar Keymark certificate is shown. As in chapter 7 the gross thermal yield with average collector temperatures of 25 °C, 50 °C and 75 °C is shown for the reference locations Athens, Davos, Stockholm and Würzburg. The results are not suitable for system dimensioning, as just the output of the single collector is determined in the certificates. Therefore, no comparisons of collectors should be made. To ensure that the diagrams are clear, only the names of the manufacturers are given and not the complete product information. The flat plate collectors from GREENoneTEC (GoT) are named to distinguish between them.

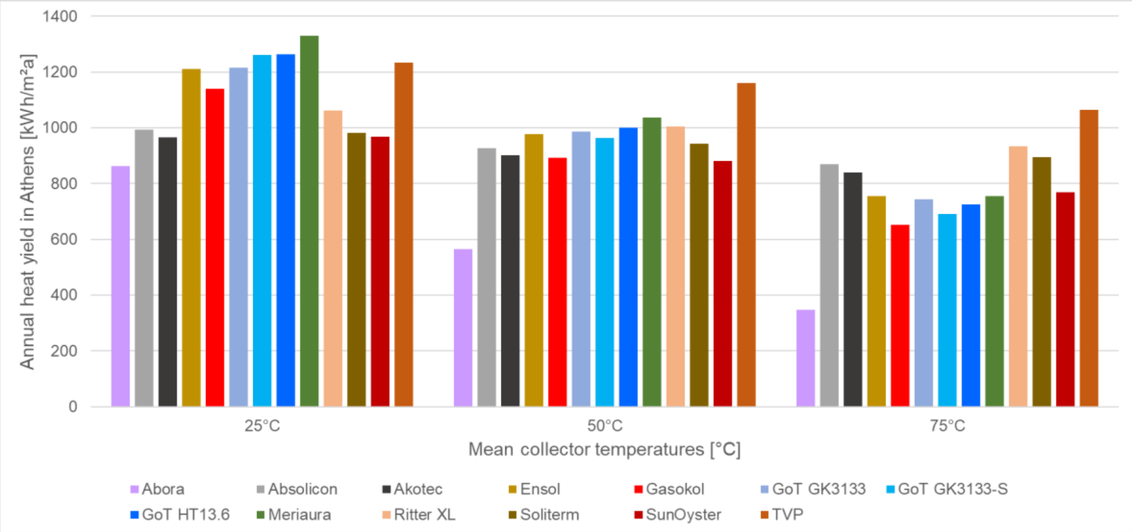

Figure 32 Comparison of gross thermal yield in Athens for different operating temperatures (Solar Keymark)

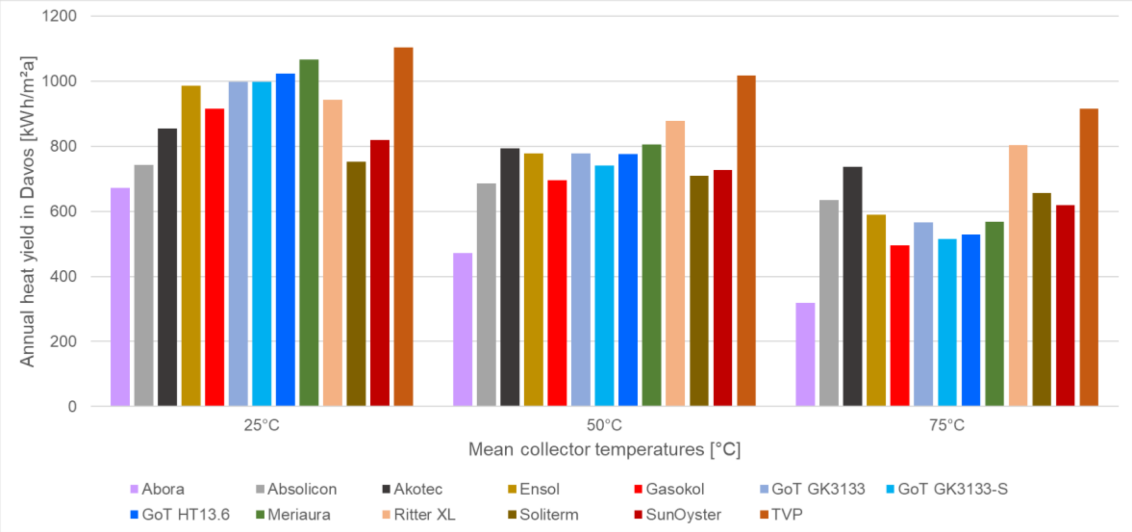

Figure 33 Comparison of gross thermal yield in Davos for different operating temperatures (Solar Keymark)

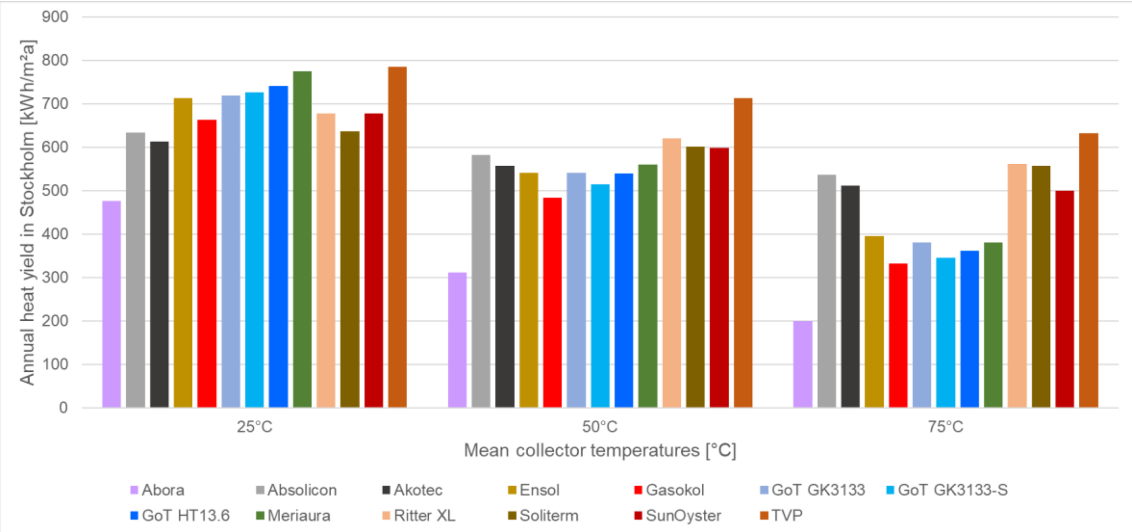

Figure 34 Comparison of gross thermal yield in Stockholm for different operating temperatures (Solar Keymark)

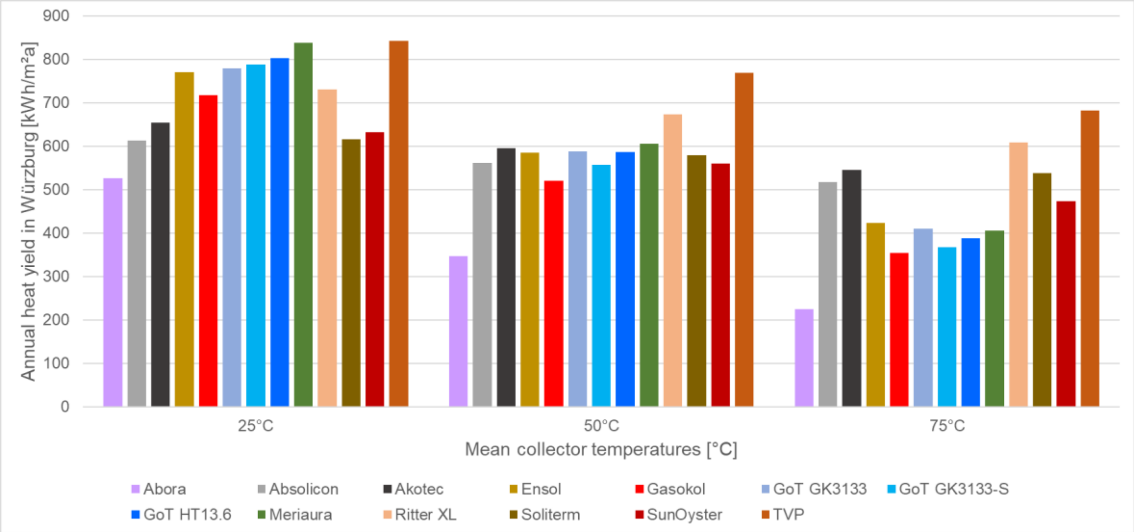

Figure 35 Comparison of gross thermal yield in Würzburg for different operating temperatures (Solar Keymark)

12.3 Structure of datasheet

A questionnaire was prepared asking for information, which allow to compare all collectors clearly. It consists of categories such as manufacturer information, main features, geometric features and certification information. Performance parameters are also requested, which are based on existing certifications if available. In addition, operational conditions and applications are asked about with possible conflict potentials and operations such as cleaning and more. In order to not only request data for Subtask A1, simulation models, investment costs and example systems and collector production were also requested. This information is required for related subtasks in Task 68, such as in Subtask C.

The information on costs relates to a gross area of 10 000 m² and is divided into as many subcategories as necessary. As cost data are sensible information due to competition, it was guaranteed that the information on costs would be treated anonymously.

12.4 Procurement of collector data

Approximately 50 collector manufacturers were contacted for this investigation. About 30 % of the manufacturers contacted filled in the questionnaire. Not every questionnaire was complete, as some information could not be provided by the manufacturers. In order to achieve a good level of participation in the survey, the manufacturers were asked by the task participants who already knew a contact person in the company.

This report presents selected collector technologies that can typically be used in district heating. Table 1 shows an overview of the analysed collector models.

12.5 Additional data

In addition to the collector data analysed in this report, further information was collected through the questionnaire. Although they were not analysed in detail, they are still relevant and may provide further insights. A list of the additional data collected with the corresponding details can be found in the following Tables. This data can serve as a basis for future research reports and can be considered as a supplement to the results presented here. The data given does not claim to be correct. They are based exclusively on the manufacturers information.

Name	**ABORA**
Model name	aH72SK
Technology	Glazed PVT – Flat Plate
Specific weight (without basements), [kg/m²]	25 kg/ m²gross
Geometrical features	

Collector height [m]	0.083
Number of collectors per solar collector assembly [-]	10
Certification	
Certification name	Solar Keymark 011-7S3118 P
Date of certification	02.02.2023
Certification Status	Valid
Source of the parameters (e.g. name of certificate, test lab etc.)	011-7S3118 P
Operation conditions and applications	
Maximum operating pressure [bar]	6
Heat transfer media (type and product)	Water-glycole
Suitable applications: Please list possible applications here	Residential buildings, tertiary sector (hotels, hospitals, nursing home, etc.), industry and district heatings.
Roof installation possible?	Flat or tilted roof and ground
Operation	
Precaution in case of frost (e.g. use of anti-freeze, thermal frost protection, other). Please specify for each heat transfer medium	Water-Glycol
Precaution in case of stagnation (e.g. defocussing of collector, use of cooler, other)	Heat dissipator recommended.
Example of an installed system	
Project Name	REBI Ólvega
Location	Ólvega
Installed on (land area, roof, other)	Land
Collector area [m²gross]	1082 m²
Ground area [m²]	2380 m²
Collector slope [°] in case of a fixed slope or tracking type (N-S tracking, E-W tracking, two-axes tracking).	35° - South
Annual energy yield [MWh/year]	1493 MWh/year
Solar fraction [%] of total heat demand	32%
Mean supply temperature [°C] of collector field	80°
Mean return temperature [°C] of collector field	70°
Commissioning date	June 2022
Description: Please describe the installed system and the application including particularities of the system (max. 300 characters)	District heating installation with Biomass boiler. PVT panels was installed combined with a w-w heat pump. The PVT panels produce heat to provide thermal energy to the source-side of the heat pump. And the photovoltaic production of the PVT is self-consumed by the heat pump. This system is electricity neutral. There are three advantages with this combination: PVT panels works at low temperatures, heat pump provides heat at high temperatures needed in the district network and the is no electrical consumption because the PVT panels generated the electricity needed.
Collector Production	
Production location	Zaragoza (Spain)
Production capacity (collectors per year)	180.000 panels/year

Name	**Absolicon**
Model name	T160
Technology	Small concentrating parabolic collector
Specific weight (without basements), [kg/m²]	24.5
specific weight of basements (for a chosen standard condition), [kg/m²]	8 (underground foundation not included)
Tracking type (none, single-axis or two axes)	Single axis
Tracking precision [°]	0.1
Power consumption of the tracking [kWhe/(m²gross*a)]	1.5
Geometrical features	
Absorber diameter [mm]	25.4
Lenght of focal line	5.51
Collector height [m]	0.358
Concentration factor C (C= aperture area/absorber area)	13
Number of collectors per solar collector assembly [-]	8
Certification	
Certification name	Solar Keymark 011-7S2902C (and ICC-SRCC 10002145)
Date of certification	07.02.2019
Certification Status	valid
Source of the parameters (e.g. name of certificate, test lab etc.)	Solar Keymark 011-7S2902C
Operation conditions and applications	
Maximum operating pressure [bar]	20
Maximum operating wind velocity [m/s]	20
Heat transfer media (type and product)	Water, Propylene Glycol
Suitable applications: Please list possible applications here	Applications in various industrial sectors such as food and beverage, brewery, textile, Pulp and paper, chemical, district heating, desalination, pharmaceutical, tea, dairy, mining.
Roof installation possible?	Flat roof, Tilted roof
Conflict potential	
Risk of glare: Please describe results from solar glare assessments if available	The antireflection coated glass reduce the risk of glare. We have done Aviation Impact Analysis in our field installations showing no impact.
Operation	
Mirror cleaning: How is mirror cleaning performed? How often the mirrors need to be cleaned?	No mirror cleaning, collector is covered with glass. The glass is self-cleaning.
Precaution in case of frost (e.g. use of anti-freeze, thermal frost protection, other). Please specify for each heat transfer medium	Propylene Glycol
Precaution in case of stagnation (e.g. defocussing of collector, use of cooler, other)	Automatic defocusing with battery backup
Example of an installed system	
Project Name	Högslätten
Location	Härnösand, Sweden
Installed on (land area, roof, other)	Land area

Collector area [m²gross]	1200 m² (1056 m² aperture area, to be expanded to 3000 m²)
Ground area [m²]	2940 m² used (9246 m² avaliable)
Collector slope [°] in case of a fixed slope or tracking type (N-S tracking, E-W tracking, two-axes tracking).	E-W tracking
Annual energy yield [MWh/year]	335
Solar fraction [%] of total heat demand	0.21% (annual) 2.58% (June/July) Up to 12.1% (daily)
Mean supply temperature [°C] of collector field	45
Mean return temperature [°C] of collector field	80
Commissioning date	Autumn 2021
Description: Please describe the installed system and the application including particularities of the system (max. 300 characters)	Solar thermal park Högslätten: The plant will be Sweden's largest solar field with small concentrating collectors connected to district heating. The solar collectors are designed to produce up to 160°C working temperature and will provide the district heating network with temperatures up to 120°C.
Collector Production	
Production location	Härnösand, Sweden
Production capacity (collectors per year)	20000
CO2 footprint of production related to collector area [g CO2e/ m2gross]	100kg/m2 (CO2 payback time 3mo in good location).

Name	**AKOTEC Produktionsgesellschaft mbH**
Model name	MEGA-Kollektor
Technology	Vacuum Tube
Specific weight (without basements), [kg/m²]	28.3
specific weight of basements (for a chosen standard condition), [kg/m²]	1.7 (Freestanding 30°)
Geometrical features	
Glass tube diameter [mm]	55.7
Absorber diameter [mm]	47
Collector height [m]	212
Concentration factor C (C= aperture area/absorber area)	none
Certification	
Certification name	Solar Keymark Certificate
Date of certification	01.02.2019
Certification Status	Active
Source of the parameters (e.g. name of certificate, test lab etc.)	011-7S2827 R
Operation conditions and applications	
Maximum operating pressure [bar]	10
Heat transfer media (type and product)	water / water-glycol
Suitable applications: Please list possible applications here	Domestic Hot Water / Combi-Systems / industrial heat / District Heating Networks
Roof installation possible?	yes

Conflict potential	
Risk of glare: Please describe results from solar glare assessments if available	Since there is no planar surface due to the use of tubes, the glare effect is negligible.
Operation	
Mirror cleaning: How is mirror cleaning performed? How often the mirrors need to be cleaned?	None
In case of evacuated absorber tube: How often is revacuuming required? Is the effort included in the maintenance costs? If not, please specify costs for mirror cleaning €/m²a	Never
Precaution in case of frost (e.g. use of anti-freeze, thermal frost protection, other). Please specify for each heat transfer medium	Water: use of anti-freeze control Water-Glycol: No need
Precaution in case of stagnation (e.g. defocussing of collector, use of cooler, other)	Use of temperature limiting heat pipe technology -> different maximum temperatures (125 / 160 °C)
Example of an installed system	
Project Name	Local heating network Weigenheim GbR
Location	Weigenheim
Installed on (land area, roof, other)	land area
Collector area [m²gross]	2261
Ground area [m²]	4047
Collector slope [°] in case of a fixed slope or tracking type (N-S tracking, E-W tracking, two-axes tracking).	20°
Annual energy yield [MWh/year]	1277
Solar fraction [%] of total heat demand	29
Mean supply temperature [°C] of collector field	75
Mean return temperature [°C] of collector field	55
Commissioning date	Nov 23
Description: Please describe the installed system and the application including particularities of the system (max. 300 characters)	Local heating network for the municipality of Weigenheim
Collector Production	
Production location	D-16278 Angermünde, Germany
Production capacity (collectors per year)	600

Name	**ELLO (ex- SUNCNIM)**
Model name	ELLO module
Technology	Linear Fresnel for Direct Steam Generation
Specific weight (without basements), [kg/m²]	19.8
specific weight of basements (for a chosen standard condition), [kg/m²]	1.5
Tracking type (none, single-axis or two axes)	Single-axis
Tracking precision [°]	± 0.03
Power consumption of the tracking [kWhe/(m²gross*a)]	0.2
Geometrical features	
Glass tube diameter [mm]	Not an evacuated absorber tube
Absorber diameter [mm]	88.9
Lenght of focal line	67

Collector height [m]	8.9 above level of mirrors
Concentration factor C (C= aperture area/absorber area)	48
Number of collectors per solar collector assembly [-]	1 single receiving tube
Certification	
Certification name	None
Operation conditions and applications	
Maximum operating pressure [bar]	85
Maximum operating wind velocity [m/s]	25
Heat transfer media (type and product)	Water and saturated steam
Suitable applications: Please list possible applications here	Direct Steam Generation, electricity production, water desalination, etc.
Roof installation possible?	Not designed for
Conflict potential	
Risk of glare: Please describe results from solar glare assessments if available	Risk of glare is negligible. Planes fly over our site at low altitude because an airstrip is nearby, and Pilots are not bothered by reflections.
Operation	
Mirror cleaning: How is mirror cleaning performed? How often the mirrors need to be cleaned?	At night, cleaning robots circulate on rows of mirrors. The more mirrors are cleaned, the better the performance. A robot takes a maximum of 3 nights to clean all its rows of mirrors.
Precaution in case of frost (e.g. use of anti-freeze, thermal frost protection, other). Please specify for each heat transfer medium	Electric heater included on the water recirculation loop and electrical tracing for outside instrumentation on dead-legs.
Precaution in case of stagnation (e.g. defocussing of collector, use of cooler, other)	Using the tracking system for defocussing
Example of an installed system	
Project Name	ELLO Solar Power Plant
Location	42.467°N 2.069°E, Llo France
Installed on (land area, roof, other)	mountainous land
Collector area [m²gross]	152 796
Ground area [m²]	282 000
Collector slope [°] in case of a fixed slope or tracking type (N-S tracking, E-W tracking, two-axes tracking).	From 0,09° to 4,73° Mean slope = 2,44°
Annual energy yield [MWh/year]	16 000
Solar fraction [%] of total heat demand	100
Mean supply temperature [°C] of collector field	130
Mean return temperature [°C] of collector field	126
Commissioning date	14.05.2019
Description: Please describe the installed system and the application including particularities of the system (max. 300 characters)	170 Linear Fresnel ELLO modules + 10 MWé superheated steam turbine

Name	Ensol
Model name	DIS 150
Technology	flat plate
Specific weight (without basements), [kg/m²]	36.77
Geometrical features	
Collector height [m]	0.173
Number of collectors per solar collector assembly [-]	1-7pcs
Certification	
Certification name	011-7S2978 F
Date of certification	20.07.2020
Certification Status	Active until 2025-07-31
Source of the parameters (e.g. name of certificate, test lab etc.)	https://www.dincertco.tuv.com /registrations/60150814?locale=en
Operation conditions and applications	
Maximum operating pressure [bar]	10
Heat transfer media (type and product)	water glycol mixture
Suitable applications: Please list possible applications here	thermal Energy storage installations
Roof installation possible?	flat roof
Operation	
Precaution in case of frost (e.g. use of anti-freeze, thermal frost protection, other). Please specify for each heat transfer medium	water glycol mixture

Name	GASOKOL GmbH
Model name	powerSol 136
Technology	Flat plate
Specific weight (without basements), [kg/m²]	25
Geometrical features	
Collector height [m]	2.166
Number of collectors per solar collector assembly [-]	11
Certification	
Certification name	Solar Keymark (DIN CERTCO)
Date of certification	03.06.2019
Certification Status	active
Source of the parameters (e.g. name of certificate, test lab etc.)	TÜV Rheinland Energy GmbH
Operation conditions and applications	
Maximum operating pressure [bar]	10
Heat transfer media (type and product)	corroStar
Suitable applications: Please list possible applications here	Free standing
Roof installation possible?	Flat roof, tilted roof
Example of an installed system	
Project Name	Nahwärme St. Ruprecht
Location	Mühlgasse 124a, 8181 St. Ruprecht/ R.
Installed on (land area, roof, other)	Land area

Collector area [m²gross]	1954
Ground area [m²]	4350
Collector slope [°] in case of a fixed slope or tracking type (N-S tracking, E-W tracking, two-axes tracking).	35
Annual energy yield [MWh/year]	1125
Solar fraction [%] of total heat demand	15
Mean supply temperature [°C] of collector field	85
Mean return temperature [°C] of collector field	50
Commissioning date	07.08.2023
Description: Please describe the installed system and the application including particularities of the system (max. 300 characters)	Installation of 1590m² ST including 100m³ puffer storage tank in April 2020. Due to extension of district heating expansion to 1955m² ST-field and 200m³ puffer storage.
Collector Production	
Production location	4351 Saxen
Production capacity (collectors per year)	50

Name	**GREENoneTEC Solarindustrie GmbH**		
Model name	GK HT13,6	GK 3133	GK 3133-S
Technology	flate plate		
Specific weight (without basements), [kg/m²]	17,8 kg/m²	25,3 kg/m²	17,6 kg/m²
specific weight of basements (for a chosen standard condition), [kg/m²]	4,5 kg/m² incl. pile-driving profiles	4,3 kg/m² incl. pile-driving profiles	
Geometrical features			
Collector height [m]	0.185	0.135	
Concentration factor C (C= aperture area/absorber area)	1		
Number of collectors per solar collector assembly [-]	ca. 7…15		
Certification			
Certification name	011-7S2819 F	011-7S2565 F	011-7S2566 F
Date of certification	18.08.2021		06.09.2021
Certification Status	issued		
Operation conditions and applications			
Maximum operating pressure [bar]	10		
Heat transfer media (type and product)	Glycol-Water		
Roof installation possible?	Flat roof / tilted roof		
Conflict potential			
Risk of glare: Please describe results from solar glare assessments if available	Anti-reflex glass has a very low glare effect.		
Operation			
Precaution in case of frost (e.g. use of anti-freeze, thermal frost protection, other). Please specify for each heat transfer medium	Use of anti-freeze		
Precaution in case of stagnation (e.g. defocussing of collector, use of cooler, other)	Use of cooler / night cooling		
Example of an installed system			

Project Name	SolarHeatGrid	Solaranlage Friesach	
Location	Ludwigsburg, Germany	Austria, 9360 Friesach, Sankt Veiter Straße	
Installed on (land area, roof, other)	land		
Collector area [m²gross]	14.808	5.750 m²	
Ground area [m²]	23.200	12.000 m²	
Collector slope [°] in case of a fixed slope or tracking type (N-S tracking, E-W tracking, two-axes tracking).	30°		
Annual energy yield [MWh/year]	5.800 MWh	2.368 MWh/a (measured)	
Solar fraction [%] of total heat demand	-	15%	
Mean supply temperature [°C] of collector field	80	92…97°C	
Mean return temperature [°C] of collector field	-	75…55°C	
Commissioning date	2020	2022	
Description: Please describe the installed system and the application including particularities of the system (max. 300 characters)	Three previously separate district heating grids were joined to form an interconnected network and in addition, Germany's largest solar plant at the time was integrated. As a result, the base load is covered by emission free solar energy.	Combination of single and double glazed collectors per row	
Collector Production			
Production location	Austria		

Name	**Heliac**
Model name	"Hørsholm SP"
Technology	Fresnel Lenses
Tracking type (none, single-axis or two axes)	Two-axes
Geometrical features	
Absorber diameter [mm]	200
Lenght of focal line	2
Collector height [m]	4
Concentration factor C (C= aperture area/absorber area)	60
Certification	
Date of certification	2020
Source of the parameters (e.g. name of certificate, test lab etc.)	Value von Heliac DTU 3rd Gen Test Report - 9-2020
Operation conditions and applications	

Maximum operating pressure [bar]	15
Heat transfer media (type and product)	Water
Suitable applications: Please list possible applications here	District heating
Roof installation possible?	Process heat
Conflict potential	
Risk of glare: Please describe results from solar glare assessments if available	None since reflections are directed towards the sun
Example of an installed system	
Location	Hørsholm, Denmark
Collector area [m²gross]	2748
Description: Please describe the installed system and the application including particularities of the system (max. 300 characters)	115C production for Norfors District Heating Network. Additionally testing of temperatures up to 180C.
Collector Production	
Production location	Denmark
Production capacity (collectors per year)	100000

Name	**Meriaura Energy (former Savosolar)**
Model name	Savo 16S
Technology	Large scale flat plate
Specific weight (without basements), [kg/m²]	27.7
specific weight of basements (for a chosen standard condition), [kg/m²]	5
Tracking type (none, single-axis or two axes)	Fixed. Single-axis in option for +20% to +30% production.
Tracking precision [°]	2
Power consumption of the tracking [kWhe/(m²gross*a)]	3
Geometrical features	
Collector height [m]	165
Number of collectors per solar collector assembly [-]	No limit
Certification	
Certification name	Solar Keymark
Date of certification	03.11.2023
Certification Status	Valid
Source of the parameters (e.g. name of certificate, test lab etc.)	Solar Keymark from SPF lab 011-7S3222 F
Operation conditions and applications	
Maximum operating pressure [bar]	10
Maximum operating wind velocity [m/s]	≈ 45 (according to SKM tests)
Heat transfer media (type and product)	Water or Water-ME Glycol
Suitable applications: Please list possible applications here	District Heating Heat for Industrial Process
Roof installation possible?	Flat and tilted possible
Conflict potential	
Risk of glare: Please describe results from solar glare assessments if available	Glare reports had been made on several locations and all had been negative, meaning especially the

	both side etched glass treatment version is OK for installation near airports, roads, etc.
Operation	
Precaution in case of frost (e.g. use of anti-freeze, thermal frost protection, other). Please specify for each heat transfer medium	Anti-freeze (Food grade biodegradable Mono Ethylen Glycol)
Precaution in case of stagnation (e.g. defocussing of collector, use of cooler, other)	• "Sun-switch" by defocussing if use of tracker, • Dry cooler, • Night cooling, • Conservative system size (a frequently stagnating system is expensively over-dimensioned)
Example of an installed system	
Project Name	Malt plant of Issoudun (Owner: Kyotherm)
Location	Issoudun, France
Installed on (land area, roof, other)	Land area
Collector area [m²gross]	14 252
Ground area [m²]	35 000
Collector slope [°] in case of a fixed slope or tracking type (N-S tracking, E-W tracking, two-axes tracking).	30
Annual energy yield [MWh/year]	8 500 – 9 000
Solar fraction [%] of total heat demand	30
Mean supply temperature [°C] of collector field	90
Mean return temperature [°C] of collector field	60
Commissioning date	2021
Description: Please describe the installed system and the application including particularities of the system (max. 300 characters)	Solar thermal plant splitted in 3 differents field to maximized the use of a former landfill. Supply of heat for the drying process of the malting plant nearby.
Collector Production	
Production location	Finland
CO2 footprint of production related to collector area [g CO2e/ m2gross]	61 500 According to principals in ISO 14067:2018 and Greenhouse Gas Protocol Product Standard

Name	**Protarget**
Model name	PT950
Technology	Parabolic trough
Specific weight (without basements), [kg/m²]	45
specific weight of basements (for a chosen standard condition), [kg/m²]	Foundation depending on soil conditions
Tracking type (none, single-axis or two axes)	Single-axis
Geometrical features	
Glass tube diameter [mm]	125
Absorber diameter [mm]	48.3
Lenght of focal line	0.95
Collector height [m]	3.5
Concentration factor C (C= aperture area/absorber area)	62

Number of collectors per solar collector assembly [-]	8
Certification	
Certification name	Solar Keymark
Certification Status	Solar Keymark listed, project specific certification
Source of the parameters (e.g. name of certificate, test lab etc.)	Heat loss coefficients: DLR thermal loss test 28.02.2023
Operation conditions and applications	
Maximum operating pressure [bar]	40
Maximum operating wind velocity [m/s]	18
Heat transfer media (type and product)	Silicone based HTF oil Mineral based HTF oil Pressurised Water
Suitable applications: Please list possible applications here	Electricity generation Heat generation for food and beverage industry Process steam generation
Roof installation possible?	No
Conflict potential	
Risk of glare: Please describe results from solar glare assessments if available	PTC system are considered like green houses from the glare risk point of view. So no issue at all
Operation	
Mirror cleaning: How is mirror cleaning performed? How often the mirrors need to be cleaned?	Mirrors would be cleaned 20 to 30 times per year depending on the condition. This is covered in the annual O&M cost.
In case of evacuated absorber tube: How often is revacuuming required? Is the effort included in the maintenance costs? If not, please specify costs for mirror cleaning €/m²a	Protarget Vacuum Receiver Tubes are designed to last 25 years without maintenance. Re-vacuuming is not necessary
Precaution in case of frost (e.g. use of anti-freeze, thermal frost protection, other). Please specify for each heat transfer medium	HTF (silicon oil) is operational until -15°C. For temperatures below, heating elements in the expansion tank or storage will be installed
Precaution in case of stagnation (e.g. defocussing of collector, use of cooler, other)	Defocussing of collector
Example of an installed system	
Project Name	Heineken Greece
Location	Patras
Installed on (land area, roof, other)	Land
Collector area [m²gross]	13.248
Ground area [m²]	34000 m²
Collector slope [°] in case of a fixed slope or tracking type (N-S tracking, E-W tracking, two-axes tracking).	1° slope, N-S with 40° offset
Annual energy yield [MWh/year]	10500
Solar fraction [%] of total heat demand	3000%
Mean supply temperature [°C] of collector field	300
Mean return temperature [°C] of collector field	240
Commissioning date	Feb 25
Description: Please describe the installed system and the application including particularities of the system (max. 300 characters)	PTC System with Thermal Storage to supply the Heineken Brewery in Patras with process steam
Collector Production	
Production location	Cologne, Germany

Production capacity (collectors per year)	40.000 m²/a

Name	**Ritter XL Solar**
Model name	XL 19/49
Technology	CPC Vacuum Tube
Specific weight (without basements), [kg/m²]	14.7
Tracking type (none, single-axis or two axes)	None
Geometrical features	
Glass tube diameter [mm]	47
Absorber diameter [mm]	36.2
Lenght of focal line	1.862
Collector height [m]	0.122
Concentration factor C (C= aperture area/absorber area)	1.01
Number of collectors per solar collector assembly [-]	6/8
Certification	
Certification name	Solar Keymark
Date of certification	13.02.2023
Certification Status	valid
Source of the parameters (e.g. name of certificate, test lab etc.)	Solar Keymark 011-7S2866 R
Operation conditions and applications	
Maximum operating pressure [bar]	10
Maximum operating wind velocity [m/s]	70
Heat transfer media (type and product)	Water
Suitable applications: Please list possible applications here	district heating, local heating, process heating, solar cooling
Roof installation possible?	Yes
Conflict potential	
Risk of glare: Please describe results from solar glare assessments if available	Possible, but never had any issues
Operation	
Mirror cleaning: How is mirror cleaning performed? How often the mirrors need to be cleaned?	Cleaning only when required, normally no separate cleaning process necessary
In case of evacuated absorber tube: How often is revacuuming required? Is the effort included in the maintenance costs? If not, please specify costs for mirror cleaning €/m²a	Not required
Precaution in case of frost (e.g. use of anti-freeze, thermal frost protection, other). Please specify for each heat transfer medium	Thermal frost protection
Example of an installed system	
Project Name	Greifswald
Location	Greifswald, Germany
Installed on (land area, roof, other)	Land
Collector area [m²gross]	18.732 m²
Collector slope [°] in case of a fixed slope or tracking type (N-S tracking, E-W tracking, two-axes tracking).	20

Annual energy yield [MWh/year]	8100
Solar fraction [%] of total heat demand	3-4%
Mean supply temperature [°C] of collector field	98
Mean return temperature [°C] of collector field	60
Commissioning date	June 2022
Description: Please describe the installed system and the application including particularities of the system (max. 300 characters)	This system will transfer an annual yield of approx. 8.1 GWh to the Greifswald grid or to the future storage facility of the municipal utilities. The solar heat generated in the generated in the collector field is transferred to the heating plant via pipeline. There, depending on the load situation of the grid, the heat will be released directly into the grid or temporarily stored in the heat storage tank in the future. https://www.ritter-xl-solar.de/anwendungen/waermenetze/greifswald/
Collector Production	
Production location	Dettenhausen, Germany

Name	**Solarlite / Azteq**
Model name	HYT6000
Technology	Parabolic trough
Specific weight (without basements), [kg/m²]	35
specific weight of basements (for a chosen standard condition), [kg/m²]	150
Tracking type (none, single-axis or two axes)	Single axis/Electrohydraulic drive system
Tracking precision [°]	± 0.05 °
Power consumption of the tracking [kWhe/(m²gross*a)]	< 1 (For a site in Central Europe with ~ 1100 kWh/m²/a)
Geometrical features	
Glass tube diameter [mm]	130
Absorber diameter [mm]	70
Lenght of focal line	1.71
Collector height [m]	Maximum height of 6-6.2m reached while facing Horizon
Concentration factor C (C= aperture area/absorber area)	82.5
Certification	
Certification name	DLR
Date of certification	Multiple test reports from 2011 until 2019
Certification Status	Solar Keymark Planned for 2024
Operation conditions and applications	
Maximum operating pressure [bar]	40
Maximum operating wind velocity [m/s]	15
Heat transfer media (type and product)	Water/ Steam, Thermal oil/ Silicon Oil
Suitable applications: Please list possible applications here	Industrial process heat, district heating, power plants
Roof installation possible?	Mostly not
Conflict potential	

Risk of glare: Please describe results from solar glare assessments if available	Has been proven to be a trivial/negligible effect based on DLR studies. At least 2 of our projects are not far from airport runways.
Operation	
Mirror cleaning: How is mirror cleaning performed? How often the mirrors need to be cleaned?	Mirrors are self-cleaning by rain, active cleaning only 1 to 2 times during the year for most central European locations. Dry dusty environment like southern Spain require 5-10 washings per annum. Costs are included.
In case of evacuated absorber tube: How often is revacuuming required? Is the effort included in the maintenance costs? If not, please specify costs for mirror cleaning €/m²a	Revacuuming is possible when needed, but the receivers vaccum usually lasts a lifetime if no further unexpected events occur
Precaution in case of frost (e.g. use of anti-freeze, thermal frost protection, other). Please specify for each heat transfer medium	Pressurized water and molten salt can be kept in circulation by pumps or have an accompanied heating system, anyways pressurized water has a deeper freezing point. Silicone Oil has pout point of -45 °C and hence uncritical
Precaution in case of stagnation (e.g. defocussing of collector, use of cooler, other)	Defocussing of collector
Example of an installed system	
Project Name	Proviron CST project
Location	Oostende, Belgium
Installed on (land area, roof, other)	Land area
Collector area [m²gross]	1108
Ground area [m²]	2600 m²
Collector slope [°] in case of a fixed slope or tracking type (N-S tracking, E-W tracking, two-axes tracking).	N-S tracking
Annual energy yield [MWh/year]	468 (Possible output without interruption from client: ~500)
Solar fraction [%] of total heat demand	< 10
Mean supply temperature [°C] of collector field	200 – 220
Mean return temperature [°C] of collector field	300 – 330
Commissioning date	June 2020
Description: Please describe the installed system and the application including particularities of the system (max. 300 characters)	Project Proviron (500 kWth): The primary oil circuit contains a silicone oil with water hazard class of 1 for optimal environmental protection. The oil is heated to 330 °C after which it is converted into steam at a specific pressure and temperature via a steam generator. After the start-up of this project, this solar boiler will supply max. 500 MWh of thermal heat for 20 years, without emissions.
Collector Production	
Production location	China / Europe – part of the solar collector assembly produced in China (own production), and the other parts are produced/procured locally in Europe
Production capacity (collectors per year)	100,000 m² gross aperture area

Name	**Soliterm group**
Model name	PTC 1800
Technology	Parabolic trough
Tracking type (none, single-axis or two axes)	Single-axis

Tracking precision [°]	0.1
Geometrical features	
Glass tube diameter [mm]	65
Absorber diameter [mm]	38
Lenght of focal line	0.78
Collector height [m]	1.8
Concentration factor C (C= aperture area/absorber area)	43
Certification	
Certification name	Solar Keymark
Date of certification	12.01.2022
Certification Status	valid
Source of the parameters (e.g. name of certificate, test lab etc.)	Solar Keymark SK0805570
Operation conditions and applications	
Maximum operating pressure [bar]	16
Heat transfer media (type and product)	Water/steam, thermal oil
Suitable applications: Please list possible applications here	Feed water of the preheating boiler 30°C - 90°C, Heating of the production plant 40°C - 80°C, process cooling down to - 60°C, drying 30°C - 90°C Washing 40°C - 80°C Pasteurizing 80°C - 110°C Boiling 95°C - 105°C Cleaning 140°C - 150°C Preheating 40°C - 60°C
Example of an installed system	
Location	Izmir, Turkey
Installed on (land area, roof, other)	Roof
Collector area [m²gross]	6000
Ground area [m²]	15000
Annual energy yield [MWh/year]	4200
Solar fraction [%] of total heat demand	75
Commissioning date	7.202
Description: Please describe the installed system and the application including particularities of the system (max. 300 characters)	Supply of a cardboard packaging manufacturer (Mayr-Melnhof Graphia) with heating and cooling
Collector Production	
Production location	Ankara, Turkey
Production capacity (collectors per year)	40000

Name	**Sun Oyster GmbH**
Model name	Sun Oyster 16 HEAT
Technology	Parabolic trough. During storms, it moves into a flat protective position, just like an oyster closes when in danger
Tracking type (none, single-axis or two axes)	Two-axis
Geometrical features	
Collector height [m]	3.4

Certification	
Certification name	Solar Keymark 011-7S3050R
Date of certification	27.07.2021
Certification Status	valid
Source of the parameters (e.g. name of certificate, test lab etc.)	Solar Keymark 011-7S3050R
Operation conditions and applications	
Maximum operating pressure [bar]	6
Heat transfer media (type and product)	Water
Suitable applications: Please list possible applications here	Hot water 50°C-70°C, heating 25°C-90°C, desalination 25°C-120°C, process heat 60°C-170°C, cooling 55°C-170°C, ORC machine 90°C-170°C, Storage -30°C-170°C, Preheating of steam power plants 100°C-170°C

Name	**TVP Solar SA**
Model name	MT-Power v4
Technology	High-Vacuum Flat Plate (HVFP) collector
Specific weight (without basements), [kg/m²]	53kg / 1.96m2 = 27,04
specific weight of basements (for a chosen standard condition), [kg/m²]	Around 20kg/m2 in the case of using plinths (made of concrete)
Geometrical features	
Collector height [m]	0.115
Number of collectors per solar collector assembly [-]	1 (for large deployments it can be up to 6x3=18)
Certification	
Certification name	Solar Keymark 011-7S1890F
Date of certification	14.06.2017
Certification Status	valid
Source of the parameters (e.g. name of certificate, test lab etc.)	Solar Keymark 011-7S1890F
Operation conditions and applications	
Maximum operating pressure [bar]	16
Maximum operating wind velocity [m/s]	36 (130km/h)
Heat transfer media (type and product)	water, water glycol, diathermic oil
Suitable applications: Please list possible applications here	Large-scale applications of: industrial process heat, district heating and cooling
Conflict potential	
Risk of glare: Please describe results from solar glare assessments if available	Similar to traditional Flate Plate Collector
Operation	
In case of evacuated absorber tube: How often is revacuuming required? Is the effort included in the maintenance costs? If not, please specify costs for mirror cleaning €/m²a	Vacuum is retained across the lifetime of the HVFP

Precaution in case of frost (e.g. use of anti-freeze, thermal frost protection, other). Please specify for each heat transfer medium	Water - glycol
Precaution in case of stagnation (e.g. defocussing of collector, use of cooler, other)	Use of dry cooler
Example of an installed system	
Project Name	Groningen Solar District Heating
Location	Dorkwerd, Groningen, Netherlands
Installed on (land area, roof, other)	Land area
Collector area [m²gross]	48'000
Ground area [m²]	120'000
Collector slope [°] in case of a fixed slope or tracking type (N-S tracking, E-W tracking, two-axes tracking).	35
Annual energy yield [MWh/year]	25'000
Solar fraction [%] of total heat demand	25%
Mean supply temperature [°C] of collector field	93
Mean return temperature [°C] of collector field	69
Commissioning date	Within spring 2024 (currently under construction)
Description: Please describe the installed system and the application including particularities of the system (max. 300 characters)	One of the largest solar district heating plants is being constructed in Groningen, Netherlands. Within spring 2024, 48'000m2 of High Vacuum Flat Panels will provide 25GWh of clean, carbon-free heat to 10'000 citizens, all year round reducing emissions by 6000 tCO2/year and achieving 25% of solar share.
Collector Production	
Production location	Avellino, Italy
Production capacity (collectors per year)	40000
CO2 footprint of production related to collector area [g CO2e/ m2gross]	91.5kg CO2e/m2 (production, installation, operation over the 25 years of lifetime)