Task 55 Towards the Integration of Large
SHC Systems into DHC Networks

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

C-D1. Simulation and design of collector array units within large systems

IEA SHC FACT SHEET 55.C.D.1.3.

Subject:	Collector types for large collector fields: Thermal performance
Description:	Investigations of different collector types for large collector fields. Flat Plate collectors, medium concentrating PTC collectors. Investigation of system performance of different collector types
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Intro

Solar collectors are the core components of solar district heating plants. Annual solar heat yield of solar heating plants on average is around 400-500 kWh/m^2 in Denmark [1][2]. Most solar collectors in the large solar district heating plants in Denmark are ground-mounted flat plate collectors. Arcon-Sunmark A/S is the main manufacturer of the large flat plate collectors for district heating in Denmark. Arcon-Sunmark A/S has installed more than 80% of the world's large solar heating plants connected to district heating networks. Flat plate collectors without and with FEP foils are usually used together in series in the solar district heating plants to get more energy output. Large flat plate collector is the most mature commercialized solar collector technology in large solar district heating plants so far.

The flat plate collector field supplies the heat to the district heating networks via a heat exchanger. Therefore the operation temperature of flat plate collectors is 3-4 K higher than the temperatures on the district heating side. The required supply temperature is 85-95 °C for typical Danish district heating networks. The efficiency of flat plate collectors decreases sharply at these temperature levels. Solar collectors include flat plate collectors, evacuated tube collectors, compound parabolic collectors and concentrating solar power collectors. Compared to flat plate collectors, the heat loss of parabolic trough collectors is very low at these temperature levels. And the efficiency of the parabolic trough collectors is almost constant for low-medium temperature application. More and more parabolic trough collectors are used in the industrial process heat in the last decades [3].

Frank et al. [4] evaluated the daily and monthly performance of two solar plants with parabolic trough collectors in Switzerland. The apertures of the two solar heating plants are 115 m^2 and 630 m^2, respectively. The second plant is located at an altitude of 1000 m. Even though the yearly DNI is low (1183 kWh/m^2/a), both the daily and the monthly evaluation show that the collector field performance could be high when the operation temperature of the parabolic trough collectors is low, such as 125°C. Silva et al. [5], [6] did simulations and thermo-economic design optimization on parabolic trough collectors for heat production for industrial processes. LCOE (Levelized Cost Of Energy) of 5 c€/kWh and a PBT (payback time) of 8 years could be achieved in the base scenario conditions considered. Kizilkan et al. [7] proposed a parabolic trough solar collector-based integrated system for an ice-cream factory in Turkey and discussed the thermal performance. The payback period of the proposed integrated system was found to be 8.5 years. The payback period was similar as reported by Silva et al [5], [6].

On the one hand, flat plate collectors are cheaper and have higher efficiency than parabolic trough collectors at low temperature levels. On the other hand, parabolic trough collectors retain high efficiency at high temperature levels of the district heating networks. Thirdly parabolic trough collectors can use more beam radiation during the daytime, due to the tracking. A hybrid solar district heating plant consisting of flat plate collectors and parabolic trough collectors in series can harvest the good performance of both solar collector technologies. The barrier of parabolic trough collectors for application in district heating networks is the high price. The yearly DNI in Denmark is not high and Denmark has not been regarded as a suitable place for concentrating solar power technologies for a long time. So a techno-economic analysis of hybrid solar district heating plants should be determined in order to figure out which collector type and field design is the most favourable one.

A preliminary case study of parabolic trough collectors for district heating at high latitudes with low solar radiation resources was carried out in 2000 [8]. The economic comparison indicated that parabolic trough systems could be competitive with flat plate collectors. But few practical projects with parabolic trough collectors for district heating are found during the last decades. The Danish company Aalborg CSP A/S [9] and Technical University of Denmark (DTU) [10] started to investigate the feasibility of parabolic trough collector for district heating networks in large solar heating plants through an Energy Technology Development and Demonstration Programs project (EUDP) supported by the Danish Energy Agency in 2013. A hybrid solar district heating plant with flat plate collectors and parabolic trough collectors in series was constructed in Taars, in the northern Jutland of Denmark in 2015 [11].

Flat plate collector field and parabolic trough collector field in Taars solar heating plant

Taars plant is the first large-scale demonstration project with flat plate collectors and parabolic trough collectors in series developed for district heating in Europe, even worldwide. The plant was put into operation in the middle of August, 2015. The return water from the district heating network is preheated up to 65 - 75°C by the heat exchanger connected to the flat plate collector field. Then the preheated water from the flat plate collector field is heated to the required temperature by going through the parabolic trough collector field, see Fig. 1. The solar collector fluid of the parabolic trough collectors is water, while that of FPC is a glycol/water mixture (35%). The aperture areas of the flat plate collector field and the parabolic trough collector field are 5960 m^2 and 4039 m^2, respectively. The flat plate collector field consists of flat plate collectors half without and half with FEP foils. The flat plate collectors were delivered by Arcon-Sunmark A/S [12]. Geometry parameters of the flat plate collectors and parabolic trough collectors can be found in Table 1 and 2. The parabolic trough collectors were delivered by Aalborg CSP A/S [9]. Two natural gas boilers with 9.1 MW in total are used as the back-up systems. Two tanks with 2430 m^3 in total in the existing boiler system are used as short-term storage. The district heating network supplies hot water for space heating and domestic hot water for about 850 buildings with about 1900 residents.

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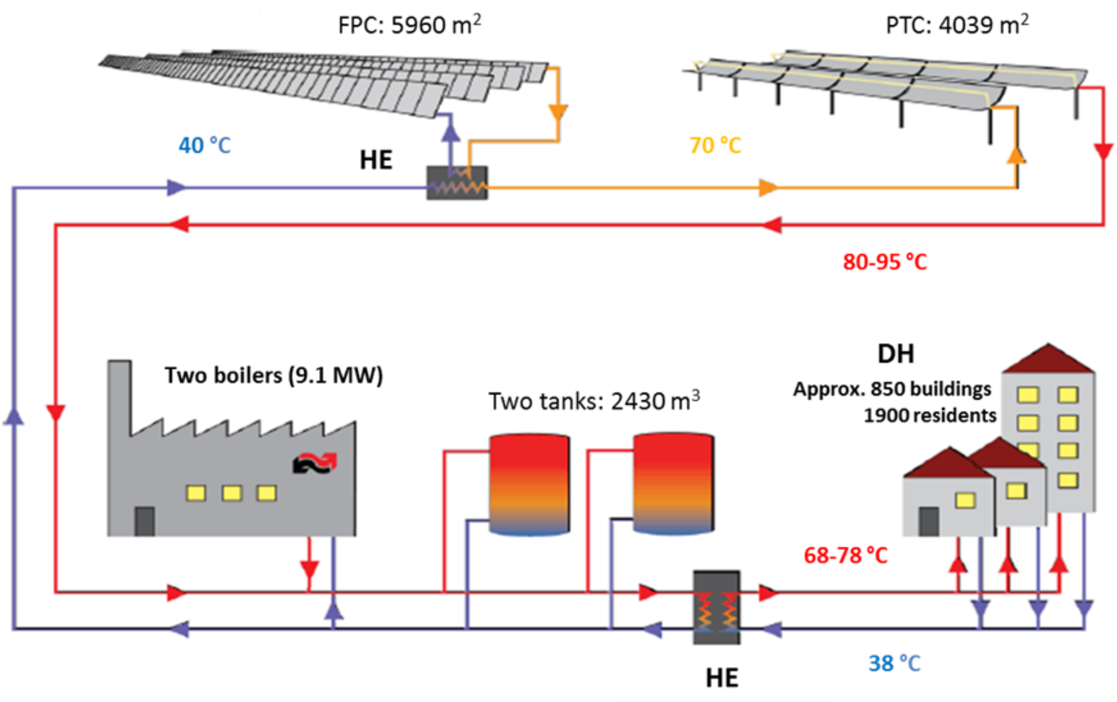

Fig. 1 Simplified illustration chart of the Taars plant.

Fig. 2 The hybrid solar collector field of the Taars plant (Source: Aalborg CSP A/S).

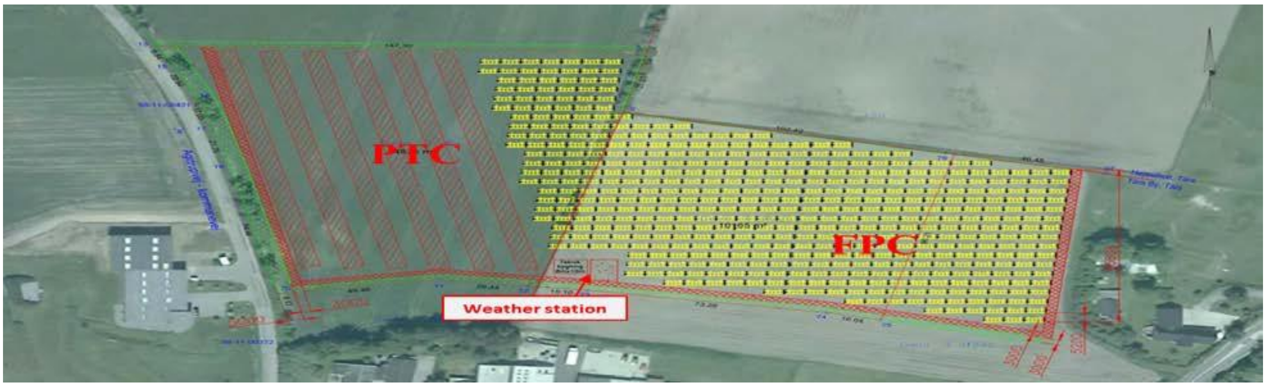

Fig. 3 Layout of the hybrid solar collector field in Taars (Source: Aalborg CSP A/S).

Fig. 2 shows the photo of the hybrid solar collector field in Taars. Fig. 3 illustrates the layout of the flat plate collector field and parabolic trough collector field. The row distance of parabolic trough collector field and flat plate collector field is 12.6 and 5.67 m, respectively. The parabolic trough collector field consists of six rows of around 125 m collector loop. The orientation of parabolic trough collectors is 13.4° towards west from south. The tilt of flat plate collectors is 50 °。

Table 1 Geometry parameters of the flat plate collectors.

Collector length, m		5.96
Width, m		2.27
Thickness, m		0.14
Gross area, m2		13.57
Aperture area, m2		12.60
Solar collector volume, L		10.6
Absorber	Material	Cu pipe /Al plate
	Absorption	0.95
	Emission	0.05
Insulation	Backside	75 mm mineral wool
Cover(s)	side	30 mm mineral wool
	Antireflex glass (AR:3.2mm)-with/without FEP foil	

Table 2 Geometry parameters of the parabolic trough collectors.

Absorber tube outer diameter (m)	0.070
Absorber tube inner diameter (m)	0.066
Glass envelope outer diameter (m)	0.125
Glass envelope inner diameter (m)	0.119
Parabola width (m)	5.77
Numbers of modules per row	10
Mirror length in each module (m)	12
Geometric concentration ratio	26.2

Thermal performance

Measured and simulated thermal performances of the Taars hybrid solar heating plant for the first operation year from September 2015 to August 2016 are shown in this section, see Table 3. The weighted average operation temperature of the parabolic trough collectors is 80 °C. The weighted average operation temperature of the flat plate collector collectors is in the range of 50 -60 °C.

Table 3 Monthly measured and simulated heat output for the flat plate collector field and parabolic trough collector field (kWh/m²).

	Sep. 2015	Oct. 2015	Nov. 2015	Dec. 2015	Jan. 2016	Feb. 2016	Mar. 2016	Apr. 2016	May. 2016	Jun. 2016	Jul. 2016	Aug.	Sum	
Measured	53.0	22.8	1.9	0.4	0.9	22.4	30.2	53.3	76.0	66.8	58.7	61.7	448	FPC
Modelled	51.2	21.1	2.28	0.4	0.6	22.9	28.6	52.3	77.5	68.6	60.1	62.4	448	
Measured	38.3	13.9	1.51	0.3	1.5	15.4	24.4	57.6	59.3	29.0	54.7	58.2	354	PTC
Modelled without defocus	40.4	15.3	2.01	0.18	0.9	16.7	25.1	60.0	101.8	96.9	64.4	66.8	490	

Flat plate collector field

As is shown in Fig. 4 and Fig. 5 both the flat plate collector field and the parabolic trough collector field produced not much solar heat from Nov.2015 to Jan.2016. In this period the backup natural gas boiler systems were the main heat sources for the district heating network. Measured and modelled yearly thermal performances of the flat plate collector field were about 450 kWh/m^2. The solar heat of the flat plate collector field in the summer could be higher than 60 kWh/m^2 in May, June and August of 2016, as shown in Fig. 4.

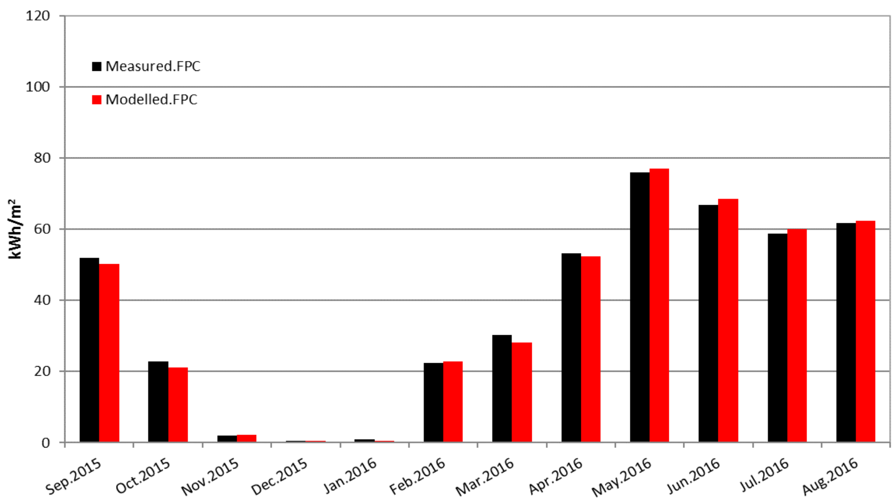

Fig. 4 Measured and modelled energy output of flat plate collector field for the period Sep.2015-Aug.2016.

Parabolic trough collector field

In the summer of 2016, the heat demand is low and the storage volume is too small. Therefore, the parabolic trough collectors were defocused in some sunny days, which resulted in a low energy output for the parabolic trough collector field. The measured monthly thermal performance and simulated thermal performance without defocus of parabolic trough collector field can be seen in Fig. 5. The yearly measured thermal performance of parabolic trough collector field is 354 kWh/m^2 for the period Sep.2015- Aug.2016.

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Without defocus, the thermal performance can reach close to 490 kWh/m^2 in the studied period. The potential monthly energy output of parabolic trough collector field in the summer can be higher than 90 kWh/m^2.

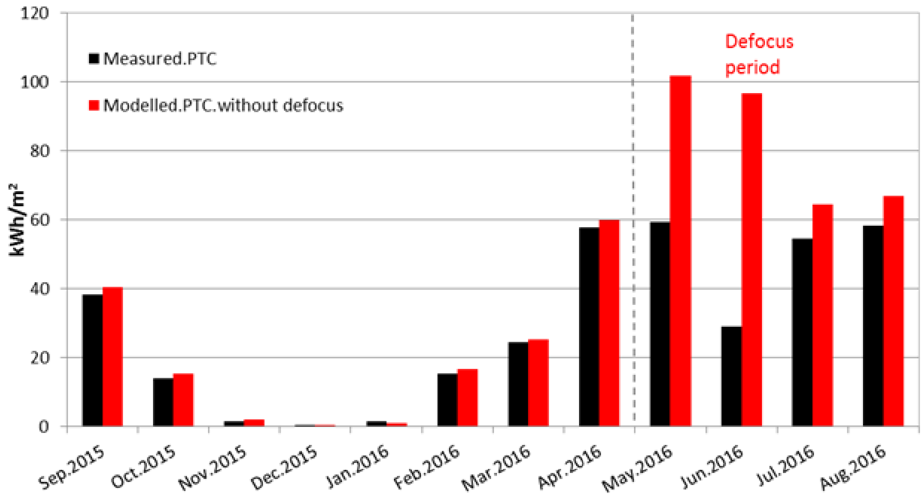

Fig. 5 Measured and modelled energy output of parabolic trough collector field for the period Sep.2015-Aug.2016.

Utilized efficiency

Flat plate collectors utilize total radiation on the tilted collector plane, while parabolic trough collectors mainly utilize beam radiation on the collector plane. To compare the thermal performances of both collector technologies, solar heat as a function of global radiation on the horizontal surface for both collector fields is shown in Fig. 6 and Fig. 7. Fig. 6 shows measured data. Due to defocusing of parabolic trough collectors in some sunny days, the energy output is zero, which is indicated by the green dots in the x axis. Fig. 7 shows the simulated thermal performance of both collectors, if there is no defocus of the parabolic trough collectors. It can be seen that the parabolic trough collector can produce more solar heat than the flat plate collector field when the daily solar radiation is higher than 2 kWh/m^2. The maximum daily global radiation on the horizontal surface was not more than 7 kWh/m^2 for the period September 2015- August 2016. The daily solar heat produced by the parabolic trough collectors can be higher than 7 kWh/m^2, while the daily solar heat of flat plate collectors cannot exceed 5 kWh/m^2 in the studied period.

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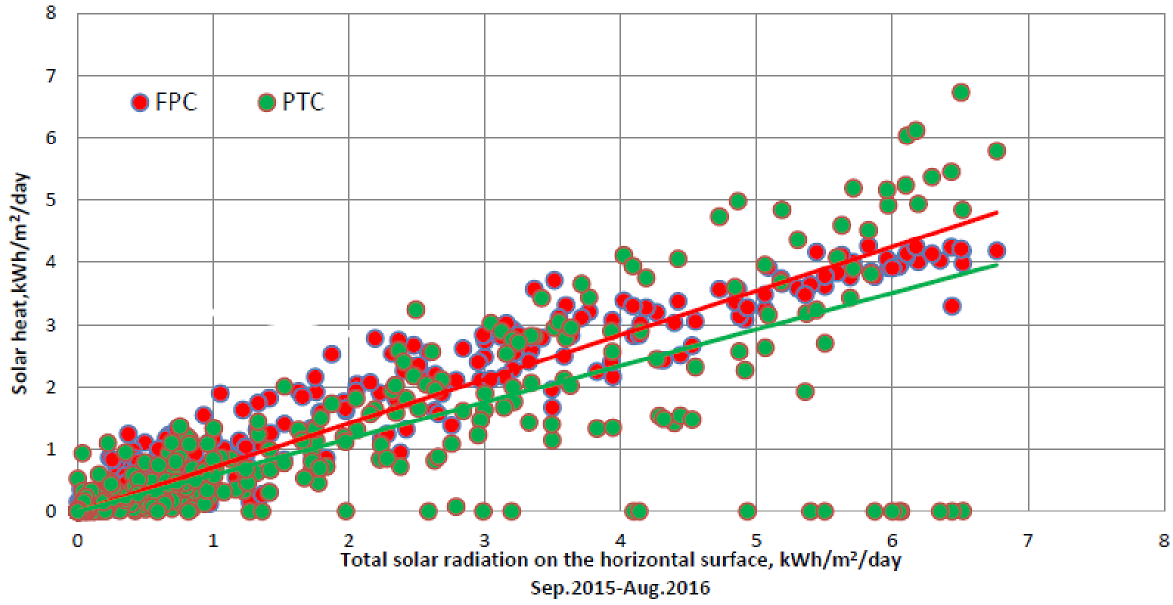

Fig. 6 Measured daily solar heat as a function of daily global radiation for both collector fields

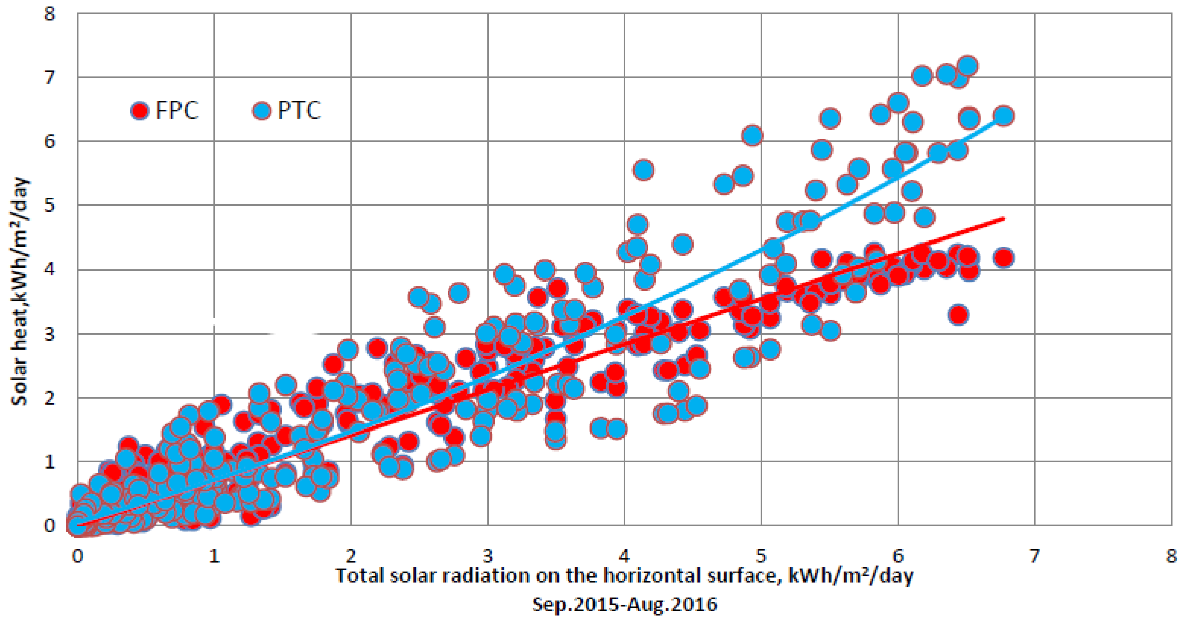

Fig. 7 Modelled daily solar heat as a function of daily global radiation for both collector fields

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