46 Solar District Heating

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Date	Ref.	Description

Brief technology description

Collecting energy from the sun using it to heat water is a technology, which has been in use for many years. Today, more than 580 million m^2 of solar collectors are installed around the globe, with a total installed capacity of 410 GW$_{th}$. Although the majority of this capacity is used for small domestic hot water systems, the fastest growth rate is for large systems (mainly for district heating) [1].

Three different types of solar panels are produced:

- Flat Plate Collectors (FPC) (Basic principle visualised in **Error! Reference source not found.**)
- Evacuated Tubular Collectors (ETC)
- Concentrated Solar Power (CSP)

Flat plate large module collectors are by far the most common collector type used for district heat in Denmark. ETC-collectors are more efficient than flat panels at higher temperatures, but also more expensive. CSP can produce heat at high temperatures. It is possible to combine different collector types in one system; e.g. using flat plate collectors in the "cold section" of the field in order to preheat the heat transfer-fluid before evacuated tubes or CSP collectors in the "hot section". Currently one solar heating plant has both flat plate panels and CSP (Taars). Due to the applicability in the context of Danish district heating, focus in this catalogue is on FPC.

As shown in Figure 1, the principle of flat solar panels in a district heating system is to absorb the solar energy in order to heat a fluid. Corrugated copper or aluminium-sheets serve typically as absorber, with the transfer-fluid being circulated behind these. The absorbers are surrounded by a glass layer, protecting the absorber from the surrounding environment. The back of the panel is insulated, in order to reduce heat loss, cf. Figure 2. The heat is transferred from the circulated fluid to district heating water via a heat exchanger.

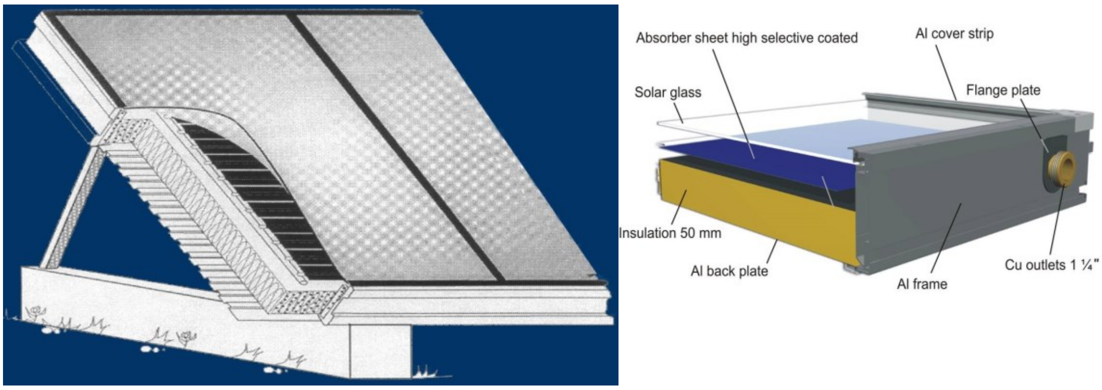

Figure 1 Basic principle of a flat plate solar collector

For district heating systems, the collectors are typically installed on the ground in long rows connected in series. In Danish systems, the solar heating system normally takes in the return water and heats it up to the desired forward flow temperature. All plants have the solar collectors mounted on the ground. Ground mount foundations can be concrete blocks, concrete foundations or steel foundations.

In principle, solar district heating is operating all hours of the year, but of course, the heat production depends on the solar irradiation, weather conditions, time of day and the season of the year. The seasonal variation can be compensated using a seasonal storage. Typical performance of large solar collector fields in Denmark is ca. 450 kWh/m^2/year. This corresponds to an efficiency of around 40 % (40 % of the solar irradiation is utilized).

Efficiency and energy yield

The yield of a solar collector depends on the solar collector type and size, the solar radiation, the temperature of the collectors and the ambient temperature. The efficiency is defined by efficiency parameters, and values for these are available in the Solar Keymark Database [7], [8]. Figure 2 visualises the source of radiation, optical losses and thermal losses of a solar thermal system (FPC).

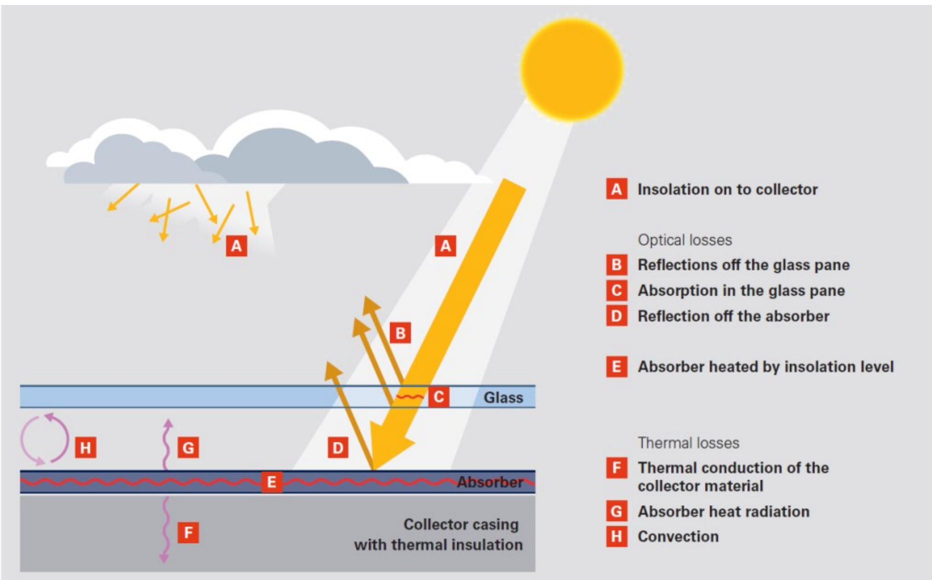

Figure 2 Example of utilisation rate of solar energy and effects influencing the efficiency. [10]

The efficiency of a FPC depends on the temperature difference between the ambient air and the average temperature of the fluids. The lower the temperature difference, the higher the efficiency. Therefore, the thermal performance at a given radiation level is higher at lower temperature differences. The efficiency depends on the flow, since this is how the temperature difference is controlled. The dependency between efficiency and temperature difference is illustrated in Figure 3.

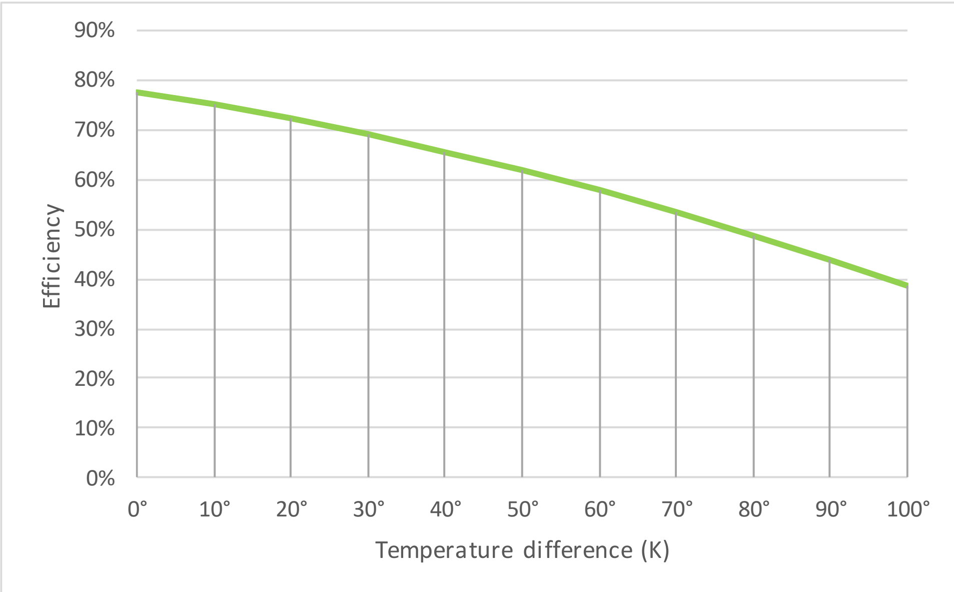

Figure 3 Efficiency as a function of temperature difference.
(Based on data from [8], example with G=1.000 W/m^2, η_0=0.777, a_1=2.41, a_2=0.015)[20]

FPCs are typically produced in two product classes that differ by the energy efficiency of the collectors. Higher efficiencies may be achieved by applying an additional insulating layer, e.g. polymer foil or an extra layer of glass. The SUNSTORE 3-project [15] evaluated the business economic optimal ratio of FPC with/without an extra insulating layer for the solar district heating system for Dronninglund District Heating. In the project it was concluded that under the given circumstances regarding temperature levels, the economic optimum was to only install collectors with an extra insulating layer. In other projects, it is chosen to combine the two levels of insulation, in order to let the less insulated panels preheat the absorber fluid, before boosting it in the better insulated ones. Whether only high efficient or a combination of efficient and high efficient panels are installed, is evaluated from case to case.

The specific yearly thermal output of flat plate solar collectors is around 300-600 kWh/m^2, with an average of around 450 kWh/m^2 in the years 2012-2015. This shows variation due to solar radiation and site-specific conditions, as well as other aspects [4].

A performance guarantee may be given by the contractor. Fact Sheet 3.3 in [13] describes a method for performance guarantees. A performance guarantee may be given for certain operation situations at given solar radiation and temperatures (mean absorber fluid and outdoor temperatures). However, the guarantees provided by the producers do not ensure yearly specific annual thermal outputs. Yet given the performance

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[20] G = Total (global) irradiance on the collector surface
η_0 = Maximum efficiency if there is no heat loss (also referred to as the "optical efficiency").
a_1 and a_2=first and second order heat loss coefficients cf. European Standard EN12975 for efficiency of solar collectors.

guarantees, likely yearly outputs may be assessed quite accurately, when also taking into consideration the uncertainties regarding solar radiation and temperature variations.

Application of solar thermal systems in district heating systems

A solar thermal plant consists of:

- Solar collectors
- Transmission pipeline
- Tank storage
- Tank and collection tank for heat-transfer fluid (e.g. glycol/water)[21]
- Heat exchanger, including pumps, valves etc.
- Integration of control with the existing plant

A schematic drawing of a solar thermal system integrated with a district heating grid can be seen in Figure 4.

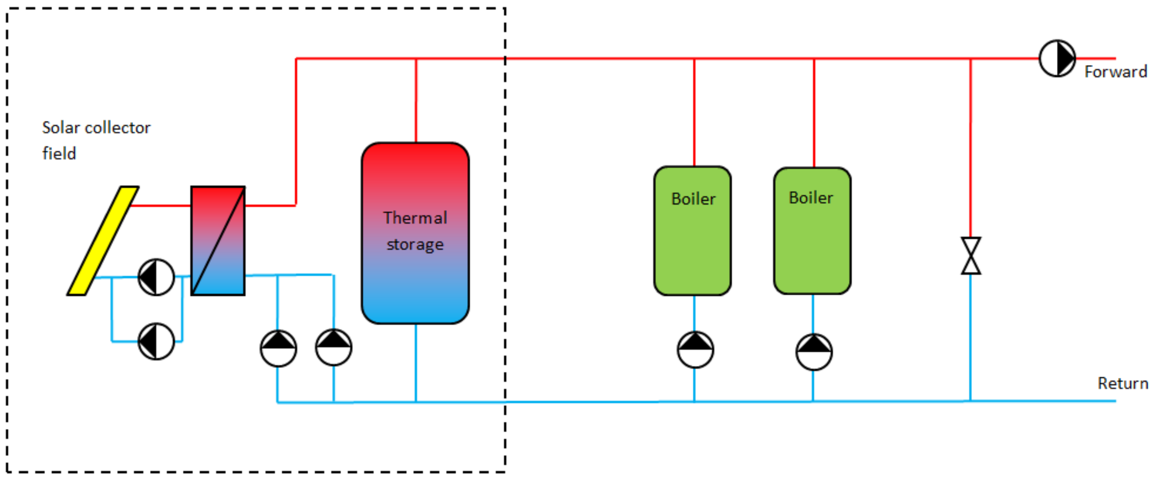

Figure 4 Schematic drawing of a possible system integration of solar district heating [5].

When properly designed, solar collectors can work when the outside temperature is well below freezing, and they are protected from overheating on hot, sunny days.

All district heating systems equipped with solar heating utilize them as a supplement to other heat generating units, thereby ensuring that all consumers' heat demands are met, also when there is insufficient solar irradiation available.

The tilt of the collector panels can impact both annual total yield and production curve production over the year. Hence the tilt of the collector panels becomes an optimization parameter as production can be increased in the autumn at the expense of max. thermal effect and hence production during the summer (where the solar irradiation typically peaks).

Production of solar heating is taking place when the heat demand is lowest – both on daily and seasonal basis. The share of solar heating in a district heating system without heat storage is relatively low (5-8 % of yearly heat demand). Hence, the most common application is the combination of a solar thermal system with

[21] Circulated in the solar thermal collectors. The heat-transfer fluid is typically separated from the district heating water by a heat exchanger, cf. the illustration.

a diurnal heat storage, which will enable approximately 20-25 % share of solar district heating in a district heating system. A typical Danish system with a short-term heat storage of 0.1 - 0.3 m^3 per m^2 solar collector covers correspondingly 10 – 25 % of the annual heat demand [4].

Moreover, the combination with a seasonal heat storage can increase the share of solar heating to 30-50 % and in theory up to 100 %. Hence, there is an important synergy with seasonal storage technologies, cf. chapter 60 "Seasonal Heat Storage".

Input

The input is solar radiation.

Outside the atmosphere of the Earth, the solar radiation is 1367 W/m^2 [6]. The solar radiation is highest perpendicular to the solar beams; this is why solar collectors in Denmark are placed with an angle of approximately 30-40 degrees, while also taking into consideration the cast of shadows [13].

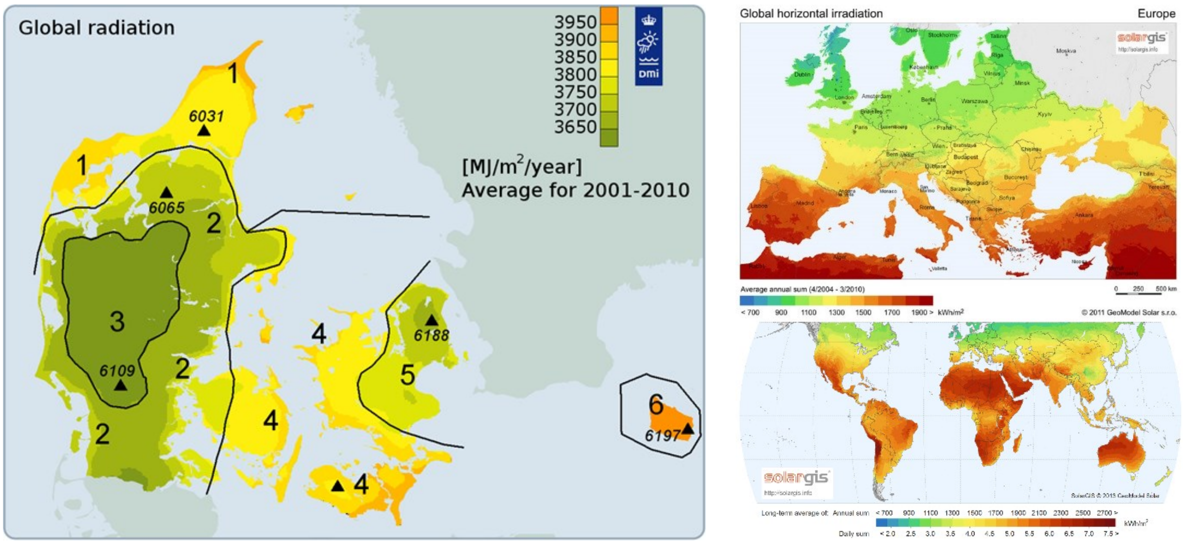

Figure 5 The amount of radiation in Denmark, Europe and the World is illustrated in the maps [6].

As mentioned earlier, the production from solar collectors are highly depended on the seasonal variations of radiation. Figure 6 shows the seasonal variation of the heat generation from a typical solar collector in Denmark as generation in the specific month as the percentage of the average monthly generation.

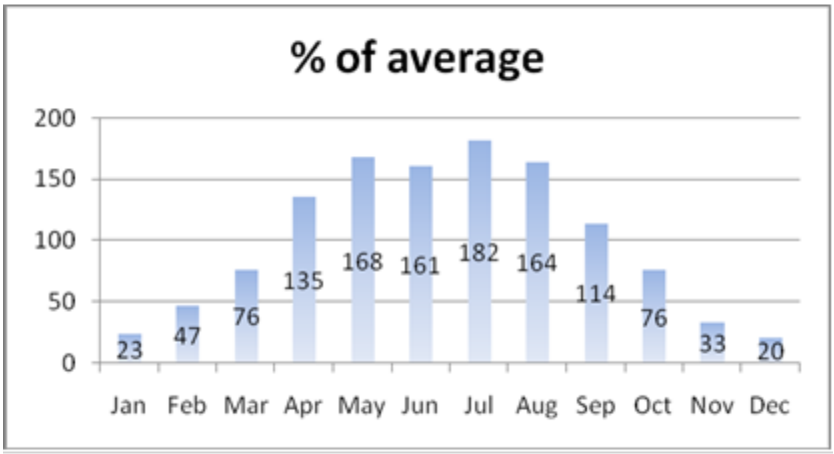

Figure 6 The seasonal variation of heat generation from typical solar collectors in Denmark [3].

Output

Hot water for district heating.

The thermal performance of solar heating plants is first of all influenced by the temperature level of the solar collector fluid. Besides that, the thermal performance is also influenced by the weather, the collector type, the solar collector fluid, the flow volume and the collector tilt.

Typical capacities

The typical application of solar thermal plants for district heating purposes aims at a solar share of 10-25 % of the annual heat demand [4]. Thus, the installed capacity varies by the plant.

Figure 7 shows the development in number of plants and collector area, illustrating that the plants being implemented now is larger than previous plants. Cf. Figure 7 the average plant size has increased rapidly in recent years, indicating two key trends: Larger systems in general and higher solar shares in the plants that decide to invest in solar thermal district heating.

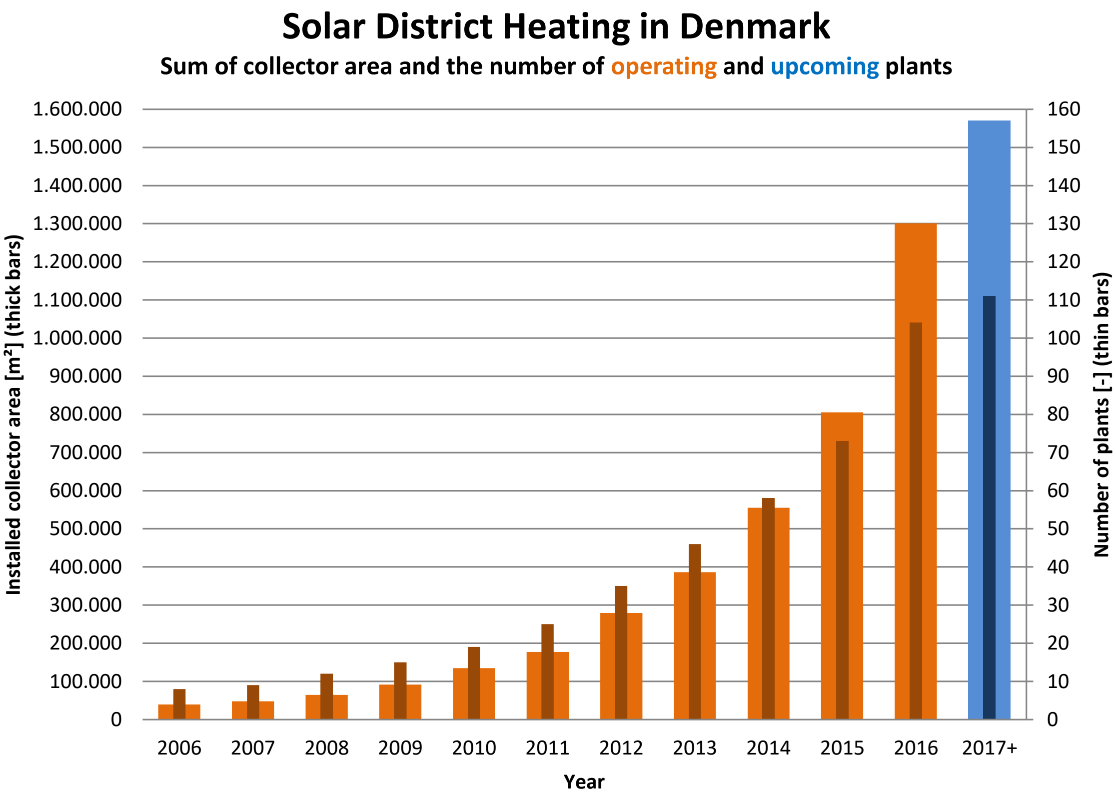

Figure 7 Solar district heating plants in Denmark in operation (until 2017) and planned. The trend is that the new plants are larger and include seasonal heat storages [5].

In the context of the size and heat demand in Danish district heating plants, typical sizes for solar thermal installations are in the range of 5-15,000 m^2. With increasing plant sizes and/or increased solar coverage share, this figure increases. The biggest plant in operation in Danish district heating grids (as of June 2017) is the solar thermal at Silkeborg District heating at 156,694 m^2, followed by Vojens with approx. 70,000 m^2 (completed in two steps).

Examples of best available technology

There are several suppliers of FPC for solar district heating, [14], with the panels from Danish Arcon-Sunmark being the most widely applied option in Denmark. From an international perspective, manufacturers like Austrian GREENoneTEC, TiSUN and Finish SavoSolar offer large FPC-panels too. As of early 2017, there are in total more than 100 plants and 1.3 million m^2 collectors installed in district heating plants around Denmark (while only considering plants sizes >1,000 m^2). This is a significant increase from less than 100,000 m^2 in 2009. The placement, plant data and production data can be found for several plants in [2] and is visualised in Figure 8.

Figure 8 Solar heating plants in Denmark – more than 100 plants with a total installed collector size of more than 1.3 million m2. The map is interactive and includes detailed information on solar heating plants [2].

Examples of plants are:

- Brædstrup, Denmark: A combined energy system including 18,600 m^2 of solar collectors, 7,500 m^3 heat storage tanks, 19,000 m^3 pilot borehole seasonal heat storage (corresponding to approximately 9,000 m^3 of water), an electrical driven heat pump, an electrical boiler, a natural gas fired engine (combined heat and power production) and natural gas fired heat-only boilers. Also an advanced control system, balancing maximum solar heat and maximum electricity sales. Solar coverage: 22 %. Established in 2007, expanded in 2012 [9].
- Dronninglund, Denmark: Solar panel field of 35,000 m^2, combined with a seasonal pit heat storage, filled with 60,000 m^3 of water. The pit storage is used to store the heat produced in the summer, to be utilised during the winter. The solar plant yields 16,000 MWh per year and provides 40 % of the heat for the local district heating network with its 1,350 customers. Other heat sources are a natural gas fired engine and a boiler with an absorption heat pump, cooling the storage. The solar district heating (SDH) plant was commissioned in 2014 [9].
- Vojens, Denmark: The experiences made with the 17,000 m^2 large collector field since 2012 convinced Vojens Fjernvarme to plan adding another 52,500 m^2 (36.75 MW_{th}) to the field as well as seasonal storage, which should increase the annual solar share from the 14 % measured in 2014 to an expected 45 %. The expansion was commissioned in May 2015 [9].
- Silkeborg, Denmark: Solar panel field of 156,694 m^2. Commissioned late 2016, making it the world's largest SDH-plant at the time. Other heat sources in the system are natural gas fired CHP, an electric boiler and industrial excess heat.

An overview of the World's largest installations can be found in [9] and [14].

Research and development objectives

More suppliers have entered the market in Denmark, offering different technologies. This implies that there is a process of improvement of the efficiency of the panels as well as reduction of the costs of the panels.

Examples of research and development objectives include:

- Production of panels – e.g. extruded absorber aluminium panels (Savo-Solar)
- Absorbers – increased absorbance and reduced emittance
- Improved absorber design – increased heat transfer to fluid and better flow distribution
- Use of concentrating collectors (CSP)
- Improved plant layout – serial connection of different collector types in rows and optimised serial/parallel connections for solar collector fields
- Control strategies – optimised integration of solar in existing district heating plants

Additionally, [4] contains an extensive list of possible development aspects of solar heating.

Regulation ability and other system services

Regulation with regard to electricity is not relevant for solar thermal plants.

There are however other relevant regulation aspects for solar thermal collectors, e.g. the possibility to vary the flow of the absorber fluid. By varying the flow of the absorber fluid, the temperature in the plant can be regulated. This is especially important, considering the variation in intensity of solar radiation. Varying the flow secures the possibility to optimize the flow rate according to the external circumstances and desired output temperature.

Boiling of the absorber fluid can cause reduction of the corrosion protection. Ways to avoid boiling are the installation of conventional cooling towers or the scheduled and preventive cooling of stored heat by circulating water through the plant at night. The latter is applied in many Danish plants, as it reduces the installation costs, but the cooling capacity of collectors is practically limited to FPC-technology and has decreased in recent years, due to the increased energy efficiency of collectors.

In the event that the thermal solar district heating plant is oversized compared to the available cooling capacity, the absorber fluids remains at risk of boiling.

Advantages/disadvantages

Advantages:

- Simple, robust and proven technology. More than 100 Danish district heating plants have solar thermal plants
- Long technical lifetime, proven at least 25-30 years
- Low maintenance costs, based on current plants approximately <1 €/MWh_{th} [11]
- Low electricity consumption required (3-4 kWh pr. produced MWh solar heating, primarily electricity consumption for circulation pumps) [11]
- No continuous presence of operation personnel required during operation
- Heat production price not sensitive to variable costs of fuel, easier budgeting of the heat price, when a share of the heat price is known
- CO_2-free energy source
- High energy yield pr. occupied land-area compared to e.g. biomass, in terms of possible energy production on a given area
- Easy reestablishment of area, no or low impact on the soil from the foundations
- Approx. 98 % of a plant can be recycled after decommission [12]
- Can be combined with heat pumps to increase yields

Disadvantages:

- Production dependent on solar radiation and weather conditions
- Summer load defines the size of the capacity in case of diurnal storage only
- Produces approx. 80 % of the heat energy during the period April – September, when the heat demand is lowest. Can be mitigated by including a seasonal heat storage [3]
- High area occupation, compared to other district heating technologies like boilers or heat pumps, approximately 3 m^2 ground area for each m^2 solar panel collector, near by the district heating network – although this can be mitigated with a transmission pipeline e.g. some km, which may imply additional costs
- High initial investment pr. MW, but with a depreciation period of 15-20 years, the heat production cost is competitive with e.g. biomass based heat production.

Environment

No emissions related to the heat production.

Anti-freezing agents such as organic glycols are typically added to the water in the system, in order to avoid frost damages in the winter. Leakage risks can be mitigated by installing monitoring systems, monitoring e.g. pressure in the system as well as moisture in the insulation material of the pipes.

The basic components of solar thermal collectors consist of metals, insulation material, glass and the above-mentioned anti-freezing agents. Thus, most of the used materials can be recycled after decommission.

Assumptions and perspectives for further development

Solar district heating has developed significantly during the recent years towards category 4 “Commercial, limited development potential”. This is illustrated by the significant deployment of solar district heating cf. Figure 7. Figure 9 visualizes the technological development phases for solar thermal.

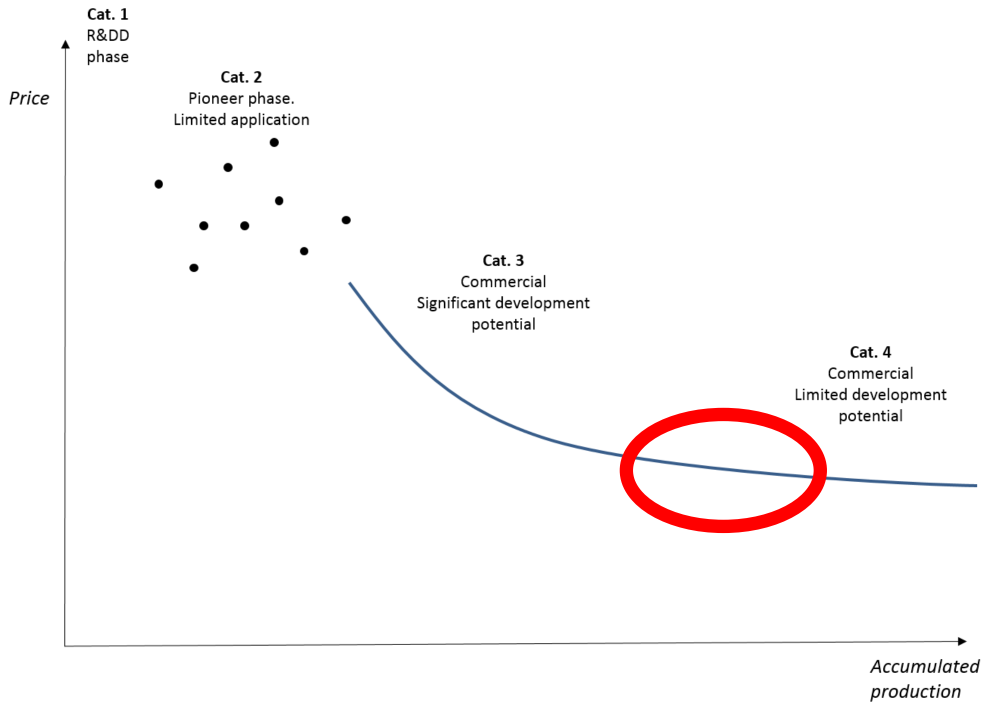

Figure 9 Technological development phases. Correlation between accumulated production volume (MW) and price.

There has been an increase of efficiency of production of solar thermal panels through automation. During the past decade, the production of solar panels has matured, resulting in lower production costs, which results in better business cases for the district heating utilities, due to a reduction in investment costs.

The cost of installation has been reduced by applying steel profiles instead of concrete foundations. This enables faster installation and is independent on the weather conditions at the time of installation – both these parameters contribute towards a reduction of the installation costs.

Design of the solar fields is another parameter, which can imply further reduction of the investment costs.

The yield of the solar panels has improved substantially during the past decade. This is due to various improvements in the materials and the elimination of thermal bridges that have improved the efficiency.

A potential for further development of solar district heating is control of the operation of the solar plants, i.e. flexibility. This relates to the role of solar district heating as one element in a complex system of different production and storage technologies – even at the same plant – thus efficiently utilizing the solar energy, while efficiently fulfilling the heat demand. The flexibility also includes meeting demands at lower supply temperature – which would improve the efficiency of the solar panels (cf. Figure 3).

The development potentials for solar thermal plants and how they are expected to influence the market situation for solar district heating are characterized by:

- Increased applications of solar district heating systems internationally
- Solar thermal with large storages (Economy of scale and increased independency of fluctuations in energy prices due to increased substitution of conventional heat production)
    - Leading to up to 80 % solar fraction of yearly heat demand

- More suppliers (an increased number of competitors is expected to result in increased development and competition):
    - Cf. the overview of suppliers in [4]
- Combination of solar thermal and biomass for 100% RES-district heating systems
    - Solar thermal already is business economically feasible in combination with wood chips and straw (including ”energy saving” subsidy)
    - If designed correctly, SDH-plants can improve the operation of other heat producing capacity in the summer time, by covering the entire heat demand and thus eliminating inefficient part-load-operation etc.
- Other hybrid systems
    - Combinations with other technologies such as long term storages and heat pumps
- Solar thermal for large cities (Economy of scale and increased attention to these kinds of projects):
    - Graz; 265,000 inhabitants, 450,000 m^2 solar panels, 2.0 million m^3 storage
    - Silkeborg, 156,694 m2 solar panels
    - Belgrade – under investigation
- Solar with higher temperatures (new product developments):
    - Supply of industrial heat demands (i.e. for process energy demands)
        - E.g. CSP (concentrated solar power) and ORC (organic rankine cycle)

The correlation between the collector area and investments costs of solar heating plants in Denmark can be seen in Figure 10.

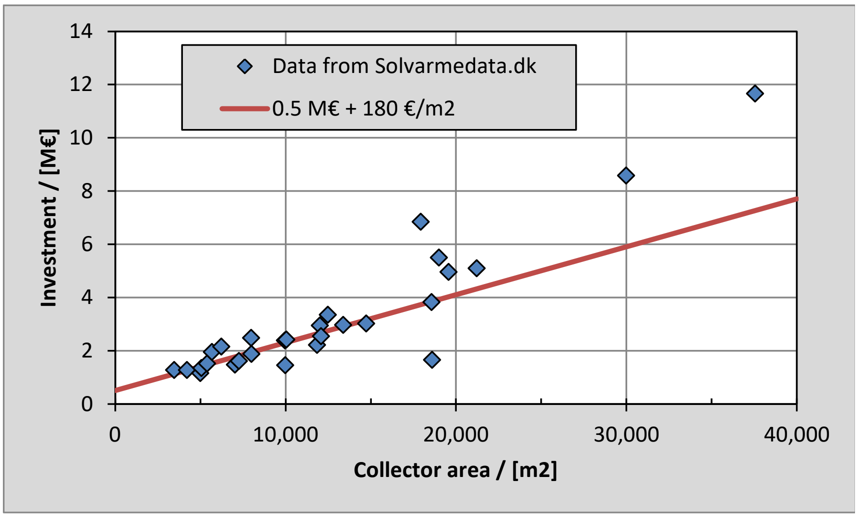

Figure 10 Solar plant investment for Danish SDH projects. The plant in the upper right corner is “Dronninglund” with 37,573 m2 which includes a seasonal heat storage – and the investment for that is 2.4 M€ (see the section below on the seasonal heat storage), bringing this plant closer to the red line [5].

Different suppliers provide different quality at different prices. There seem to be a balance between quality and price, resulting in heat production prices on the same level due to different yields. Hence, there is increasing competition between suppliers, resulting in improved quality and lower prices.

As shown in Figure 10, there is a close correlation between investment costs and solar collector area for plants with a collector area below 15,000 m^2. When considering the investment costs of thermal solar plants with a collector area above 15,000 m^2 the investment costs is increasing faster than what is predicted by the regression line (the red line). This is predominantly because the larger plants include a seasonal heat storage (for example when considering the plant in the upper right corner, Dronninglund with a collector area of

37,573 m^2 and a seasonal heat storage). The investment for the seasonal heat storage alone is approx. 2.4 M€ (cf. Section 1.1.11, on *additional remarks* regarding the seasonal heat storage).

In conclusion, the above considerations illustrate that solar thermal is a well-proven and robust technology with a long technical lifetime. Solar thermal district heating is also competitive in large-scale applications in combination with other technologies, including seasonal heat storage technologies. The development potential for energy yields and cost reductions are estimated to be limited.

Uncertainty

Solar thermal plants are a low risk technology, which has matured in terms of reduction of production costs and improvement of the yield of the solar panels during the past few years. Consequently, the uncertainty on the provided parameters is considered small.

Additional remarks

Relevant sources of information includes:

- Factsheets from the IEA SHC Task 45 Project, www.Task45.iea-shc.org
- Guidelines developed in the Solar District Heating Project, http://solar-district-heating.eu/Documents/SDHGuidelines.aspx, i.a. detailed technical descriptions and considerations regarding operation economy and organization of an SDH-plant
- www.solvarmedata.dk and www.solarheatdata.eu, include data on specific plants
- Homepages of suppliers. Please refer to http://solar-district-heating.eu/ServicesTools/FindProfessionals.aspx for a list of suppliers.

Some district solar heating systems also have seasonal heat stores (cf. chapter '60 Seasonal heat storage'). Under Danish climatic conditions, a district heating system, which is based entirely on solar energy, needs a seasonal store with a volume of about 4 m^3 per m^2 of solar collector, provided a heat pump is installed to extract the heat energy from the storage. This ratio is based on a 50^o C temperature difference T_{out} - T_{in} of the storage water.

Figure 11 shows calculated data for the seasonal storage requirement as a function of solar heat coverage in the DH system, based on the data sheet below and data for seasonal heat storage in this publication technology catalogue, chapter 60 on seasonal heat storage.

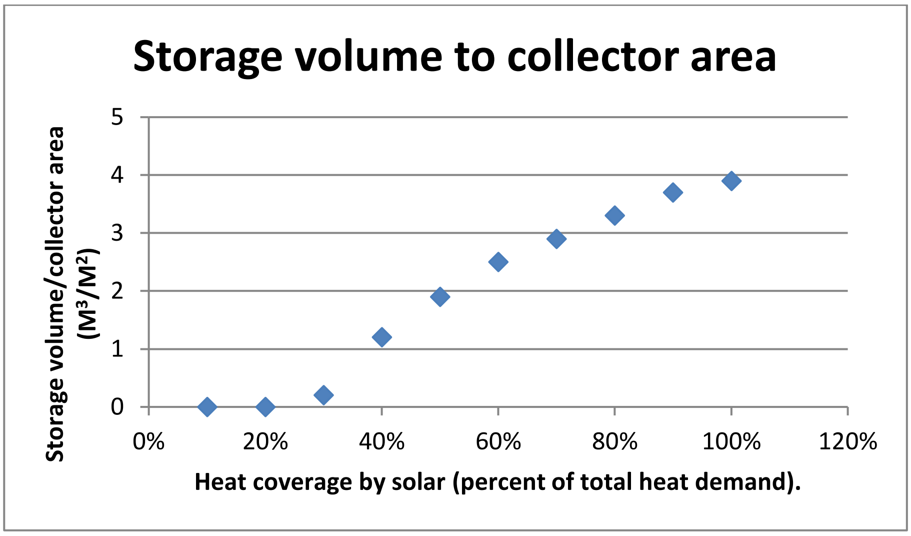

Figure 11 Ratio of seasonal storage volume to collector area (y-axis) as a function of solar heat coverage [4] and [5].

Data sheets

Technology	Solar District Heating									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Typical plant size (collector area), m^2	10000	13000	21000	55000	10000	20000	10000	100000	L	
Collector input, $kWh/m^2/year$	1046	1046	1046	1046	1013	1079	1013	1079	Q	
Collector output, $kWh/m^2/year$	450	473	497	522	450	496	497	548	A	4
Total efficiency , net (%), annual average	43%	45%	48%	50%	42%	49%	46%	54%	P	
Auxilary electricity consumption (share of heat gen.)	0.3%	0.3%	0.3%	0.3%	0.2%	0.4%	0.2%	0.4%		
Forced outage (%)	0.5%	0.5%	0.5%	0.5%	0%	1%	0%	1%	K	
Technical lifetime (years)	30	30	30	30	30	30	30	30	I	17
Construction time (years)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25		
Space requirement (1000m^2 per MWh/year)	6.7	6.3	6.0	5.7	6.0	6.7	5.5	6.0	J	
Environment										
SO_2 (g per GJ fuel)	0	0	0	0	0	0	0	0		
NO_X (g per GJ fuel)	0	0	0	0	0	0	0	0		
CH4 (g per GJ fuel)	0	0	0	0	0	0	0	0		
N2O (g per GJ fuel)	0	0	0	0	0	0	0	0		
Financial data										
Investment cost of total solar systems excluding diurnal heat storage, €/MWh$_{output}$/year	429	395	362	325	371	422	292	362	C, H, N	
- of which is equipment	85	85	85	85	85	85	85	85	O	
- of which is installation	15	15	15	15	15	15	15	15	O	
Investment cost of diurnal heat storage, €/MWh$_{output}$/year	60	57	54	52	41	75	37	68	D, M	
Total investment cost of total solar system including diurnal heat storage, €/MWh$_{output}$/year	489	452	416	377	412	497	329	430	E	
Fixed O&M €/MWh$_{output}$/year/year	0.09	0.09	0.08	0.08	0.08	0.10	0.07	0.08	B	
Variable O&M €/MWh$_{output}$	0.19	0.21	0.30	0.35	0.14	0.28	0.23	0.47		
- of which is electricity costs, €/MWh$_{output}$	0.19	0.21	0.30	0.35	0.14	0.28	0.23	0.47		
- of which is other O&M costs, €/MWh$_{output}$	0	0	0	0	0	0	0	0		
Technology specific data										
Investment cost of total solar systems excluding diurnal heat storage, €/m2 (collector area)	193	187	180	170	184	190	160	180	G, H, N	16
Fixed O&M, €/m2/year (collector area)	0.04	0.04	0.04	0.04	0.04	0.05	0.04	0.04	B	

Notes

A The yield is weather dependent and very site-specific, depending much on the temperatures of the district heating network. The quoted yield the average measured output from 40 Danish solar heating plants for 2015.

B Estimate is 0,2 €/MWh heat output in 2015, excluding electricity consumption.

C Applying the formula 250,000 € + 167 €/m2 solar panel collector for plants <50.000m2, cf. figures from Note G.

D Including a diurnal storage is mandatory, 0.2 m3/m2 being a typical average storage size. This figure can vary, dependent on the local conditions and desired solar fraction.

E Can be combined with seasonal storage, cf. corresponding chapter.

F Solar thermal plants can be regulated by varying the flow of the heat transfer fluid. The regulation ability is limited by the available heat demand in the heat sink (incl. available storage capacity) and solar radiation.

G 2015-Prices of different plant sizes [1]:

Size	m^2	5,000	10,000	20,000	50,000	100,000
Price pr. m^2	€/m^2	216	193	180	175	170
Total price	M€	1.08	1.93	3.60	8.73	17.00

H Prices include leveling of ground, laying of district heating pipelines in the ground inkl. 50 m of transmission pipeline to the district heating plant, heat exchanger connected to solar panel field and installed with collection tank and expansion with flanges to secondary side, control and electricity works, design and project management, start-up regulation and documentation.

I The lifetime is minimum 25-30 years, proven in actual plants still in operation. Critical component is the teflon foil, not the material itself, but the application method. The pipes have been improved, designed for the relatively large number of temperature variations, compared to normal district heating pipelines. The fluid is well managed.

J Space requirement is approximately 3 m2 for each m2 gross collector area. No development of this parameter is expected, since the main reason is to avoid the shadow effect. Minor optimization of the sides of the panels may be obtained, increasing the ratio of aperture/gross area. Other types of solar collectors such as vacuum and CSP (concentrated solar power) may have lower space requirement.

K The forced outage is very small, therefore in practice close to 0 %. The modular construction makes it possible to maintain sections of the panels. Outage of critical components such as the heat exchanger is very limited.

L The average plant size increases, but with large variations since both small plants and increasingly larger plants are installed. A 5 % annual increase of the average size is assumed. The plant size is rather dependent on the heat demand in the district heating grid, it is connected to. The collector area is, cf. international standards, stated as gross area.

M Estimate of cost of tank storage (diurnal storage) is 135 €/m3. The required size of the storage differs, but a typical size is 0.1-0.3 m3 storage for each m2 of solar panels, hence a 10,000 m2 solar thermal plant requires 1-3,000 m3 of diurnal storage.

N Considering a reduction in prices for 2015-2020 / 2020-2030 / 2030-2050 of 0.6 / 0.4 / 0.3 % p.a.

O The division of cost elements is site- and plant specific. An indicative distribution of costs are; Solar collectors and piping (48%), heat exchanger, pumps etc. (8%), accumulation tank (11%), transmission pipeline (13%), building (2%), control, operation and startup (5%), land purchase, ground works (7%), design, permits, unforeseen (6%). Total for equipment is 85% and for installation is 15% (design, permits, unforeseen, ground works, control and start up), but including accumulation tank and a transmission pipeline.

P Please refer to www.solvarmedata.dk for display of efficiencies of Danish solar district heating plants. Chose a plant, select "Production and efficiency" and a chart will display the efficiency - typically varying between 20 and 50%.

Q The solar radiation on the horizontal surface.

R The cost of auxiliary electricity consumption is calculated using the following electricity prices in €/MWh: 2015: 63, 2020: 69, 2030: 101, 2050: 117. These prices include production costs and transport tariffs, but not any taxes or subsidies for renewable energy.

Definitions

CSP	Concentrated Solar Power
ECT	Evacuated Collector Tubes
FPC	Flat Plate Collector
SDH	Solar District Heating
Specific collector output	Heat production pr. gross collector area (e.g. kWh/m^2)

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