SDH solar district heating

Solar district heating guidelines

Collection of fact sheets

WP3 – D3.1 & D3.2

August 2012

This project is supported by:

INTELLIGENT ENERGY EUROPE

Introduction

This document consist of a number of fact sheets each describing a topic within the field of solar district heating in a short, concrete way. The fact sheet configuration provides a quick overview of the different subjects so the reader can easily pick out the desired information. That being said, this document may also be used as a "read through"-report.

The goal is to bridge the gap between wanting a plant and actually having a plant, i.e. describing both the processes and which obstacles that might occur as well as how to avoid or overcome them.

The fact sheets include both technical and "non-technical" topics. The "non-technical" subjects describe what to be aware of when considering investing in a solar district heating plant – from the idea is formed until the actual plant is constructed and operating. The technical subjects describe the plant design, its components and the control of the operating plant.

Disclaimer

Table of Contents

Chapter:	Introduction to SDH – from idea to operating system
Date:	April 2012
Size:	4 pages
Description:	Overview of both the preliminary topics to be addressed when considering a solar district heating plant, what needs to be done in terms of permissions, tendering and contract(s) when the preliminary investigations turned out positive, and what to remember when it is decided to built the plant.
Author:	Per Alex Sørensen, PlanEnergi – pas@planenergi.dk
Co-author(s):	-
Available languages:	English
Version id:	1.1-2
Download possible at:	www.solar-district-heating.eu

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Introduction

The steps from the idea of a solar district heating plant to an implemented and full functioning plant are described briefly in this fact sheet to give an overview of the topics to be addressed. The description indicates that the process is linear and first one step is taken, then the next step is taken and so on. That is not the reality because steps can be taken in parallel and during the implementation process new information and new possibilities will mean that some steps might have to be taken again.

The steps in this fact sheet are divided in 3 phases: “Preliminary investigations”, “Permissions and tendering” (including contracts) and “Implementation”.

Overview of preliminary investigations

Solar heat combined with other fuels

Solar heat can be combined with all other fuels, but in some cases the idea of solar heat production can be eliminated because the summer load in the district heating system comes from waste incineration, waste heat from industries or from combined heat and power plants producing cheap heat which would be expensive/difficult to close down. Normally solar heat cannot compete with heat production prices lower than 3 € cents/kWh in Northern Europe and 2 € cents/kWh in Southern Europe. But for instance natural gas fired combined heat and power plants are in Denmark combined with solar heat in several district heating plants. So don’t give up beforehand. – *Use fact sheet 2.1 “Solar heat combined with other fuels”.*

Where to place the solar collectors

Solar collectors can a.o. be placed on ground, on roofs, beside roads, as shadowing element above parking places. The collector areas can be connected directly to the district heating plant or to the distribution system.

Ground mounted solar collectors is the cheapest solution unless the price for land is very high (> 50 €/m^2). Farm land might be used if costs for the transmission pipe don’t spoil the economy.

Roof mounted solar collectors are interesting solutions on large new buildings or large buildings that needs new roof or have large flat roof areas.

– Use fact sheet 2.2 “Where to place the solar collectors” to estimate the areas available on ground, roofs etc.

Feasibility study

Knowing that the summer load is not engaged by very cheap heat and that areas for solar collectors can be found, a feasibility study can be made to have a first idea about the economical feasibility for solar plants of different sizes. – *Use fact sheet 2.3. "Feasibility study".*

Who shall be owner and who shall operate the plant?

If the economical feasibility is satisfying the district heating company often will decide to invest in the plant and operate it, but financial circumstances might change this so that investors from outside might be invited. Also ownership of solar collectors being the roof of a house not owned by the district heating company might be complicated and finally the district heating company might be interested in involving consumers also economically in the project. – *Use fact sheet 2.4 "Ownership and financing" to find solutions.*

Overview of permissions and tendering

If the result of the preliminary investigations is positive, next steps will be to get permissions and to make tendering and contracts with entrepreneurs. But before starting these steps the coming plant owners have to have access to space for the solar collectors. If land is needed the land owner should sign a contract, where he offers to sell/let the area for a certain price. The offer must have a time limit of for instance one year.

Planning and environmental permissions

When the owner(s) know where to place the solar district heating plant authorities permissions have to be applied for. If collectors are ground mounted a planning permission for the area (local plan) might be needed and also solar collectors placed on roofs, as shadows for park places etc. might need planning permission.

The risk for environmental damage from solar collectors is very low. There can be leakages from collector fluids to the ground or as steam, reflections from the solar collectors or esthetical "damages". These problems are normally handled in the planning permission, so that a special environmental permission can be avoided. – *Use fact sheet 3.1 "Permissions from authorities".*

Detailed design

Before tendering the plant owner has to decide if he will make a detailed design study and maybe make different tenders for solar collectors, piping, control system etc. or he will just decide the functions of the plant and let a total contractor make the detailed design. – *Use the guidelines in chapter 6, 7 and 8 if detailed design is carried out by the plant owner.*

Tendering and contract(s)

A call for tender is necessary to get the best price per produced kWh for the solar district heating plant. In the tender document as a minimum requirement for thermal output, quality of components and work, guarantees for the efficiency of the plant and how to compare the bids has to be defined. If the district heating company is the plant owner EU´s directive coordinating procurement procedures of entities in the water, energy, transport and postal service sectors (Directive 2004/17/EC of 31. March 2004) has to be followed for implementation projects larger than 4.845 million €.

If the plant is delivered by a total contractor guarantees are easier to define and enforce because the contractor can give guarantees for the total plant.

– Use fact sheet 3.2 “Tendering and contracts” and fact sheet 3.3 “Guarantees” for the tendering process and the fact sheets in chapter 7 for requirements for components etc.

Implementation

The building process

When contracts and authorities permissions are ready the implementation process can start. During the implementation the plant owner (and/or his consultant) has to follow the process and to gather all contractors in a meeting at least every second week to discuss state of the art of the implementation, unsolved problems and the work in the coming weeks. Especially the plant owner shall be aware of the time table for installation of the control system. – *Use fact sheet 4.1 “Supervision of construction and commissioning” as help.*

Commissioning

After implementation the contractors has to show, that the plant works as promised. At the delivery day the plant owner and the contractors have to agree upon that work is OK and from that point guarantees are in function. – *Use fact sheet 4.1 “Supervision of construction and commissioning” as help.*

The SDH fact sheets addresses both technical and non-technical issues, and provide state-of-the-art industry guidelines to which utilities can refer when considering/realizing SDH plants. For further information on Solar District Heating and the SDHtake-off project please visit www.solar-district-heating.eu.

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Solar heat combined with other fuels

Chapter:	Preliminary investigations
Date:	August 2012
Size:	5 pages
Description:	Description of different combination options for solar heat including economic issues when it is combined with other fuels such as biomass.
Author:	Per Alex Sørensen, PlanEnergi – pas@planenergi.dk
Co-author(s):	-
Available in:	English
Version id:	2.1-4
Download possible at:	www.solar-district-heating.eu

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Introduction

Solar heat can technically be combined with all other fuels for district heating, but it is not always environmentally and economically feasible to do it. The production price from a solar heating plant will in Northern Europe be at least 3 € cents/kWh and in Southern Europe at least 2 € cents/kWh which have to be compared to heat production prices from other sources including possible changes in the total efficiency of the combined heat generation system.

Combination with heat from waste incineration and industrial processes

Heat from waste incineration will normally be wasted if it is not utilised as district heating. Therefore the heat is approx. free. Also heat from industrial processes can be very cheap to utilize as district heating. If the total summer load is covered by heat from waste incineration and/or heat from industrial processes, there will be no increase but a loss in energy efficiency and there is environmentally no advantage for solar heat. Also the solar heat will normally not be able to compete on prices. Also environmentally there is no advantage for solar heat.

Combination with geothermal heat

Geothermal heat comes from the earth, often from more than 500 m deep drilled holes.

Both solar heat and geothermal heat have high investment costs and low operational costs. Therefore investment in both technologies in the same heating system has to be carefully calculated.

Combination with fossil fired CHP-plants

The high efficiency of fossil fired combined heat and power systems are based on the total cover of the summer load in the DH-network. In an established system the total efficiency of the CHP-system could only decrease if the heat production is substituted by solar thermal heat. Also the heat production price of CHP-plants is low and combination with solar heat will thus be difficult.

Combination with biomass CHP

The biomass combined heat and power system normally covers the total summer load in a district heating system and once the plant is established the heat production price is low and combination with solar heat will thus be difficult.

Combination with biomass fired heating plants

Heating plants using wood chips or straw has a marginal heat production price of 2-3 € cent/kWh. But prices for biomass are up going and a future demand for biomass for transport and other purposes might mean a lack of biomass. Solar heating can cover the summer load and thus the biomass boiler can be turned off for a longer period.

To cover the summer load an accumulation tank is needed. The accumulation tank will in addition make it possible to run the biomass boiler with a fixed (and lower) load during the winter and function as back up if the biomass boiler has a brake down.

There are two technical aspects, which shall be taken into account when biomass and solar are combined.

The biomass boiler has a minimum load limit. That means, that the boiler has to be run on/off, if the solar fraction is too high but not high enough to turn the biomass boiler off for longer periods. Therefore the solar fraction has to be near 100% in the summer period.

If the biomass system is with flue gas condenser the biomass boiler and the solar collectors has to be in parallel to optimize the efficiency.

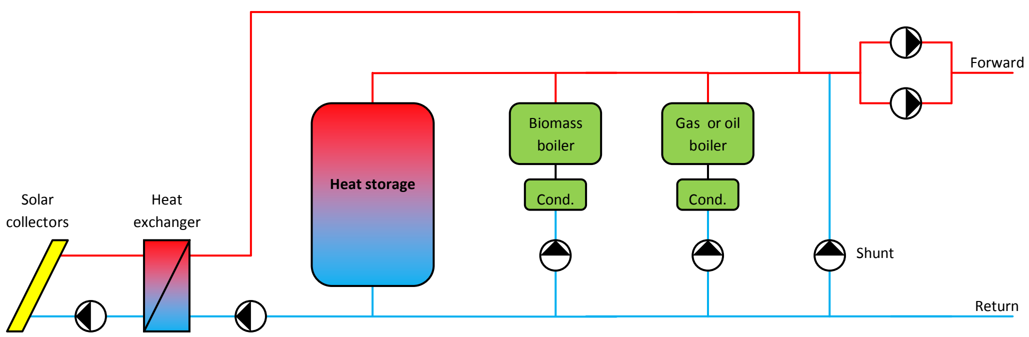

Fig. 2.1.2. Example of diagram for solar heat combined with biomass boiler. (Source: PlanEnergi)

Combination with natural gas fired CHP

Natural gas fired combined heat and power plants use a more expensive fuel than biomass or coal fired CHP plants. In table 2.1.1 is seen the price of natural gas including tax when it is used for district heating (only).

Table 2.1.1. Price of natural gas produced district heat. All values are in €/MWh.

Country	Price for gas	Tax	Total
Austria [1]	35	11	46
Czech Republic [2]	33	12	45
Denmark [3]	30	28	58
Germany [4] & [5]	36	10	46
Italy [6]	37	24	61

Referring to table 2.1.1 it has to be mentioned, that district heating utilities in some countries e.g. Germany have different contracts with the natural gas suppliers (e.g. with long term conditions). This means that the price market is very heterogeneous and that prices which differ from the shown table, must be expected in "real life".

Natural gas fired CHP plants are quickly to start and stop (especially for engines). If the percentage of wind power produced electricity goes up, regulation of other power producers (or end use) are necessary. Natural gas fired CHP plants are in Denmark used for that kind of regulation. That means stop for the engines in longer and longer periods when the amount of wind power is extended. Heat production in these periods is usually done with gas boilers, which is very expensive. Solar heat can be produced much cheaper. Therefore a lot of Danish SDH-systems are installed in combination with natural gas fired CHP-plants.

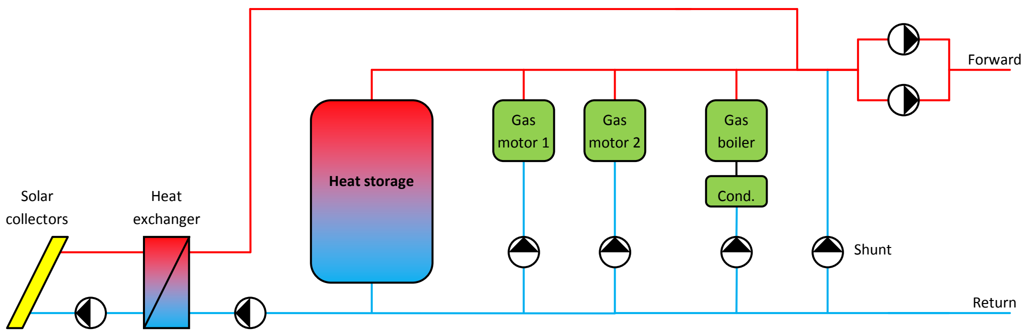

Fig. 2.1.3. Example of diagram for solar heat combined with natural gas fired CHP. (Source: PlanEnergi)

If wind produced electricity is a large part of the electricity production in the summer period similar possibilities for solar heat in district heating might occur in other countries.

References

[1] www.e-control.at for nationwide taxes; there are different extra taxes on gas in regions

[2] Materials from the ADH CR 2011, currency rate 24,225 Kč/euro (official rate for date 8/3/2011)

[3] Punktafgiftsvejledning 2011-1, F.4 Natur-og bygas, February 2011.

[4] Bundesministerium für Wirtschaft und Technologi, "Energiedaten – ausgewählte Grafiken" p. 40, www.bmwi.de/BMWi/Navigation/Energie/Statistik-und-Prognosen/Energiedaten/energiepreise-energiekosten.html, January 2011.

[5] Stadtwerke Bochum GmbH, www.stadtwerke–bochum.de/index/privatkunden/energiepreise/steuern_erdgas.html;jsessionid=037B6542E6C518E20256D4057383BC91.pwc1, February 2011.

[6] AIRU, Italian District Heating Association, 2011.

The SDH fact sheets addresses both technical and non-technical issues, and provide state-of-the-art industry guidelines to which utilities can refer when considering/realizing SDH plants. For further information on Solar District Heating and the SDHtake-off project please visit www.solar-district-heating.eu.

Chapter:	Preliminary investigations
Date:	August 2012
Size:	8 pages
Description:	Description of the location and orientation options for placement of solar collectors for district heating. Pictures are shown for the different examples.
Author:	Per Alex Sørensen, PlanEnergi – pas@planenergi.dk
Co-author(s):	-
Available languages:	English
Version id:	2.2-3
Download possible at:	www.solar-district-heating.eu

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Introduction

As a main rule the area for solar collectors for district heating can be found on the ground, on roofs, as shadowing over park places, on noise protection walls etc. It is “only” a question of price and esthetical demand where to place the solar collectors.

Ground mounted collectors

Ground mounted collector areas for district heating are seen in e.g. Sweden, Denmark, Austria and Holland. They are oriented towards south and the distance between the solar collector rows and the angle from horizontal is optimised for each place and collector type.

Normally large collectors (10-15 m^2) placed in parallel rows of up to 20 collectors are used. For 1 m^2 solar collector 3-4 m^2 land is needed.

If the collector type, field design, the distance between the collectors, in- and outlet temperatures from district heating, consumption, cost of land area, storage capacity and heat exchangers are known the optimal slope of collectors can be found by calculating the output in for instance TRNSYS (computer software).

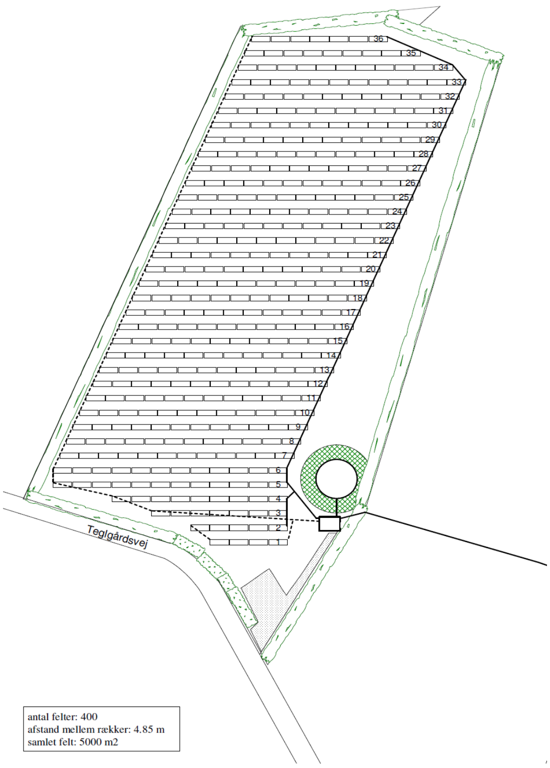

Fig.2.2.1. Example of field design for 5000 m^2 solar collectors including accumulation tank, Ulsted, DK. (Source: PlanEnergi)

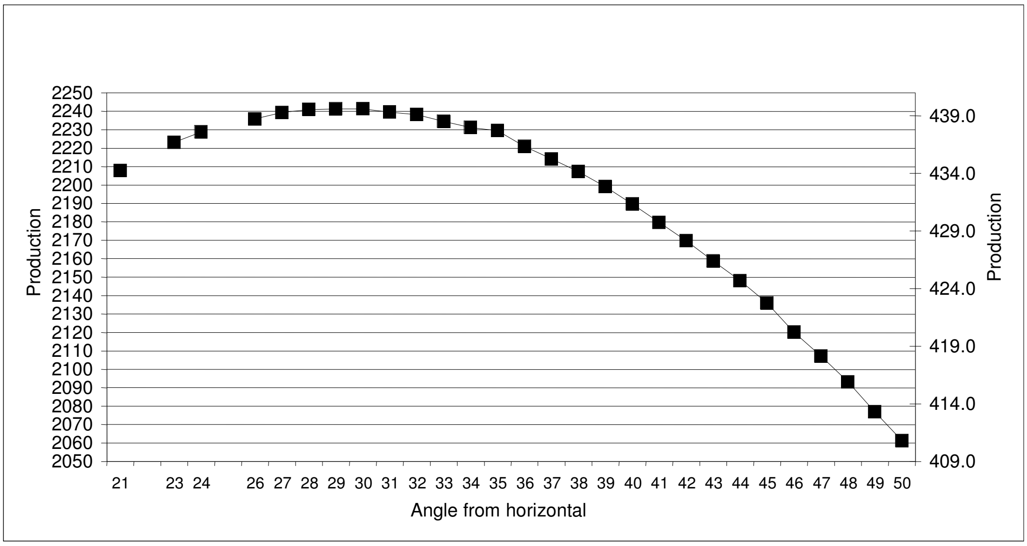

Fig.2.2.2. Example of calculation of output for the 5000 m² solar collectors shown in Fig. 2.2.1. The production is calculated for different angles from horizontal, Ulsted, DK. (Source: PlanEnergi)

The distance between the solar collector rows is normally at least 4.5 m (depending on the collector height) – measuring from the front of a collector row to the front of the next row – allowing people to move around between the rows. Larger distances give higher production because of less shadowing but also higher costs for ground and piping.

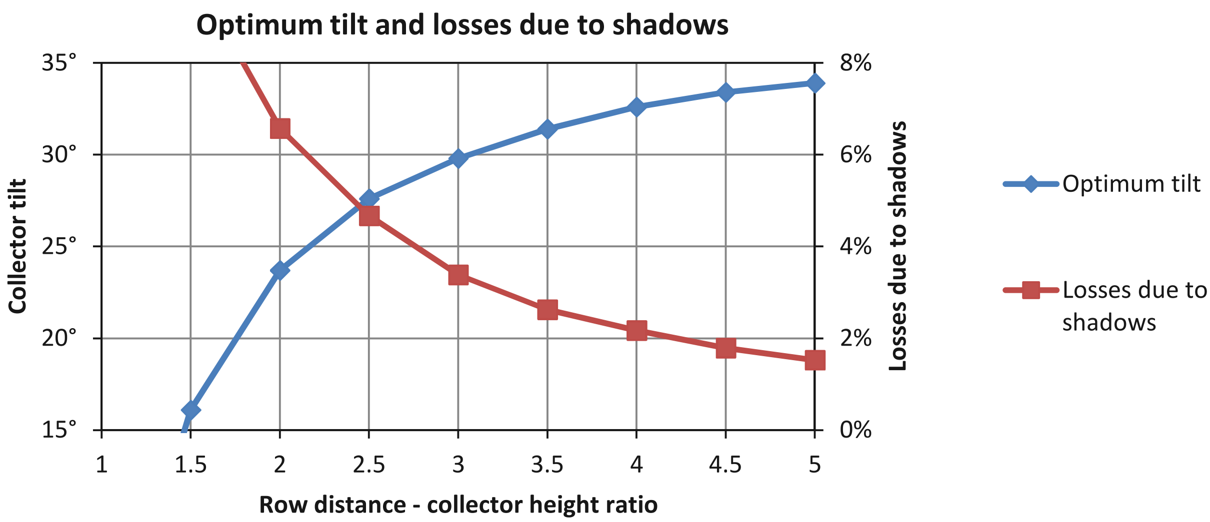

Fig. 2.2.3. Optimum tilt and losses due to shadows as function of the ratio between row distance and collector height. In the example a SDH plant in Tørring, Denmark is used. (Source: PlanEnergi)

Ground mounted collectors are normally the cheapest solution and it can be used as an aesthetic element in the landscape.

Fig. 2.2.4. "Collector Island" (SUNMARK), Almere, Holland [1].

Compared with other types of land use the gain/area is high. Using a rough estimate, solar thermal can be compared with other types of renewable energy in terms of annual yield per land area.

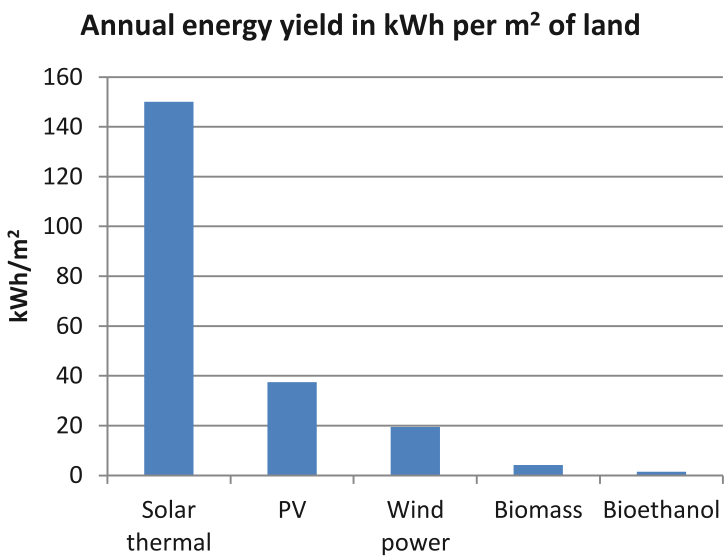

*Fig. 2.2.5. Annual yield per m^2 of land used for different renewable energies in Northern Europe.**

* *Assumptions: Output from an SDH plant: 15 % of the total solar irradiation. Photovoltaics (PV): ¼ of solar thermal. Wind turbines: 8 MW/km2 in 2400 full load hours per year. Biomass: 1000 tonnes/km2 (calorific value: 15 GJ/tonne). Bioethanol: ¼ liters per kg of biomass (calorific value: 22 MJ/liter).*

Roof mounted collectors

For large flat roofs the rules mentioned above for ground mounted collectors can be used.

For roofs with slope there are the following possibilities:

- Roof modules
- Roof integrated solar panels
- Solar panels on the roof

Roof modules and roof integrated solar panels can be used in new buildings and if a roof has to be refurbished. Solar panels on the roof can also be used on existing roofs.

Fig. 2.2.6. Implementation of roof modules (Wagner), Marstal, Denmark [2].

Fig. 2.2.7. Roof integration (Sonnenkraft), Austria [3].

Fig. 2.2.8. Collectors on the roof (ARCON), Denmark [4].

Other possibilities

Fig. 2.2.9. On the wall (Wagner), Germany [5].

Fig. 2.2.10. As shadowing for cars (ARCON), Neckarsulm, Germany [6].

Fig. 2.2.11. On a slope (Schüco), Crailsheim, Germany (by Stadtwerke Crailsheim GMBH) [7]. *Notice the size compared to the car on top and the man in the background.*

References

[1] Photo: Sunmark

[2] Photo: Marstal Fjernvarme

[3] Photo: Knud Erik Nielsen, Arcon Solar

[4] Photo: Arcon Solar

[5] Photo: Wagner homepage, www.wagner-solar.com

[6] Photo: Arcon Solar

[7] Stadtwerke Crailsheim GMBH homepage, www.stw-crailsheim.de

The SDH fact sheets addresses both technical and non-technical issues, and provide state-of-the-art industry guidelines to which utilities can refer when considering/realizing SDH plants. For further information on Solar District Heating and the SDHtake-off project please visit www.solar-district-heating.eu.

Chapter:	Preliminary investigations
Date:	August 2012
Size:	11 pages
Description:	Rough calculations of the costs and expected yield from a solar district heating plant.
Author:	Jan Erik Nielsen, PlanEnergi – jen@planenergi.dk
Co-author(s):	Riccardo Battisti, Ambiente Italia – riccardo.battisti@ambienteitalia.it
Available languages:	English
Version id:	2.3-6
Download possible at:	www.solar-district-heating.eu

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Availability of solar radiation

For assessing the feasibility of a SDH plant, the first parameter to take into account is the available solar resource.

The key figure needed is the global solar irradiation on a horizontal plane (G_0), usually expressed in kWh/m² per year. This figure must be related to the location where the plant will be installed or to a different location, but very close to the real one and with similar climatic characteristics.

The solar radiation data could be taken from different sources:

- Meteonorm software: www.meteonorm.com (example given in the figure below)
- National solar maps - from e.g. national meteorological institute.
- Photovoltaic Geographical Information System (PV GIS): re.jrc.ec.europa.eu/pvgis. Though created for photovoltaic, this **online platform** provides solar radiation data, which can be used also for the assessment of solar thermal plants. It also allows calculations of solar radiation on tilted surfaces.

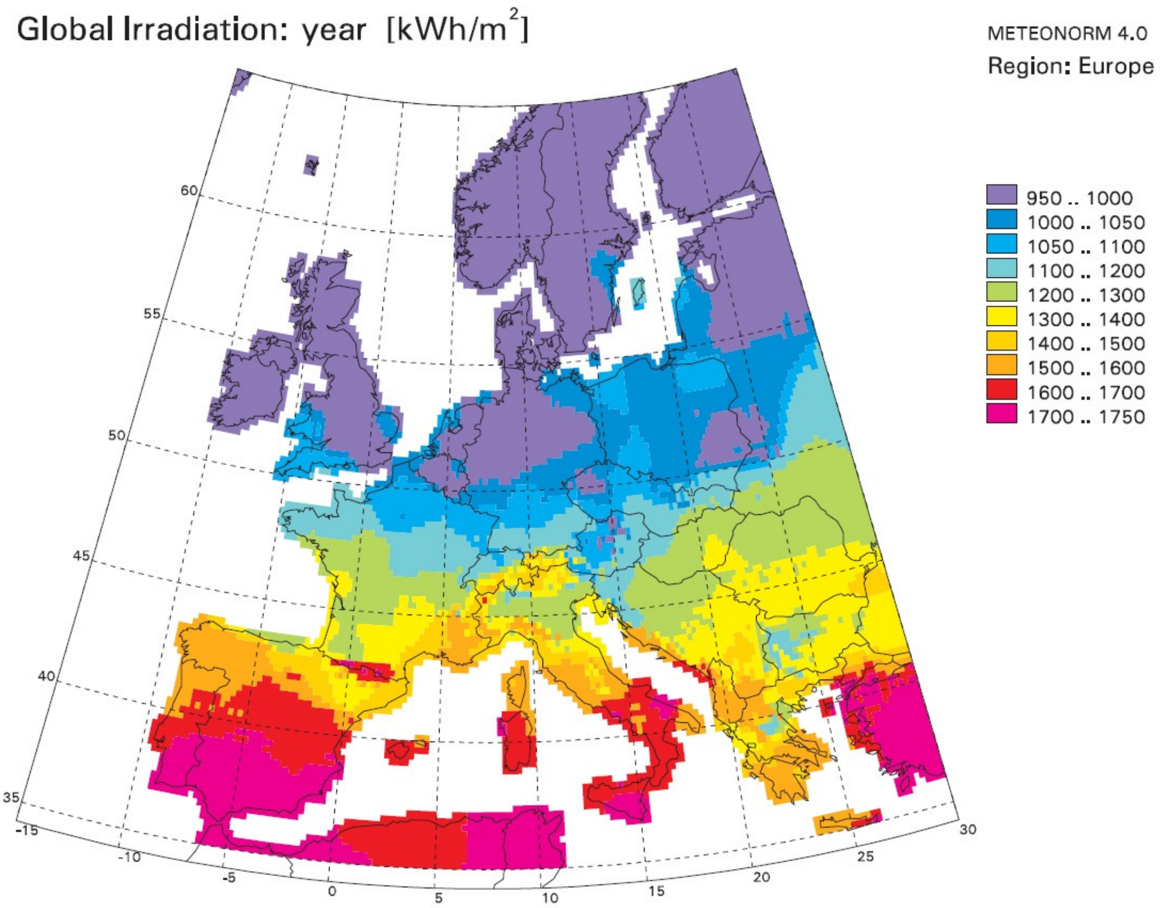

Fig. 2.3.1. Average global annual solar irradiation in Europe on horizontal surfaces [1].

By tilting the collectors the irradiation on the surface is increased. In general the further away from equator the location is, the more tilt is needed, but there are several things to consider when optimizing the tilt. This issue is addressed in fact sheet 2.2 *"Where to place the collectors"* in the subsection *"Ground mounted collectors"*. Below is seen a similar map with average daily irradiation levels for surfaces tilted 40° to the south.

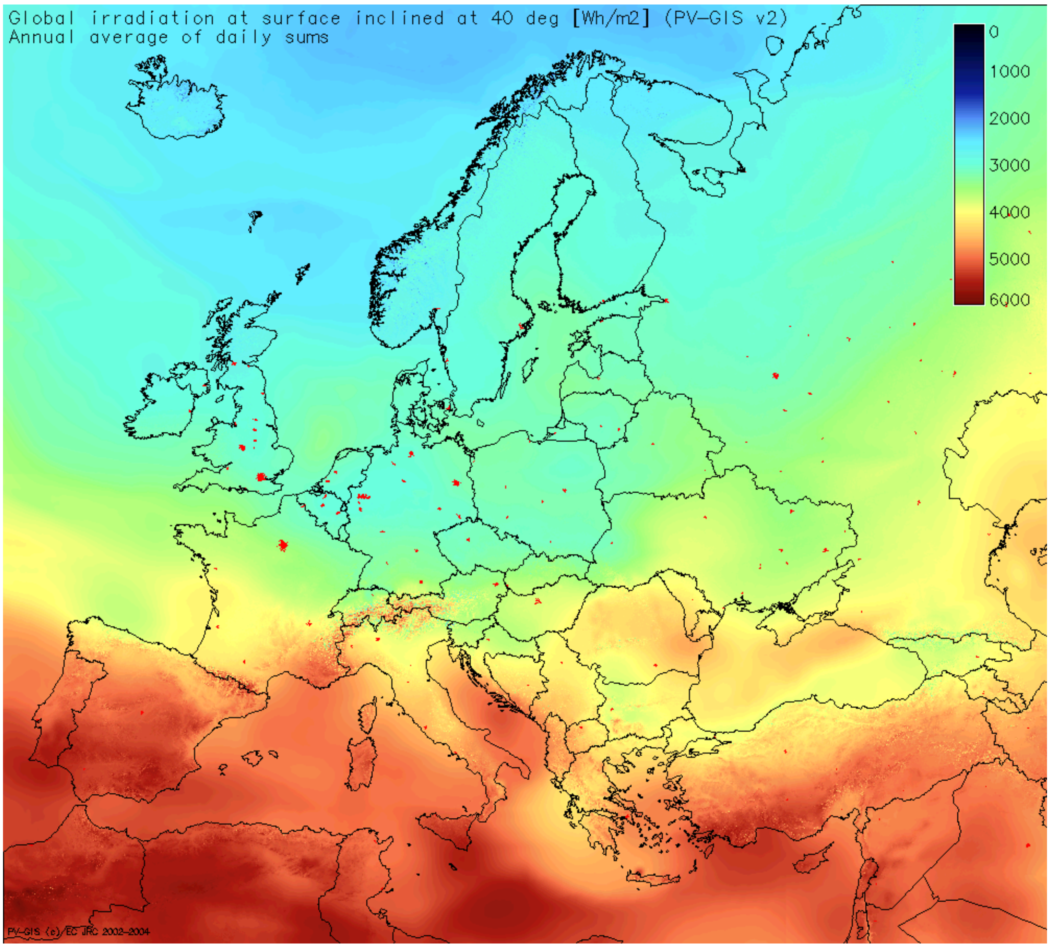

Fig. 2.3.2. Average global daily solar irradiation on a surface tilted 40° from horizontal, facing south [2].

Define locations available for collectors, storage, and the costs of land

Another key issue to be taken into account is the location of the collectors:

- How much area is available both for the collectors and the storage?
- Where should they be placed – on the ground and/or mounting on roofs?
- What is the cost of renting the land/roof for installing the plant?

Collectors on roofs

It is important to differentiate between “roof-mounted collectors” (normally flat roof) and “roof-integrated collectors” where tilt and orientation of roof has to be suitable for collector integration.

The cost of a roof-mounted collector field heavily depends on the characteristics of the building and the roof:

- structural analysis of roof and building: are reinforcements necessary? Is it possible to use concrete blocks in order to resist wind forces (often cheapest solution)?
- if concrete blocks are not possible: how can collectors get connected to the roof? Often construction/renovation of roof is the best moment for integration of collector mountings. Drilling into flat roofs otherwise often results in leakage problems.

In best-case scenario the collector field and the technical equipment can be mounted with concrete blocks on the roof just like a ground-mounted solar plant. Costs for land preparation works are saved but there are maybe some extra costs for stronger substructures because of higher wind loads on top of the building than on ground level.

Worst-case scenario is that reinforcements and expensive mounting works are necessary for each collector and that the technical equipment needs to be installed in a remote room of the building below.

For roof-integrated collectors costs for roof tiles are saved, but there are extra costs in terms of special methods necessary for leak-proof roof integration.

Collectors on land

For each possible collector land area the investment costs [€] are given by

$$pr_{land,location} = A_{land} \cdot pr_{land} + D_{location} \cdot pr_{location} \qquad \text{(eq. 2.3.1)}$$

where

A_{land}:	Area of land used for the collector field	[m²]
pr_{land}:	Price of land	[€/m²]
$D_{location}$:	Distance from collector field to network connection point (half the length of the total transmission pipe length)	[km]
$pr_{location}$:	Price per km distance	[€/km]
	(as a first estimate one could use $pr_{location} = 1400 \cdot \sqrt{A_{land}}$ *[€/km])*	

Another relevant factor linked to the use of land, is the consideration of heat loss from long transmission pipe, which will influence the total energy output of the plant. Below in fig. 2.3.3 the loss in % of collector output is given for 1 km distance between collector field and network connection point. It is assumed here that the area of land is around 3.5 times the area of collectors. It is common to use the *aperture area*[*] when referring to the collector area. This is also the case in this fact sheet.

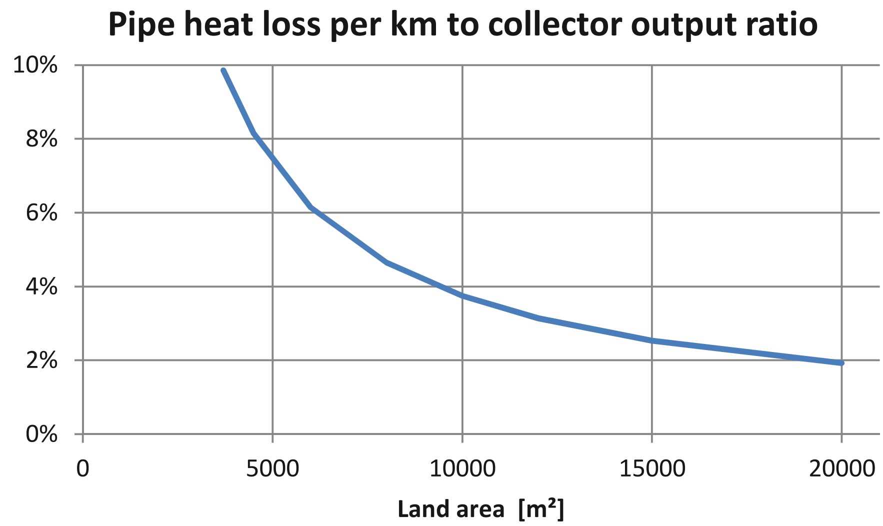

Fig. 2.3.3. Pipe heat loss per km distance between collector field and district heating network connection point related to collector output for varying land area (3.5 m² of land is used per m² of collector). (Source: PlanEnergi)

The equation behind the figure is:

$$Q_{pipe,loss} / Q_{collector,output} = 350 / A_{land} + 0.24 / \sqrt{A_{land}} \quad [-] \qquad \text{(eq. 2.3.2)}$$

where

$Q_{pipe,loss}$:	Heat loss from pipe in kWh/y per km distance between collector field and network connection point	[kWh/y/km]
$Q_{collector\ output}$:	Collector output	[kWh/y]

It is seen that for large collector fields it is possible to transport the heat over long distances without loosing very much in percent.

<u>Example:</u>

[*] *See fact sheet 7.1 Solar collectors for a description of the area definitions.*

It is possible to use an area of 20000 m² 2 km outside the town. From the figure you can see that the performance reduction will be 2 % per km, so 2 km · 2 %/km = 4 % of the collector output.

Estimated solar output

A first rough estimate on the solar energy output for simple systems operating around an average annual operating temperature of 50 °C [kWh per m^2 of land used and per year]:

$$q_{land} = 0.15 \cdot G_0 \quad \text{(eq. 2.3.3a)}$$

This equation can be used only for system with low solar fraction (< 10 %), that is when storage heat losses are negligible.

However, the solar output depends very much on the operating temperatures of the DH network, as well as on the collector technology and on several additional parameters[†]. An example of temperature correction can be seen in figure 2.3.4. Here the relative values for the annual output, corresponding to constant DH network operating temperatures, are shown (reference collector temperature is 50 °C).

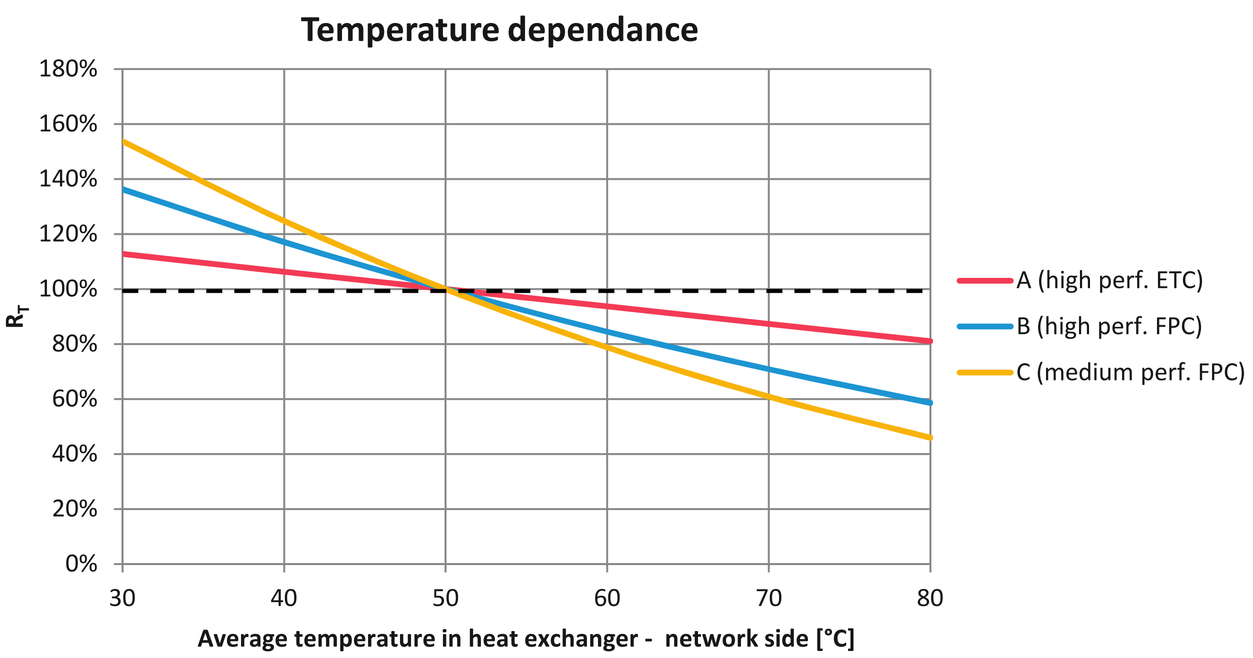

Fig. 2.3.4. Example of how the annual output is influenced by the DH network operating temperature (the temperature on the secondary side of the collector loop heat exchanger). (Source: PlanEnergi)

[†] *Collector orientation, distance between collector rows, control strategy, heat exchanger, storage type, combination with other energy technologies, etc.*

R_T is a "temperature correction factor" defined as the solar output at the actual operating temperature related to the solar output at 50 °C:

$$R_T = Q_{solar,actual} / Q_{solar,50} \quad \text{(eq. 2.3.4)}$$

Figure 2.3.4 shows that the solar output depends strongly on the operating temperature of the DH network. An increase of 1 °C in operating temperature reduces the solar output 1-2 %, since higher temperatures imply lower operating efficiency for the solar collectors.

Solar fraction

The solar fraction tells you how much the solar system contributes to the total production from the entire heat generating system:

$$S_F = Q_{solar\ output} / Q_{total,production} \quad \text{(eq. 2.3.5)}$$

where $Q_{solar\ output}$ is solar system output and $Q_{total,production}$ is the total heat production of all units.

For low solar fractions (< 10 %) it will often be possible to keep the average operating temperature down around the 50 °C and equation 2.3.3a can be used in the following way:

$$Q_{solar,low} = 0.15 \cdot G_0 \cdot A_{land} \quad \text{(eq. 2.3.3b)}$$

$$S_F = Q_{solar,low} / Q_{total,production} \quad \text{(eq. 2.3.6)}$$

Beware that the uncertainty of eq. 2.3.3b is increased for S_F higher than 10 % since the storage heat losses will not be as negligible in this case. For high solar fractions and if a long term storage is included, it is necessary to make more detailed calculations. The higher the solar fraction and the longer the storage time - the higher the average operating temperature and the lower the solar output. A feeling of the performance reduction could be obtained looking at figure 2.3.4 showing for different types of collectors the influence of the operating temperature.

Storage size

The size of the storage depends on several different parameters e.g.:

- Collector area
- Solar fraction
- Other heat generating systems (heat pump, gas motor etc.)

- Total load

In figure 2.3.5 the "optimal" storage size in m^3 per m² collector is plotted against the solar fraction. This can be used as a first estimate on storage size; but especially for large solar fractions - and if combined with a heat pump - the storage size should be carefully optimized with detailed calculations/simulations - and the optimum could differ significant from what is suggested in figure 2.3.5. See fact sheet 7.2 *"Storage"* for more information.

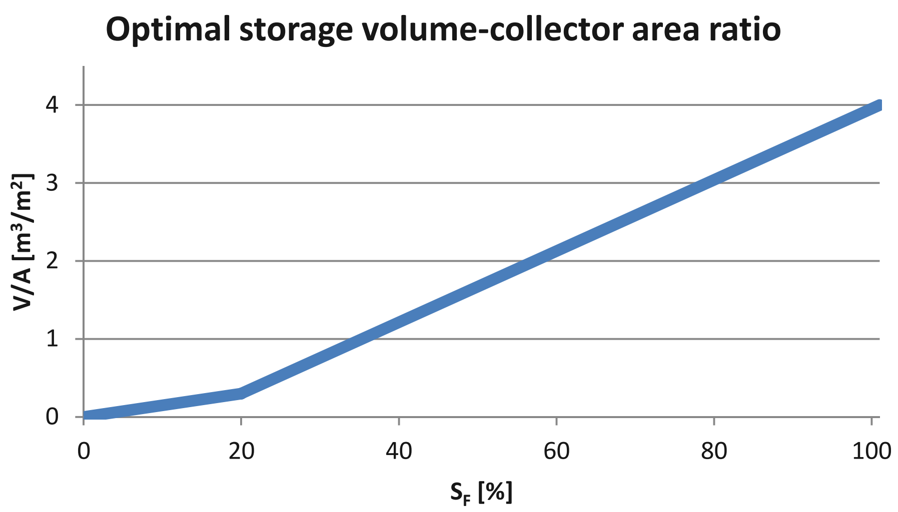

Fig. 2.3.5. First rough estimation of optimal ratio between storage volume and collector area as function of solar fraction [3].

Cost estimation

Based on experiences from existing solar district heating plants the approximated component costs can be estimated. The total costs of the solar district heating system comprise:

- Cost of land
- Collectors
- Collector field installation including piping in the field
- Anti-freeze fluid
- Transmission piping (collector field to heat exchanger unit)
- Heat exchanger (HX) unit (including pumps, expansion vessels, control, etc.)
- Connection to existing district heating system
- Storage

- Control system
- Design & optimization
- Miscellaneous (e.g. building, ground shaping, fence, plants)

The cost of land has to be determined for the specific location.

Costs of collectors, collector field installation (on flat ground) including field piping and fluid, and heat exchanger unit can be estimated by the curve shown in figure 2.3.6.

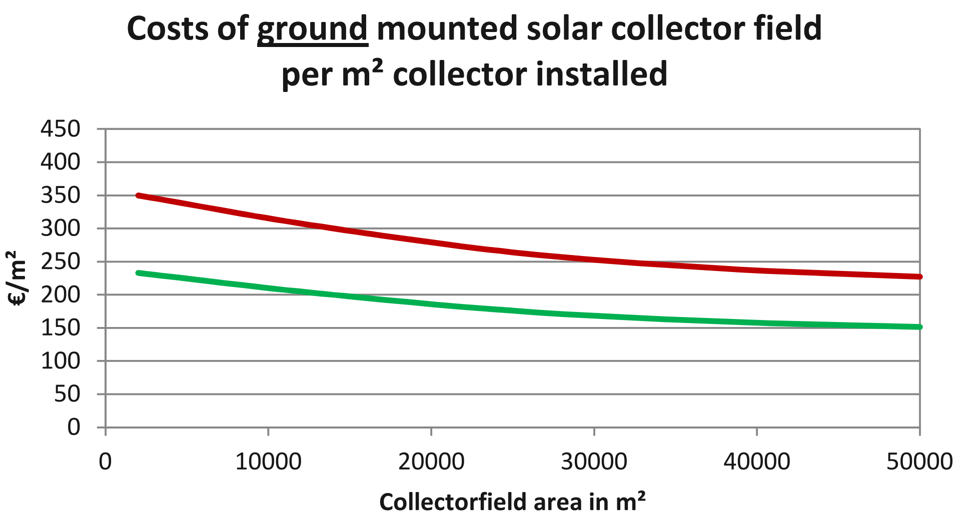

Fig. 2.3.6. Approx. price per m² collector field - including installation, piping, HX-unit, etc. (excl. storage and VAT). Prices will typically be between the upper red and the lower green line. Values valid for ground mounted collectors‡. (Source: PlanEnergi)

The cost of transmission piping has been estimated in the section "Define locations available for solar collectors and storage, and the costs of land" above.

An approximate price of the glycol-water mixture is 1000 €/m^3. This corresponds roughly to a price per m^2 collector of 3 €/m^2 - but depends of course very much on the fluid content in the chosen collectors.

For collectors installed on roofs the prices are seen in figure 2.3.7.

‡ *Based on Danish examples.*

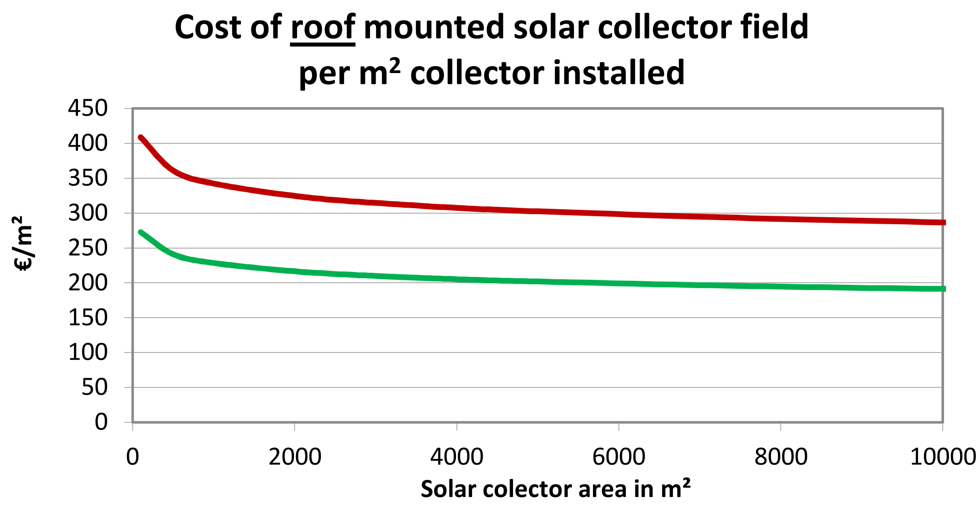

Fig. 2.3.7. Approx. price per m² collector - including installation, piping, HX-unit, etc. - but excl. storage, designing and VAT. Prices will typically between the upper red and the lower green line. Values valid for roof mounted collectors§. (Source: Solites)

In figure 2.3.8 the cost of pit storages are seen for different volumes. The blue curve represents the experiences from Marstal Denmark. The red curve represents the costs incl. possible extra costs due to difficult excavation etc. The green curve represents the expected lower costs due to a newly designed lid type. Examples from different realized storage systems in Germany are shown in fact sheet 7.2 *"Storage"*.

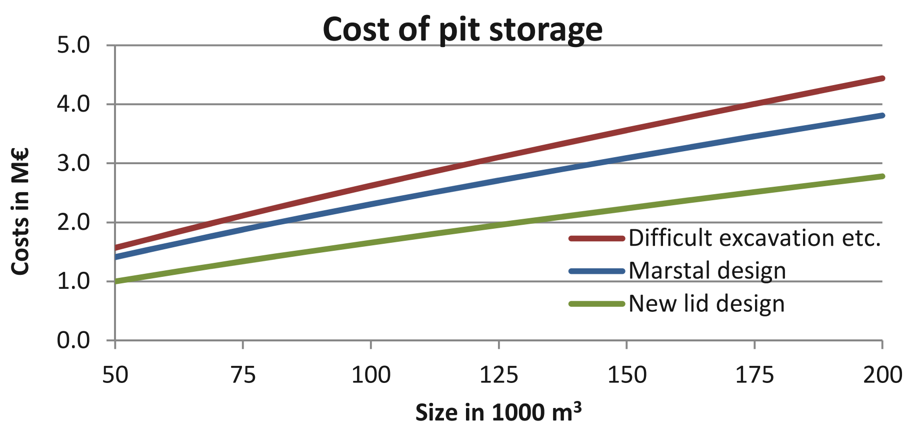

Fig. 2.3.8. Approximated price of total storage as function of volume [4].

The cost of the planning, designing & optimization is approximately 2-5 % of the total investments. Other

---

§ *Based on German examples.*

costs than mentioned here, have to be considered before summing up the approximated total installation costs e.g. the costs of shaping the ground for the collector field which depend highly on how extensive the work has to be.

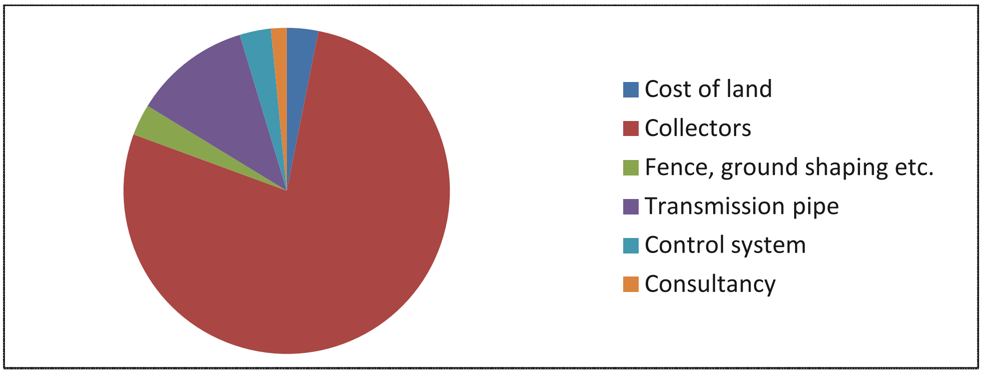

Fig. 2.3.9. Example of cost distribution (Tørring, DK). Note that storage is not included. (Source: PlanEnergi)

An on-line calculation tool has been created to give - in a quick and easy way - such kind of rough estimations based on experiences from existing SDH plants:

www.solarkey.dk/f-easy/f-easy.xlsx

Fact sheet 2.4 *"Questionnaire for SDH site assessment"* contains a template which can be used when collecting the base data for assessing the feasibility of a solar district heating system at a specific site.

References

[1] Meteonorm, www.meteonorm.com

[2] "PVGIS", European Commission, Joint Research Centre re.jrc.ec.europa.eu/pvgis/solres/solrespvgis.htm#inclined

[3] "Energistyrelsens Teknologikatalog" (*The Danish Energy Agency Technology Catalog)*, 2010, p. 163, www.ens.dk/Documents/Netboghandel%20-%20publikationer/2010/Technology_data_for_energy_plants.pdf

[4] SUNSTORE 4, WP5 - European level concept study, Feasibility/simulation studies, Draft 1, p. 34.

The SDH fact sheets addresses both technical and non-technical issues, and provide state-of-the-art industry guidelines to which utilities can refer when considering/realizing SDH plants. For further information on Solar District Heating and the SDHtake-off project please visit www.solar-district-heating.eu.

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Questionnaire for SDH site assessment

Chapter:	Preliminary investigations
Date:	April 2012
Size:	6 pages
Description:	This fact sheet provides a questionnaire for collecting the base data for assessing the feasibility of a solar district heating system at a specific site.
Author:	Thomas Schmidt, Solites – schmidt@solites.de
Co-author(s):	-
Available languages:	English
Version id:	2.4-2
Download possible at:	www.solar-district-heating.eu

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Introduction

In order to be able to make an investigation on the most profitable energy generation mix and the potential of renewable energy sources as e.g. large scale solar thermal collector fields and thermal energy storage for a specific site numerous conditions including the electrical and thermal loads of consumers, existing and new technical equipment, climatic and economical boundary conditions etc. have to be evaluated. This document provides a questionnaire to collect the required information. The information should be given as complete and detailed as possible. The quality of an assessment is strongly depending on the quality of the provided information.

General description of supply area and consumers

General description

Please describe the supply area and the consumers. Please also list existing and intended installations. More detailed information is asked for below.

Site map

Please provide a site map and indicate the location of consumers and existing installations as well as possible locations for solar collectors and storage.

- What is the approximate amount of area available for placing solar collectors?
- How much is available on the ground and/or on roofs?
- Which is the state of the roof?
- What would be the cost of buying/renting land and/or roof?

Climatic data

Please fill in Table 2.4.1.

Table 2.4.1 Required climatic data.

Month	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	**Year**
Ambient temperature (Mean value)													
Horizontal irradiation (Sum value)													
Heating degree days													
Room reference temperature:													
Ambient reference temperature:													
Cooling degree days (if required)													
Room reference temperature:													
Ambient reference temperature:													
Source of data:													

Note: If detailed (hourly) climatic data is available it should be attached as a separate data file.

Chronological development of the heat load

Please describe the chronological development of the supply area for the next years (e.g. changes in heat demand due to extension or refurbishment measures in the coming years etc.)

Electrical and thermal energy demand, distribution systems and temperature levels

Please fill in one Table 2.4.2 for each consumer / consumer group at the site.

Table 2.4.2 Consumer data template sheet.

Consumer or consumer group?	C/CG	
Consumer shortname	-	
No. of equal consumers	-	for groups of identical consumers, demand values will be multiplied by this number
Type of usage	-	e.g. residential, office, industrial, etc.
No. of users / inhabitants	-	
Gross floor area	m^2	
Heated floor area	m^2	
Cooled floor area	m^2	

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Reference area
Monthly electricity demand	kWh/ m^2a													
Monthly heat demand for DHW*	kWh/ m^2a													
Monthly heat demand for space heating	kWh/ m^2a													
Total monthly heat demand (incl. e.g. process heat etc.)	kWh/ m^2a													
Total monthly cold demand	kWh/ m^2a													

Type of heat distribution system	-	e.g. radiator system, floor heating system, etc.
Design values for heating supply / return temperature and dependency on ambient conditions	°C	
Type of DHW* prep. system	-	e.g. tank system, direct heating by heat exchanger, circulation system yes / no
Design DHW* temperature	°C	
Thermal DHW* circulation system	-	available? continuous or intermittent operation?
Thermal DHW* disinfection measures	-	e.g. regular temperature raises

* *DHW ~ domestic hot water.*

Note: For the assessment short term (hourly) values of the demand are desirable. If short term demand values are available for consumer buildings e.g. from dynamic buildings simulations or from monitoring data they should be attached in an extra data file. If detailed values are not available they can be generated. Accuracy of results will be less in this case.

Technical equipment

Please list the relevant existing and / or foreseen technical equipment producing and storing thermal energy in Table 2.4.3. Please multiply the table for more than one supply system.

Table 2.4.3 Technical equipment producing and storing thermal energy.

	existing/ remaining/ intended	**size**	**fuel**	**supply area**
Boilers		kW		
Chillers		kW		
CHP-units		kW_{el} / kW_{th}		
Heat pumps		kW_{el} / kW_{th}		
Solar thermal collectors		m^2 (absorber)		
Thermal storages		m^3		
Others				

	existing/ intended	**length**	**supply area**
Supply network for heat			
Supply networks for cold			

Geological data

Please provide available data about undisturbed groundwater level and natural groundwater flow.

Note: Usually the responsible water authorities have information about the general geological situation in a specific area.

Stratigraphic sequence

Please provide available information about the stratigraphic sequence down to a depth of 50 – 100 m below ground surface.

Economical data

- Natural gas purchase price in €/kWh (incl./excl. VAT)
- Electricity purchase price in €/kWh (incl./excl. VAT)
- Time dependency of the electricity price (e.g. on the hour of the day etc.)
- Capacity dependency of the electricity price (e.g. on contracted power, maximum electric load etc.)
- Financial limit for energy generating and storing installations
- Description of existing incentives for renewable / high efficiency generation units (e.g. cogeneration) (e.g. subsidies or tax reductions for purchasing the installation, feed-in tariff during operation, etc.)

Legal situation

Development scheme

Please include a summary of relevant boundary conditions from the development scheme.

Other legal boundary conditions / restrictions

Please give information about other legal boundary conditions / restrictions if appropriate.

ESCOs

Please provide contact details of existing ESCOs (Energy Service Company) in the area.

┘ *The SDH fact sheets addresses both technical and non-technical issues, and provide state-of-the-art industry guidelines to which utilities can refer when considering/realizing SDH plants. For further information on Solar District Heating and the SDHtake-off project please visit www.solar-district-heating.eu.* ┌

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Chapter:	Preliminary investigations
Date:	April 2012
Size:	8 pages
Description:	Different possibilities for the combination of ownership and financing.
Author:	Per Alex Sørensen, PlanEnergi – pas@planenergi.dk
Co-author(s):	Solites – info@solites.de
Available languages:	English
Version id:	2.5-2
Download possible at:	www.solar-district-heating.eu

Contents

Introduction

Normally for investments in district heating production the implementation costs are relativity low and the costs for fuel and running the plant calculated as net present value is higher. But for solar district heating the situation is, that nearly all costs are in the implementation phase. Thus the investor is paying the costs for heat for the next 20-30 years already in the implementation phase. Since heat production prices from alternative sources (gas, oil, biomass) are fluctuating and the technological development might bring new solutions on the market investors might be cautious when investing in solar district heating. On the other hand solar district heating offers stabile heat prices for a part of the heat production. This argument is often one of the reasons for establishment of solar district heating.

In the following different combinations of ownership and financing are explained.

We have chosen examples from different European countries where 1) **The district heating utility** owns the solar collector plant. This is a legally uncomplicated solution often used in Denmark for ground mounted solutions, 2) The solar collectors are **roof mounted and owned by the utility or private owned.** This solution is common in Germany, 3) The solar collectors are **financed and owned by a 3rd part.** A solution that has been used a.o. in Austria and 4) . The solar collectors are **co-operative owned**, where public authorities or utilities can be a partner also.

If someone else than the utility owns the solar collector plant a contract has to be made between the utility and the plant owner. A check list of important issues in such a contract can be found in the last part of this fact sheet.

Utility as owner

If the utility owns, finances and runs the solar district heating plant no contracts and feed in tariffs have to be made with 3rd parties. This is the simplest situation for the district heating utility and the normal way if they trust the technology and can find financing.

Financing of ground mounted solar collectors in Denmark is as a main rule with annuity loans, where the local municipality gives a 100% guarantee for the loan. The municipality can do this with nearly no risk because the consumers have a contract with the district heating utility, saying that they are obliged to be a customer and thus the income for the district heating utility is secured.

Private ownership

If the solar collectors are placed on a private roof or integrated in the roof, there is a risk for losing the investment if the owner of the building goes bankrupt. It is crucial that the party who made the investment for the collectors always keeps ownership of the collectors and is thus not affected by bankruptcy of the building's owner.

There are different solutions to handle this issue. In Sweden central plants with collectors on roofs are built by municipal companies and they own the buildings, the heating plant and the collectors. In the most recent decentralized plants, the collectors are owned by the building owner and then he is buying and selling heat according to a contract with the district heating net owner (in the same way as it is done for a grid-connected PV-plant).

In Germany some cases exist where the building is privately owned and the roof-mounted collectors are owned by the utility. However, according to German law everything that is fixed to the building and that is necessary for the function of the building passes into the ownership of the building owner after installation. This can be avoided by a private contract between the building owner and the utility. The owner of the building and the utility also have to sign a contract that defines the easement on the real estate as well as maintenance, liability for premises and deconstruction of the solar collectors. It is further recommended to install a sub-roof below the solar collectors and to define exactly the ownership interface. The legal base for such a contract has been elaborated in [1].

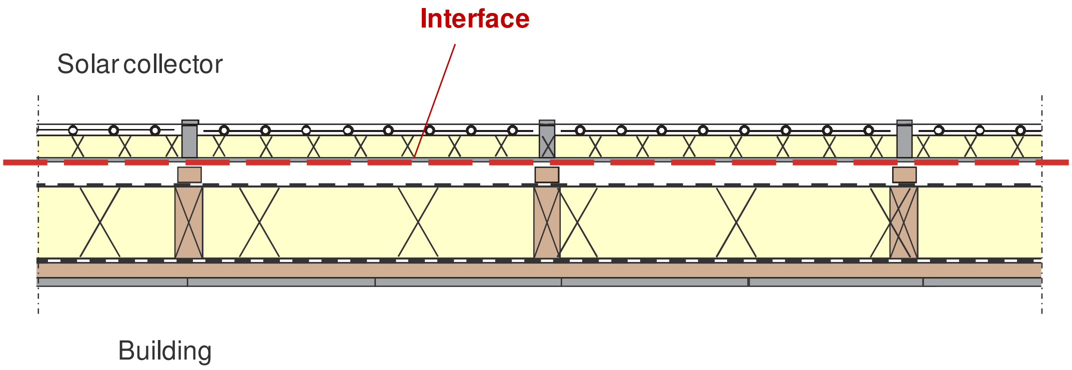

Fig. 2.5.1. Definition of ownership interface for roof mounted solar collectors. (Source: Solites)

There will also be risk for extra costs from leakages. Therefore the district heating utility might prefer private ownership and financing.

In this case a contract between the utility and the plant owner including feed in tariffs for delivering heat to the district heating network is needed. This contract might also include service obligations if the utility runs the solar plant.

The most important issues are mentioned in the check list in the last part of this fact sheet. A more detailed description can be found in [2].

Private ownership and 3rd part financing

The implementation of solar heating requires a major investment while the operation costs are very low. One prerequisite to make the investment is that the plant owner judges the risk in a favourable way. As most utilities and building owners lack experience from solar heating the risk is judged to be too large, even if the long term economic feasibility looks interesting. One way to overcome this problem is to create an Energy Service Company (ESCO) that makes the investment, operates the plant and sells the heat to a housing facility owner or to a district heating utility. The main driver behind the solar ESCO development is the local company S.O.L.I.D. The development has led to a number of realised solar heating plants in Austria, especially four large plants in the district heating system in Graz. Further description can be found in [3]. Use the check list in the last part of this guideline for contracts between utility and plant owner.

Solar collectors in co-operative ownership

A solar assisted district heating system was built in a new housing development of Neckarsulm (DE) in the late 1990s. The district heating system includes several solar collector fields and is operated by the Utility of Neckarsulm.

One of those solar collector fields was installed as roof of a carport with an aperture area of 454 m² (see Fig.2.5.2. At first the financing of the solar collectors (incl. piping, substructure, etc.) was done by the utility Neckarsulm. Afterwards the collector field was sold in units of 20 m² to private persons but is still operated by the utility Neckarsulm until today. The administration and the accounting are done by the Solar- und Energie-Initiative Heilbronn e.V.

Fig. 2.5.2. Solar collector field "carport" in Neckarsulm (DE). (Source: Solites)

The calculation of the costs is done according to the energy value of the heat meter once a year. The financing concept bases on an annual output of 300 kWh/(m^2·a) of the solar collector field. The dividend of the solar collector field consists of the demand charge which is fixed to 97.15 € per year and unit and the energy price that is linked to the gas price. From the dividend an administration fee and reserve is subtracted. Per unit the stakeholders get an annual dividend of about 130 to 180 €.

Types of loans

As mentioned in the beginning of this fact sheet the cost structure of renewable energy systems is totally different from the cost structure in an energy system with fossil fuels. Therefore it can be difficult to make a fair comparison of prices.

In the following production prices for renewable energy systems are calculated with two different loan types and under different conditions:

Serial loans, where write-off is linearly and annuity loans where the yearly costs of the loan are fixed (same amount every year).

If the loan is 1 million €, interest rate is 5%, period of payment 20 years and inflation is 2% the payment will develop as shown in fig. 2.5.1 below.

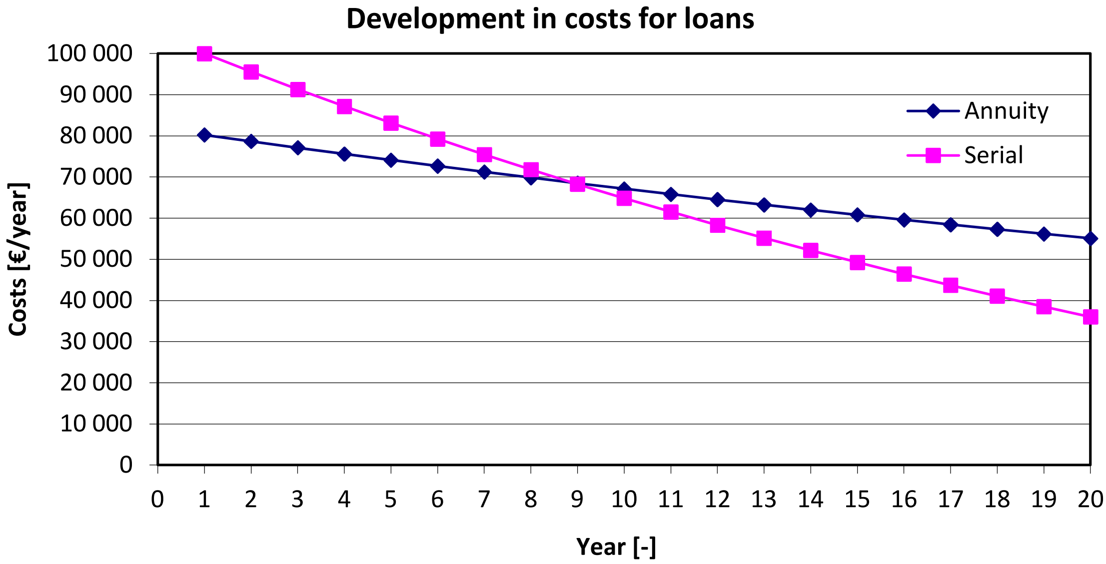

Fig. 2.5.3. Development in costs for annuity loans and serial loans, interest rate 5%, inflation 2%.

If all the costs are implementation costs the yearly costs in the example in figure 2.5.1 will in year 20 be 36% of the first year costs with a serial loan and 55% of the first year costs with an annuity loan. Thus it is not fair to compare first year costs only. Below is shown the differences for calculation under different assumptions.

Table 2.5.1. Yearly costs for loans, interest 5%, 20 years, inflation 2%.

Assumption	Cost in % of serial loan
Serial loan, 5%, 1st year	100
Serial loan, 4%, 1st year	90
Annuity loan, 5%, 1st year	80
Annuity loan, 4%, 1st year	74
Annuity loan, 6%, average	67
Annuity loan, 4%, average	61

Check list of important issues in a contact between utility and plant owner

1. Subject of the contract

Fixes the basics of the solar energy supply:

- Who is the plant owner, who is the utility
- General information on the system integration of the solar thermal plant
- Start of the energy supply, usually fixed within a certain period of time or with a latest starting date.

2. Duration of the contract

Fixes the beginning and the end of the energy supply, and additionally:

- Exit clauses and exit terms for contracting out of the agreement for both contractual parties. This can be a tricky paragraph, and it is important to negotiate conditions which assure long-term stability for selling the solar energy!

3. Installation of the solar plant, property line

- Who is responsible for the installation of the technical equipment?

- Describes in all detail where the limits of performance are drawn, in particular the utilities responsibilities are defined. Moreover, the energy delivery point (usually position and integration of heat exchanger) is specified.
- Certifications requested
- Who pays the electrical energy for pumps and other equipment?
- Who cares for the ongoing service and maintenance of the solar plant?
- Property structure of the areas which are going to be affected by the solar plant in some way (tech room, roof, space for piping, …)

4. Details on the energy supply and the operation of the plant

Fixes all details between the plant owner and the utility that are related to the solar energy supply service:

- For the plant owner, is there an obligation or a right to deliver the system's energy output to the utility? Required forward temperature and max flow?
- For the utility, is there an obligation or a right to buy the solar energy? How about required return temperature?
- All the risks concerning damage of the solar plant and damages or consequential damages that are due to some improper operation of the plant are for the plant owners' account.
- Date for earliest and / or latest begin of the energy delivery to the utility.

5. Solar energy price

This part specifies all questions related to the tariff model of the solar energy. It is completely arbitrary for both contract parties to agree upon a model which serves both sides' interests.

- Same price for the whole year or difference between summertime and wintertime?
- Price reduction for lower temperatures than required?
- Solar energy indexed to consumer price index / some other energy / any other reasonable factor? What's the effective date that serves as a basis for the indexing calculations?
- What happens if one of these factors changes drastically? New definition of this part of the contract?
- What happens if solar energy prices are related to other fossil fuel prices?

6. Measurement and charging of the solar energy

- How is the solar energy measured?
- Any prerequisite for the measuring facilities or the measurement system in general?

- How is the solar energy going to be metered and charged to the customer?
- Who calibrates the measurement equipment?
- Term of payment for the solar energy invoices

7. Other contract clauses

- How are withdrawals from the energy supply contract handled? States all circumstances under which one of the contract parties could exit the contract without legal consequences.

8. Legal venue

- Fixes the legal venue for any misconceptions between the contract parties
- Usually, there are appendices to the energy supply contract. Most commonly, the following appendices are included:
  - Hydraulic scheme of the energy delivery station with integration of the solar plant
  - Hydraulic scheme of the solar thermal plant.

References

[1] von Oppen, M.: Rechtliche Rahmenbedingungen für große Solarwärmeanlagen - Vorstellung einer Studie im Auftrag des BMU, OTTI 20. Symposium Thermische Solaranlagen, May 2010.

[2] IEE-project ST-ESCOs.

[3] Jan-Olof Dalenbäck: Success Factors in Solar District Heating, January 2011, www.solar-district-heating.eu

The SDH fact sheets addresses both technical and non-technical issues, and provide state-of-the-art industry guidelines to which utilities can refer when considering/realizing SDH plants. For further information on Solar District Heating and the SDHtake-off project please visit www.solar-district-heating.eu.

Chapter:	Permissions, tendering, contracts and guarantees
Date:	August 2012
Size:	6 pages
Description:	Permissions needed to make sure the construction of the plant is legal.
Author:	Per Alex Sørensen, PlanEnergi – pas@planenergi.dk
Co-author(s):	-
Available languages:	English
Version id:	3.1-3
Download possible at:	www.solar-district-heating.eu

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Introduction

When having an idea of where to place the solar collectors in a solar district heating project it is a good idea to visit the municipal authorities to find out what kind of permissions are needed.

This could be e.g. planning permission, environmental permission, permission according to heat planning, energy planning and building permission.

If a long term storage (boreholes, pit heat storage) is needed, special permissions according to drinking water protection will also be needed.

If the solar collectors are roof mounted there might be building restrictions for the roof (especially for old buildings in historical parts of cities) or restrictions about reflections, but normally the only permission needed is a building permission. So the following text is mainly for ground mounted solar collectors.

Planning permission

The planning authorities take care of use of land in and around the city. Different areas can already be pointed out for recreation, industry, apartments etc. Or there can be restrictions caused by min. distances to churches, archeologically sites, forests, rivers, lakes, sea...

When one or more areas has been fund, the land owner(s) has to be contacted and an agreement according the price for buying or renting the land has to be made.

If there are high trees directly next to the plant, these trees could shadow the collectors significantly. It has to be considered that for cutting down the trees you need in most cases a permission from the local authority.

You should also be aware, that there could be any supply pipes under the ground where you would like to mount the collectors. It is very important to collect information about possible underground pipes from the land owner or the authorities.

Then the planning procedure can start. Try to find one contact person by the authorities. In the planning process the authorities will need a disposition plan (see example in fig.3.1.1) and they might also require visualisations (see example in fig.3.1.2).

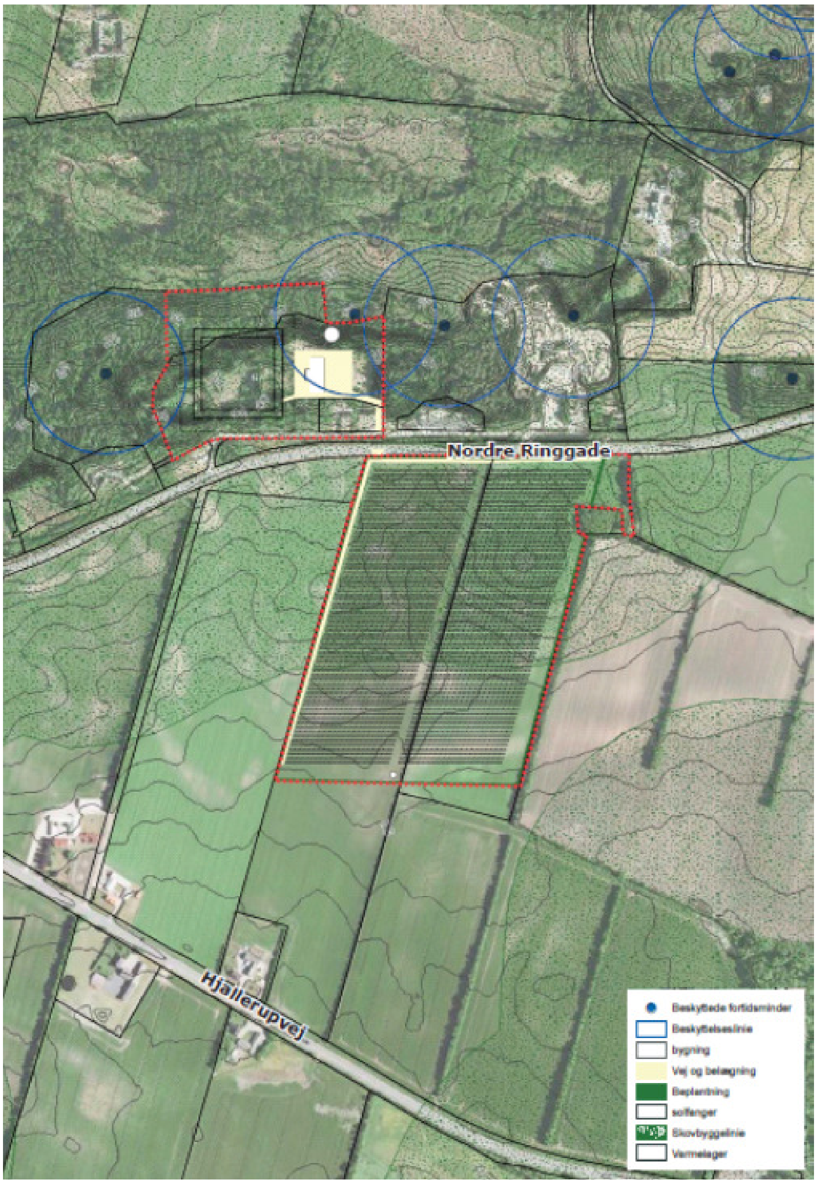

Fig. 3.1.1. Example of disposition plan for 35.000 m^2 solar collectors and 60.000 m^3 pit heat storage, Dronninglund, Denmark. (Red lines mark the area for the plant (storage and collector field). The blue circles indicate a distance of 100 m from relics.) (Source: District plan for SUNSTORE 3 project)

Fig. 3.1.2. Example of visualisations, Dronninglund, Denmark. (Source: District plan for SUNSTORE 3 project)

Environmental permission

For the environmental permission, emissions to air, ground and water has to be explained.

There are no emissions to the air from the solar collectors, but the solar collectors normally replace other fuels and thus save emissions. Saved emissions can be calculated when fuel is known.

Table 3.1.1. Emissions in kg/MWh fuel [1]

Fuel	**SO_2**	**NO_x**	**CO_2**
Straw	0.47	0.32	0
Oil boiler	0.08	0.23	266
Gas boiler	0	0.15	204
Gas engine	0	0.49	204
Biogas	0.07	0.73	0
Electricity*	1.18	0.45	364
Wood	0.09	0.32	0
Waste	0.03	0.37	117

* *Average for Danish electricity production 2011.*

Emissions to water can be caused by leakages of collector fluid. Therefore the chemical content of collector fluid has to be given to the authorities (normally water + glycol) including measures to prevent leakages.

In case of leakages, most of the time the authorities requires an “Action plan”.

These measures can be alerts in the control system (for pressure drop) and blow off systems for too high temperatures and pressure.

Permission according to heat planning / energy planning

Heat plans or energy plans might put restrictions on the kind of fuel used for heat production. As an example a new biomass boiler cannot be approved together with a natural gas fired CHP-plant in Denmark and solar district heating can only be approved if the socio economy is positive.

Building permission

A building permission is normally not needed for ground mounted solar collectors unless a building or an accumulation tank is included. At least you have to register the solar plant at the authorities.

For roof mounted collectors a building permission might be needed since it has to be proven that the weight of the solar collectors is not too high for the construction.

A check list of permissions is seen in the next page.

Check list of permissions

1. Local plan
   - Is it a protected area (landscape, flora, fauna)
   - Is there a required minimum distance to
     - churches
     - archaeological sites
     - forests
     - rivers
     - lakes
     - sea
     - (others?)

2. Environmental permission
   - Emissions to air, ground, water
   - Noise
   - Check that reflections will not disturb traffic and neighbours (is not a problem if the glass has undergone an antireflective treatment)

3. Check that there is no conflict with heat plan / energy plan

4. Building permission (if mounted on roof or a new building are included in the project)

References

[1] The Danish Energy Agency, "Forudsætninger for samfundsøkonomiske analyser på energiområdet" (*Assumptions for socioeconomic analysis on the energy field*), table 8 and 9, April 2011, www.ens.dk/da-DK/Info/TalOgKort/Fremskrivninger/beregningsforudsatninger/Sider/Forside.aspx

The SDH fact sheets addresses both technical and non-technical issues, and provide state-of-the-art industry guidelines to which utilities can refer when considering/realizing SDH plants. For further information on Solar District Heating and the SDHtake-off project please visit www.solar-district-heating.eu.

Chapter:	Permissions, tendering, contracts and guarantees
Date:	April 2012
Size:	4 pages
Description:	Legislation regarding tendering and decisions which the SDH plant owner has to make in terms of the design, suppliers and the contracting.
Author:	Per Alex Sørensen, PlanEnergi – pas@planenergi.dk
Co-author(s):	-
Available languages:	English
Version id:	3.2-2
Download possible at:	www.solar-district-heating.eu

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Introduction

The coming owner(s) of the solar district heating plant normally wants prices from more than one supplier to be sure to get most value for money. If the coming owner is a utility and the expected costs are more than 4.845 million € the EU-directive coordinating procurement procedures of entities in the water, energy, transport and postal service sectors (Directive 2004/17/EC of 31 March 2004) has to be followed. The rules can be found at http://ec.europa.eu/legislation, but are normally available at national homepages in the national language.

If the price is lower than 4.845 million € the EU-directive can be followed, giving suppliers from other EU-countries a chance to give their bid, or national rules can be followed.

How detailed design?

Many suppliers of solar heating panels are also able to design plants and to include piping, control systems, accumulation tanks, implementation and commissioning in their price and thus act as a total contractor.

Therefore the design phase for the owner does not have to be very detailed. If he knows where to place the solar collectors, the inlet and outlet temperatures and flows and the heat consumption on a monthly base for the district heating system that might be enough. But normally a design calculation has been carried out and therefore he can also point out collector area, size of accumulation tank(s) and needed flows for pumps, size of heat exchangers and control strategy. A total contractor is then able to give a price for the plant.

To be sure, that the quality of the plant will be as wanted by the building owner, the tender document should include specifications for

- Pipes and insulation of pipes
- Pressure level for components
- Temperature level for components
- Quality of steel for heat exchangers
- % of glycol in collector fluid
- Quality of pumps and ability to frequency regulation
- Pressure test of pipes and panels
- Alarm systems
- Security systems for boiling
- Guarantees of performance at system and/or at component level
    - System performance

    - Collector efficiency
    - Heat exchanger efficiency
- Control system

Total contractor or more contractors

If the coming owner of the SDH plant details the project, it will be possible to have separate contractors for pipes, accumulation tank, control system etc. This will cost more time and money for coordination for the owner, but often the supplier don't produce for example steel tanks and therefore has to buy a tank from a sub-supplier. He will then take extra to cover his risk. This can be avoided by dividing the work.

The disadvantage is that if the work is divided into panels, piping, control system etc., it will be more complicated to coordinate the implementation process and commissioning, and it might be impossible to get a guarantee for the total system. Also the issue of who is responsible for what, is of high importance, when several contractors are involved.

A check list for the contract (provided by a total contractor) is seen in the next page.

Check list for contract (total contractor)

1. Subject of the contract
   Fixes the basics of the solar energy supply and defines the partners.

2. Legal background
   - Tender documents
   - Offer from the total contractor
   - E.g. national rules for total enterprises
   - P&I diagram

3. Description of work
   - Definition of work delivered from the contractor
   - Definition of work delivered from the utility

4. Specifications for components and guarantees (if not already specified in the tender document) Especially the control system has to be detailed defined including precise definitions for when delays start.

5. Specifications for commissioning (if not already specified in the tender document)

6. Price and payment rules

7. Guarantees for pre payment

8. Time schedule and rules for calculation of compensation if the construction of the plant is delayed

9. Responsibility for damages during the construction process

10. Contact persons (responsible persons) for the total contractor and for the utility

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Chapter:	Permissions, tendering, contracts and guarantees
Date:	August 2012
Size:	14 pages
Description:	Procedures for how to give performance guarantees for large collector fields and heat exchangers. Procedures for how to check performance guarantees for large collector fields and heat exchangers.
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Available languages:	English
Version id:	3.3-4
Download possible at:	www.solar-district-heating.eu

Contents

Giving performance guarantees

The performance guarantees described here are related to an instant performance of the collector field and the heat exchanger* under some fixed/stationary ("full load") operating conditions.

The procedures described here do not pretend to give a guarantee on the annual output of the system.

Give solar collector field guarantee

Guarantee for the collector field performance can be given in the form of a guarantee equation:

$$P_g = A_c \cdot [\eta_0 \cdot G - a_1 \cdot (T_m - T_a) - a_2 \cdot (T_m - T_a)^2] \cdot f_P \cdot f_U \cdot f_O \qquad \text{(eq. 3.3.1)}$$

where:

P_g:	Guaranteed performance (thermal power output)	[W]
A_c:	Collector area corresponding to the collector efficiency parameters: η_0, a_1 and a_2 (could be taken from collector test report) *Note: This will typically be the collector aperture area*	[m²]
η_0:	Optical efficiency	[-]
a_1:	1st order heat loss coefficient	[W/(K·m²)]
a_2:	2nd order heat loss coefficient	[W/(K²·m²)]
G:	Solar irradiance on collector plane	[W/m²]
T_a:	Ambient air temperature	[°C]

$$T_m = (T_{c,in} + T_{c,out}) / 2 \qquad \text{(eq. 3.3.2)}$$

where:

T_m:	Mean temperature of solar collector fluid	[°C]
$T_{c,out}$:	Hot side of collector field (= collector outlet temperature)	[°C]
$T_{c,in}$:	Cold side of collector field (= collector inlet temperature)	[°C]

f_P:	Safety factor taking into account the pipe heat losses in the collector field and transmission lines; f_P = 1 – pipe heat loss ratio i.e. pipe losses estimated to be 3 % results in f_P = 0.97.	[-]
f_U:	Safety factor taking into account measurement uncertainty; f_U = 1 – measurement uncertainty. If the total measurement uncertainty is estimated to be 5 %, f_U will be 0.95.	[-]

* *More information on heat exchangers for SDH systems can be found in fact sheet 7.4 "Heat exchanger".*

f_O: Safety factor for other things. Could typically be 0.95 to take into account non-ideal flow distribution and unforeseen heat losses. [-]

Restrictions:

$G \geq 850$ W/m²
No shadows on collectors
No snow/ice/condensation on solar radiation sensors
$T_a > 10$ °C
No significant change (< 2 K) in collector mean operating temperature during an hour

Example 1: *Give a guarantee for a collector field performance*

Collector data (from test report):

Module area (aperture area): 13.2 m²

Corresponding collector efficiency parameters

- $\eta_0 = 0.8$
- $a_1 = 3.0$ W/(K·m²)
- $a_2 = 0.01$ W/(K²·m²)

Other data:

- Estimated pipe heat losses: 2 %
- Estimated uncertainty on measurements: 10 %
- Safety factor other things 0.95
- Number of collector modules: 1000

Guarantee equation 3.3.1 with the values inserted is then:

$$P_g = 13200 \cdot [0.8 \cdot G - 3.0 \cdot (T_m - T_a) - 0.01 \cdot (T_m - T_a)^2] \cdot 0.98 \cdot 0.90 \cdot 0.95 \quad \text{[W]}$$

$$= 11060 \cdot [0.8 \cdot G - 3.0 \cdot (T_m - T_a) - 0.01 \cdot (T_m - T_a)^2] \quad \text{[W]}$$

Give guarantee for heat exchanger performance

The performance guarantee for the heat exchanger ("hx") in the solar collector loop can be given as a maximum logarithmic mean temperature difference between the primary ("prim") and secondary ("sec") side of the heat exchanger:

$\Delta T_{g,hx}$ = *guaranteed value* [K]

for a given set of requirements on in- and outlet temperatures on primary side:

$T_{hx,prim,in,min}$ ≥ *given value 1* (e.g. 80 °C) [°C]

$T_{hx,prim,out,min}$ ≥ *given value 2* (e.g. 40 °C) [°C]

It is recommended to set these minimum temperature values 10 K below the typical full load situation in order to be sure to have valid data points for checking the guaranty, i.e.

$T_{hx,prim,in,min} = T_{hx,prim,in,full} - 10$ K

$T_{hx,prim,out,min} = T_{hx,prim,out,full} - 10$ K

Power value:
The guarantee should be given for a certain value of the power transferred through the heat exchanger; a natural choice would be the power corresponding to a typical full load situation, e.g.:

$P_{hx} = P_g$ [W]

with

G: chosen to 900 [W/m²]

T_m: chosen to be the mean collector temperature at full load[†]

T_a: chosen to 15 °C.

It is recommended to include some safety margin on $\Delta T_{g,hx}$ e.g. 0.5 K.

It is important to specify the fluid (*brand name, type name, glycol percentage*) and to give maximum allowed tolerance on the capacity flows (w) on primary and secondary side of the heat exchanger (e.g. $0.95 \leq w_{prim} / w_{sec} \leq 1.05$). The capacity flow is the power which can be transferred to or from the liquid per degree (K) in difference between inlet and outlet temperature of the heat exchanger. The calculation is described in fact sheet 7.4 *"Heat exchanger"*.

[†] *If the temperature decrease between $T_{c,out}$ and $T_{hx,prim,in}$ is negligible, these values can be assumed equal here. The same thing accounts for $T_{hx,prim,out}$ and $T_{c,in}$. Equation 3.3.2 can then be used to determine T_m. These assumptions depend on the physical distance between the measurement points, i.e. whether or not they are placed close to each other.*

Example 2: *Give a guarantee for a heat exchanger performance*

The typical full load situation is defined as:

$T_{hx,prim,in,full}$	= 90	[°C]
$T_{hx,prim,in,min}$	= 80 (10 K lower as recommended)	[°C]
$T_{hx,prim,out,full}$	= 50	[°C]
$T_{hx,prim,out,min}$	= 40 (10 K lower as recommended)	[°C]
T_a	= 15	[°C]
$T_m - T_a$	= (90 + 50) / 2 –15 = 55	[K]
G	= 900	[W/m²]
P_{hx}	= P_g	[W]

$0.95 \leq w_{prim} / w_{sec} \leq 1.05$

Assuming same collector field as before:

P_g	$= 11060 \cdot [0.8 \cdot 900 - 3.0 \cdot 55 - 0.01 \cdot 55^2]$	[W]
	$= 11060 \cdot 525$	[W]
	$= 5.80$	[MW]

Choosing a heat exchanger specified (with the actual glycol mixture) to

a) transfer 5.8 MW at primary side
b) run with temperatures in and out of primary side at 80 °C and 40 °C respectively
c) have a mean temperature difference across the heat exchanger of 3 K

it should then be safe[‡] to give a guarantee of:

$\Delta T_{g,hx}$ = 3.5 [K]

(including a safety interval of 0.5 K).

The guarantee could look like the following text box:

[‡] *Note: It might be wise to have the provider/manufacturer of the heat exchanger involved in this guarantee.*

The logarithmic mean temperature difference across the heat exchanger (from primary side to secondary side) is maximum 3.5 K *under the following conditions:*

- *Fluid: Primary side: Tyforop Chemie GmbH type "Tyfocor HTL", 30 % wt; secondary side: water*
- *Power transferred = 5.8 MW*
- *Temperatures: Primary side: Inlet temperature ≥ 80 °; outlet temperature ≥ 40 °C*
- *Tolerance on the capacity flows on primary and secondary side of the heat exchanger: $0.95 \le w_{prim} / w_{sec} \le 1.05$)*

For the example given (example no. 2) the influence of the heat exchanger ΔT§ on the instant performance is seen in fig.3.3.1. The figure shows the reduction in collector performance for the collector described in example no. 1, running at the given "full load situation". It is seen that the reduction in performance in this case approximately equals the ΔT.

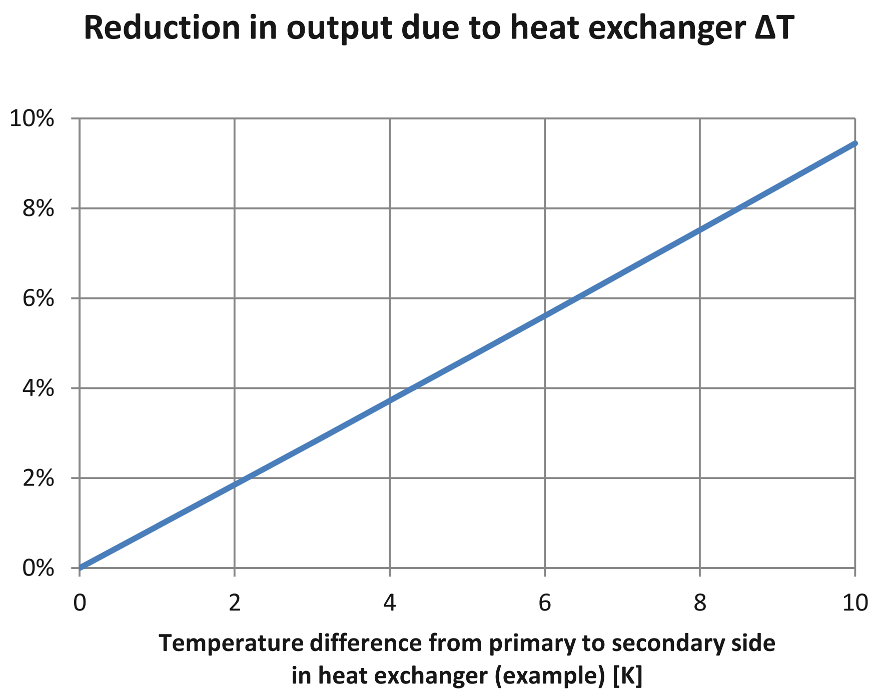

Figure 3.3.1. Example of the influence of the heat exchanger on the performance of the solar system. The higher the temperature difference across the heat exchanger (ΔT) the higher the temperature in the collector loop - and the lower the collector performance. The influence of the heat exchanger depends on the heat loss coefficient of the solar collector: The higher the collector heat loss coefficient - the larger the influence of the heat exchanger. (Source: PlanEnergi)

§ *This ΔT corresponds to the ΔT_{mean} calculated in fact sheet 7.4 "Heat exchanger".*

Checking performance guarantees

In the following procedures are given to check the guarantees described above.

Measurements needed for checking guarantees

To check the solar collector field performance guarantee it is necessary (at least) to measure the following data points (see figure 3.3.2 below):

- $T_{c,out}$: Outlet temperature from collector field (measured at heat exchanger inlet) [°C]
- $T_{c,in}$: Inlet temperature to collector field (measured at heat exchanger outlet) [°C]
- P_{hx}: Thermal power supplied to (or from) heat exchanger [W] (or kW)
- G: Solar irradiance on collector plane [W/m²]
- T_a: Ambient air temperature (shadowed and ventilated) [°C]

To check also the guarantee on the heat exchanger the following additional points shall be measured:

- w_{prim} Capacity flow in collector loop primary side (glycol mixture side)** [W/K]
- $T_{hx,sec,out}$ Outlet temperature from heat exchanger secondary side (water side) [°C]
- $T_{hx,sec,in}$ Inlet temperature to heat exchanger secondary side (water side) [°C]
- w_{sec} Capacity flow in heat exchanger secondary side (water side)** [W/K]

Requirements:

- Logging time ≤ 2 minutes
- Recording time = 1 hour
- Time and date for all recorded data are needed. The values in the record shall represent the average values over the last hour. (ex.: data in the record saved 2011:04:31:12:00 represent the average values in the hour from 11:00 to 12:00 on April 31st 2011).
- Time indication shall always be "standard time" (not daylight saving time or "summer time").

** *w is calculated as described in fact sheet 7.4 "Heat exchanger".*

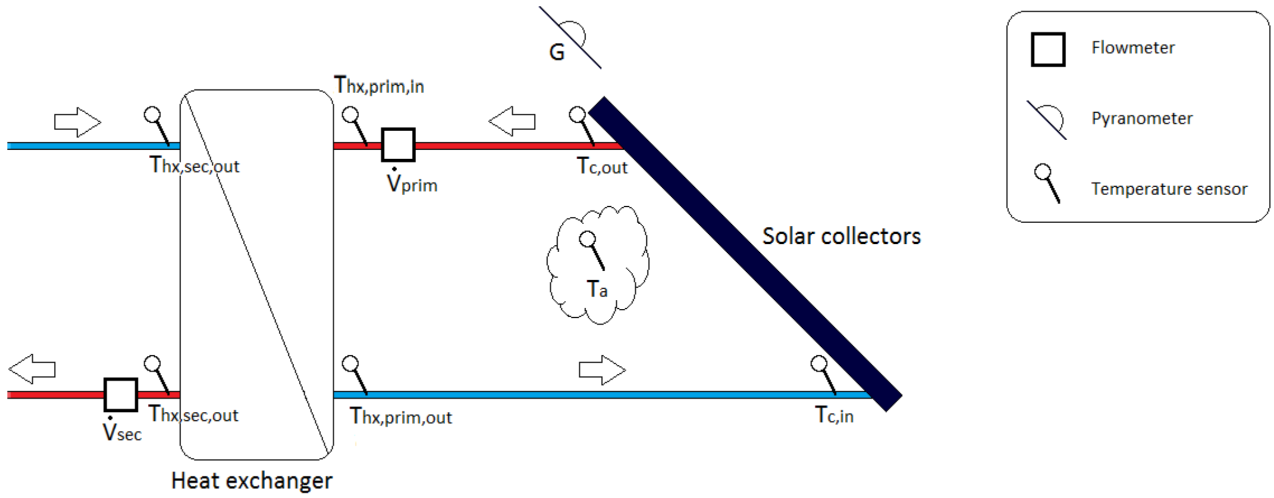

Fig. 3.3.2. Schematic drawing showing the measurement points. (Source: PlanEnergi)

Referring to figure 3.3.2 the heat exchanger power is calculated either for the primary or the secondary side, e.g. for the primary side as:

$$P_{hx} = \dot{V}_{prim} \cdot \rho_{prim} \cdot c_p \cdot (T_{hx,prim,in} - T_{hx,prim,out}) \quad \text{(eq. 3.3.3)}$$

where

P_{hx}:	Thermal power supplied to (or from) heat exchanger	[W]
$\dot{V}_{prim}$	Flow rate in primary loop	[m^3/s][††]
ρ_{prim}	Density of the collector fluid	[kg/m^3]
c_p	Heat capacity of solar collector fluid	[J/(kg·K)]
$T_{hx,prim,in}$	Inlet temperature on the primary side of the heat exchanger	[°C]
$T_{hx,prim,out}$	Outlet temperature on the primary side of the heat exchanger	[°C]

The calculation is the same for the secondary side except for the fact that the inlet and outlet temperatures are switched in the formula.

[††] *Normally measured in m^3/h and converted to m^3/s by multiplying with 3600 s/h.*

Valid data points

Only data points (hourly average values) fulfilling the following requirements are valid:

- $G \geq 850$ W/m²
- $T_a \geq 10$ °C
- No snow or ice or condensing on/in collectors and solar radiation sensor
- No shadows on any collector in the field
- Incidence angle of direct solar radiation ≤ 30°

For checking the collector performance, the measuring period shall have at least 20 data records. All valid data records in the period shall be used unless it is obvious that errors in data or very atypical operating conditions occur (omitting valid data points shall be reported and explained).

Checking collector field performance guarantee

The summarized measured ("meas") energy output for all valid data point are compared with the corresponding energy calculated according to the guarantee formula (eq.3.3.1), using the measured weather data and temperatures in collector loop. If this measured energy is equal to or greater than the energy corresponding to the guarantee calculation, then the guarantee is fulfilled:

$$\sum Q_{hx,meas} \geq \sum Q_g \Rightarrow \text{Guarantee OK}$$

Each $Q_{hx,meas}$ and Q_g is calculated as $P_{hx,meas}$ and P_g multiplied by time (3600 s) respectively [J].

Plot of corresponding data points for measured and calculated thermal power should be made to check for deviations. See example below in figure 3.3.4.

<u>Example 3: *Checking collector field performance guarantee*</u>

Data points from a performance check of a Danish system is used to illustrate the checking and plotting. 28 valid data points were recorded.

Summing up hourly measured energy output and comparing with the sum of guaranteed energy output shows that $\sum Q_{hx,meas} \geq \sum Q_g$.

Guarantee is then OK.

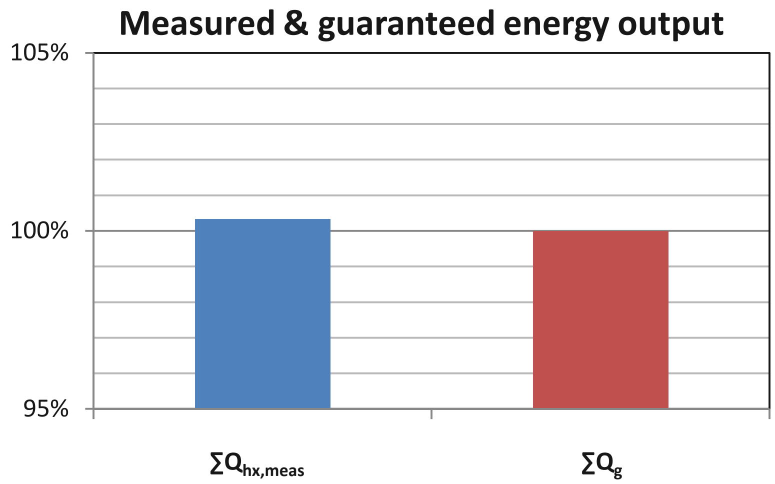

Fig. 3.3.3. Plot of summarized measured energy and corresponding guaranteed energy.
(Source: PlanEnergi)

Plotting the measured data points against the corresponding guaranteed ones shows that the variation of the data points looks reasonable - see fig. 3.3.4.

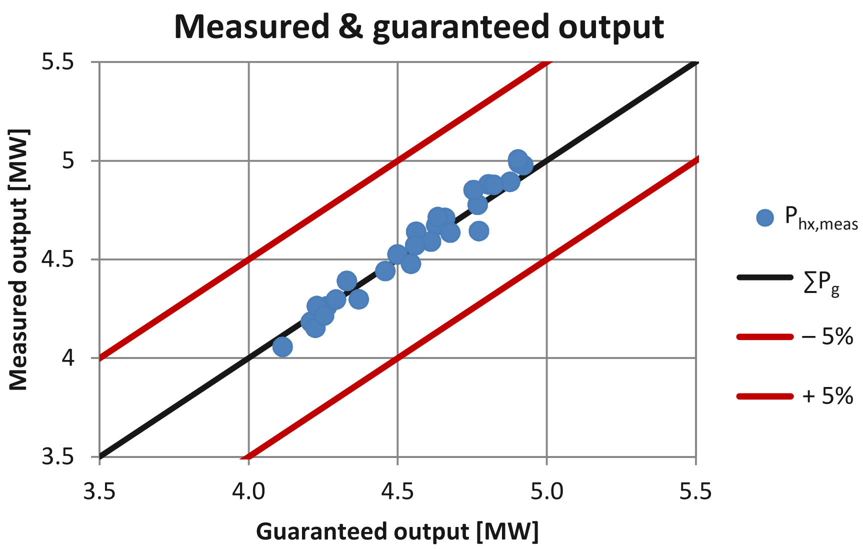

Fig. 3.3.4. Plot of measured thermal power point against corresponding guaranteed thermal power points.
(Source: PlanEnergi)

Checking heat exchanger performance guarantee

The performance guarantee of the heat exchanger can be checked by plotting the measured logarithmic mean temperature difference across the heat exchanger against the transferred thermal power. A linear regression based on these measurements has the expression

$$f(P_{hx,meas}) = c_1 \cdot P_{hx,meas} + c_2 \qquad \text{(eq. 3.3.4)}$$

where

$f(P_{hx,meas}) = \Delta T_{hx,meas}$ [K]

c_1 and c_2 are constants determined by the linear regression.

When the power for which the guarantee was made (P_g) is inserted in equation 3.3.4, it is revealed whether or not the temperature difference is too large since the calculated value

$$\Delta T_{check} = f(P_g) = c_1 \cdot P_g + c_2 \qquad \text{[K]}$$

must be lower than or equal to the guaranteed maximum temperature difference $\Delta T_{g,hx}$. Hence the guarantee is fulfilled if

$$\Delta T_{check} = f(P_g) \leq \Delta T_{g,hx}$$

It shall be documented that the temperature and capacity flow requirements are fulfilled.

The example below illustrates this checking.

Example 4: *Checking heat exchanger performance guarantee*

The temperature difference across the heat exchanger is maximum **5 K** under the following conditions:

- Fluid: Primary side: <*fluid specification*>; secondary side: water
- Power transferred = 4.5 MW
- Temperatures: Primary side: Inlet temperature ≥ 80 °; outlet temperature ≥ 40 °C
- Tolerance on the capacity flows on primary and secondary side of the heat exchanger: $0.95 \leq w_{prim} / w_{sec} \leq 1.05$)

Checking temperature difference:

The plot in figure 3.3.5 shows

- measured temperature difference points $\Delta T_{hx,meas}$
- a linear regression based on the measurement points
- the guaranteed maximum temperature difference $\Delta T_{g,hx}$ (in this case 5 K) for the given heat exchanger power P_g for which the guarantee is given (in this case 4.5 MW):

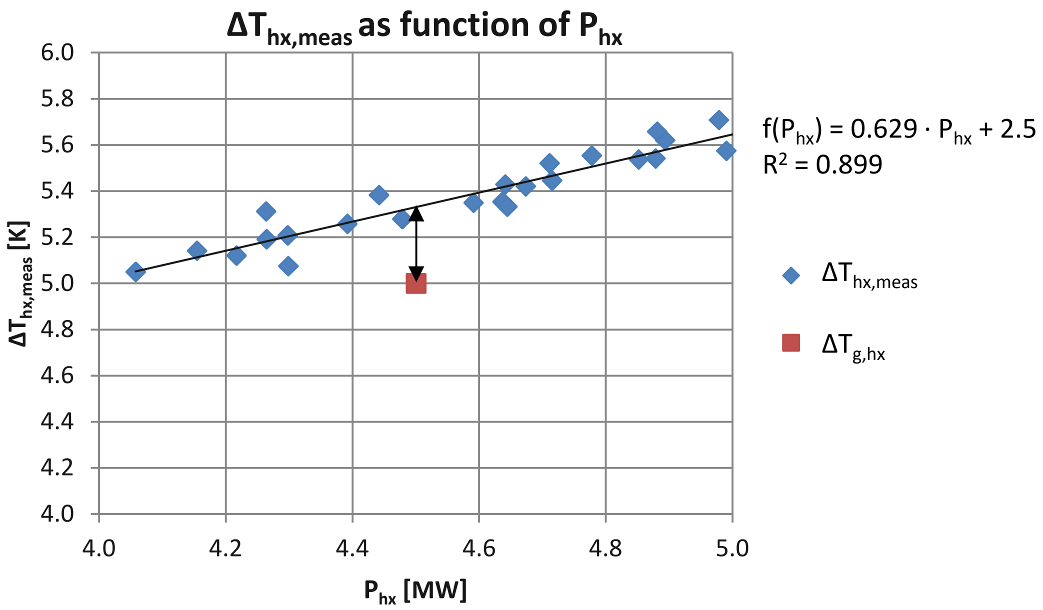

Fig.3.3.5. Logarithmic mean temperature difference across heat exchanger as function of the transferred power. Guarantee point indicated with red square at 4.5 MW; 5 K. It is seen that in this case the guarantee is NOT fulfilled! (Source: PlanEnergi)

Check of temperatures:

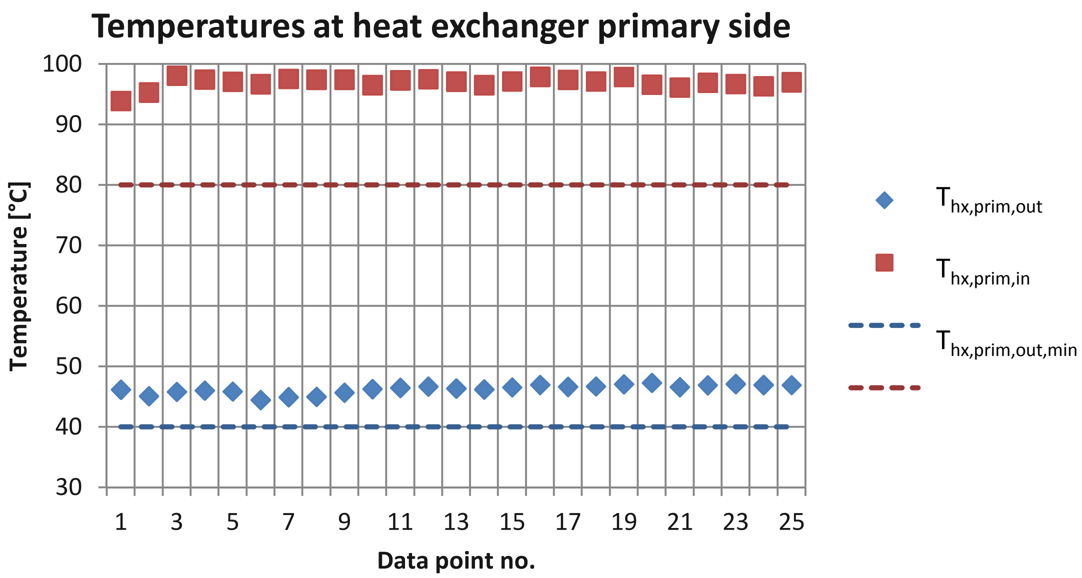

Fig.3.3.6. Temperature requirements fulfilled since $T_{hx,prim,out}$ is above $T_{hx,prim,out,min}$ (40 °C) and $T_{hx,prim,in}$ is above $T_{hx,prim,in,min}$ (80 °C) as required. (Source: PlanEnergi)

Checking thermal capacity flow rate ratio:

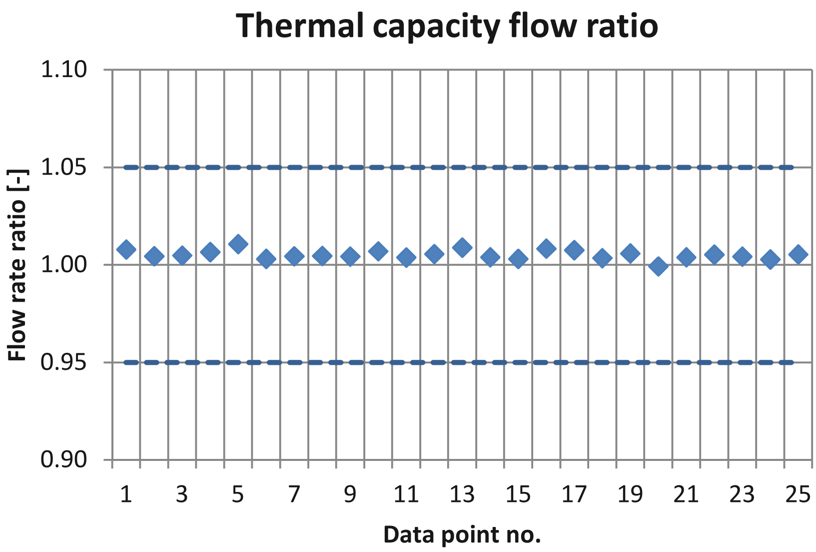

Fig.3.3.7. Capacity flow rate ratio requirement fulfilled since the measurement points are between 0.95 and 1.05 as required. (Source: PlanEnergi)

It is seen that the requirements given in the heat exchanger performance guarantee is fulfilled (as seen in figure 3.3.6 and 3.3.7) BUT the guarantee is in this case NOT fulfilled (as seen in figure 3.3.5). Only if the red, square marker in figure 3.3.5 is above the regression line the guarantee is fulfilled - and this is not the case here.

In the next page is seen a template which can be used to check that all necessary component details are noted as well as the collector fluid properties.

Template for taking notes of the equipment used for data logging

Table 3.3.1. Properties of the equipment used for measuring the collector and heat exchanger efficiency.

Equipment type	Name of manufacturer and component	Placement and orientation	Measurement range	Uncertainty +/- [%]
Solar radiation sensor			[W/m²]	
Flowmeter 1			[m³/h]	
Flowmeter 2			[m³/h]	
Temperature sensors			[°C]	

Template for taking notes of the solar collector fluid properties

Table 3.3.2. Solar collector fluid properties of the fluid used in the tests.

Name of manufacturer		[-]
Product name		[-]
Concentration		[wt %]
Heat capacity (40 °C)		[J/(kg·K)]
Heat capacity (80 °C)		[J/(kg·K)]
Density (40 °C)		[kg/m³]
Density (80 °C)		[kg/m³]

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Chapter:	Implementation
Date:	April 2012
Size:	3 pages
Description:	Things to be aware of during the building process and the commissioning.
Author:	Per Alex Sørensen, PlanEnergi – pas@planenergi.dk
Co-author(s):	-
Available languages:	English
Version id:	4.1-2
Download possible at:	www.solar-district-heating.eu

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Construction

During the building process coordination meetings with representatives for the utility and all contractors has to be held. Before the meeting status of the work should be checked and during the meeting status of work, time schedule and work of the next two weeks shall be discussed. All changes in payments etc. shall be registered in the notes of the meetings.

If the work is divided on different contractors, the utility has to be careful, that the responsibility between the contractors is clear. Especially in the following situations:

- If one contractor has prepared the area (for ground mounted solar collectors) and another contractor shall implement the solar collectors, there has to be a written agreement in advance about the requirements on land preparation of the solar collector installer. Before collector mounting, the contractor has to state that the ground is prepared in an acceptable way.
- If one contractor is doing the piping and another contractor shall implement the solar collectors, there has to be a written agreement with result of pressure test (with air) of the pipes and acceptance that the pipes are clean and accepted by the solar collector entrepreneur.
- Before anti freeze fluid is added to the system a test of tightness (with air or nitrogen at max 0.5 Bar) can be done (after sunset) for the solar collector part, and a cold test of the control system has to ensure, that pumps, heat meters etc. is functioning. When anti freeze fluid is added a pressure test (1.5 x the operation pressure) has to be done (also after sunset)

Large collector fields can be divided in sections and anti freeze fluid added sector by sector.

The following activities should be made before the constructions phase begins:

a) Immediately after signing the contract:

- Project briefing for contractor at site
- Preparing of detailed time schedules in coordination with staff on site including determining work schedule and off-times
- Finalization of substructure and details of fixation
- Clarification of infrastructure and coordination of construction works

b) At the beginning of collector mounting

- Final clarification of all relevant details for installation and mounting on construction site with the client (f.e. clarification of shop drawings)
- Approval of substructure for collectors
- Installation training for elevation construction and for mounting collectors and their needed connections

c) Before start up

- Approval of all components (pressure tests etc.)
- Test operation and performance control
- Training with local responsible persons / maintenance staff
- Joint taking over

Commissioning

Before commissioning there must be a period (2 weeks) where the plant runs automatically and the following instructions for operation of the plant have to be delivered to the utility:

- technical data for components
- description of how the plant is operating
- how to check, that the plant is running normally and maintenance routines (check list)
- how to solve typical problems (adding of anti freeze liquid, unbalanced heat exchanger etc.)

During the commissioning the entrepreneur(s) deliver drawings and P&I diagram showing the actual work.

A commissioning report including list of faults and when they are corrected has to be written and signed by the partners.

After the commissioning there will still be a run-in period where the entrepreneur(s) has to support the utility.

When air is removed from the system and there has been a period with much solar, the entrepreneur(s) shall balance the flow in the total system.

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Chapter:	Implementation
Date:	April 2012
Size:	4 pages
Description:	Purpose of monitoring systems; information about the selection of data points, recording of data and accuracy of monitoring equipment. Description of which data the control system should monitor and the recommended accuracy of the logging as well as how frequent the logging should occur.
Author:	Per Alex Sørensen, PlanEnergi – pas@planenergi.dk
Co-author(s):	Thomas Schmidt, Solites – schmidt@solites.de
Available languages:	English
Version id:	4.2-2
Download possible at:	www.solar-district-heating.eu

Contents

Introduction

Monitoring of heating installations is a basic necessity for a charcterisation and observation of system behaviour and efficiency. The main purposes for doing monitoring and evaluation thus usually are:

- Get insight in system and component behaviour and interaction
- Do optimisation of system, components and control strategy
- Derive design improvements
- Ensure and demonstrate efficiency and feasibility

This is achieved by means of:

- Short term system and component analysis and characterisation
- Short and long term energy balances

What should be measured?

All data points necessary for setting up a complete energy balance of the energy system have to be measured. This includes:

- Quantity of heat for all involved components and/or main circuits
- Quantity of electricity for instruments, pumps, components, electricity producers and/or main circuits
- If applicable fuel supply, waste energy etc.

A measurement of relevant system temperatures and pressure levels enables for detailed analysis and control optimisation, e.g.:

- Supply / return temperatures of main components and circuits
- Pressure levels in main circuits
- Storage temperatures

Climatic data as ambient temperature, solar irradiation and where required wind speed gives additional information about the systems boundary conditions.

Recording of data

The minimum time resolution should be **10 minutes** when logging the following data:

- Logging of heat meter data
  - Heat
  - Thermal power
  - Flow rate
  - Supply / return temperatures
- Solar irradiation
- Temperatures in the storages
- Ground temperatures and heat flux sensors (resolution could be 30-60 minutes)
- Mean values for temperature (T) in pipes should be weighted by flow rate $\left(\dot{V}\right)$ or power:

$$T_{mean,pipe} = \frac{\sum_i \left(T_i \cdot \dot{V}_i\right)}{\sum_i \dot{V}_i} \qquad \text{(eq. 4.2.1)}$$

Data collection, processing and storage systems have to be able to process and store the data with an accuracy and resolution corresponding to the accuracy of the sensors, see next section.

Accuracy of monitoring equipment

The monitoring equipment and the kind of data that has to be stored in the control system (and *how* this is done) often has to be defined in the tendering document or in the contract. From IEA SHC Task 38 the accuracies given in figure 4.2.1 are recommended.

		relative accuracy [-]	with	value	unit	absolute accuracy [+/-]
Density	$\Delta\rho/\rho$	0.001	ρ	1000	kg/m³	1.00
Volume flow	Δ(dV/dt)/(dV/dt)	0.02	(dV/dt)	1.56	m³/h	0.03
Heat capacity	$\Delta c_p/c_p$	0.01	cp	4.18	kJ/(kgK)	0.04
Temperature difference	ΔΔT/ΔT	0.02	ΔT	7	°C	0.14
Power	Δ(dQ/dt)/(dQ/dt)	0.030	dQ/dt	15	kW	0.45
		Accuracy [+/-]				
Signal conditioning devices		The proposal is to use a Data Aquisition System with at least the same accuracy as the sensor				
Electric energy counter	ΔEel./Eel.	0.002				
Pyranometer (solar irradiation)	ΔG/G	0.03				

Fig. 4.2.1. Accuracy of monitoring equipment. [1]

References

[1] IEA SHC task 38 – Solar Air Conditioning and Refrigeration, Monitoring Procedure for Solar Cooling Systems, www.iea-shc.org/task38, 2011.

┘ *The SDH fact sheets addresses both technical and non-technical issues, and provide state-of-the-art industry guidelines to which utilities can refer when considering/realizing SDH plants. For further information on Solar District Heating and the SDHtake-off project please visit www.solar-district-heating.eu.* ┌

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Chapter:	System
Date:	April 2012
Size:	4 pages
Description:	This fact sheet provides an overview of the classification of solar district heating systems into different categories
Authors:	Oliver Miedaner, Solites – miedaner@solites.de, Thomas Pauschinger, Solites – pauschinger@solites.de
Co-author(s):	Jan-Olof Dalenbäck, CIT Energy Management – Jan-Olof.Dalenback@chalmers.se
Available languages:	English
Version id:	6.1-2
Download possible at:	www.solar-district-heating.eu

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Overview of solar district heating system categories

In general solar district heating systems consist of large collector fields integrated into a district or block heating system for supplying heat to residential and industrial areas. In practice this integration is realised in rather different ways under quite varying boundary conditions. This fact sheet provides an overview of the classification of solar district heating systems into different categories.

Main aspects for distinguishing solar district heating systems are:

District heating (DH) system

- Size of DH system: District heating (large) ⇔ Block heating (small e.g. for a group of buildings or a residential area)
- Heat generation: Combined heat and power (CHP) ⇔ Heating plant

Storage system

- Seasonal heat storage (with or without multiple usage) ⇔ Short term storage

Solar thermal system

- Design: Pre-heating with solar fraction < 10 % ⇔ Average solar fraction of 10 - 30 % ⇔ High solar fraction > 30 % with long term thermal energy storage.
- Solar feed-in: Central (at heating plant) ⇔ Distributed (at any point of the district heating network)
- Type of solar feed-in: Between forward pipe and return pipe ⇔ Raising of forward pipe temperature ⇔ Raising of return pipe temperature.
- Collector field location: Central (at heating plant) ⇔ Distributed and distributed feed-in (e.g. on buildings) ⇔ Distributed (e.g. on buildings) and central feed in via collecting network.

The two main categories are related to the solar feed-in point of the solar system (centralized ⇔ distributed system) and to the size of the district heating system (solar district heating system ⇔ solar block heating system).

Central systems

In a central solar district heating system the solar thermal system feeds in at the main heating plant of the DH system. The collector field is typically ground mounted in close connection to the heating plant. Alternatively the collectors can be roof mounted on buildings and the heat is transferred to the heating plant via a collecting grid. A large long term storage connected to the heating plant enables high solar fractions. The plant is typically owned and operated by the owner of the district heating system e.g. the local utility.

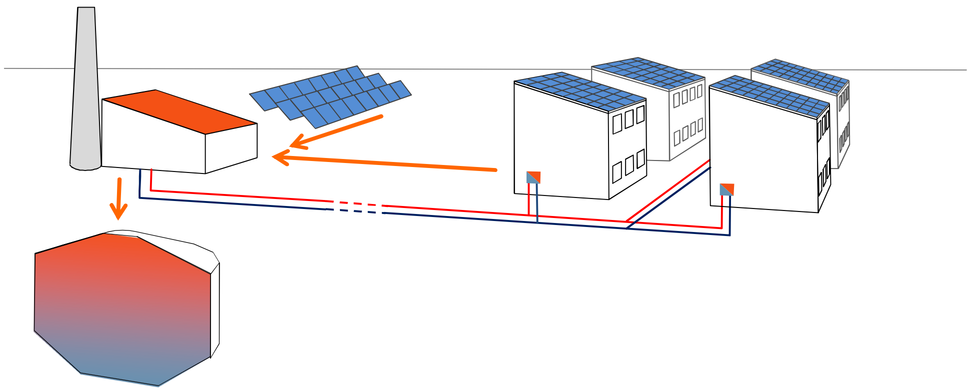

Fig. 6.1.1. Central solar district heating system. (Source: Solites)

Central solar district heating systems

Plants of this type were mainly built in Denmark, Sweden and Austria. In general these systems are connected to combined heat and power (CHP) units (often biomass, see also fact sheet 2.1 *"Solar heat combined with other fuels"*).

Central solar block heating systems

Smaller central solar district heating plants are called solar block heating plants. Several plants were realised in Germany, often applied on new residential areas in combination with heating plants (without CHP). Eleven of these systems were designed for a solar fraction of ~50 % of the total heat demand and large seasonal heat stores were applied (see fact sheet 7.2 *"Storage"*).

Distributed systems

In distributed solar district heating plants the solar collector fields are installed at suitable locations at any place of the district heating network and connected directly to the district heating primary circuit on site. Often these plants utilise the district heating network as storage (as long as they provide a minor amount of heat in comparison to the total load in the district heating system).

Systems realised so far are owned and managed either by a housing company or by an energy service company (ESCO) or by the district heat supplier (see also factsheet 2.5 *"Feasibility study"*).

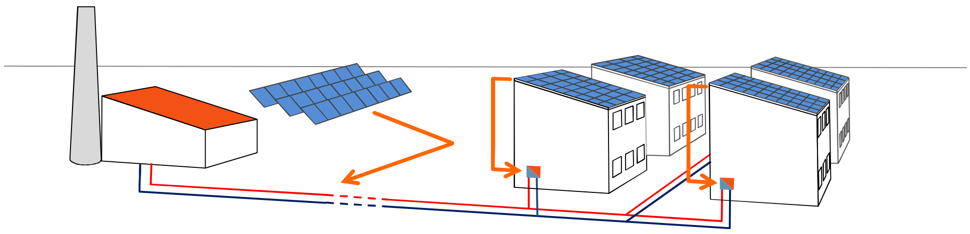

Fig. 6.1.2. Distributed solar district heating system. (Source: Solites)

Distributed solar district heating plant

Large distributed solar district heating plants are e.g. operated by an ESCO in the city of Graz, Austria. They are connected directly to the district heating network on site.

Distributed solar block heating plant

Distributed solar block heating plants are realised e.g. in Sweden. In recent plants net-metering is applied, i.e. the collector fields are owned by the building owner who trades the solar heat according to a net-metering contract with the district heating net owner as it is known from the grid-connected PV plants.

References

[1] Jan-Olof Dalenbäck: Success Factors in Solar District Heating, Dec. 2010, www.solar-district-heating.eu.

The SDH fact sheets addresses both technical and non-technical issues, and provide state-of-the-art industry guidelines to which utilities can refer when considering/realizing SDH plants. For further information on Solar District Heating and the SDHtake-off project please visit www.solar-district-heating.eu.

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Chapter:	System
Date:	July 2012
Size:	5 pages
Description:	The position of the solar thermal (ST) plant in the heating grid, feed-in principles, feed-in direction and feed-in capacities are described in this fact sheet.
Author:	Moritz Schubert, SOLID – m.schubert@solid.at
Co-author(s):	-
Available languages:	English
Version id:	6.2-3
Download possible at:	www.solar-district-heating.eu

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Position in the heating grid

If the position of the solar thermal plant is decentral, thorough analysis of the district heating (DH) grid has to be performed in advance. “Decentral” means that the solar thermal plant is not close located to another major heat generator like a biomass or fossil fuel fired plant. A central feed-in point can also be a transfer station from a connection line to a remote power or heat plant.

Feed-in principles

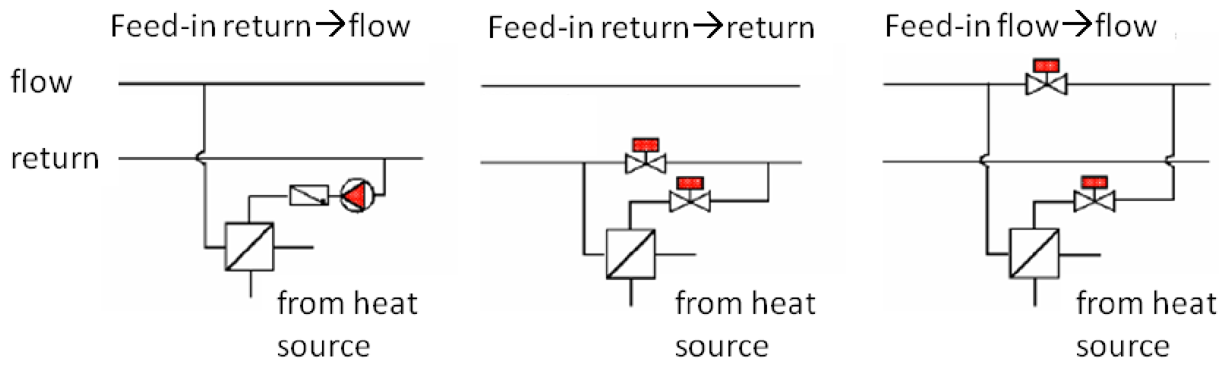

Fig. 6.2.1. Hydraulic integration of solar thermal feed-in. (Source: Streicher)

Feed-in return→flow

At this feed-in mode, the required temperature hub in the heat generator is defined by flow and return temperatures of the heating grid. The solar plant has to be operated at matched flow volumes, adjusted to the required flow temperature. The feed-in pump has to overcome the pressure difference between return and flow. This temperature difference is at several bar quite high compared to the pressure loss of collectors and pipes (several 100 mbar). Heating grid operators prefer this feed-in principle, as there is no change in return temperatures and part of the pump cost has to be beared by feed-in-operator.

Feed-in return→return

Here operating temperature of the solar plant is lowest compared to other feed-in modes. Thus highest solar yields can be expected. No pumping energy is required at feed-in point as pressure loss of pipes and heat exchangers is covered by grid pumps. Mass flow in the collector circuit can be constant. Return-return-feed-in is not favourable for heating grid operators as they have to install a flow resistance in the grid pipe for control of the flow in the heat exchanger for feed-in. Additionally high return temperatures are not favourable for most heating grid operators as heat losses rise and the efficiency of other heat generators tends to decrease.

Feed-in flow→flow

This feed-in mode results in high collector temperatures and low efficiencies of the solar plant. Here also the grid operator has to install a flow resistance in the grid pipe for control of the flow in the heat exchanger for feed-in. Due to low efficiency, this principle is normally not in use.

Feed-in capacities

For decision about installing and sizing a heat storage at the solar plant, it is important to know the heat demand of the feed-in area during peak irradiation times. Overheating or stagnation of the solar plant is to avoid for both technical and economical reasons.

Yield from solar plant: as a rule of thumb, 3 kWh/m² collector area during 6 hours (9-15h) can be assumed as maximum for most locations worldwide. The exact value depends on collector tilt angle, orientation, temperature levels etc.

When heat supply and demand match in summer months, operation during shoulder season and winter is normally possible with sufficient heat demand. But temperature levels in the DH grid could rise in winter months and thus an efficient operation strategy has to be found, see chapters below.

Summer months operation

As the majority of solar irradiation is in most regions not during heating season, summer time operation is crucial for economics of a solar thermal plant.

Heat demand (9-15h) in the feed-in area (to be examined for summer days, when no room heating is required):

- domestic hot water consumption in supplied buildings
- hot water consumption of large consumers (industry, hospitals etc.); to be checked also for weekends and holidays
- circulation losses in supplied buildings
- heat losses in district heating grid (can be significant in summer months)
- if possible, using the district heating grid as heat storage.

When using the district heating grid as heat storage, also the return flow heats up during plant operation. For effective and safe solar plant operation, return temperature should be as low as possible. Thus when heating up the DH grid, return temperature should be as low as possible in the morning before start of feed-in from solar plant.

The yield of the solar plant decreases when return temperature rises. This is important in late afternoon, when return temperature increases and irradiation decreases. In this case the solar plant has to be switched off earlier in the afternoon than with constant return temperature. The resulting loss of operation time impairs the economics of the solar plant.

For evaluating the heat demand between 9 and 15 o'clock in summer months in a certain part of the heating grid, a profound analysis is necessary and in most cases also measurements on heat demand, flow volumes and temperature levels.

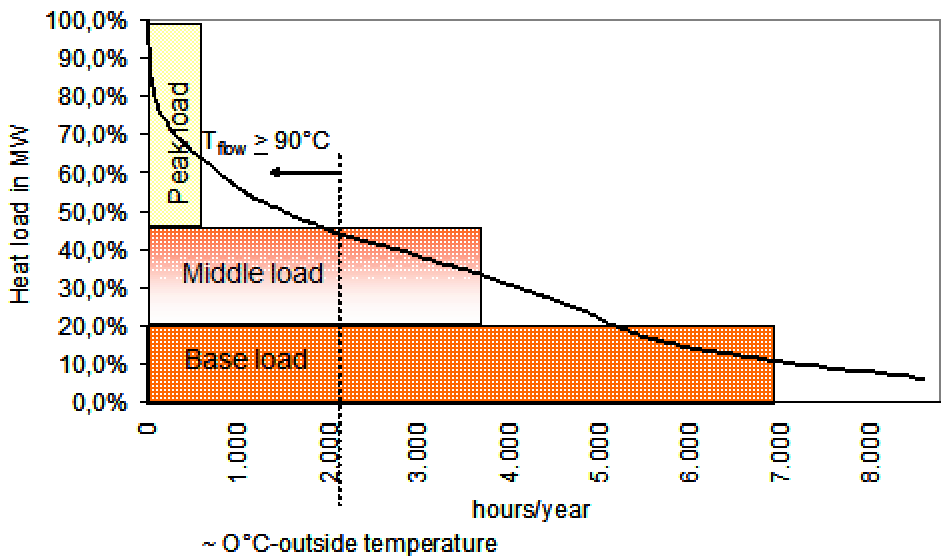

Fig. 6.2.2: Typical heat load of a DH-System in Germany over the year, combined with the check mark for the flow pipe temperature > 90°C. (Source: AGFW e.V.)

Winter months operation

In winter months, the minimum feed-in temperature of the flow can go beyond 90 or 100 °C, depending on the operation parameters determined by the DH grid operator. It is possible to generate these temperatures with solar thermal also in winter. For economical and technical reasons, maximum temperatures of 60 to 80 °C are more favourable for winter time operations of a solar thermal plant. If heat can't be fed in at these temperatures to the grid, the solar plant can supply other buildings directly. As heat demand is mainly early in the morning, a heat storage needs to be integrated. Also a heat pump can be integrated in the solar circuit or the heat storage for increasing the efficiency at low temperature operation time.

Heat storage

For increasing the flexibility in operation of the solar plant, a heat storage can be useful (see factsheet 7.2 *"Storage"*).
The heat storage should be used both for the solar thermal plant and for load management of the DH grid. It is hardly feasible to finance a large heat storage by solar-only use.

Operation of district heating grid

For maintenance and installation work at the district heating grid, shut-off of a branch of the grid might be needed for some hours. Shut-off should be done at times, when no feed-in from the solar plant is planned. I.e. when there is enough capacity for charging the buffer tank or, even better, in hours when there is no solar irradiation on the collector field.

Otherwise unplanned shut-off of the district heating grid might cause stagnation in the solar system (see factsheet 8.2 *"Safety equipment"*).

References

[1] Wolfgang Streicher, Christian Fink: Einspeisung von Solaranlagen in (bestehende) FW-Netze, Gleisdorf Solar 2006.

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Chapter:	System
Date:	April 2012
Size:	6 pages
Description:	The energy output of the solar district heating system is highly dependent on the conditions on which it is operated. In order to get the most out of the plants potential, it is necessary to consider what the optimum control strategy will be for the given system, i.e. pros and cons for every control setting.
Author:	Moritz Schubert, SOLID – m.shubert@solid.at
Co-author(s):	Daniel Trier, PlanEnergi – dt@planenergi.dk
Available languages:	English
Version id:	6.3-2
Download possible at:	www.solar-district-heating.eu

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Introduction

The control of the SDH plant is a very important parameter in terms of getting the most out of the systems potential. Several parameters should be considered carefully in order to utilize as much of the solar energy as possible. One example is the temperature level in the solar collector loop. As described further in fact sheet 7.1 *"Solar collectors"* the efficiency of the collectors are highly dependent on the solar collector fluid temperature.

Several partly contradicting targets have to be met by an effective control of a solar district heating plant:

- provision of required temperatures for grid operation
- avoidance of stagnation of the solar system
- optimal use of heat storages
- minimization of heat losses in collectors, pipes and storages
- minimal wear of the solar plant, i.e. reduction of changes in temperature and pressure
- minimal electricity consumption of pumps
- minimum requirement of human intervention
- optimal use of other heat sources like heat pumps, boilers, waste heat

The flow temperature often has to be at a certain required level:

- It could be 90 °C for charging a heat storage. However – depending on the storage – it might also be possible to charge the storage at different temperature and height levels.
- It could be 70-80 °C if the solar heat is directly connected to the flow pipe of the DH network (depending of course on the DH network supply temperature)
- It could be 50-60 °C if return temperature of the grid is <40 °C and solar thermal is used for pre-heating of condensation heat recovery of a boiler's exhaust air.

Normally the supply levels are kept below 95 °C because of the boiling point of water and because of temperature limits in several devices of a solar thermal plant.

Normal operation control

Effect of chosen flow rate

The mean temperature of the solar collector fluid is determined not only by the inlet temperature, the ambient temperature and the solar radiation, but also the flow rate. The faster the flow rate, the less time for the fluid to heat up as it flows through the collectors, and the lower the outlet temperature (for given weather conditions and inlet temperature). Lower outlet temperature means lower heat loss from the collectors and thereby higher collector efficiency (to a certain extend). However the flow rate should be within a reasonable range in order to have evenly distributed flow throughout the collector as described in fact sheet 7.1 *"Solar collectors"*.

On one hand you could say that the flow rate should only be kept just high enough to supply the heat to the DH network at the desired temperature level. On the other hand a high flow rate will increase the electricity consumption of the pump. Choosing a low flow rate for the typical operation will even make it possible to have smaller (and thereby cheaper) pipes since the pressure losses are lower.

For large solar plants, pumps and controls for variable flow proved to be very efficient.
Experiments at Marstal District Heating, Denmark, showed, that variable flow results in electricity savings of about 75 %. Electricity consumption for pumps dropped from over 16 kWh_{el} to 3-5 kWh_{el} per MWh of solar thermal heat.

The combination options are numerous and it is the task of the consulting engineers to include all variables in both the designing of the plant, and the operation strategy to calculate the optimum overall SDH plant solution.

The effect of storage type and size

For storages with daily charging and discharging, high charging temperatures up to 80-90 °C are possible at moderate heat losses in the storage. These high temperatures should only be chosen in case of limitations in storage size or if there is a demand for high temperature in the DH grid in order to avoid the need for auxiliary heating. Lower charging temperatures, 5-10 K above flow temperature of DH grid, are more favorable for collector efficiency in cases of sufficient buffer storage volume.

For seasonal storages it might be desirable to have high inlet temperatures in order to avoid destroying the thermal stratification of the storage. The thermal stratification makes it possible to concentrate the insulation on the top part of the storage. If the storage has inlets at several height levels, it is possible to utilize solar heat at a wider temperature range since the heat can enter the storage at the corresponding temperature level thus maintaining the thermal stratification. When the temperature of a seasonal storage reaches a certain lower level, the heat cannot be used directly in the DH network. If the solar collector outlet temperature were matched to be exactly equal to the minimum temperature required by the DH network, the heat loss of the seasonal storage would result in a decrease in temperature thus making the stored heat useless in terms of *direct* heating (without auxiliary heating). Hence the auxiliary energy supply plays a role in the choice of operation strategy as well. A (widely used) option is to use auxiliary boilers to boost the temperature to the required DH temperature. Another option is to use a heat pump to accumulate heat in the top of the storage. This way heat at a moderate temperature can be used i.e. the solar collector outlet temperature can be reduced.

Flow rate control by collector temperature measurement

With this control mode, collector temperatures at several points in the SDH plan are measured continuously and the needed pump speed is calculated from these values. Normally one temperature sensor per 1000 m² is sufficient for solar system control. Additional temperature sensors are often installed for checking hydraulic balance of the system.
Control by collector temperature has the advantage of using rather cheap sensors for measurement of the actual temperatures in the collector array. This is especially useful at cloudy conditions, when parts of the solar plant have irradiation and other parts do not. In this case, having many sensors is useful for calculation of appropriate pump speed. However in very large SDH plants the thermal inertia is high enough to cause a delay of the system control which may cause fluctuating pump regulations lagging behind the optimum pump setting. Therefore optimal control algorithms and control parameters are to be found during commissioning phase of the solar plant.

Flow rate control by irradiation measurement

By measurement of irradiation at the solar plant, pump speed can be controlled by calculation with collector efficiency, temperature levels and fluid volume and heat capacity (eq. 6.3.1). Measurement of irradiation makes quick reaction of the control possible, as there is no thermal inertia as with measurement of collector temperature. Pyranometers which are used for irradiation measurement at high accuracy cost more than 500 € including signal amplifier. Thus normally only one pyranometer is installed per collector array and partial clouding of the SDH plant can be hardly detected.

To avoid adjustments of the pump speed for very small deviations in the weather conditions (e.g. if a small cloud passes by the sun) mean values for short periods (e.g. 2 minutes), are used to calculate the flow rate.

In equation 6.3.1 the flow rate is derived by combining the formula for a) the solar collector energy* output and b) the energy required to provide the increase in the collector fluid temperature.

$$\dot{V}_{prim} = \frac{\eta_c \cdot G \cdot A_c \cdot 3600}{\rho_{prim} \cdot c_{p,prim} \cdot (T_{c,out} - T_{c,in})} \qquad \text{(eq. 6.3.1)}^\dagger$$

* *See equation 7.1.2 in fact sheet 7.1 "Solar collectors".*

† *The factor 3600 is seconds per hour which is used to convert the unit from m³/s to m³/h.*

where

$\dot{V}_{prim}$:	Flow rate on primary side of the heat exchanger	[m^3/h]
η_c:	Actual solar collector efficiency (for the given time step) depending on temperature level (eq. 6.3.2)	[-]
G:	Solar irradiance on collector plane	[W/m²]
A_c:	Total collector area	[m^2]
ρ_{prim}:	Density of the solar collector fluid	[kg/m^3]
$c_{p,prim}$:	Heat capacity of solar collector fluid	[J/(kg·K)]
$T_{c,out}$:	Collector fluid outlet temperature	[°C]
$T_{c,in}$:	Cold fluid inlet temperature	[°C]

The collector efficiency used in eq. 6.3.1 is calculated by the following equation:

$$\eta_c = \eta_0 - a_1 \frac{(T_m - T_a)}{G} - a_2 \frac{(T_m - T_a)^2}{G} \qquad \text{(eq. 6.3.2)}$$

where

η_c:	Collector efficiency	[-]
G:	Total (global) irradiance on the collector surface	[W/m^2]
T_m:	Mean collector fluid temperature	[°C]
T_a:	Temperature of the ambient air.	[°C]

The flow rate on the secondary side is calculated and controlled to maintain an equal capacity flow on both sides of the heat exchanger. See fact sheet 7.4 *"Heat exchanger"* and 7.1 *"Solar collectors"* for more information.

Start up

In some systems the fluid is circulated in the primary loop without starting the secondary pump which transports the heat from the solar collector field to the DH network. This is done in order to heat up all the pipes which are naturally cooled down during the night, thus being ready to provide heat at a given (chosen) minimum temperature when the secondary pump is started.

The minimum irradiance for starting up the primary pump may vary depending on the storage temperature. If the storage temperature is low, even small irradiances may be acceptable whereas a high storage temperature means that a higher (minimum) irradiance level is required to charge the storage. [1]

References

[1] Planning & Installing Solar Thermal Systems, 2. ed., p. 159, Earthscan, 2010.

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Chapter:	Components
Date:	August 2012
Size:	15 pages
Description:	Different types of collectors, their efficiencies and calculation of energy output is described along with the solar collector fluid properties.
Author:	Daniel Trier, PlanEnergi – dt@planenergi.dk
Co-author(s):	-
Available languages:	English
Version id:	7.1-3
Download possible at:	www.solar-district-heating.eu

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Efficiency expression

General terms

The efficiency of a solar collector depends on the ability to absorb heat and the reluctance to "lose it" once absorbed. Figure 7.1.1 illustrates the principles of energy flows in a solar collector.

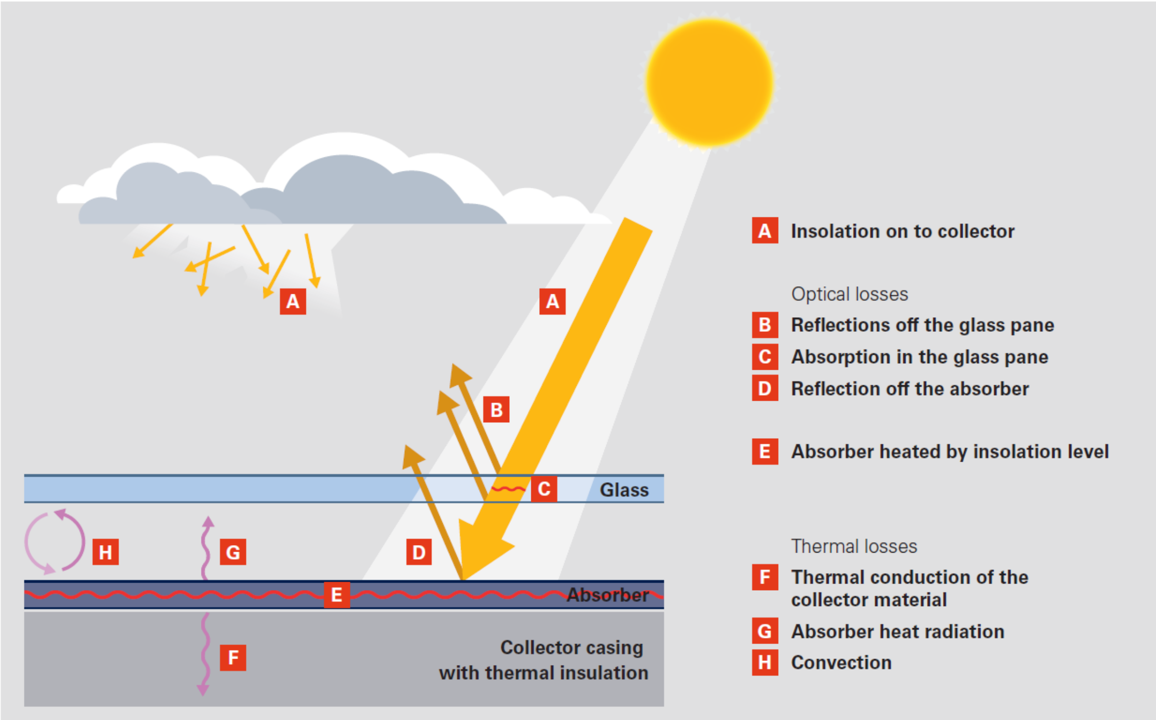

Fig. 7.1.1. Principle of energy flows in a solar collector [1].

A simple way to calculate the efficiency is to use equation 7.1.1 below and the parameters found on the data sheet of the collector:

η_0:	Maximum efficiency if there is no heat loss*	[-]
a_1	1^{st} order heat loss coefficient	$[W/(K \cdot m^2)]$
a_2:	2^{nd} order heat loss coefficient	$[W/(K^2 \cdot m^2)]$

These parameters should be determined according to the European standard EN12975 and provide the basic information to determine the efficiency:

$$\eta_c = \eta_0 - a_1 \frac{(T_m - T_a)}{G} - a_2 \frac{(T_m - T_a)^2}{G} \quad \text{(eq. 7.1.1)}$$

* *Also referred to as the "optical efficiency".*

where

η_c:	Collector efficiency	[-]
G:	Total (global) irradiance on the collector surface	[W/m^2]
T_m:	Mean collector fluid temperature	[°C]
T_a:	Temperature of the ambient air.	[°C]

The efficiency parameters of a wide range of collectors can be found at www.solarkeymark.org. This website list only collectors which have been tested according to the standard EN12975 by an impartial test institute.

The optical losses are constant regardless of the temperature. To minimize these losses some manufacturers use anti reflective (AR) treated glass which increases the amount of radiation transmitted through the cover glass by reducing the reflection. The AR treatment can be made in different ways. It can consist of an etching of the glass surface by subjecting the glass into a pool with certain chemicals (before the collector assembly)† or it can be made as a coating, i.e. a layer on the glass. Glass with low iron content, which helps to minimize the optical losses, is standard.

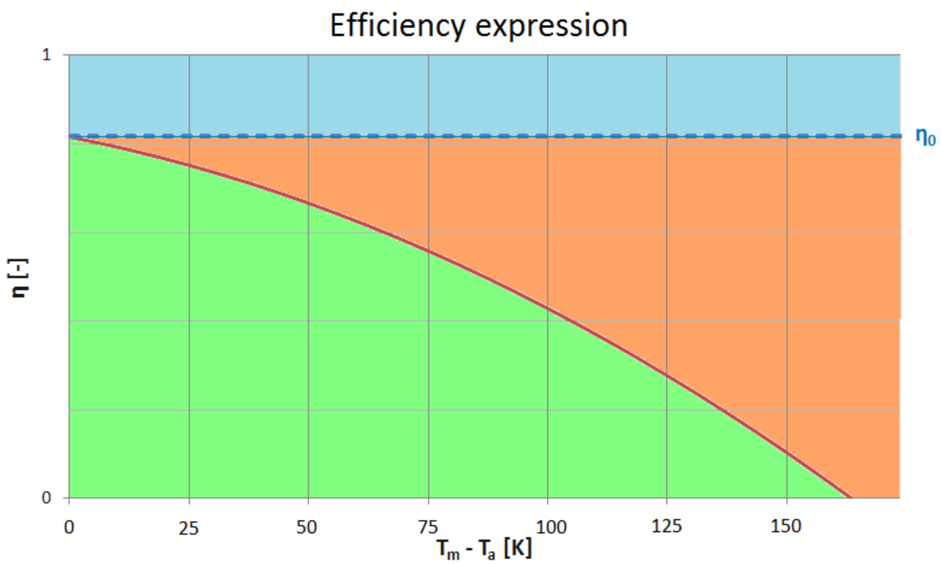

Fig. 7.1.2. Example of the efficiency expression from equation 7.1.1 (red line) illustrating the losses and useful energy for a given irradiation level (e.g. 1000 W/m^2). The efficiency is plotted as function of the temperature difference between the mean collector temperature and the ambient temperature. The colours indicate the ratio between the optical losses (blue), the heat losses (orange) and the useful energy (green) which can be compared to the total amount of energy from the irradiation (equal to 100 % on the secondary axis).

† *Further info on AR treatment by etching can be found at www.sunarc.net.*

The collector power output can then be calculated as:

$$P_c = A_c \cdot \eta_c \cdot G \qquad \text{(eq. 7.1.2)}$$

where

P_c:	Power output from the collectors	[W]
A_c:	Collector area	[m^2]

It is very important that the efficiency parameters are based on the same area as used in equation 7.1.2 e.g. collector *aperture* area.

Incidence angle modifier

The part of the irradiation reflected at the glass and absorber surface is not constant. It depends on the incidence angle of the solar irradiation. To account for this, an incident angle modifier (IAM) is multiplied by the maximum collector efficiency η_0 in equation 7.1.1.

Figure 7.1.3 shows an example of the IAM as function of incident angle for a flat plate collector. In the test report of the collector the IAM is generally given for the incident angles of 10°, 20°, 30°, 40°, 50°, 60° and 70°, but it can also be given as one of the following expressions:

$$K_\theta = 1 - b_0 \cdot \left(\frac{1}{\cos(\theta)} - 1 \right) \qquad \text{(eq. 7.1.3)}$$

where

K_θ:	IAM	[-]
b_0:	Constant stated in data sheet provided by manufacturer and/or test institute	[-]
θ:	Incidence angle on collector plane	[°]

or

$$K_\theta = 1 - \tan^p \left(\frac{\theta}{2} \right) \qquad \text{(eq. 7.1.4)}$$

where

p:	Constant stated in data sheet provided by manufacturer and/or test institute	[-]

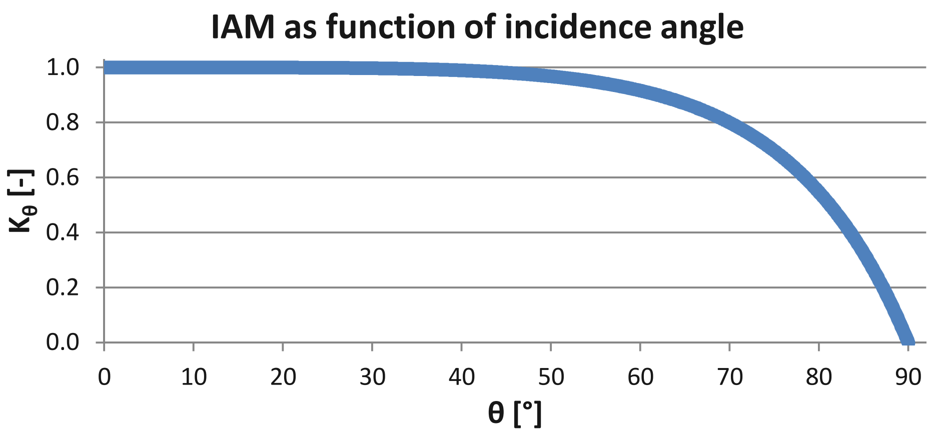

Fig. 7.1.3. Example of IAM as function of incidence angle for a flat plate collector type used for SDH (based on eq. 7.1.4).

The radiation going directly from the sun onto the collectors is called *beam* radiation or *direct* radiation. Some of the solar radiation is scattered by the molecules in the atmosphere. A part of this radiation is again reflected in clouds or small particles in the air and onto the collectors. This is referred to as diffuse irradiation. Even on a sunny day with clear blue sky, not all of the irradiation comes directly from the sun – some comes from the rest of the hemisphere though the percentage in this case is small. Reflectance from the ground and nearby obstacles may be calculated as a separate part, but is sometimes included in the calculation as part of the diffuse radiation.

For very detailed calculations equation 7.1.1 and 7.1.2 are split in two using

- the direct and diffuse irradiation instead of the global irradiation and
- the IAM for direct and diffuse irradiation separately.

Equation 7.1.2 then becomes:

$$P_c = A_c \cdot \left(\eta_0 \cdot (G_b \cdot K_\theta + G_d \cdot K_{60}) - a_1 \cdot (T_m - T_a) - a_2 \cdot (T_m - T_a)^2 \right) \qquad \text{(eq. 7.1.5)}$$

where

G_b:	Beam radiation (direct) on collector plane	[W/m^2]
G_d:	Diffuse radiation	[W/m^2]
K_θ:	IAM for the incidence angle at the given time step	[-]
K_{60}:	IAM for diffuse radiation	[-]

Diffuse radiation is coming from all incidence angles between 0° and 90°, therefore an average value of IAM at θ = 60° is used.

Often an approximated average IAM can be multiplied by η_0 in equation 7.1.1 thus including the IAM in the calculations without having to use the more complex equation 7.1.5.

Flow rate

Though the efficiency of the *collectors* is high if the flow is maximized (thereby minimizing the operating temperature thus lowering the collector heat loss), it is often not optimal for the overall plant efficiency since high flow requires more pump power and/or larger pipe diameter. Besides, there is a maximum limit for the flow rate, to avoid erosion corrosion. However a flow high enough to be turbulent, ensures good thermal conductivity between the absorber pipes and the fluid.

The pressure loss of the collectors as well as the pipe system is of high importance when it comes to calculating the collector array design. The more collectors connected in series, the less total system pipe length and the less heat loss from these pipes. This requires a high flow rate to avoid the temperature to be too high at the outlet and a high flow rate will result in a high pressure loss over the row. As for all parts of a SDH plants, the design of collector array and the associated pipe system requires an optimization which provides the lowest heat price.

The efficiency expression in the data sheet from the certified test institutes is based on a certain flow level (typically 0.02 kg/s per m^2 collector). In some collectors the flow rate should be at a certain minimum level to ensure a uniform flow distribution in the absorber. As indicated in figure 7.1.4 the buoyancy effect may in some cases be significant enough to result in a lower flow in the top absorber strips if the flow is at a certain lower level (specific for the given collector type and operating conditions). If the flow is non-uniform the temperature distribution will be uneven which will lead to a decreased efficiency and it may even lead to boiling locally in some absorber strips without showing it at the measured (mixed) outlet temperature. Theoretical and experimental testing [2] of a 12.5 m^2 flat plate collector resulted in a recommendation of not using a flow rate lower than 6 liters/min for the given collector model. However the flow rate distribution is dependent on several things such as manifold diameter, riser pipe diameter, exact geometry of inlet and outlet, T-junctions between manifold and riser pipes, fluid temperature and viscosity. This means that whether the buoyancy effect may be significant or not depend on the specific collector model.

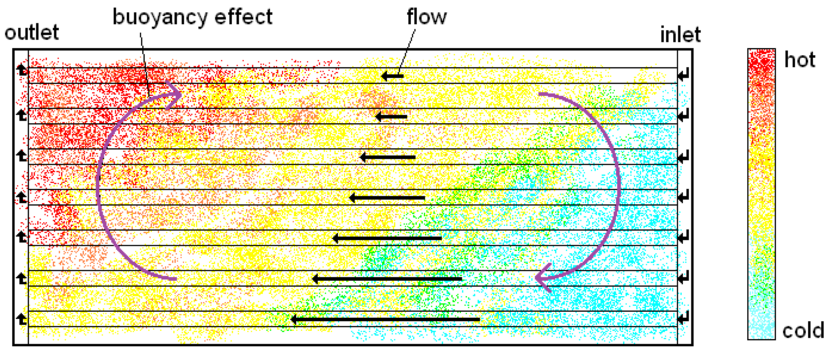

Fig. 7.1.4. Principle sketch of a FPC with too low flow leading to a non-uniform flow distribution. (Based on [2].)

Different solar collector types

The most common collector types are evacuated tubular collectors (ETC) and flat plate collectors (FPC) without vacuum. Different types of these collectors are described below. Concentrating collectors (Parabolic trough, Fresnel etc.) may also be used, but since a large part of the annual irradiation is diffuse – especially in the northern part of Europe – and these types do not utilize the diffuse part, they are not described further in this fact sheet.

Flat plate collectors

FPCs can be made with or without a convection barrier between the absorber and the cover glass. Often the convection barrier consists of a thin plastic foil (e.g. made of EFTE or FEP[‡]) stretched out between the absorber and the glass cover or an extra layer of glass. Just as the distance between absorber and cover glass is important to minimize the heat losses due to convection and conduction, it is important to get the optimum distance between the absorber and the convection barrier. The thermal expansion of a thin plastic foil must be taken into account since the foil should never be allowed to touch the absorber. In that case it will not function as convection barrier, but still decrease the total transmittance.

[‡] *EFTE ~ Ethylene tetrafluoroethylene. FEP ~ Fluorinated ethylene propylene.*

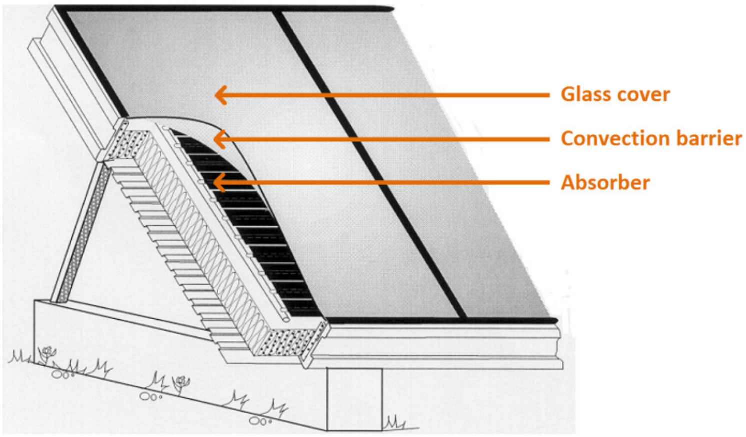

Fig. 7.1.5. Flat plate collector with convection barrier [4].

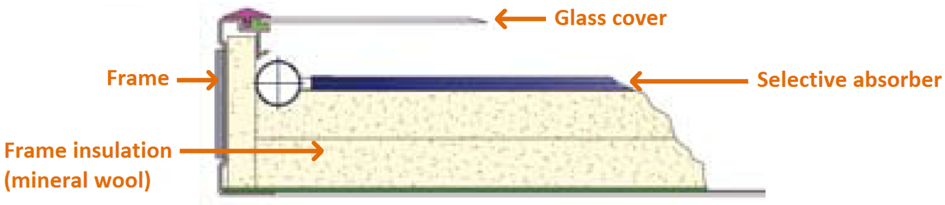

Fig. 7.1.6. Cross section of flat plate collector without heat barrier. [5].

The convection barrier shown in figure 7.1.5 reduces the circulation of air between the hot absorber and the colder glass cover. In this way it minimizes the heat loss from convection. Since the convection barrier is not 100 % transparent, it reduces the irradiance on the absorber slightly. This means that there is a certain (temperature) limit which distinguishes between whether or not it is advantageous to include a convection barrier, with regard to the efficiency.

In order to make the choice of collector type the extra costs due to the convection barrier should be compared with the extra annual energy output. To benefit from the optimal conditions from each collector type, a few collectors without convection barrier could be used in the first part of a series-coupled collector row and “convection barrier-collectors” then used as the rest of the row.

Evacuated tubular collectors

ETCs are made in many different ways, but all of them use vacuum to insulate the absorber. An example of a ETC-unit is seen in figure 7.1.7.

Fig. 7.1.7. Example of evacuated tubular collector unit [6].

In ETCs the heat can either be gathered by means of a solar collector fluid flowing through the absorber as in flat plate collectors or it can be collected by means of the heat pipe principle. In a heat pipe there is only a small amount of fluid sealed inside each evacuated tube. The energy transfer takes place in four steps:

1. This fluid is evaporated by the solar radiation.
2. The vapour rises to the top where it meets a (colder) pipe where a liquid flows through.
3. The vapour is condensed thus transferring the latent heat to the liquid in the top pipe.
4. The condensed fluid in the evacuated tubes runs back to the bottom of the tube where the process can start again.

In practice the process is continuous and not stepwise. The difference between heat pipes and direct flow ETCs can be seen in figure 7.1.8 and 7.1.9 below.

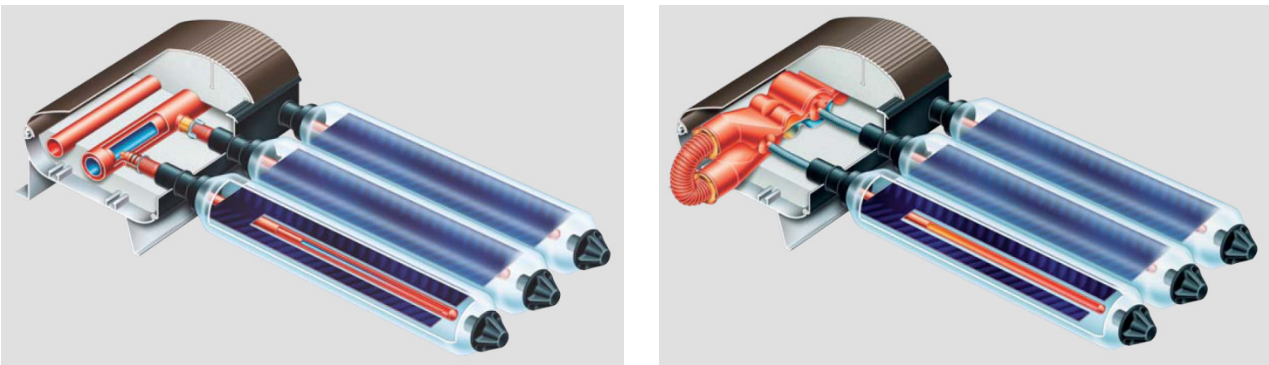

Fig. 7.1.8. Heat pipe (left) and direct flow ETC (right) [1].

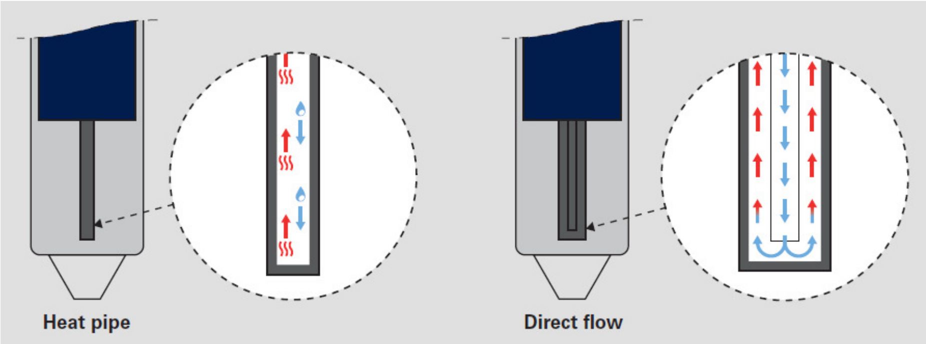

Fig. 7.1.9. Heat pipe principle (left) and direct flow ETC principle (right) [1].

Instead of co-axial direct flow, ETCs can also be made as "U-pipe" where the solar collector fluid runs through one single pipe shaped as a U.

Often concave mirrors are placed behind the collectors. This way almost all of the irradiation, which would otherwise slip between the collector tubes, will be reflected onto the tubes from behind. The reflectors can be made of cheap material e.g. polished aluminium. However for this solution to be efficient, it requires that the back side of the absorber have a selective surface just as the front.

Comparison of FPC and ETC

To illustrate how the efficiency parameters and the collector temperature affect the efficiency, the data for one evacuated tube collector and two flat plate collectors are listed in table 7.1.1 and the corresponding efficiencies are plotted in figure 7.1.10 assuming a solar radiation of 1000 W/m^2. B corresponds to a FPC with AR treated cover glass and convection barrier and C corresponds to a cheaper FPC without AR treatment or convection barrier.

Table 7.1.1. Efficiency expression constants for 3 different collectors – one evacuated tubular collector (ETC) and two flat plate collectors (FPC)[§].

Collector name	Collector type	η_0 [-]	a_1 [W/(K·m^2)]	a_2 [W/(K^2·m^2)]
A	High performing ETC	0.75	1.0	0.005
B	High performing FPC	0.80	3.0	0.008
C	Medium performing FPC	0.75	4.0	0.010

[§] *The figures in the table are fictional. Collector efficiencies may range widely even within the same the category.*

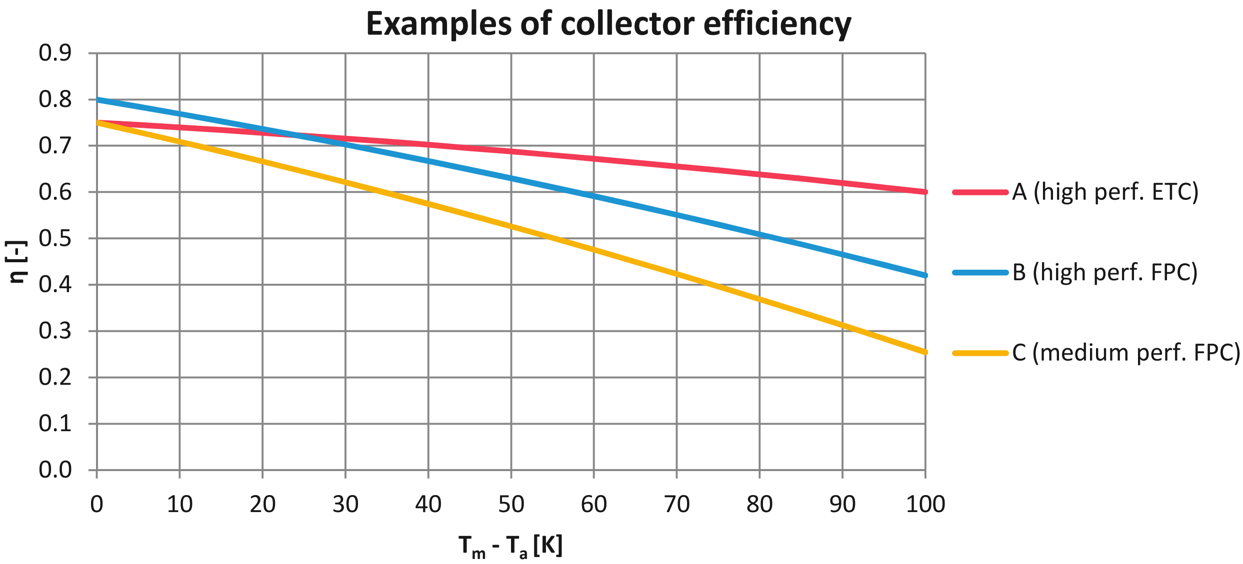

Fig. 7.1.10. Examples of collector efficiency based on aperture area as function of temperature difference between collector fluid and ambient air. Total solar irradiation is 1000 W/m² on the collector plane.

It is seen that in this example the ETC is best at high collector temperatures, the FPC with convection barrier is good at medium to high temperatures and that the FPC without convection barrier is good at low temperatures.

In many SDH plants FPC have been chosen instead of ETC because of the lower price/performance ratio. Using the efficiency expression above and weather data for a given location, the approximated annual output per m^2 collector is plotted for the three collectors in figure 7.1.11 and 7.1.13 based on aperture and gross area respectively (Copenhagen, Denmark chosen as example).

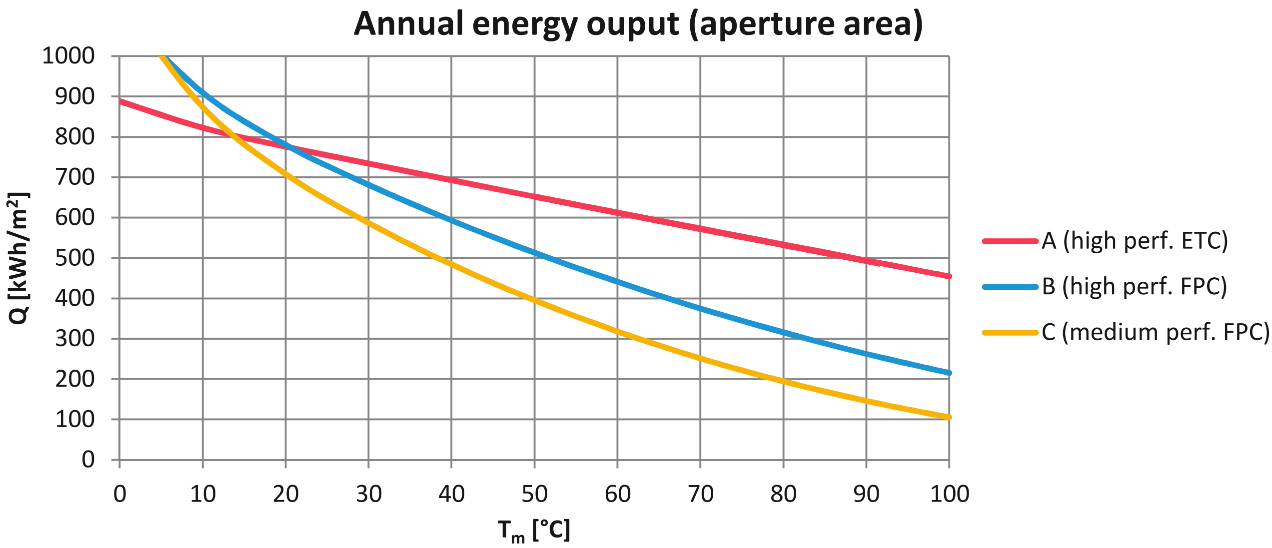

*Fig. 7.1.11. Annual solar output as function of collector mean temperature (T_m) for the ETC and the two FPCs described in table 7.1.1. Please note that the output (Q) is given in kWh per m² collector aperture area and per year. The aperture area can be much less than the gross area – see figure below and explanation in text below**.*

Figure 7.1.11 above shows the output per m² of *aperture* area. The aperture area is the area of the collector which actually takes part in the energy conversion. This is the area normally used for the collector efficiency parameters (collector test results). The standard ISO 9804 states: "...*aperture area is the maximum projected area through which un-concentrated solar radiation enters the collector"*. Figure 7.1.12 illustrates the definition of this aperture area.

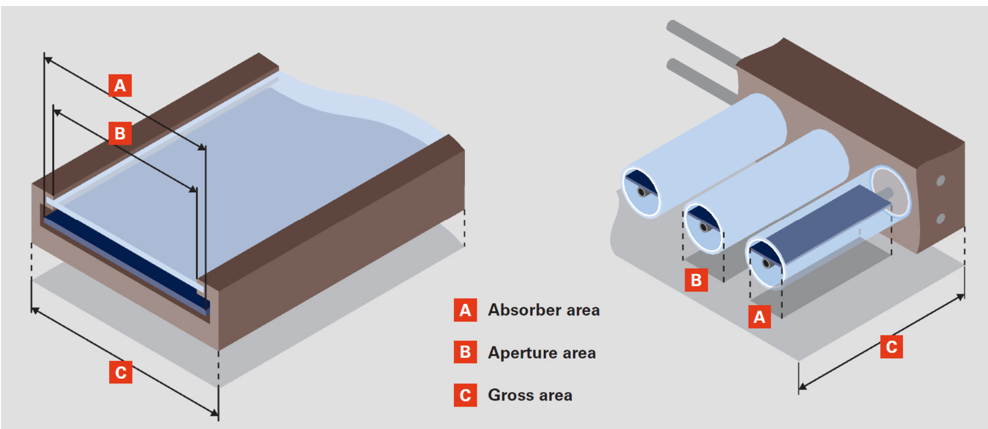

Fig. 7.1.12. Comparison of different ways to indicate the collector area [1].

** *The calculations are based on eq. 7.1.1 and 7.1.2 using Meteonorm hourly weather data.*

Due to the definition, the aperture area of a collector is always less than the area corresponding to the outer dimensions (gross area) of a collector. For evacuated tubular collectors the gross area is typically much larger than the aperture area (30-70 % larger). For flat plate collectors the gross area is typically only 5-10 % larger than the aperture area.

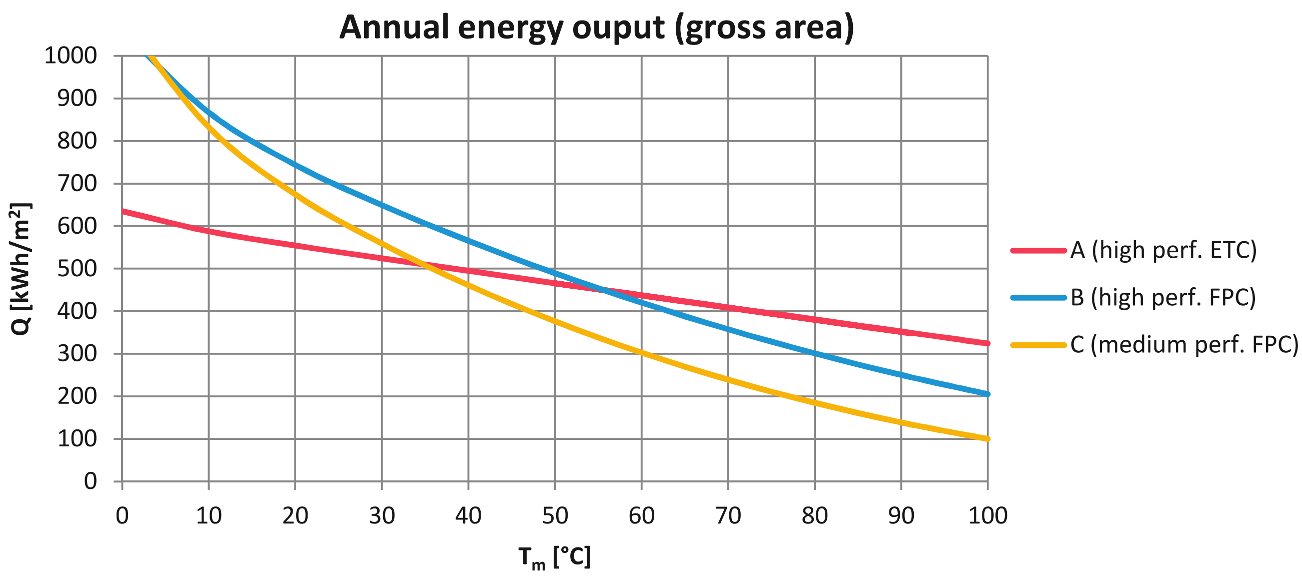

Fig. 7.1.13. Annual solar output as function of collector mean temperature (T_m) for the ETC and the two FPCs described in table 7.1.1. Please note that the output (Q) is given in kWh per m^2 collector gross area and per year.

This way it can be estimated roughly how much a certain temperature increase/decrease will affect the collector output, thus making it possible to choose the most profitable control strategy. The temperature is assumed to be constant during operation. More detailed calculations are needed for estimations which should include deviations in inlet and outlet temperatures.

The choice of collector type depends on several factors such as

- Price
- Efficiency
- Operating temperature
- Location (available solar radiation, ambient temperatures)

In most of the large systems flat plate collectors are used. One advantage of FPCs is that they are made in larger units compared to ETCs. The most commonly used collectors for large SDH plants in Denmark have an aperture area of 13-14 m^2. Larger units mean a lower number of pipes connecting the collector units which normally contributes significantly to the pressure losses. Another reason for the larger amount of FPC in SDH is that the durability of ETCs so far has not been proved in large SDH systems.

Collector fluid

In most SDH systems a mixture of water and glycol is used as the collector fluid. This lowers the freezing point and the amount of anti freeze is determined by the minimum ambient temperature of the given location. Most SDH plants cannot be emptied and the solar collector fluid must therefore be able to withstand sub-zero ambient temperatures without freezing to avoid damaging the collectors and pipes.

The downside of glycol is that it decreases the efficiency due to the higher viscosity and lower heat capacity; hence the amount should be minimized. Another way to secure the plant from freezing is to activate the pumps whenever the temperature reaches a level where the risk of freezing is imminent. This way the plant is in “reverse operation” taking heat from the DH grid and heating up the collectors. Since the minimum ambient temperature will only occur rarely during the lifetime of the plant, it is probably not preferable to keep the glycol amount high enough to have the freezing point at this temperature at all times. The optimum solution often is a mix of the two solutions: Instead of using a high percentage of glycol all year around to secure the plant a few hours during the winter where it is needed, a lower glycol percentage secures the plant during most of the winter and minimizes the need for “reverse operation” to zero or a few times a year.

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[1] "Technical guide – Solar thermal systems", Viessmann GmbH, 2009.

[2] "Buoyancy Effects on Thermal Behavior of a Flat-Plate Solar Collector", Jianhua Fan & Simon Furbo, Dep. of Civil Engineering – Technical University of Denmark, 2008, www.aseanenergy.info/Abstract/31029901.pdf

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[6] Sales brochure for Kingspan Solar collector www.kingspansolar.com/kingspansolar/pdfs/sales/thermomax8pp.pdf

The SDH fact sheets addresses both technical and non-technical issues, and provide state-of-the-art industry guidelines to which utilities can refer when considering/realizing SDH plants. For further information on Solar District Heating and the SDHtake-off project please visit www.solar-district-heating.eu.

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Chapter:	Components
Date:	August 2012
Size:	13 pages
Description:	This fact sheet provides information on construction concepts, costs and design guidelines for large-scale or seasonal thermal energy storages.
Author:	Thomas Schmidt, Solites – schmidt@solites.de
Co-author(s):	Oliver Miedaner, Solites – miedaner@solites.de
Available languages:	English
Version id:	7.2-3
Download possible at:	www.solar-district-heating.eu

Contents

Why storage?

When heat from solar collector fields is integrated into a district heating network thermal energy storage is necessary. The main reason is that the storage of thermal energy enables to cope with the deviating solar heat production during the course of one day, several days or even of a year. So the surplus heat supply during high solar irradiation can be stored for heat demand phases with low solar fraction e.g. during the night or winter time. This increases the solar contribution to the system. At the same time the thermal energy storage helps to balance the demand of varying heat capacity rates.

Furthermore the storage of thermal energy decouples the supply of electricity from the supply of heat. This is of importance when e.g. CHP plants are integrated into district heating networks.

Storage categories

There are three applications of thermal energy storage:

a) Buffer storage for short term energy storage

b) Large scale thermal energy storage (1,000 - 50,000 m³) for long term / seasonal thermal energy storage

c) Large scale thermal energy storage for multiple usage (e.g. solar heat and waste heat)

Application a) is state of the art. Consequently this fact sheet deals with large scale thermal energy storages of application b) and c) (see figure 7.2.1). Of special interest is the sub-function within a district heating network with large scale solar thermal collector fields or replaceable thermal energy sources (e.g. surplus heat or waste heat from CHP plants in biogas and waste incineration).

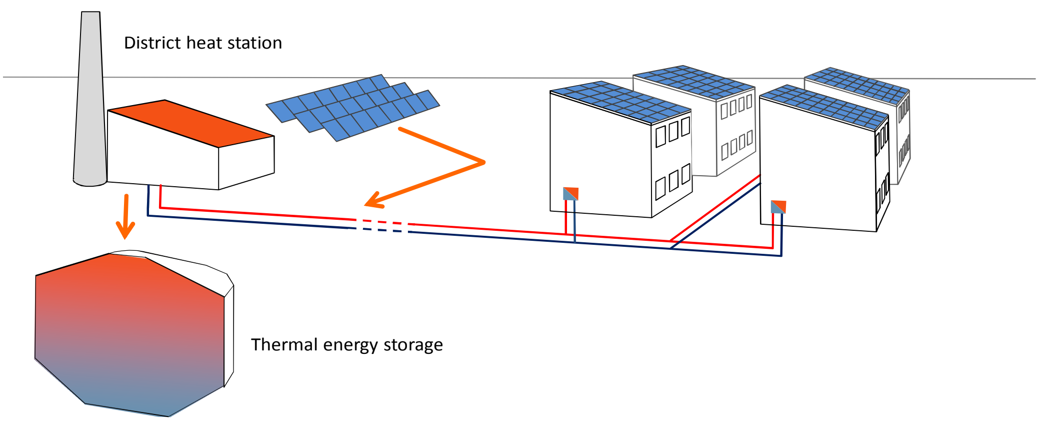


Fig. 7.2.1. Seasonal thermal energy storage within a district heating network. (Source: Solites)

Construction concepts for large-scale or seasonal thermal energy storages

Four main types of large-scale or seasonal thermal energy storages are used worldwide. The four storage concepts shown in figure 7.2.2 include tank and pit thermal energy storage (TTES and PTES), borehole thermal energy storage (BTES) and aquifer thermal energy storage (ATES).

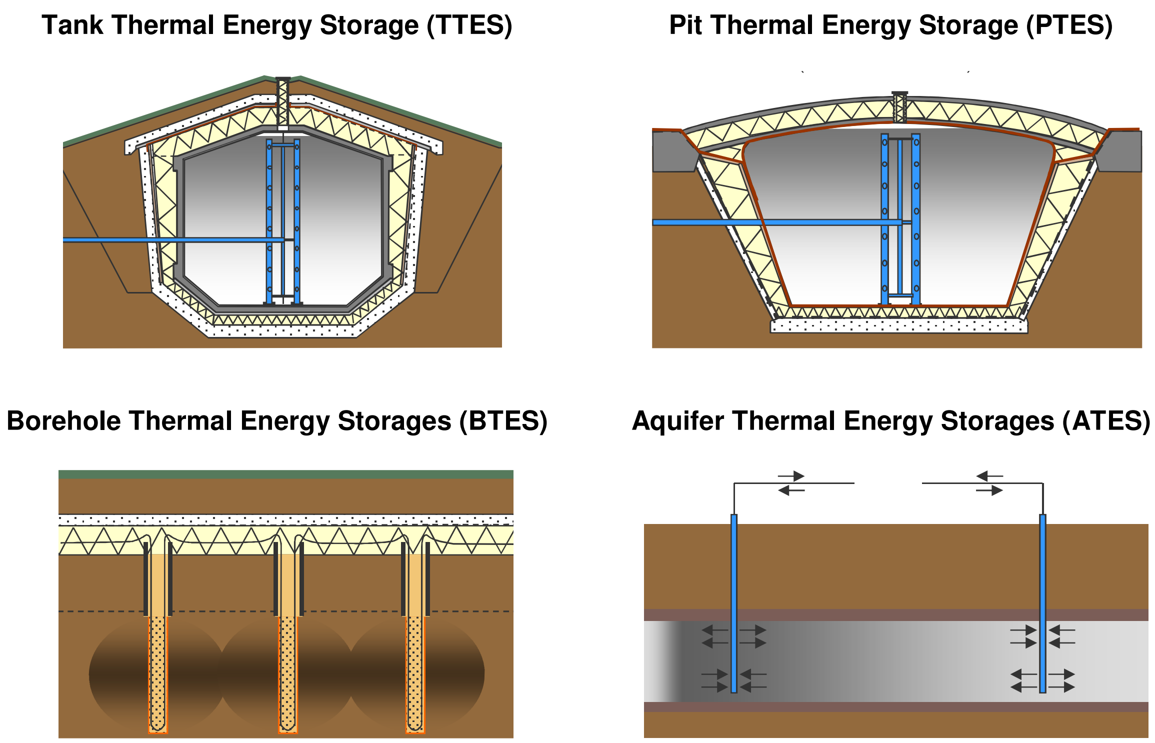


Fig. 7.2.2. Construction concepts for large-scale or seasonal thermal energy storages. (Source: Solites)

New advanced storage techniques are phase change materials (PCM), thermo chemical storages and sorption storages. These techniques are not yet ready for the use in seasonal thermal energy storage applications. For more details see [1].

Table 7.2.1 shows a comparison of the in figure 7.2.2 mentioned storage concepts regarding heat capacity and geological requirements. Because of the lower specific heat capacities of a gravel-water mixture and different underground materials storage volumes have to be significantly higher compared to a water storage to be able to store the same amount of heat at the same temperature difference.

Tab. 7.2.1. Comparison of storage concepts regarding heat capacity and geological requirements (source: Solites)

TTES	PTES		BTES	ATES
storage medium				
water	water*	gravel-water*	soil / rock	sand-water
heat capacity in kWh/m³				
60 - 80	60 - 80	30 - 50	15 - 30	30 - 40
storage volume for 1 m³ water equivalent				
1 m³	1 m³	1.3 - 2 m³	3 - 5 m³	2 - 3 m³
geological requirements				
- stable ground conditions - preferably no groundwater - 5 – 15 m deep	- stable ground conditions - preferably no groundwater - 5 – 15 m deep		- drillable ground - groundwater favourable - high heat capacity - high thermal conductivity - low hydraulic conductivity ($k_f < 10^{-10}$ m/s) - natural ground-water flow < 1 m/a - 30 - 100 m deep	- natural aquifer layer with high hydraulic conductivity ($k_f > 10^{-5}$ m/s) - confining layers on top and below - no or low natural groundwater flow - suitable water chemistry at high temperatures - aquifer thickness of 20 - 50 m

*: Water is more favourable from the thermodynamic point of view. Gravel-water is often used if the storage surface is to be designed for further usage (e.g. for streets, parking lots etc).

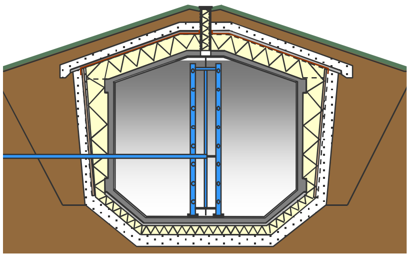
TTES and PTES

For the construction of ground buried thermal energy storages there are no standard procedures regarding wall construction, charging device, etc. available.

Due to the size and geometry and also due to the requirements in terms of leakage detection and lifetime most techniques and materials have their origin in landfill construction. However, with respect to high operation temperature materials and techniques cannot be simply transferred.

Dimensions of pilot and research tank thermal energy storages and pit thermal energy storages that have been realized over the last 25 years for solar assisted district heating systems, range from several 100 m³ up to 75,000 m³ [1, 7].

Tank Thermal Energy Storage (TTES)



Tank thermal energy storages have a structure made of concrete, of steel or of glass fibre reinforced plastic (sandwich elements). Concrete tanks are built utilizing in-situ concrete or prefabricated concrete elements. An additional liner (stainless steel) is normally mounted on the inside surface of the tank to ensure water- and steam diffusion tightness. The insulation is fitted outside the tank.

Above ground tanks (see figure 7.2.3) are state of the art. Because of the high investment cost they are in general only used as buffer tanks with volumes up to 200 m³. Yet some above ground large-scale steel storage tanks are available in Austria, Denmark and Sweden [1].

In Crailsheim a 100 m³ buffer storage was built using prefabricated concrete elements and a stainless steel liner. A further 480 m³ in-situ concrete storage serves as a buffer for a 39,000 m³ BTES. Both tanks can be operated at temperatures up to 108°C as they are operated with a pressure level of three bars [2].

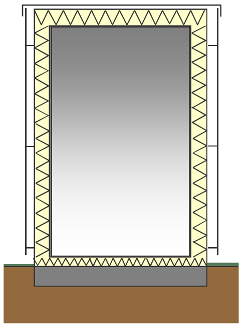
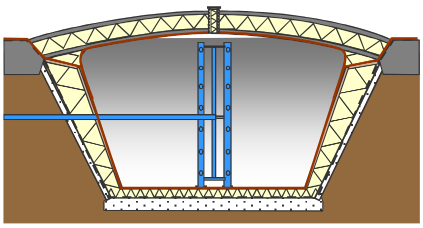


Fig. 7.2.3. Above ground tank (source: Solites)

Additional TTES facts:

- Multifunctional application area (short / long term storage)
- Special case: Retrofitted TTES in Hamburg (DE): Used as seasonal thermal energy storage of solar heat and for optimization of the connected CHP-heating network [3]
- Charging equipment has to avoid mixture of the thermal stratification
- Waterproof liner made from stainless steel panels (if no special concrete mixture is used)
- Un-pressurized operation temperature up to 95°C
- Wall construction has to consider combined heat and mass transport (steam)
- To avoid corrosion in steel tanks an automatic nitrogen application is often installed in the top of the tank to remove the oxygen in the air above the water level.

Pit Thermal Energy Storage (PTES)



Pit thermal energy storages are constructed without static constructions, by means of mounting insulation and a liner in a pit. The design of the lid depends on the storage medium and geometry, whereas in the case of gravel- or soil / sand-water thermal energy storages the lid may be constructed identical to the walls. The construction of a lid of a water PTES requires major effort and is the most expensive part of the thermal energy storage. Typically it is not supported by a construction underneath but floats on top of the water.

By definition, pit thermal energy storages are entirely buried. In large PTES the soil dug from the ground is used to create banks which make the storage somewhat higher than the ground level. The lid can be only equipped with a membrane for rain and UV protection.

In Denmark a number of large water-filled PTES were realised. The largest one is in Marstal and has a storage volume of 75,000 m³ [7].

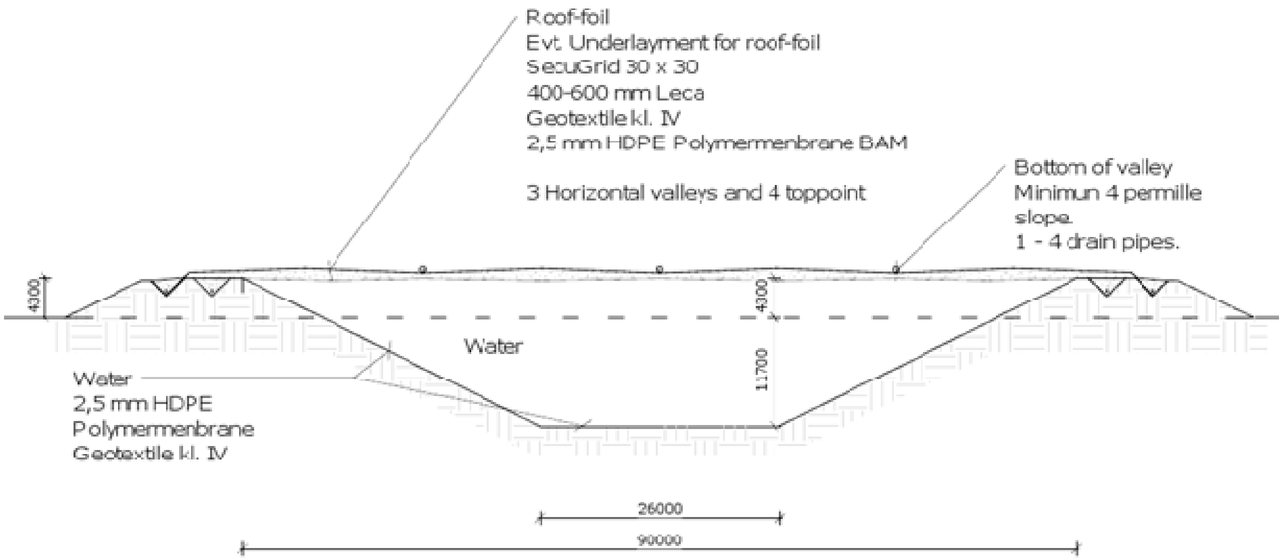


Fig. 7.2.4. Construction Cross section of the 75,000 m³ PTES in Marstal. (Source: PlanEnergi)

Tab. 7.2.2. Hot water vs. gravel water pit thermal energy storage [1]

Hot water **pit thermal energy storage**	**Gravel / sand / soil water** **pit thermal energy storage**
+ thermal capacity + operation characteristic + thermal stratification + maintenance / repair	+ low static requirements + simple cover
- sophisticated and expensive cover - low static cover load - costs for landfill of excavated soil (if applicable)	- thermal capacity - charging system - additional buffer storage (if applicable) - maintenance / repair - gravel costs

Additional PTES facts:

- Gravel fraction of 60 to 70 % (*if* gravel is used)

- Soil / sand instead of gravel can be used alternatively
- Thermal insulation of cover (optionally of side walls and bottom) is necessary (depending on storage volume)
- Charging and discharging process, indirect by plastic pipes in gravel layer or by direct water exchange
- Max. storage temperature 80 - 90℃, depending on temperature stability of liner
- Wall construction has to consider combined heat and mass transport (steam)
- Less vertical thermal stratification with gravel-water compared to pure water as storage medium

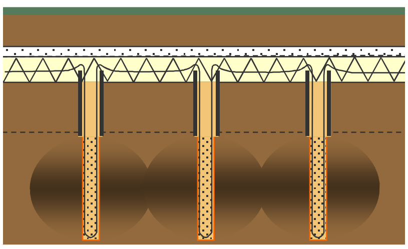
BTES and ATES

Underground thermal energy storage systems can be divided into two groups [4]:

- Systems where a technical fluid (water in most cases) is pumped through heat exchangers in the ground, also called "closed" systems (BTES)
- Systems where groundwater is pumped out of the ground and injected into the ground by the use of wells, also known as "open" systems (ATES)

An advantage of closed systems is the independency from aquifers and water chemistry, an advantage of open systems is the generally higher heat transfer capacity of a water well compared to a borehole. This makes ATES usually the cheapest alternative, if the subsurface is hydrogeologically and hydrochemically suitable.

Borehole Thermal Energy Storages (BTES)



In a BTES the underground is used as storage material. There is no exactly separated storage volume. Suitable geological formations for this kind of storage are rock or water-saturated soils without natural groundwater flow. Heat is charged or discharged by vertical borehole heat exchangers (BHE) which are installed into boreholes with a depth of typically 30 to 100 m below ground surface. BHEs can be single- or double-U-pipes or concentric pipes mostly made of synthetic materials (see figure 7.2.5).

BTES do not have a vertical but a horizontal temperature stratification from the centre to the borders. This is because the heat transfer is driven by heat conduction and not by convection. At the boundaries there is a temperature decrease as a result of the heat losses to the surroundings. The horizontal stratification in the ground is supported by connecting the supply pipes in the centre of the storage and the return pipes at the boundaries. A certain number of BHEs are hydraulically connected in series to a row and a certain number of rows are connected in parallel. During charging, the flow direction is from the centre to the boundaries of the storage to obtain high temperatures in the centre and lower ones at the boundaries of the storage. During discharging the flow direction is reversed.

At the top surface of the storage an insulation layer reduces heat losses to the ambient. Side walls and bottom are normally not insulated because of inaccessibility.

Compared to ATES systems BTES systems are easier to realise and to operate. They need less maintenance and have a high durability. Because of the closed loop system BTES systems usually require more simple procedures for authority approvals, unless high storage temperatures (approx. more than 50℃) are foreseen. Table 7.2.3 shows typical general values for BTES systems.

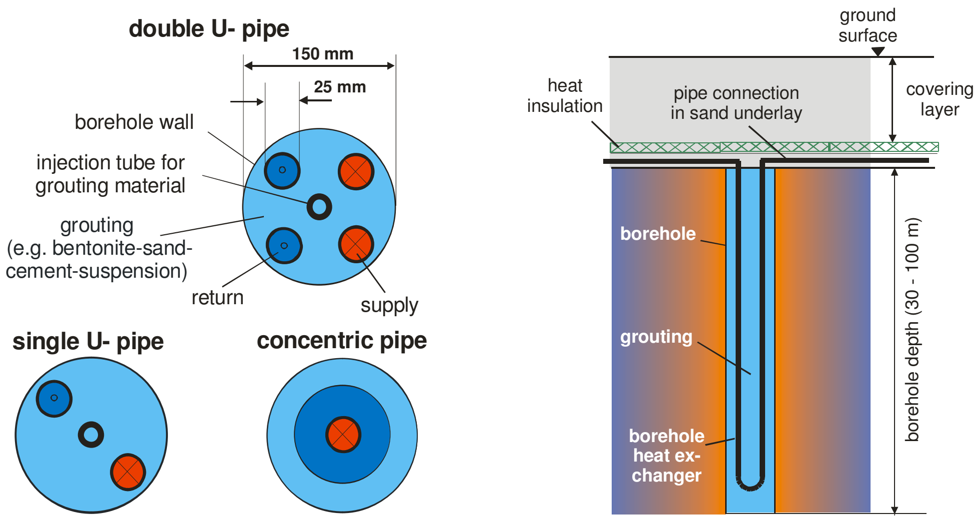


Fig.7.2.5. Common types and vertical section of borehole heat exchangers. (Source: ITW, University of Stuttgart)

Tab. 7.2.3. Typical values of BTES system for heat storage application

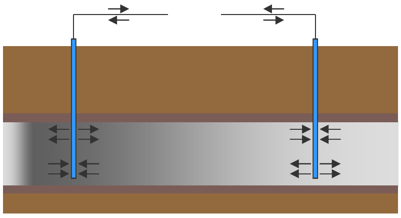
Borehole diameter	100 - 150 mm	Flow rate in U-pipes	0.5 - 1.0 m/s
Borehole depth	30 - 100 m	Average capacity per m borehole length	20 - 30 W/m
Distance between boreholes	2 - 4 m	Min. / max. inlet temperature	-5 / > +90℃
Thermal ground conductivity	2 - 4 W/(m·K)	Typical cost of BTES storage per m borehole length	50 - 80 €/m

Additional BTES facts:

- Modular design: additional boreholes can be easily connected and the storage can be expanded

- Because of low capacity rate for charging and discharging often a buffer storage is integrated into the system
- Permission from water authorities normally necessary for heat storage application

Aquifer Thermal Energy Storages (ATES)



Aquifers are below-ground widely distributed and water filled permeable sand, gravel, sandstone or limestone layers with high hydraulic conductivity. If there are impervious layers above and below and no or only low natural groundwater flow, they can be used for thermal energy storage. In this case, two wells (or groups of wells) are drilled into the aquifer layer and serve for extraction or injection of groundwater. During charging periods cold groundwater is extracted from the cold well, heated up by the heat source and injected into the warm well. In discharging-periods the flow direction is reversed: warm water is extracted from the warm well, cooled down by the heat sink and injected into the cold well. Because of the different flow directions both wells are equipped with pumps, production- and injection pipes.

Because the storage volume of an ATES cannot be thermally insulated against the surroundings heat storage at high temperatures (above approx. 50 °C) is normally only efficient for large storage volumes (more than 20,000 m³ of ground volume) with a favourable surface to volume ratio. For low temperature or cooling applications also smaller storages can be feasible.

Properties and conditions that have to be considered are:

- Stratigraphy (sequence of layers)
- Grain size distribution (mainly prime porosity aquifers)
- Structures and fracture distribution (mainly fractured aquifers)
- Aquifer depth and geometry, hydraulic boundaries included
- Storage coefficient (hydraulic storage capacity)
- Leakage factor (vertical hydraulic influence)
- Degree of consolidation (hardness)
- Thermal gradient (temperature increase with depth)
- Static head (ground water level)
- Natural ground water flow and direction of flow
- Water chemistry

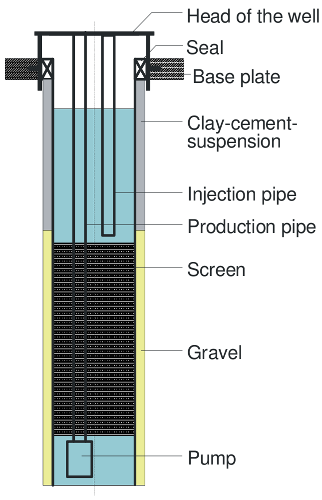


Fig.7.2.6. Layout of a well for charging and discharging. (Source: Geothermie Neubrandenburg GmbH)

Additional ATES facts:

- Aquifers near to the surface are often used for drinking water extraction
- At high charging temperatures water treatment can be necessary (chemical and biological processes can lead to deposition, corrosion and degradation in the system)
- Permission from water authorities normally necessary for heat storage application

Cost of storages

Construction cost of the four storage concepts vary significantly. However, there is not one optimum storage concept for all applications and not every storage concept can be built everywhere. Figure 7.2.7 shows a typical cost allocation for one example of each of the four storage concepts.

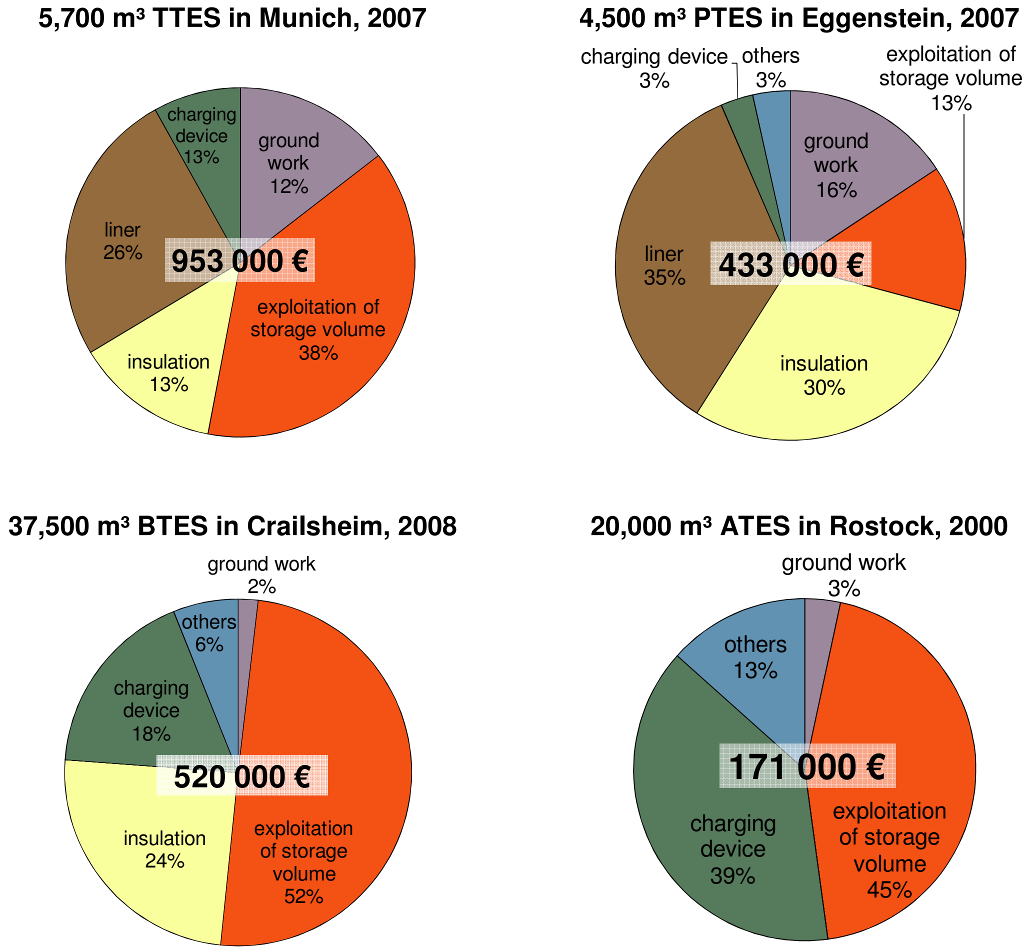


Fig. 7.2.7. Exemplary allocation of construction cost for different storage concepts (cost figures without planning and VAT). (Source: Solites)

Figure 7.2.8 presents the cost data of built pilot and demonstration plants. The listed storages are high temperature heat storages (working temperatures up to 95 °C) and are mostly integrated into central solar heating plants with seasonal storage (CSHPSS).

Figure 7.2.8 shows the cost decrease with an increasing storage volume. Appropriate volumes for seasonal heat storage are larger than 2,000 m³ water equivalent. In this case the investment costs vary between 40 and 250 €/m³. Generally, TTES are the most expensive ones. On the other hand, they have some advantages concerning the thermodynamical behaviour and they can be built almost everywhere. The lowest costs can be reached with ATES and BTES. However, they often need additional equipment for operation like buffer storages or water treatment and they have the highest requirements on the local ground conditions.

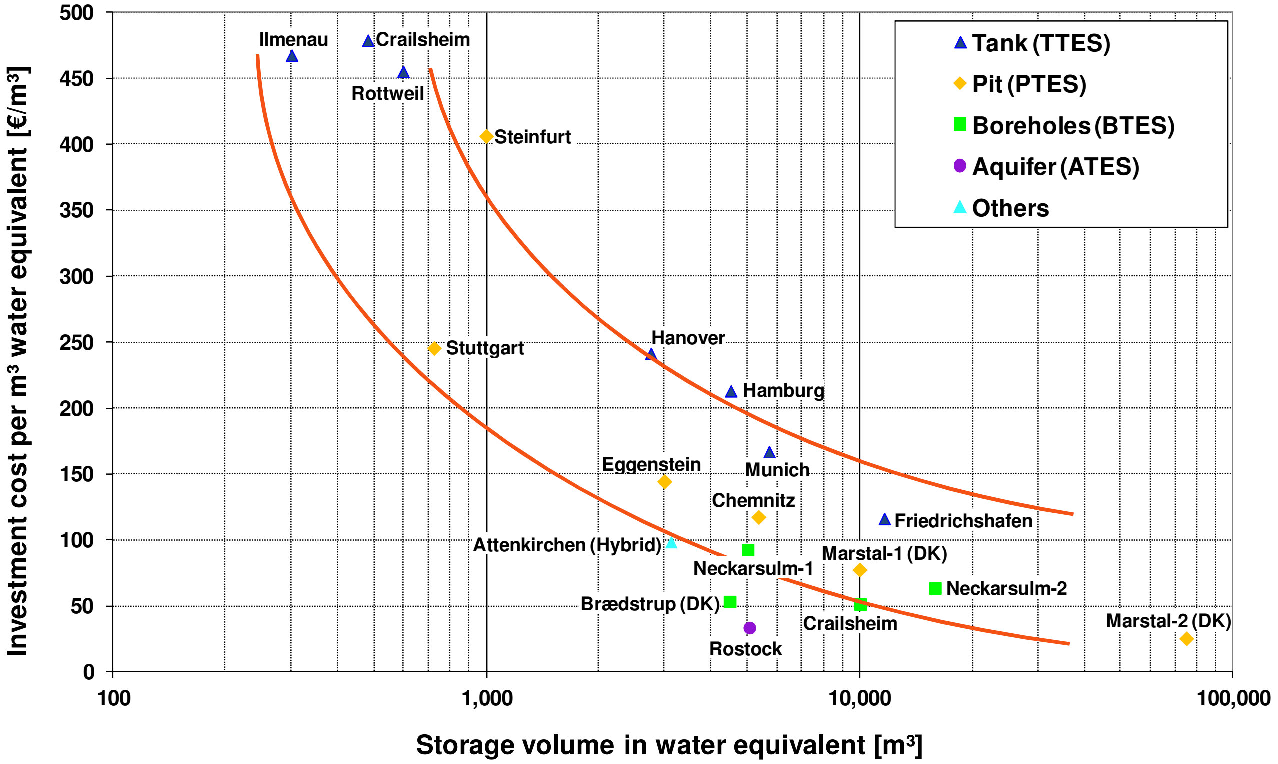


Fig. 7.2.8. Specific storage costs of demonstration plants (cost figures without VAT, storages without country code are located in Germany). (Source: Solites)

The economy of a storage system depends not only on the storage costs, but also on the thermal performance of the storage and the connected system. Therefore each system has to be examined separately. To determine the economy of a storage, the investment, maintenance and operational costs of the storage have to be related to its thermal performance.

Design guideline

For the choice of a suitable storage concept for a specific plant all relevant boundary conditions have to be taken into account: local geological situation, system integration, required size of the storage, temperature levels, power rates, no. of storage cycles per year, legal restrictions etc. Finally, decisions should be based on an economic optimisation of the different possibilities.

For all concepts a geological investigation has to be made in the pre-design phase. The highest demands with regard to this are made by ATES and BTES. The legal requirements have to be checked in the pre-design phase as well. In most countries the usage of the ground for heat storage has to be approved by the local water authorities to make sure that no interests regarding drinking water are affected. This can also become necessary if the ground surrounding a storage tank is heated up by heat losses.

After construction the storages have start-up times between two to five years, depending on the storage concept, to reach normal operating conditions. Within this time, the surrounding ground is heated up and the heat losses of the storage are higher than during long-term operation.

One crucial point in all storage applications are return temperatures from the heat distribution systems. In systems without a heat pump the return temperature defines the lowest temperature level in a system – and by this the lowest usable temperature level for discharging the storage. In many installations measured return temperatures are much higher than design values. This results directly in a strongly reduced heat capacity and a lower performance of the connected heat storage.

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Chapter:	Components
Date:	August 2012
Size:	13 pages
Description:	Considerations regarding the dimensioning of both pipes and pumps in the SDH plant.
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Available languages:	English
Version id:	7.3-3
Download possible at:	www.solar-district-heating.eu

Contents

Introduction

It is possible to distinguish between two types of pipes used in SDH systems according to their purpose. The first is utilized in the solar system itself as connection between the heat source (collectors) and other components. These are sometimes referred to as “solar pipes”. The second group of piping is used in the distribution grid of the district heating system.

Solar pipes

General requirements for solar pipes

Solar system piping must meet requirements on functionality, operation life and resistance to effects of the collector fluid and external environment. Pressure and temperature conditions are equally important in the solar system. The size of the pump(s) has to match the dimension of the pipes in order to achieve the desired flow. Typically a flow corresponding to a ΔT over the collector of 25-45 K is chosen. The cost of the pipes increases with the pipe’s diameter, but if the pipe diameter is increased, the pressure loss and corresponding required pump power is decreased. As for ordinary DH systems, the pipe dimensions and annually pump costs has to be optimized with respect to lowest lifetime costs. The pressure loss in the system depends as well on the setup of the collector area. If the collectors in the collector field are coupled in series, it results in a larger pressure drop over the rows than if they were coupled in parallel. However the extra distribution pipes required due to the parallel setup lead to an increase in the pressure drop - and investment costs. Control valves in each collector row can be used to ensure that the temperature increase is equal in all of the collector rows regardless of location in the field (i.e. distance from pump) and the number of collectors in the row.

For large scale applications steel pipes are used. There is also the possibility to use copper pipes (as well), but the advantage of the easy installation is at the expense of a significantly higher price. It is also possible to utilize compact systems using pre-insulated pipes including wiring between regulator and temperature sensor that is placed in the collector.

Thermal expansion

Thermal expansion and soil-pipe interaction must be taken into account. Since the pipes in the solar collector loop is exposed to much more fluctuating temperatures than ordinary DH pipes, it is important to take precautions in terms of both the pipe materials, pipe configuration and surrounding soil (if buried). Regarding the pipe design please check EN 13941.

To handle the thermal expansion of the pipes, a lyre is often used. Figure 7.3.1 shows an example of such an installation. More information on the effect of temperature variations can be found in fact sheet 8.1 *"Temperature variations"*.

Fig. 7.3.1. Built in lyre to withstand stress in the pipe system. [1]

District heating pipes

General requirements for DH pipes

For the assembly of small district heating networks (DH-network) with small expansion mainly radial distribution systems are put into practice which will be defined in the following section.

In radial distribution systems one or more routes run directly from the heat supplier to the domestic stations. Flow and return pipes are dimensioned symmetrically. The diameter has its major amplitude at the heat supplier and decreases it in accordance to the heat demand. The pressure stabilisation is configured in a way that ensures the agreed pressure difference for the last domestic station at the end of the network. In comparison with other structures this one has the minimal length of the network.

The route planning of the DH network is based on heat density, building positions and routes of the public roads. Since valve chambers are to be avoided, due to high investment and operating costs, buried valves should be used instead.

Usual directly buried pre-insulated bonded pipe systems are used for the main and distribution route. Since, in case of reparation or new connection, the surface recreation costs are much lower, favourably the pipeline route is to be made in the area of sidewalks or green fields.

Costs can be saved by installing pipes together with other service pipes in a stepped trench before the roads are built so that the excavation expenses can be shared with other utilities.

For economic reasons, the pipes should be installed as close to the surface as possible with the minimum cover necessary.

For economic reasons a multiple-service house entry for water, district heating and electricity should be preferred. Open line pipes frequently show the lowest investment and operating costs. Therefore areas, where houses are built with cellars, should be examined for cost advantages for installation by using open line pipes instead of buried pipelines.

Principally the installation of buried pipes is horizontal and parallel in routes. However an installation on top of each other is feasible if required. In case of reparation the lower positioned pipeline is not as easy to get to, so it has to be considered that a special foundation material is needed.

Network parameters

With the help of the key plan (land-use plan) and a topographical map for the geographic structure the general requirements for the DH network can be revealed.

Flow pipe temperature:

The temperature of the flow pipe is the most important parameter towards the design of the network. It influences the selection of heat generation as well as the selection of material of service pipes. Therefore it is necessary to consider its impact on economy. Likewise special customer requirements are able to affect the temperature of the flow pipe.

Experiences show that a flow pipe temperature of 90 °C is practical for networks with small expansion and > 110 °C for networks with large expansion.

The minimum flow pipe temperature normally has to exceed 70 °C to consider appearing temperature losses within the network and safety measures to avoid Legionella (DVGW W 551) for domestic hot water processes.

Return pipe temperature:

The set temperature of the return flow is supposed to be defined to a maximum of 40-45 °C (and 50-55 °C for domestic hot water preparation). To ensure an economic supply the return temperature should not extend this limitation. The lower the return temperature, the higher the efficiency of the DH System.

Network operation mode:

To define the network operation mode it is important to know about the annual load duration curve of heat demand for customer installations. In summertime the heat demand is only one fifth of the demand in wintertime (there is more or less only a heat demand for the domestic hot water system).

For the operation mode of the flow pipe temperature the heating curve according to outside temperature and heat demand is defined. To adjust the operating mode curve the lowest outside temperature appropriate DIN EN 4701 is chosen. Normally the highest temperature is set at +15 ℃.

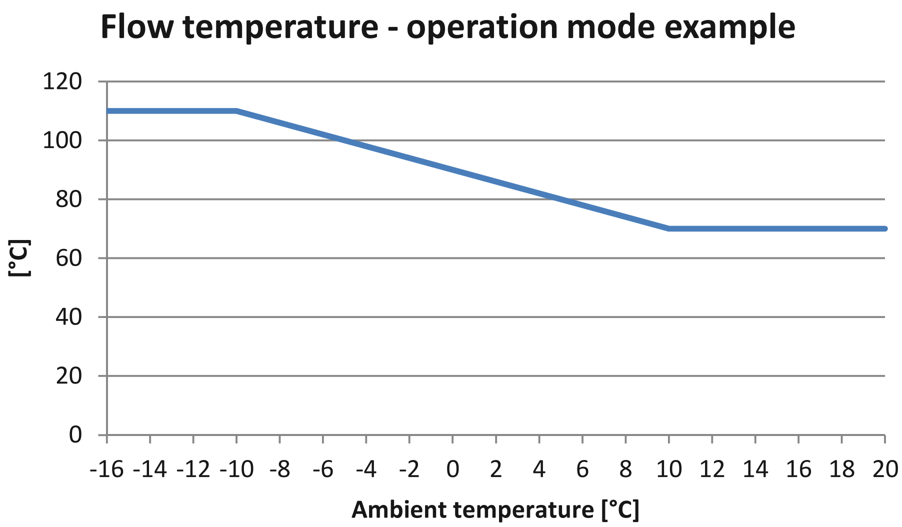

Fig. 7.3.2. Example for the operation mode of the flow temperature at the range of 100 ℃ variable / constant to 70°.

Figure 7.3.2 shows an example for an operation mode between -10 ℃ and +10 ℃ which is variable for the flow pipe temperature. Beyond these parameters the flow pipe temperature remains constant.

Short term fluctuations of heat demand are controlled by mass flow adjustment, because the variation of temperature is very slow and would affect the last customer not until hours later.

Installation systems

The selection of the installation system depends on operating flow and return temperatures, operating pressure and local requirements at the domestic station. Also it has to be decided if a surveillance and fault location system is required.

Pipeline construction companies and companies which carry out sleeve mounting must fulfil different special requirements for DH networks. Table 7.3.1 opposes applicable installation systems, followed by criteria that have to be considered for the draft planning.

Table 7.3.1. Special features of common installation systems.

System parameters	Rigidly pipe system Pre-insulated pipes KMR	flexible pipe systems Metallic service pipes MMR	 Polymer service pipes PMR
EN-rules	EN 253 (singel pipe) EN 15698-1 (twin pipe)	EN 15632-1 EN 15632-4	EN 15632-1 EN 15632-2 EN 15632-3
AGFW-rules	FW 401	FW 420-2 and -3	FW 420-1
Material grade and preperation	Steel pipe	Steel or copper pipe Corrugated stainless steel or copper pipe	PE-X and PB
Insulation	PUR-foam	PUR- or PIR-foam	PUR-foam Polyolefin-foam
Outer casing	PE-HD	PE-LD /PE-LLD Steel case or steel tissue	PE-LD (PE-LLD)
Pipe joints for service	Welding joints	Metallic screwing joint Braze joint (for Cu) Welding joint. (for St)	Pressing joint (for PE-X und PB) Welding joint (for PB)
Pipe system	Single- or twin pipe system	Single pipe system	Single- or twin pipe system
Operating temperature	120 °C	120 °C	80 °C
Peak temperature (occasional)	Max. 140 °C	Max. 140 °C	Max. 95 °C
Pressure	Up to PN 25	Up to PN 25	Operation pressure up to 10 bar
Available nominal diameters	≥ DN 15 to DN 1200	DN 15 to DN 200	Up to ~ D_A 110 mm

KMR:

The pre-insulated bonded pipe system (KMR) is the currently most applied installation system. It can be used for DH networks without any constrictions. It is a non self compensative system. Therefore pipe statics (like in FW 401) are essential and compensation arrangements should be made:

- thermal and mechanical pre-stressing
- expansion bends (U-, L- and Z- bends)
- Single-use compensators

Bonded pipes can be manufactured with wire conductors for surveillance and fault location. The functional requirements of these systems are listed in EN 14419. Design and installation requirements for pre-insulated bonded pipe system are to be found in the AGFW rule FW 401.

Flexible metallic service pipes:

The application area of metallic service pipes predominantly covers nominal diameters up to DN 50. Therefore they are used for sub-distribution and house entry. The self compensation of metallic medium pipes is effected by special manufacturing processes of medium pipes such as soft annealing or corrugation of the copper pipe, installation in form of sinus waves or application of certain materials like stainless steel.

Due to flexibility and self compensation this technology enables a fluctuating and simple pipeline routing. Furthermore it is possible to adapt to local circumstances, obstacles can be easily avoided. Also, because fewer joints are needed, installation requires much less time and effort. Generally it is possible to respond to structural barricades without evaluating a new statistic and/or insert additional adaptors as it would have to be done for the KMR system.

Flexible service pipe systems with corrugated medium pipe have a higher pressure loss per meter than other systems. It could be compensated by using the next larger nominal diameter. For monitoring and fault location the same systems as the ones of KMR are used.

Flexible Polymer Service Pipes:

Flexible polymer service pipes are suitable for DH networks with small structural expansion such as for housing areas with small domestic houses. Similar to metallic service pipes no static is required.

Flexible polymer service pipes remain economical solely within small nominal diameters. No monitoring systems with conductors for surveillance and fault location are required. Furthermore polymer service pipes are only ‘low diffusion’ and not ‘no diffusion’ towards oxygen and water vapour, even if there are built after DIN 4725. Therefore only such pipe systems with a diffusion blocking tissue have to be used for saving the insulation against water steam output and the system against active oxygen input.

Possibilities of combination of installation systems:

Each individual case is to be verified for coast advantages due to a combination of the pipe systems instead of using only one technology. By combining the systems it has to be considered that network parameters for the whole network are defined by the system with the lowest requirements. Accordingly the flow temperature for a combination of KMR with polymer service pipe is limited at 80 °C and the pressure at 5 bar. Since combinations of different systems arouse measurement errors, there has to be agreed on a uniform monitoring system.

For pipes > DN 50 it is suggested to use KMR. For the distribution of the small to medium dimensions all other systems are possible. The problem of contact corrosion between different materials is overcome by the use of specific transition pieces.

Sizing

For an estimated sizing table 7.3.2 may be consulted. For known temperature deviation and heat demand the essential nominal diameter can be assessed. The loss of pressure has been nominated with 2 mbar/m of pipe (4mbar/m route). The diameters are based of steel pipes of DIN 2458.

Table 7.3.2. Transportable heat demand at a pressure loss of 4 mbar per route meter (VL+RL) incl. 20 % for installations.

Nominal diameter	Outside diameter [mm]	Inside diameter [mm]	Flow rate [m/s]	Δp [mbar/m]	Δt [K]		
					70	60	40
					Q_{max}		
					[kW]	[kW]	[kW]
DN 15	21.3	17.3	0.48	2.1	33	28	19
DN 20	26.9	22.9	0.58	2.1	70	60	40
DN 25	33.7	29.7	0.68	2.04	139	119	79
DN 32	42.4	37.8	0.80	2.06	264	226	150
DN 40	48.3	43.7	0.88	2.06	380	330	220
DN 50	60.3	55.7	1.02	2.03	730	620	410
DN 65	76.1	70.9	1.20	2.07	1 390	1 190	790
DN 80	88.9	83.1	1.32	2.05	2 100	1 800	1 200
DN 100	114.3	107.9	1.55	2.04	4 160	3 570	2 380
DN 125	139.7	132.5	1.77	2.06	7 170	6 150	4 100
DN 150	168.3	160.3	2.00	2.08	11 860	10 170	6 780
DN 200	219.1	210.1	2.35	2.06	23 950	20 530	13 680

With table 7.3.2 it is also possible to check the nominal flow temperature against 85 °C or 110 °C.

It has to be considered that accordant with the decrease of heat demand the diameter of route decreases as well, otherwise very low flow speeds would be resulted due to the small heat demand in summertime. To size the house service pipe not only the heat demand for heating is important, but also the one for hot water. Therefore both factors have to be regarded separately. At first the house service pipe nominal diameter is sized according to the heat demand of the winter time and its ΔT. After that the pressure loss at this nominal diameter for the heat demand of summertime and its resulting ΔT has to be calculated. If it is too high, the diameter has to be decreased.

Pipe heat loss calculations

Heat losses of pipes are based on the formula:

$$Q_{loss} = U \cdot l \cdot (T_{c,out} - T_a) \quad \text{(eq. 7.3.1)}$$

where

Q_{loss}:	Total heat loss of pipes from collectors to heat exchanger	[W]
l:	Length of the pipe	[m]
$T_{c,out}$:	Temperature of the solar collector fluid when it exits the collectors	[°C]
T_a:	Temperature of the environment	[°C]
U	Pipe heat loss coefficient calculated by formula 7.3.2 below [2]	[W/(m·K)]

$$U = \frac{\pi}{\frac{1}{2 \cdot \lambda_{iz}} \cdot \ln\left(\frac{d_e + 2 \cdot s_{iz}}{d_e}\right) + \frac{1}{\alpha_e} \cdot \frac{1}{(d_e + 2 \cdot s_{iz})}} \quad \text{(eq. 7.3.2)}$$

where

λ_{iz}:	Thermal conductivity of the insulation	[W/(m·K)]
d_e:	Diameter of pipe (external)	[m]
s_{iz}:	Thickness of thermal insulation	[m]
α_e:	Heat transfer coefficient on the external surface of thermal insulation	[W/(m^2·K)]

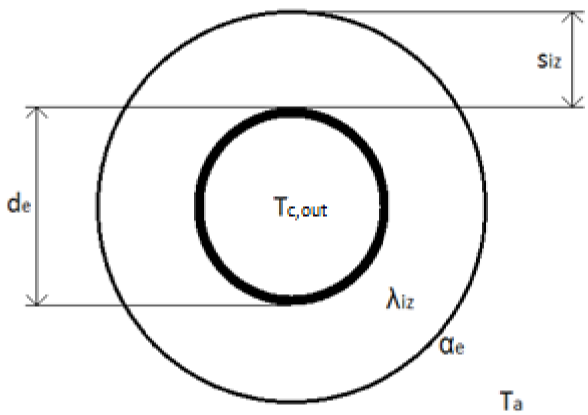

Fig. 7.3.2. Values used in the formula 7.3.2 above.

Determined values of heat loss coefficient related to the length unit for piping placed in the ground is shown in table 7.3.3.

Table 7.3.3. Examples of nominal diameter (DN) and corresponding heat loss coefficient for solid piping (A) and flexible and double piping (B) [3].

DN [mm]		**20**	**25**	**32**	**40**	**50**	**65**	**80**	**100**	**125**	**150**	**175**	**200**
U [W/(m·K)]	**A**	0.14	0.17	0.18	0.21	0.23	0.25	0.27	0.28	0.32	0.36	0.38	0.39
	B	0.16	0.19	0.20	0.24	0.26	0.30	0.31	0.32	0.36	0.40	0.44	0.46

European standard EN 12976-2 recommends thickness of thermal insulation 20 mm for pipes with external diameter lower than 22 mm and 30 mm for pipes with external diameter between 28 and 42 mm. For the pipes with higher diameters there should be used thermal insulation with thickness equal to the pipe diameter. It is assumed that the thermal conductivity of used insulation is lower than 0.04 W/(m·K). Often polyurethane (PUR) with a thermal conductivity of 0.027 W/(m·K) is used as insulation in the pipes.

Pumps and pressure rating

The transport of collector fluid between collector array and heat exchanger (and back again) is provided by pump(s). The pump in the primary loop has to be powerful enough to overcome the pressure losses and still maintain the desired flow[*]. This means that the dimensioning of the pumps and the pipes has to be done simultaneously in a way that minimizes the total sum of:

- Buying and installing pipes
- Buying and installing pumps
- Electricity costs for the pumps during operation throughout the lifetime

In other words the optimal balance between the following scenarios must be found:

a) Small pipe diameter => large pressure loss => low costs for pipes but high electricity costs for pumps
b) Large pipe diameter => low pressure loss => high costs for pipes but low electricity costs for pumps.

The pump on the secondary side of the heat exchanger has to be able to maintain a capacity rate similar to the one in the primary loop[†]. Since the capacity rate only depends on the flow rate and the fluid properties, the pump on the secondary side of the heat exchanger is not affected by the choice of pipe diameter – only by the choice of operating flow rate.

Pressure rating

The minimum pressure rating in the network usually depends on network size and geodetic differences (a growing difference in altitude implies a higher nominal pressure rating). The maximum operating pressure will be influenced by the highest located user and the user at the end of the network. This is transferable to the static pressure, which has to be maintained during standstill periods of the system (no pump operation).

The higher the operating pressure, the more effort is needed for pressure stabilisation, safety requirements and circulation pumps. Therefore the operating pressure should be remained as low as possible (see EN 13480-3 and AGFW rules FW 442).

Another important parameter is the nominal pressure rating, due to its influence on the minimum pressure rating for pipes, fittings, valves, domestic stations and customer installations.

The nominal pressure rating level is defined through the static pressure and the delivery head H of the pump with consideration of the geodetic altitude of the network. Small DH networks often need PN 6 and large DH networks PN 16. The maximal operating pressure within the network has to be lower than the nominal pressure rating level.

The static pressure has to be higher than the saturated steam pressure at the highest geodetic point of the network at the maximum flow pipe temperature, so that it is impossible to have evaporating fumes within the

[*] *For more information on flow rate control see fact sheet 6.3 “Control strategies”.*
[†] *Capacity flow rate is explained in fact sheet 7.4 “Heat exchanger”.*

network. Also, in direct DH networks, where customer installations are directly served with DH network water, the maximum height for customer installations has to be defined.

Example for the calculation of the static pressure (p_{RU}) at a flow temperature at 110 °C:

Height of the supplier (H_H):	100 m asl‡
Highest point of the network (H_A)	137 m asl
Saturated steam pressure at 110 °C ($p'(t_v)$)	1.43 bar
Safety factor for saturation (p_S)	0.5 bar (e.g.)
Density for water at 110 °C (ρ)	950 kg/m^3
Gravitational acceleration (g)	9.81 m/s^2

$$p_{RU} = p'(t_v) + p_s + \frac{\rho \cdot g(H_A - H_H)}{100\,000}$$

(eq. 7.3.3)

$$= 1.43 + 0.5 + \frac{950 \cdot 9.81 \cdot (137 - 100)}{100\,000} = 5.37 \text{ bar}$$

The max. operating pressure (p_{Bmax}) is defined by the factors static pressure, the pressure losses of the plant (Δp_H), of the network (Δp_N), the pressure difference at the last customer station ($\Delta p_{Ü}$) and a safety factor for pressure fluctuations (p_{SD}).

$p_{B,max} = p_{RU} + \Delta p_H + \Delta p_{Ü} + \Delta p_N + p_{SD}$ (for return flow pressure stabilization).

Pump characteristics

It is possible to use hydrodynamic or hydrostatic pumps. More often are used hydrodynamic pumps especially those that are resistant to influence of collector fluid and higher temperatures. For solar systems with special requirements on adjusting of flow according to operating conditions (e.g. constant temperature at the collector output) pumps with variable speed are used.

‡ *asl = above sea level.*

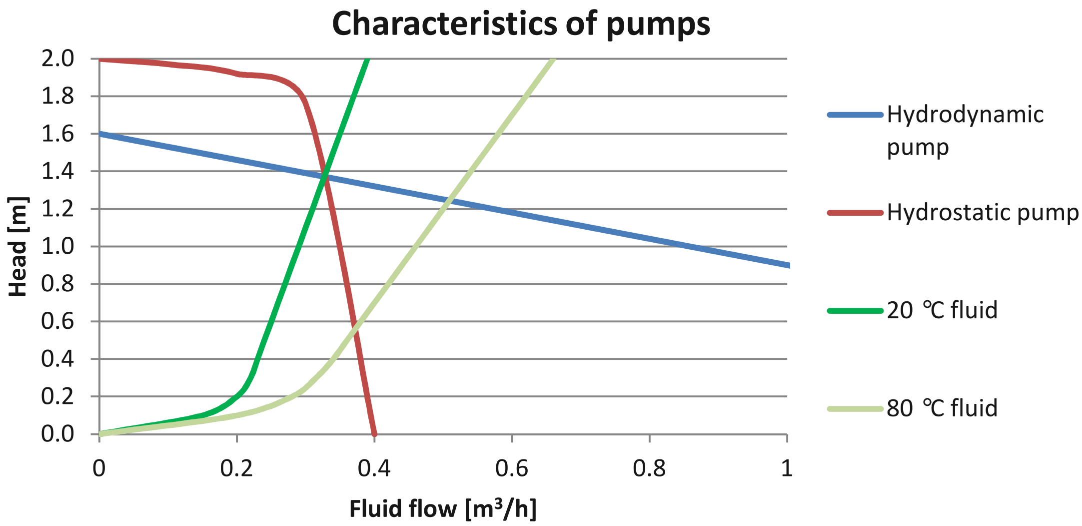

Fig. 7.3.3. Characteristics of pumps along with the characteristics of the pipe network [2].

Comparison of pump's characteristics along with the characteristics of the pipe network (propylene glycol + water at 20 °C and 80 °C) shows that change of the fluid temperature causes significantly lower variation of fluid flow in case of using hydrostatic pumps.

The optimal operating point of the selected pump should be in the range of its maximum efficiency. Dimensioning and operating parameters adjustment of the pump has a significant impact on energy consumption and thus operating costs of the system.

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Chapter:	Components
Date:	August 2012
Size:	6 pages
Description:	Heat exchangers are used for transferring heat gained in collector array into demanded application (another heat-transfer fluid).
Author:	David Borovský, CityPlan spol. s.r.o. – david.borovsky@cityplan.cz
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Available languages:	English
Version id:	7.4-3
Download possible at:	www.solar-district-heating.eu

Contents

Introduction

The heat exchanger unit provides the actual useful performance of the system. It is the sole component linking the solar heat to the district heating network. Therefore it is crucial for the overall plant efficiency to have a well performing heat exchanger with a properly balanced capacity flow on both sides as described below.

Heat transfer coefficient and temperature difference

The heat (Q) transferred from the solar collector loop (primary side) to the DH network (secondary side) is equal to the heat transfer coefficient of the heat exchanger (UA) times the temperature difference between primary and secondary side (ΔT) i.e. $Q = UA \cdot \Delta T$. The UA-value of the heat exchanger is provided by the heat exchanger manufacturer. If the UA is doubled, then ΔT can be halved and the heat delivered to the DH network will still be the same. By decreasing ΔT, the solar collector efficiency is increased as indicated in figure 7.4.1. η_{high} is the efficiency of the collectors if there had been no heat exchanger. η_{low} is the collector efficiency during operation. This indicates that ΔT should be minimized and the capacity compensated by a large heat transfer coefficient for the heat exchanger.

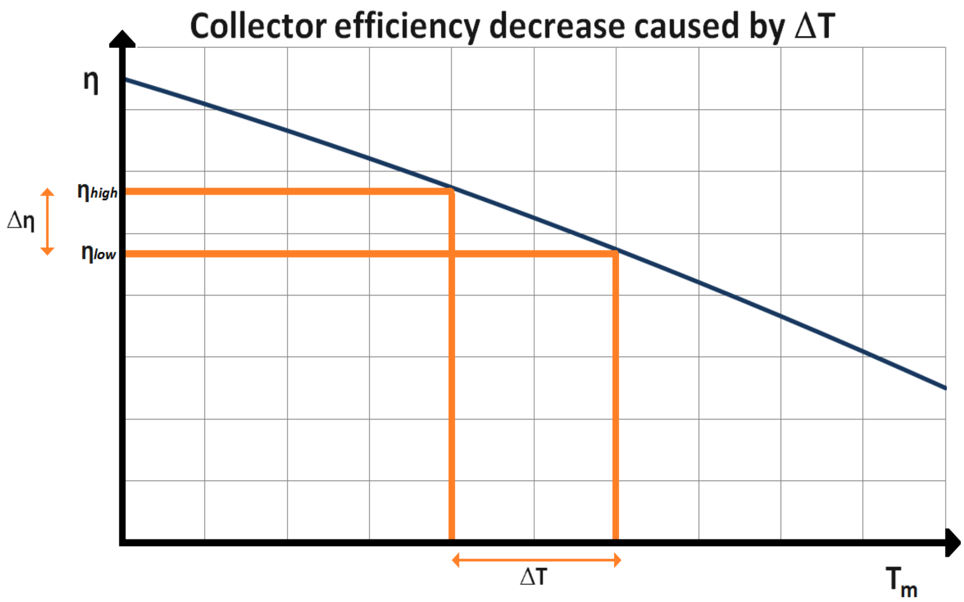

Fig. 7.4.1. Efficiency decrease caused by the temperature over the heat exchanger (difference between primary and secondary side temperature). (Source: PlanEnergi)

Heat exchangers can be sorted according to the several characteristics (e.g. parallel-flow / counter-flow, internal / external, shell and tube / plate). Normally a counter flow plate heat exchanger is used for large systems. For both parallel-flow and counter flow heat exchangers, the temperature difference is calculated as the logarithmic mean temperature difference (LMTD):

$$\Delta T_{mean} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \qquad \text{(eq. 7.4.2)}^*$$

where

ΔT_1:	$T_{prim,in} - T_{sec,out}$	[K]
ΔT_2:	$T_{prim,out} - T_{sec,in}$	[K]

i.e. ΔT_1 is the temperature difference between the *inlet* temperature on the *primary* side and the *outlet* temperature on the *secondary* side, and ΔT_2 is the temperature difference between the *outlet* temperature on the *primary* side and the *inlet* temperature on the *secondary* side. This is indicated in figure 7.4.2 for counter-flow and parallel-flow heat exchangers.

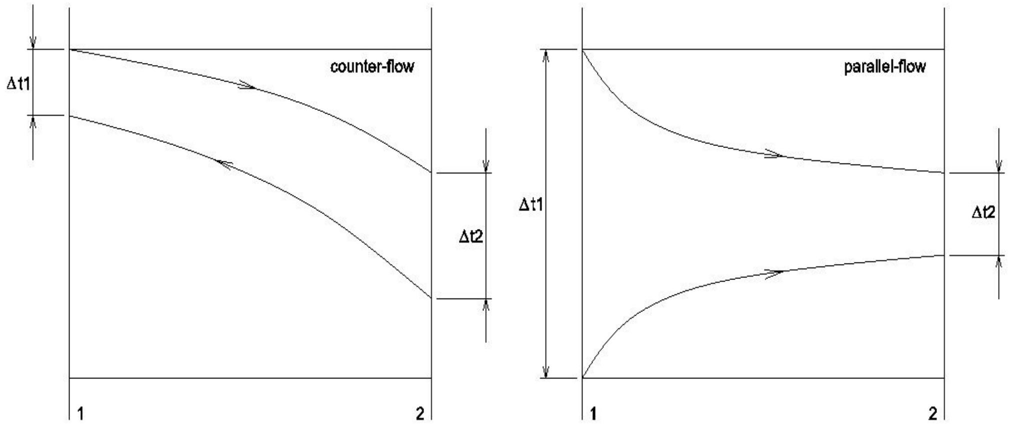

Fig. 7.4.2. Progression of temperatures in a parallel-flow and counter-flow heat exchanger [2].

Plate heat exchangers are often used in large-scale solar systems. The exchanger is consisted of thin plates (mostly made of stainless steel), that are connected together to create a net of channels. Brazing or welding represents one way of connecting plates together. These methods symbolize the cheaper solution of plate heat exchangers manufacturing. The second possibility is to use supporting plates and screw exchanger together with bolts, nuts and gaskets. Main advantage of screwed exchangers is their ability to be demounted and cleaned properly. Clogging of exchanger has a significant influence on its performance and

* *Note that if $\Delta T_1 = \Delta T_2$, then eq. 7.4.2 becomes obsolete and $\Delta T_{mean} = \Delta T_1 = \Delta T_2$.*

pressure loss so dirt separators or dirt traps are used to prevent pollution of heat exchangers. Another way of preventing exchanger pollution lies in chemical treating of the heating water, before it is filled into the system.

Capacity flow

The capacity flow is the power which can be transferred to or from the liquid *per degree* (K) in difference between inlet and outlet temperature of the heat exchanger e.g. for the primary side ("prim"):

$$w_{prim} = \dot{V}_{prim} \cdot \rho_{prim} \cdot c_{p,prim} \qquad \text{(eq. 7.4.2)}$$

where

w_{prim}:	Capacity flow on primary side	[W/K]
$\dot{V}_{prim}$:	Flow rate on primary side of the heat exchanger	$[m^3/s]^{\dagger}$
ρ_{prim}:	Density of the solar collector fluid	$[kg/m^3]$
$c_{p,prim}$:	Heat capacity of solar collector fluid	[J/(kg·K)]

The capacity flow is calculated in the same way for the secondary side ("sec") where water is the fluid.

It is important to keep the capacity flow rates as close as possible e.g. $0.95 \leq w_{prim} / w_{sec} \leq 1.05$. This way the upper and lower curve in figure 7.4.2 keep as close to each other as possible, resulting in the lowest average ΔT. This is ensured by controlling the flow rate according to the properties of the used fluids (e.g. water/glycol-mixture and water in the primary and secondary loop respectively).

Heat exchanger factor

It is seen in figure 7.4.1 that the more efficient the collector is (i.e. the slope of the collector efficiency curve is small), the less affected is the η by ΔT. This means that for high performance collectors the heat exchanger efficiency is less significant. The efficiency of transferred energy from the primary to the secondary side is expressed by the heat exchanger factor F''' which is equal to the ratio η_{low} / η_{high} based on the values from figure 7.4.1. In figure 7.4.3 is seen three examples of the heat exchanger factor as function of UA-value. The loss due to a too small heat exchanger can be considerable. If F''' is 0.9 it means that 10 % of the solar heat is wasted in the heat exchanger; hence the UA-value of the heat exchanger is important for the *total* SDH plant efficiency.

† *Normally measured in m^3/h and divided by 3600 s/h in order to make the unit fit in the equation.*

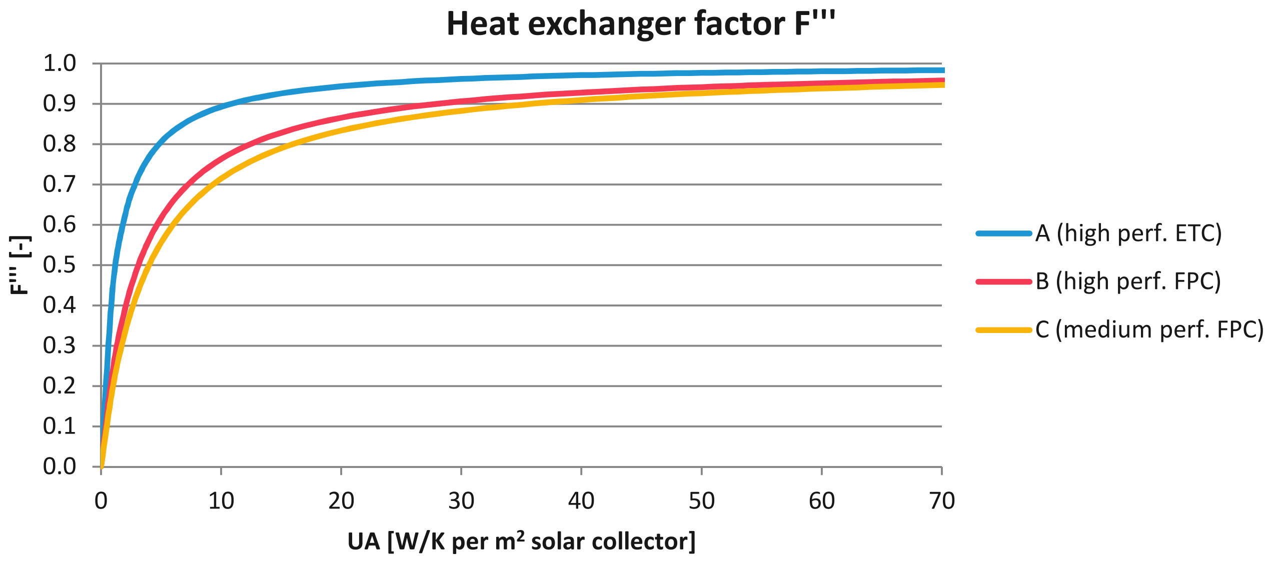

Fig. 7.4.3. Heat exchanger efficiency factor F''' as function of UA-value. (Source: PlanEnergi)

The calculation of F''' is shown on the next page. The heat capacity rate is assumed to be equal at both sides of the heat exchanger.

Calculation of heat exchanger factor F'''

The influence of the UA-value can be expressed by means of the heat exchanger factor F''' [1], defined as:

$$F''' = \left(1 + \frac{F''}{\omega_c} \cdot \left(\varepsilon^{-1} - 1\right)\right)^{-1}$$

where

$$F'' = \left(1 - \exp\left(-\frac{1}{\omega_c}\right)\right) \cdot \omega_c \qquad \omega_c = \frac{\dot{m} \cdot c_p}{a_1 + a_2 \cdot (T_{collector} - T_a)} \qquad \varepsilon = \frac{\frac{U.A}{\dot{m} \cdot c_p}}{\frac{U.A}{\dot{m} \cdot c_p} + 1}$$

and

F''' Heat exchanger factor [-]

F''	Efficiency factor [-] The efficiency factor describes how well the absorber-tube transports the energy from the outside of the tube into the solar collector fluid. F'' = 1 means that the heat resistance from the outside of the tube into the solar collector fluid is zero.
$\dot{m}$	Mass flow in primary loop [kg/s]
c_p	Heat capacity of solar collector fluid [J/(kg·K)]
$T_{collector}$	Solar collector fluid temperature [°C]
T_a	Ambient temperature [°C]
a_1	1^{st} order collector heat loss coefficient [W/(m^2·K)]
a_2	2^{nd} order collector heat loss coefficient [W/(m^2·K^2)]
UA	Heat transfer coefficient in heat the exchanger [W/K]. *High value* => low temperature difference between collector loop side and load side => decreased heat losses in collector end collector loop. *Low value* => high temperature difference between collector loop side and load side => increased heat losses in collector end collector loop.

The following parameters are assumed: Collector efficiency parameters as shown in table 7.1.1, a glycol concentration of 40 wt%, 1 m^2 of collector area, ($T_{collector}$ – T_a) = 50 K and a flow rate of 0.3 l/min per m^2.

References

[1] The calculations are described in "Solar engineering of thermal processes" 3rd ed. by Duffie & Beckman section 10.2 "Collector heat exchanger factor" p. 427 where F'_R/F_R is used instead of F'''.

[2] Solární tepelné soustavy (Solar thermal systems), MATUŠKA T. Společnost pro techniku prostředí – odborná sekce Alternativní zdroje energie, 2009.

The SDH fact sheets addresses both technical and non-technical issues, and provide state-of-the-art industry guidelines to which utilities can refer when considering/realizing SDH plants. For further information on Solar District Heating and the SDHtake-off project please visit www.solar-district-heating.eu.

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Chapter:	Precautions
Date:	August 2012
Size:	4 pages
Description:	The temperatures in a solar collector loop are more deviating than in a conventional district heating network and the equipment must therefore be able to withstand the thermal stress.
Author:	Daniel Trier, PlanEnergi – dt@planenergi.dk
Co-author(s):	-
Available languages:	English
Version id:	8.1-3
Download possible at:	www.solar-district-heating.eu

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Introduction

The difference in temperature of the components can be quite large between night and day – especially in Northern European countries. In some situations the temperature may go from -30 °C (ambient temperature) to 95 °C (operating temperature) during start up of normal operation, i.e. a difference of 125 K. It might even be higher if a higher operating temperature is used. All components and each connection in the system have to be able to cope with the expansion and contraction associated with the temperature variations. If the pipes are dimensioned for one load cycle* per day during a lifetime of 30 years, they have to be able to withstand a total of (30 years x 365 days) 10950 load cycles.

Due to this increased number of load cycles compared to normal district heating network pipes the type of soil surrounding the pipes can play a role concerning the lifetime of the pipes. Preliminary investigations show that certain soil types may have a potentially destructive effect on the pipes. The pipe manufacturer should be consulted before choosing the filling material for the trenches where the pipes are placed. [1]

Expansion of components

In table 8.1.1 the temperature expansion of different component materials are listed. The "maximum expected expansion at normal operation" is based on variations which may appear on a daily basis in some regions. The "extreme expansion" should preferably be avoided completely, but in case of stagnation of collector fluid, as a result of pump failure, it might be inevitable. The system must be able to comprehend such an extreme expansion to avoid the considerable damage repair costs if the extreme situation should arise.

Table 8.1.1. Temperature expansion of different component materials.

Material	Linear temperature expansion coefficient [2] [10^{-3} mm/(m·K)]	Maximum expected expansion at normal operation (ΔT = 125 K) [mm/m]	Extreme expansion in case of fluid stagnation (ΔT = 185 K) [mm/m]
Aluminium	22.2	2.8	4.1
Brass	18.7	2.3	3.5
Copper	16.6	2.1	3.1
Steel	13.0	1.6	2.4
Iron (forged)	11.3	1.4	2.1

* *One load cycle: Heated up from ambient temperature to operating temperature and cooled down to ambient temperature again.*

For cobber pipes an example of the expansion is seen in figure 8.1.1 below.

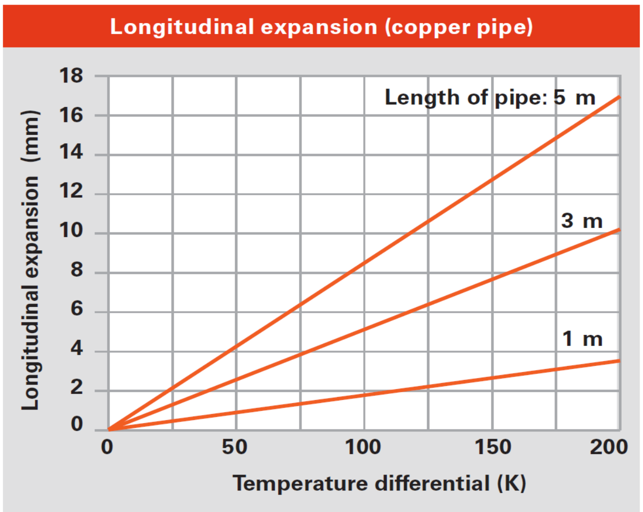


Figure 8.1.1. Longitudinal expansion of cobber pipes [3]*. As seen in table 8.1.1 the expansion is almost 30 % larger than for steel pipes.*

To avoid too large mechanical stresses, several options are possible which will handle the expansion of the pipes. Three examples are shown in figure 8.1.2.

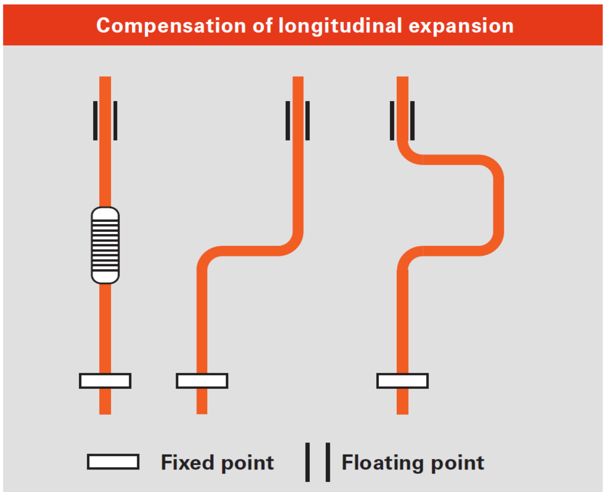


Figure 8.1.2. Pipes including compensation for longitudinal expansion [3].

Solar collector fluid expansion

An expansion device is necessary for all large solar systems. This allows for volume changes of collector fluid caused by volumetric thermal expansion without unallowable increasing of pressure and unnecessary collector fluid loss that is caused by opening of the safety valve. Several smaller expansion vessels instead of one large vessel minimize the risk of damage if a failure in one of the vessels should occur. The membrane of the expansion vessel(s) must be resistant to collector substance exposure, high temperatures and pressures. Usually a nitrile membrane is used.

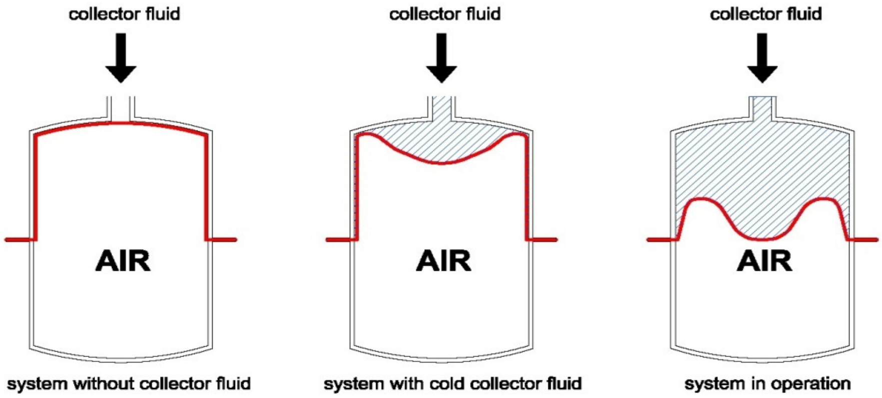


Figure 8.1.3. Cross section of expansion vessel in different situations. (Source: CityPlan – based on [4])

In case of extreme pressure in the solar collector loop due to pump failure, a safety valve should open to let some of the fluid out of the loop and into a container in order to decrease the pressure. The boiling may continue inside the collectors and they should be able to cope with the associated pressure in short periods. Further information on handling stagnation pressure and temperatures are described in fact sheet 8.2 *"Safety equipment"*.

References

[1] Pipe-Soil interaction in large solar thermal heating and cooling plants, I. Weidlich & D. Trier, August 2011.

[2] The Engineering Toolbox www.engineeringtoolbox.com/linear-expansion-coefficients-d_95.html

[3] "Technical guide – Solar thermal systems" p. 82, Viessmann GmbH, 2009.

[4] Solární tepelné soustavy (Solar thermal systems), MATUŠKA T. Společnost pro techniku prostředí – odborná sekce Alternativní zdroje energie, 2009.

The SDH fact sheets addresses both technical and non-technical issues, and provide state-of-the-art industry guidelines to which utilities can refer when considering/realizing SDH plants. For further information on Solar District Heating and the SDHtake-off project please visit www.solar-district-heating.eu.

Chapter:	Precautions
Date:	August 2012
Size:	5 pages
Description:	To avoid damages in case of boiling, the system must be able to comprehend such occurrences. This is done partly by installing several safety components and partly by proper dimensioning.
Author:	David Borovský, CityPlan spol. s r.o. – david.borovsky@cityplan.cz
Co-author(s):	Daniel Trier, PlanEnergi – dt@planenergi.dk
Available languages:	English
Version id:	8.2-3
Download possible at:	www.solar-district-heating.eu

Contents

Introduction

Since the energy supply in a solar district heating plant cannot be controlled as in an ordinary district heating plant, it is necessary to consider that “extreme” temperature levels may damage the system in case of:

- Freezing
- High stagnation temperature (approx. 200 °C)

Normally antifreeze liquid is used as solar collector fluid in order to avoid freezing. This is explained in fact sheet 7.1 *“Solar collectors”*.

The necessary precautions in terms of avoiding damages due to high temperatures are described in the following sections.

Safety valve

A safety valve must be installed in order to release the pressure by letting some or all of the fluid out of the loop if necessary. A collecting vessel must be able to contain all overflowing liquid since it is normally not allowed to pour the most commonly used solar collector fluids into a drain.

Each heat source must be equipped with directly connected safety device. This means that the piping between the collectors and the safety valve must not contain any closing elements. The safety valve should resist extreme temperature conditions attainable in the system, especially the highest temperature that can occur (stagnation temperature). Important is also resistance to the collector fluid.

The flow cross-section of the safety valve is calculated by equation 8.2.1 below [1]:

$$S_0 \geq \frac{P_p}{\alpha_w \cdot K} \qquad \text{(eq. 8.2.1)}$$

where

S_0:	Cross section of safety valve	[mm^2]
P_p:	Heat performance of determined collector array	[kW]
α_w:	Safety valve outflow coefficient (specified by the valve manufacturer)	[-]
K:	Pressure dependant coefficient interpolated from table 8.2.1	[kW/mm^2]

Table 8.2.1. Pressure dependant coefficient used in equation 8.2.1. [1]

Pressure [kPa]	**50**	**100**	**150**	**200**	**250**	**300**	**400**	**500**	**600**	**700**
K [kW/mm^2]	0.5	0.67	0.82	0.97	1.12	1.26	1.55	1.83	2.10	2.37

If the expansion vessel(s)* can contain all the solar collector fluid, they will automatically fill up the system when the pressure is decreased, but this solution is normally too expensive for large systems.

Handling stagnation

Stagnation may occur in case of

- power failure
- pump failure
- overheated buffer storage
- too low heat demand.

In that case, the temperature in the solar collectors may reach > 200 °C. Since the fluid does not circulate in the solar collector loop, and therefore is not cooled, it boils inside the collectors which may cause damages if the pressure becomes too high. The boiling point is highly dependent on pressure as shown in figure 8.2.1. It is only slightly dependent on the glycol concentration† and this does not have a large effect for the concentrations normally used (below 50 %).

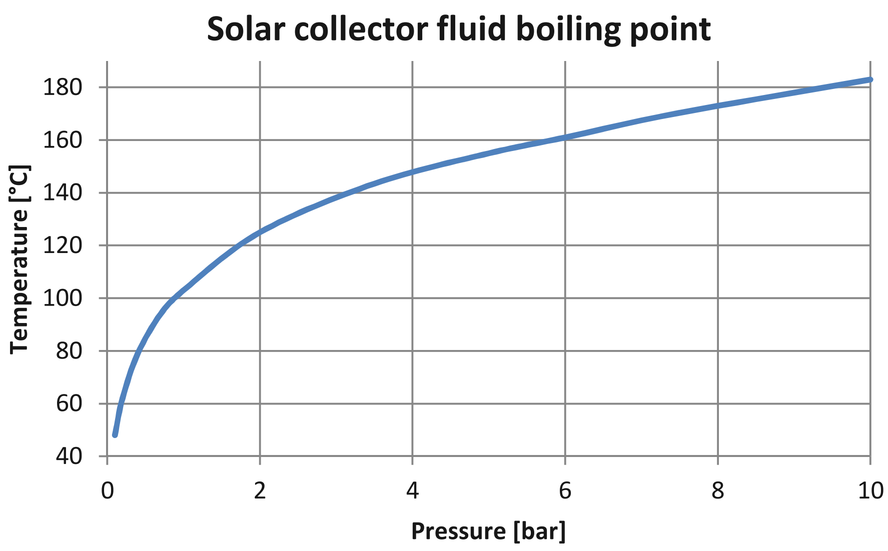


Fig. 8.2.1. Boiling point as function of pressure for a glycol concentration of 40 % [2].

* *The expansion vessel is described in fact sheet 8.1 "Temperature variations".*
† *Slightly higher boiling point with higher glycol concentration.*

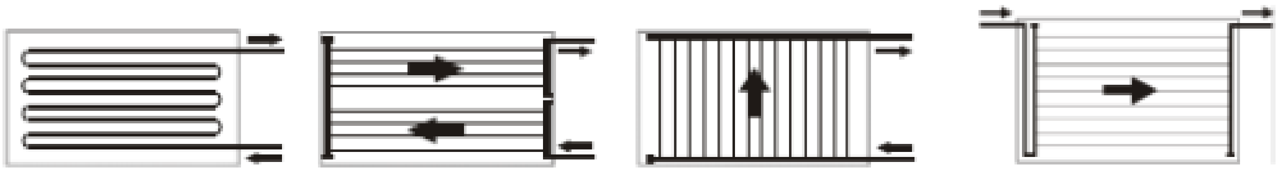
A stand-by backup pump can avoid "blow offs" where the solar collector fluid is forced out of the pipes through the safety valve resulting in the need for filling the plant, i.e. lost energy due to downtime. However in case of failure in the electrical power grid, an extra pump will do no good unless it has an autonomic power supply e.g. diesel and a battery supplied control system.

Coping with high pressure

The system must be able to withstand pressure levels which can occur in case of stagnation. For large systems it can be a challenge to ensure that the pressure does not exceed the tolerable limit since the boiling does not start simultaneously. If steam builds up in the collector furthest away from the safety valve, the pressure increase due to evaporation may be larger than the decrease due to liquid spilling into the containment vessel because of the delay caused by the liquid blocking the way for the steam. When there is a clear passage for the steam to the safety valve, the pressure is quickly decreased. Collectors for large systems are typically tested at pressure levels up to 8 or 10 bar and both the collectors and all pipes between collectors and safety valve shall be dimensioned in such way that pressure in collectors and pipes will not exceed maximum allowed pressure if boiling occurs. It is important to make sure that steam coming from the containment vessel cannot endanger personnel.

Good emptying behaviour

One way to handle stagnation is to make sure the liquid is forced out of the collector loop. The collector designs in figure 8.2.2 all have the option of being emptied completely without disconnecting pipes. In case of stagnation, only a small part of the fluid will evaporate thus increasing the pressure and forcing the fluid backwards in the pipes and into a containment vessel.



(a) (b) (c) (d)

Fig. 8.2.2. Examples of collector design with good emptying behavior. Arrows indicate flow direction at normal operation [3].

In figure 8.2.2-d the manifold on the left side is made so that if stagnation occurs, the fluid in the (horizontal) absorber tubes are forced into the (vertical) manifold on the left and via the bottom up and out of the collector left side. If both inlet and outlet are made as the manifold on the right side of figure 8.2.2-d, the pressure increase from the first small amount of evaporated fluid would only force the liquid in the top part of the absorber tubes backwards through the collector array. A large part of the liquid would be kept inside the rest of the absorber tubes while boiling.

The inlet in the collector in figure 8.2.2-d could also have been made at the bottom, but this would require extra piping *outside* the insulated collector box when connecting several units in serial.

Collectors cannot be made with both inlet and outlet at the bottom since it is necessary to be able to let out trapped air.

Most large systems in Denmark use collectors which simply has a manifold each side and an inlet as the one on the right side of figure 8.2.2 d. In case of a pump failure, most of the fluid will continue to boil inside the collector as long as the irradiation is large enough to keep the temperature above the boiling point or until all the fluid is evaporated.

Studies [4] have shown little or no effect on the collector fluid due to boiling for a small system, but it is necessary to check the collector fluid after boiling to ensure that the pH-value have not decreased making the liquid acidic. Boiling can also cause an exclusion of corrosion inhibitors on walls of pipes in collector absorber. It is recommended to check concentration of corrosion inhibitors in collector liquid to decrease a risk of corrosion in the system. [1]

References

[1] Solární tepelné soustavy (Solar thermal systems), MATUŠKA T. Společnost pro techniku prostředí – odborná sekce Alternativní zdroje energie, 2009.

[2] Based on a data sheet for "Tyfocor® L concentrate for long-term antifreeze and corrosion protection of heating and cooling circuits, solar and heat pump systems" by TYFO.

[3] Stagnation behaviour of solar thermal systems, IEA-SHC task 26, R. Hausner & C. Fink, November 2002.

[4] Solfangerkreds med stor ekspansionsbeholder og fordampning i solfanger ved faretruende høje temperaturer til sikring af solfangervæske og anlæg, Janne Dragsted et al. DTU Byg-Sagsrapport SR-10-04 (DK), May 2010.

The SDH fact sheets addresses both technical and non-technical issues, and provide state-of-the-art industry guidelines to which utilities can refer when considering/realizing SDH plants. For further information on Solar District Heating and the SDHtake-off project please visit www.solar-district-heating.eu.

Nomenclature

Chapter:	Miscellaneous
Date:	August 2012
Size:	5 pages
Description:	Overview of abbreviations, symbols and subscripts used in these fact sheets.
Author:	Daniel Trier, PlanEnergi – dt@planenergi.dk
Co-author(s):	-
Available languages:	English
Version id:	9.1-3
Download possible at:	www.solar-district-heating.eu

Contents

* *Subscripts including entire words which are self explaining are not included.*

Abbreviations

AR	Anti reflective
asl	Above sea level
ATES	Aquifer thermal energy storage
BHE	Borehole heat exchanger
BTES	Borehole thermal energy storage
CHP	Combined heat and power
CSHPSS	Central solar heating plants with seasonal storage
DH	District heating
EFTE	Ethylene tetrafluoroethylene
ESCO	Energy service company
ETC	Evacuated tubular collector
FEP	Fluorinated ethylene propylene
FPC	Flat plate collector
HX	Heat exchanger
IEE	Intelligent Energy Europe
PCM	Phase change material(s)
PTES	Pit thermal energy storage
PV	Photovoltaic
SDH	Solar district heating
ST	Solar thermal
TTES	Tank thermal energy storage
UV	Ultraviolet (radiation)
VAT	Value added tax

Symbols

Subscripts are included when they are a part of a “non-stand alone” symbol.

Symbol	Description	Unit
α_e	Heat transfer coefficient on the external surface of thermal insulation	[W/(m²·K)]
α_w	Safety valve outflow coefficient	[-]
η	Efficiency	[-]
λ_{iz}	Thermal conductivity of the insulation	[W/(m·K)]
ρ	Density of fluid	[kg/m³]
A	Area	[m²]
a_1	1st order collector heat loss coefficient	[W/(K·m²)]
a_2	2nd order collector heat loss coefficient	[W/(K²·m²)]
b_0	Constant in incident angle modifier expression	[-]
c_1	Slope of the linear function $f(P_{hx,meas})$	[K/W]
c_2	Constant of the linear function $f(P_{hx,meas})$	[K]
c_p	Heat capacity of solar collector fluid	[J/(kg·K)]
d_e	Diameter of pipe (external)	[m]
$D_{location}$	Distance from collector field to network connection point (half the length of the total transmission pipe length)	[km]
f	Safety factor	[-]
F’’	Efficiency factor	[-]
F’’’	Heat exchanger factor	[-]
$f(P_{hx,meas})$	Linear function of $P_{hx,meas}$	[K]
G	Global solar irradiance (if nothing else is mentioned: On collector plane)	[kWh/y]
g	Gravitational acceleration	[m/s²]
H_H	Height of the heat supplier	[m]
H_A	Highest point of the network	[m]
K	Pressure dependant coefficient of safety valve	[kW/mm²]
K_θ	Incidence angle modifier for the solar collector	[-]
K_{60}	Incident angle modifier for diffuse radiation	[-]
l	Length of pipe	[m]
$\dot{m}$	Mass flow	[kg/s]
Δp_H	Pressure loss of the plant	[bar]
Δp_N	Pressure loss of the network	[bar]
$\Delta p_{Ü}$	Pressure difference at the last costumer station	[bar]
P	Power	[W]

p	Constant in incident angle modifier expression	[-]
$p'(t_v)$	Saturated steam pressure	[bar]
$p_{B,max}$	Maximum operating pressure	[bar]
$p_{land,location}$	Investment costs for collector land area	[€]
p_{RU}	Static pressure	[bar]
p_S	Pressure safety factor for saturation	[bar]
p_{SD}	Pressure fluctuations safety factor	[bar]
pr	Price	[€ per...]
Q	Energy	[kWh/y]
q_{land}	Solar energy output in kWh per m^2 of land used and per year	[kWh/m^2/y]
Q_l	Total heat loss of pipes (from collectors to heat exchanger)	[W]
$Q_{pipe,loss}$	Heat loss from pipe in kWh/y per km distance between collector field and network connection point	[kWh/y/km]
R_T	Temperature correction factor	[-]
S_0	Cross section of safety valve	[mm^2]
S_F	Solar fraction	[-]
s_{iz}	Thickness of thermal insulation	[m]
T	Temperature	[°C]
ΔT	Temperature difference	[K]
$T_{hx,prim,in,min}$	Minimum inlet temperature on the primary side of the heat exchanger	[°C]
U	Heat loss coefficient for the pipes from collectors to the heat exchanger (loss per m of pipe length)	[W/(m·K)]
UA	Heat transfer coefficient (e.g. of heat exchanger)	[W/K]
$\dot{V}$	Flow rate	[m^3/h][†]
w	Capacity flow	[W/K]

[†] *Normally measured in m^3/h and converted to m^3/s by multiplying with 3600 s/h.*

Subscripts

0	Horizontal (e.g. global radiation *on horizontal*) or maximum/optical (efficiency)
50	At 50 °C
60	At 60°
a	Ambient air
θ	Incidence angle (current for the given irradiation onto the collector plane)
actual	actual operating temperature
b	Beam
c	Collector
d	Diffuse
e	External
f	At full load
g	Guarantee
hx	Heat exchanger
in	Inlet (e.g. collector fluid inlet)
land	land used for the collector field or ...per m^2 of land used.
location	distance to location or ...per km in distance to location
low	At low solar fractions
m	Mean
max	Maximum
meas	Measured
min	Minimum
O	Other things
out	Outlet (e.g. collector fluid outlet)
p	Performance
P	Pipe heat loss
prim	Primary side (of heat exchanger) i.e. solar collector loop
sec	Secondary side (of heat exchanger) i.e. district heating network side
solar	Provided by solar energy
U	Uncertainty

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