Aluminium Solar Collectors
For District Heating

1. Project details

Project title	Aluminium Solar Collectors for District Heating
Project identification (program abbrev. and file)	64012-0206
Name of the programme which has funded the project	EUDP 2012

Project managing company/institution (name and address)	**SAPA Precision Tubing Tønder A/S** Hydrovej 6 6270 Tønder
CVR (central business register)	51584511
Date for submission	February 2017
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2. Short description of project objective and results

English

The project should develop and demonstrate two types of solar collectors with aluminium absorbers in cooperation with the two largest Danish manufactures of solar collector plants for district heating. Thus Hydro Aluminium (now SAPA Precision Tubing Tønder A/S) could get access to the solar district heating market. The solar collectors should be demonstrated in full scale at Løgumkloster Fjernvarme.

The results are that one type of solar collector with aluminium absorbers has been developed and demonstrated in full scale both in a 1st generation version and a 2nd generation version.

Commissioning of the last part of the demonstration plant was in spring 2016 and the plant produces as expected.

Dansk

I projektet skulle to typer solfangere med aluminiumsabsorbere udvikles og demonstreres i samarbejde med de to største danske fabrikanter af solvarmeanlæg til Fjernvarme, hvorved Hydro Aluminium (nu SAPA Precision Tubing Tønder A/S) kunne komme ind på fjernvarmemarkedet. Solfangerne skulle demonstreres i fuld skala hos Løgumkloster Fjernvarme.

Resultaterne er, at én type solfangere med aluminium absorbere er udviklet og demonstreret i fuld skala i såvel en 1. generation som en 2. generations udgave.

Sidste del af demonstrationsanlægget blev taget i brug i foråret 2016 og anlægget producerer som forventet.

3. Executive summary

In the project "Aluminium Solar Collectors for District Heating" aluminium solar collectors have been developed, implemented and measured. The work in the project has been organized in work packages.

Work package 1 has included optimisations of solutions with aluminium solar collectors. The Finnish company Savo-Solar has developed optimised and tested a 1st generation solar panel with multiport pipe panel solutions (MPE-solutions) and a 2nd generation solar panel with MPE-solutions.

Detailed design of the solar collector field has been carried out by Rambøll. The solar collector field is divided in fields with a reference Cu-absorber (Field 1) and fields with 1st generation MPE absorbers (Field 4 and 5) and Field 3 with 2nd generation MPE absorbers making it possible to compare the products under equal conditions.

Parts of the design are P&I diagram and component list for the total system, design parameters for solar circuits with aluminium absorbers and operation strategy.

Løgumkloster Fjernvarme and PlanEnergi were partners in this process too and the design work package was finalized with **contracts between Savo-Solar and Løgumkloster Fjernvarme**, where special conditions for aluminium MPE-absorbers was taken into account.

Work package 2 included implementation and running in of the solar collector fields (including implementation and running in of the rest of the energy plant not included in this EUDP-application).

Altogether 15,275 m^2 of solar collectors were implemented, divided in 2,225 m^2 Cu-absorbers, 7,474 m^2 1st generation aluminium MPE-absorbers and 5,576 m^2 2nd generation aluminium MPE-absorbers.

There was no extraordinary problems during implementation and running in.

Work package 3 included a measuring program where the performance of the Cu-absorbers and the 1st generation aluminium MPE-absorbers was measured.

The performance of the 2nd generation aluminium MPE-absorbers is also included in the measuring program, but a defect temperature sensor caused, that a measuring period has to be added in spring 2017 (after finalising the project) to control performance of these absorbers. The performance of the 1st generation MPE-absorbers is as expected.

Development of a **"real time control"** of the production from the solar collector field was also part of work package 3.

Algorithms for the real time control was developed by PlanEnergi and implemented in the control system for the energy plant. The real time control compares the calculated outlet temperature with a measured values hour by hour.

Corrosion might be a problem when using aluminium panels. Therefore the liquid in the solar circuit is controlled regularely and aluminium test pipes are placed in the solar cirucuit and regularely taken out for control.

During the project Løgumkloster Fjernvarme has been the host for several visitors from other district heating utilities. Also the project has been presented in "Fjernvarmen" issued by Danish district Heating Association and presented for members of the solar district heating ERFA group under Danish District Heating Assosiation.

During SDH-conference in Billund, September 2016, a special technical tour was arranged by Savo-Solar to visit the collector array in Jelling.

The real time control was presented in an ISES webinar in December 2016.

4. Project objectives

4.1 Purpose and result of the project

The objectives of the project was

- Detailed design of a complete energy production system for Løgumkloster Fjernvarme's implementation of phase 1. including detailed design of a solar collector field with two circuits with aluminium collectors and two circuits with traditional solar collectors.
- Optimization of two types of aluminium solar collectors.
- To implement a demonstration plant (Løgumkloster, phase 1) with a.o. a solar collector field with two circuits with aluminium solar collectors and two circuits with traditional solar collectors and including a hybrid heat pump.
- To monitor the production from the four different solar collector types in the solar collector field and implement a system for continuous control of solar production and corrosive elements in the solar collector liquid.
- To disseminate the results primarily to district heating companies in Denmark and EU27 and secondary to public authorities in cities with and without district heating in Denmark and EU27.

The expected results was that the two Danish solar collector producers ARCON Solar A/S and SUNMARK A/S would improve the price/performance for their collectors and that Hydro Aluminium enters the market as supplier for the two producers and thus as supplier to most of the European projects with large scale collector plants.

The background was, that Hydro Aluminium had developed a solar thermal absorber in a new alloy of aluminium (Hylife^{TM}Solar).

This absorber was before the present project tested in a version with small solar collectors for production of domestic hot water and space heating for single buildings. If the collector could be produced in a district heating version it could replace copper solutions. This could at the same time give a higher heat production/m^2 and save the limited copper resource.

The project kick-off was in January 2013. According to the time table the solar collectors should be optimized in the first 6 months of 2013 and implementation should start in July 2013. But the project was delayed because Tønder Municipality decided that an Environmental Impact Assessment (VVM-undersøgelse) had to be elaborated before the local plan could be accepted. That postponed the implementation one year.

In the meantime the solar collector optimization should take place in cooperation with ARCON Solar and SUNMARK. Each should supply 1,000 m^2 of their traditional collectors and 6,000 m^2 of the new aluminium version. ARCON should develop a drop-in solution, where aluminium tubes should replace copper tubes. ARCON therefore tested aluminium welding to be sure to avoid production problems. The result of the test was, that ARCON did not dare to change their product and therefore had to give up being supplier in the project.

SUNMARK should develop a MPE solution, but in January 2014 SUNMARK was forced into receivership by their bank. The company was reconstructed, but dropped out of the project. Instead Savo-Solar from Finland, who was the company coating the aluminium absorbers, decided to start production of large solar collectors for district heating.

Therefore EUDP was asked to accept a change to Savo-Solar as supplier of solar collectors and a prolongation of the project period with one year to 31.12.2016. This was accepted.

Also Hydro Aluminium merged with SAPA and took the name SAPA Precision Tubing Tønder A/S.

Call for tender and implementation of all other parts than the solar collector nearly followed the original timetable. For the solar collectors Savo-Solar developed and produced a 1st generation during winter 2014-15. Implementation took place from spring 2015 until June 2015.

Altogether
150 collectors with copper tubes (2,225 m^2)
504 1st generation aluminium MPE collectors (7,474 m^2)
376 2nd generation aluminium MPE collectors (5,576 m^2)
has been implemented.

One of the risks using aluminium absorbers is corrosion. Therefore test pipes are placed in the collector circuit and the solar collector liquid is tested every ½ year.
In the last 6 months of 2016 monitoring results has been collected. Also a real time solar production control has been added to the control system.

5. Project results and dissemination of results

The project has been divided in 4 work packages:

1) Detailed design
2) Implementation
3) Monitoring program and
4) Project management and dissemination

The activities and results from each work package and subtask are described in the following text.

5.1 Detailed design of phase 1 of the energy plant

5.1.1 Optimization of aluminium solar collector from Savo-Solar

First generation (CSAV9002) + second generation (CSAV9003)

The collector with MPE absorber was developed for this project including two generations. Collectors were tested at SP Technical Research Institute of Sweden during the development work. Tests included performance and pressure loss measurements according to ISO 9806:2013. Mechanical load test was performed by Savo-Solar.

The collector is characterised by a direct flow aluminium absorber, which is manufactured from MPE profiles. The absorber is coated with a highly selective PVD MEMO coating and the use of the MPE profiles minimises the average distance between the coated surface and the heat transfer fluid. This leads to a uniform temperature distribution where conductive heat losses are minimised. Collectors have integrated connection hoses which allows mounting with no more than 40 mm distance between collectors. Flexible hoses reduce heat loss since the connection hoses are protected by the collector's insulation.

Figure 5.1.1. Row end collector with stanchion

1st Generation

The absorber size was optimized according to the coating line and transportation. Main components of the absorbers are MPE-profiles, header tubes and integrated metal hoses. Absorber is designed and manufactured according to Pressure Equipment Directive (PED). Brazing methods and brazers were inspected and approved by a third party according to PED module A2.

The collector box was designed around the MPE absorber. The absorber determines the outer dimensions of the collector. The main components of the collector box are frames, back plates, back supports, insulations, glazing supports and glasses. Collectors are assembled by gluing the parts together. Galvanized steel was selected as frame material because of the mechanical properties. Additional external supports were added to meet the mechanical requirements. Frames are joined with corner pieces.

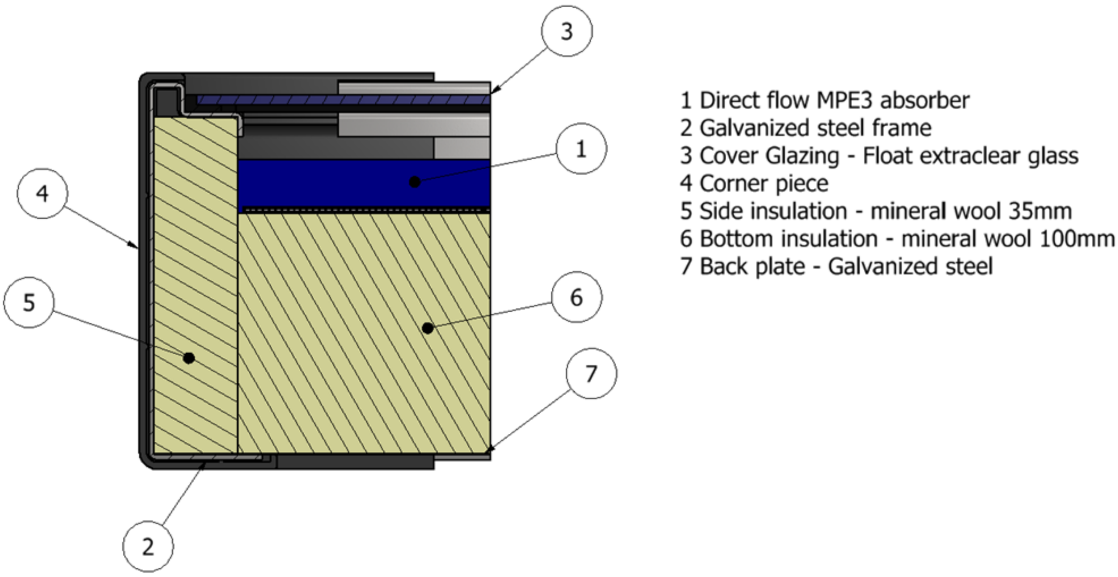


Figure 5.1.2. 1st generation sectional view

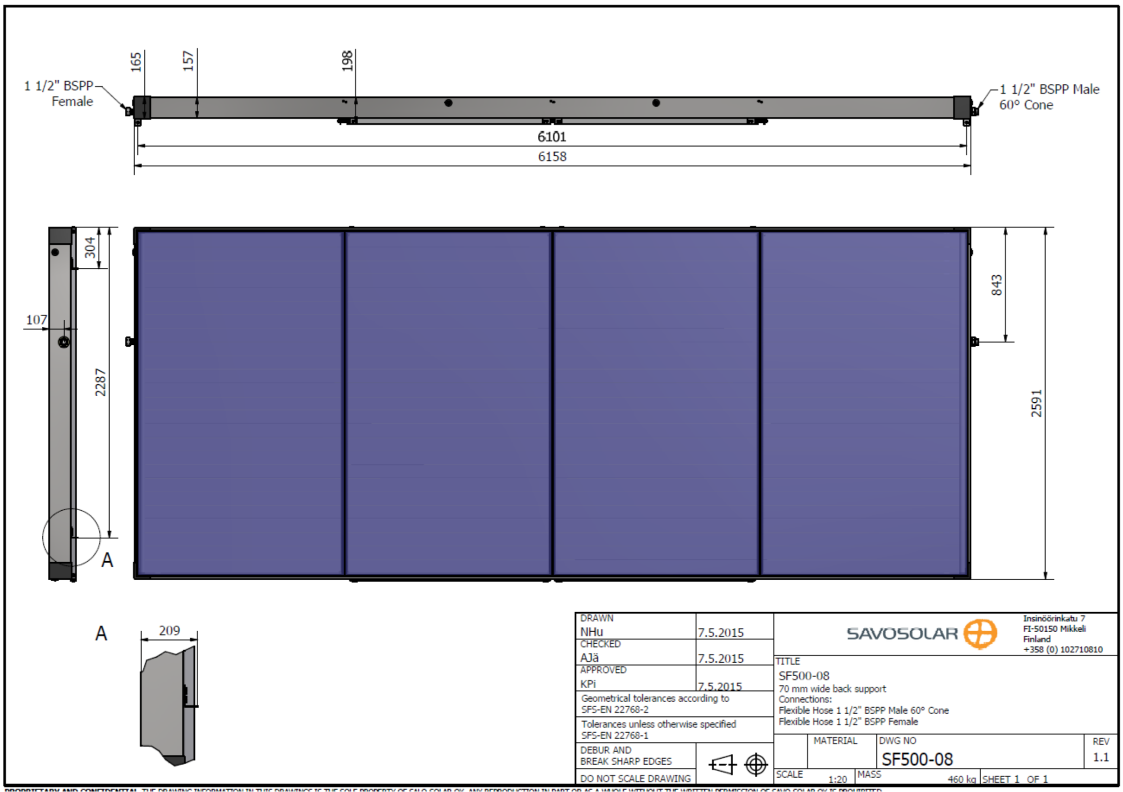


Figure 5.1.3. Main dimensions of SF500-08, 1st generation collector

2nd generation

The main targets were to reduce the pressure loss to be able to connect more collectors in series and reduce costs. MPE-profile and flexible hose designs were redesigned to decrease the pressure loss. Cost reduction was achieved with a new frame design and simplified design of the integrated hoses. External supports were not needed with new frame design. Insulation thickness was reduced from 100mm to 80mm because the behaviour of the absorber and variation in the insulation thickness.

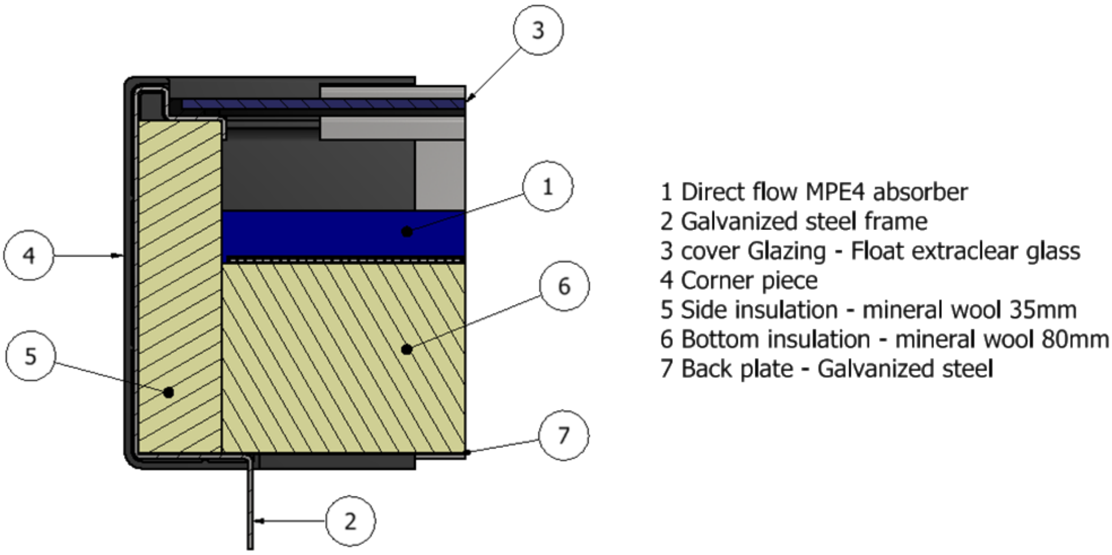


Figure 5.1.4. 2nd generation sectional view

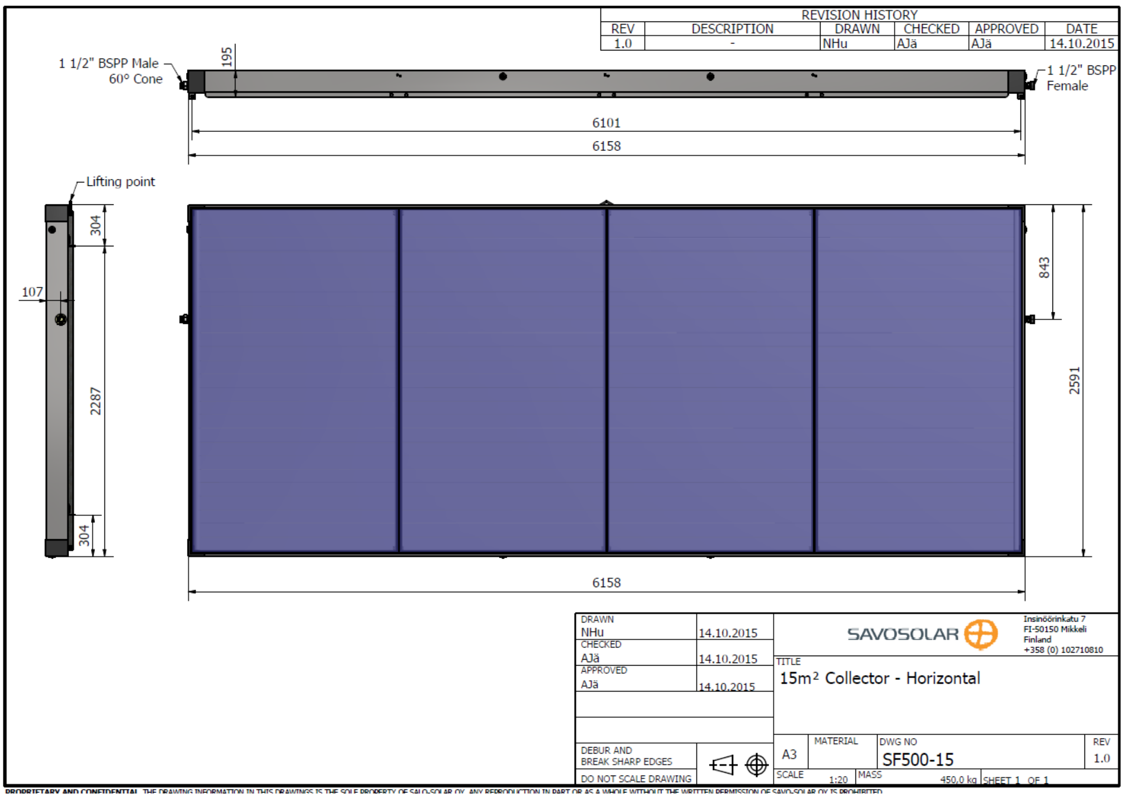


Figure 5.1.5. Main dimensions of SF500-15, 2nd generation collector

Materials in the solar circuit delivered by Savo-Solar are stainless steel, aluminium and brass. Balancing valves are made from brass and are located at the cold side of the collector rows. There is no direct contact between brass and aluminium.

Approved glycols per. January 2017 to be used with SAPA's HyLife Solar ® Alloy:

- Antifrogen® SOL HT Conc. (*) from Clariant International Ltd
- Antifrogen® SOL HT from Clariant International Ltd
- Coracon Sol 5 (*) from Aqua Concept GmbH
- Coracon Sol 5F from Aqua Concept GmbH
- ®PEKASOLar 100 (*) from pro KÜHLSOLE GmbH
- ®PEKASOLar 30 - 50% from pro KÜHLSOLE GmbH
- Solarliquid L (*) from Staub & Co Chemiehandels GmbH
- Solarliquid L gebrauchsfertig from Staub & Co Chemiehandels GmbH
- Tyfocor ® L Concentrate (*) from Tyforop GmbH
- Tyfocor ® L from Tyforop GmbH

(*) concentrated products. Antifrogen® SOL HT Conc., Coracon Sol 5 and Solarliquid L to be diluted with a max. amount of 50% vol. distilled water. ®PEKASOLar 50 to be diluted with a max. amount of 55% distilled water, Tyfocor ® L Concentrate to be diluted with a max. amount of 60% vol. distilled water.

5.1.2 Detailed design of the energy plant including solar collector field and operation strategy

The detailed design of the complete system was done by Rambøll during February 2013. Based on extensive knowledge and experience from previous solar thermal projects, a series of calculations was conducted using internal developed software adapted to the new types of solar collectors. A short review of these calculations including design parameters as well as diagrams and a brief operation strategy is attached to this report as annexes.

In this phase, the following are of importance, when designing plants with alu absorbers.

1. Type of glycol is to be set by the manufacturer of the panels. See the list of approved types.
2. When brand and type of glycol is chosen, eventually limitations in metals used in the rest of the installation, have to be settled.
   In general, A-metal, steel, cast iron and stainless steel can be used.
3. The MPE absorber contains quite more liquid than traditional sunstrip absorbers. This extra amount have to be taken into account, when designing expansion tanks, tank for overflow and to order enough to fill panels, pipes , heat exchanger etc.
4. In an eventual boiling situation, the larger amount in the panels, are heated to the boiling point, resulting in a higher loss of antifreeze in such an occasion. (lost by evaporation of water and antifreeze). Specific precoursions have to be arranged around the airvent from the tank, to avoid injuries from the hot steam, leaving the airvent in a boiling situation.
5. The pressure drop is informed by the manufacturer, and is a basis for the pressure loss calculation.
6. Like in copper pipes, the velocity in the alu-pipes and channels do not have to exceed a specific value. (normally 1 – 1,5 m/second.)

Design parameters can be found in Annex 1.

5.1.3 Contract negotiation with solar collector supplier

Savo-Solar promised, that the new solar collector was of at least same quality as the present solar collectors for district heating on the market. Therefore the contract between Savo-Solar and Løgumkloster Fjernvarme is a standard contract with standard efficiency and durability guarantees.

But since the absorber is new Løgumkloster Fjernvarme has added special clauses about components and component guarantees.

All components must be according to specifications from SAPA Precision Tubing Tønder A/S and in a special 5-years test has to be proved, that lifetime of all components is expected not to be shorter than for in standard solar collector systems. A guarantee given by SAPA to Savo-Solar ensures that the responsibility is held by SAPA as long as the components are made in accordance with their predefined specifications.

For the 2nd generation of solar collectors with MPE absorber it was specified that the solar collectors should be able – with 15 collectors in a row at 40 ^{o}C – to have less than 3.5 bar as pressure drop.

5.1.4 Production of tender documents, tendering and contracts for other parts than the solar collectors

In June 2013 Rambøll released the documents of five individual tenders, for 15 prequalified entrepreneurs to review and provide their offers upon. The tenders were separated in the following categories: Site Preparation, Mechanical Installation, Storage Tank, Electrical Installation and Buildings. Furthermore two individual tenders were held in order to locate a supplier of the wood pellet boiler and the absorption heat pump, which would be installed in correlation to the optimization of the plant.
Each offer had to be delivered no later than the 3rd of September 2013, and was evaluated based on the terms of being the most economically advantageous. After a thorough evaluation process, five entrepreneurs were invited for further negotiation.

The following companies were awarded contracts:

- Site Preparation: Chr. Johansen A/S
- Mechanical Installation: Averhoff Energi Anlæg A/S
- Storage Tank: F. W. Rørteknik A/S
- Electrical Installation: Tjæreborg Industri A/S
- Building: Chr. Johansen A/S
- Absorption Heat Pump: Danstoker A/S
- Wood Pellet Boiler: Tjæreborg Industri A/S

5.2 Implementation

The construction of the district heating plant in Løgumkloster started in April 2013, and continued until September 2016. In that period of time various parts of the project was completed, including the first and second stage of the solar field installation. Despite the new type of solar collectors, Rambøll did not face any unexpected issues during the process.

The implementation phases are [1)] welding and implementation of pipes in the solar circuit, [2)] implementation of supporting poles, [3)] implementation of solar panels and [4)] connection of solar panels to solar circuit pipes.

Pictures from the implementation:

Further information can be found in
Annex 2. Solar collector field
Annex 3. P&I diagram
Annex 4. List of components
Annex 5. Operation strategy
Annex 6. Brochure Savo-Solar

5.3 Monitoring program

5.3.1 Design of monitoring program including P&I diagram and list of components

For calculating the performance from different collector types and set up the real time monitoring the following parameters must be measured:

- Solar radiation on the collector plane
- Ambient temperature
- Temperature at the inlet and outlet of the collector field
- Flow
  Often an "energy meter" measures flow and temperature difference, and calculates the "measured" energy level by using assumed figures for specific heat capacity and density of the fluid.

See PI diagram sections with the collector fields in annex 7.

The following recommendations has been referred to regarding the accuracy of the measurement equipment.

		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	$\Delta\Delta T/\Delta T$	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				

Table 5.3.1. Recommended accuracies for monitoring equipment. [1]

For measuring the solar radiation, three different types of solar irradiation measurements are installed[1]:
3 pcs. of Indium Sensors type 3.3
1 pcs. of SPN1 from Delta-T Devices
1 pcs. of SMP10 from Kipp & Zonen
Two of the Indium Sensors are placed at the top of the storage tank at the district heating plant. The average of these two is used to control the system operation (in a calculation of required pump speed). The third Indium Sensor is installed alongside the SPN-1 and SMP10 pyranometers next to collector field no. 4 as seen in figure 5.3.1.

[1] Data sheets found in annex 8.

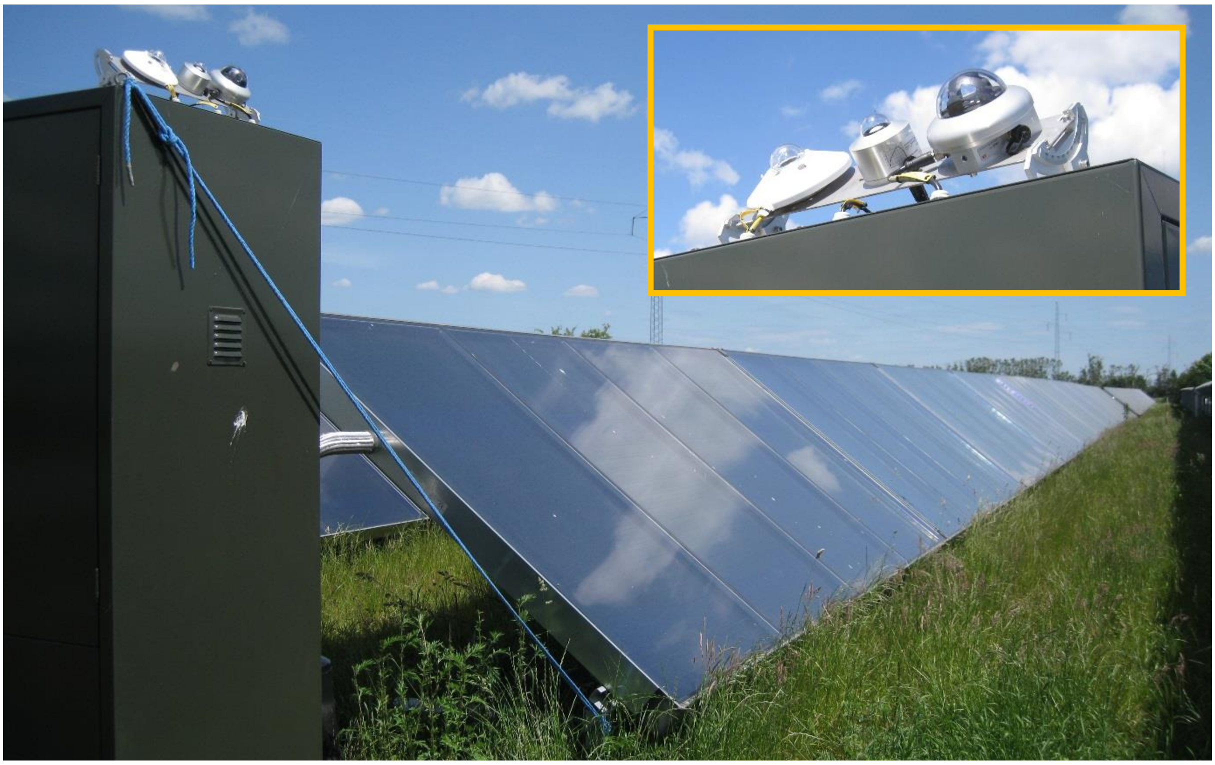


Figure 5.3.1. Solar radiation measuring from three different type of units. (From left to right: Kipp & Zonen SMP10, Indium Sensor type 3.3 and Delta-T Devices SPN1.)

It is important to make sure the sensors are placed exactly in the same orientation as the collectors (i.e. tilt and azimuth) since even small deviations, which are barely visible, can result in significant errors in the measured radiation levels. This is illustrated in figure 5.3.2.

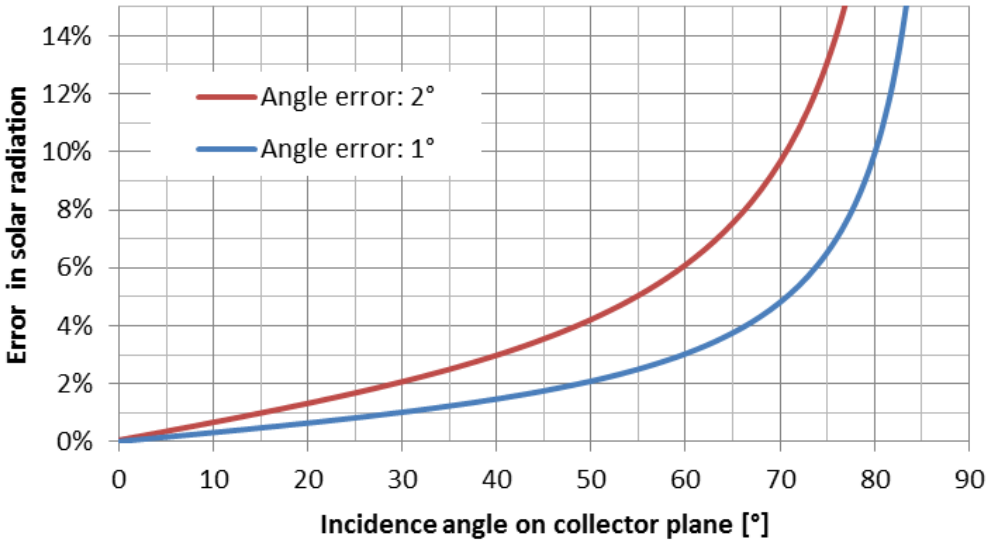


Figure 5.3.2. Illustration of the principle regarding error in measured solar radiation due to a difference in the sensor orientation. In the example, 1 and 2 degrees are used as differences between the sensor's plane and the collector plane.

5.3.2 Monitoring results

5.3.2.1 Expression for calculating expected performance

The expected performance is calculated according to:

- $Q_{exp} = A_{total} \cdot [\ \eta_0 \cdot G - a_1 \cdot (T_m - T_a) - a_2 \cdot (T_m - T_a)^2\ ]$ W

where[2]:

• Q_{exp} :	Expected solar heat output	W
• A_{total}:	Total collector area corresponding to the used collector efficiency parameters, η_0, a_1 and a_2	m²
• η_0 :	"Zero loos efficiency" (max. theoretical solar collector efficiency)	-
• a_1:	Solar collectors 1st order heat loss coefficient	$W/(K \cdot m^2)$
• a_2:	Solar collectors 2nd order heat loss coefficient	$W/(K^2 \cdot m^2)$
• G:	Solar radiation on collector plane	W/m^2
• T_a:	Ambient air temperature (ventilated, shadowed)	°C
• T_m	$= (T_{c,f} + T_{c,r})/2$	°C

where

$T_{c,f}$:	Forward temperature from collector field to heat exchanger	°C
$T_{c,r}$:	Return temperature to collector field from heat exchanger	°C

For a data record to be valid in the performance calculation, sunshine is assumed ($G \geq 800\ W/m^2$) and no shadows on collectors; no icing and no big temperature change (< 5 K within an hour).

[2] Nomenclature is found as annex 9.

5.3.2.2 Collector parameters

The collector parameters below are from the latest collector test certificate (se annex 10. Since the standard for test reports use *gross* area and not *aperture* area, the number below differs from the (aperture area) numbers stated in section 4.
Collector module parameters referring to module gross area (A_{module}):

- A_{module}: 15.96 m²
- η_0 : 0.812 -
- a_1: 2.936 W/(K·m²)
- a_2: 0.009 W/(K²·m²)

Collector field parameters for "field 4" seen in annex 2

- Number of modules: 352
- A_{total}: 5614 m²

Note that A_{total} corresponds to the collector gross area.

5.3.2.3 Data selection

The following criteria have been used for selection of data:

- Solar radiation: G ≥ 800 W/m²
- No icing/snow (T_l ≥ 5°C)
- No shadows (solar height big enough to ensure that shadow from front rows do not shadow rows behind)
- Incidence angle ≤ 30°
- Chance in collector loop mean temperature ≤ 5 K within an hour

Permitted periods chosen for selecting data [2]:

Period		Permitted times for recording mean values for the hour before				hours / day	days/ period	Expected no. valid records
		11:00	12:00	13:00	14:00			
12-mar	18-mar			X		1	6	1
19-mar	31-mar		X	X		2	12	5
01-apr	22-apr		X	X	X	3	21	20
23-apr	26-jul	X	X	X	X	4	94	100
27-jul	06-sep		X	X	X	3	41	40
07-sep	28-sep		X	X		2	21	10
Year							195	176

Table 5.3.2. Periods for valid data records; Danish conditions.

The periods in the table have been selected so to avoid influence from:

- reflections due to high incidence angle
- shadowing from row in front

The actual measuring period from 10/6 to 17/8 contains 43 valid data records. All valid data records are taken into account.

5.3.2.4 Check of performance

Data from three fields at Løgumkloster have been investigated (see annex 2):

- Field 1: 150 modules with cupper strips absorber
- Field 3: 376 modules with extruded aluminium absorber (2nd generation)
- Field 4: 352 modules with extruded aluminium absorber (1st generation)

The data covers the periods:

- 13/6 - 19/6 2016
- 5/8 - 17/8 2016
- 3/10 – 30/10 2016

Unfortunately data from Field 3 were not useable due to a malfunctioning temperature sensor. By the time the sensor was replaced, the restrictions in table 5.3.2 implied that no further measurement points could be retrieved within the project period. An additional measurement of Field 3 will be carried out in spring 2017, when measurement conditions are acceptable.

By analysing the measurements, it has been observed that the measured energy yield does not take the use of a glycol-water mixture into account. The sensor assumes water when calculating the solar energy yield, but a 30 % glycol mixture has been used (Coracon) with a specific heat capacity of approx. 3.920 kJ/(kg·K) and a density of 996 kg/m^3 and a density of 996 kg/m^3 (at 60 °C). The corresponding properties of water at 60 °C is 4.185 kJ/(kg·K) and 983 kg/m^3. The measured energy yield must therefore be multiplied with a "glycol factor" of:

$$F_{glycol} = 3.920 \cdot 996 / (4.185 \cdot 983) = 0.95$$

	Field 1	Field 4	Units
Measured output for valid data points per m²	16.6	18.1	kWh/m²
Calculated output for valid data points using parameters given in section 5.3.2.2	19.8[3]	17.5	kWh/m²
Measured-to-calculated ratio	83 %	104 %	
Measured output in whole period per m²	68.5	73.8	kWh/m²
Average temperature difference (T_m – T_a) in total operation time	39.1	53.0	°C
Average temperature difference (T_m – T_a) in valid data records	47.1	65.3	°C

Table 5.3.3. Results from measurements. Measured values have been corrected for glycol using a factor of 0.95.

It is seen from the table that Field 4 is performing better that Field 1 – even though the operating temperature is almost 15 K higher. This temperature difference is the reason why the calculated output is higher for Field 1 as this field has the lowest temperature.

In figure 5.3.3 an input-output diagram ("I/O diagram") shows the measured yield as a function of solar irradiation for all data points. Field 4 ("y4") is generally performing better than Field 1 ("y1"), which is in accordance with the values in table 5.3.3.

[3] Since no collector test certificate exist for the collector used in field no. 1 (copper absorber) the data sheet used is the one for the other type of collector. Hence the values are not expected to match.

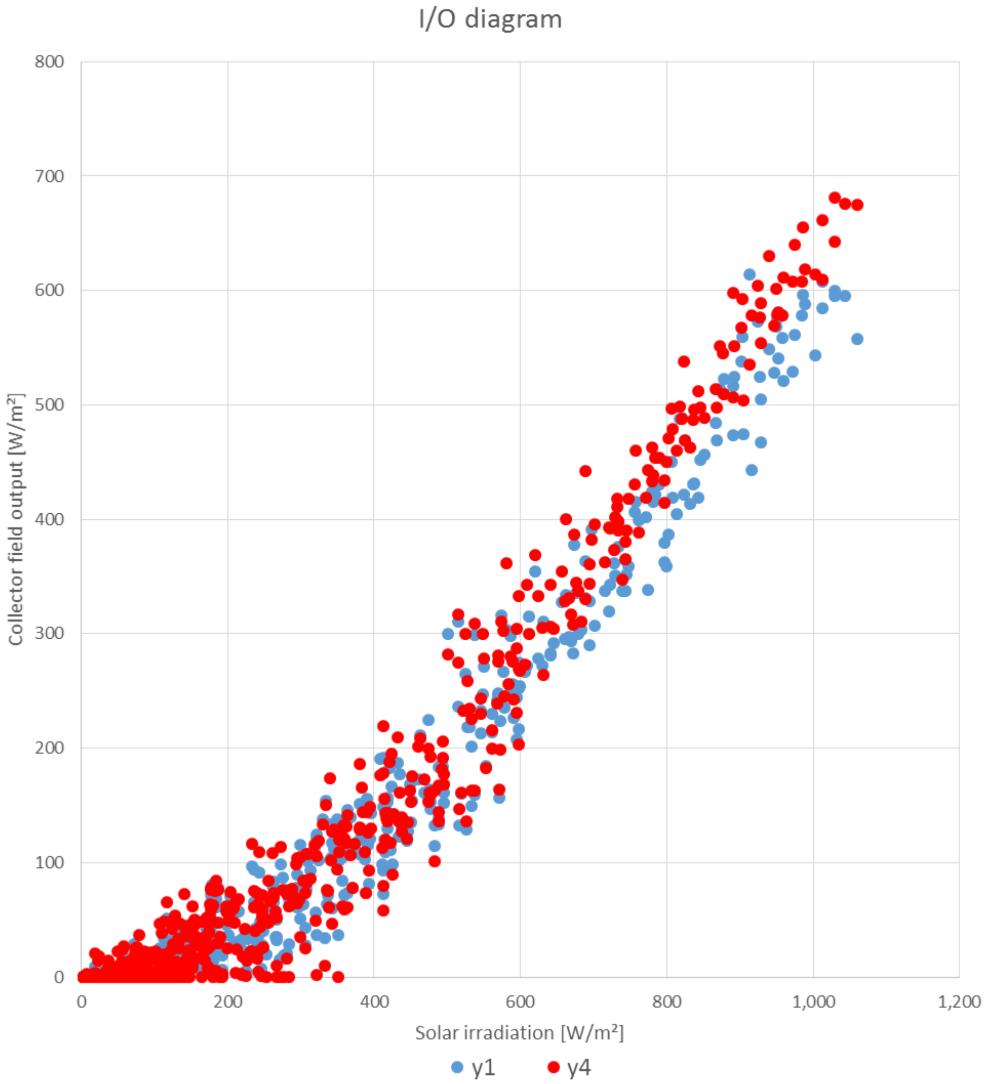


Figure 5.3.3. Input/output diagram for Field 1 and 4 including all data points.

In figure 5.3.4 and 5.3.5 the observed efficiency of the collector fields are shown.

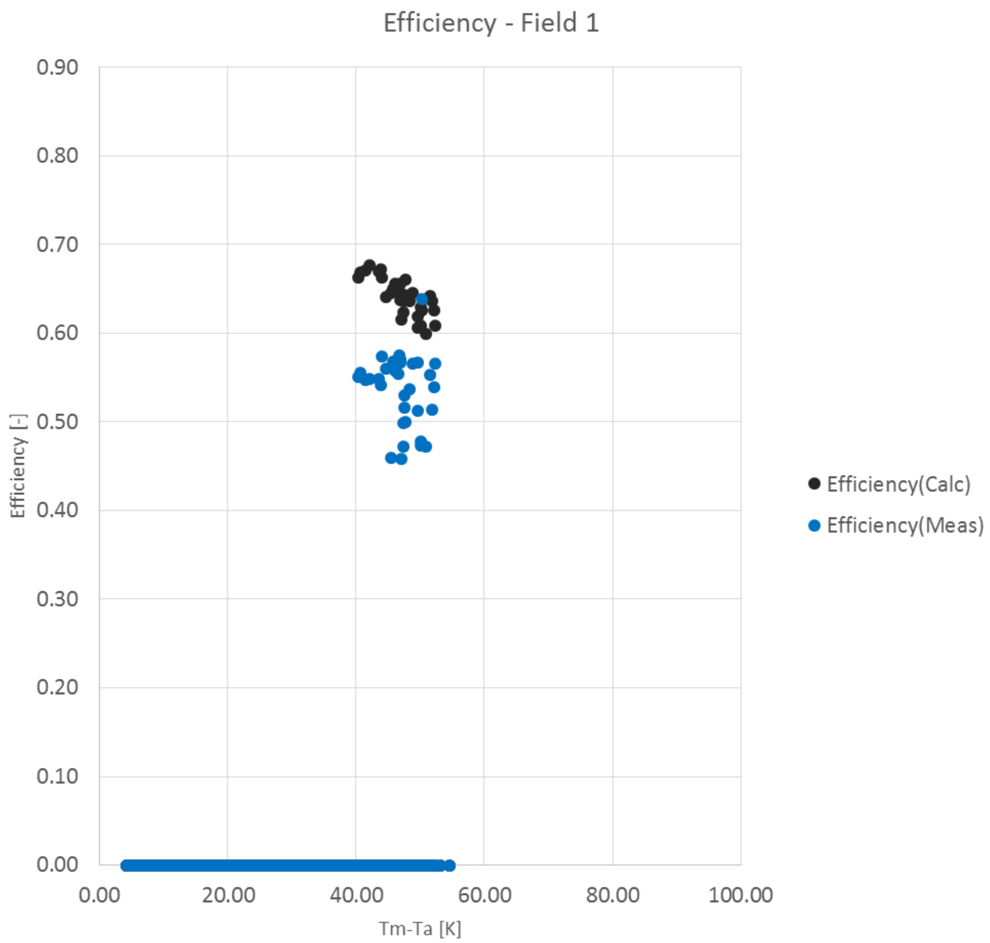


Figure 5.3.4. Efficiency - Field 1. Measured data records and corresponding calculated values (however calculated with aluminium efficiency parameters).

For Field 1 the calculated efficiencies are significantly higher than the measured. However, one should bear in mind that the parameters used for calculation are parameters not corresponding to the actual collector. The collector in Field 1 has a cupper strip absorber – in Field 4 it is the multi-port aluminium absorber, which is used. Efficiency parameters for the latter one is used (as seen in annex 10 shows parameters for this aluminium multiport type collector.

A large spread of the data points in figure 5.3.4 is observed. This could indicate that the operation of the field could be optimised. A low operating temperature (around 47 °C) is observed.

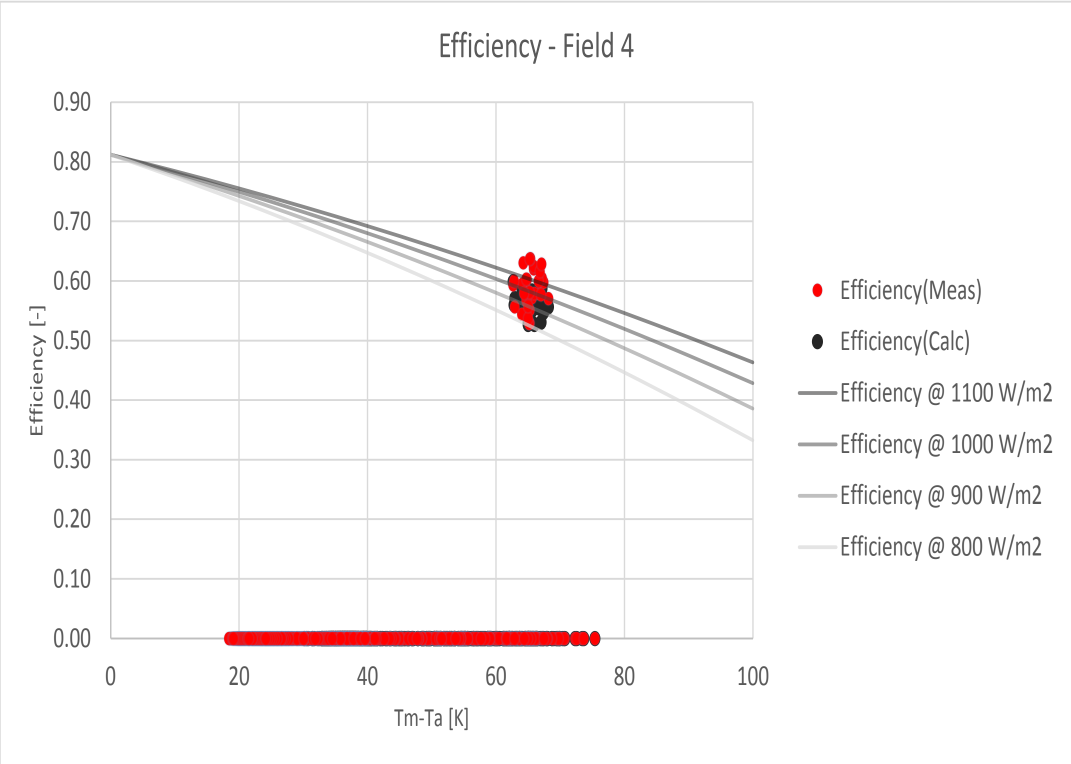


Figure 5.3.5. Efficiency - Field 4. Measured data records and corresponding calculated values.

The collector Field no. 4 performs extremely well according to these measurements. The performance for the valid data points is 4 % higher than calculated with the collector parameters from annex 10.

5.3.2.5 Summary of measurements – Field 4 (MPE absorber) vs. Field 1 (copper strips absorber)

From the performance check of collector Field no. 1 and 4 in Løgumkloster it seems that the collector Field 4 performs very well and clearly better that Field 1. Before final conclusions an evaluation based on a longer data period checked for sensor errors should be done. This underlines the relevance of the real time measurements, which can monitor the system continuously (see section 5.3.3) though the check is not similar to this one[4].

5.3.2.6 Comparison between measured solar radiation levels

When comparing the measured solar radiation at collector field no. 4 and sensors at the top of the storage tank, both a displacement in time and differences in absolute values are seen. This is indicated in figure 5.3.6 below where "sensor 1" is the SPN-1 sensor and "sensor 2" is the mean value of the two sensors at the storage tank roof. For a two-week period in June 2016, "sensor 2" shows approx. 2 % higher values than "sensor 1".

[4] Where the performance check implies optimum conditions, the real time control monitors at various weather conditions.

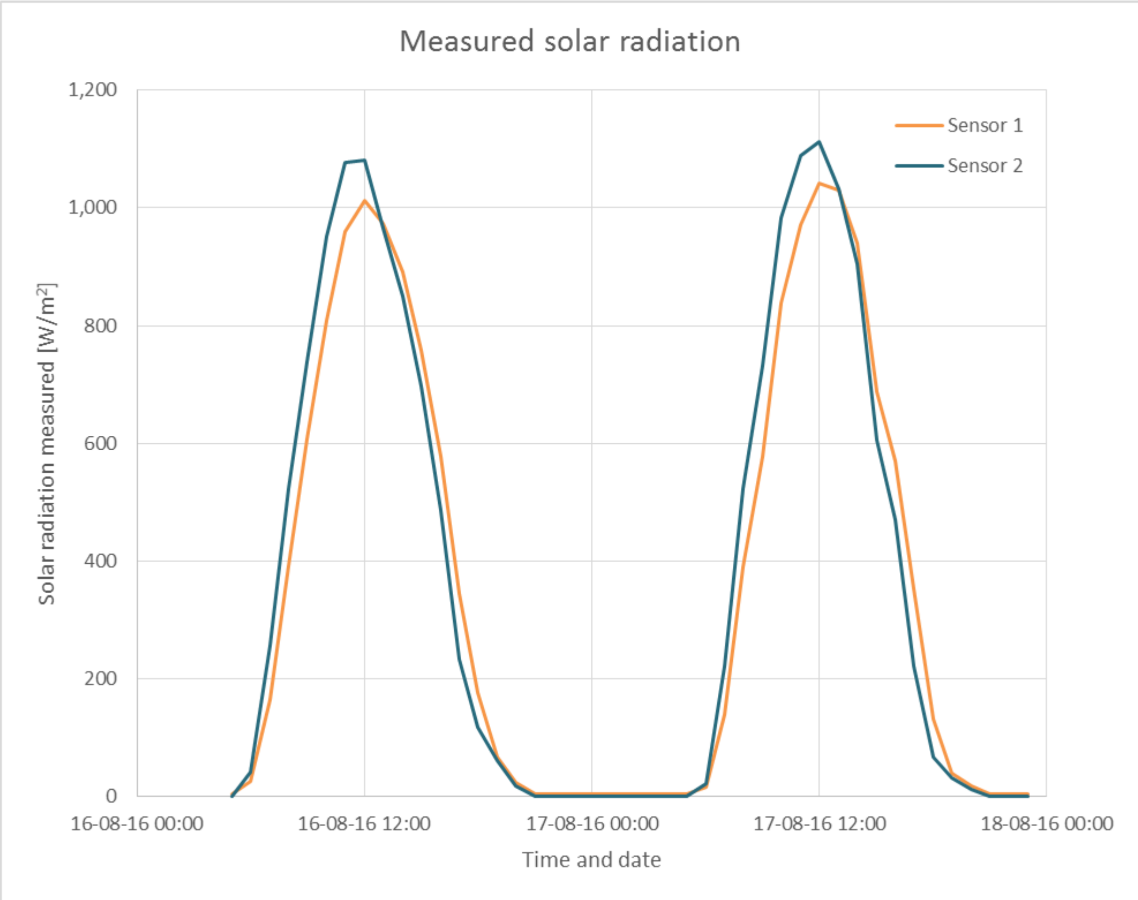


Figure 5.3.6. Example of two days measured solar irradiation (hourly values).

The trend can be clearly seen when looking at an example of measurements with a time step of one minute as shown in figure 5.3.7.

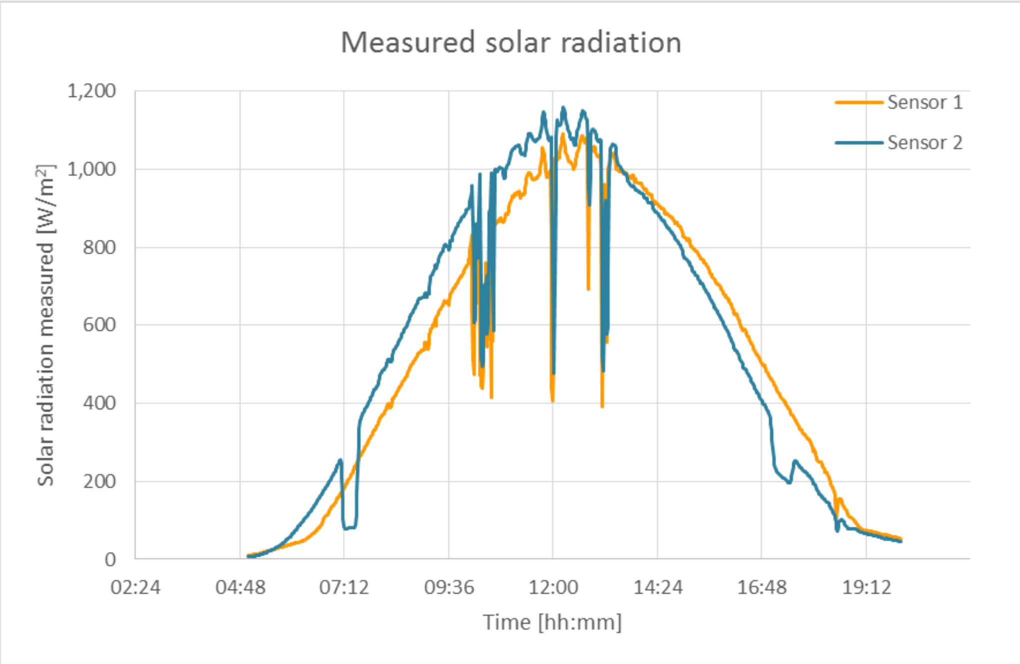


Figure 5.3.7. Example of measured solar irradiation on June 6, 2016 (1-minute time step).

5.3.3 Real time control

Below is described a calculation method for solar collector fields, which (among other things) takes the thermal capacity of the collector fluid into account. The real time control system makes it possible to calculate the expected solar yield continuously (and not only at optimum conditions).

5.3.3.1 Methodology

In the following differential equation, the change in the heat capacity of the solar collector loop is equal to "gathered" solar heat minus heat losses, minus the heat delivered to the district heating plant by means of the heat exchanger:

$$C \cdot dT_m/dt = \eta_0 \cdot G_{res} - U_L \cdot (T_m - T_a) - \mathbf{m} \cdot c_p \cdot (T_o - T_i) \qquad (1)$$

where:

C	Heat capacity in solar collector loop per m^2 of collector	J/(K·m²)
dT_m	Change in solar collector mean temperature over one time step	K
dt	Time step (e.g. 1 hour = 3600 s)	s
G_{res}	Resulting radiation on collector surface	W/m²
U_L	Solar collector heat loss coefficient (linearised)	W/(m²·K)
T_m	Mean temperature in solar collector loop (mean over a time step)	°C
m	Mass flow rate in collector loop (mean over time step) per m^2 collector	kg/(s·m²)
c_p	Specific heat capacity of solar collector fluid	J/(kg·K)
T_o	Solar collector loop outlet temperature (mean over a time step)	°C
T_i	Solar collector loop inlet temperature (mean over a time step)	°C

Since the collector fluid represent the vast majority of the thermal capacity of the collector loop, only the liquid is used when calculating the thermal capacity, C:

$$C = V_{fluid}/1{,}000 \cdot \rho \cdot c_p \qquad (2)$$

where

V_{fluid}	Fluid content in pipes and solar collector field per m² solar collector[5]	l/m²
ρ	Density of solar collector fluid	kg/m³

The linearised heat loss coefficient for the solar collector loop, U_L is approximated by

$$U_L = a_1' + a_2 \cdot (T_{m,0} - T_a) \qquad (3)$$

where

a_1'	Solar collectors 1st order heat loss coefficient plus heat loss in pipes[6]	W/(m²·K)
a_2	Solar collectors 2nd order heat loss coefficient	W/(m²·K²)
$T_{m,0}$	Mean temperature in solar collector loop in the beginning of time step	°C

In general an index "comma null" or "comma one" is added to a parameter to describe a value at the beginning or at the end of a time step respectively. This means for example that $T_{m,0}$ is the parameter T_m in the beginning of a time step, while $T_{m,1}$ is the same parameter at the end of a time step. The mean temperature in the solar collector loop in the beginning of a time step ($T_{m,0}$) is equal to the mean temperature in the solar collector loop in the end of the previous time step i.e. $T_{m,1}$ from the previous time step.

The mass flow rate in kg/s per m² solar collector is calculated based on measured flow in m³/h:

$$\mathbf{m} = \mathbf{V}/3600 \cdot \rho / A_{total} \qquad (4)$$

where

V	Volume flow rate in solar collector loop	m³/h

By defining two expressions for B1 and B2 respectively as:

$$B_1 = (U_L + 2 \cdot m \cdot c_p) \cdot dt/C \qquad (5)$$

$$B_2 = (\eta_0 \cdot G_{res} + U_L \cdot T_a + 2 \cdot m \cdot c_p \cdot T_i) \cdot dt/C \qquad (6)$$

Equation (1) can be rewritten to:

$$dT_m + T_m \cdot B_1 = B_2 \qquad (7)$$

Per definition, the change in T_m (i.e. dT_m) is equal to the difference between the value at the end of a time step and at the beginning of the time step, which as is stated in equation (8):

[5] See section 5.3.3.3.

[6] Heat loss in pipes refers to the total pipe losses per m² of solar collector calculated in section 5.3.3.3.

$$dT_m = T_{m,1} - T_{m,0} \quad (8)$$

Correspondingly, T_m is defined as the average of values during the time step, which is calculated by:

$$T_m = (T_{m,1} + T_{m,0})/2 \quad (9)$$

(i.e. the mean value of the value at the beginning and end of a time step).

By inserting the expression for T_m from equation (9) into equation (7) and also inserting the expression for dT_m from equation (8) into equation (7), an expression is created of which $T_{m,1}$ can be isolated:

$$T_{m,1} = [T_{m,0} \cdot (1 - B_1/2) + B_2] / [1 + B_1/2] \quad (10)$$

where:

$T_{m,0}$ is the mean collector loop temperature in the beginning of the present time step (which is known from the previous time step) and
$T_{m,1}$ is the mean collector loop temperature in the end of the present time step (which is saved and used as $T_{m,0}$ for the upcoming calculation of the next time step)

T_m can be expressed both by equation (9) and can be calculated as

$$T_m = (T_o + T_i)/2 \text{ (mean of inlet and outlet temperature)} \quad (11)$$

By combining these two expressions, T_m can be eliminated and the outlet temperature can be isolated:

$$T_o = T_{m,1} + T_{m,0} - T_i \quad (12)$$

This calculated outlet temperature is in the validation compared with the measured outlet temperature.

With a known T_o the energy yield Q can be calculated for the given values of flow and inlet temperature.
The measured energy yield is given by equation (13). (Since **m** is the mass flow rate in the solar collector loop <u>per m^2 of solar collector</u>, it is necessary to multiply with the total collector area, A_{total} to get the total energy yield.)

$$Q = \mathbf{m} \cdot A_{total} \cdot c_p \cdot (T_o - T_i) \cdot dt \quad (13)$$

The unit for Q is joule, but if a time step (dt) of 1 hour is used, i.e. dt = 3600 seconds, Q can be calculated in MWh by the expression

$$Q\ [MWh] = m \cdot A_{total} \cdot c_p \cdot (T_o - T_i)/10^6$$

The calculated energy yield is validated by the measured yield.

5.3.3.2 Input data for model

Solar collector module[7]

A_{module}	14.83	m²
η_0	0.872	-
a_1	2.019	W/(m²·K)
a_2	0.028	W/(m²·K²)
IAM_{50}	0.95	-
Fluid content	26.0	l per module
c_p for collector fluid	3920	J/(kg·K) (30 % glycol at 60 °C)
ρ for collector fluid	996	kg/m³ (30 % glycol at 60 °C)

Solar collector field

Number of collectors	352	-
Total transparent area, A_{total}	5220	m²
Number of rows	11	-
Distance between rows	5.0	m
Azimuth	13	° east
Tilt from horizontal	38	°

Weather data etc.

As input for weather data, and flow & temperatures in the system, data from Løgumkloster Field 4 is used – based on the period 5/8 – 17/8 2016; almost 13 days with very varying solar radiation. Weather data is given as hourly values (mean values over the hour). The number to the right represent the parameter name in the logging system.

G_{tot}	Total radiation onto solar collector plane (W/m²)	IO03_GS2375_3_XQ01
G_{dif}	Diffuse radiation onto solar collector plane (W/m²)	IO03_GS2375_3_XQ02
T_a	Ambient temperature (°C)	IO03_TT2340_6_XQ01
T_i	Collector loop inlet temperature (excl. transm. pipe) (°C)	IO03_TT2340_1_XQ01
V	Flowet in the collector loop (m³/h)	IO03_FT2310_XQ01
Q_{meas}	Measured yield for the field (MW)[8]	SRO01_ENERGI_PRI_TESTFELT_3

Radiation is corrected to take shadows etc. into account. The resulting radiation on collector surface, G_{res} becomes:

$$G_{res} = G_{dir} \cdot F_{dir} + G_{dif} \cdot F_{dif} \quad (14)$$

where

$G_{dir} = G_{tot} - G_{dif}$ (W/m²)

and

F_{dir}	Factor for correction of shadows and incidence angle modifier related to direct radiation	(-)
F_{dif}	Factor for correction of shadows and incidence angle modifier related to diffuse radiation	(-)

[7] The development of the real time control model was carried out before the latest collector test certificate was created.

[8] As mentioned in section 5.3.2.4 the measured values has to be corrected due to the use of a glycol-water mixture as solar collector fluid. See annex 11.

F_{dir} and F_{dif} is retreived as hourly values based on calculations from Fjernsol Pro [3] with the actual colletor setup and orientation. The values relevant for the present time step is found by lookup in the table in annex 12

Input data record then becomes:

Time	G_{tot}	G_{dif}	T_a	T_i	**V**	**m**	$T_{m,0}$	F_{dir}	F_{dif}

5.3.3.3 Pipes

A table with pipe diameters and lengths provides the calculation of both fluid volume per m² solar collector and heat loss coefficient per m² of solar collector.

Pipes in the solar collector field	Length, l (m)	Diameter, d (mm)	Radius, r (m)	Volume, V (m³)	Volume, V (litres)	Volume in pipes per collector, V (l/rmodule)	Heat loss coefficient per meter pipe, U/l (W/(K·m))	Heat loss coefficient (W/K)
Warm side	75	150	0.075	1.325	1325	3.77	0.22	16.5
	100	100	0.050	0.785	785	2.23	0.19	19.0
	38	75	0.038	0.168	168	0.48	0.17	6.5
	38	50	0.025	0.075	75	0.21	0.14	5.3
Cold side	100	100	0.050	0.785	785	2.23	0.26	26.4
	38	75	0.038	0.168	168	0.48	0.24	9.1
	38	50	0.025	0.075	75	0.21	0.18	6.8
Total				3.381	3381	**9.61**		**89.6**

Transmission pipes	l (m)	d (mm)	r (m)	V (m³)	V (l)	V (l/ module)	U/l (W/(K·m))	U (W/K)
Warm side	176	250	0.125	8.639	8639	24.54	0.25	44.0
Cold side	176	250	0.125	8.639	8639	24.54	0.37	65.1
Total				21.688	21688	61.61		109.1
48 % allocated to Field 4						**29.79**		**52.8**
Total allocated to Felt 4						**39.4**		**142.4**

Solar collector field (352 modules)	**26.5**

Total fluid in pipes and solar collector field in litres per collector module	**65.9**

Fluid content in pipes and solar collector field can be converted to the unit litres per m^2 solar collector by dividing with the area per module, A_{module} (see section 5.3.3.2):

Fluid content in pipes and solar collector field in litres per m^2 solar collector, V_{fluid}	**4.44**

Correspondingly the total heat loss coefficient for pipes allocated to Field 4 can be converted to the unit W/K per m^2 solar collector, i.e. W/(m²·K) by dividing "Total allocated to Field 4" with the total collector area for Field 4 (see section 5.3.3.2):

Total pipe loss in W/K per m² solar collector	**0.027**

The total pipe loss per m^2 solar collector is added to the solar collector efficiency parameter a_1 to get the resulting 1st order heat loss coefficient a_1'. a_1' is used in the expression for the linearised heat loss coefficient U_L, equation (3), which afterwards is used in equation (1).

5.3.3.4 Validation

Measured values are compared with calculated values for the same period below.

The measured yield is corrected with the factor 0.952 (see annex 11) to take into account that the measured values are based on water properties and not the glycol-water mixture which is actually used.

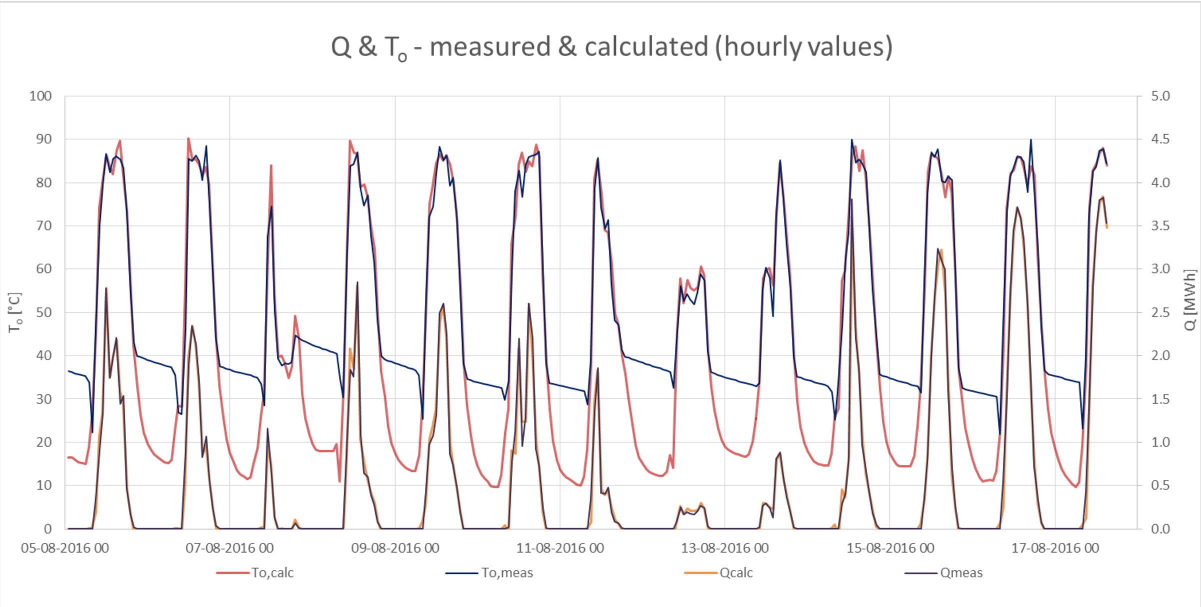


Figure 5.3.8. Comparison of measured (meas) and calculated (calc) yields (Q) and outlet temperature, T_o (hourly values). It is seen that the calculated outlet temperature is slightly above the measured values during operation.

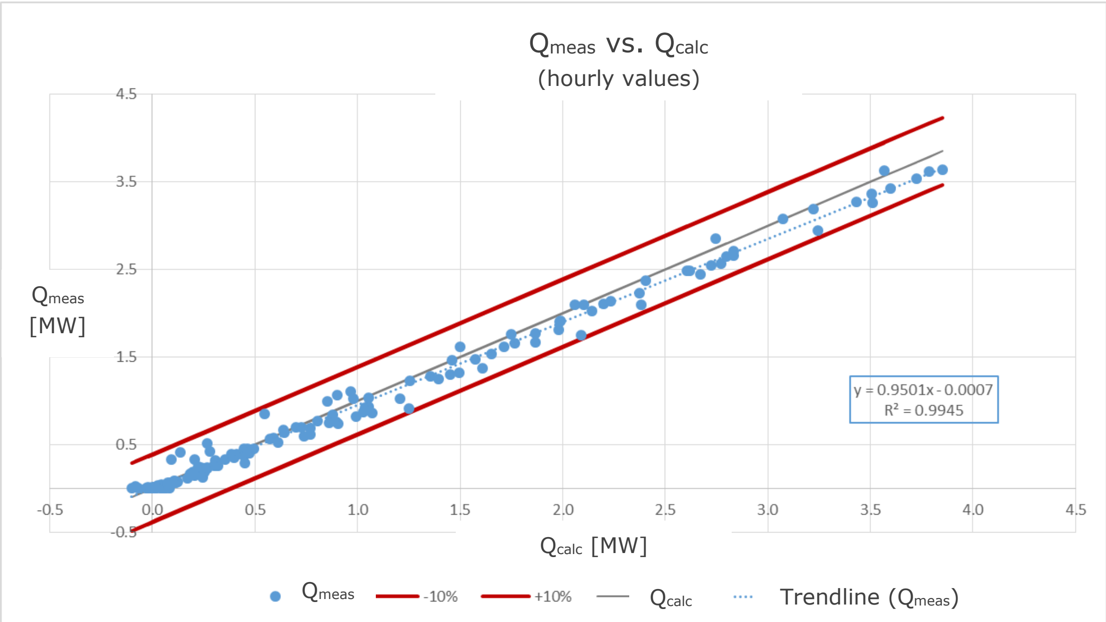


Figure 5.3.9. Hourly values of measured (Q_{meas}) and calculated (Q_{calc}) yield. The trendline for the measured values is seen as a dotted line. The linear expression for this line is seen in the blue box in the figure. The red lines indicates +/- 10 % of maximum calculated yield in the period.

It is seen that all hourly values lies within the error band of +/- 10 % of maximum calculated yield in the period. It is also seen that the measured yield in general is about 5 % lower than the calculated one. However, this comparison has been made prior to the latest collector test certificate and is therefore based on other collector assumptions than what is shown in annex 10.

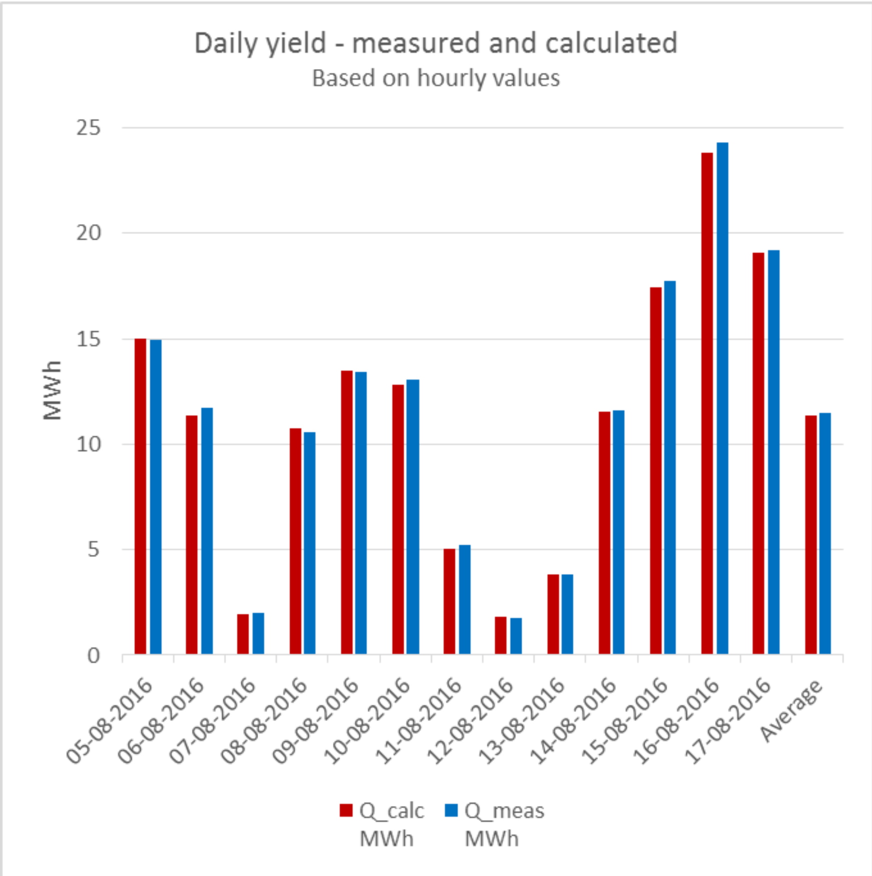


Figure 5.3.10. Daily measured (Q_{meas}) and calculated (Q_{calc}) yield based on hourly values.

Based on the chosen input parameters, the calculated values are all days somewhat higher than the measured ones – in average approx. 5 %.

5.3.3.5 Surveillance

The following measured and calculated values are compared for each time step:

- Measured outlet temperature, $T_{o,meas}$ with the calculated outlet temperature $T_{o,calc}$
- Measured energy yield Q_{meas} from the field with the calculated energy yield Q_{calc}

Criteria for warnings and error messages are based on differences between measured and calculated values for the points above. At small energy yields, the deviation can be large in percent even though the system operates as expected. Therefore a fixed error band based on a percentage of a "nominal yield". This nominal yield can be set to an estimated maximum yield, which can be calculated as

$$Q_{nom} = A_{total} \cdot [\eta_0 \cdot G_{res} - a_1 \cdot (T_m - T_a)]/10^6 \qquad (10)$$

with

- G_{res} = 1,000 W/m²
- $T_m - T_a$ = 50 K

With the solar collector properties for the model, this becomes:

$$Q_{nom} = 5220 \cdot (0.872 \cdot 1{,}000 - 2.019 \cdot 50)/10^6 = 4.02 \text{ MW}$$

5.3.3.6 Warnings

Warnings can be given when measured outlet temperature deviates significantly from a calculated value:

- $T_{o,meas} > T_{o,calc} + \Delta T_{warning}$ =>
  "WARNING: Measured outlet temperature is [$\Delta T_{warning}$ value] higher than calculated"
- $T_{o,meas} < T_{o,calc} - \Delta T_{warning}$ =>
  "WARNING: Measured outlet temperature is [$\Delta T_{warning}$ value] lower than calculated"

where $\Delta T_{warning}$ can for example be set to 10 K.
Warnings are in general only applied when the system is in operation since the outlet temperature is located in a pipe which is not affected by the collector field when it is not in operation.

Warnings can be given when measured yield deviates significantly from a calculated value:

- $Q_{meas} - Q_{calc} > \Delta Q_{warning}$ =>
  "WARNING: Measured minus calculated yield > [$\Delta Q_{warning}$ value]"
- $Q_{calc} - Q_{meas} > \Delta Q_{warning}$ =>
  "WARNING: Calculated minus measured yield > [$\Delta Q_{warning}$ value]"

$\Delta Q_{warning}$ can for example be set to 10 % of Q_{nom}.

5.3.3.7 Error messages

Error messages can be provided when measured outlet temperature deviates critically from a calculated value:

- $T_{o,meas} > T_{o,calc} + \Delta T_{error}$ =>
  "ERROR: Measured outlet temperature is [ΔT_{error} value] higher than calculated"
- $T_{o,meas} < T_{o,calc} - \Delta T_{error}$ =>
  "ERROR: Measured outlet temperature is [ΔT_{error} value] lower than calculated"

where ΔT_{error} can for example be set to 20 K.

Error messages can be given when measured yield deviates critically from a calculated value:

- $Q_{meas} - Q_{calc} > \Delta Q_{error}$ =>
  "ERROR: Measured minus calculated yield > [ΔQ_{error} value]"
- $Q_{calc} - Q_{meas} > \Delta Q_{error}$ =>
  "ERROR: Calculated minus measured yield > [ΔQ_{error} value]"

ΔQ_{error} can for example be set to 20 % of Q_{nom}.

Error messages are only applied when the system is in operation.

5.3.3.8 Example of surveillance

In section 5.3.3.9 is seen examples of warnings and errors, which would be given for Field 4 in a period of operation during the summer of 2016, by using the model and criteria described above. It is seen in figure 5.3.11 that there is several warnings during start-up in the morning – even with a margin of 10 K. This indicates that the model is not accurate for calculating outlet temperature in phase from standstill to start-up. If the criteria for warnings due to deviation in yield is set to 5 %

of nominal yield and 10 % is set for error messages, several warnings are seen (not only at start-up), but no error messages[9].

5.3.3.9 Recommendations for surveillance criteria

Field 4 in Løgumkloster is operating well in the chosen period in the example. Therefore, criteria should be chosen to avoid error messages and maximum very few warnings.

One option is to choose only to have the surveillance (and associated warnings and error messages) connected to the energy yield.

In the example below a margin for warnings of 5 % is chosen to show some examples of warnings. This is however a small margin when taking model and measurement uncertainties into account. A margin for warnings of 10 % and an error margin of 15-20 % are deemed more realistic.

General recommendations for the Løgumkloster system:

- For hourly mean values of the solar energy yield the margin for warnings are set to 10 % of nominal yield.
- For hourly mean values of the solar energy yield the margin for errors are set to 20 % of nominal yield.

(For outlet temperature, warning and error messages are deactivated.)
Measurements and system operation should be checked if error messages or several warnings are seen.

[9] Based on the example for Q_{nom} described in section 5.3.3.5.

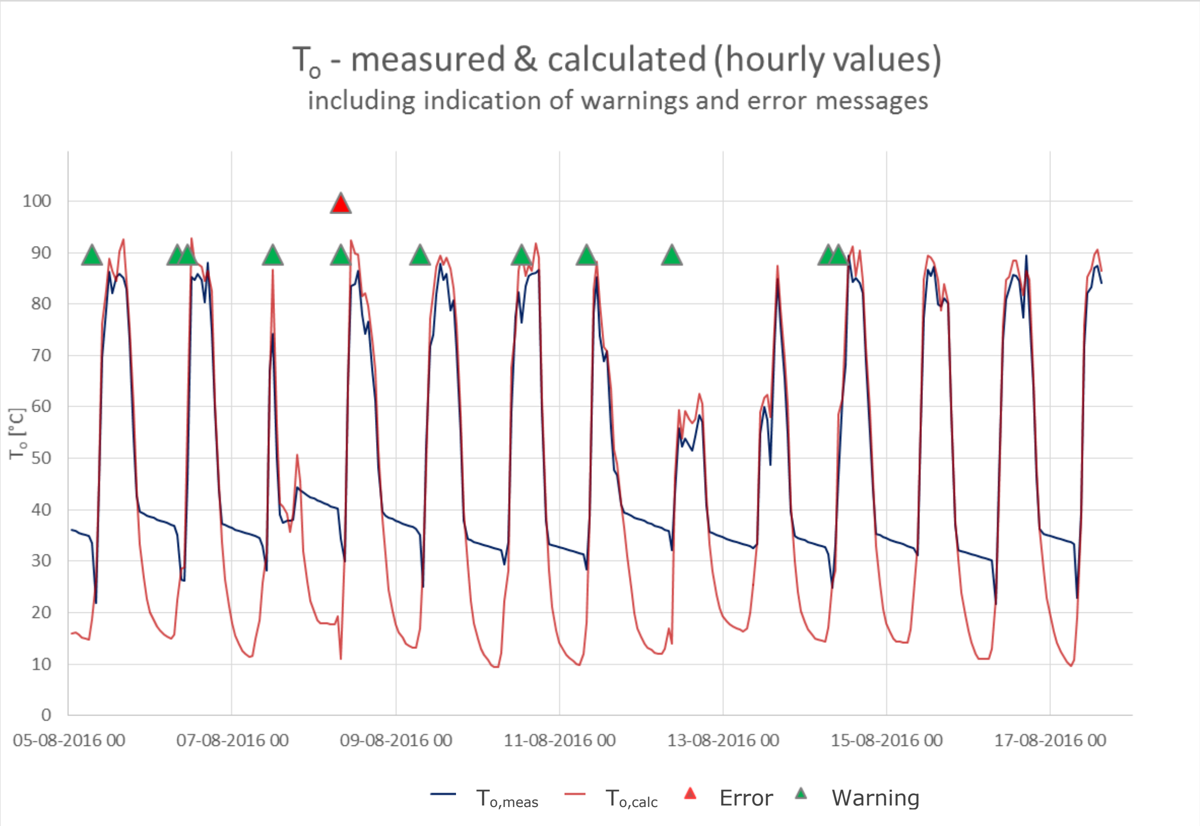


Figure 5.3.11. Example of comparison between measured and calculated outlet temperatures including indication of warnings and error messages. $\Delta T_{warning}$ = 10 K; ΔT_{error} = 20 K.

It is seen that warnings is only found at start-up. With the chosen method it is hard to calculated a correct outlet temperature during start-up. No warnings/errors are sent if the plant is not in operation. One error is seen at start-up on day 4 in the period. Here is seen a sudden dip in the calculated outlet temperature.

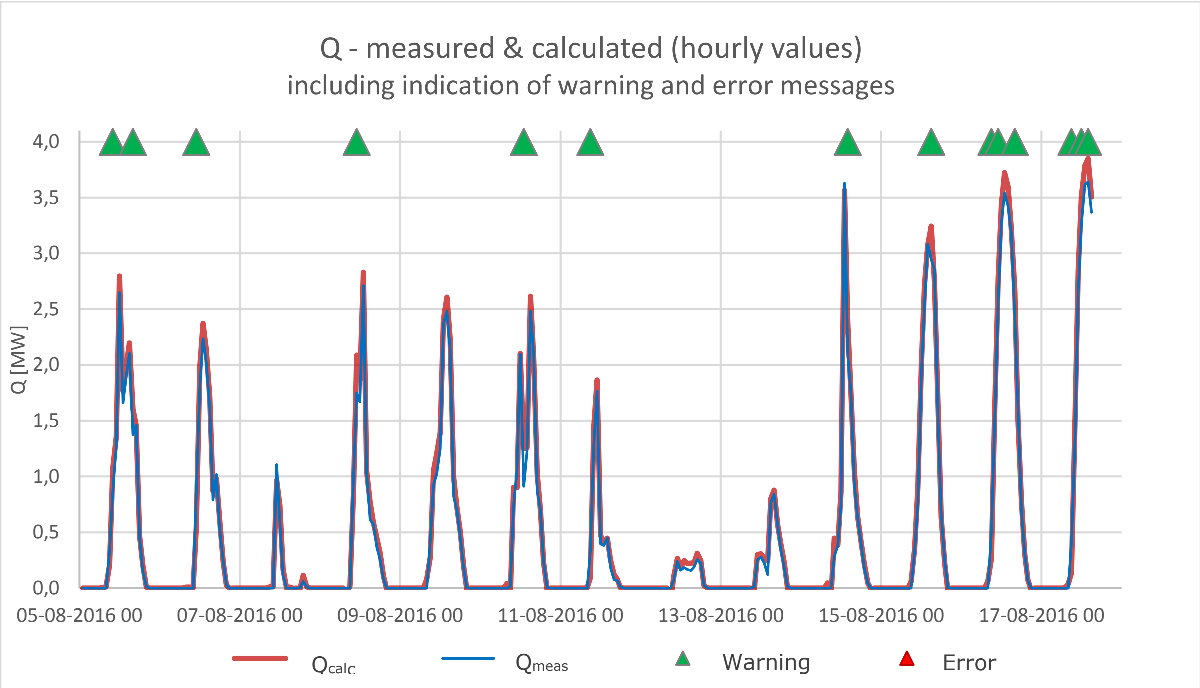


Figure 5.3.12. Example of comparison between measured and calculated energy yields including indication of warnings and error messages. $\Delta Q_{warning}$ = 5 % of Q_{nom}; ΔQ_{error} = 10 % of Q_{nom} (at Q_{nom} set to 4 MW).

There are no error messages if ΔQ_{error} is set to 10 % of Q_{nom} – all hourly values is therefore within +/- 10 % of the chosen Q_{nom}.

5.3.4 Control of liquid and corrosion

In order to control a tube on the outlet side of the system will be taken out for analyse yearly for the next five years. On 29.08.2016 one tube was taken out for inspection. The tube was sent to Sapa Precision Tubing Technology Centre (SPTTC) for Characterisation where the following conclusions were made:

- Macro and microstructural characterisation of the HyLife™ Solar tube when split longitudinally showed that after one year of exposure, a yellowish inhibitor coating or layer, approximately 5-14 µm thick but up to 70 µm at the most at the outlet, had formed.
- The amount of corrosion is in line with what has been observed in the accelerated corrosion testing.
- Any further corrosion is expected only to develop at a very low rate.
- If the corrosion should continue at the same rate, it would mean that after 10 years max corrosion depth would be ~60 µm, which is not considered to be significant at all.

Liquid test is performed by Løgumkloster Fjernvarme.

5.4 Project management

5.4.1 Dissemination of results

Løgumkloster: Presentation in "Fjernvarmen", Dansk Fjernvarmes ERFA group, newspapers, TV, visits

PlanEnergi: Presentation of real time measuring for Dansk Fjernvarmes ERFA group September 2016. Presentation at ISES Webinar "Think big - Design rules and monitoring results of solar district heating systems", December 2016: "Monitoring and simulation of large solar district heating fields: An example from Denmark"[10].

DTU: Results from the project will be used by teaching students inclusive Ph.D. students how to measure thermal performance of solar collector fields and how to check that the thermal performance is acceptable.

Savo-Solar: The results will be used in marketing materials and presentations to the international DH community, to further grow the interest in the MPE absorber technology and solar district heating in general.

5.4.2 Design manual for large aluminium based collector fields

Based on the experience and knowledge gained from the large aluminum based collector field at Løgumkloster Fjernvarme, only minor changes had to be considered during the design of the system. In regards to the construction of the system, a list of approved materials and components such as the type of heat transferring fluid, filter mesh sizes and the piping material has to be provided by the supplier of the collectors.

[10] solarthermalworld.org/content/recording-webinar-think-big-design-rules-and-monitoring-results-solar-district-heating

6. Utilization of project results

Since the delivery of Løgumkloster, Savo-Solar has marketed its collector fields with MPE absorber technology in several countries and received notable interest. Several potential customers have visited the Løgumkloster site to learn more about the project, MPE absorber technology, and solar district heating in general. Due to other markets not yes being as developed for solar district heating as Denmark, the biggest recognition of the MPE collectors' competition feasibility is the fact that an additional three Danish district heating plants are now also using collectors with this technology from Savo-Solar. These plants are Jelling, Søllested and Jyderup, and all three projects were won in commercial tender processes and in competition against suppliers of collector fields with traditional absorber technology.

7. Project conclusion and perspective

The result of the project is that

- A solar collector with aluminium MPE absorber has been developed, optimised, demonstrated in full scale and measured during the project.
- The performance is as expected, and the product is in production and implemented at until now further 3 district heating utilities.
- A real time performance check system is developed and tested.

Thus the objectives of the project has been reached. The perspective for SAPA and for Savo-Solar is to get a part of the world market for solar district heating. This market is expanding and the product seem to be competitive since it can offer a solution that can compete on feasibility and at the same time avoid use of the limited resource copper.

References

[1] IEA SHC task 38 – Solar Air Conditioning and Refrigeration, "Monitoring Procedure for Solar Cooling Systems", www.iea-shc.org/task38, 2011.
[2] "Procedure for check af ydelsesgaranti for solfangerfelter" v.13, JE Nielsen, 1/3 2016.
[3] "FJERNSOL PRO", Version 2.0, Simpel beregning af solfangerfelter - vurdering af tilbud, PlanEnergi, 2014.

Annexes

Annex overview:

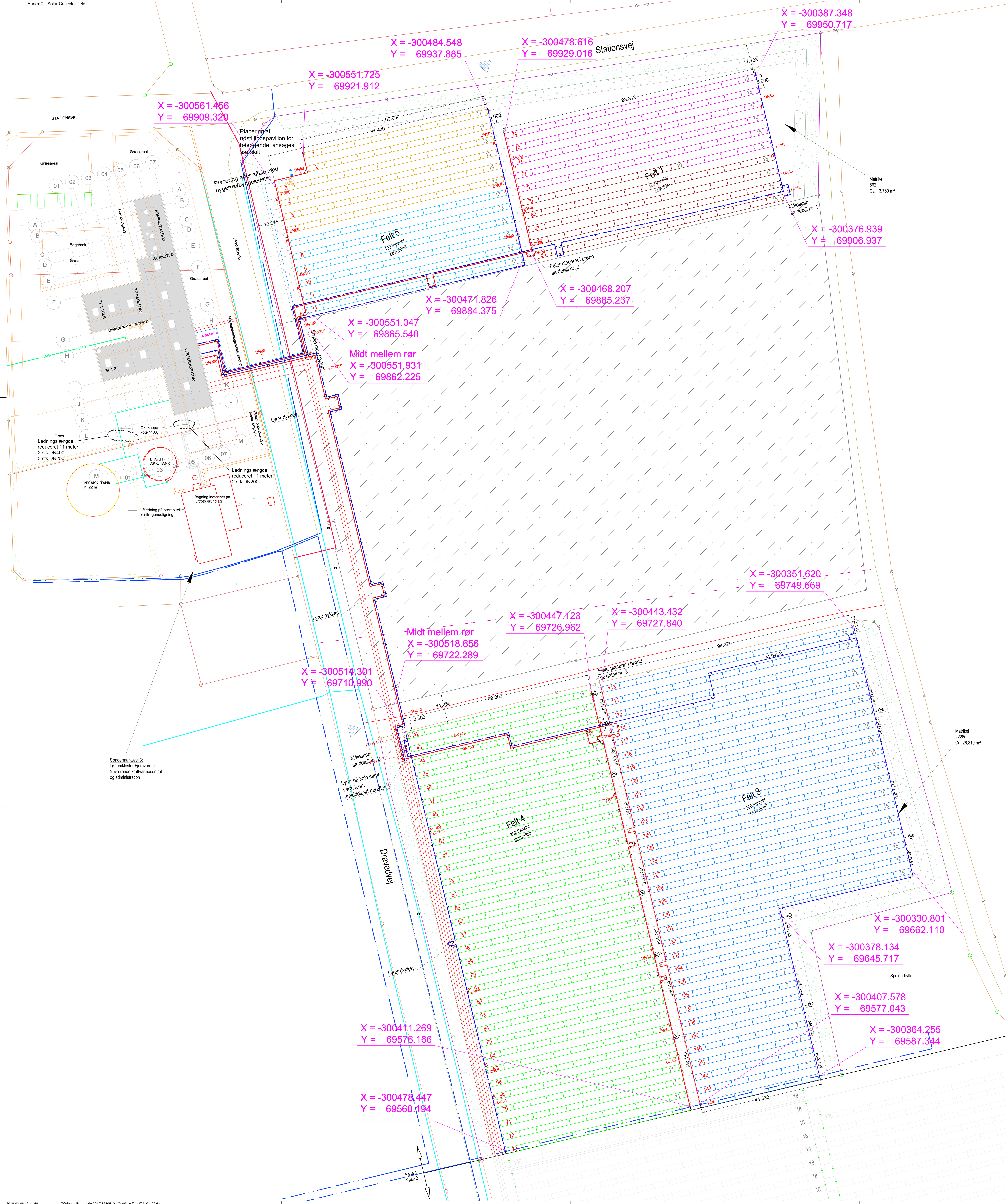
- Annex 1 – Design parameters
- Annex 2 – Solar collector field
- Annex 3 – P&I diagram
- Annex 4 – List of components
- Annex 5 – Operation strategy
- Annex 6 – Brochure Savo-Solar
- Annex 7 – PI diagram for part 1 and part 2 of the solar collector field
- Annex 8 – Data sheets of solar radiation sensors
- Annex 9 – Nomenclature
- Annex 10 – Solar Keymark test certificate of the Savosolar MPE collector
- Annex 11 – Collector fluid properties
- Annex 12 – Lookup table for radiation correction factors

Annex 1 – Design Parameters

Brand name: SF500-08				
Dimensions:				
Length			6.158	m
Width			0.213	m
Height			2.591	m
Aperture area			14.83	m^2
Gross area			15.89	m^2
Coefficient based on aperture area:				
η_0			0.872	-
a_1			2.019	$W/m^2\ K$
a_2			0.028	$W/m^2\ K^2$
IAM(50°) incidence angle modifier at 50°			No answer	-
Pressure drop, 1 collector excl. connection hose	36	kPa at	5.0	m^3/h
Pressure drop, 1 collector incl. connection hose	-	kPa at	-	m^3/h
Max. operating pressure			10.0	bar
Test pressure				bar
Fluid content, 1 collector incl. connection hose			26.5	litre
Max flow			-	m^3/h
Min. flow			-	m^3/h
Max flow temperature			-	° C
Stagnation temperature			194	° C

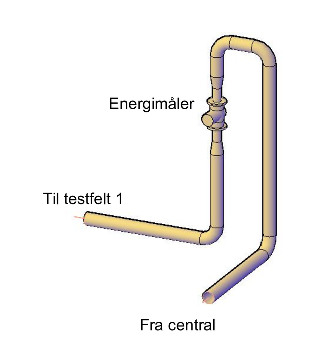
Materials in solar collector circuit - common

Component	Placement	Material	Approved or alternative
Balancing valve	Collector row entrance, cold side	A-Metal (TA speciallegering)	
Three way ball valve	Collector row exit, hot side	Stainless steel	
Pipes	-	Steel	
Valves	Heating plant	EPDM + stainless steel	
Pumps	Heating plant	Cast iron	
Safety valve	Heating plant	Cast iron	
Strainer	Heating plant	Cast iron	
Flowmeter	Heating plant	EPDM	
Heat exchanger	Heating plant	Stainless steel	

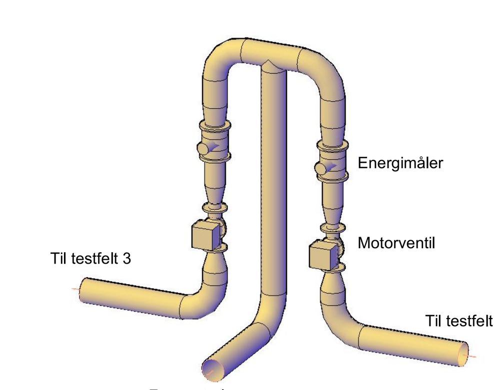


PANELOVERSIGT			Projekterede værdier				
Række	Panel	Effekt	Nominelt flow	Ventil type	Pro. Ventil DN	Beregnet tryktab	Beregnet indstilling
nr.	antal	Watt	l/h		mm	kPa	
1	MPE 11	123.965	2.823	STAD	20	299	1,8
2	MPE 11	123.965	2.823	STAD	20	300	1,8
3	MPE 13	146.504	3.337	STAD	25	225	1,5
4	MPE 13	146.504	3.337	STAD	25	227	1,5
5	MPE 13	146.504	3.337	STAD	25	228	1,5
6	MPE 13	146.504	3.337	STAD	25	230	1,5
7	MPE 13	146.504	3.337	STAD	25	232	1,5
8	MPE 13	146.504	3.337	STAD	25	234	1,5
9	MPE 13	146.504	3.337	STAD	25	236	1,5
10	MPE 13	146.504	3.337	STAD	25	238	1,5
11	MPE 13	146.504	3.337	STAD	25	241	1,5
12	MPE 13	146.504	3.337	STAD	25	242	1,5
42	MPE 11	123.965	2.823	STAD	20	250	1,9
43	MPE 11	123.965	2.823	STAD	20	250	1,8
44	MPE 11	123.965	2.823	STAD	20	252	1,8
45	MPE 11	123.965	2.823	STAD	20	255	1,8
46	MPE 11	123.965	2.823	STAD	20	255	1,8
47	MPE 11	123.965	2.823	STAD	20	253	1,8
48	MPE 11	123.965	2.823	STAD	20	252	1,8
49	MPE 11	123.965	2.823	STAD	20	249	1,9
50	MPE 11	123.965	2.823	STAD	20	246	1,9
51	MPE 11	123.965	2.823	STAD	20	243	1,9
52	MPE 11	123.965	2.823	STAD	20	240	1,9
53	MPE 11	123.965	2.823	STAD	20	238	1,9
54	MPE 11	123.965	2.823	STAD	20	233	1,9
55	MPE 11	123.965	2.823	STAD	20	231	1,9
56	MPE 11	123.965	2.823	STAD	20	229	1,9
57	MPE 11	123.965	2.823	STAD	20	227	1,9
58	MPE 11	123.965	2.823	STAD	20	224	1,9
59	MPE 11	123.965	2.823	STAD	20	223	1,9
60	MPE 11	123.965	2.823	STAD	20	222	1,9
61	MPE 11	123.965	2.823	STAD	20	219	1,9
62	MPE 11	123.965	2.823	STAD	20	216	1,9
63	MPE 11	123.965	2.823	STAD	20	211	2,0
64	MPE 11	123.965	2.823	STAD	20	208	2,0
65	MPE 11	123.965	2.823	STAD	20	207	2,0
66	MPE 11	123.965	2.823	STAD	20	205	2,0
67	MPE 11	123.965	2.823	STAD	20	203	2,0
68	MPE 11	123.965	2.823	STAD	20	201	2,0
69	MPE 11	123.965	2.823	STAD	20	198	2,0
70	MPE 11	123.965	2.823	STAD	20	195	2,0
71	MPE 11	123.965	2.823	STAD	20	192	2,0
72	MPE 11	123.965	2.823	STAD	20	191	2,0
73	MPE 11	123.965	2.823	STAD	20	191	2,0
113	MPE2 15	152.996	3.485	STAD	32	43	2,2
114	MPE2 15	152.996	3.485	STAD	32	42	2,2
115	MPE2 15	152.996	3.485	STAD	32	40	2,2
116	MPE2 15	152.996	3.485	STAD	32	39	2,2
117	MPE2 15	152.996	3.485	STAD	32	37	2,3
118	MPE2 15	152.996	3.485	STAD	32	35	2,3
119	MPE2 15	152.996	3.485	STAD	32	34	2,3
120	MPE2 15	152.996	3.485	STAD	32	31	2,4
121	MPE2 15	152.996	3.485	STAD	32	28	2,5
122	MPE2 15	152.996	3.485	STAD	32	25	2,5
123	MPE2 15	152.996	3.485	STAD	32	22	2,6
124	MPE2 15	152.996	3.485	STAD	32	20	2,7
125	MPE2 15	152.996	3.485	STAD	32	18	2,8
126	MPE2 15	152.996	3.485	STAD	32	17	2,8
127	MPE2 15	152.996	3.485	STAD	32	15	2,9
128	MPE2 15	152.996	3.485	STAD	32	14	3,0
129	MPE2 15	152.996	3.485	STAD	32	11	3,3
130	MPE2 15	152.996	3.485	STAD	32	8	3,6
131	MPE2 15	152.996	3.485	STAD	32	6	4,0
132	MPE2 07	71.398	1.626	STAD	20	280	1,3
133	MPE2 07	71.398	1.626	STAD	20	277	1,3
134	MPE2 07	71.398	1.626	STAD	20	274	1,3
135	MPE2 07	71.398	1.626	STAD	20	272	1,3
136	MPE2 07	71.398	1.626	STAD	20	270	1,3
137	MPE2 07	71.398	1.626	STAD	20	269	1,3
138	MPE2 07	71.398	1.626	STAD	20	268	1,3
139	MPE2 07	71.398	1.626	STAD	20	265	1,3
140	MPE2 07	71.398	1.626	STAD	20	263	1,3
141	MPE2 07	71.398	1.626	STAD	20	261	1,3
142	MPE2 07	71.398	1.626	STAD	20	260	1,3
143	MPE2 07	71.398	1.626	STAD	20	260	1,3
144	MPE2 07	71.398	1.626	STAD	20	260	1,3
			216.704				

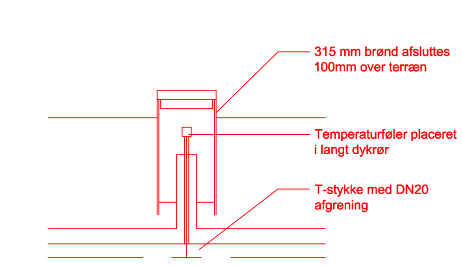
PANELOVERSIGT			Projekterede værdier				
Række	Panel	Effekt	Nominelt flow	Ventil type	Pro. Ventil DN	Beregnet tryktab	Beregnet indstilling
nr.	antal	Watt	l/h		mm	kPa	
74	ALM 15	149.000	3.394	STAD	32	6	4,0
75	ALM 15	149.000	3.394	STAD	32	6	3,9
76	ALM 15	149.000	3.394	STAD	32	8	3,6
77	ALM 15	149.000	3.394	STAD	32	11	3,2
78	ALM 15	149.000	3.394	STAD	32	12	3,1
79	ALM 15	149.000	3.394	STAD	32	15	2,9
80	ALM 15	149.000	3.394	STAD	32	18	2,7
81	ALM 15	149.000	3.394	STAD	32	20	2,6
82	ALM 15	149.000	3.394	STAD	32	23	2,5
83	ALM 15	149.000	3.394	STAD	32	24	2,5
			33.935				



Detail nr. 1



Detail nr. 2



Detail nr. 3

Snit i brønd med temperaturføler

NOTE:

Opstandere er DN32 og føres 300mm over terræn.
Ekspansionskappe omkring opstandere Ø300mm føres 200mm over terræn.
Opstandere afsluttes med R 1¼" gevind, ISO 7/1.
Uisoleret rørstykke og gevind skal være rustfri AISI 316.
Enden af opstandere afsluttes med endcap.

Ved bagerste række afsluttes ledningen i jord med T-stykke og afspærringsventil, så jordledninger kan gennemskylles uden om opstandere ved cirkulation af solvarmevæske gennem bypass ved bagerste række.

Enden af opføringsrør afsluttes med endcap. Omkring opføringsrøret monteres løs PE-kappe, ført helt ned til hovedrøret for sikring af ekspansion. Prærøret centreres i kappe med afstandsholder før jorddækning. Efter reetablering af terræn fjernes afstandsholder for at sikre fri ekspansion.

SIGNATURER: VX.1.02 11

- Fjernvarme frem
- Fjernvarme retur
- Eksisterende fjernvarme frem
- Eksisterende fjernvarme retur
- Drikkevand
- Gas
- Eksisterende gas
- Brugsvand koldt
- Nitrogen
- Rør demonteres
- Afpropning af rør
- Ventil for gennemskylning
- Solpanel
- Plantebælte
- Kørevej
- Midlertidig vejadgang

Rev.	Dato	Konst./Tegn.	Kontrol.	Godk.	
11	2016-03-08	BKL/MOLH	-	BKL	Rørføring fra Isoplus + Skema opdateret
10	2015-09-30	BKL/AB	-	BKL	Felt 3 - panelafstd ændret fra 40 til 80 mm
09	2015-06-29	BKL/MOLH	-	BKL	Felt 3 påført + Paneloversigt rettet
08	2014-12-01	BKL/AB	-	BKL	Koordinater rør, panel og rk. nr. påført
07	2014-10-30	BKL/MOLH	-	BKL	Koordinater og pæle påført
06	2014-09-12	BKL/MOLH	-	BKL	Mål påført + Ventiler for gennemskylning
05	2014-09-08	BKL/MOLH	-	BKL	Revideret layout
04	2014-08-12	BKL/MOLH	-	BKL	Ændring af rørføring
03	2014-07-04	BKL/MOLH	-	BKL	Revideret layout
02	2014-02-19	BKL/HKU	-	BKL	Vandstik flyttet
01	2013-10-24	BKL/AB	-	BKL	Bygning flyttet 11 meter, se tillige skyer
	2013-06-28	BKL/AB	CHTL	BKL	

Projektnr. 12495101 Mål 1:500

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Løgumkloster Fjernvarme
Ny varmecentral og solvarme

VVS-installationer i terræn og solvarme - Etape 1
Situationsplan

Tegning nr. VX.1.02 Rev. 11

molh

NOTE:

Der skal monteres udluftninger i alle toppunkter.
Der skal monteres aftap i alle bundpunkter og på begge sider af afspærringer, således at alle dele af installationer kan tappes af fornuftigt.

Alt der ikke er indrammet til entrepriser er
Entreprise D: Maskininstallation (etape1) og
Entreprise H: El og SRO if. komponentliste.

FK: xx m³/h = Fuldboret kuglehane: Dimensionerende flow

SIGNATURER:

- Varme frem
- Varme retur
- Mellem temperatur
- Glycol frem
- Glycol retur
- Hedtvand frem
- Hedtvand retur
- Kølerør frem
- Kølerør retur
- Luftindtag
- Afkast
- Eksisterende varme frem
- Eksisterende varme retur
- Tilslutning til eksisterende rør
- Pre rør i jord
- Rør videreføres
- Afpropning af rør
- Dimensionsændring
- Flowmåler
- Aftapningsventil med prop
- Afspærrings- regulerings- eller styreventil
- Kontraventil, strømretning mod højre
- Strengreguleringsventil
- Termostatisk ventil
- 2-vejs ventil med elektrisk motor
- 2-vejs ventil med modulerende elektrisk motor
- 3-vejs ventil med modulerende elektrisk motor
- Magnetventi
- Reduktionsventil
- Solindfaldsmåler
- EG: Entreprisegrænse
- Motorspjæld, On/Off
- Ventilator (i aggregat)
- Luftfilter
- Pumpe
- Frekvensomformer, omdrejningsregulator
- Delstrømsfilter
- Snavssamler
- Automatisk luftudlader
- Sikkerhedsventil, fjederbelastet, vinkelventil
- TT Temperaturføler
- PT Trykføler
- TSH Temperatur switch high
- TSL Temperatur switch low
- PI Pressure indicator
- PS Pressure switch
- LS Level switch
- LI Niveauvisning
- O2 iltmåler
- PH PH-måler

VX.6.01 07

Rev.	Dato	Konst./Tegn.	Kontrol.	Godk.	
07	2015-09-11	BKL/AB	-	BKL	Påført flow for FK
06	2015-07-01	BKL/MOLH	-	BKL	Revisioner se skyer
05	2014-12-01	BKL/AB	-	BKL	Revisioner se skyer
04	2014-09-18	BKL/MOLH	-	BKL	Revisioner se skyer
03	2014-09-08	BKL/MOLH	-	BKL	Revision ved solfelter
	2013-06-28	BKL/MOLH	CHTL	BKL	

Projektnr. 12495101 Mål -

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Løgumkloster Fjernvarme
Ny varmecentral og solvarme

VVS-installationer
PI-diagram

Tegning nr. VX.6.01 Rev. 07

AB

Løgumkloster Fjernvarme - Solar Thermal Plant	Case no. Diagram Drawing No. Date	12495101 VX-6-01-03 28-06-2013	Created by Control Rev. date / init.	BKL BEM 2014-09-08/BKL	RAMBØLL

Component Overview

Solar Stage 2 Primary Circuit - medium: 30 % propylenglykol, min. PN 10, max. temp. 110° C									
TAG no.	**Component**	**Amount**	**Description and Function**	**Dimension**	**Specification**	**Delivery**	**Mounting**	**Installation**	**Operation**
101	Kugleventil	6	Afspærring	DN 300	Med svejsestudse, gear og spindelforlænger.	D	D		D
102	Kuglehane	6	Afspærring bypass arrangement	DN 50	Med langt håndtag	D	D		D
102-1	Kugleventil	4	Afspærring	DN 65	Med langt håndtag	D	D		D
103	Butterflyventil	2	Afspærring ved pumpe	DN 300	Med gear og spindelforlænger.	D	D		D
104	Kuglehane	2	Afspærring manometer	DN 25		D	D		D
105	Butterflyventil	1	Afspærring ved veksler	DN 250	Med gear og spindelforlænger.	D	D		D
106	Butterfly motorventil	1	Bypass af vekslere (frostsikring)	DN 150	Med aktuator, 2 endestop.	H	D	H	H
107-1	Butterfly motorventil (modulerende)	1	Fordeling mellem vekslere	DN 100 kvs 690 m3/h	Med aktuator, 2 endestop, 4-20 mA stillingsindikering.	H	D	H	H
108	Kontraventil	1		DN 300	Sandwich-type med fjeder.	D	D		D
109	Kuglehane	2	Aftapningsventil		Med slangestuds	D	D		D
110	Flowmåler	1	Flowmåling	DN 250	Med transmitter, 30-1095 m3/h.	H	D	H	H
120-1	Pumpe	1	Cirkulationspumpe	DN 300/250 200 kW	Normpumpe med motor på ramme iht. EN 733. End-suction long coupled. 757 m3/h, 60 mVs, egnet for glykol η pumpe: min. 80 %, η motor: min. 95 %	D	D	H	H
125-1	Frekvensomformer	1	Regulering af cirkulationspumpe	200 kW	Effektivitet ved fuld last min. 98 %.	H	H	H	H
130	Snavssamler	1	Grov filtrering	DN 300	Maskestørrelse 1,6 mm	D	D		D
131	Delstrømsfilter	1	Fin filtrering		Posetrykfilter på ramme som bypassarrangement	D	D	H	D
140	Temperaturtransmitter	3	Temperaturer i primær kreds		PT100 med følerlomme.	H	H	H	H
141	Temperature switch high	1	Sikkerhedstermostat	70-150°	Med max. reset.	H	H	H	H
160	Sikkerhedsventil	1	Primær sikkerhedsventil	4,0 MW	Damp, åbningstryk 4,5 bar	D	D		D
161	Sikkerhedsventil	1	Sikkerhedsventil	0,5 MW	Damp, åbningstryk 4 bar	D	D		D
162	Sikkerhedsventil	1	Sikring af veksler ved afspærring		Åbningstryk 10 bar	D	D		D
170	Tryktransmitter	3	Tryk i primær kreds	0-10 bar	Inkl. afspærringsventiler og afgrening med kobling for ekstern måling.	H	H	H	H
171	Manometer	1	Differenstryk over snavssamler	0-10 bar	Klasse 1, inkl. afspærringsventiler.	D	D		D
175	Pyranometer	2	Solindfaldsmålere for regulering	0-1200 W/m2	Som fabrikat Soldata type SPC80	H	H	H	H
180	Ekspansionsbeholder	2	Ekspansion af glykolkreds	5000 L	Hydrofor tryktank med nitrogenpude. Fortryk 0,5 bar	D	D		D
190	Automatisk luftuflader	1	Udluftning	DN40	Inkl. afspærringsventil.	D	D		D
191	Mikrobobleaflufter	1	Udluftning	DN50	Bypassarrangement med trykreduktion før og trykforøgning efter til 1,5 bar.	D	D	H	D
199	PH-måler	1	PH overvågning af solvarmevæske	PH 0-14		H	H	H	H
Solar Stage 2 - Filling Circuit - medium: 30 % propylenglykol, min. PN 10, max. temp. 110° C									

TAG no.	Component	Amount	Description and Function	Dimension	Specification	Delivery	Mounting	Installation	Operation
301	Kugleventil	3	Afspærring	DN 80	Med langt håndtag	D	D		D
302	Kugleventil	1	Afspærring	DN 200	Med langt håndtag	D	D		D
308	Kontraventil	1		DN 80		D	D		D
309	Kuglehane	1	Aftapningsventil		Med slangestuds	D	D		D
320	Pumpe	1	Påfyldningspumpe	DN 50 2,2 kW	Trykpumpe egnet for glykol. In-line. 10 m3/h, 20 mVs, NPSH maks. 1,0 mVs	D	D	H	H
330	Snavssamler	1	Grov filtrering	DN 80	Maskestørrelse 1,25 mm	D	D		D
371	Manometer	1	Driftstryk foran pumpe	0-10 bar	Klasse 1, inkl. afspærringsventiler.	D	D		D
380	Opsamlingstank	1	Lager for solvarmevæske	50 m3 Ø2,9m	Enkeltvægget konsol ståltank. Se i øvrigt arbejdsbeskrivelse.	D	D		D
385	Niveaumåler	1	Mængdemåling af solvarmevæske		Hydrostatisk måler	H	D	H	H
Solar Stage 2 Secondary Circuit - medium: Water, min. PN 6, max. temp. 110° C									
TAG no.	**Component**	**Amount**	**Description and Function**	**Dimension**	**Specification**	**Delivery**	**Mounting**	**Installation**	**Operation**
403	Butterflyventil	3	Afspærring ved pumpe	DN 250	Med gear og spindelforlænger.	D	D		D
406	Butterfly motorventil	5	Temperaturfordeling, frostsikring og natkøling.	DN 250	Med aktuator, 2 endestop.	H	D	H	H
409	Kuglehane	2	Aftapningsventil		Med slangestuds	D	D		D
410	Flowmåler	1	Flow og energimåling	DN 200	Med transmitter. Energi beregnes i PLC.	H	D	H	H
420	Pumpe	1	Cirkulationspumpe	DN 250/200 22 kW	Normpumpe med motor på ramme iht. EN 733. End-suction long coupled. 394 m3/h, 11 mVs η pumpe: min. 83 %, η motor: min. 90 %	D	D	H	H
425	Frekvensomformer	1	Regulering af cirkulationspumpe	22 kW	Effektivitet ved fuld last min. 98 %.	H	H	H	H
440	Temperaturtransmitter	2	Temperaturer i sekundær kreds		PT100 med følerlomme.	H	H	H	H
450	Varmeveksler	1	Boltet varmeveksler sol/fjv.	18 MW DN 250	AISI 316 plademateriale, inkl. isoleringskappe. Hot side 83,5°/43,5° (30% propylenglykol) Cold side 80,0°/40,0° (fjernvarmevand) Maks. tryktab 0,5 bar. BxHxL ca. = 1,0 m x 3,5 m x 3,3 m	D	D		D
460	Sikkerhedsventil	1	Sikring af veksler ved afspærring		Åbningstryk 6 bar	D	D		D
470	Tryktransmitter	3	Tryk i sekundær kreds	0-10 bar	Inkl. afspærringsventiler og afgrening med kobling for ekstern måling.	H	H	H	H
District Heating Circuit - medium: Water, min. PN 6, max. temp. 110° C									
TAG no.	**Component**	**Amount**	**Description and Function**	**Dimension**	**Specification**	**Delivery**	**Mounting**	**Installation**	**Operation**
601-1	Kugleventil	2	Afspærring	DN 400	Med svejsestudse, gear og spindelforlænger.	D	D		D
601-1	Kugleventil	1	Afspærring	DN 400	Med svejsestudse, gear og spindelforlænger.	E	E		E
601-2	Kugleventil	5	Afspærring	DN 250	Med svejsestudse, gear og spindelforlænger.	D	D		D
601-3	Kugleventil	4	Afspærring	DN 200	Med svejsestudse, gear og spindelforlænger.	D	D		D
602	Kugleventil	1	Afspærring	DN 80	Med svejsestudse og spindelforlænger.	D	D		D
603	Butterflyventil	9	Afspærring ved pumpe	DN 200	Med gear og spindelforlænger.	D	D		D
604	Butterflyventil	2	Afspærring ved pumpe	DN 150	Med gear og spindelforlænger.	D	D		D
605-1	Butterfly motorventil (modulerende)	1	Fordeling shunt	DN 80 kvs 491 m3/h	Med aktuator, 2 endestop, 4-20 mA stillingsindikering.	H	D	H	H
605-2	Butterfly motorventil (modulerende)	1	Fordeling shunt	DN 80 kvs 491 m3/h	Med aktuator, 2 endestop, 4-20 mA stillingsindikering.	H	D	H	H

605-3	Butterfly motorventil	1	Returpumper bypass	DN 200	Med aktuator, 2 endestop.	H	D	H	H
606-1	Butterfly motorventil	1	Retur indkobling	DN 200	Med aktuator, 2 endestop.	H	D	H	H
606-2	Butterfly motorventil	1	Retur indkobling	DN 200	Med aktuator, 2 endestop.	H	D	H	H
606-3	Butterfly motorventil	1	Retur indkobling	DN 250	Med aktuator, 2 endestop.	H	D	H	H
606-4	Butterfly motorventil	1	Mellemtemperatur indkobling	DN 250	Med aktuator, 2 endestop.	H	D	H	H
606-5	Butterfly motorventil	1	Mellemtemperatur indkobling	DN 250	Med aktuator, 2 endestop.	H	D	H	H
607	Butterfly motorventil	1	Akkumuleringstanke serieforbindelse	DN 400	Med aktuator, 2 endestop.	H	D	H	H
608-1	Kontraventil	3		DN 200	Sandwich-type med fjeder.	D	D		D
608-2	Kontraventil	1		DN 150	Sandwich-type med fjeder.	D	D		D
609	Kuglehane	10	Aftapningsventil		Med slangestuds. De på diagrammet ikke viste placeres efter god skik for god udluftning eller efter aftale med	D	D		D
610	Flowmåler	1	Flow og energimåling fjernvarme	DN 200	Med transmitter og regneenhed inkl. temperatur følere. 40-272 m3/h.	H	D	H	H
611	Flowmåler	1	Flow og energimåling shunt	DN 200	Med transmitter. Energi beregnes i PLC. 40-217 m3/h.	H	D	H	H
615	Kugleventil	6	Afspærring afgrening for fancoil	DN 50	Med svejsestudse og spindelforlænger.	D	D		D
620	Pumpe	2	Cirkulationspumpe Fremløb netpumpe	DN 125/100 45 kW	Normpumpe med motor på ramme iht. EN 733. End-suction long coupled. 272 m3/h, 40 mVs η pumpe: min. 83 %, η motor: min. 92 %	D	D	H	H
621	Pumpe	1	Cirkulationspumpe Netshunt	DN 150/125 7,5 kW	Normpumpe med motor iht. EN 733. End-suction close coupled. 209 m3/h, 7 mVs η pumpe: min. 79 %, η motor: min. 88 %	D	D	H	H
622	Pumpe	2	Cirkulationspumpe Retur netpumpe	DN 150/125 18,5 kW	Normpumpe med motor på ramme iht. EN 733. End-suction long coupled. 272 m3/h, 15 mVs η pumpe: min. 84 %, η motor: min. 89 %	D	D	H	H
623	Pumpe	1	Cirkulationspumpe Fremløb netpumpe Sommerpumpe	DN 80/65 11 kW	Normpumpe med motor iht. EN 733. End-suction close coupled. 87 m3/h, 20 mVs η pumpe: min. 86 %, η motor: min. 90 %	D	D	H	H
625	Frekvensomformer	2	Regulering af cirkulationspumper 620	45 kW	Effektivitet ved fuld last min. 98 %.	H	H	H	H
626	Frekvensomformer	1	Regulering af cirkulationspumpe 621	7,5 kW	Effektivitet ved fuld last min. 98 %.	H	H	H	H
627	Frekvensomformer	2	Regulering af cirkulationspumper 622	18,5 kW	Effektivitet ved fuld last min. 98 %.	H	H	H	H
628	Frekvensomformer	1	Regulering af cirkulationspumpe 623	11 kW	Effektivitet ved fuld last min. 98 %.	H	H	H	H
630	Snavssamler	1	Grov filtrering	DN 200	Maskestørrelse 1,6 mm	D	D		D
640	Temperaturtransmitter	2	Temperaturer i fjernvarmekreds		PT100 med følerlomme.	H	H	H	H
641	Temperaturtransmitter	3	Temperaturer i netshunt		PT100 med følerlomme.	H	H	H	H
645	Temperaturtransmitter	20	Temperaturer i akkumuleringstank		PT100 med følerlomme.	E	E	E/H	H
660	Overtryks og vakuumventiler	1	Tryksikring af akkumuleringstank		Iht. arbejdsbeskrivelse.	E	E	E	E
670	Tryktransmitter	9	Tryk i fjernvarmekreds	0-10 bar	Inkl. afspærringsventiler og afgrening med kobling for ekstern måling.	H	H	H	H
671	Manometer	1	Differenstryk over snavssamler	0-10 bar	Klasse 1, inkl. afspærringsventiler.	D	D		D

675	Tryktransmitter	1	Tryk i nitrogenpude akkumuleringstank			E	E	E	H
690	Automatisk luftuflader	10	Udluftning	DN40	Inkl. afspærringsventil. De på diagrammet ikke viste placeres efter god skik for god udluftning eller efter aftale med tilsynet.	D	D		D
691	Niveaumåler	1	Vandstand akkumuleringstank		Iht. arbejdsbeskrivelse.	E	E	E/H	H
692	Niveaumåler	1	Alarm overløb		Iht. arbejdsbeskrivelse.	E	E	E/H	H
Solar Stage 1 Primary Circuit - medium: 30 % propylenglykol, min. PN 10, max. temp. 110° C									
TAG no.	**Component**	**Amount**	**Description and Function**	**Dimension**	**Specification**	**Delivery**	**Mounting**	**Installation**	**Operation**
2101	Kugleventil	2	Afspærring	DN 80	Med svejsestudse, gear og spindelforlænger.	D	D		D
2102	Kuglehane	8	Afspærring bypass arrangementer mv.	DN 50	Med langt håndtag	D	D		D
2103	Butterflyventil	3	Afspærring ved pumpe	DN 100	Med gear og spindelforlænger.	D	D		D
2104	Kuglehane	2	Afspærring manometer	DN 25		D	D		D
2106	Butterfly motorventil	2	Bypass af vekslere (frostsikring)	DN 80	Med aktuator, 2 endestop.	H	D	H	H
2108	Kontraventil	1		DN 50	Sandwich-type med fjeder.	D	D		D
2109	Kuglehane	4	Aftapningsventil		Med slangestuds	D	D		D
2110	Flowmåler	1	Flow og energimåling	DN 50	Med transmitter. Energi beregnes i PLC.	H	D	H	H
2120	Pumpe	1	Cirkulationspumpe	DN 65 5,5 kW	In-line pumpe med motor. 34 m3/h, 39 mVs, egnet for glykol η pumpe: min. 72 %, η motor: min. 87 %	D	D	H	H
2121	Pumpe	1	Påfyldningspumpe	DN 25/32 0,55 kW	Trykpumpe egnet for glykol. In-line. 5 m3/h, 20 mVs, NPSH maks. 1,0 mVs	D	D	H	H
2125	Frekvensomformer	1	Regulering af cirkulationspumpe	5,5 kW	Effektivitet ved fuld last min. 98 %.	H	H	H	H
2130	Snavssamler	1	Grov filtrering	DN 100	Maskestørrelse 1,2 mm	D	D		D
2131	Snavssamler	1	Grov filtrering	DN 50	Maskestørrelse 1,0 mm	D	D		D
2140	Temperaturtransmitter	4	Temperaturer i primær kreds		PT100 med følerlomme.	H	H	H	H
2141	Temperature switch high	1	Sikkerhedstermostat	70-150°	Med max. reset.	H	H	H	H
2150	Varmeveksler	1	Boltet varmeveksler sol/fjv.	1,4 MW DN 100	AISI 316 plademateriale, inkl. isoleringskappe. Hot side 83,5°/43,5° (30% propylenglykol) Cold side 80,0°/40,0° (fjernvarmevand) Maks. tryktab 0,5 bar. BxHxL ca. = 0,6 m x 2,8 m x 1,1 m	D	D		D
2160	Sikkerhedsventil	1	Primær sikkerhedsventil	1,0 MW	Damp, åbningstryk 4,5 bar	D	D		D
2161	Sikkerhedsventil	1	Sikkerhedsventil	0,3 MW	Damp, åbningstryk 4 bar	D	D		D
2162	Sikkerhedsventil	1	Sikring af veksler ved afspærring		Åbningstryk 10 bar	D	D		D
2170	Tryktransmitter	3	Tryk i primær kreds	0-10 bar	Inkl. afspærringsventiler og afgrening med kobling for ekstern måling.	H	H	H	H
2171	Manometer	2	Differenstryk over snavssamler og tryk i påfyldningskreds.	0-10 bar	Klasse 1, inkl. afspærringsventiler.	D	D		D
2180	Opsamlingstank	1	Lager for solvarmevæske	5 m3 Ø1,6m	Enkeltvægget vertikal ståltank. Se i øvrigt arbejdsbeskrivelse.	D	D		D
2181	Ekspansionsbeholder	1	Ekspansion af glykolkreds	500 L	Ekspansionsbeholder for glykol. Fortryk 0,5 bar	D	D		D
2185	Niveaumåler	1	Mængdemåling af solvarmevæske		Hydrostatisk måler	H	D	H	H
2190	Automatisk luftuflader	1	Udluftning	DN40	Inkl. afspærringsventil.	D	D		D

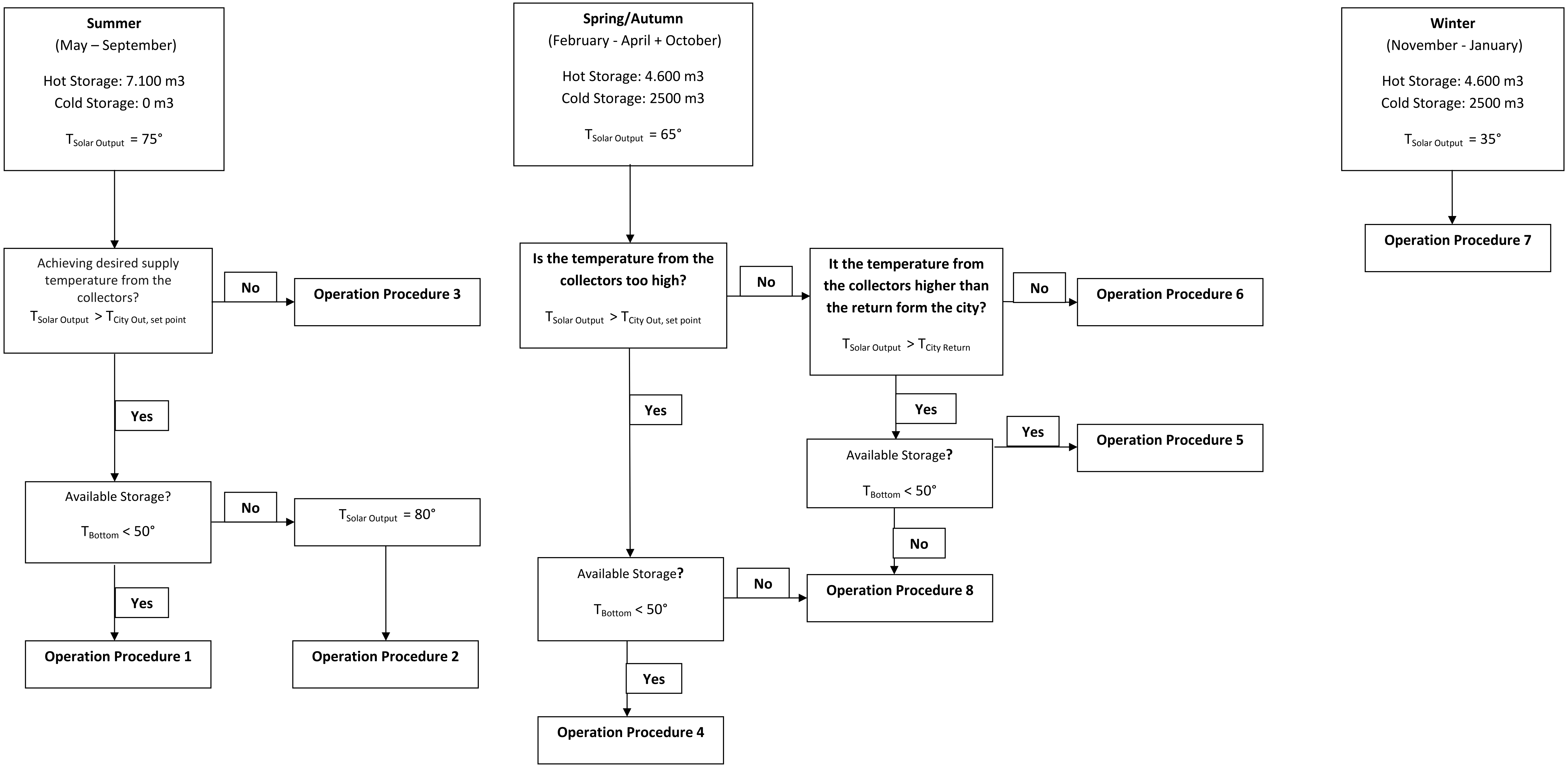
2199	PH-måler	1	PH overvågning af solvarmevæske	PH 0-14		H	H	H	H
Solar Stage 2 - Test Area 3 - medium: 30 % propylenglykol, min. PN 10, max. temp. 110° C									
TAG no.	**Component**	**Amount**	**Description and Function**	**Dimension**	**Specification**	**Delivery**	**Mounting**	**Installation**	**Operation**
2305	kugleskals motorventil (modulerende)	1	Fordeling mellem testfelter	DN 50 kvs 150 m3/h	Med aktuator, 2 endestop, 4-20 mA stillingsindikering.	H	D	H	H
2310	Flowmåler	1	Flow og energimåling	DN 125	Med transmitter. Energi beregnes i PLC.	H	D	H	H
2340	Temperaturtransmitter	2	Temperaturer i primær kreds		PT100 med følerlomme.	H	H	H	H
Solar Stage 2 - Test Area 4 - medium: 30 % propylenglykol, min. PN 10, max. temp. 110° C									
TAG no.	**Component**	**Amount**	**Description and Function**	**Dimension**	**Specification**	**Delivery**	**Mounting**	**Installation**	**Operation**
2405	kugleskals motorventil (modulerende)	1	Fordeling mellem testfelter	DN 50 kvs 150 m3/h	Med aktuator, 2 endestop, 4-20 mA stillingsindikering.	H	D	H	H
2410	Flowmåler	1	Flow og energimåling	DN 125	Med transmitter. Energi beregnes i PLC.	H	D	H	H
2440	Temperaturtransmitter	2	Temperaturer i primær kreds		PT100 med følerlomme.	H	H	H	H
Solar Stage 2 Secondary Circuit - medium: water, min. PN 6, max. temp. 110° C									
TAG no.	**Component**	**Amount**	**Description and Function**	**Dimension**	**Specification**	**Delivery**	**Mounting**	**Installation**	**Operation**
2503	Butterflyventil	3	Afspærring ved pumpe	DN 100	Med langt håndtag/spindelforlænger.	D	D		D
2506	Butterfly motorventil	5	Temperaturfordeling, frostsikring og natkøling.	DN 100	Med aktuator, 2 endestop.	H	D	H	H
2509	Kuglehane	1	Aftapningsventil		Med slangestuds	D	D		D
2510	Flowmåler	1	Flow og energimåling	DN 65	Med transmitter. Energi beregnes i PLC.	H	D	H	H
2520	Pumpe	1	Cirkulationspumpe	DN 65 1,5 kW	In-line pumpe med motor. 30 m3/h, 9 mVs η pumpe: min. 78 %, η motor: min. 80 %	D	D	H	H
2525	Frekvensomformer	1	Regulering af cirkulationspumpe	1,5 kW	Effektivitet ved fuld last min. 98 %.	H	H	H	H
2540	Temperaturtransmitter	2	Temperaturer i sekundær kreds		PT100 med følerlomme.	H	H	H	H
2560	Sikkerhedsventil	1	Sikring af veksler ved afspærring		Åbningstryk 6 bar	D	D		D
2570	Tryktransmitter	2	Tryk i sekundær kreds	0-10 bar	Inkl. afspærringsventiler og afgrening med kobling for ekstern måling.	H	H	H	H

Lev. The column specifies the contractor to supply components for the contractor that install them.
Mont. The column specifies the contractor that will mount the components in the system.
Tilslut. The column specifies the contractor that will install the electrical components
Idrifts. The column specifies the contractor that will test and operate the components
η Efficiency

Each contractor is defined by a letter refering to the contacts established during the tender process
On all modulating valves a deviations of ± 25% of the KVS-value is accepted, due to limited manufactures

Operation Strategy

Løgumkloster Fjernvarme



Savo large area collector – SF500-08

Savosolar collector with Direct Flow MPE absorber

Key features

- Direct flow MPE absorber with optimised heat transfer, compared to traditional design
- Highly effective, selective PVD MEMO absorber coating applied to the complete absorber (patent pending)
- High transmittance with antireflective solar glass
- Internally integrated connection hoses which minimise heat loss
- Glued sealings and venting elements with protective membrane to minimise condensation or dust contamination
- PED II certification according to directive 97/23/EC of the European commission and EU law

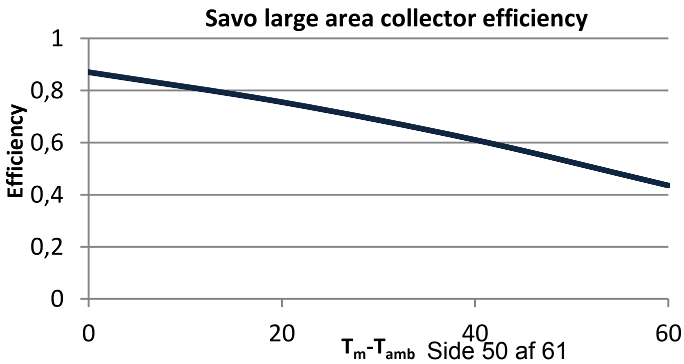
Savo large area collector

The Savo large area collector is characterised by a direct flow aluminium absorber, which is manufactured from MPE profiles. This technology is adopted from the automotive industry, where it has dominated heat exchanger designs the past 30 years, and has now been optimised for solar heating by Savosolar.

The absorber is coated with a highly selective PVD MEMO coating (patent pending) and the use of MPE profiles minimises the average distance between the coated surface and the heat transfer fluid. This leads to a uniform temperature distribution where conductive heat losses are minimised.

Just as modern cars and aircraft are assembled with glue, Savosolar assembles its collectors by gluing the galvanised steel frames, molded corner pieces and anti-reflective solar glass together. In combination with a protective membrane in the venting elements, this minimises condensation or dust contamination.

The Savo large area collector is tested according to EN 12975 by SP in Sweden.



Integrated connections

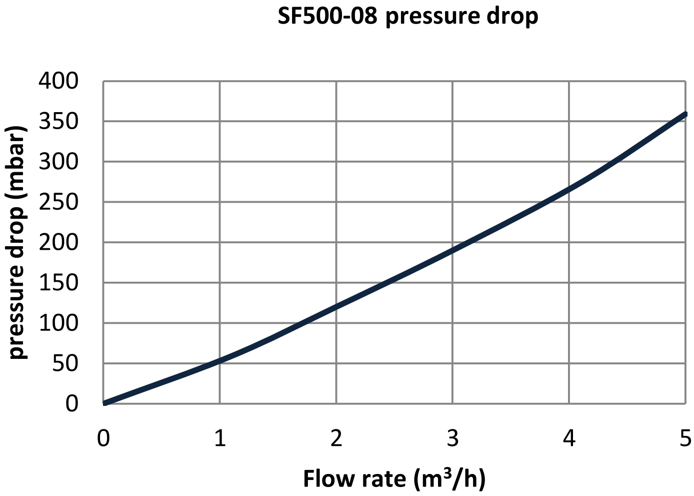
Savosolar's large area collector for district heating and industrial installations has integrated connection hoses within the collector which allows mounting with no more than 40 mm distance between collector (patent pending).

This technology reduces heat loss since the connection hoses are protected by the collector's insulation.

Technical data

Product number	SF500-08
External Dimensions	6158 x 2591 x 213 mm
Gross area	15.89 m²
Aperture area	14.83 m²
Absorber area	15.20 m²
Efficiency	η_0= 0.872 a_1= 2.019 a_2= 0.028
Stagnation temperature	194 °C
Absorber coating	3 layer selective PVD MEMO
Coating absorption	96 +/- 2 %
Coating emission	5 +/- 2%
Max. operating pressure	1000 kPa (10 bar)
Thermal insulation	100/35 mm mineral wool
Glass	Tempered solar safety antireflective glass
Solar glass transmittance	95 %
Liquid content	26.5 liters
Weight empty	443 kg
CE marking	Yes

Pressure drop



Quality

Savosolar has been ISO 9001 certified since 2013 and has also received PED II certification for the production of its large area collectors according to the European commission's directive 97/23/EC.

Savosolar is the only producer of collectors for district heating and industrial applications with PED II certification.

SAVOSOLAR

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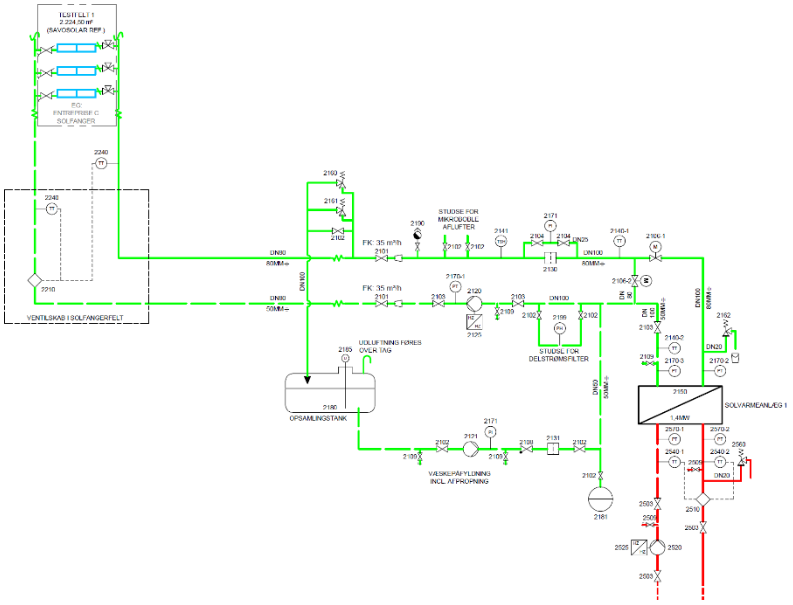
Phone: +358 (0) 10 271 0810 • info@savosolar.com • www.savosolar.com

Annex 7 – PI diagram for part 1 and part 2 of the solar collector field

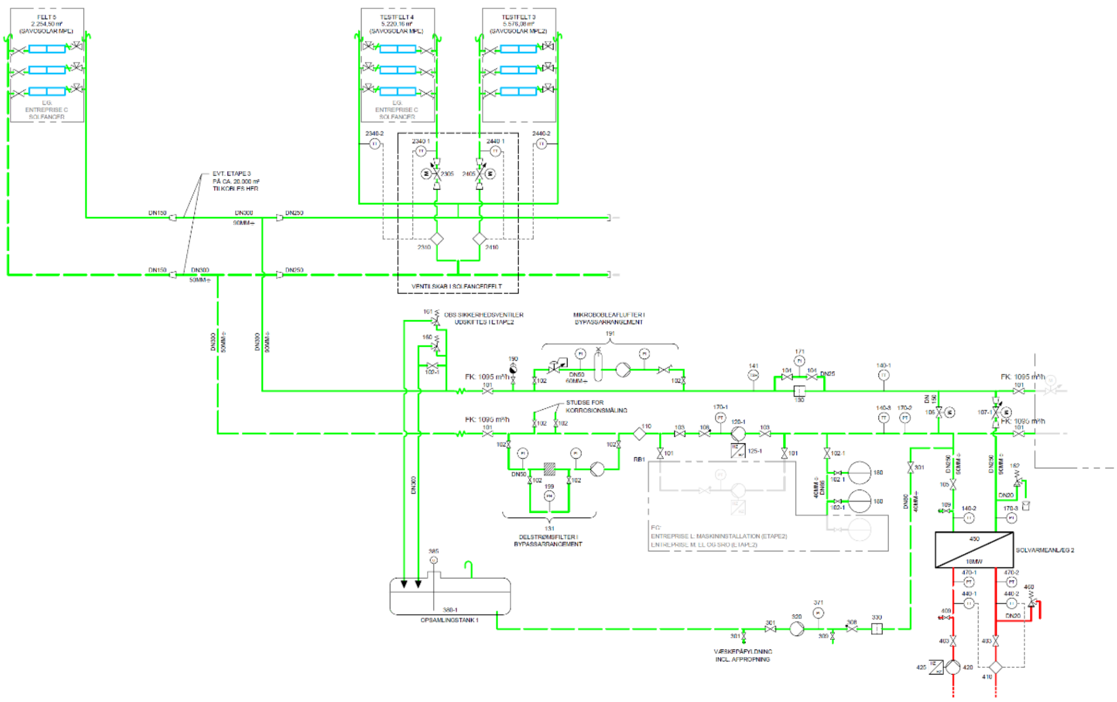
Section of the Løgumkloster PI diagram related to part 1 of the solar collector field.

(Green is solar collector loop)



Section of the Løgumkloster PI diagram related to part 2 of the solar collector field.

(Green is solar collector loop)



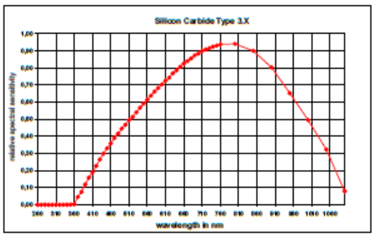
INDIUM SENSOR

Elektronische Geräte für Industrie und Umwelt

Global radiation measuring head type 3.3

Global radiation
All diffuse and direct solar radiation reaching the surface of the earth is called global radiation.
It ranges from short (300nm (UV-B)) to long (5000 nm (IR)) wavelength.

Global measuring head type 3.3
The sensor detects almost 90% of sunlight in the range of wavelength between 400 nm and 1100 nm and is covering the range of the uv-, vis- and some of the ir-light.
The measuring results are allowing conclusions about medical and biological connections by comparing to other spectral ranges.
The measuring head can be used in medical and biological research, in weather information and forecast systems, in climate research, in agriculture and for public information in general.
The measuring head type 3.3 features a weatherproof aluminum housing. The results are cosine corrected. The dome is made of plastic (PMMA). This device can be equipped with 4 different output signal variations.

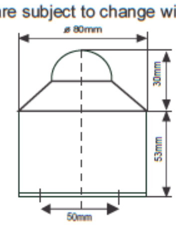


Technical specifications

Global measuring range	0 - ca. 1300 W/m²
Spectr. sensitivity	400 nm - 1100 nm
Max. spectral sensitivity	780 nm
Sensor system	Silicon
Working temperature	-55 - +80°C | -70 - +170 °F
Signal output	0V - 5V/0V-10V*/ 4mA-20mA/0mA-20mA**
Power supply	+9V - +24V/*+14V-+24V **RL(0-100Ohm)
Installation	2 screws M4 in the bottom
Connector cable	downward
Diffusor material	PTFE
Dome material	PMMA
Cosine correcture	error f2 < 3%
Linearity	< 1%
Abs. error	< 10 %
Dark voltage (E=0)	< 10 mV
Weight	400g | 14 oz

Specifications are subject to change without prior notice.

Dimensions:



Indium Sensor
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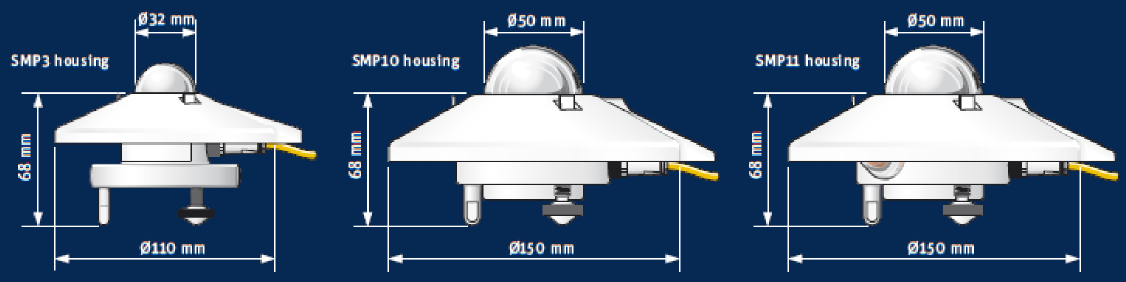
15366 Neuenhagen
Germany
Tel: +49(0)3342 80239
Fax: +49(0)3342 207886

Delta-T Devices SPN-1

SPN1

	Reading Units	Energy W.m-2
Accuracy	Overall accuracy: Total	±5% Daily integrals ±5% ±10 $W.m^{-2}$ Hourly averages ±8% ±10 $W.m^{-2}$ Individual readings
	Overall accuracy: Diffuse	±5% Daily integrals ±5% ±10 $W.m^{-2}$ Hourly averages ±8% ±10 $W.m^{-2}$ Individual readings
	Resolution	0.6 $W.m^{-2}$
	Range	0- to >2000 $W.m^{-2}$
	Analogue output sensitivity	1 mV = 1 $W.m^{-2}$
		0-2500mV
	Analogue output range	120 $W.m^{-2}$ in the direct beam
	Sunshine hours	±10%
	Cosine reponse	±2% over 0-90° Zenith angle
	Azimuth angle	± 5% over 360° rotation
	Spectral Response	400-2700 nm
Temperature	Tempco	± 0.02 % /°C typical
	Range	-20 to + 70°C
	Stability	Recalibration recommended every 2 years.
	Response time	100 ms (typical)
	Latitude capability	-90° to +90°
	Environmental sealing	IP67
	Sunshine status : contact closure	No sun = open circuit Sun = short circuit to ground
Power	Internal Battery	No internal battery
	Current	2 mA, (awake, excluding heater) <30 µA (asleep)
	Battery Lifetime	No internal battery
	External power	5 to 15 VDC
	Fuse trip point, on sunshine status signal, (when in switch-closure mode)	0.5 A, 30 V (self resetting)
	Max applied voltage to sunshine status output, in contact closure mode	0 to 24 V.
Heater	Heater output below 0°C	15 W reducing to 2 W between 0° and 5°C
	Heater output above 5°C	2 W reducing to 0 W at 35°C
	Lowest snow & ice-free temperatures	-20°C at 0 m/s wind speed -10°C at 2 m/s wind speed
	Heater : max power	15 W at 12 V DC
	Heater : max current	1.5 A at 15 V
	Fuse: max voltage, current	24 V, 1.6 A (self resetting)
	Heater input voltage range	12 to 15 VDC
Cabling	Serial (RS232) output & power-in connector	5-pin M12
	Analogue signal output & power-in	8-pin M12
Mounting options:		3 x M5 tapped holes in base at 108 mm dia, 120° spacing
Size & Weight		126 mm dia. x 94 mm high, 786 g

Kipp & Zonen SMP10



Specifications	SMP3	SMP10 & SMP11
Classification to ISO 9060:1990	Second Class	Secondary Standard
Spectral range (50 % points)	300 to 2800 nm	285 to 2800 nm
Analogue output • V-version Analogue output range	0 to 1 V -200 to 2000 W/m²	0 to 1 V -200 to 2000 W/m²
Analogue output • A-version Analogue output range	4 to 20 mA 0 to 1600 W/m²	4 to 20 mA 0 to 1600 W/m²
Serial output	RS-485 Modbus®	RS-485 Modbus®
Serial output range	-400 to 2000 W/m²	-400 to 4000 W/m²
Response time (63 %) Response time (95 %)	< 1.5 s < 12 s	< 0.7 s < 2 s
Zero offsets (a) thermal radiation (at 200 W/m²) (b) temperature change (5 K/h)	 < 15 W/m² < 5 W/m²	 < 7 W/m² < 2 W/m²
Non-stability (change/year)	< 1%	< 0.5 %
Non-linearity (100 to 1000 W/m²)	< 1.5 %	< 0.2 %
Directional response (up to 80° with 1000 W/m² beam)	< 20 W/m²	< 10 W/m²
Spectral selectivity (350 to 1500 nm)	< 3 %	< 3 %
Temperature response	< 3 % (-20 °C to +50 °C) < 5 % (-40 °C to +70 °C)	< 1% (-20 °C to +50 °C) < 2 % (-40 °C to +70 °C)
Tilt response (0° to 90° at 1000 W/m²)	< 1%	< 0.2 %
Field of view	180°	180°
Accuracy of bubble level	< 0.2°	< 0.1°
Supply voltage	5 to 30 VDC	5 to 30 VDC
Power consumption (at 12 VDC)	-V version: 55 mW -A version: 100 mW	-V version: 55 mW -A version: 100 mW
Detector type	Thermopile	Thermopile
Software, Windows™	Smart Sensor Explorer Software, for configuration, test and data logging	Smart Sensor Explorer Software, for configuration, test and data logging
Operating temperature range	-40 °C to +80 °C	-40 °C to +80 °C
Storage temperature range	-40 °C to +80 °C	-40 °C to +80 °C
Humidity range	0 to 100 % non-condensing	0 to 100 % non-condensing
Ingress Protection (IP) rating	67	67
Recommended applications	Economical solution for efficiency and maintenance monitoring of PV power installations, routine measurements in weather stations, agriculture, horticulture and hydrology	High performance for PV panel and thermal collector testing, solar energy research, solar prospecting, materials testing, advanced meteorology and climate networks

Note: The performance specifications quoted are worst-case and/or maximum values

KIPP & ZONEN
SINCE 1830

Annex 9 – Nomenclature

a_1	Solar collectors 1st order heat loss coefficient	W/(m²·K)
a_1'	Solar collectors 1st order heat loss coefficient plus heat loss in pipes[11]	W/(m²·K)
a_2	Solar collectors 2nd order heat loss coefficient	W/(m²·K²)
A_{module}	Area of one solar collector module	m^2
A_{total}	Total solar collector area[12]	m^2
B1	Variable (to simplify expression)	-
B2	Variable (to simplify expression)	°C
C	Heat capacity in solar collector loop per m^2 of collector	J/(K·m²)
c_p	Specific heat capacity of collector fluid	J/(kg·K)
dt	Time step (e.g. 1 hour = 3600 s)	s
dT_m	Change in solar collector mean temperature over one time step	K
ΔQ_{error}	Accepted deviation in energy output before error message	MWh
$\Delta Q_{warning}$	Accepted deviation in energy output before warning message	MWh
ΔT_{error}	Accepted deviation in output temperature before error message	K
$\Delta T_{warning}$	Accepted deviation in output temperature before warning message	K
η_0	”Zero loss efficiency” (max. theoretical solar collector efficiency)	-
F_{dir}	Correction factor for shadows and IAM[13] related to direct radiation	-
F_{dif}	Correction factor for shadows and IAM[13] related to diffuse radiation	-
G_{res}	Resulting radiation on collector surface	W/m²
m	Mass flow rate in collector loop (mean over a time step) per m^2 collector	kg/(s·m²)
Q	Solar collector yield[14]	J
Q_{calc}	Calculated solar yield (mean over a time step) during one hour	MWh
Q_{meas}	Measured solar yield (mean over a time step) during one hour	MWh
Q_{nom}	Nominal yield (estimated maximum yield)	MW
ρ	Density of collector fluid	kg/m^3
T_a	Ambient temperature (mean over a time step)	°C
T_i	Solar collector loop inlet temperature (mean over a time step)	°C
T_m	Mean temperature in solar collector loop (mean over a time step)	°C
$T_{m,0}$	Mean temperature in solar collector loop in the beginning of a time step	°C
$T_{m,1}$	Mean temperature in solar collector loop in the end of a time step	°C
T_o	Solar collector loop outlet temperature (mean over a time step)	°C
$T_{o,calc}$	Calculated solar collector loop outlet temperature (mean over a time step)	°C
$T_{o,meas}$	Measured solar collector loop outlet temperature (mean over a time step)	°C
U_L	Solar collector heat loss coefficient (linearised)	W/(m²·K)

[11] Heat loss in pipes refers to the total pipe losses per m^2 of solar collector calculated in section 5.3.3.3.

[12] It is important that the efficiency parameters (η_0, a_1' and a_2) applies to the used area (e.g. gross area).

[13] IAM: Incidence angle modifier.

[14] The SI-unit for Q is joule, but often the energy is converted to MWh.

V	Volume flow rate in solar collector loop	m^3/h
V_{fluid}	Fluid content in pipes and solar collector field per m^2 solar collector	l/m^2

Annex 10 – Collector properties from Solar Keymark test certificate
The efficiency parameters are based on the Solar Keymark certificate seen below.

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Annex to Solar Keymark Certificate - Summary of EN ISO 9806:2013 Test Results		**Licence Number**	**011-7S2688 F**
		Date issued	**2016-10-07**
		Issued by	
Licence holder	**Savo-Solar Oyj**	**Country**	Finland
Brand (optional)	-	**Web**	www.savosolar.fi
Street, Number	Insinöörinkatu 7	**E-mail**	info@savosolar.fi
Postcode, City	50150 Mikkeli	**Tel**	+358 (0)50 410 5247
Collector Type		Flat plate collector, glazed	

Collector name	Gross area (A_G)	Gross length	Gross width	Gross height	Power output per collector Gb = 850 W/m²; Gd = 150 W/m² ϑm - ϑa 0 K	10 K	30 K	50 K	70 K	130 K
	m²	mm	mm	mm	W	W	W	W	W	W
SF500-15	15.96	2'591	6'158	213	12'960	12'477	11'424	10'257	8'976	4'440
Power output per m² gross area					812	782	716	643	562	278

Performance parameters test method	Steady state - outdoor		
Performance parameters (related to AG)	η0,hem	a1	a2
Units	-	W/(m²K)	W/(m²K²)
Test results	0.812	2.936	0.009

Incidence angle modifier test method	Steady state - outdoor									
Bi-directional incidence angle modifiers	Yes									
Incidence angle modifier	Angle	10°	20°	30°	40°	50°	60°	70°	80°	90°
Transversal	$K_{\theta T,coll}$	1.00	1.00	1.00	0.99	0.97	0.91	0.75	0.42	0.00
Longitudinal	$K_{\theta L,coll}$	1.00	1.00	1.00	0.99	0.98	0.94	0.84	0.59	0.00

Heat transfer medium for testing	Water-Glycole		
Flow rate for testing (per gross area, A_G)	dm/dt	0.020	kg/(sm²)
Maximum temperature difference for thermal performance calculations	$(\vartheta_m-\vartheta_a)_{max}$	130	K
Standard stagnation temperature (G = 1000 W/m²; ϑ_a = 30 °C)	ϑ_{stg}	210	°C
Effective thermal capacity, incl. fluid (per gross area, A_G)	C/m²	10.2	kJ/(Km²)
Maximum operating temperature	ϑ_{max_op}	225	°C
Maximum operating pressure	$p_{max,op}$	1000	kPa

Testing laboratory	SPF, CH-8640 Rapperswil	www.spf.ch	
Test report(s)	C1704LPEN C1704QPEN	**Dated**	28.09.2016 28.09.2016

Comments of testing laboratory Datasheet version: 5.01, 2016-03-01

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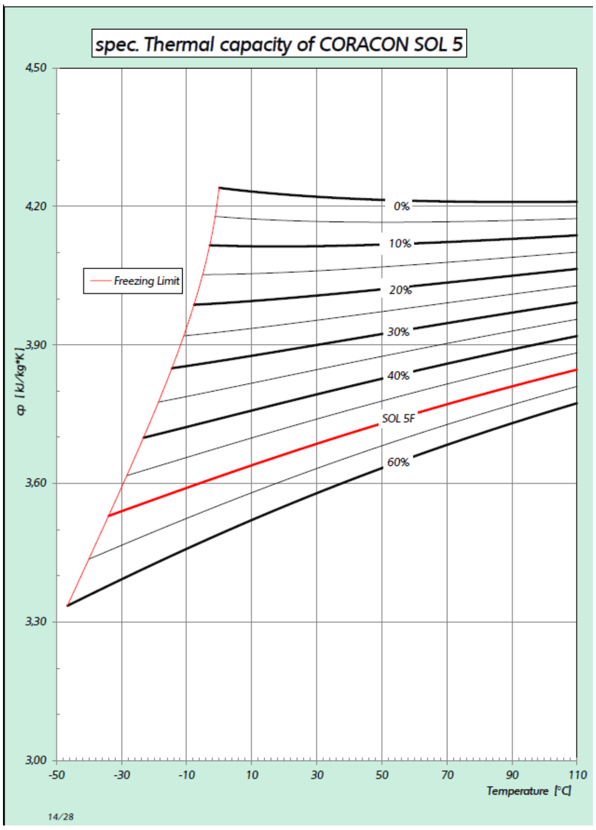
Annex 11 – Collector fluid properties
A mean temperature of 60 °C in the solar collector loop during operatio nis assumed.

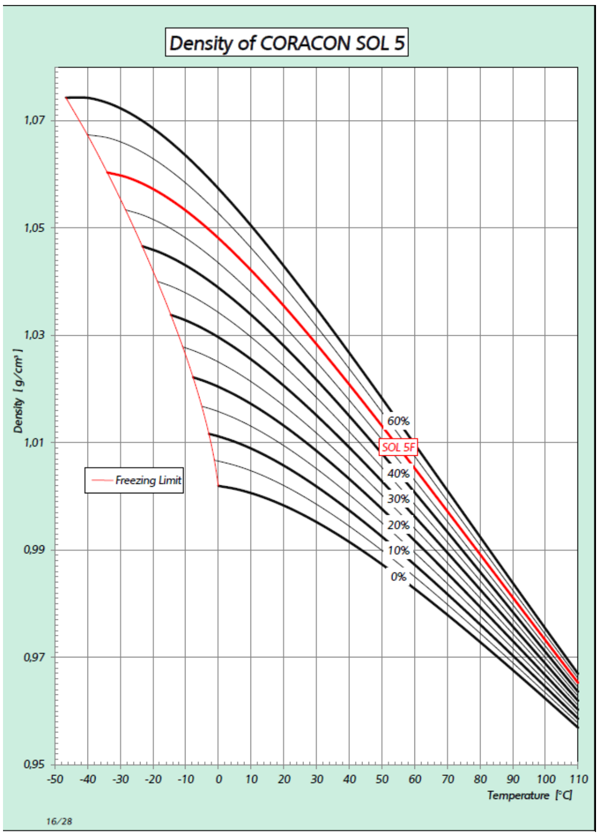
c_p, specific heat capacity (30 % glycol) is read from the left figure below: 3.934 kJ/(kg·K)
ρ, density (30 % glycol) is read from the right figure below: 996 kg/m^3
$[\rho \cdot c_p]_{collectorfluid}$ = 3918 kJ/m^3

For water the corresponding numbers at 60°C are:
c_p, specific heat capacity for water [Glent Ventilation, Glent & Co., 1982]: 4.185 kJ/(kg·K)
ρ, density for water [Glent Ventilation, Glent & Co., 1982]: 983 kg/m^3
$[\rho \cdot c_p]_{water}$ = 4114 kJ/m^3

The ratio $[\rho \cdot c_p]_{collectorfluid}/[\rho \cdot c_p]_{water}$ which is called F_{60} becomes: 0.952

A corresponding calculation for 40 and 80 °C respectively results in almost the same factor:
F_{40}: 0.952
F_{80}: 0.950





Annex 12 – Lookup table for radiation correction factors

F_{dif} = 0.845

Month	Day	Hour	F_{dir}
8	5	1	0.000
8	5	2	0.000
8	5	3	0.000
8	5	4	0.000
8	5	5	0.000
8	5	6	0.000
8	5	7	0.054
8	5	8	0.444
8	5	9	0.794
8	5	10	0.966
8	5	11	0.993
8	5	12	0.999
8	5	13	1.000
8	5	14	1.000
8	5	15	0.997
8	5	16	0.982
8	5	17	0.930
8	5	18	0.787
8	5	19	0.342
8	5	20	0.000
8	5	21	0.000
8	5	22	0.000
8	5	23	0.000
8	6	0	0.000
8	6	1	0.000
8	6	2	0.000
8	6	3	0.000
8	6	4	0.000
8	6	5	0.000
8	6	6	0.000
8	6	7	0.051
8	6	8	0.439
8	6	9	0.788
8	6	10	0.966
8	6	11	0.993
8	6	12	0.999
8	6	13	1.000
8	6	14	1.000
8	6	15	0.997
8	6	16	0.981
8	6	17	0.929
8	6	18	0.786
8	6	19	0.336
8	6	20	0.000
8	6	21	0.000
8	6	22	0.000
8	6	23	0.000
8	7	0	0.000
8	7	1	0.000
8	7	2	0.000
8	7	3	0.000
8	7	4	0.000
8	7	5	0.000
8	7	6	0.000
8	7	7	0.049
8	7	8	0.433
8	7	9	0.783
8	7	10	0.966
8	7	11	0.993
8	7	12	0.999
8	7	13	1.000
8	7	14	1.000
8	7	15	0.997
8	7	16	0.981
8	7	17	0.929
8	7	18	0.784
8	7	19	0.330
8	7	20	0.000
8	7	21	0.000
8	7	22	0.000
8	7	23	0.000
8	8	0	0.000
8	8	1	0.000
8	8	2	0.000
8	8	3	0.000
8	8	4	0.000
8	8	5	0.000
8	8	6	0.000
8	8	7	0.046
8	8	8	0.428
8	8	9	0.778
8	8	10	0.966
8	8	11	0.993
8	8	12	0.999
8	8	13	1.000
8	8	14	1.000
8	8	15	0.997
8	8	16	0.981
8	8	17	0.928
8	8	18	0.777
8	8	19	0.323
8	8	20	0.000
8	8	21	0.000
8	8	22	0.000
8	8	23	0.000
8	9	0	0.000
8	9	1	0.000
8	9	2	0.000
8	9	3	0.000
8	9	4	0.000
8	9	5	0.000
8	9	6	0.000
8	9	7	0.043
8	9	8	0.422
8	9	9	0.772
8	9	10	0.965
8	9	11	0.993
8	9	12	0.999
8	9	13	1.000
8	9	14	1.000
8	9	15	0.997
8	9	16	0.981
8	9	17	0.928
8	9	18	0.771
8	9	19	0.317
8	9	20	0.000
8	9	21	0.000
8	9	22	0.000
8	9	23	0.000
8	10	0	0.000
8	10	1	0.000
8	10	2	0.000
8	10	3	0.000
8	10	4	0.000
8	10	5	0.000
8	10	6	0.000
8	10	7	0.041
8	10	8	0.417
8	10	9	0.767
8	10	10	0.965
8	10	11	0.993
8	10	12	0.999
8	10	13	1.000
8	10	14	1.000
8	10	15	0.997
8	10	16	0.981
8	10	17	0.927
8	10	18	0.764
8	10	19	0.310
8	10	20	0.000
8	10	21	0.000
8	10	22	0.000
8	10	23	0.000
8	11	0	0.000
8	11	1	0.000
8	11	2	0.000
8	11	3	0.000
8	11	4	0.000
8	11	5	0.000
8	11	6	0.000
8	11	7	0.038
8	11	8	0.411
8	11	9	0.761
8	11	10	0.965
8	11	11	0.993
8	11	12	0.999
8	11	13	1.000
8	11	14	1.000
8	11	15	0.997
8	11	16	0.981
8	11	17	0.927
8	11	18	0.757
8	11	19	0.303
8	11	20	0.000
8	11	21	0.000
8	11	22	0.000
8	11	23	0.000
8	12	0	0.000
8	12	1	0.000
8	12	2	0.000
8	12	3	0.000
8	12	4	0.000
8	12	5	0.000
8	12	6	0.000
8	12	7	0.036
8	12	8	0.406
8	12	9	0.755
8	12	10	0.965
8	12	11	0.993
8	12	12	0.999
8	12	13	1.000
8	12	14	1.000
8	12	15	0.997
8	12	16	0.980
8	12	17	0.926
8	12	18	0.750
8	12	19	0.296
8	12	20	0.000
8	12	21	0.000
8	12	22	0.000
8	12	23	0.000
8	13	0	0.000
8	13	1	0.000
8	13	2	0.000
8	13	3	0.000
8	13	4	0.000
8	13	5	0.000

8	13	6	0.000
8	13	7	0.034
8	13	8	0.400
8	13	9	0.749
8	13	10	0.965
8	13	11	0.993
8	13	12	0.999
8	13	13	1.000
8	13	14	1.000
8	13	15	0.997
8	13	16	0.980
8	13	17	0.925
8	13	18	0.743
8	13	19	0.289
8	13	20	0.000
8	13	21	0.000
8	13	22	0.000
8	13	23	0.000
8	14	0	0.000
8	14	1	0.000
8	14	2	0.000
8	14	3	0.000
8	14	4	0.000
8	14	5	0.000
8	14	6	0.000
8	14	7	0.032
8	14	8	0.394
8	14	9	0.744
8	14	10	0.965
8	14	11	0.993
8	14	12	0.999
8	14	13	1.000
8	14	14	1.000
8	14	15	0.997
8	14	16	0.980
8	14	17	0.925
8	14	18	0.736
8	14	19	0.282
8	14	20	0.000
8	14	21	0.000
8	14	22	0.000
8	14	23	0.000
8	15	0	0.000
8	15	1	0.000
8	15	2	0.000
8	15	3	0.000
8	15	4	0.000
8	15	5	0.000
8	15	6	0.000
8	15	7	0.029
8	15	8	0.388
8	15	9	0.738
8	15	10	0.965
8	15	11	0.993
8	15	12	0.999
8	15	13	1.000
8	15	14	1.000
8	15	15	0.997
8	15	16	0.980
8	15	17	0.924
8	15	18	0.728
8	15	19	0.274
8	15	20	0.000
8	15	21	0.000
8	15	22	0.000
8	15	23	0.000
8	16	0	0.000
8	16	1	0.000
8	16	2	0.000
8	16	3	0.000
8	16	4	0.000
8	16	5	0.000
8	16	6	0.000
8	16	7	0.027
8	16	8	0.383
8	16	9	0.732
8	16	10	0.965
8	16	11	0.993
8	16	12	0.999
8	16	13	1.000
8	16	14	1.000
8	16	15	0.997
8	16	16	0.980
8	16	17	0.923
8	16	18	0.720
8	16	19	0.267
8	16	20	0.000
8	16	21	0.000
8	16	22	0.000
8	16	23	0.000
8	17	0	0.000
8	17	1	0.000
8	17	2	0.000
8	17	3	0.000
8	17	4	0.000
8	17	5	0.000
8	17	6	0.000
8	17	7	0.025
8	17	8	0.377
8	17	9	0.726
8	17	10	0.965
8	17	11	0.993
8	17	12	0.999
8	17	13	1.000
8	17	14	1.000
8	17	15	0.997