

# Solar heating system monitoring at solarheatdata.eu

*Key monitoring methods and  
main features of the website*



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## 1 Introduction

This document describes how a basic level of solar heating system monitoring can be carried out. Such monitoring does not make the general system control redundant. Where the general system control manages the operation, the “monitoring” can indicate the general performance – possibly including a highlight of any unacceptable deviations to warn the operating manager.

While the descriptions are general, they also represent the methods applied at the online monitoring platform *solarheatdata.eu*, which is the international equivalent of the Danish *solvarmedata.dk*. A solar heating system can be connected to this website and thereby have the below described monitoring presented online. This way the document can be used as a guide on how to connect a solar heating system (existing or upcoming) to *solarheatdata.eu* besides representing a general description of basic monitoring of solar heating systems. *solarheatdata.eu* continuously shows monitored and collected data for the heat production of solar heating systems connected to district heating systems. It is possible to access general plant information, real-time and historical solar heat production data. Furthermore, *solarheatdata.eu* gives the operating manager a number of benefits, e.g. automatically generated analysis of solar plant efficiency and warnings in case of monitoring errors. Everything is provided via a simple interactive European map, giving the user a quick overview of the available solar heating plants.

This manual for basic monitoring consist of two main sections:

- Features of *solarheatdata.eu* (as example of how basic monitoring can be carried out)
- How to connect your own solar heating system to *solarheatdata.eu*

## 2 Features of solarheatdata.eu

*solvarmedata.dk* has been online since 2008. Most of the large Danish solar district heating plants are connected to *solvarmedata.dk*. *solvarmedata.dk* is an online platform providing monitoring data for solar district heating plants; while giving publicity to the operators, the technology and the Danish success story of solar district heating. In the autumn of 2016, the international version *solarheatdata.eu* was launched to widen the scope of solar district heating systems also beyond Denmark and to include an upgrade with several new features. The two websites *solvarmedata.dk* and *solarheatdata.eu* include the exact same features, but simply use different languages (Danish and English respectively) and geographical focus areas.

Historical solar heat production data can be displayed and exported for an hourly, daily, weekly or monthly time resolution. The different options for exporting data, and displaying data and data evaluations are described below.

### 2.1 Solar heating system details

Each solar heating system connected to *solarheatdata.eu* shares a certain amount of background information about the plant, which form a general introduction when a user clicks on the given system (icon) on the website map. Some of the background information is necessary to calculate expected solar heat production; e.g. solar collector area (m<sup>2</sup>). Other information details are shared with the users of the website to give a more comprehensive idea about the type of system, and under which circumstances the plant is operating; e.g. alternative heat production and expected share of solar heat. Another function of the back-

ground information is to give stakeholders in- and outside the solar heating industry an overview of possible system sizes and setups.

## 2.2 Data and data export

Solar heat production data can be downloaded. The text file format is .csv. The user can freely choose the timeframe and time resolution of the data. The data columns include total solar system heat production (MWh), specific solar yield (Wh/m<sup>2</sup>) and solar radiation (Wh/m<sup>2</sup>). The first column of the rows of the export file ("proddata.csv") is a date/time stamp of the dataset.

By offering the export option, the website users can freely make their own further analysis. Note however, that since the systems are connected on a voluntary basis, no one can be held reliable for errors in the data.

## 2.3 Solar efficiency

The solar efficiency can be shown as a graph for every single plant. The solar efficiency is the ratio between the solar heat production and the total solar radiation on the collector plane. This ratio is a performance measure on how well the system utilizes the available solar radiation. The solar efficiency is very dependent on the operating conditions; e.g. temperature levels and intensity of the solar radiation. Hence, a low solar efficiency is not necessarily caused by a poorly operating system or an inefficient collector type.

The solar efficiency,  $\eta$  is calculated according to:

- $\eta = P_{\text{sol,meas}} / (G \cdot A_{\text{total}})$  -

where

• $P_{\text{sol,meas}}$ :	Measured solar heat production	W
• $G$ :	Solar radiation on collector plane	W/m <sup>2</sup>
• $A_{\text{total}}$ :	Total collector area corresponding to the used collector efficiency parameters, $\eta_0$ , $a_1$ and $a_2$	m <sup>2</sup>

*Important note:*

*A new version of the international solar collector standard EN/ISO 9806 was released in 2013. One of the important changes was a change related to the collector area. Before 2013, the efficiency parameters should be related to the "aperture area", but in the new standard they shall be related to the "gross area". The "gross area" is typical some percent larger than the "aperture area", so it is important to be sure that the correct area is used with the efficiency parameters!*

## 2.4 Input/output plot

solarheatdata.eu automatically evaluates the yield of a connected solar heating system. The evaluation is based on the specific solar heat production (Wh/m<sup>2</sup>) as a function of the measured solar radiation on the collector plane (Wh/m<sup>2</sup>). The yield from each time step can be compared to trend lines for the system and/or for all other connected systems. This enables the user to get an impression if the plant is well performing. Most importantly, it helps the plant operator to know if the system performance deviates significantly from its normal operation – this might help to take action and solve issues in case of malfunctioning plant operation.

By using the mouse-over feature it is possible to get input/output information about a specific data point; time/date, input (solar radiation) and output (specific solar heat production).

This can help identify why points are above or below the trend line, which could be considered as deviations from “normal” operation. Figure 1 shows an example of such an input/output plot. The blue dotted lines indicate an “error band”, i.e. an upper and lower limit for the data points. Within this error band, deviations are considered acceptable which indicates normal operation. As seen in the figure, the error band represent the trend line +/- 500 Wh/m<sup>2</sup> per day for most data points. For low solar radiation values, the uncertainties can however be quite large. Therefore the upper limit is made as a straight line between the coordinates (0 , 500) and (3000 , EB<sub>upper</sub>), where “EB<sub>upper</sub>” is the error band upper value at a solar radiation level of 3000 Wh/m<sup>2</sup> per day. Besides this, the lower limit is never negative.

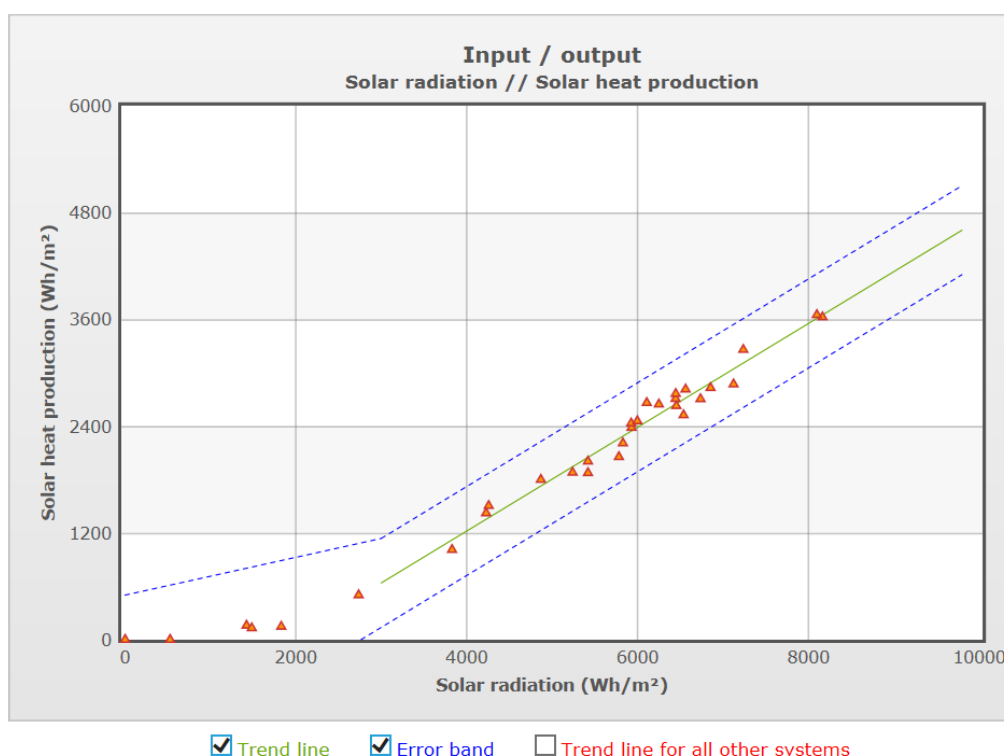


Figure 1: Example of input/output plot for one month of daily values (orange triangles) incl. trend line (green) and error band (blue upper and lower limit)

## 2.5 Solar fraction

The solar fraction (the ratio between the solar heat production and the total heat production of the total heat supply system – e.g. the whole district heating plant, including the solar system), is evaluated hour-by-hour. A figure showing the solar fraction can be chosen for a user-specified time interval and time resolution. The solar fraction is a measure for how much of the alternative heat supply (e.g. boiler operation) are replaced by solar heat in the given heat production system.

The solar fraction evaluation is based solely on the heat production. The calculation does not consider actual heat demand nor thermal storage. Thus, it is possible to have an hourly or daily solar fraction of more than 100 %. The solar fraction (Sf) is here defined as:

- $Sf = P_{sol,meas} / P_{total,heat}$  -

where:

- $P_{sol,meas}$ : Measured solar heat production W
- $P_{total,heat}$ : Total heat production of connected heating system W

An example of the solar heat production for three days of operation is shown in comparison to the total heat production (to supply the demand) in figure 2. The solar heat production (black) is in this case not entirely proportional to the trend of the total heat production (shown in grey). The solar fraction is seen as the yellow curve.

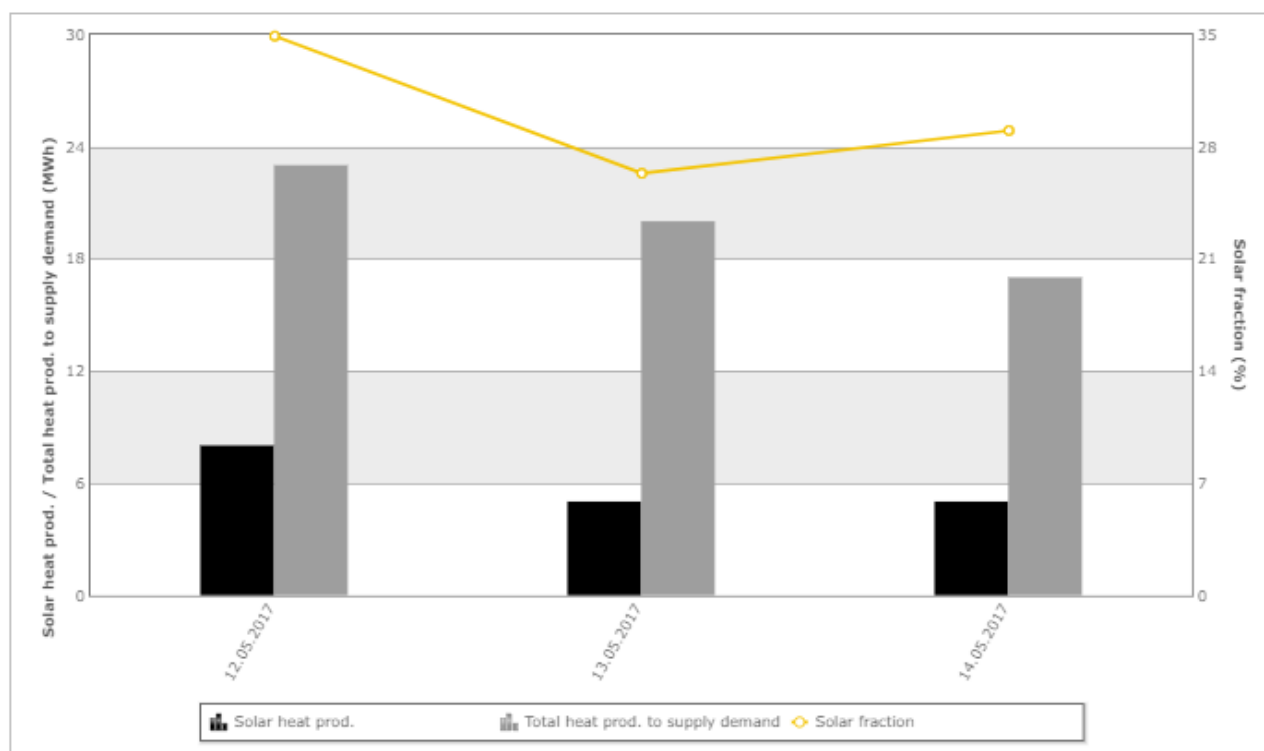


Figure 2: Example of solar heat production (black, left axis), total heat production (grey, left axis) and solar fraction (yellow curve, right axis)

## 2.6 Temperature levels

The temperature level of the district heating network has a high impact on the solar yield. The temperature levels of inlets and outlets to the heat exchanger are monitored to calculate the theoretical solar heat production. The system operator\* can see the fluctuations of the mean temperature (of inlet and outlet temperature) on the secondary side of the heat exchanger (e.g. district heating network). It is possible to compare the mean temperature level of a specific plant to the average of all other systems. This gives an indication whether good boundary conditions for high solar performance are available for the given system. The mean temperature on the secondary side of the heat exchanger ( $T_{\text{mean,sec}}$ ) is defined as:

- $T_{\text{mean,sec}} = (T_{\text{sec,f}} + T_{\text{sec,r}}) / 2$  °C

where:

- $T_{\text{sec,f}}$ : Forward temperature from secondary side of heat exchanger °C
- $T_{\text{sec,r}}$ : Return temperature to secondary side of heat exchanger °C

## 2.7 Performance check

solarheatdata.eu automatically generates a performance check by comparing measured and expected solar yield (in MW). The performance check is similar to the method described in

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\* This is only visible for your own solar heating system and requires a login provided when the connection is established. Other website users cannot see this evaluation. With the login it is also possible to edit the general information of the solar heating system.

“Guaranteed power output” from IEA SHC Task 45 and the SDH guidelines fact sheet 3.3 “Performance guarantees”<sup>†</sup>.

The performance check could possibly be considered sensitive information. Therefore, the result of the performance check is only visible when the plant operator is logged in\*. As for the input/output diagram, this performance check helps the plant operator to identify if the system performance suddenly drops due to an error or continuously decreases (e.g. due to degradation or dust). Thereby the operator can try to take action and solve possible issues.

### 2.7.1 Available check periods

The performance check is only based on data during stable operation and close-to optimum solar conditions as prescribed in before mentioned guidelines.

The available “check periods” are dependent on the climate of the solar heating plant and the path of the sun. Important solar plant information to calculate the check periods is the latitude of the location, azimuth angle of the collectors, the tilt of the collector field, height of collector modules and distance between the collector rows. It is important that the sky is free of clouds and that the direct solar radiation can freely pass to the full surface of all collectors. The following conditions are used as a standard:

- Solar radiation > 800 W/m<sup>2</sup>
- No snow/ice (ambient temperature > 5°C)
- No shadows (from obstacles, mountains or collector rows)
- No significant change to solar collector operating mean temperature (< 5 K/hour)
- Only one data set must be utilized per hour
- Incidence angle < 30°

A low incidence angle between direct solar radiation and the collector field is needed to avoid reflections. The incidence angle can be calculated based on the path of the sun, and information on which direction the collector field faces.

### 2.7.2 Performance check calculation

The expected solar heat production is calculated according to:

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

where:

- $P_{\text{exp}}$ : Expected solar heat output W
- $A_{\text{total}}$ : Total collector area corresponding to the used collector efficiency parameters,  $\eta_0$ ,  $a_1$  and  $a_2$  m<sup>2</sup>
- $\eta_0$ : “Zero loss efficiency” (max. theoretical collector efficiency) -
- $a_1$ : Solar collectors 1<sup>st</sup> order heat loss coefficient W/(K·m<sup>2</sup>)
- $a_2$ : Solar collectors 2<sup>nd</sup> order heat loss coefficient W/(K<sup>2</sup>·m<sup>2</sup>)
- $G$ : Solar radiation on collector plane W/m<sup>2</sup>
- $T_a$ : 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

<sup>†</sup> See [www.solar-district-heating.eu/Documents/SDHGuidelines](http://www.solar-district-heating.eu/Documents/SDHGuidelines).

For comparison, the ratio between the measured solar heat production,  $P_{\text{sol,meas}}$ , and the expected solar heat production,  $P_{\text{exp}}$ , is calculated as:

- $P_{\text{sol,meas}} / P_{\text{exp}}$  -

This ratio is shown for each time step (e.g. hour-by-hour) as points in the performance check plot. If the value is above 100 %, the solar heat production is higher than theoretically expected. See example in figure 3 where the used (and valid according to section 2.7.1) measurement points are shown as orange triangles. Points laying exactly on the blue curve means 100 % fit between measured and expected performance. A majority of the points of this specific example is on the right side of the blue line. Thus, the measured performance is slightly lower than expected. Below the graph, the average measured performance is evaluated to be 97 % of the expected solar production. The measured yield is actually higher than expected for peak production hours (> 4 MW). This could indicate that this solar heating system has slightly different efficiency properties than expected.

*solarheatdata.eu* also calculates the overall ratio based on an interval (dates chosen by the user) to know if the solar system generally performs as expected. All data are summed up to find the total measured solar heat production from valid check periods  $Q_{\text{sol,meas}}$ .

- $Q_{\text{sol,meas}} = \sum(P_{\text{sol,meas}} \cdot \Delta t)$  Wh

where

- $P_{\text{sol,meas}}$  is the measured solar heat transferred from the heat exchanger W
- $\Delta t$  is the time step for storing (one hour) h

The expected solar heat production of all periods is calculated according to:

- $Q_{\text{exp}} = \sum(P_{\text{exp}} \cdot \Delta t)$  Wh

For comparison, the ratio between  $Q_{\text{sol,meas}}$  and  $Q_{\text{exp}}$  is calculated as:

- $Q_{\text{sol,meas}} / Q_{\text{exp}}$  -

This ratio is shown below the figure of the performance check. If the value is more than 100 %, the average solar heat production is higher than expected.



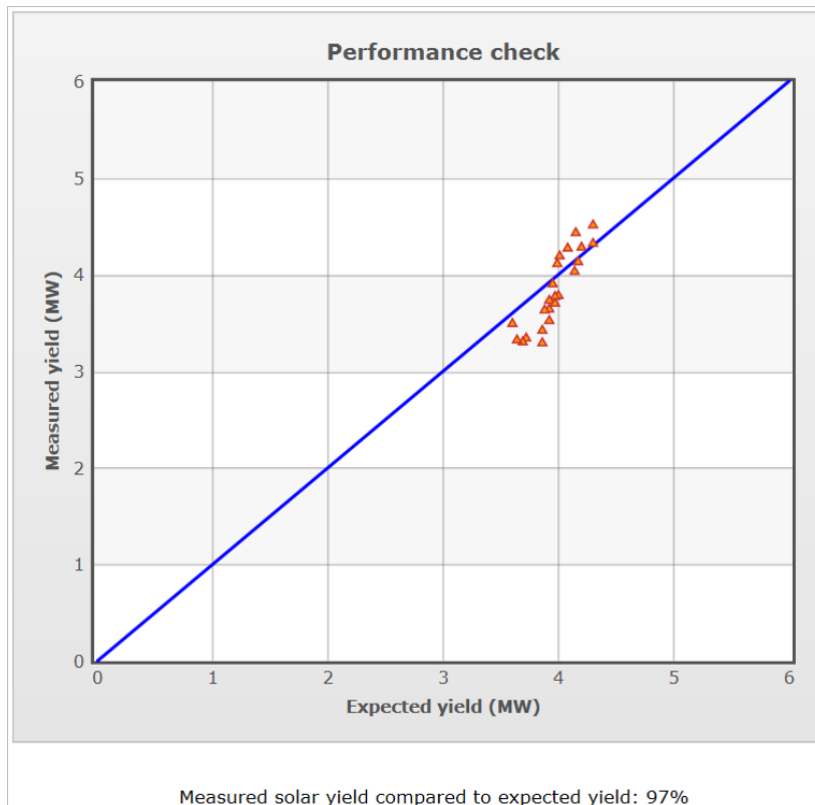


Figure 3: Example of a performance check. Measurement points (orange triangles) vs. expected performance (blue line)

## 2.8 Quality check of data input

*solarheatdata.eu* evaluates the data input continuously. It detects a range of possible monitoring errors based on the collected data. If the same exact value is detected for 24 hours, *solarheatdata.eu* will warn the online user since it is not possible to have exactly constant solar heat production over a period of 24 hours. Besides this, it is possible to send an error warning message to the operating manager. Table 1 shows which parameters are evaluated by the quality check. Some parameters are continuously evaluated (hour-by-hour) while other parameters are evaluated on a daily basis.

<b>Continuous quality check</b>	Max.	Min.	
Ambient temperature	60	-50	°C
Total radiation on collector surface	1300	-10	W/m <sup>2</sup>
Direct beam radiation on collector surface (if available)	1300	-10	W/m <sup>2</sup>
Diffuse radiation on collector surface (if available)	1000	-10	W/m <sup>2</sup>
Temperature of collector loop at outlet from heat exchanger	200	-50	°C
Temperature of collector loop at inlet to heat exchanger	200	-50	°C
Flow of the collector loop	0.12	-0.01	m <sup>3</sup> /h/m <sup>2</sup>
Measured heat production, primary side of heat exchanger	1300	-200	W/m <sup>2</sup>
Temperature of outlet at secondary side of heat exchanger	200	-50	°C
Temperature of inlet to secondary side of heat exchanger	200	-50	°C
Flow of the secondary side of the heat exchanger	0.12	-0.01	m <sup>3</sup> /h/m <sup>2</sup>
Measured heat production, secondary side of heat exchanger	1300	-200	W/m <sup>2</sup>
<b>Quality check on daily basis</b>			
Total radiation on collector surface	10 000	0	Wh/(d·m <sup>2</sup> )
Direct beam radiation on collector surface (if available)	10 000	0	Wh/(d·m <sup>2</sup> )
Diffuse radiation on collector surface (if available)	10 000	0	Wh/(d·m <sup>2</sup> )
Measured heat production on primary side of heat exchanger	10 000	0	Wh/(d·m <sup>2</sup> )
Measured heat production, secondary side of heat exchanger	10 000	0	Wh/(d·m <sup>2</sup> )
Solar efficiency	100 %	0 %	-

Table 1: Performed quality checks of data input received by solar district heating plants

If the system detects possible errors in a dataset, the user will be warned by red exclamation marks (!). If warnings appear, the user should be aware about the reliability of the dataset. An example of a log with warnings is found in figure 4.

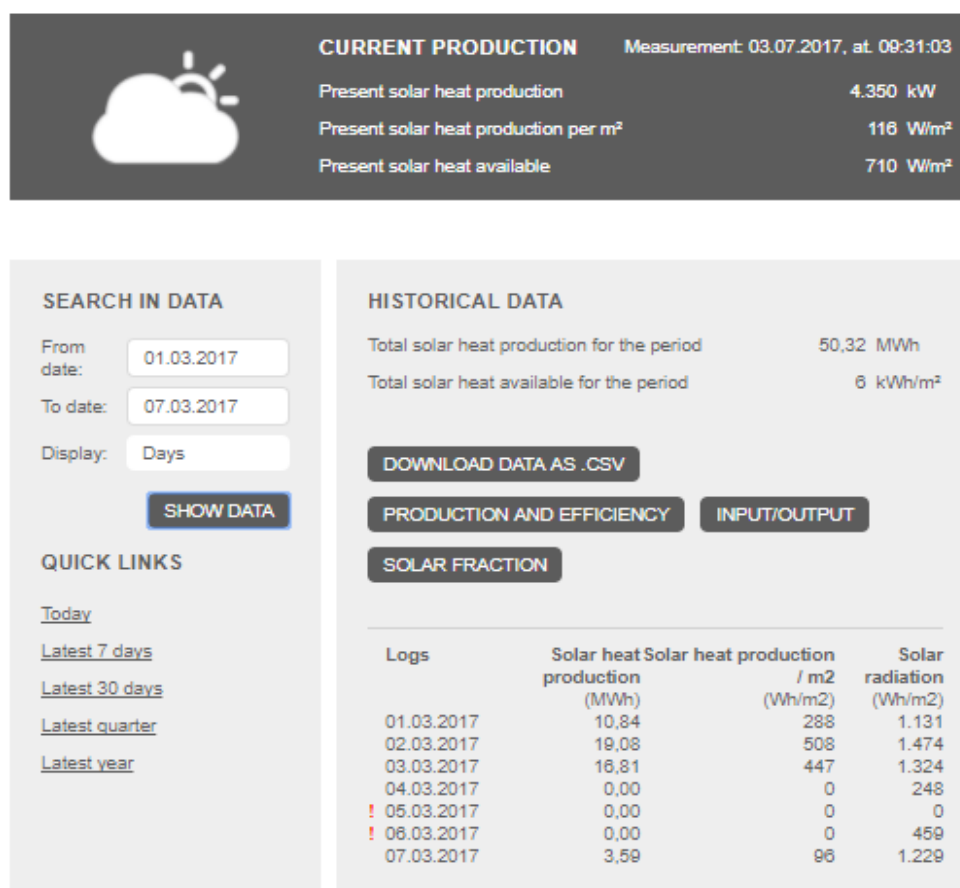


Figure 4: Example of a dataset marked with warnings (!) due to unrealistic values according to the data quality check.

## 2.9 Using the website

The website front-page shows the total current solar heat production of all monitored solar heating systems. This way the user get an impression about the scale of the current implementation/connection status. Different icons show the status of each solar heating plant based on solar radiation data. The icons are shown in figure 5. The four possible states of operation are:

- Sunshine
- Partly cloudy
- Cloudy
- Night-time

Clicking one of the first four icons takes the user to the general information about the chosen solar heating system and the possibility to access other features for the specific system. The one on the far right illustrates “multiple layers of solar collectors”. This indicates that more than one solar system is located in the area. A click on this icon lists these systems. Alternatively, the user can zoom in on the map until this icon dissolves into several of the other (“single system”) icons.



Figure 5: The icons used on the front-page to show the status of the solar heating plants. From left to right: sunshine, partly cloudy, cloudy and night-time. The icon to the far right indicates several solar collector fields are relatively close to each other.

## 3 How to connect your own solar heating system

Large scale solar heating systems are invited to connect to *solarheatdata.eu*. More connected plants will result in better data for analysis and comparison, as well as increased publicity for solar heating.

To connect a solar heating system, your control system (often referred to as SCADA system for Supervisory Control And Data Acquisition) needs to monitor and feed a number of variables continuously. The data is needed for *solarheatdata.eu* to show the present solar heat production, log the historical production data, carry out performance checks, calculate system efficiency etc. Typically, data is updated every 5 minutes. Hence, an internet-based connection must be established and able to upload data automatically. See further information on this point in section 3.2.

Note that the responsibility of the cybersecurity related to having an internet connection at the solar heating system (possibly coupled to the system control) lies solely on the one who want to connect the plant (i.e. normally the plant owner). The authors of this document, the Danish District Heating Association (owners of the websites), easynet (the website hosts), the SDHp2m consortium and the European Commission can in no way be held reliable for any security breach caused by the connection to *solarheatdata.eu*.

### 3.1 Establishing the connection

To connect your system go to *solarheatdata.eu*, and find the box on right side: “Connect your own system”.

When creating a new plant, the user will be asked to fill out a range of background information; mainly regarding the specific solar plant. The information will partly be used to

make performance check and data quality check. Some background information about the solar heating plant are shown publicly at the tab “About the Plant”.

A list of the background information required for the plant to access the full range of *solar-heatdata.eu* features is found in table 2.

<i>Name of the solar plant/district heating plant</i>
<i>Address</i>
<i>Contact person and email (for warnings and error messages)</i>
<i>Alternative heat production units</i>
<i>Heat storages</i>
<i>Key dates (commissioning, and demolition if applicable)</i>
<i>Specific collector type</i>
<i>Number of collector modules</i>
<i>Area per collector module [m<sup>2</sup>]</i>
<i>Collector dimensions (height and width) [m]</i>
<i>Orientation [°] (deviation from south)</i>
<i>Distance between collector rows [m]</i>
<i>Collector tilt angle [°]</i>
<i>Collector efficiency parameters (shall relate to “Area per collector module” given above)</i> <ul style="list-style-type: none"> <li>• <math>\eta_0</math>: Maximum efficiency (or “zero-loss efficiency”) [-]</li> <li>• <math>a_1</math>: First order heat loss coefficient [W/(K·m<sup>2</sup>)]</li> <li>• <math>a_2</math>: Second order heat loss coefficient [W/(K<sup>2</sup>·m<sup>2</sup>)]</li> <li>• <math>K_{50}</math>: Incidence angle modifier (IAM)<sup>‡</sup> [-]</li> </ul>
<i>Ground area occupied by the collector field [m<sup>2</sup>]</i>
<i>Safety factor considering heat losses in the collector circuit<sup>§</sup></i>
<i>Safety factor considering measurement uncertainties</i>
<i>Equipment used for irradiation measurements</i>
<i>Equipment used for energy meters</i>
<i>Expected yield (solar heat production per year, max. power, CO<sub>2</sub> reductions per year, solar fraction)</i>
<i>Investment (price for the solar system excl. storage, expected net economic result over 25 years, contributor of subsidies and amount of subsidy (if applicable), return of investment period (years))</i>
<i>Whether the data feed includes comma or point as decimal separator</i>

*Table 2: Background information that can be filled out when connecting a plant to solarheat-data.eu*

<sup>‡</sup> Should at least be included for an incidence angle of 50°. Could be split in intervals of 10° from 10° to 80°. For other collector types than flat plate collectors, the IAM should be split into a longitudinal and a transversal IAM for 10° intervals.

<sup>§</sup> Since the performance check calculations are based on the calculated solar *collector* yield, safety factors are included to take pipe losses in the collector loop and measurement uncertainties into account when evaluating the performance.

## 3.2 Data feed

The data feed needed for the online monitoring includes solar radiation and ambient temperature along with solar heat production, flow rates and temperatures in and out of the heat exchanger. A list of the exact data feed is shown in table 3. Until the 2016 upgrade of *solvarmedata.dk* (as mentioned in section 2), the only data feed required was solar radiation and solar heat production, which formed a minimum level basic monitoring.

No.	Parameters	Unit	Number of decimals
1	Current solar heat production (measured thermal power on the secondary side of the heat exchanger)	MW	3
2	Current solar radiation in W/m <sup>2</sup> (Total solar radiation on the solar collector surface)	W/m <sup>2</sup>	2
3	Ambient (outdoor) temperature	°C	1
4	Diffuse radiation on the collector surface (if possible)	W/m <sup>2</sup>	0
5	Direct radiation on the solar surface (if possible)	W/m <sup>2</sup>	0
6	The outlet temperature at the heat exchanger for the fluid pumped towards the solar collectors (i.e. primary side) (if possible)	°C	1
7	The inlet temperature at the heat exchanger for the fluid coming from the solar collectors (primary side) (if possible)	°C	1
8	Flow in the solar collector loop (i.e. primary side of the heat exchanger) (if possible)	m <sup>3</sup> /h	1
9	Thermal power measured on the primary side of the heat exchanger (if possible)	MW	3
10	The outlet temperature at the heat exchanger secondary side (i.e. the heated water)	°C	1
11	The inlet temperature at the heat exchanger secondary side (i.e. the water to be heated by solar heat)	°C	1
12	The flow rate at secondary side of the heat exchanger (water side)	m <sup>3</sup> /h	1
13	Total heat production at the plant (in order to calculate the solar fraction)	MW	3

Table 3: Necessary parameters in data feed to connect a plant to *solarheatdata.eu*

In case some of the values are calculated (i.e. not measured) the website operator (easynet) has to be notified when the connection is established. For concentrating solar heating plants, monitoring the direct radiation (parameter 5) is mandatory to calculate expected solar yield.

Once your system is connected, your system should feed current values to the FTP-server every 5 minutes. The uploaded data is a semi-colon separated (;) text-file (txt). Comma (',') should be used as decimal separator. The file should include only one line with all of the parameters mentioned in table 3. The line should always contain 12 semi-colons. It is important that the data values are supplied in the order shown in table 3.

### 3.2.1 Example of uploaded text

An example of one line of the needed data feed is given here. The feed should be:

"2.055;650;12,3;250;400;(...)"

if:

- the current solar heat production is 2.055 MW (i.e. approx. 2 MW)
- the current solar radiation is 650 W/m<sup>2</sup>
- the outdoor air temperature is 12.3 °C
- the diffuse radiation on the solar collector surface is 250 W/m<sup>2</sup>
- the direct radiation on solar panel surface is 400 W/m<sup>2</sup>
- ...etc. (...)

If some values are not available, the space for the missing values are left empty while the semi-colons should remain in the data feed. E.g. if 'Diffuse radiation on the solar collector surface' cannot be delivered, the above example would be:

"2.055;650;12,3;;400;(...)"

Note how all semicolons are included in the last line are still included even though there is no value for diffuse radiation.

### **3.3 One-time connection fee**

To connect a solar district heating plant to *solarheatdata.eu* an initial connection fee is charged to cover expenses to set up the connection. No further fees are needed for the plant to stay online and stay connected to the solar district heating community.

The website is mainly financed by so-called *Solar Heat Partners*. The Solar Heat Partners are typically companies related to the solar heating industry interested in supporting the website while getting the benefit of promoting their business at the same time. Solar Heat Partner logos are displayed on the front page of *solarheatdata.eu* and *solvarmedata.dk*. Each Solar Heat Partner supports the website by subscribing to a fixed yearly sponsorship. More info on this (including how to become a Solar Heat Partner) is found on the website under "Solar Heat Partners".

## 4 Nomenclature

	Parameters	Unit
$a_1$	Solar collectors 1 <sup>st</sup> order heat loss coefficient	W/(K·m <sup>2</sup> )
$a_2$	Solar collectors 2 <sup>nd</sup> order heat loss coefficient	W/(K <sup>2</sup> ·m <sup>2</sup> )
$A_{total}$	Total collector area corresponding to the used collector efficiency parameters: $a_1$ , $a_2$ , $\eta_0$	m <sup>2</sup>
CSP	Concentrating solar power	
$\Delta t$	Time step for storing	h
$\eta$	Solar efficiency	-
$\eta_0$	"Zero loss efficiency" (max. theoretical solar collector efficiency)	-
FTP	File Transfer Protocol	-
G	Solar radiation on collector plane	W/m <sup>2</sup>
IAM	Incidence angle modifier	-
$K_{50}$	IAM coefficient at 50 degrees incidence angle of direct solar radiation	-
$P_{exp}$	Expected solar heat output	W
$P_{sol,meas}$	Measured solar heat production	W
$P_{total,heat}$	Total heat production of district heating plant	W
$Q_{exp}$	Expected solar heat production over a chosen period of time	Wh
$Q_{sol,meas}$	Measured solar heat production over a period	Wh
SCADA	Supervisory Control And Data Acquisition (control system)	-
SDH	Solar District Heating	-
Sf	Solar fraction	-
$T_a$	Ambient air temperature (ventilated, shadowed)	°C
$T_{c,f}$	Forward temperature from collector field to heat exchanger	°C
$T_{c,r}$	Return temperature to collector field from heat exchanger	°C
$T_m$	Mean temperature on the solar collector side of the heat exchanger	°C
$T_{mean,sec}$	Mean temperature on the secondary side of the heat exchanger	°C
$T_{sec,f}$	Forward temperature from secondary side of heat exchanger	°C
$T_{sec,r}$	Return temperature to secondary side of heat exchanger	°C

## 5 Acknowledgement & disclaimer

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