Solar district heating guidelines

Monitoring

Chapter:	Implementation
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Description:	Purpose of monitoring systems; information about the selection of data, recording of data and accuracy of monitoring equipment. Description of which data the control system should monitor and the recommended accuracy of the logging as well as how frequent the logging should occur.
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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.

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

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

This is achieved by means of:

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

General information about the solar heating system

A certain amount of background information about the solar heating system is necessary to evauate the measured yield; e.g. solar collector area (m²). Other information details are not strictly required, but are in general relevant for the operator/viewer 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 background information could be promotion of the technology i.e. providing stakeholders in- and outside the solar heating industry an overview of possible system sizes and setups.

Required information includes

- Specific collector type
- Number of collector modules
- Area per collector module [m²] (note if this is gross area or aperture area)
- Collector dimensions (height is relevant for shadow calculations) [m]
- Orientation [°] (deviation from south)
- Distance between collector rows [m]
- Collector tilt angle [°]

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- Collector efficiency parameters (shall relate to “Area per collector module” given above)
    - η_0: Maximum efficiency (or “zero-loss efficiency”) [-]
    - a_1: First order heat loss coefficient [W/(K·m^2)]
    - a_2: Second order heat loss coefficient [W/(K^2·m^2)]
    - K_{50}: Incidence angle modifier (IAM) [-]

Other relevant (but not critical) information could includes

- Name of the solar plant/district heating plant
- Address
- Contact person and email (possibly also for warnings and error messages)
- Alternative heat production units
- Heat storages (type and volume)
- Key dates (commissioning, and demolition if applicable)
- Ground area occupied by the collector field
- Equipment used for irradiation measurements
- Equipment used for energy meters
- Expected yield (solar heat production per year, max. power, CO_2 reductions per year, solar fraction)
- Investment (price for the solar system excl. storage, expected net economic result over X years, contributor of subsidies and amount of subsidy, return of investment period)

What should be measured?

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

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

A measurement of relevant system temperatures and pressure levels enables for detailed analysis and control optimisation, including the ability to identify deviations from normal operation e.g.:

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

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A list of the required data feed is shown in table 4.2.1. A minimum level basic monitoring can be carried out by monitoring simply solar radiation and solar heat production, which can then be used to calculate solar efficiency and present an input/output diagram.

Parameters	**Unit**	**Recommended number of decimals**
Current solar heat production (measured thermal power on the secondary side of the heat exchanger)	MW	3
Current solar radiation in W/m² (total solar radiation on the solar collector surface)	W/m²	2
Ambient (outdoor) temperature	°C	1
Direct radiation on the solar surface (required for concentrating SDH systems)	W/m²	0
The outlet temperature at the heat exchanger secondary side (i.e. the heated water)	°C	1
The inlet temperature at the heat exchanger secondary side (i.e. the water to be heated by solar heat)	°C	1
The flow rate at secondary side of the heat exchanger (water side)	m³/h	1
Total heat production at the plant (in order to calculate the solar fraction)	MW	3

Table 4.2.1: Necessary parameters to carry out the monitoring according to this fact sheet.

Note that if an evaluation of the heat exchanger should be carried out, temperatures and flow on the primary side (i.e. in the collector loop) is also required.

Recording of data

The minimum time resolution should be **10 minutes** when logging the following data (often 5 min. is used):

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

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

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

Accuracy of monitoring equipment

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

		relative accuracy [-]	with	value	unit	absolute accuracy [+/-]
Density	$\Delta\rho/\rho$	0.001	ρ	1000	kg/m³	1.00
Volume flow	Δ(dV/dt)/(dV/dt)	0.02	(dV/dt)	1.56	m³/h	0.03
Heat capacity	$\Delta c_p/c_p$	0.01	cp	4.18	kJ/(kgK)	0.04
Temperature difference	$\Delta\Delta T/\Delta T$	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				

Fig. 4.2.1 Accuracy of monitoring equipment. [1]

Quality check of data input

A monitoring system can be set up to evaluate the data input continuously and detect a range of possible monitoring errors based on the collected data. One example is that if the same exact value is detected for 24 hours, the systems should warn the user since it is not possible to have exactly constant solar heat production over a period of 24 hours. Besides this, it could be relevant set up the system to send an error warning message to the operating manager. Table 4.2.2 shows which parameters should be evaluated by such a quality check. Some parameters are continuously evaluated (hour-by-hour) while other parameters are evaluated on a daily basis.

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Continuous quality check	Max.	Min.	
Ambient temperature	60	-50	°C
Total radiation on collector surface	1300	-10	W/m²
Direct beam radiation on collector surface (if available)	1300	-10	W/m²
Diffuse radiation on collector surface (if available)	1000	-10	W/m²
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	m³/h/m²
Measured heat production on primary side of heat exchanger	1300	-200	W/m²
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 heat exchanger	0.12	-0.01	m³/h/m²
Measured heat production on secondary side of heat exchanger	1300	-200	W/m²
Quality check on daily basis			
Total radiation on collector surface	10 000	0	Wh/(d·m²)
Direct beam radiation on collector surface (if available)	10 000	0	Wh/(d·m²)
Diffuse radiation on collector surface (if available)	10 000	0	Wh/(d·m²)
Measured heat production on primary side of heat exchanger	10 000	0	Wh/(d·m²)
Measured heat production on secondary side of heat exchanger	10 000	0	Wh/(d·m²)
Solar efficiency	100 %	0 %	-

Table 4.2.2: Example of parameters and ranges for quality checks of data input from a SDH plant.

If the system detects possible errors in a dataset, the user should be warned in some way (e.g. by inserting a warning sign next to the data point such as a red exclamation mark. This way, if warnings appear, the user should be aware about the (possible un-)reliability of the dataset.

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 utilises 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, η is calculated according to:

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

where

- $P_{sol,meas}$: Measured solar heat production W
- G: Solar radiation on collector plane W/m²
- A_{total}: Total collector area corresponding to the used collector efficiency parameters, η_0, a_1 and a_2 m²

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It is important to note that 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.

Input/output plot

One way to evaluate the yield of a solar heating system is to base it on the specific solar heat production (Wh/m^2) as a function of the measured solar radiation on the collector plane (Wh/m^2). The yield from each time step can be compared to trend lines for the same system. 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.

Figure 4.2.2 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^2 per day for most data points. For low solar radiation values, the uncertainties can however be relatively large. Therefore, the upper limit is made as a straight line between the coordinates (0 , 500) and (3000 , EB_{upper}), where “EB_{upper}” is the error band upper value at a solar radiation level of 3000 Wh/m^2 per day. Besides this, the lower limit is never negative.

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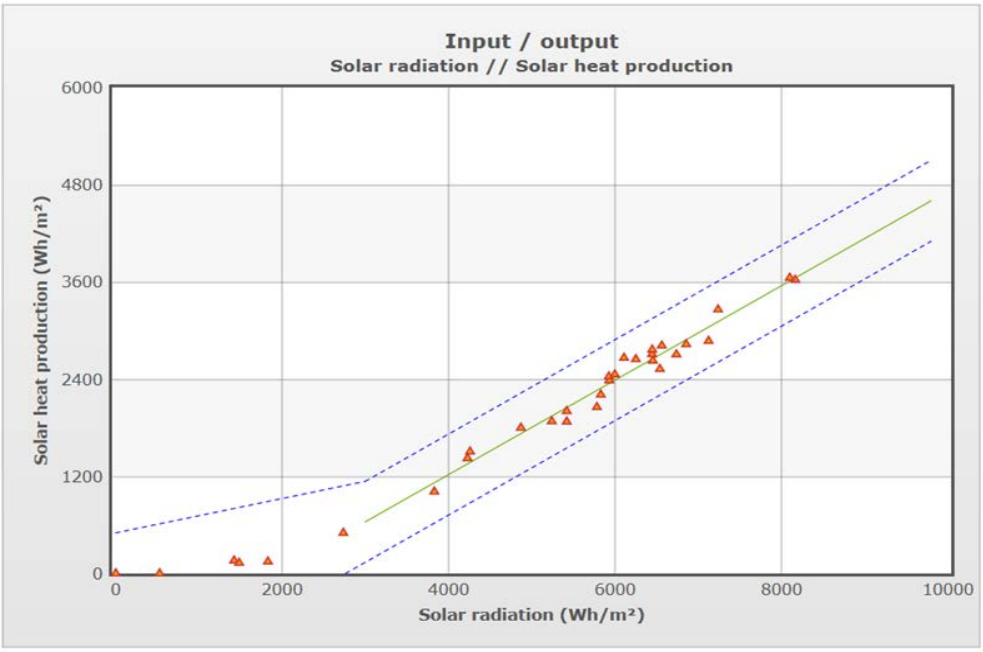

Fig. 4.2.2: Example of input/output plot for one month of daily values (orange triangles) incl. trend line (green) and error band (blue upper and lower limit).

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 con-sider 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 the 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 4.2.3. The solar heat production (black) is in this case not entirely

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proportional to the trend of the total heat production (shown in grey). The solar fraction is seen as the yellow curve.

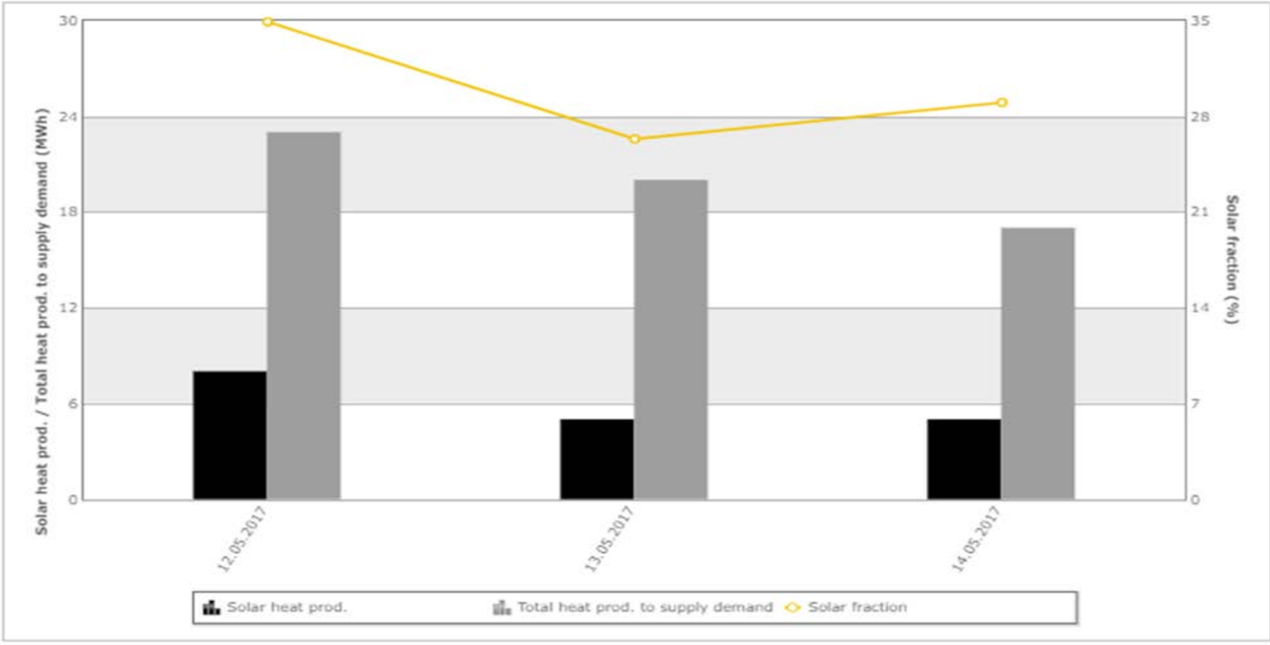

Fig. 4.2.3: Example of solar heat production (black, left axis), total heat production (grey, left axis) and solar fraction (yellow curve, right axis).

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 ($T_{mean,sec}$) is defined as:

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

where:

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

Performance check

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Performance check can be carried out using the methods described in fact sheet 3.3 “Performance guarantees”. This can also be set up as an automatic check (carried out only when the criteria for the calculations are fulfilled). An example of how such a check (measured vs. expected yield) can be illustrated is seen below.

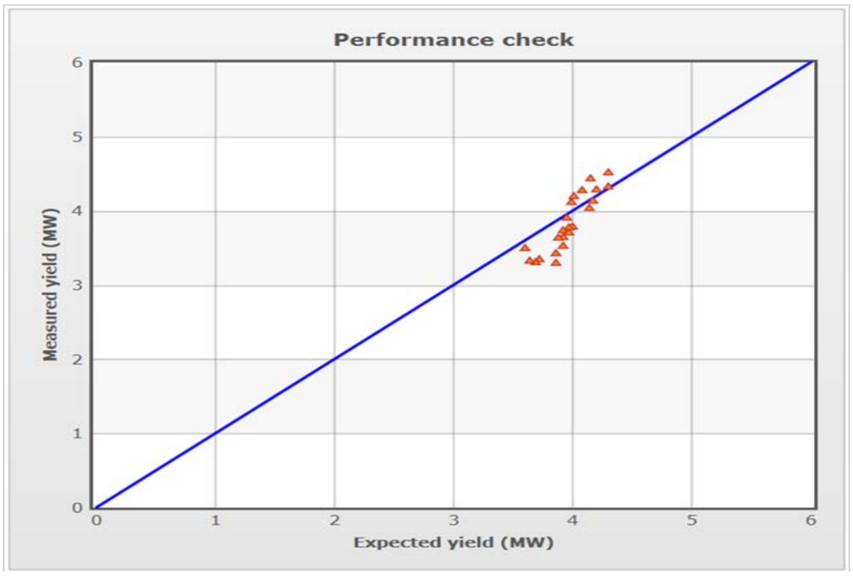

Fig. 4.2.4: Example of a performance check. Measurement points (orange triangles) vs. expected performance (blue line).

Online access to monitoring data

If there is a desire to monitor the solar heating system online either an online access to the control system (often referred to as SCADA system for Supervisory Control And Data Acquisition) is required or a number of variables needs to be fed continuously to an online server. On this server the calculations should then be carried out and the results presented on a website such as solarheatdata.eu. To have a real time access to the present yield, this should be done as often as approx. every 5 minutes. Hence, an internet-based connection must be established and able to upload data automatically.

Note that in principle any internet connection to a control system generates a potential cyber security risk. Hence, it is important to make sure that proper precautions are taken in relation to that, regardless if the internet connection is established for setting up a solar heating system monitoring or other another reason. 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 SDHp2m consortium and the European Commission can in no way be held reliable for any security breach caused by online monitoring of a solar heating system.

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References

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

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

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