Guarantee of annual output

Subject:	Giving and checking **guarantee for annual output** of collector fields
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Description:	Procedures for how to **give annual output guarantees** for large collector fields. Procedures for how to **check annual output guarantees** for large collector fields.
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Contents

Introduction

A methodology for giving and checking the annual output of collector fields is described. The method takes into account that the weather and operating temperatures may vary from year to year. The method works with monthly average operation temperatures and hourly average weather data and will work for systems having approx. constant operating temperatures on a monthly basis – like e.g. solar district heating systems. The basic idea is shown in the bullet list here:

i. Define/describe reference operating conditions for the collector field
ii. Calculate annual output for reference conditions
iii. Calculate the annual output sensitivity to annual differences in weather and operating conditions
iv. Give guarantee for annual output based on the calculation of the annual output for reference conditions – but conditional to variations in weather and operating conditions
v. Check guarantee for the actual operation conditions

Calculations should be done by a validated calculation tool doing hour-by-hour simulation of the collector field. It is assumed that the load side temperatures are varying only on a monthly basis (this will often be the case in district heating applications).

Reference operating conditions for the collector field

In the previous section, the operating conditions influencing the collector field output are listed and described. Now guidelines for how to determine **reference conditions** are given.

Reference weather conditions

A typical/average weather data file should be used with hourly values of:

- Direct radiation on collector plane[1]
- Diffuse radiation on collector plane[3]
- Ambient air temperature
- Precipitation (in case of risk of significant snow or dust)
- Wind velocity (for collectors with high heat loss coefficient sensitive to the wind velocity)

[1] Could be calculated from data for:

- global radiation
- diffuse radiation on horizontal OR beam radiation on plane normal to the beam radiation.

Such data could be data from a nearby weather station (typical/average year should be selected) – or artificially weather data generated by e.g Meteonorm [3] (average data should be selected).

Reference operating temperatures

Reference temperatures in and out of the heat exchanger, should be:

- When the collector delivers to the flow temperature and takes from the return:
  - Inlet temperature: Estimated typical return temperature from district heating network
  - Outlet temperature: Estimated typical flow temperature to the district heating network
- When the collector preheats the return temperature[2]:
  - Inlet temperature: Estimated typical return temperature from district heating network
  - Outlet temperature: Inlet temperature + estimated temperature increase in collector loop[3]

The temperatures in and out of the heat exchanger are the $T_{hx,sec,in}$ and $T_{hx,sec,out}$ shown in fig.1.

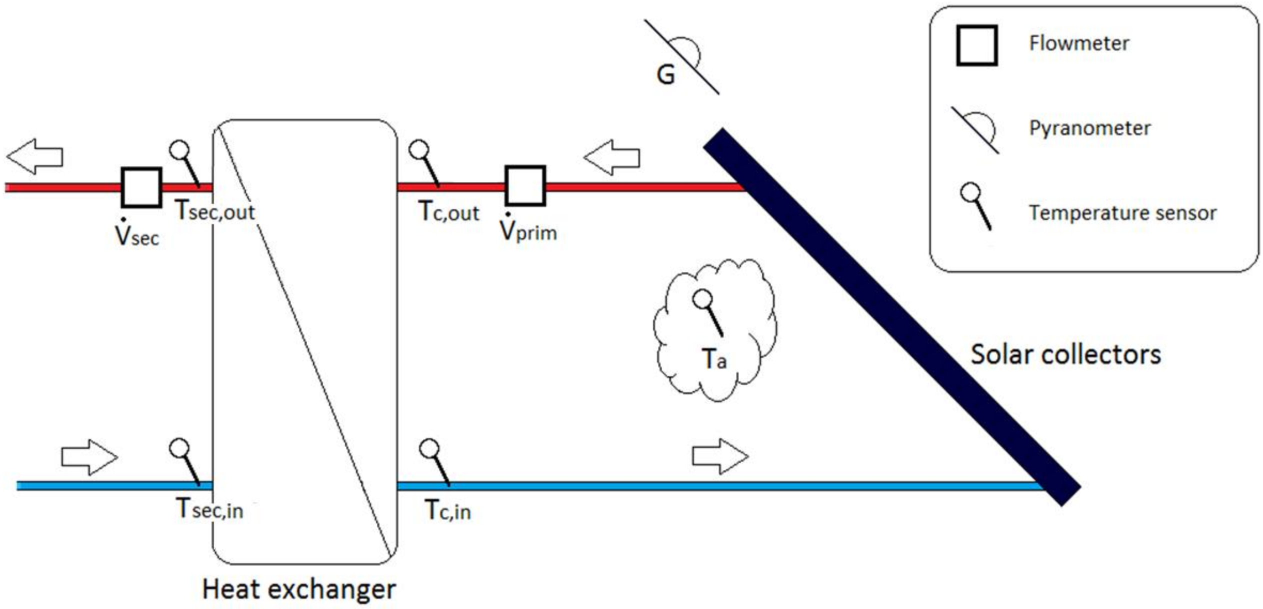

Figure 1. Schematic drawing showing the measurement points. (Source: PlanEnergi)

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[2] Or delivers to a storage and is fed from the return

[3] Depends on the control strategy for the collector loop

If the system has a high solar fraction and/or a long-term storage, detailed calculations of the whole system are necessary to get a good estimate of the typical operating temperatures.

Annual collector field output for reference conditions

To calculate the annual output of the collector field for reference conditions, the following input data for the system are needed:

Collector dimensions:	Height	m
	Length	m
Collector orientation:	Direction	
	Tilt	° from horizontal
Collector field dimensions:	Number of collectors	
	Number of rows	
	Distance between rows	m (from collector forefront to collector forefront)
Collector efficiency parameters:	Collector module reference area	m^2 (the reference area is the area related the efficiency parameters below)
	$\eta 0$	-
	a1	$W/(K\ m^2)$
	a2	$W/(K^2\ m^2)$
	IAM50	-
Pipe heat loss	Option 1:	% of collector output
	Option 2:	W/K total pipe heat loss coefficient
		Ambient temperature for pipes on hourly or monthly basis
Heat exchanger:	UA-value	MW/K (for the actual fluid used)
	flow rate	m3/h (same heat capacity rate on both sides of the HX)
	temperature from collector	°C
	temperature to collector	°C
Snow issues?		No – or description/estimation of the impact of dust
Dust issues?		No – or description/estimation of the impact of dust
Shading issues?		No – or description/estimation of the impact of periodical and/or increasing shading of collector field

Table 1.Template for system description

Furthermore the operation conditions are needed, see section 4. Below an example how to calculate the annual output of the collector field for a set of the reference conditions.

Example

Collector dimensions:	Height	2.1	m
	Length	5.2	m
Collector orientation:	Direction	South	
	Tilt	30	° from horizontal
Collector field dimensions:	Number of collectors	1000	
	Number of rows	50	(all with 20 collectors in series)
	Distance between rows	5	m (from collector forefront to collector forefront)
Collector efficiency parameters:	Reference module area	10	m² (area related the efficiency parameters below)
	η0	0.8	-
	a1	3	W/(K m²)
	a2	0	W/(K² m²)
	IAM50	0.95	-
Pipe heat loss	Option 1:	3	% of collector output
	Option 2:	-	W/K total pipe heat loss coefficient
		-	Ambient temperature for pipes on hourly or monthly basis
Heat exchanger:	UA-value	2.5	MW/K (for the actual fluid used)
	Flow rate	120	m3/h (same heat capacity rate on both sides of the HX)
	Temp. from collector	80	°C
	Temperature to collector	40	°C
Snow issues		Unsignificant	No – or description/estimation of the impact of snow
Dust issues?		No	No – or description/estimation of the impact of dust
Shading issues?		No	No – or description/estimation of the impact of periodical and/or increasing shading of collector field

Table 2.System description

Weather data: Meteonorm data for Copenhagen, Denmark (average year) – hourly values of:

- Direct radiation on collector plane
- Diffuse radiation on collector plane
- Ambient air temperature
- Precipitation (in case of risk of significant snow or dust)
- Wind velocity (for collectors with high heat loss coefficient sensitive to the wind velocity)

Monthly **operating temperatures** for secondary side (the water side) of the heat exchanger:

Month	*Januar*	*Februar*	*March*	*April*	*May*	*June*	*July*	*August*	*September*	*October*	*November*	*December*	*Year*
Treturn	**40**	**40**	**40**	**40**	**40**	**50**	**50**	**50**	**40**	**40**	**40**	**40**	**42.5**
Tflow	**50**	**50**	**60**	**70**	**80**	**80**	**80**	**80**	**70**	**60**	**50**	**50**	**65**

Table 3.Monthly average operating temperatyres on the secondary (water) side of the heat exchanger.

The calculation tool FJERNSOL PRO[4] [1] is used to calculate the annual collector field reference output. The annual output of the collector under reference conditions are calculated to be: 4 440 MWh, corresponding to 444 kWh/m²with the annual total radiation on the collector plane under reference conditions: 1 151 kWh/m² and the annual average ambient air temperature 9.2 °C.

Sensitivity to operating conditions

Sensitivity to weather conditions - example

Calculation of the sensitivity to the weather condition is illustrated by following example:

To find the sensitivity of the collector field output to the weather conditions the following weather data are used instead of the reference weather data:

- Year with low solar radiation – but same ambient temperatures as for reference year
- Year with high solar radiation – but same ambient temperature as for reference year
- Year with low ambient temperature – but same solar radiation as for reference year
- Year with high ambient temperature (same solar radiation as for reference year

To do this e.g. the Meteonorm software can be used choosing “10 years minimum and maximum” for radiation respectively ambient temperature, where the “10 years minimum radiation year” is the year

[4] FJERNSOL PRO is a calculation tool made and used by PlanEnergi. Other tools like e.g. TRNSYS can be used.

within a 10 years period having the lowest annual sum of radiation – and the “10 years maximum ambient temperature year” is the year with highest annual average ambient temperature.

Weather data	Gtot kWh/m²	Ta °C	Qout kWh/m²	% from reference
GaveTave - reference	1151	9.2	444	0%
GminTave	1051	9.2	380	-14%
GmaxTave	1265	9.2	506	14%
GaveTmin	1151	8.2	438	-1%
GaveTmax	1151	11.4	455	2%
GminTmin	1051	8.2	375	-16%
GmaxTmax	1265	11.4	520	17%
GminTmax	1051	11.4	393	-11%
GmaxTmin	1265	8.2	500	13%

Table 4. Calculation of the collector field output for different weather data.

Gave refers to: 10 years average G0 *Tave refers to: 10 years average Ta*

Gmin refers to: 10 years minimum G0 *Tmin refers to: 10 years minimum Ta*

Gmax refers to: 10 years maximum G0 *Tmax refers to: 10 years maximum Ta*

It is seen that the expected variation in the output during a 10 years period due to the variations in solar radiation is within ± 14 %.

It is seen that the expected variation in the output during a 10 years period due to the variations in ambient air temperature is within ± 3 %.

The results are plotted in fig.2 and fig. 3 in the next pages.

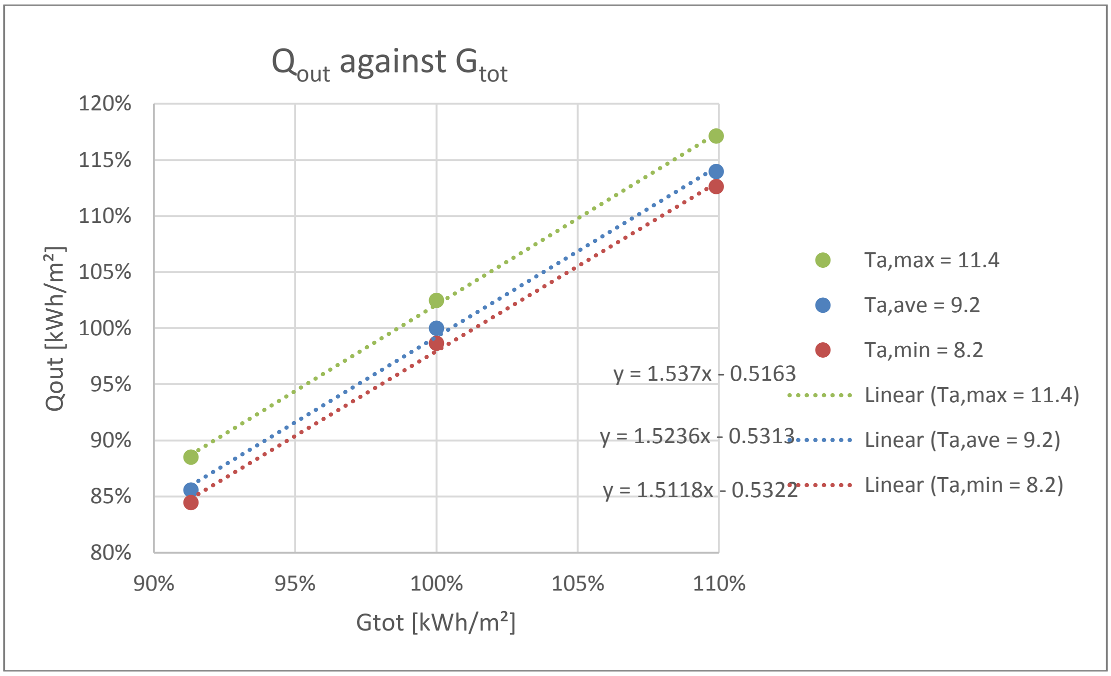

Figure 2. Influence on the output from the weather.

Outputs are calculated for 10 years average, minimum and maximum of Gtot and Ta.

It is seen that if the annual solar radiation change 1 % then the collector output changes approx. 1.5 %. This slope of 1.5 is not significantly influenced by the annual average temperature.

Defining a *radiation factor*, F_G:

$$F_G = c1_G * G/Gref - c2_G,$$

makes it possible to give a simple equation for dependency of the collector field output on the radiation related to the reference output calculated:

$$Qout = F_G * Qout,ref$$

F_G is found from the linear regression equations taking the average values of the regression constants from fig. 2:

$$F_G = 1.52 * G/Gref - 0.53$$

The *radiation factor* shall be calculated for the specific collector in the specific climate.

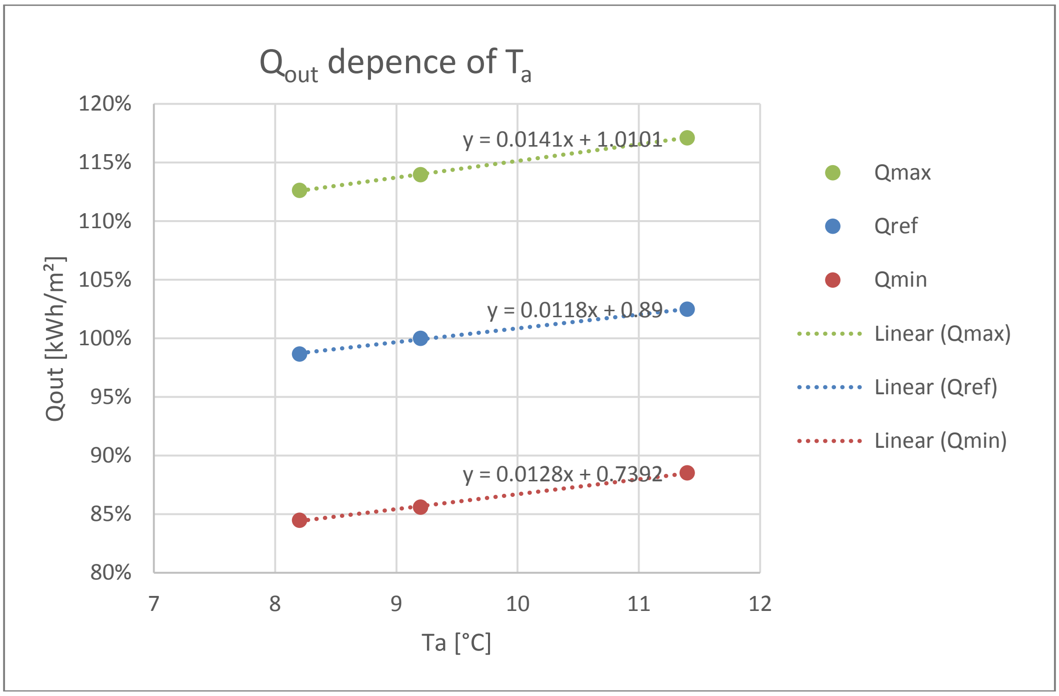

Figure 3. Influence on the output from Ta.

Outputs are calculated for 10 years average, minimum and maximum of Gtot and Ta.

It is seen that if the annual average ambient temperature level change 1 K then the collector output changes approx. 1.3 %. This slope of approx. 1.3 % per K is not significantly influenced by the annual average solar radiation level.

Influence of the annual ambient air temperature level is taken into account by the *ambient temperature factor* F_{Ta}:

$$Qout = F_{Ta} * Qout,ref$$

$$F_{Ta} = 1 - 0.013 (Ta,ref – Ta)$$

The *ambient temperature factor* shall be calculated for the specific collector in the specific climate.

Sensitivity to operating temperatures

Calculations have been done with operating temperatures 5 K higher and 5 K lower to find the influence of operating temperature. The results are seen in table 5 and fig.4.

Level of operating temperatures	Qout kWh/m²
-5 K	474
Reference	444
+5 K	416

Table 5. Dependence of operating temperature level

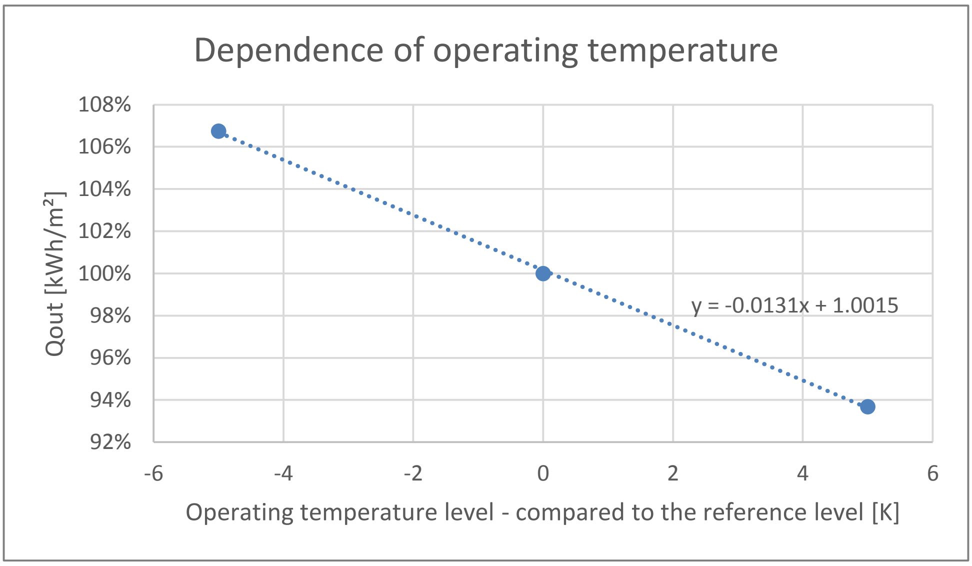

Figure 4 Dependence on the level of operating temperature

It is seen from the "trend equation" in fig.4, that for each degree the temperature level is lowered, the output increase 1.3 %. This is specific for this collector operating in this climate.

Influence of the annual operation temperature level is taken into account by *the operation temperature factor* F_{Top}:

$$Qout = F_{Top} * Qout,ref$$

$$F_{Top} = 1 + 0.013\ (Top,ref - Top)$$

The *operating temperature factor* shall be calculated for the specific collector in the specific climate.

Sensitivity to snow and dust

Looking into the average weather data of Copenhagen it is seen that although there will potential be snow on the collector 5 % of the time – this will only reduce the solar radiation with approx. 1 %.

Looking into the "10 years minimum temperature" weather data year of Copenhagen it is seen that although there will potential be snow on the collector 7 % of the time – this will only reduce the solar radiation with approx. 1.5 %.

As the snow is typically a problem in the winter at low solar heights – and as the collectors are placed in rows behind each other, the collectors covered with snow will anyway already be partly shaded. Hence snow is not considered significant.

Dust is not considered to be significant due to regular rain.

Give guarantee for annual output

Now a conditional guarantee for the annual output of collector field in Example 5.1 can be derived.

The annual reference output Qout,ref of the collector field under reference weather and operation conditions (see 5.1) has been calculated to be:

Qout,ref = 4 440 MWh (444 kWh/m²)

Influence of annual solar radiation level

Influence of the annual solar radiation is taken into account by the solar radiation factor, F_G:

$Qout = F_G * Qout,ref$

$F_G = 1.52 * G/Gref – 0.53$,

where

Gref = 1151 kWh/m²

Influence of annual ambient temperature level

Influence of the annual ambient air temperature level is taken into account by the ambient temperature factor F_{Ta}:

$Qout = F_{Ta} * Qout,ref$

$F_{Ta} = 1 - 0.013 (Ta,ref – Ta)$

where

Ta,ref = 9.2 °C

Influence of annual operation temperature level

Influence of the annual operation temperature level is taken into account by the operation temperature factor F_{Top}:

$Qout = F_{Top} * Qout,ref$

$F_{Top} = 1 + 0.013 (Top,ref – Top)$

where

Top,ref = 53.75 °C

Merged influence of temperature levels

In this case – as the dependency slope for ambient air temperature and operation temperature is the same value with different sign (+/-) - the ambient and operating temperature factors can be merged (with good accuracy) into one *temperature factor,* F_T - using the variable ΔTm = Top – Ta:

$$F_T = 1 + 0.013\ (\Delta Tm,ref - \Delta Tm)$$

where

$$\Delta Tm,ref = 53.75\ °C - 9.2\ °C = 44.55\ °C.$$

Others

In order to take into account other less significant influences (snow, dust, …) and uncertainty in the calculations, a *safety factor* F_O is introduced:

$$F_O = 0.9$$

Now the **guarantee equation** can be written taking into account the factors derived above:

$$Qout,gar = F_G * F_T * F_O * Qout,ref$$

Check guarantee for annual output

The check of the annual output guarantee is rather straight forward and illustrated by the example below.

System from 5.1 is again used as example. The calculated reference output is then 4440 MWh.

The system has been in operation for a year without any operation problems. The following annual measured values have been obtained:

- Annual collector field output Qout,meas: 3810 MWh
- Annual radiation on collector plane: 1090 kWh/m²
- Annual mean ambient temperature: 8.9 °C
- Annual mean operation temperature: 55.1 °C
- Annual mean ΔTm: 55.1 – 8.9 = 46.2 °

The factors are calculated:

$$F_G = 1.52 * G/Gref - 0.53 = 1.52 * 1090/1151 - 0.53 = 0.902$$

$$F_T = 1 + 0.013\ (\Delta Tm,ref - \Delta Tm) = 1 + 0.013\ (44.55 - 46.2) = 0.979$$

$$F_O = 0.9$$

The guaranteed output for the actual conditions are then:

$Q_{out,gar}$ = 0.902 * 0.979 * 0.9 * 4 440 MWh = 0.838 * 4 440 MWh

= 3529 MWh

It is seen that the guarantee is fulfilled as:

$Q_{out,meas}$ (3810 MWh) ≥ $Q_{out,gar}$ (3529 MWh)

So, although in this case the measured output is 14 % below the calculated reference output, the guarantee is still fulfilled.

ANNEX A Templates

Template for the equipment used for data logging

Table A.1. Properties of the equipment used for measuring the collector and heat exchanger efficiency.

Equipment type	Name of manufacturer and component	Location and orientation	Measurement range	Uncertainty +/- [%]
Solar radiation sensor			- [W/m2]	
Flowmeter 1			- [m3/h]	
Flowmeter 2			- [m3/h]	
Temperature sensors T1 T2 ..			- [°C] - [°C]	

Template for the solar collector fluid properties

Table A.2. Solar collector fluid properties of the fluid used in the tests.

Name of manufacturer		[-]
Product name		[-]
Concentration		[wt %]
Heat capacity (40 °C)		[J/(kg·K)]
Heat capacity (80 °C)		[J/(kg·K)]
Density (40 °C)		[kg/m^3]
Density (80 °C)		[kg/m^3]