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# Solar energy — Collector fields — Check of performance

*Energie solaire — Champs de capteurs — Vérification de la performance*

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This document was prepared by Technical Committee ISO/TC 180, *Solar energy*, Subcommittee SC 4, *Systems - Thermal performance, reliability and durability*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 312, *Thermal solar systems and components,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

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# Introduction

This document specifies procedures for checking the performance of solar thermal collector fields. Measured performance is compared with calculated performance - and conditions for conformity are given.

Three levels for accuracy in the checking can be chosen:

— Level I - giving possibility for giving a very accurate estimate (with low safety retention, e.g. $f_{safe}$ = 0,95) - but with requirements for use of expensive measurement equipment.

— Level II/III - allowing for a less accurate estimate (with higher safety retention, e.g. $f_{safe}$ = 0,90) - but possibility to use less expensive measurement equipment.

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# Solar energy — Collector fields — Check of performance

## 1 Scope

This document specifies two procedures to check the performance of solar thermal collector fields. This document is applicable to glazed flat plate collectors, evacuated tube collectors and/or tracking, concentrating collectors used as collectors in fields.

The check can be done on the thermal power output of the collector field and also be on the daily yield of the collector field.

The document specifies for the two procedures how to compare a measured output with a calculated one.

The document applies for all sizes of collector fields.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9060, *Solar energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation*

ISO 9488, *Solar energy — Vocabulary*

ISO 9806, *Solar energy — Solar thermal collectors — Test methods*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 9488 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

**3.1**
**transversal plane**
plane defined by the normal to the plane of the collector and the line orthogonal to the concentrator axis, or the shortest symmetry line for flat biaxial geometries

## 4 Symbols

| | | |
|---|---|---|
| $A_G$ | Gross area of collector as defined in ISO 9488 | $m^2$ |
| $A_{GF}$ | Gross area of collector field | $m^2$ |
| $a_{1,\Delta Q}$ | Heat loss coefficient at $(\vartheta_m - \vartheta_a) = 0$ | $W/(m^2 \cdot K)$ |
| $T_{\Delta Q}$ | Temperature dependence of the heat loss coefficient | $W/(m^2 \cdot K^2)$ |

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| | | |
|---|---|---|
| $v_{\Delta Q}$ | Wind speed dependence of the heat loss coefficient | $J/(m^3 \cdot K)$ |
| $T_s$ | Sky temperature dependence of the heat loss coefficient | — |
| $a_5$ | Effective thermal capacity. In some literature and data sheets denoted $C_{eff}$. Note that $C_{eff}$ unit is $kJ/m^2K$. | $J/(m^2 \cdot K)$ |
| $v$ | Wind speed dependence of the zero-loss efficiency | s/m |
| $v_{IR}$ | Wind speed dependence of IR radiation exchange | $W/(m^2 \cdot K^4)$ |
| $a_8$ | Radiation losses dependence | $W/(m^2 \cdot K^4)$ |
| $b_u$ | Collector efficiency coefficient (wind dependence) | s/m |
| $C$ | Effective thermal capacity of collector | J/K |
| $C_R$ | Geometric concentration ratio | — |
| $c_f$ | Specific heat capacity of heat transfer fluid | $J/(kg \cdot K)$ |
| $c_{f,i}$ | Specific heat capacity of heat transfer fluid at the collector inlet | $J/(kg \cdot K)$ |
| $c_{f,e}$ | Specific heat capacity of heat transfer fluid at the collector outlet | $J/(kg \cdot K)$ |
| $I_{DN}$ | Solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position | $W/m^2$ |
| $I_L$ | Longwave irradiance ($\lambda > 3$ µm) | $W/m^2$ |
| $f_P$ | Safety factor taking into account heat losses from pipes etc. in the collector loop. | - |
| $f_U$ | Safety factor taking into account measurement uncertainty. | - |
| $f_O$ | Safety factor for other uncertainties e.g. related to non-ideal conditions such as non-ideal flow distribution and unforeseen heat losses - and uncertainties in the model/procedure itself. | - |
| $f_{safe}$ | Mathematical product based on the individual safety factors $f_P$, $f_U$, $f_O$ | - |
| $f_{sh}$ | Shading factor | - |
| $D$ | Gap in between adjacent collectors | m |
| $G_{hem}$ | Hemispherical solar irradiance on the plane of collector | $W/m^2$ |
| $G_b$ | Direct solar irradiance (beam irradiance) on the plane of collector | $W/m^2$ |
| $G_d$ | Diffuse solar irradiance on the plane of collector | $W/m^2$ |
| $G_{hem,tot}$ | Total daily irradiation sum on collector plane without shadow | $kWh/m^2$ |
| $h$ | Solar altitude angle. $\sin h = \cos \theta_Z$ | ° |
| $h_{min}$ | Minimum solar altitude angle | ° |
| $H_{sh}$ | Height of the shaded area | m |
| $K_{hem}(\theta_L,\theta_T)$ | Incidence angle modifier for hemispherical solar radiation | — |

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| | | |
|---|---|---|
| $K_b(\theta_L,\theta_T)$ | Incidence angle modifier for direct solar irradiance | — |
| $K_{\theta L}$ | Incidence angle modifier in the longitudinal plane | — |
| $K_{\theta T}$ | Incidence angle modifier in the transversal plane | — |
| $K_d$ | Incidence angle modifier for diffuse solar radiation | — |
| $K_{hem,av}$ | Daily average incidence angle modifier for hemispherical solar radiation | — |
| $L$ | Length of a collector | m |
| $L_{pipe}$ | Overall Length of the pipe system without collectors | m |
| $L_{sh}$ | Length of the shaded area | m |
| $\dot{m}$ | Mass flow rate of heat transfer fluid | kg/s |
| $N_c$ | Number of collectors in a row | - |
| $P_X$ | Coordinate of the point C on the X-axis (C is the point that would reach the shadow formed by the top of the sun facing side of a collector row if it were unobstructed) | - |
| $P_Y$ | Coordinate of the point C on the y-axis | - |
| $\dot{Q}_{measured}$ | Measured power output | W |
| $\dot{Q}_{estimate}$ | Estimated power output | W |
| $Q_{cap,d}$ | Daily capacity heat losses of solar thermal system | J |
| $Q_{estimate\text{-}sys,d}$ | Daily yield estimation of solar thermal system | J |
| $\dot{Q}_{estimate\text{-}col,d}$ | Daily average gross power output collector field | W |
| $Q_{HM,d}$ | Daily yield measurement of the heat meter | J |
| $\dot{Q}_{pipe,d}$ | Daily average heat losses of piping | W |
| $q_{l\text{-}pipe}$ | Empirical specific heat loses per m pipe | W/m |
| $S$ | Spacing center to center in between adjacent rows | m |
| $T$ | Absolute temperature | K |
| $t$ | Time | s |
| $t_s$ | Time start of measurement | s |
| $t_e$ | Time end of measurement | s |
| $u$ | Surrounding air speed (wind speed) | m/s |
| $u'$ | Reduced surrounding air speed $u' = u - 3$ m/s | m/s |
| $V_f$ | Fluid capacity of the collector | $m^3$ |
| $\dot{V}$ | Volumetric flow rate | $m^3/s$ |
| $\dot{V}_e$ | Volumetric flow rate at the outlet of the solar collector | $m^3/s$ |

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| | | |
|---|---|---|
| $\dot{V}_i$ | Volumetric flow rate at the inlet of the solar collector | $m^3/s$ |
| $V_{pipe}$ | Volume of the pipe system without collectors | l |
| $w$ | Width of a collector | m |
| $\Delta t$ | Time interval | s |
| $\Delta T$ | Temperature difference between fluid outlet and inlet ($\vartheta_e$ - $\vartheta_i$) | K |
| $\beta$ | Slope (or tilt), the angle between the plane of the collector and the horizontal.<br>*Note: For collectors rotating around a North-South axis, β is positive in the morning when facing eastwards - and negative in the afternoon when facing westwards* | |
| $\gamma$ | Surface azimuth angle, the deviation of the projection on horizontal plane of the normal to the surface from the local meridian, with zero due south, east negative and west positive | ° |
| $\gamma_s$ | Solar azimuth angle, the angular displacement from south of the projection of beam radiation on the horizontal plan, east negative and west positive | ° |
| $\delta$ | Declination, the angular position of the sun at solar noon with respect to the plane of the equator, north positive. | ° |
| $\phi$ | Latitude, the angular location north or south of the equator, north positive | ° |
| $\eta_b$ | Collector efficiency based on beam irradiance $G_b$ | — |
| $\eta_{hem}$ | Collector efficiency based on hemispherical irradiance $G_{hem}$ | — |
| $\eta_{0,b}$ | Peak collector efficiency ($\eta_b$ at $\vartheta_m - \vartheta_a = 0$ K) based on beam irradiance $G_b$ | — |
| $\eta_{0,hem}$ | Peak collector efficiency ($\eta_{0,hem}$ at $\vartheta_m - \vartheta_a = 0$ K) based on hemispherical irradiance $G_{hem}$ | — |
| $\eta_{hem,\dot{m}_i}$ | Collector efficiency, with reference to mass flow $\dot{m}_i$ | — |
| $\omega$ | Hour angle, the angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15° per hour; morning negative, afternoon positive | ° |
| $\theta$ | Angle of incidence | ° |
| $\theta_L$ | Longitudinal angle of incidence: angle between the normal to the plane of the collector and incident sunbeam projected into the longitudinal plane | ° |
| $\theta_T$ | Transversal angle of incidence: angle between the normal to the plane of the collector and incident sunbeam projected into the transversal plane | ° |
| $\theta_Z$ | Zenith angle, the angle between the vertical and the line to the sun, that is, the angle of incidence of beam radiation on a horizontal surface. $\cos \theta_Z = \sin h$ | ° |

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| | | |
|---|---|---|
| $\vartheta_a$ | Ambient air temperature | °C |
| $\vartheta_{am}$ | Measured ambient air temperature | °C |
| $\vartheta_{as}$ | Ambient air temperature for the standard stagnation temperature | °C |
| $\vartheta_e$ | Collector outlet temperature | °C |
| $\vartheta_i$ | Collector inlet temperature | °C |
| $\vartheta_m$ | Mean temperature of heat transfer fluid in collector loop | °C |
| $\vartheta_{max\_op}$ | Maximum operating temperature | °C |
| $\rho_i$ | Density of heat transfer fluid at collector inlet temperature | $kg/m^3$ |
| $\rho_{i,sec}$ | Density of heat transfer fluid at heat exchanger inlet temperature | $kg/m^3$ |
| $\sigma$ | Stefan-Boltzmann constant | $W/(m^2 \cdot K^4)$ |

# 5 Procedure for checking the power performance of solar thermal collector fields

## 5.1 Stating an estimate for the thermal power output of a collector field

The estimated power output of the collector array is given as an equation depending on collector parameters according to ISO 9806 and operating conditions. The measured power shall comply with the corresponding calculated power according to this equation. Measured and calculated power are only compared under some specific conditions to avoid too large uncertainties - see 5.4.

The estimate can be given for fields of combined collector types - e.g. single glazed and double-glazed:

— If size, inlet and outlet temperatures are available for each field of collectors of same type, estimates can be given for each of these fields.

— An overall estimate for fields with two or more similar collector types can be given choosing representative collector parameters.

NOTE Similar types are e.g. flat plate collectors with single glazing and flat plate collectors with double glazing.

When giving the estimate it shall be stated if it shall be checked according to levels of accuracy I, II or level III (see Introduction and 7.2).

## 5.2 Calculating power output

### 5.2.1 General

Depending on collector type and solar measurements there are three options for formulae:

a) Formula (1): Simple equation using total radiation on the collector plane, valid for:

 — Non-concentrating collector only

b) Formula (2): A more advanced equation using direct and diffuse radiation, valid for:

 — Non-concentrating collector

 — Concentrating collectors with low concentration ratio $C_R < 20$

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c) Formula (3): Formula using direct radiation specifically for concentrating collectors with high concentrating ratio, valid for:

— Focussing collectors with concentration ratio $C_R \geq 20$

The estimate is given by stating the equation to be used for calculating the power output, including specific values for the parameters in equation. The three possible equations are given in the next three sub-sections.

The collector module efficiency parameters $\eta_{0,hem}$, $\eta_{0,b}$, $K_b(\theta_L, \theta_T)$, $K_d$, $a_{1}$,$_{\Delta Q}$ $T_{\Delta Q}$, $a_5$[1)] and $a_8$ should be based on specific[2)] test results. When an estimate is given, it shall always be stated which equation shall be used for checking the performance:

a) Simple check, using total radiation on the collector plane when checking the power output (this document, Formula (1)).

b) Advanced check, using direct and diffuse radiation on collector plane when checking the power output (this document, Formula (2)).

c) Advanced check, using only direct radiation on collector plane when checking the power output (this document, Formula (3)).

Ensure that the parameters are related to gross collector area, $A_{GF}$. If necessary, the parameters shall be converted in accordance with ISO 9806.

### 5.2.2 Non-concentrating collectors — Formula (1)

A simple power performance estimate for non-concentrating collectors is given with Formula (1):

$$\dot{Q}_{estimate} = A_{GF} \cdot \left[ \eta_{0,hem} K_{hem} (\theta_L , \theta_T ) G_{hem} - a_{1,\Delta Q} (\vartheta_m - \vartheta_a ) - T_{\Delta Q} (\vartheta_m - \vartheta_a )^2 - a_5 (d\vartheta_m / dt) \right] \cdot f_{safe} \quad (1)$$

$\vartheta_m$ is mean value of collector in - and outlet temperatures.

Using Formula (1) will normally give bigger uncertainty than using Formula (2) because there is no distinction between direct and diffuse radiation.

$f_{safe}$ is chosen considering potential influences from pipe heat loss, measurement uncertainties, model uncertainties etc. and shall be specified with an accuracy of 2 digits.

$f_{safe}$ is divided into factors considering specific influences. As an example, $f_{safe}$ could be calculated from $f_{safe} = f_P \cdot f_U \cdot f_O$, where:

$f_P$: Safety factor considering heat losses from pipes etc. in the collector loop. To be estimated based on an evaluation of the pipe losses (e.g. by Formula (23))

$f_U$: Safety factor considering measurement uncertainty. To be estimated - with the requirements given in 7.2, a factor of 0,95 (level I) and 0,9 (level II and III) can be used – or detailed documentation for the uncertainty calculation is required according to ISO/IEC Guide 98-3.

$f_O$: Safety factor for other uncertainties e.g. related to non-ideal conditions such as:

— non-ideal flow distribution. To be estimated - should be close to one.

— unforeseen heat losses. To be estimated - should be close to one.

1) In older solar keymark data sheets, $a_5$ is denoted $C_{eff}$.

2) E.g. solar keymark or similar.

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— uncertainties in the model/procedure itself. To be estimated - should be close to one.

$f_{safe}$ Combined safety factor:

$$f_{safe} = f_P \cdot f_U \cdot f_O$$

### 5.2.3 Non- or low-focussing collectors — Formula (2)

A more advanced equation for non- or low-focussing collectors ($C_R$ < 20) can be used if the direct and/or diffuse radiation on the collector plane is measured or can be calculated. Formula (2) includes the incidence angle modifiers for direct and diffuse radiation:

$$\dot{Q}_{estimate} = A_{GF} \cdot \left[ \eta_{0,b} K_b (\theta_L, \theta_T) G_b + \eta_{0,b} K_d G_d - a_{1,\Delta Q} (\vartheta_m - \vartheta_a) - T_{\Delta Q} (\vartheta_m - \vartheta_a)^2 - a_5 (d\vartheta_m / dt) \right] \cdot f_{safe} \quad (2)$$

$\vartheta_m$ is mean value of collector in - and outlet temperatures.

With respect to safety factor, $f_{safe}$ see last part of 5.2.2.

### 5.2.4 Focussing collectors with high concentration ratio — Formula (3)

Formula (3) is used for focussing collectors with high concentration ratio; $C_R \geq 20$ - tracking in one or two axis, and utilizing mainly or only the direct radiation.

$$\dot{Q}_{estimate} = A_{GF} \cdot \left[ \eta_{0,b} K_b (\theta_L, \theta_T) G_b - a_{1,\Delta Q} (\vartheta_m - \vartheta_a) - a_5 (d\vartheta_m / dt) - a_8 (\vartheta_m - \vartheta_a)^4 \right] \cdot f_{safe} \quad (3)$$

$\vartheta_m$ is mean value of collector in - and outlet temperatures.

With respect to $f_{safe}$ see last part of 5.2.2.

## 5.3 Stating a performance estimate

The performance estimate is given by specifying the “collector equation” (Formulae (1), (2) or (3)), and listing the values of the parameters to be used when calculating the power output. It shall be stated if checking shall be done according to level I, II or level III. In Annex B a template for stating the performance estimate is given.

All the collector parameters and safety factors shall be indicated in the reporting sheet (see Annex A).

## 5.4 Restrictions on operating conditions

To limit uncertainties, it is important to give restrictions on the operation conditions for which the estimate is valid. The restrictions given here means that only measurement points taken when the collector field is close to stable full power operation are valid.

**Table 1 — Restrictions on operation conditions (power method). Measured and calculated power shall only be compared for data fulfilling restrictions above.**

| Operation condition | Limits | | | Comments |
|---|---|---|---|---|
| | Formula (1) | Formula (2) | Formula (3) | |
| Shadows | No shadows | | | See 5.5 |
| Change in collector mean temperature | ≤5 K | | | To avoid big change in collector temperature during one hour |
| Ambient temperature | ≥5 °C | | | To avoid snow, ice, condensation on solar radiation sensors |

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**Table 1** *(continued)*

| Operation condition | Limits | | | Comments |
|---|---|---|---|---|
| | Formula (1) | Formula (2) | Formula (3) | |
| Wind velocity | ≤10 m/s | | | To be measured so it is representative for the wind velocity 1 m to 3 m above highest point of collectors |
| $G_{hem}$ | ≥800 W/m$^2$ | - | - | |
| $G_b$ | - | ≥600 W/m$^2$ | ≥600 W/m$^2$ | |

## 5.5 Shadows

### 5.5.1 Shadows on fixed collectors in rows

To limit uncertainties, it is important to avoid shadows on the collectors. Shadows on the collectors could be from rows in front or from other objects.

Related to shadows from rows in the front, only data points for which the solar altitude angle ($h$) is large enough to avoid shadows shall be included - corresponding to $h > h_{min}$ in Figure 1.

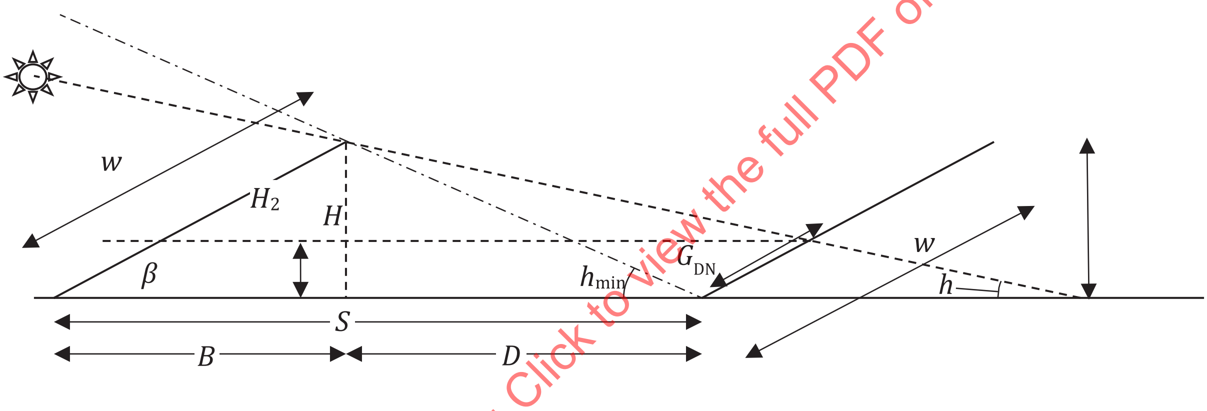


**Figure 1 — Geometry for collectors placed in rows behind each other**

For fixed (non-tracking) collectors placed in rows behind each other, $h_{min}$ can be calculated as a fixed value from the geometry of the row set-up, see Figure 1. For tracking collectors $\beta$ will vary - see 5.5.2.

The solar altitude, $h$ can be calculated from Formula (4) depending on location of the collector field and the time of year and day:

$$\sin h = \cos\phi \cdot \cos\delta \cdot \cos\omega + \sin\phi \cdot \sin\delta \quad (4)$$

For fixed collectors $h_{min}$ can be calculated from Formula (5):

$$\tan h_{min} = \sin\beta / [S / w - \cos\beta] \quad (5)$$

The declination, $\delta$ can be calculated from Formula (6):

$$\delta = 23{,}45 \cdot \sin\left(360 \frac{284 + n}{365}\right) \quad (6)$$

where $n$ is day number.

Shadows could also origin from building, chimneys, trees, etc. Data points at times when such shadows occur on part(s) of the collector field shall be excluded.

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### 5.5.2 Shadows on one-axis tracking collectors in row

One-axis tracking collectors aims at continuously minimizing the angle of incidence according to one axis of rotation.

Placed on a flat terrain, the angle formed by the collectors around its rotational axis, $\beta$, can be assimilated to the tilt of fixed collectors.

It has always a positive value if the tracker is orientated southward - tracking rotational on an East-West axis.

If the tracker is tracking rotational on a North-South axis, it has a positive value in the morning when it the tracker is orientated eastward, and negative in the afternoon when its orientation is westward

The expression of the angle of incidence presented in Formula (18) can be minimized to find the ideal tracking angle, as given by following Formula (7):

$$\frac{\mathrm{d}\theta}{\mathrm{d}\beta}(\beta=\beta_{\mathrm{ideal}})=0\Rightarrow\beta_{\mathrm{ideal}}=\tan^{-1}\left(\frac{\cos(\gamma_{\mathrm{S}}-\gamma)}{\tan(h)}\right) \qquad (7)$$

Typically, one-axis tracking collectors have their rotational axis oriented North-South. Their surface azimuth angle, $\gamma$, is then $-\frac{\pi}{2}$.

Similarly to fixed collectors it is important to avoid self-shading on collectors from adjacent rows to limit uncertainties during the performance test. Reciprocating shadows can be represented through the following figures:

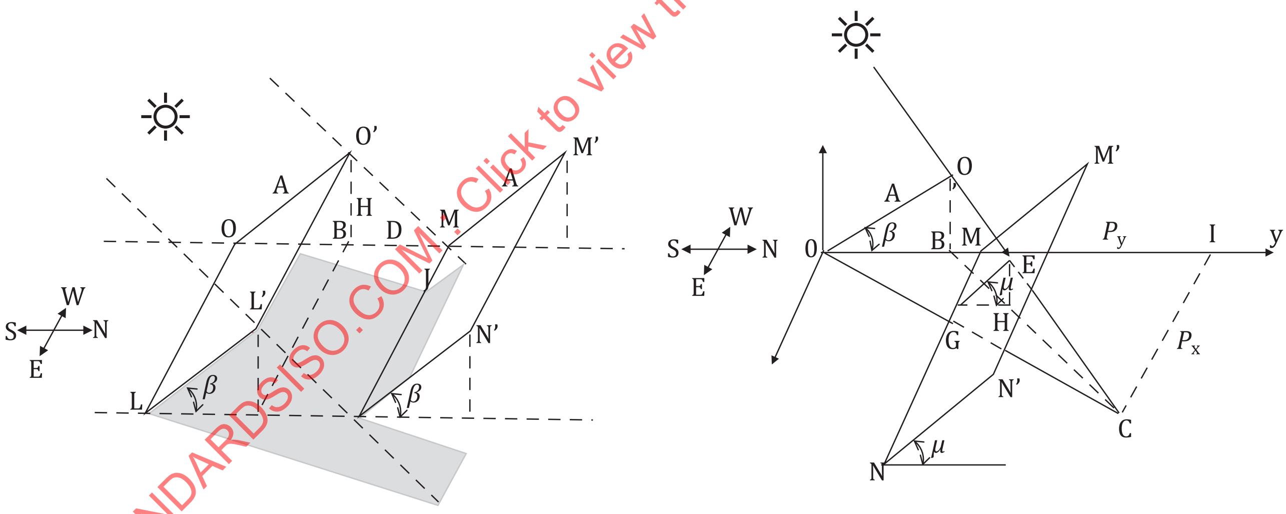


**Figure 2 — Shadow of one collector row to another (left), coordinates system to characterize it (right)**

From the above geometrical representation, Appelbaum and Bany have deduced the following shadows characteristics in Reference [2]:

$$P_{\mathrm{X}}=w\cdot|\sin(\beta)|\cdot\frac{|\sin(\gamma_{\mathrm{S}}-{}^{3})|}{\tan(h)} \qquad (8)$$

$$P_{\mathrm{Y}}=w\cdot\left[\cos(\beta)+|\cos(\gamma_{\mathrm{S}}-\gamma)|\cdot\frac{|\sin(\gamma_{\mathrm{S}}-\gamma)|}{\tan(h)}\right] \qquad (9)$$

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$$H_{sh} = \max\left\{0;\ \min\left[w \cdot \left(1 - \frac{S}{P_Y}\right);\ w\right]\right\} \quad (10)$$

$$L_{sh} = \max\left\{0;\ \min\left[L \cdot N_c + D \cdot (N_c - 1) - S \cdot \frac{P_X}{P_Y};\ L \cdot N_c + D \cdot (N_c - 1)\right]\right\} \quad (11)$$

where

$S$ spacing center to center in between adjacent rows

$D$ gap in between adjacent collectors

$L$ length of a collector

$w$ width of a collector

$N_c$ number of collectors in a row

$P_X$ coordinate of the point C on the x-axis (C is the point that would reach the shadow formed by the top of the sun facing side of a collector row if it were unobstructed)

$P_y$ coordinate of the point C on the y-axis

$H_{sh}$ height of the shaded area

$L_{sh}$ length of the shaded area

The absence of shadows on a collector row means that the calculation result for the shadow height, $H_{sh}$, is either a negative or a null value: $H_{sh} \leq 0$.

This equation can be solved by injecting the expression of $P_y$ into Formula (10). Its solution introduces a range of ideal tracking angles in which no shading occurs. Its endpoints are constants ideal tracking angles. Those angles are opposite numbers:

$$-\beta_{sh} \leq \beta_{ideal} \leq \beta_{sh} \quad (12)$$

$\beta_{sh}$ is a fixed ideal tracking angle value depending on the geometry of the row set-up:

$$\beta_{sh} = \tan^{-1}\left(\sqrt{\frac{S^2}{w^2} - 1}\right) \quad (13)$$

A real tracking system will be limited to a maximum tracking range due to mechanical constraints. In the morning, as long as the ideal tracking angle is superior to the maximum value, it will stay idle then follow the ideal course and finally stopped in the afternoon when the ideal value is inferior to the maximum range. This limitation implies:

$$-\beta_{max} \leq \beta_{real} = \beta_{ideal} \leq \beta_{max} \quad (14)$$

Depending on the collector field geometry the calculated ideal tracking angle at which no shadowing occurs ($\beta_{sh}$) might be superior to the maximum tracking range ($\beta_{max}$). This specific case means that all year long, self-shadowing will stop in the morning and start in the afternoon before the collectors start tracking and after it stops tracking, respectively, while it is maintained at its maximum position. In that situation, the collector field is equivalent to a fixed tilt installation regarding shading analysis.

In the above-mentioned case, the resolution of the equation $H_{sh} \leq 0$ (no self-shading occurring onto the collector field) leads to following results:

a) When $\beta_{max} \geq \beta_{sh}$

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$$\left|\left(\frac{\tan(h)}{\cos(\gamma_s-\gamma)}\right)_{\beta=\beta_{real}}\right| \geq \left(\frac{\tan(h)}{\cos(\gamma_s-\gamma)}\right)_{\beta=\beta_{sh}} \tag{15}$$

with:

$$\left(\frac{\tan(h)}{\cos(\gamma_s-\gamma)}\right)_{\beta=\beta_{sh}} = \frac{\sin(\beta_{sh})}{\frac{S}{w}-\cos(\beta_{sh})} \tag{16}$$

when:

$$\beta_{max} \geq \beta_{sh} \tag{17}$$

b) When $\beta_{max} < \beta_{sh}$

$$\left(\frac{\tan(h)}{\cos(\gamma_s-\gamma)}\right)_{\beta=\beta_{real}} = \frac{\sin(\beta_{max})}{\frac{S}{w}-\cos(\beta_{max})}$$

## 5.6 Collector incidence angle

The collector incidence angle can be calculated from [Reference [1]]:

$$\cos\theta = \cos\theta_Z \cdot \cos\beta + \sin\theta_Z \cdot \sin\beta \cdot \cos(\gamma_s - \gamma) \tag{18}$$

where the zenith angle $\theta_Z$ can be calculated from:

$$\cos\theta_Z = \cos\phi \cdot \cos\delta \cdot \cos\omega + \sin\phi \cdot \sin\delta \tag{19}$$

Or if using $\theta_Z = \frac{\pi}{2} - h$: $\cos\theta = \sin h \cdot \cos\beta + \cos h \cdot \sin\beta \cdot \cos(\gamma_s - \gamma)$

where

$\beta$ is the slope of collector;

$\delta$ is the declination; $\delta = 23{,}45 \sin[360/365 \cdot (284 + n)]$; $n$ being day number of the year;

$\gamma_s$ is the solar azimuth angle;

$\gamma$ is the collector surface azimuth angle;

$\phi$ is the latitude;

$\omega$ is the hour angle.

NOTE A good reference for detailed description of calculating the collector incidence angle is Reference [1].

## 5.7 Example of setting up an equation for calculating performance estimate

Available radiation measurements:

— Total radiation on collector plane only ($G_{hem}$)

Collector field area:

— Type of collector: Flat-plate collector

— Module gross area: 13,2 m$^2$

— Number of collector modules: 1 000

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— $A_{GF}$ = 13 200 m$^2$

Corresponding collector efficiency parameters

— $\eta_{0,hem}$ = 0,80

— $K_{hem}(\theta_L,\theta_T)$ = 1

— $a_{1,\Delta Q}$ = 3,0 W/(K·m$^2$)

— $T_{\Delta Q}$ = 0,01 W/(K$^2$·m$^2$)

— $a_5$ = 10,0 kJ/(m$^2$K)

Other data:

— Estimated pipe heat losses: 3 % → $f_P$ = 0,97

— Estimated uncertainty on measurements: 5 % → $f_U$ = 0,95

— Safety factor other things: $f_O$ = 0,95 (simple Formula (1) is used as diffuse radiation is not measured)

— $f_{safe} = f_P \cdot f_U \cdot f_O$ = 0,88

Diffuse radiation is not measured, so the Formula (1) is used:

$$\dot{Q}_{estimate} = A_{GF} \cdot \left[ \eta_{0,hem} K_{hem}(\theta_L, \theta_T) G_{hem} - a_{1,\Delta Q}(\vartheta_m - \vartheta_a) - T_{\Delta Q}(\vartheta_m - \vartheta_a)^2 - a_5 (d\vartheta_m / dt) \right] \cdot f_P \cdot f_U \cdot f_O$$

$$= 13\,200 \cdot [0{,}80 \cdot I - 3{,}0 \cdot (\vartheta_m - \vartheta_a) - 0{,}01 \cdot (\vartheta_m - \vartheta_a)^2 - 10{,}0 \cdot (d\vartheta_m/dt)] \cdot 0{,}88 \text{ W}$$

$$= 11\,616 \cdot [0{,}80 \cdot I - 3{,}0 \cdot (\vartheta_m - \vartheta_a) - 0{,}01 \cdot (\vartheta_m - \vartheta_a)^2 - 10{,}0 \cdot (d\vartheta_m/dt)] \text{ W}$$

$\vartheta_m$ is mean value of collector inlet ($\vartheta_i$) and outlet ($\vartheta_e$) temperatures - measured close to the heat exchanger if such one is in the loop, see 7.1.

It shall be specified where the power shall be measured. In the collector primary loop - or in the secondary loop ("after" heat exchanger).

An example of a comparison is given in Figure 3.

NOTE The primary loop will often have some fraction of anti-freeze liquid (glycol). This may introduce some uncertainty on the physical parameters (fluid density and fluid specific heat capacity) - hence, this may be a good reason to do power measurement in the secondary loop (after the heat exchanger) which will normally be pure water with known physical parameters. The heat loss from the heat exchanger is normally insignificant compared to the power measured for the valid data points. In case of significant additional heat capacity in the primary circuit (e.g. tank or hydraulic shunt) the measurement shall be done in the primary circuit.

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## 5.8 Determination of potential valid periods

Only periods without shading (see 5.5) under the prescribed restrictions (see 5.4) are used to verify the estimated performance.

## 5.9 Checking collector field power performance

The average measured power output ($\dot{Q}_{meas}$) for all valid data point are compared with the corresponding average power calculated ($\dot{Q}_{estimate}$) according to the formula (Formulae (1), (2) or (3)), using the measured weather data and temperatures in collector loop.

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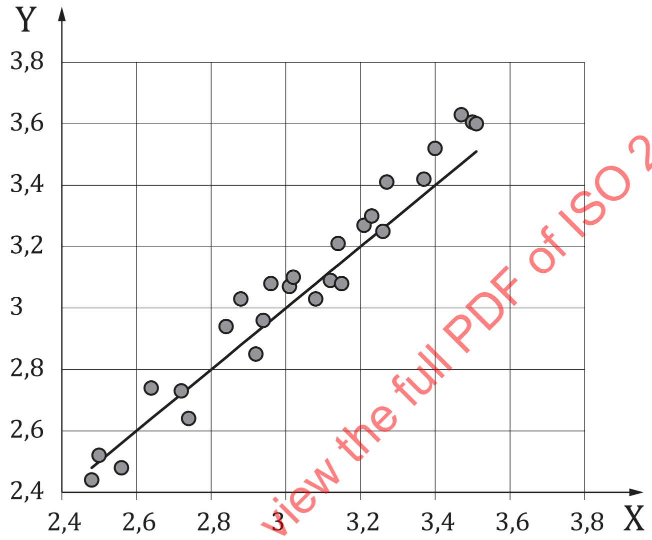
If the average measured power (for at least 20 consecutive valid data points) is equal to or greater than the average power corresponding to the calculation of the estimated power, then the estimated power is verified:

$$\text{Average}[\dot{Q}_{\text{meas}}] \geq \text{Average}[\dot{Q}_{\text{estimate}}] \text{=> Estimate verified}$$

Plot of corresponding data points for measured and calculated thermal power shall be made to check for deviations.

EXAMPLE Checking collector field performance.

27 artificial valid data points for corresponding measured and estimated power are show in Figure 3.




**Key**

X estimated output (MWh)

Y measured output (MWh)

**Figure 3 — Example plot of measured hourly energy against corresponding estimated hourly points. (Artificial data)**

The corresponding average hourly measured, and average estimated power output is compared in Figure 4.

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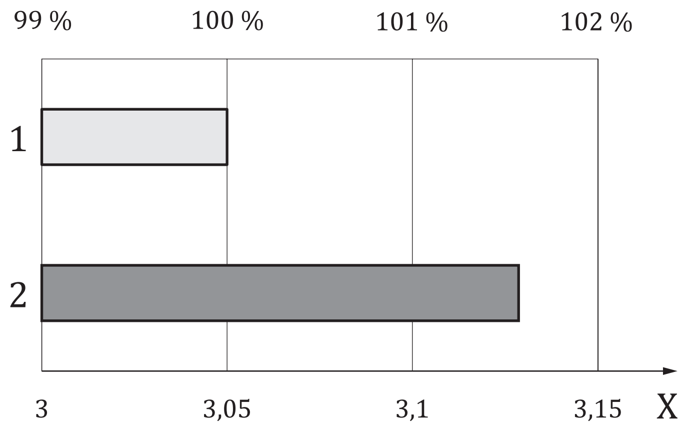


**Key**

X average power for valid points MW

1 average power (Est.)

2 average power (Meas.)

**Figure4 — Plot of average measured power and corresponding estimated average power**

It is seen that:

$$\text{Average}[\dot{Q}_{\text{meas}}] \geq \text{Average}[\dot{Q}_{\text{estimate}}]$$

The estimate is then verified.

# 6 Procedure for checking the daily yield of solar thermal collector fields

## 6.1 Stating an estimate for the daily yield of a collector field

The estimated yield of the collector array is given as an equation depending on collector parameters according to ISO 9806 and operating conditions. The measured yield shall comply with the corresponding calculated yield according to this equation. Measured and calculated yield are only compared under some specific conditions to avoid too large uncertainties – see Tables 2 and 3.

The estimate can be given for fields of combined collector types – e.g. single glazed and double-glazed:

— If size, inlet and outlet temperatures are available for each field of collectors of same type, estimates can be given for each of these fields.

— An overall estimate for fields with two or more collector types can be given choosing representative collector parameters. This method is limited to collectors of similar construction and operation.

When giving the estimate it shall be stated if it shall be checked according to level I, II or III (see Introduction and 7.2).

## 6.2 Calculating daily energy yield

### 6.2.1 General

The estimated daily yield results from the average calculated optical efficiency minus the average calculated heat loss of the collector array multiplied by the measurement time, deducted by the capacity losses and finally multiplied with a safety factor.

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The calculation according Formula (20) is using total radiation on the collector plane and can be applied to non-tracking and non-concentrating collectors

The collector module efficiency parameters $\eta_{0,hem}$, $\eta_{0,b}$, $K_b(\theta_L, \theta_T)$, $K_d$, $a_{1,\Delta Q}$, $T_{\Delta Q}$ and $C$ shall be based on certified[3] test results. Ensure that the parameters are related to gross collector area $A_{GF}$. If necessary, the parameters shall be converted in accordance with ISO 9806.

### 6.2.2 Non-tracking and non-concentrating collectors — Formula (20)

A simple daily system yield estimate for non-tracking and non-concentrating collectors is given with the energy balance of Formula (20):

$$Q_{\text{estimate-sys,d}} = \left[\left(\dot{Q}_{\text{estimate-col,d}} - \dot{Q}_{\text{pipe,d}}\right)\cdot\left(t_e - t_s\right) - Q_{\text{cap,d}}\right]\cdot f_{\text{safe}} \quad (20)$$

where the estimated average gross power output of the collector field is calculated with an average value for the incidence angle modifier $K_{\text{hem,av}}$ (see Formula (25)), the average irradiance $\overline{G_{\text{hem}}}$ over the measurement period ($t_e$-$t_s$) and the arithmetic mean of the temperature measuring points $\overline{\vartheta_m}$ and $\overline{\vartheta_a}$ during the measurement period . Additionally, an empirical shading factor $f_{sh}$ is used for different latitudes and one-dimensional land use ratio W/S from Table 3 to compensate the influence of shadow.

$$\dot{Q}_{\text{estimate-col,d}} = A_{\text{GF}}\cdot\left[\eta_{0,\text{hem}}\cdot K_{\text{hem,av}}\cdot f_{\text{sh}}\cdot\overline{G_{\text{hem}}} - a_{1,\Delta Q}\cdot\left(\overline{\vartheta_{\text{m}}} - \overline{\vartheta_{\text{a}}}\right) - T_{\Delta Q}\cdot\left(\overline{\vartheta_{\text{m}}} - \overline{\vartheta_{\text{a}}}\right)^2\right] \quad (21)$$

and average heat losses from the piping are determined by

$$\dot{Q}_{\text{pipe,d}} = q_{\text{l-pipe}}\cdot L_{\text{pipe}}\cdot\left(\overline{\vartheta_{\text{m}}} - \overline{\vartheta_{\text{a}}}\right) \quad (22)$$

with empiric specific heat losses per m pipe

$$q_{\text{l-pipe}} = 0{,}32\cdot\left(\frac{V_{\text{pipe}}}{L_{\text{pipe}}}\right)^{0{,}22} \quad (23)$$

and daily capacity losses of collector and pipe system, where $\varrho_m$ is the average density and $c_{f,m}$ is the average specific heat capacity of the fluid at the arithmetic mean of $\vartheta_m$ at the start $\vartheta_{m,s}$ and at the end $\vartheta_{m,e}$ of the measurement period.

$$Q_{\text{cap,d}} = \left(A_{\text{GF}}\cdot a_5 + \varrho_{\text{m}}\cdot V_{\text{pipe}}\cdot c_{f,\text{m}}\right)\cdot\left(\vartheta_{\text{m,e}} - \vartheta_{\text{m,s}}\right) \quad (24)$$

where $a_5$ is the effective thermal capacity, $C/A_G$ and $\vartheta_{m,s}$ is the minimum of $\vartheta_{in}$ and $\vartheta_e$ after the pump has started to operate and during the period of the first complete circulation of the fluid on the day of measurement and $\vartheta_{m,e}$ is the arithmetic mean of $\vartheta_{in}$ and $\vartheta_e$ at time stamp $t_e$.

The safety factor $f_{safe}$ is chosen considering potential influences like measurement uncertainties, model uncertainties etc. and shall be specified with an accuracy of 2 digits. For using Formula (20) the value can be set to 0,9.

## 6.3 Stating a performance estimate

The performance estimate is given by specifying the “collector equation” (Formula (20)) and listing the values of the parameters to be used when calculating the daily energy yield. It shall be stated, if checking shall be done according to level I, II or III (see 7.2).

3) E.g. solar keymark or similar.

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In Annex B a template for stating the performance estimate is given.

## 6.4 Restrictions on operating conditions

To limit uncertainties, it is important to give restriction on the operation conditions for which the estimate is valid. The restrictions given here means that daily yield measurement are valid only when the collector field can deliver its energy without limitation.

**Table 2 — Restrictions on operating conditions (daily yield method)**
**Measured and calculated power shall only be compared for data fulfilling restrictions**

| Operation condition | Limits | Comments |
|---|---|---|
| Shadows | Only shading losses of the collector rows taken into account are permitted | Shadows of collector rows are normal and are considered in the calculation (see. Formula (21)) |
| Daily Irradiation $H_{hem}$ | ≥5,5 kWh/m² | This restriction prevents invalid points |
| Total irradiance $G_{\mathrm{hem}}$ | ≥100 W/m² | Lower radiation not relevant |

## 6.5 Shadows

The shading effect on the daily irradiation sum was determined as a function of the land-use ratio $w/S$ (see Figure 1) and the latitude. The shading factor can be taken from Table 3.

**Table 3 — Shading factor $f_{\mathrm{sh}}$**

| latitude | land-use ratio $w/S$ | | | | | | | | | | | | | valid period |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 35 % - 40 % | 40 % - 45 % | 45 % - 50 % | 50 % - 55 % | 55 % - 60 % | 60 % - 65 % | 65 % - 70 % | 70 % - 75 % | 75 % - 80 % | 80 % - 85 % | 85 % - 90 % | 90 % - 95 % | 95 % -100 % | |
| 55° - 60° | 0,99 | 0,99 | 0,98 | 0,98 | 0,97 | 0,95 | - | - | - | - | - | - | - | summer half year |
| 50° - 55° | 0,99 | 0,99 | 0,99 | 0,98 | 0,98 | 0,98 | 0,97 | 0,96 | 0,95 | - | - | - | - | |
| 45° - 50° | 0,99 | 0,99 | 0,99 | 0,99 | 0,98 | 0,98 | 0,97 | 0,97 | 0,96 | - | - | - | - | |
| 40° - 45° | 0,99 | 0,99 | 0,99 | 0,99 | 0,98 | 0,98 | 0,97 | 0,97 | 0,96 | - | - | - | - | |
| 35° - 40° | 0,99 | 0,99 | 0,99 | 0,99 | 0,99 | 0,98 | 0,98 | 0,97 | 0,97 | 0,96 | 0,95 | - | - | |
| 30° - 35° | 1,00 | 1,00 | 0,99 | 0,99 | 0,99 | 0,99 | 0,98 | 0,98 | 0,98 | 0,97 | 0,96 | - | - | |
| 25° - 30° | 1,00 | 0,99 | 0,99 | 0,99 | 0,99 | 0,99 | 0,98 | 0,98 | 0,97 | 0,97 | 0,96 | - | - | |
| 0 - 25° | 0,99 | 0,99 | 0,99 | 0,99 | 0,99 | 0,98 | 0,98 | 0,97 | 0,97 | 0,96 | - | - | - | all year |

## 6.6 Collector incidence angle

For non-tracking and non-concentrating collectors the daily average incidence angle modifier for hemispherical solar radiation $K_{\mathrm{hem,av}}$ in Formula (21) is determined as:

$$K_{\mathrm{hem,av}} = 1{,}03 \cdot K_{\mathrm{d}} \qquad (25)$$

where $K_{\mathrm{d}}$ is calculated according ISO 9806:2017, Annex B.

## 6.7 Example of setting up an equation for calculating performance estimate

Latitude

— 52° N

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Measured day:

— 27.03.

Measurements and averaged values:

| | |
|---|---|
| — measurement time $G_{hem}$ >100 W/m²: | $t_s$ = 07:30 to $t_e$ =18:00 |
| — measurement period at $G_{hem}$ >100 W/m²: | $(t_e\text{-}t_s)$=10,5 h |
| — total irradiation sum on collector plane: | $H_{hem}$= 6,8 kWh/m² |
| — average hem. irradiance: | $G_{hem}$= 6,8/10,5 × 1 000 |
| | = 648 W/m² |
| — mean fluid temperature in the collector loop in starting phase: | $\vartheta_{m,s}$ = 0 °C |
| — mean fluid temperature in the collector loop at $t_e$: | $\vartheta_{m,e}$ = 80 °C |

Collector field area

| | |
|---|---|
| — Type of collector: | Flat-plate collector |
| — Module gross area: | 13,2 m² |
| — Number of collector modules: | 1 000 |
| — Gross areas collector field: | $A_{GF}$ = 13,200 m² |
| — one-dimensional land use ratio: | $w/S$ = 54 % |
| — shading factor: | $f_{sh}$ = 0,98 |

Corresponding collector efficiency parameters

— $\eta_{0,hem}$ = 0,80

— $a_{1,\Delta Q}$ = 3,0 W/(m²·K)

— $T_{\Delta Q}$ = 0,01 W/(m²·K)

— $K_d$ = 0,95

— $K_{hem,av}$ = 0,94

— $C/A$ = 5,0 kJ/(K²·m²)

System parameters

| | |
|---|---|
| — Volume of piping: | $V_{pipe}$ = 15,000 l |
| — Overall length of piping: | $L_{pipe}$ = 700 m |
| — Average specific heat loss of piping: | $q_{l\text{-}pipe}$ = 0,628 W/(m·K) |

## 6.8 Determination of potential valid periods

Only days in the summer half-year between 21.03. and 21.09. in the northern hemisphere and between 21.09. and 21.03. in the southern hemisphere at latitudes ≥ 25° shall be used.

In latitudes <25° days can be used all year round.

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### 6.9 Checking collector field daily yield performance

The estimated daily yield $Q_{\text{estimate-sys,d}}$ is compared to the daily measurement of the heat meter $Q_{\text{HM,d}}$. of the system. Because of capacity and dynamic effects of the solar system the measuring period for the heat meter shall start one hour before and end one hour after the measurement period.

If the average measured yield (for at least 5 consecutive valid data points) is equal to or greater than the average of the calculation of the estimated yield, then the estimated yield is verified:

Average [$Q_{\text{HM,d}}$] ≥ Average [$Q_{\text{estimate-sys,d}}$]=> Estimate verified

## 7 Measurements needed

### 7.1 General

To check the solar collector field performance estimate, it is necessary (at least) to measure the following data points using Formula (1) and Formula (20)(see Figure 5):

| | | |
|---|---|---|
| $\vartheta_e$ | is the outlet temperature from collector field (measured in collector loop at heat exchanger inlet, if such one in the loop) [°C] | |
| $\vartheta_i$ | is the inlet temperature to collector field (measured in collector loop at heat exchanger outlet, if such one in the loop) | [°C] |
| $\dot{Q}$ | is the thermal power supplied from collector field / heat exchanger | [W] |
| $G_{\text{hem}}$ | is the hemispherical solar irradiance on collector plane | [W/m$^2$] |
| $\vartheta_a$ | is the ambient air temperature (shadowed and ventilated) | [°C] |

Using Formula (2) it is also necessary to know direct and diffuse radiation on collector plane ($G_b$ and $G_d$); so at least one of these radiations has to be measured - the other one could then be calculated subtracting the measured one from the $G_{\text{hem}}$

Using Formula (3) it is necessary to measure direct radiation on the (tracking) collector plane.

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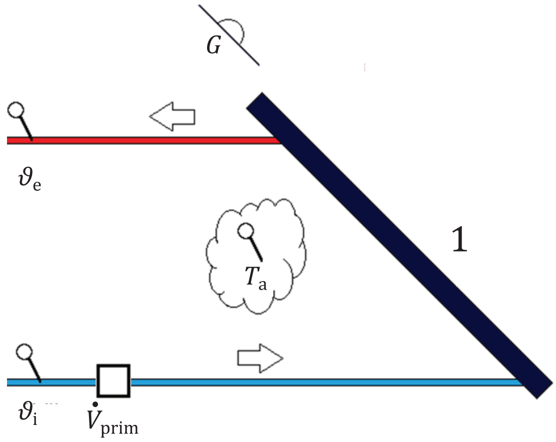


**Key**

| | |
|---|---|
| 1 | solar collectors |
|  | flowmeter |
|  | pyranometer |
|  | temperature sensor |

**Figure 5 — Schematic drawing showing the measurement points. System without heat exchanger**
(Source: PlanEnergi)

All measurement instruments/sensors should be installed as specified in 6.1 and as recommended by the supplier.

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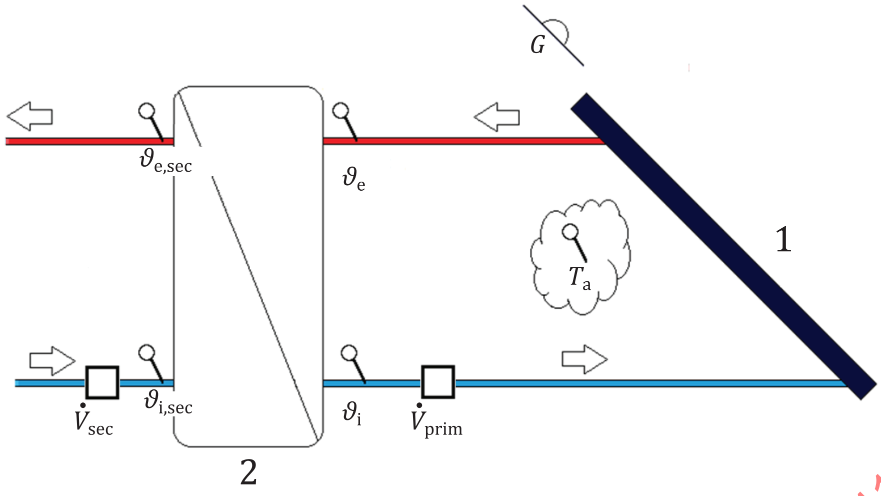


**Key**

1 solar collectors

2 heat exchanger

☐ flowmeter

pyranometer

temperature sensor

**Figure 6 — Schematic drawing showing the measurement points. System with heat exchanger**
(Source: PlanEnergi)

If there is a heat exchanger in the collector loop (see Figure 6), the collector field power $Q_{sec}$ shall be measured on the secondary side of the heat exchanger, based on flow and temperature measurements:

$$\dot{Q}_{sec} = \dot{V}_{i,sec} \cdot \rho_{sec} \cdot c_{f,sec} \cdot (\vartheta_{e,sec} - \vartheta_{i,sec}) \quad (26)$$

where

| | | |
|---|---|---|
| $\dot{V}_{i,sec}$ | is the volume flow at heat exchanger inlets | [m³/s] |
| $\vartheta_{e,sec}$ | is the heat exchanger outlet temperature (measured in secondary loop at heat exchanger outlet) | [°C] |
| $\vartheta_{i,sec}$ | is the heat exchanger inlet temperature (measured in secondary loop at heat exchanger inlet) | [°C] |
| $\dot{Q}_{sec}$ | is the thermal power supplied from heat exchanger | [W] |
| $\rho_{sec}$ | is the density of heat transfer fluid at flow meter position/temperature | [kg/m³] |
| $c_{f,sec}$ | is the specific heat capacity of heat transfer fluid at mean temperature | [J/(kg K)] |

## 7.2 Requirements on measurements and sensors

### 7.2.1 Accuracy

The instrumentation and sensors shall have valid calibration.

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Three levels of accuracy is given here:

— Level I: Measured solar radiation: ±3 % and power output ±2 %

— Level II: Measured solar radiation ±5 % and power output ±3 %

— Level III: Measured solar radiation ±5 % and power output ±5 %

### 7.2.2 Time

Time and date for all recorded data are required. The values in the record shall represent the average values for:

Formulae (1), (2) and (3): Over the last hour (e.g. data in the record saved 2018-04-01 12:00 represent the average values in the hour from 11:00 to 12:00 on April 1st 2018).

Formula (20): Over the measurement period ($t_e$-$t_s$) – and heat meter reading for 1 h before the measurement period $Q_{HM}$ ($t_s$ -1 h) and 1 h after $Q_{HM}$ ($t_e$ +1 h)

Time indication shall always be in zone time (neither summer, nor winter time).

The solar time in the middle of the standard time hour shall be calculated and used for calculation of incidence angles and checking of shadowing. The solar time is calculated from Formula (27):

$$\text{Solar time - Standard time} = 4\,(L_{st} - L_{loc}) + E,\ [\text{minutes}] \qquad (27)$$

where

$L_{st}$ Standard meridian for the local time zone

$L_{loc}$ Longitude for location

$E$ Equation of time; calculated from

$$E = 0{,}017 + 0{,}43\cos B - 7{,}35\sin B - 3{,}35\cos 2B - 9{,}36\sin 2B,\ [\text{minutes}], \text{ where}$$

$$B = (n-1)\,360/365$$

Other requirements:

Formulae (1), (2) and (3):

Logging time ≤1 min

Recording time ≤1 h

Tolerance on time measurement:

— Level I: ≤0,1 %

— Level II: ≤0,1 %

— Level III: ≤0,1 %

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### 7.2.3 Solar radiation measurement

#### 7.2.3.1 General

The pyranometer shall be mounted such that its sensor is coplanar, within a tolerance of <2° with the collector plane. Care shall also be taken to prevent energy reflected from the solar collector onto the pyranometer:

— Sensors for fixed flat plate collector fields: place on top of collectors.

— Sensors for tracking collector fields: close to the tracking axis, close to the southern end of the row in the northern hemisphere and close to the northern end in the southern hemisphere. (reflection avoided thanks to the edge effect).

The body of the pyranometer and the emerging leads of the connector shall be shielded to minimize solar heating of the electrical connections.

For highly concentrating collectors ($C_R$ > 3) mounted on the original manufacturer's solar tracking device, a pyrheliometer of Class 2[4)] or better, as specified in ISO 9060, shall be used to measure the direct normal irradiance ($I_{DN}$). The pyrheliometer shall be mounted on a separate solar tracking device. The pyrheliometer field of vision shall be no more than 6° of arc. The tracking errors associated to the mounting on the tracker shall not exceed ±1°.

Beam irradiance shall be calculated by $G_b = I_{DN} \cdot \cos(\theta)$.

Diffuse irradiance shall be calculated by $G_d = G_{hem} - G_b$.

The sensors shall be installed such as to receive the same levels of direct, diffuse and reflected solar radiation as are received by the complete collector field. For very large collector fields this means that several sensors might be necessary.

In fields of flat plate collectors, the first pyranometers/pyrheliometer shall be placed in the middle of the collector field.

#### 7.2.3.2 Accuracy of solar sensors

— Level I: Pyranometers, Class 2 or better, as specified in ISO 9060, pyranometer(s) shall be used to measure the hemispherical solar radiation ($G_{hem}$) following the recommendation given in ISO/TR 9901. Class I or better pyranometer(s) equipped with a shading ring or alternatively a pyrheliometer, together with a pyranometer, shall be used to measure the diffuse short-wave radiation.

— Level II/III: Solar sensors with accuracy ± 5 % in the range of 600 W/m$^2$ - 1 000 W/m$^2$ shall be used to measure the hemispherical solar radiation ($G_{hem}$) and the diffuse short-wave radiation. Satellite data can be used. But due to the lack of international standards for the satellite data, a comparable accuracy of the data has to be proven on a case-by-case basis by the providing source.

#### 7.2.3.3 Location of solar sensors

The required minimum number of pyranometers / pyrheliometers are determined by the size of the collector field:

— Level I: Maximum distance from any collector to nearest pyranometer / pyrheliometer ≤500 m

— Level II/III: Maximum distance from any collector to nearest pyranometer / pyrheliometer ≤1 000 m

— Level III: Satellite data can be used

4) From ISO 9060:2018 Class I is now Class A and Class II is now Class B.

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All radiation measurements shall be recorded. Average values for all instruments are used for the estimation of collector performance.

#### 7.2.3.4 Cleaning of solar sensors

— Level I: If clean air (no smoke and no particles in the air) the solar sensors shall be cleaned twice a week in the measuring period. If the air is not free of smoke and particles the solar sensors shall be cleaned every day.

— Level II and III: The solar sensors shall be cleaned every week in measuring the period (not required in case of satellite data)

NOTE It is strongly recommended always to have at least two solar sensors.

### 7.2.4 Temperature measurements

#### 7.2.4.1 General

Three to five temperature sensors are required. These are the fluid temperatures and ambient air temperature:

Fluid temperatures:

Collector loop side:

Collector inlet

Collector outlet

Secondary side of heat exchanger, if such one in the loop:

Heat exchanger inlet

Heat exchanger outlet

Ambient air temperature

#### 7.2.4.2 Fluid temperatures

Maximum permissible error for absolute values of collector outlet and inlet temperatures:

— Level I, II and III: <0,35 K (Class A)

The sensor for temperature measurement of the heat transfer liquid shall be mounted at no more than 1 m from the heat exchanger, if such one in the loop, and insulation shall be placed around the pipe work both upstream and downstream of the sensor. If it is necessary to position the sensor more than 1 m away from the heat exchanger, then a test shall be made to verify that the measurement of fluid temperature is not affected. The position of temperature measurement shall be in the centre of the pipe in a pipe section without any possibility for air being trapped near the sensor.

#### 7.2.4.3 Ambient air temperature

Maximum permissible error:

— Level I/II/III: <0,35 K (Class A)

The sensor shall be shaded from direct and reflected solar radiation by means of a white-painted, well-ventilated shelter. The shelter itself shall be shaded and placed at least 1 m above the local ground surface to ensure that it is removed from the influence of ground heating. The shelter shall be positioned not more than 100 m distance to the collector field.

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### 7.2.5 Flow rate measurement

The flow meters shall be calibrated for fluid density over the relevant range of fluid flow rates and temperatures.

— Level I: Standard uncertainty: <1 % in relevant range

— Level II/III: Standard uncertainty: <2 % in relevant range

Alternative to separate flow rate measurement on secondary side is integrated power measurement - see below.

### 7.2.6 Power measurement/calculation

The thermal power output and energy output on the secondary side can be measured directly by integrated instrument or calculated from separate flow and temperature sensors:

— The thermal power and energy output can be measured[5)] by an integrated measurement device "heat meter" (calibrated for water).

  — Level I: Standard uncertainty<2 % in relevant range

  — Level II/III: Standard uncertainty<3 % in relevant range

— The thermal power output can be calculated from measured flow and temperature difference:

$$\dot{Q} = v \cdot c_p \cdot \varrho \cdot \Delta T$$

where

$\dot{Q}$ is the power, W

$v$ is the flowrate, $m^3/s$

$\Delta T$ is the difference between outlet and inlet temperature, K

$c_p$ is the temperature dependent specific heat capacity of the circulation water J/(kgK)

$\varrho$ is the temperature dependent density of the circulating water $kg/m^3$

Flow rate shall be measured on inlet side (cold side), and the temperature for determination of and density of the fluid shall be the inlet temperature. The temperature for determination specific heat capacity shall be the arithmetic mean of inlet and outlet temperatures.

### 7.2.7 Measurement of wind speed

Tolerance in both levels 1 m/s. Measurement of wind speed shall be done 1 m to 3 m above the highest point of the collector field - not more than 100 m from the collector field.

NOTE Measurement of wind velocity is only done to check if the requirement given in Table 1 that wind velocity shall be less than 10 m/s is fulfilled.

## 7.3 Valid data records

Only data records fulfilling the requirements (hourly average values) in 5.4 for the power check and the requirements in 6.4 for the daily yield check are valid.

5) Care to be taken if the liquid is not water.

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