Annual Yield Check of Large Scale Solar Thermal Systems

IEA SHC TASK 68 | Efficient Solar District Heating Systems - Subtask A: Concepts for Efficiently Providing Solar Heat at Medium-High Temperature Level

Technology Collaboration Programme
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Annual Yield Check of Large Scale Solar Thermal Systems

This is a report from SHC Task 68: Efficient Solar District Heating Systems and work performed in Subtask A: Concepts for Efficiently Providing Solar Heat at Medium-High Temperature Level

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1 Executive Summary

This document describes a simple methodology for verifying the predicted annual yield of large-scale solar systems. This method was developed by Fraunhofer ISE and Solar Experience GmbH as part of the ProSolNetz project (FKZ: 03EN603F) (Bundesministerium für Wirtschaft und Klimaschutz [BMWK.IIB5] & Forschungszentrum Jülich GmbH [PT-J.ESN6], 2025) and is described in ISO/DIS 24194. This report is divided into an overview of currently available methods for field characterization, which are relevant in the context of method development. It shows the global objectives that were at the forefront of the development of a method for checking the annual yield of a large-scale solar installation, presents the most important changes in the revision of ISO 24194 in this context and describes the practical application of the annual yield check as well as the restrictions that the procedure imposes on the operating and environmental conditions.

2 Field measurement methods

The general procedures for evaluating the thermal performance of solar thermal collectors are described in ISO 9806:2017 (International Organization for Standardization, 2017). The aim is generally a valid parameterisation based on steady state laboratory tests or quasi-dynamic laboratory or in-situ tests. The option of quasi-dynamic in-situ testing was implemented in the standard in 2017. The aim was to be able to parameterise very high-performance collector technologies, such as parabolic trough collectors or linear Fresnel collectors, for which no suitable test laboratory infrastructure is available. The complete parameterisation based on field measurement data of collectors with bi-axial IAM behaviour requires the extension of the methods given within ISO 9806:2017. The methods of ISO 9806:2017 form the basis for the development of a method for checking the annual yield of large scale solar thermal collector applications is presented in this report.

The European standard EN 12975:2022 (Deutsches Institut für Normung [DIN], 2022) forms the basis for the Solar Keymark certification of thermal solar collectors. It incorporates the procedures for assessing the thermal performance of ISO 9806:2017. It also contains a procedure for calculating the "Gross Thermal Yield" (GTY). This is calculated based on the parameters described in ISO 9806. The aim is to compare the gross annual yield of a collector unit depending on the location and three constant average collector temperatures. The claim of this method lies in the standards and thus comparable determination of a KPI for the annual gross yield. The procedure is implemented within the Solar Keymark certification in the "ScenoCalc" (The Solar Keymark CEN Keymark Scheme, 2023) calculation tool. The results calculated in this way are published for all certified collectors in the "Solar Keymark Data Base" (*The Solar Keymark Database)*. The GTY can also be used to determine the annual efficiency of a collector as a function of the assumed constant difference between the collector mean temperature and the ambient temperature for a specific location. The development of the method for checking the annual yield of a collector field is based on the methodology for calculating the GTY and thus ensures that the developed procedure is compatible with the normative procedures for characterising thermal solar collectors.

The methods of EN12975:2022 and ISO 9806:2017 are used to describe the product behaviour depending on the operating conditions and form the basis for yield forecasting. ISO 24194 prescribes to a different belief and describes methods that standardise the verification of the predicted performance of a collector field. ISO 24194 deals with checking the field performance of large scale solar thermal systems and thus provides standardised methods for quantifying the current field performance (Performance Check) and the daily field yield (Daily Yield Check). The Performance Check method was also described in the fact sheet "IEA SHC TECH SHEET 45.A.3.2" (Jan Erik Nielsen, 2014) as a procedure for checking the performance guarantees for large collector fields. A guide to ISO 24194 was created within IEA SHC Task 68 (Daniel Tschopp et al., 2025). This guide supplements the standard regarding the performance check method. It contains explanations and clarifications of complex issues, offers comments and recommendations, presents practical real-world application examples and provides guidance on how to implement the standard. The guide also highlights current limitations and addresses issues not covered by the ISO standard yet. Method extensions are also suggested to improve the practical applicability of the method. Among other things, it is shown that the Performance Check method of ISO 24194 allows, due to limited stationary operating conditions, only selective statements on the thermal performance of the solar field but does not yet generate reliable statements on the overall operating behaviour. The Daily Yield Check depicts the effects of the operating behaviour but is limited to one day and to stationary collector technologies.

3 Objective of the method development

The aim was to develop a simplified method for checking the predicted annual yield of large collector arrays, which can also be used for concentrating and tracking collectors. The method should have a marketable simplicity to ensure its broad application, even in a non-scientific context. The need for method development was derived from the above-mentioned standards. Based on the performance parameters of individual collectors based on laboratory measurements or field measurement data, the methods of ISO 24194 were used for this purpose. The results of this work were directly incorporated into the current revision of ISO 24194.

4 Revision of ISO 24194

The Guide to ISO 24194 contains detailed information on the shortcomings of ISO 24194 and the need for further development, so only those shortcomings of the standard that were important for the development of the method for verifying the annual yield are mentioned here again.

The most important adjustments and changes made within the procedures of ISO 24194 concern the existing part of the Power Check and Daily Yield Check methods and the introduction of a new methodology for checking the annual yield of solar thermal fields.

For the performance check, different or incomplete formulas were used within ISO 24194 compared to ISO 9806:2017. For this reason, the modelling within ISO 24194 was adapted to the generally applicable equations of ISO 9806:2017 during the revision process of the standard. This means that in future it will also be possible to differentiate between global, direct and diffuse radiation components. The introduction of this differentiation was one of the basic prerequisites for the successful development of a method for checking the annual yield of large scale solar thermal systems.

The daily yield check was also previously limited to non-tracking and non-concentrating collectors. Here, too, the reason was the lack of differentiation between diffuse and direct radiation. To remedy this, a general formula was determined that can be used for all collectors. This means that the daily yield method now calculates with an effective average irradiation power $\overline{G_{\text{eff}}}$ over the measurement period. This consists of a proportion of average direct radiation $\overline{G_b}$, which is weighted with an average incidence angle modifier $\overline{K_b}$ and a proportion of average diffuse radiation, which is multiplied by K_d.

$$\overline{G_{\text{eff}}} = \overline{K_b}(\theta_T, \theta_L)\overline{G_b} + K_d\overline{G_d} \tag{1}$$

While direct radiation is typically included in the relevant basic solar potential for all collectors, for concentrating collectors the diffuse radiation is only available proportionally weighted with K_d. Since the verification of an annual field yield is a correlation procedure, those components that are not involved in the correlation must be eliminated, as they would otherwise interfere with the significance of the correlation. It was therefore necessary to relate the correlation only to the effective radiation H_{eff}. This is calculated according to

$$H_{\text{eff}} = H_b + K_d \cdot H_d \tag{2}$$

For collectors with low concentration factors $C_R \leq 1{,}25$ or an associated diffuse angle correction factor $K_d \geq 0{,}8$ this can be simplified to

$$H_{\text{eff}} = H_{\text{hem}}. \tag{3}$$

With this simplification, the relative deviation is approximately 2% and thus corresponds approximately to the inaccuracy that can be expected from the collector test according to ISO 9806:2017.

Consequently, the creation of a methodology for checking the annual yield (Annual Yield Check) was also subject to the requirement of finding a single formula that is valid for all collector technologies. However, to avoid complex and maintenance-intensive measurement technology for the separate recording of direct and diffuse radiation, which is not necessary for the operation of large-scale systems with flat-plate and vacuum tube collectors, a simplified formula based on the hemispheric irradiation sum should also be available for determining the daily and annual yield if possible.

In addition to the concretisation of existing methods and the introduction of a new method, the applicability of 24194:2022 has been further simplified, for example by the usability of satellite-based irradiation data. ISO 24194 is currently in DIS stage (Draft International Standard).

5 Method for checking the annual yield

The method implemented in ISO 24194 for checking the annual yield consists of the procedural steps shown in Figure 1.

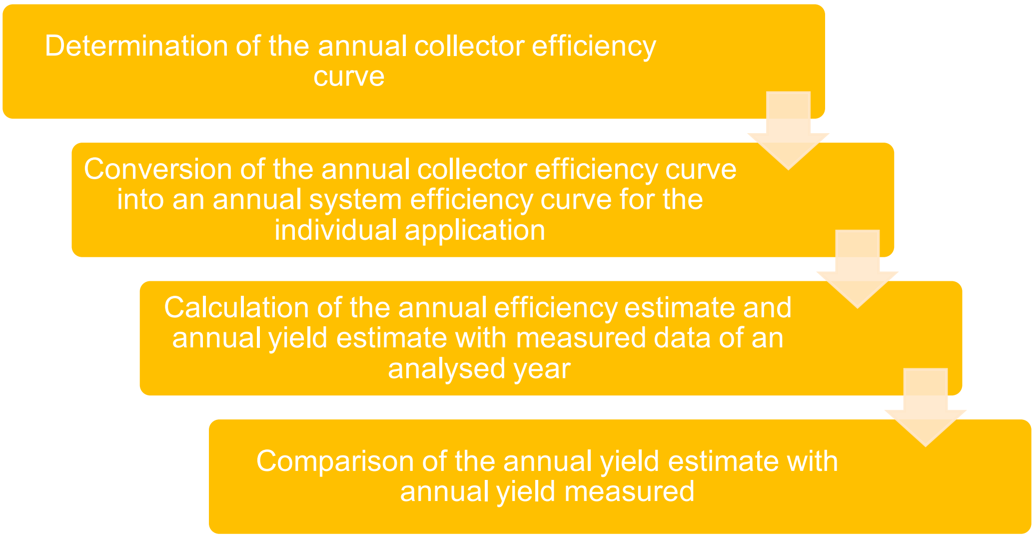


Figure 1 Process steps of the method for checking the annual yield

5.1 Determination of the annual collector efficiency curve

Based on the parameterisation according to ISO 9806:2017, the GTY_a is calculated for three mean collector temperatures equally distributed over the working temperature range of the collector. These values form the basis for determining the annual efficiency curve

$$\eta_a = a \cdot x^2 + b \cdot x + c, \tag{4}$$

based on annual efficiency values

$$\eta_{a,i} = \frac{\mathrm{GTY}_{a,i}\,(\vartheta_{\mathrm{op},i}, \Lambda)}{H_{\mathrm{eff,sel}}} \tag{5}$$

at the selected location Λ.

The parameters a, b and c of the annual efficiency curve are calculated by quadratic regression of the annual efficiency $\eta_{a,i}$ over the reduced temperature difference

$$x_i = \frac{\Delta T_i}{H_{\mathrm{eff,sel}}}. \tag{6}$$

In the following steps, these regression parameters are used for the conversion of the annual collector efficiency curve into an annual system efficiency curve for the individual application and the calculation of the annual efficiency estimate and annual yield estimate with measured data of an analysed year.

To reduce the effort required to create the annual efficiency curve, the calculation can be carried out based on the weather data of the corresponding climate zone of ISO 9459 (ISO 9459, 2025). Previous analyses show no significant difference in the determination of the annual efficiency curve between the use of specific weather data at the selected location and the weather data of the corresponding climate zone. It would therefore even be conceivable to calculate this for each Solar Keymark certified collector once for all nine climate zones and to provide the user with this information as a basis for checking the field yield (e.g. within the Solar Keymark data sheet). Table 1 shows the nine climate zones with their corresponding irradiation and temperature data.

Table 1 Climate zones with their corresponding irradiation and temperature data

Climate zone	Location	Latitude	Longitude	Ghoris	Gdiff-horis	Gb-horis	Gbn	Ta
Unit	-	[°]	[°]	[kWh/m²]	[kWh/m²]	[kWh/m²]	[kWh/m²]	[° C]
ALPINE	Davos	46,813	-9,8435	1412	579	833	1678	4
COLD	Edmonton	53,3	113,583	1268	499	769	1662	3
DRY	Kairo	30,083	-31,283	1880	773	1107	1715	22
HOT	Abu Dhabi	24,43	-54,65	2027	841	1186	1759	28
Mediterranean	Roma/Ciampino	41,8	-12,583	1605	619	986	1732	16
Subtropic	Madras	13	-80,183	1950	935	1015	1445	28
TEMPERATE	London	51,517	-0,117	975	530	445	886	12
Tropical	Dhaka	29,983	-90,25	1629	801	827	1328	21
Wet	Manaus	-3,133	60,017	1796	886	911	1291	27

5.2 Conversion of the annual collector efficiency curve into an annual system efficiency curve for the individual application

To determine the annual system efficiency curve, the annual collector efficiency curve is reduced by the system losses as a function of the temperature difference between the mean system temperature and the ambient temperature:

$$\eta_{n,\mathrm{sys}} = a \cdot x^2 + b \cdot x + c \; - U_{\mathrm{sys}} \cdot x \qquad (7)$$

with

$$U_{\mathrm{sys}} = \frac{1}{\Delta T_{\mathrm{op,ref}}} \cdot \frac{(Q_{\mathrm{col,ref}} - Q_{n,\mathrm{ref}})}{A_{\mathrm{GF}}} \qquad (8)$$

The system losses U_{sys} consider the operating temperature difference $\Delta T_{\mathrm{op,ref}}$ between the average system temperature and the ambient temperature under reference conditions at the system location. The average system temperature thereby is weighted with the hemispheric irradiance of the weather data set for the reference year. The system losses U_{sys} consider the difference between the annual collector yield and the nominal system yield specified by the supplier. The information provided by the supplier, which is usually based on simulations and/or empirical values, is of crucial importance. The formulae and the exact procedure for determining the system losses U_{sys} and thus the annual system efficiency curve can be found in ISO/DIS 24194.

5.3 Calculation of the annual efficiency estimate and annual yield estimate with measured data of an analysed year

To determine the annual efficiency estimate, a safety factor is applied to the annual system efficiency curve:

$$\eta_{\mathrm{estimate}} = \left[a \cdot x^2 + b \cdot x + c \; - U_{\mathrm{sys}} \cdot x\right] \cdot f_{\mathrm{safe}} \qquad (9)$$

This safety factor must be determined individually and includes measurement and process uncertainties. ISO 24194 specifies three different safety levels depending on the quality of the measurement technology used. Further information on this topic can be found in the Guide to ISO 24194.

In contrast to the determination of the annual system efficiency, the annual efficiency estimate is now calculated using the real measurement data of the corresponding year. In comparison to the operating temperature difference $\Delta T_{\text{op,ref}}$ mentioned above, the operating temperature difference ΔT_{op}, used here is not weighted with the hemispheric irradiance of the weather data set of the reference year, but with the real measured specific thermal output $\dot{q}_i$ of the system in the period under consideration.

This results in the annual yield estimate

$$Q_{\text{estimate},a} = A_{GF} \cdot \eta_{\text{estimate,op}} \cdot H_{\text{op}}, \tag{10}$$

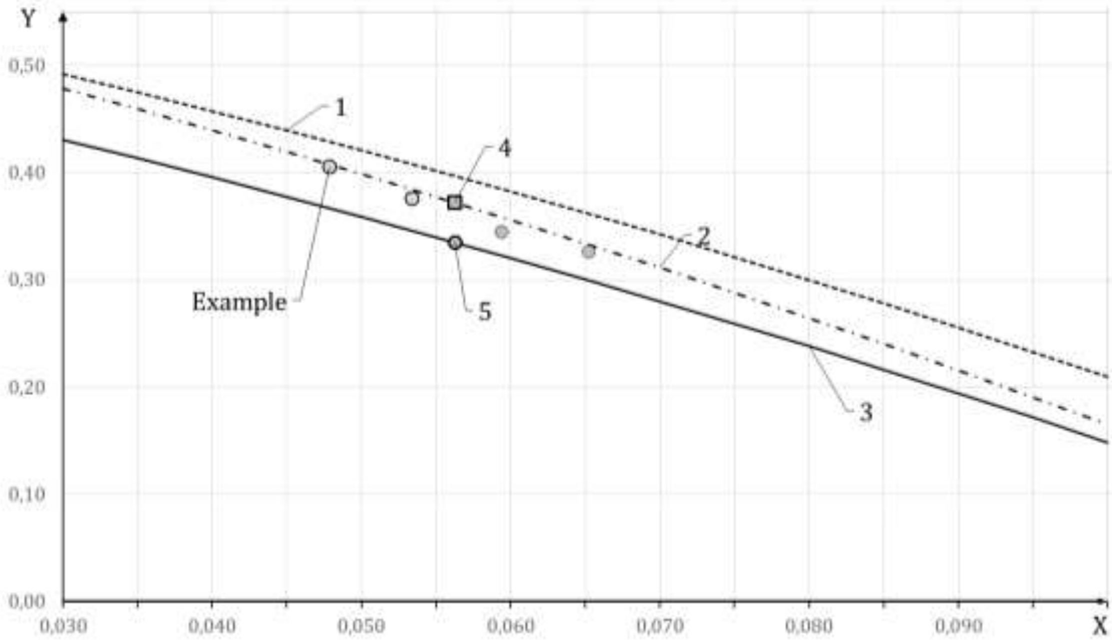
which reads with (9)

$$Q_{\text{estimate},a} = A_{GF} \left[a \cdot \frac{\Delta\, T_{\text{op}}^2}{H_{\text{op}}} + b \cdot \Delta\, T_{\text{op}} + c \cdot H_{\text{op}} - U_{\text{sys}} \cdot \Delta\, T_{\text{op}} \right] \cdot f_{\text{safe}} \,. \tag{11}$$

The formulae and the exact procedure can be found in the ISO/DIS 24194.

5.4 Comparison of the annual yield estimate with annual yield measured

The estimated annual yield is compared with the annual measurement of the system's heat meter in the same annual period. The estimated yield is verified, if the measured yield is equal to or greater than the calculated estimated yield. By creating a diagram like Figure 2, this verification can also be provided in a very clear way.



Key

X operating conditions ΔT/H

Y annual efficiency

1 annual collector efficiency curve η_a

2 annual nominal system efficiency curve $\eta_{n,\text{sys}}$

3 annual estimate system efficiency curve η_{estimate}

4 nominal system efficiency under reference conditions $\eta_{\text{n,ref}}$

5 estimated system efficiency under reference conditions $\eta_{\text{estimate,ref}}$

Figure 2 Example plot of measured annual efficiency points against estimated curve. (DIN EN ISO 24194 - 2023-06 - DIN Media, 2025).

5.5 Method validation

The methods developed are currently being validated in the project ProSolNetz using already existing annual data sets of CST-Plants. It is also planned to apply the methodology to two CST pilot plants. Aim of currently ongoing data preparation and data analysis is to identify and correct or exclude erroneous data and to aggregate the temporal resolution to hourly intervals, as required by the method. The cleaned data set will then be used to validate the annual yield methodology. To this end, it is planned to map the annual yield methodology to ensure sustainable application.

5.6 Restriction of available operating times

Large-scale solar installations must be able to be taken out of operation (e.g. for maintenance and cleaning) for operational reasons, i.e. without a fault occurring. This must be considered methodically through so-called "switch-off" hours $n_{h,\mathrm{off},p}$ by reducing the effective irradiation $H_{\mathrm{eff,ref}}$ for the nominal point accordingly to $\mathrm{H}_{\mathrm{ref,red}}$.

$$H_{\mathrm{ref,red}} = H_{\mathrm{eff,ref}} - H_{\mathrm{ref,off}} - H_{\mathrm{ref,ctrl}} \tag{12}$$

The irradiation $H_{\mathrm{ref,off}}$ denotes unused effective irradiation during planned switch-off hours. i.e. times during which the system is planned to be out of operation. The irradiation $H_{\mathrm{ref,ctrl}}$ is the unused portion of the effective irradiation at times when control strategies reduce the output, e.g. to avoid premature stagnation or to adjust the output to the demand.

The same applies to the measurement. Here, too, the corresponding "switch-off" hours in the operating year $n_{h,\mathrm{off,op}}$ and the corresponding radiation quantities are considered when determining the effective radiation sum H_{op}.

$$H_{\mathrm{op}} = H_{\mathrm{eff},m} - H_{\mathrm{op,off}} - H_{\mathrm{op,ctrl}} \tag{13}$$

The irradiation $H_{\mathrm{op,off}}$ stands for unused effective irradiation during planned switch-off hours, the irradiation $H_{\mathrm{op,ctrl}}$ is the unused portion of the effective irradiation at times when control strategies reduce the output.

The deducted radiation sum is calculated by multiplying the hours by the collector-specific irradiation reduction factor per hour.

$$h_{\mathrm{red}} = (0{,}85 + 0{,}15 \cdot K_d) \cdot 1\ \mathrm{kWh/(m^2h)} \tag{14}$$

The measurement of the annual radiation sum should be reliable and accurate. When taking measurements at the installation, there is always interference or soiling, which can severely impair accuracy. This can be remedied by accessing high-quality satellite data worldwide (https://cds.climate.copernicus.eu/). From the data for hemispheric, direct and diffuse radiation on a horizontal plane, simple factors can be determined with the help of the reference data as a quotient of the radiation sum on the collector surface to the horizontal radiation sum.

$$f_{\mathrm{hem}} = \frac{H_{\mathrm{hem,ref}}}{H_{\mathrm{global,ref}}}; f_b = \frac{H_{b,\mathrm{ref}}}{H_{b,\mathrm{horiz,ref}}}; f_d = \frac{H_{d,\mathrm{ref}}}{H_{d,\mathrm{horiz,ref}}} \tag{15}$$

This allows the respective radiation to sum at collector level to be calculated for each measurement year.

$$H_{m,\mathrm{hem}} = f_{\mathrm{hem}} \cdot H_{m,\mathrm{global}}; H_{m,b} = f_b \cdot H_{m,b,\mathrm{horiz}}; H_{m,d} = f_d \cdot H_{m,d,\mathrm{horiz}} \tag{16}$$

Further operating restrictions exist, for example, in undesirable shading of the collector array. In principle, only times when there is no shading at all shall be considered for the evaluation according to the Performance Check. Depending on the location and ambient conditions, this severely limits the analysable evaluation periods. This is a point that should be given more attention in the next revision of the standard. Mutual shading of collector rows is considered by a shading actor· f_{sh} in the Daily Yield Check. In the Annual Yield Check, yield-reducing shading effects must be considered by means of the safety factor specified by the supplier.

Existing restrictions on the operating conditions for predicting an estimated annual yield and for determining the annual yield from the measurement can be found in ISO 24194.

5.7 Required measurement technology

The measurement technology required to measure the annual yield depends on the respective collector technology and can be found in ISO 24194. IAE SHC Task 68 also produced the report RB.1 "Efficient Data Management and Validation" (Lukas Feierl et al., 2024), which deals with efficient data acquisition, storage, distribution and validation and presents data management topics - from sensor selection to permanent data storage. The report is primarily aimed at system designers and plant operators and provides checklists and recommendations on these topics.

6 Symbols

A_G	Gross area of collector as defined in ISO 9488	m^2
A_{GF}	Gross area of collector field	m^2
f_C	Safety factor for cleanliness for the operating time between two cleanings	-
f_P	Safety factor considering heat losses from pipes etc. in the collector loop.	-
f_U	Safety factor considering 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}	Value given by the supplier and/or mathematical product based on the individual safety factors f_P, f_U, f_O	-
G_{global}	Hemispherical solar irradiance on a horizontal plane	W/m^2
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_{bn}	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
G_d	Diffuse solar irradiance on the plane of collector	W/m^2
GTY_a	Annual gross thermal yield	kWh/m^2
$H_{global,a}$	Annual hemispherical irradiation on a horizontal plane	kWh/m^2
$H_{hem,a}$	Annual hemispherical irradiation on collector plane	kWh/m^2
$H_{hem,d}$	Daily hemispherical irradiation on collector plane	kWh/m^2
H_{sh}	Height of the shaded area	m
h	Solar altitude angle $\sin h = \cos \theta_Z$	°
h_{min}	Minimum solar altitude angle	°
$K_{hem}(\theta_L, \theta_T)$	Incidence angle modifier for hemispherical solar radiation	—
$K_b(\theta_L, \theta_T)$	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	—
$\dot{Q}_{meas}$	Measured power output	W
$\dot{Q}_{estimate}$	Estimated power output	W
$\dot{q}$	Specific measured power output per m² collector gross area	W/m²
$Q_{cap,d}$	Daily capacity heat losses of solar thermal system	J
$Q_{estimate,d}$	Daily yield estimation of solar thermal system	J
$Q_{estimate,a}$	Annual yield estimation of solar thermal system	J
$\dot{Q}_{estimate\text{-}col,d}$	Daily average gross power output collector field	W
$Q_{HM,a}$	Annual yield measurement of the heat meter	J
$Q_{HM,d}$	Daily yield measurement of the heat meter	J
$\dot{Q}_{pipe,d}$	Daily average heat losses of piping	W
U_{sys}	Fictitious constant heat loss coefficient of the system	kWh/K
η_a	Annual collector efficiency based on GTY_a and H_a	—
η_b	Collector efficiency based on beam irradiance G_b	—
η_{hem}	Collector efficiency based on hemispherical irradiance G_{hem}	—
$\eta_{0,b}$	Peak collector efficiency (η_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 $\dot{m}_i$	—
θ	Angle of incidence	°
θ_L	Longitudinal angle of incidence: angle between the normal to the plane of the collector and incident sunbeam projected into the longitudinal plane	°
θ_T	Transversal angle of incidence: angle between the normal to the plane of the collector and incident sunbeam projected into the transversal plane	°
θ_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. $\cos \theta_Z = \sin h$	°
ϑ_a	Ambient air temperature	°C
ϑ_e	Collector outlet temperature	°C
ϑ_i	Collector inlet temperature	°C
ϑ_m	Mean temperature of heat transfer fluid in collector loop	°C

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