International Standard

ISO 24194

Solar energy — Collector fields — Check of performance

Energie solaire — Champs de capteurs — Vérification de la performance

Second edition
2026-09

Reference number
ISO 24194:2026(en)

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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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).

This second edition cancels and replaces the first edition (ISO 24194:2022), which has been technically revised. It also incorporates the Amendment ISO 24194:2022/Amd 1:2024.

The main changes are as follows:

— Introduction revised;

— Scope specifies liquid heating collectors;

— Clause 5: added summarizing validity for all 3 procedures, methodology and operating conditions explained, source of input information described and possible applications mentioned;

— Clause 6: Incorrect formula for direct irradiance deleted and only one general formula according to ISO 9806 for liquid heating collectors introduced using direct and diffuse irradiance; example with calculation and result included;

— Clause 7: Daily yield method generalized so that it is applicable for all collectors in the scope; example with calculation and result included;

— Clause 8: New method for annual yield added that is applicable for all collectors in the scope; example with calculation and result included;

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

0.1 General

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_U = 0,95), but with requirements for use of expensive measurement equipment and maintenance.

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

0.2 Relevance of solar thermal collector fields in the context of the energy transition and heat supply

Heat accounts for half of the world's total energy consumption - significantly more than electricity (20 %) and transport (30 %), and heat accounts for more than 40 % of the global energy-related carbon dioxide emissions. Solar thermal technologies use the sun's energy directly to produce heat that can be used in a wide range of applications. Solar thermal technologies are therefore key technologies for the reduction of global carbon dioxide emissions. The core element of any solar thermal system is the solar thermal collector and is dealt within ISO 9806. This document applies especially to large-scale applications that can generate large quantities of heat. Solar thermal collector fields have, compared to all other heat generators, the highest efficiency in converting solar energy into heat and thus they require the least amount of space. Large solar thermal systems are typically used in the following areas of application.

— District heating with solar fractions from a few percent to 100 % in combination with seasonal storages.

— Industrial processes for food production such as dairies, breweries etc.

— Industrial cleaning processes.

— Chemical processes.

— Desalination.

— Swimming pool heating.

— Solar thermal process heat systems provide heat for industrial processes such as drying, food processing, pasteurisation, washing, cleaning and all other manufacturing processes at medium temperatures.

— Electricity generation based on heat.

— All other application where heat is needed up to a temperature level of 450 °C.

The achievable temperature level depends on the type of collector used. Today, collectors covered by this document are available for a temperature range from 25 °C to 450 °C. The heat transfer fluid used in solar thermal collectors is usually water, water-based antifreeze or silicon oil.

0.3 Application range of this document

This document is currently limited to liquid heating collectors.

This document sets out procedures for checking the thermal power output, daily and annual yield of solar thermal fields to verify performance expectations.

This document is intended to provide a solid basis for monitoring these fields during the commissioning and operating phase and over the course of their lifetime, which is typically more than 25 years. It is therefore a suitable tool to check the influence of soiling and degradation, which can also be linked to increased stresses caused by climate change, for example.

0.4 Environmental impact of solar thermal systems

As these systems consist mainly of solar collectors, more specific details can be found in ISO 9806. By checking the performance, this document directly demonstrates energy savings, and by replacing fossil fuels, also the accompanying greenhouse gas reductions.

The efficiency of converting incoming solar radiation into useful heat can reach > 80 %, depending on the temperature required and the technology chosen. The annual yield depends significantly on the geographical location and the use of the collector. The annual energy yield per area is higher with solar collectors than with any other renewable technology. The yield is considered to be around three times higher than photovoltaic power generation and 50-100 times higher than for biomass. Given the range of different products and applications, it is not possible to quantify the greenhouse gas reduction or climate change mitigation potential of this technology in general terms. The greenhouse gas reduction potential of a solar thermal collector depends on the application in which it is used and what kind of conventional fuel and system is replaced.

For the determination of the greenhouse gas reduction of a system in which a solar thermal system is used, it is recommended to make this quantification using the global warming potential (GWP) for each GHG as per Table 7.15 of the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) by aggregating the reduction potential in carbon dioxide equivalents (CO2eq) [1].

0.5 Supporting the UN Sustainable Development Goals (SDGs)

This document is aligned with the following United Nations Sustainable Development Goals by promoting and supporting the following.

— Solar thermal collectors and solar thermal technologies to reduce dependence on energy prices to increase the resilience of humanity to climate-related extreme events and other economic, social and environmental shocks and disasters (SDG 1.5).

— Solar thermal collectors and solar thermal technologies for water treatment and disinfection to reduce water-borne diseases (SDG 3.3).

— Solar thermal collectors and solar thermal technologies as a clean and safe energy source to replace other energy sources, to significantly reduce the number of deaths and illnesses from hazardous chemicals and polluted air caused by combustion of fossil fuels (SDG 3.9).

— Solar thermal collectors and solar thermal technologies in water purification and desalination facilities to achieve universal and equitable access to safe and affordable drinking water for all (SDG 6.1).

— Solar thermal collectors and technologies as a key technology in capacity building programmes for water treatment activities in developing countries (SDG 6.A).

— Solar thermal collectors to ensure access to affordable, reliable and modern energy for all (SDG 7.1).

— Solar thermal collectors to significantly increase the share of renewable energy for all (SDG 7.2).

— Solar thermal collectors in various applications to increase the overall global energy efficiency (SDG 7.3).

— International cooperation in solar thermal technologies to facilitate access to clean energy research and technology, especially in the fields of renewable energy, energy efficiency and fossil fuel-free technologies as well as to facilitate investments in solar thermal based energy infrastructure and clean energy technologies (SDG 7.A).

— Solar thermal collectors to develop infrastructure and technologies for modern and sustainable energy that is accessible to all in developing countries, in particular least developed countries, small island developing states and landlocked developing countries, and to provide a sound basis for the development of appropriate support programmes. (SDG 7.B).

— Solar thermal collectors and technologies as a technology well suited for local production, thereby achieving higher levels of economic productivity through diversification, technological upgrading and innovation, including focusing on high value-added and labour-intensive sectors (SDG 8.2).

— Solar thermal collectors and solar thermal technologies as locally manufacturable devices with low requirements for production technologies and financial investments, to promote and support productive activities, decent job creation, entrepreneurship, creativity and innovation, and to promote the formalisation and growth of micro, small and medium-sized enterprises, including through access to financial services (SDG 8.3).

— Solar thermal collectors and technologies to progressively improve the global resource efficiency of consumption and production, and to endeavour the decoupling of economic growth from environmental degradation. (SDG 8.4).

— Solar thermal collectors as part of high quality, reliable, sustainable and resilient infrastructure thereby supporting the economic development and human well-being, with a focus on affordable and equitable access for all (SDG 9.1).

— Solar thermal collectors to contribute to the inclusive and sustainable industrialisation and to significantly increasing the industry's share of employment and gross domestic product, particularly in least developed countries, in accordance with national circumstances. (SDG 9.2).

— Solar thermal collectors as a cost-effective means to increase the availability of energy and the predictability of energy costs by reducing dependence on fossil energy, and thereby to facilitate the access of small industrial and other enterprises, particularly in developing countries, to financial services, including affordable credit, and to integrate these industries into value chains and markets (SDG 9.3).

— Solar thermal collectors to upgrade infrastructure and retrofit industries to make them sustainable, with increased efficiency in resource use and greater adoption of clean and environmentally sound technologies and industrial processes (SDG 9.4).

— Scientific research and technological capacity building in the field of solar thermal technologies in all countries, particularly developing countries, including the promotion of innovation, research and development activities (SDG 9.5).

— Solar thermal collectors and solar thermal technologies to facilitate sustainable and resilient infrastructure development in developing countries and to facilitate financial, technological and technical assistance to African countries, least developed countries, landlocked developing countries and small island developing states (SDG 9.A).

— Solar thermal collectors as a way to enhance domestic technology development, research and innovation in developing countries. In addition, the standard supports the development of an enabling policy environment for solar thermal technologies for industrial diversification and commodity value addition (SDG 9.B).

— Solar thermal collectors for fossil and biomass free production of heat and hot water to reduce the adverse per capita environmental impact of cities and in particular by contributing to better air quality. (SDG 11.6).

— Solar thermal collectors as an element of sustainable and resilient buildings, using local materials and local production capacity (SDG 11.C).

— Solar thermal collectors for local and affordable thermal food processing to reduce global food waste and food losses along production and supply chains, including post-harvest losses (SDG 12.3).

— Solar thermal collectors as a product that significantly reduces waste generation through its repairable designs and through material reduction, the possibility of using recycled materials, and the reuse of components (SDG 12.5).

— Solar thermal collectors and solar thermal technologies to encourage companies to adopt sustainable practices and integrate sustainability information into their reporting cycles (SDG 12.6).

— Solar thermal collectors and solar thermal technologies as a locally manufactured technology, using mainly recycled materials, as part of sustainable public procurement practices. (SDG 12.7)

— Solar thermal collectors and solar thermal technologies to strengthen the technological capacity to move towards more sustainable patterns of consumption and production, not only in developing countries (SDG 12.A).

— Subsidy schemes for solar thermal collectors, and thus also the reduction and phasing out of inefficient fossil fuel subsidies, especially in developing countries, and minimising adverse impacts on their development in a manner that protects the poor and affected communities (SDG 12.C).

— Solar thermal collectors and solar thermal technologies to reduce the overuse of biomass for heat generation, thereby also supporting the implementation of sustainable management of all types of forests, halting deforestation and even enabling afforestation and reforestation worldwide (SDG 15.2).

— The transfer of know-how, dissemination and diffusion of environmentally sound technologies to developing countries on favourable terms (SDG 17.7).

Solar energy — Collector fields — Check of performance

1 Scope

This document specifies three procedures to check the performance of solar thermal collector fields. This document is applicable to most collector types addressed by ISO 9806. This includes glazed liquid heating flat plate collectors, evacuated tube collectors, and tracking, concentrating collectors. However, certain limitations apply in comparison to ISO 9806, specifically concerning wind and infrared sensitive collectors (WISC), hybrid collectors, and air collectors:

— WISC collectors are included only when both wind speed data measured on the collector plane and longwave radiation data are available.

NOTE Such data is rarely available in practical applications.

— Hybrid collectors ("collectors co-generating thermal and electrical power" in ISO 9806, commonly PVT) are excluded. The reason is that their thermal performance in real-world operation depends on the operation of the electrical part: If the electrical part is switched off, limited, or curtailed for any reason, while the thermal part remains active, this would lead to an overestimation of the thermal power output, based on performance parameters determined under MPP conditions (maximum electrical power generation), as specified in ISO 9806.

— Solar air heating collectors (SAHC) are excluded due to the complexity of accurately assessing their performance: Testing and evaluating SAHC performance is complex, because it requires accounting for the enthalpy difference in the primary loop. Additionally, their thermal efficiency is highly dependent on mass flow rate, and their performance is tested at three different air mass flow rates, resulting in three separate parameter sets. For the ISO 24194 Power Check, this makes it challenging to select the appropriate parameters for estimating thermal power output.

This document specifies procedures for performance check of the thermal power output of the collector field as well as on the daily yield and annual yield of the collector field. For the three procedures, this document specifies how to compare a measured output with the calculated one.

The document is applicable to collector fields of all sizes.

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*

ISO/TR 9901, *Solar energy — Pyranometers — Recommended practice for use*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 9488 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/

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	Heat loss coefficient	$W/(m^2 \cdot K)$
a_2	Temperature dependence of the heat loss coefficient	$W/(m^2 \cdot K^2)$
a_3	Wind speed dependence of the heat loss coefficient	$J/(m^3 \cdot K)$
a_4	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.	$J/(m^2 \cdot K)$
a_6	Wind speed dependence of the zero-loss efficiency	s/m
a_8	Radiation losses dependence	$W/(m^2 \cdot K^4)$
C	Effective thermal capacity of collector	J/K
C_R	Geometric concentration ratio	—
c_f	Specific heat capacity of heat transfer fluid	$J/(kg \cdot K)$
D	Gap in between adjacent collectors	m
E_L	Longwave irradiance ($\lambda > 3$ µm)	W/m^2
f_C	Performance factor for cleanliness for the operating time between two cleanings	-
f_P	Performance factor taking into account heat losses from pipes etc. in the collector loop.	-
f_U	Safety factor taking into account measurement uncertainty.	-
f_O	Performance 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_{perf}	Overall performance factor given by the supplier and/or mathematical product based on the individual factors f_C, f_P, f_U, f_O	-
f_{sh}	Shading factor	-
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}	Direct normal solar irradiance	W/m^2

G_d	Diffuse solar irradiance on the plane of collector	W/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
$H_{op,a}$	Effective annual irradiation on collector plane during operating hours	kWh/m^2
$H_{op,d}$	Effective daily irradiation on collector plane during operating hours	kWh/m^2
H_{sh}	Height of the shaded area	m
h	Solar altitude angle sin h = cos θ_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	—
L	Length of a collector (from bottom to top)	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	-
Q_{GTY}	Annual gross thermal yield	kWh/m^2
$\dot{Q}_{estimate}$	Estimated power output	W
$\dot{Q}_{meas}$	Measured power output	W
$\dot{q}_{meas}$	Specific measured power output per m^2 collector gross area	W/m^2
$Q_{cap,d}$	Daily capacity heat losses of solar thermal system	J
$Q_{estimate,a}$	Annual yield estimation of solar thermal system	J
$Q_{estimate,d}$	Daily yield estimation of solar thermal system	J
$\dot{Q}_{estimate\text{-}col,d}$	Daily average gross power output collector field	W

$Q_{HM,a}$	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
$q_{l\text{-}pipe}$	Empirical specific heat loses per m pipe	W/(m·K)
S	Spacing center to center in between adjacent rows	m
T	Absolute temperature	K
U_{sys}	Fictitious constant heat loss coefficient of the system	kWh/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
V_f	Fluid capacity of the collector	m^3
$\dot{V}$	Volumetric flow rate	m^3/s
V_{pipe}	Volume of the pipe system without collectors	l
w	Width of a collector (from left to right)	m
x_i	x-axis value of collector operating points as ratio of temperature difference and irradiation	$(m^2\ K)/kWh$
z	Number of days with reduced heat output	-
ΔT	Temperature difference between fluid outlet and inlet (ϑ_e - ϑ_i)	K
β	Slope (or tilt), the angle between the plane of the collector and the horizontal. 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	°
γ	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	°
γ_s	Solar azimuth angle, the angular displacement from south of the projection of direct radiation on the horizontal plan, east negative and west positive	°
δ	Declination, the angular position of the sun at solar noon with respect to the plane of the equator, north positive.	°
ϕ	Latitude, the angular location north or south of the equator, north positive	°
η_a	Annual collector efficiency based on Q_{GTY} and H_a	—
η_b	Collector efficiency based on direct 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 direct 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 $\dot{m}_i$	—
Ω	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	°
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 direct radiation on a horizontal surface. cos θ_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
ρ_{prim}	Density of heat transfer fluid in primary loop at flow meter position/temperature	kg/m^3
ρ_{sec}	Density of heat transfer fluid in secondary loop at flow meter position/temperature	kg/m^3
σ	Stefan-Boltzmann constant	W/(m^2·K^4)

5 General

5.1 Validity

The procedures described in this document can only be applied if the thermal performance of the collector has been tested in accordance with ISO 9806 and modelled with the corresponding collector parameters. The typical operating temperature of the system for the check shall be within the valid range. This means that the operating temperature shall be in a range above measured ambient air temperature –10 K and below the resulting temperature of measured ambient air temperature and the maximum temperature difference between the collector and the ambient air during the collector test +30 K.

NOTE The wind related parameters a_3, a_6 and the infrared related parameter a_4 are included in the procedure for checking the power performance. It is assumed that the procedure can also be applied to these types of collectors and the aim is to provide an opportunity to gain experience. However, this requires additional measurements not described in this document.