EuroSun 2026

On the experimental characterization of the diffuse incident angle modifier: an update to ISO 9806:2025

The diffuse incident angle modifier is a key parameter in the modeling of solar thermal collectors under variable sky conditions, particularly under partially and fully overcast skies. Its experimental determination is typically performed according to standardized procedures such as ISO 9806, one of the most widely adopted international standards. A recently published revision of this standard introduces modifications to the determination of this parameter. In the previous version of the standard (ISO 9806:2017), the diffuse incident angle modifier was determined differently for the steady-state (SST) and quasi-dynamic testing (QDT) methods: under SST, it was derived from the direct incident angle modifier through all-sky integration assuming an isotropic distribution of diffuse radiation, followed by normalization, whereas in QDT it was estimated by fitting it directly to experimental data. In the revised version (ISO 9806:2025), the SST procedure is maintained but complemented by an additional step accounting for anisotropic diffuse radiation effects, and for QDT, while the conventional fitting approach remains valid, the SST-based procedure is now also permitted. This study evaluates the impact of these modifications on parameter identification and on the consistency between test methods for a flat-plate collector and an evacuated tube collector.

Keywords: Incident angle modifier, diffuse solar irradiance, anisotropic effects, ISO 9806.

Field of application for the findings: test and certification.

Addressed audience: testing laboratory, researchers.

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1. Introduction

The diffuse Incident Angle Modifier (K_d, diffuse IAM) is a key parameter in the long-term performance assessment of solar thermal collectors under variable atmospheric conditions. Its experimental determination is generally carried out following standardized procedures such as ISO 9806, one of the most widely adopted international standards, which defines two testing methodologies: steady-state testing (SST) and quasi-dynamic testing (QDT). A recently published revision of this standard [4] introduces relevant modifications to the determination of the diffuse IAM, which are described below.

In the previous version of the standard [3], the SST methodology determined the diffuse IAM from the direct IAM through all-sky integration assuming an isotropic distribution of diffuse radiation, followed by normalization (i.e., dividing the integral by the same integral evaluated assuming the direct IAM equal to unity). In contrast, the QDT approach estimated this parameter by fitting it to the experimental data, implicitly accounting for anisotropic effects under measured conditions. As shown in [5], these differing approaches led to inconsistencies between test methods, resulting in discrepancies in useful power predictions.

The revised standard [4] maintains the original SST procedure but incorporates an additional correction step to explicitly account for anisotropic diffuse radiation effects. For the QDT method, the conventional parameter-fitting approach is retained, while also allowing the determination of K_d using the SST-based procedure. A similar approach was previously explored in [5], among other alternatives [1, 2], where extending the SST procedure to QDT was identified as the most suitable strategy in terms of test method consistency and ease of implementation. However, that approach assumed isotropic conditions and was not allowed under the former version of the standard, nor did it include the additional anisotropy correction introduced in the 2025 revision.

This paper evaluates the impact of the standard modification on diffuse IAM and updates the results of the previous study [5] with respect to the identification of collector parameters and consistency between testing methodologies. The analysis is performed for two technologies: a flat-plate collector and an evacuated tube collector. Recommendations are provided on the basis of the obtained results.

2. Diffuse incident angle modifier estimation and research methodology

This section briefly presents the general thermal model adopted in this work as a framework for the subsequent analysis, with specific focus on the determination of the parameter K_d, and outlines the research methodology applied.

2.1 Diffuse incident angle modifier estimation

For low-temperature glazed collectors, the recommended QDT model is given in Eq. 1:

$$\frac{\dot{Q}_u}{A_G} = \eta_{0,b}\left[K_b\left(\theta\right)\ G_{bt} + K_d\ G_{dt}\right] - a_1\left(\vartheta_m - \vartheta_a\right) - a_2\left(\vartheta_m - \vartheta_a\right)^2 - a_5\frac{d\vartheta_m}{dt}. \tag{1}$$

The SST method employs a simplified formulation in which solar radiation is treated globally. This is achieved through the substitution $\eta_{0,b}\left[K_b\left(\theta\right)\ G_{bt} + K_d\ G_{dt}\right] = \eta_{0,hem}K_{hem}G_t$, which leads to:

$$\frac{\dot{Q}_u}{A_G} = \eta_{0,hem}K_{hem}G_t - a_1\left(\vartheta_m - \vartheta_a\right) - a_2\left(\vartheta_m - \vartheta_a\right)^2 - a_5\frac{d\vartheta_m}{dt}. \tag{2}$$

The conversion from SST to QDT parameters is described in Annex C of the standard (i.e., from $\eta_{0,hem}$ and K_{hem} to $\eta_{0,b}$, K_b, and K_d) and is summarized as follows.

First, clear-sky conditions are assumed so that $K_{hem} = K_b$. Then, the isotropic value of K_d^{iso} is obtained by averaging K_b over the solid angle seen by the collector, assuming an isotropic distribution of diffuse radiation:

$$K_d^{iso} = \frac{\int_0^{\pi/2}\int_0^{\pi/2} K_b\left(\theta,\gamma\right)\cos\left(\theta\right)\sin\left(\theta\right)d\theta d\gamma}{\int_0^{\pi/2}\int_0^{\pi/2}\cos\left(\theta\right)\sin\left(\theta\right)d\theta d\gamma}. \tag{3}$$

The standard recommends performing this integral as a summation by discretizing the integration domain into 10 ° intervals, an approach used in this study. Then, anisotropic effects are then incorporated through:

$$K_d = K_d^{iso}\left(1 - \frac{G_b}{G_{sc}}\right) + \frac{G_b}{G_{sc}}, \tag{4}$$

where the values G_b and G_{sc} are specified in the standard. Finally, $\eta_{0,b}$ is computed as follows: $\eta_{0,b} = \eta_{0,hem}/(0.85 + 0.15 \times K_d)$.

The revised standard introduces Eq. 4 and extends its use to the QDT method.

2.2 Research methodology

To evaluate the impact of these changes, the experimental data reported in [5] were reprocessed using the new procedure. Two data sets were analyzed: a flat-plate collector (FPC) and an evacuated tube collector with heat pipes (ETC). The results were compared and analyzed.

The QDT parameter identification program was modified to implement both approaches: the conventional data-fitting method and the formulation given by Eqs. 3 and 4 (QDT-1 and QDT-2). This resulted in three cases per collector for both current and former versions of the standard. The results are presented in the next section.

3. Results

Table 1 presents the estimated parameter values for both collectors (FPC and ETC-HP) under SST, QDT-1, and QDT-2 procedures, for the 2025 and 2017 versions of ISO 9806. The results for QDT-2 under the 2017 version are not included, as this procedure was not permitted in that version of the standard. For simplicity, the thermal capacity per unit gross area (a_5) and the direct incidence angle modifier values are not reported. The values of K_d are highlighted in bold to facilitate interpretation.

Tab. 1: Characteristic parameter values for both collectors and for each case: SST, QDT-1 (K_d fitted to experimental data), and QDT-2 (K_d estimated using the SST procedure). Values are reported for both the current (2025) and former (2017) versions of the ISO 9806.

Collector	FPC						ETC-HP					
Test method	SST		QDT-1		QDT-2		SST		QDT-1		QDT-2	
Standard version	2017	2025	2017	2025	2017	2025	2017	2025	2017	2025	2017	2025
$\eta_{0,b}$	0.726	0.720	0.720	0.720	-	0.719	0.371	0.371	0.365	0.365	-	0.376
K_d	**0.905**	**0.964**	**0.941**	**0.941**	-	**0.953**	**1.007**	**1.003**	**1.235**	**1.235**	-	**1.030**
a_1	4.499	4.499	4.331	4.331	-	4.239	1.682	1.682	1.678	1.678	-	1.726
a_2	0.000	0.000	0.001	0.001	-	0.001	0.000	0.000	0.000	0.000	-	0.000

First, in the SST case, the only parameter that changes is K_d, as its determination is independent of the remaining parameters. It can be seen that the new procedure leads to a higher K_d value for the FPC and a lower value for the ETC-HP.

For QDT-1, no differences are observed between the 2017 and 2025 versions of the standard. In the 2017 version, the K_d values obtained with QDT-1 are generally higher than those derived from SST, an inconsistency previously reported in the literature. In the 2025 version, this discrepancy is reduced for the FPC but becomes even more pronounced for the ETC-HP.

With the introduction of QDT-2, greater consistency with the SST results is observed for both collectors. For this reason, its use is recommended due to its improved consistency in the test method. This finding is in line with the results reported in [5], where QDT-2 was evaluated in the 2017 version as an alternative to improve consistency between the test methods. In this case, the new procedure has only a minimal influence on the determination of the remaining parameters.

4. Conclusions

The impact of the revised procedure for estimating the diffuse IAM in the latest version of ISO 9806 was evaluated for two collectors: a flat-plate collector (FPC) and an evacuated tube collector with heat pipes (ETC-HP). The results indicate that applying a consistent procedure in both testing methods improves the agreement between the identified parameters.

In the full article, all the values of the characteristic parameters will be reported, together with additional collector types, to enhance the generality of the findings. In addition, the useful power under standard reporting conditions will be presented to further complement the analysis.

References

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