

Significance of Spectral Correction of Collector Measurements Performed in Solar Simulators

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Abstract

The efficiency curve of a solar thermal collector was measured at two different institutes. One institute used natural sunlight, the other artificial light. The difference of efficiency curves was about 5%. The reason for the difference was the lack of a spectral correction of the indoor measurement which should have accounted for the spectral differences of the light sources. This correction is an established procedure in all relevant standards.

As examples, correction factors for different combinations of absorbers and glazings are presented. These figures prove that spectral corrections for indoor measurements are significant and may not be omitted. The measurements necessary for the correction, namely absorptance, transmittance and the spectrum of the light source have to be an integral part of the collector measurement and must be an integral part of the competence of an indoor testing lab.

1 Comparison Indoor versus Outdoor

One single collector was measured first at an indoor testing institute then shipped to SPF in Switzerland. The result was surprising: The indoor testing institute identified efficiency values that were about 5% (relative) higher than the ones measured at SPF (Figure 1).

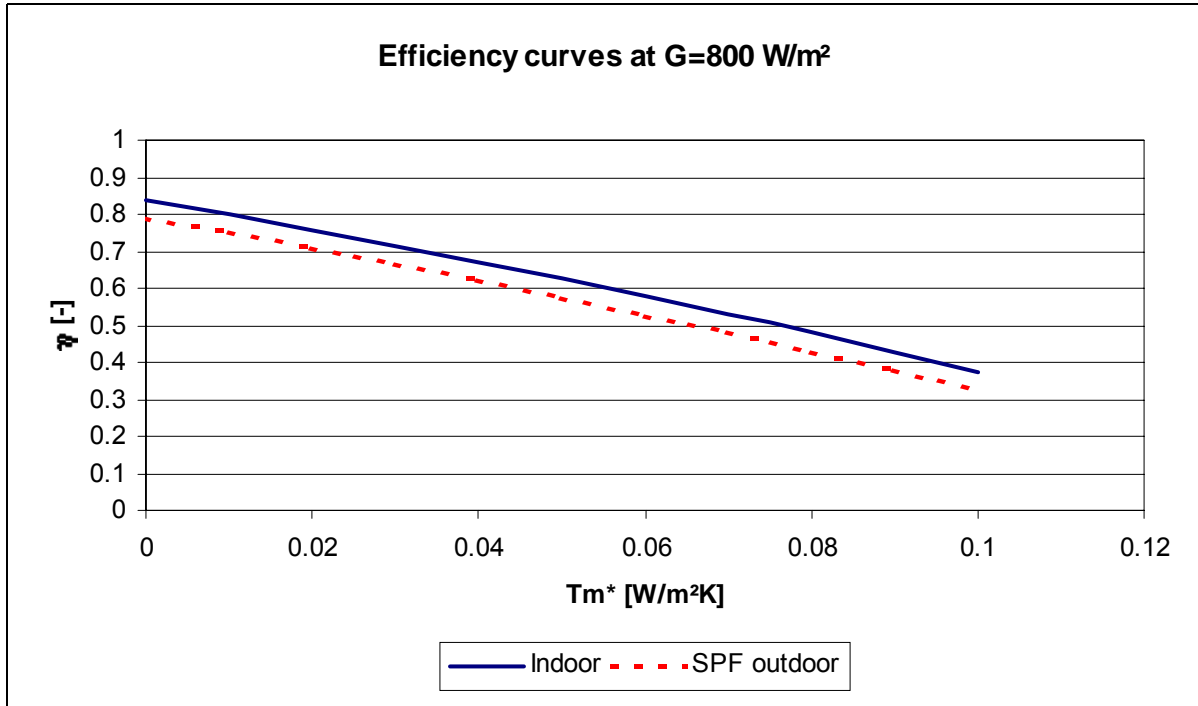


Figure 1: Comparison of efficiency curves obtained

This led to a heavy conflict among the testing institutes and the customer. SPF finally was able to identify the reason for the deviation:

The indoor testing institute had measured this specific collector as well as all other indoor measurements during its history using a solar simulator with halogen lamps. The measurement was claimed to have been performed according to the relevant standards.

2 The Forgotten Spectral Correction

When measuring indoors, all relevant standards [1], [2], [3] prescribe a spectral correction. This correction accounts for effects arising from the differences between the spectrum of the artificial light and the spectrum of natural sunlight. The correction is a “normalization” of the measured efficiency to a standard solar spectrum, usually the spectrum AM1.5 [4]. The correction accounts for properties of the spectrum of the light used for the test as well as for transmission properties of the glazing and for absorptance properties of the coating. The equation for the “effective transmission-absorption-product“ $(\tau\alpha)_{\text{eff}}$ reads (e.g.[3]):

$$(\tau\alpha)_{\text{eff}} = \frac{\int_{0.3\mu\text{m}}^{3\mu\text{m}} \tau(\lambda)\alpha(\lambda)G(\lambda)d\lambda}{\int_{0.3\mu\text{m}}^{3\mu\text{m}} G(\lambda)d\lambda} \quad (\text{Eq. 1})$$

With spectral transmittance of the glazing $\tau(\lambda)$, spectral absorptance of the coating $\alpha(\lambda)$ and spectral irradiance of the light source $G(\lambda)$.

The correction factor to be applied to the η_0 -value of a simulator measurement is:

$$corr = \frac{(\tau\alpha)_{eff,G=AM1.5}}{(\tau\alpha)_{eff,G=Sim}} \quad (\text{Eq. 2})$$

with subscript G= Sim the spectrum of the artificial light source.

3 Physical Reason Behind the Correction

The physical reasons for the necessity of this correction can be explained employing two examples with respect to Figure 2:

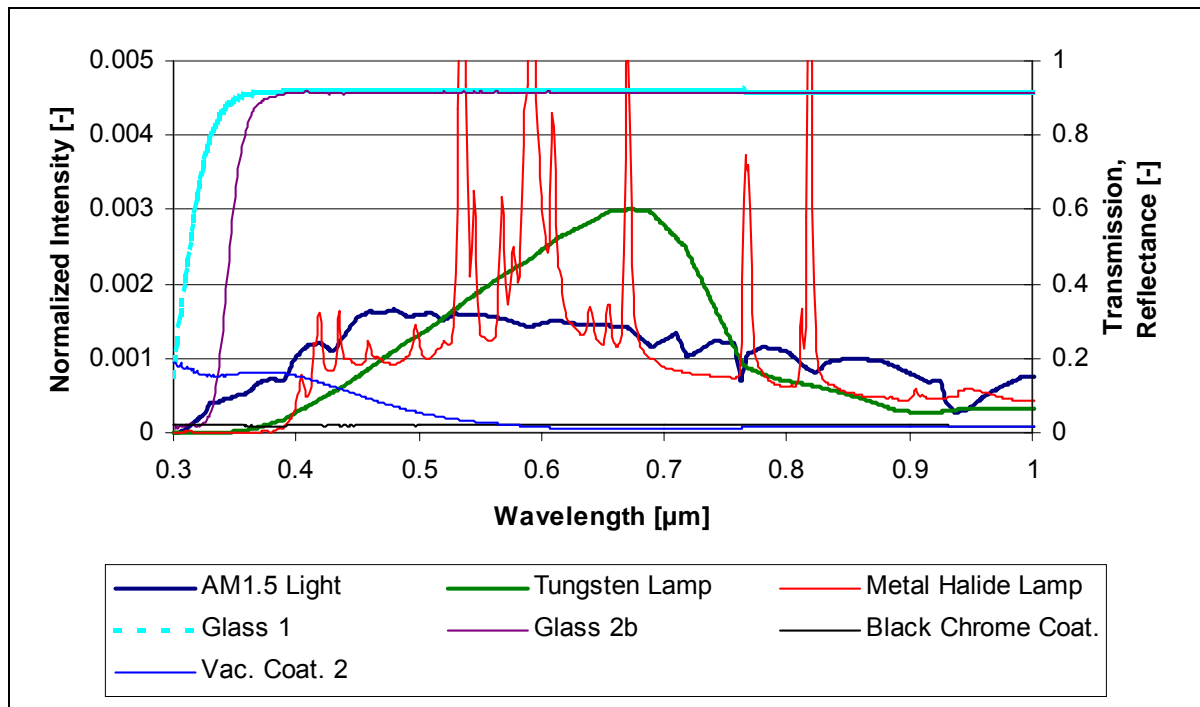


Figure 2: Spectral properties of different light sources and absorbers

Example 1:

3% of the energy of natural sunlight occur at wavelengths less than 0.38 μm. Due to the relative maximum of reflectance of “vacuum coating 2”, a significant share of this is reflected. However, in the simulator (both artificial light sources) in this spectral range, there is no radiation existing that could be reflected. This raises the apparent efficiency of the combination “artificial light and vacuum coating 2”.

Example2:

The Tungsten lamp has a maximum of intensity at about 0.65 μm. In this range, “vacuum coating 2” has a relative low plateau of its reflectance. Thus “vacuum coating 2” converts this share of the Tungsten spectrum very favourably, while there is much less energy delivered from the sun in this range. This effect raises the apparent efficiency of the combination “Tungsten lamp and vacuum coating 2”.

Both effects are also sensitive to the question if and to what degree differences exist in the transmission of different glasses to the respective spectral proportions of radiation of artificial and natural light sources.

The diagram also shows that the spectrum of the black chrome coating is rather flat and thus does not produce as much imbalances as more recently developed coatings do.

4 Example Values for the Simulator Correction

Considering that

- a) there are a number of different glass products,
- b) there are a number of different coating products
- c) optical properties of one coating product are subject to variations by production date and by the position where the piece of absorber was cut out of the width of the coated metal coil,
- d) there are solar simulators with different light spectra,

the following values are only examples assuming a widely used radiation source and employing real measured data of glasses and coatings.

Vacuum coatings 1a and 1b are different samples taken from the same collector (same for vacuum coating 2a and 2b).

Glass 1 is well transparent in the UV region. Glass 2a and glass 2b are the same type of glass from the same manufacturer, but from different production dates. Glass 2a was used in the example (clause 1). Glass 2b has a relatively low transmittance in the UV region. Glass 3 is ferruginous. Glass 4 is antireflectively coated.

	Galvanic Black Chrome	Vacuum Coating 1a	Vacuum Coating 1b	Vacuum Coating 2a	Vacuum Coating 2b
Glass 1	0.991	0.964	0.970	0.976	0.985
Glass 2a	0.974	0.951	0.958	0.962	0.972
Glass 2b	0.983	0.956	0.963	0.968	0.978
Glass 3	0.975	0.954	0.960	0.966	0.976
Glass 4	0.987	0.961	0.967	0.972	0.982

Table 1 : Examples of different corrections

5 Reason for Deviations of the two Tests

The reason for the deviation of the two measurements is now clear: The indoor measurement was performed in a solar simulator with halogen lamps. The collector was equipped with glass 2a and vacuum coating 1. However, the indoor testing institute did not apply a spectral correction to the test result. According to Table 1 the correction value should have been around 0.955. If this had been correctly applied to the collector measurement, the two curves in Figure 1 would have been “identical” (with differences in the range of measurement uncertainties).

Conclusion: The test of the outdoor testing institute was clearly “out of standard”.

The design of the collector was a parallel flow absorber with parallel tubes and some absorber edges with unfavourable heat removal. Fin width was 99 mm and sheet thickness 0.3 mm, bonding technique was ultrasonic welding. From these values we estimate an F' -value of not more than 91% (regardless of test fluid) [5], [6].

Measurements of the collector components resulted in a solar absorptance of 0.94 and a solar transmittance of 0.92. As

$$\eta_0 = (\tau\alpha)_{eff} \cdot F', \quad (\text{Eq. 3})$$

the collector test result of $\eta_0 = 84\%$ obtained by the indoor institute could thus only be achieved with a F' -value of 0.97. This value is unrealistic.

F'-value calculated from absorber properties	F'-value corresponding to indoor collector test result
$F' < 0.91$	$F' = 0.97$

Table 2: Comparison of F' -values

6 Differences between “old” and “new” Coatings

“During the old days”, when black paint and early black chrome coatings predominated, the correction was very close to “1” and thus could often be omitted (standards allow a maximum difference of 1% without correction). However, the latest coating developments lead to significant correction factors which by no means may be neglected.

7 Effects on the Testing Business

The crucial point is that omitting the necessary correction, leads to higher and thus more “favourable” results. Of course, collector manufacturers tend to chose their testing institute according to the highest resulting efficiency values. They seem to forget, that their collectors never reach these values under natural sunlight. Solar systems will never deliver the amount of energy that one would expect from computer simulation with the efficiency values obtained in the simulator.

As can be seen in Table 1, there is not “one” spectral transmission function for one glass type and there is not “one” spectral absorption function for one coating type. This means, that an indoor testing institute has to perform a transmittance measurement for each single collector under test and has to perform a series of absorptance measurements evenly distributed across the absorber surface for each single collector.

Doing this in the correct way, will significantly influence the price of indoor collector measurements.

A number of indoor laboratories are planning to be accredited for collector tests within the years 2002 and 2003. We expect that accreditation bodies and experts do their job properly and refuse accreditation of indoor tests unless the correction is applied correctly. If accreditation is granted, the competence of transmittance and absorptance measurements must be an integral part of the accreditation. Otherwise,

these optical measurements may only be purchased from a laboratory that is accredited for this.

We investigated test reports from all major indoor testing institutes of Europe. In none of these reports we could detect a spectral correction. All reports were stated to be “according to DIN” or “according to EN”, which is obviously not true.

8 Conclusions

- All standards describe the procedure for the spectral correction.
- The correction has to be carried out for all indoor measurements.
- Transmittance measurements of the glazing have to be carried out for each individual collector sample.
- A series of absorptance measurements of the absorber has to be carried out.
- The spectrum of the simulator has to be measured on a regular basis.
- Obviously the standards should be clearer in describing the exact procedure.

References

- [1] ISO 9806-1:1994, clause 9.2
- [2] DIN V 4757:1995, clause 6.7.3
- [3] EN 12975-2:2001, clause 6.1.5.2
- [4] ISO 9845-1 :1992
- [5] Duffie, J.A. and Beckmann, W.A.: Solar Engineering of Thermal Processes. John Wiley & Sons, New York
- [6] Absorber Master: © SPF, Switzerland: 2002:
<http://www.spf.ch/spf.php?id=AbsorberMaster>