Training: Review of Standads

- EN 16012 and EN15976, standards related to emissivity of glasses,
- highlight on recommendations for extrapolations of total hemispherical emissivity from near-normal spectral or total emissivity results.

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16NRM06 EMIRIM

Improvement of emissivity measurements
on reflective insulation materials

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Review of Standards

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- **standards related to emissivity of membranes and foils**
  - EN 16012 and EN 15976
  - TIR-principle (TIR = thermal infrared)

- **standards related to emissivity of glasses**
  - EN 673, EN 12898 and ASTM E 1585 – 93
  - spectrometric technique

- **total hemispherical emissivity derived from**
  - spectral near-normal emissivity
  - total near-normal emissivity

Directional Emissivity versus Angle

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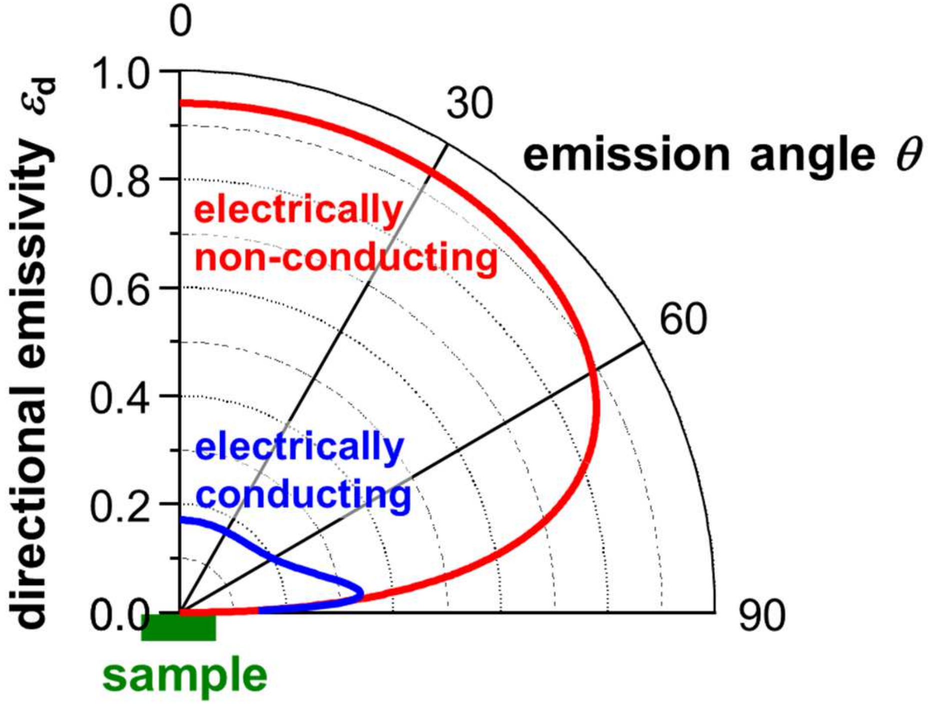
Calculation of the hemispherical emissivity from the directional emissivity

ε_d: directional emissivity

ε_n: normal emissivity

ε: hemispherical emissivity



$$\varepsilon_n = \varepsilon_d(\theta = 0°)$$

$$\varepsilon(T) = \frac{1}{\pi} \cdot \int_{\substack{\text{hemi-}\\\text{sphere}}} \varepsilon_d(\theta, \varphi, T) \cdot \cos\theta \cdot d\omega$$

Spectral Emissivity versus Wavelength

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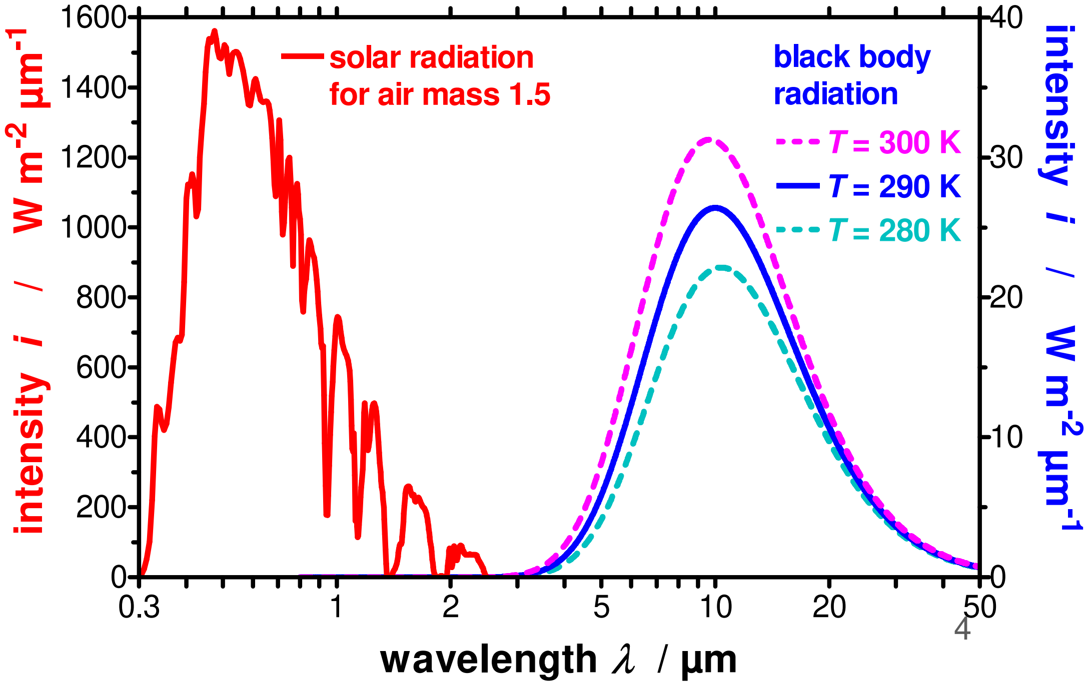
Calculation of the total normal emissivity from the spectral normal emissivity

$\varepsilon_{\mathrm{n}}(\lambda)$: **spectral normal emissivity**

ε_{n}: **total normal emissivity**

$i_{\mathrm{bb}}(\lambda)$: **intensity emitted by a black body**

$$\varepsilon_{\mathrm{n}}(T) = \frac{\int_0^\infty \varepsilon_{\mathrm{n}}(\lambda, T) \cdot i_{\mathrm{bb}}(\lambda, T) \cdot d\lambda}{\int_0^\infty i_{\mathrm{bb}}(\lambda, T) \cdot d\lambda}$$



Standards Related to Membranes / Foils

- **EN 16012 : 2012+A1:2015**

  Thermal insulation for buildings –
  Reflective insulation products –
  Determination of the declared thermal performance

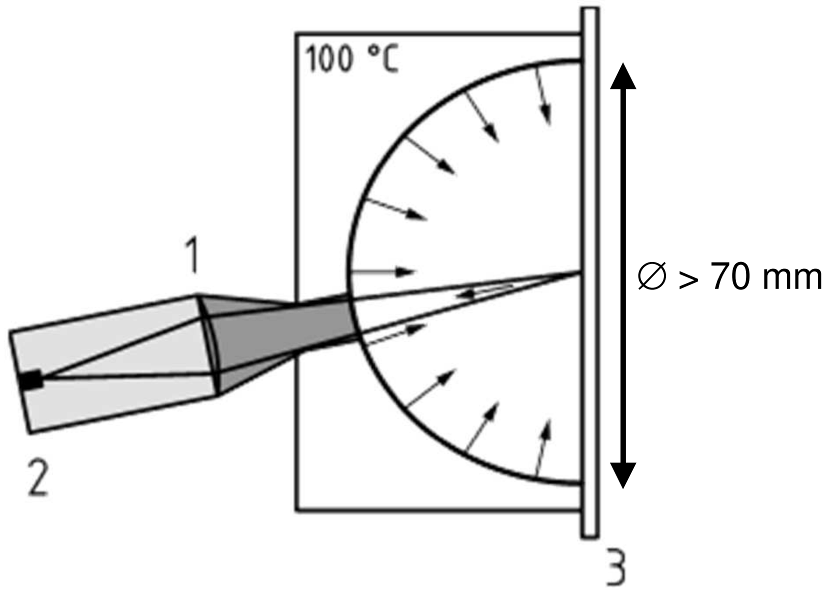
  → additionally refers to EN 15976

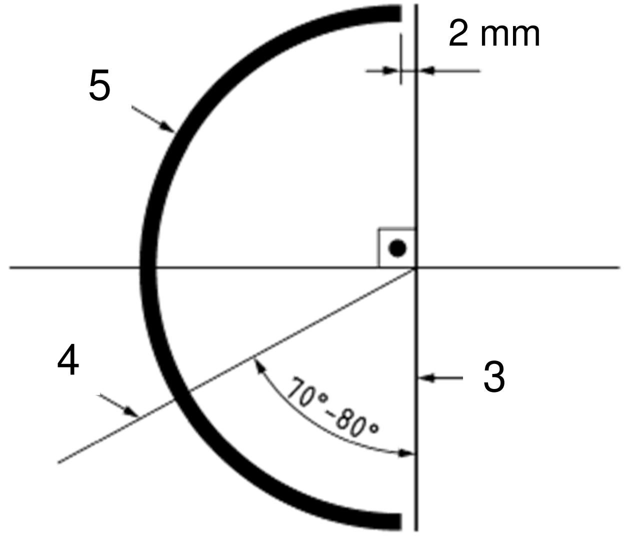
- **EN 15976 : 2011**

  Flexible sheets for waterproofing –
  Determination of emissivity

Standards Related to Membranes / Foils

Black surrounding in front of the sample with T_{sample} = 296 K, which is placed on massive sample holder (> 140 mm x 140 mm)





1 IR-lens
2 IR-thermopile sensor
3 sample

4 detected IR-beam
5 black surrounding

preheating time > 2 h

total measuring time < 3 s

Standards Related to Membranes / Foils

Recommended calibration standards

- $0.01 < \varepsilon_{\mathrm{low}} < 0.02$
- $\varepsilon_{\mathrm{high}} > 0.94$

Determination of the total near-normal emissivity of the sample

$$\varepsilon_{\mathrm{n}} = \varepsilon_{\mathrm{high}} - (\varepsilon_{\mathrm{high}} - \varepsilon_{\mathrm{low}}) \cdot \frac{U_{\mathrm{high}} - U_{\mathrm{sample}}}{U_{\mathrm{high}} - U_{\mathrm{low}}}$$

- detected signals U_{sample}, U_{high} and U_{low}

Measurement range: 0.02 … 0.94

mean values below 0.05 shall be given as 0.05

Standards Related to Glasses

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- **EN 12898 : 2001 and prEN 12898 : 2017**

  Glass in building –
  Determination of the emissivity

- **EN 673 : 1997 and EN 673 : 2011**

  Glass in building –
  Determination of the thermal transmittance *U* –
  Calculation method

  determination of the emissivity: - 1997: identical with EN 12898
  - 2011: only refers to EN 12898

- **ASTM E 1585 – 93**

  Standard Test Method for Measuring and Calculating Emittance of Architectural Flat Glass Products Using Spectrometric Measurements

EN 12898 : 2001 and prEN 12898 : 2017

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Measurement of spectral normal (near-normal) specular (directional-directional) reflectance $R_n(\lambda_i)$ at T = 283 K

→

Calculation of total normal reflectance R_n

$$R_n = \frac{1}{N} \cdot \sum_{i=1}^{i=N} R_n(\lambda_i)$$

with $N \geq 24$

Ordinal number i	Wavelength(λ_i) µm	Ordinal number i	Wavelength (λ_i) µm
1	5,5	16	14,8
2	6,7	17	15,6
3	7,4	18	16,3
4	8,1	19	17,2
5	8,6	20	18,1
6	9,2	21	19,2
7	9,7	22	20,3
8	10,2	23	21,7
9	10,7	24	23,3
10	11,3	25	25,2
11	11,8	26	27,7
12	12,4	27	30,9
13	12,9	28	35,7
14	13,5	29	43,9
15	14,2	30	50,0[a]

[a] 50 µm has been chosen because this wavelength is the limit of most commercially available spectrophotometers. This approximation has a negligible effect on the accuracy of the calculation.

EN 12898 : 2001 and prEN 12898 : 2017

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→ **Calculation of the total normal emissivity ε_n**

$\varepsilon_\mathrm{n} = 1 - R_\mathrm{n}$ if $R_\mathrm{n} = R_\mathrm{nh}$ (= only specular reflecting sample)

→ **Cacluation of the total hemisphercal emissivity ε**

- 2001: $\varepsilon = \varepsilon_\mathrm{n} \cdot (\varepsilon/\varepsilon_\mathrm{n})$

Normaler Gesamtemissionsgrad ϵ_n	Verhältnis ϵ/ϵ_n
0,03	1,22
0,05	1,18
0,1	1,14
0,2	1,10
0,3	1,06
0,4	1,03
0,5	1,00
0,6	0,98
0,7	0,96
0,8	0,95
0,89	0,94
Zwischenwerte können durch lineare Interpolation oder Extrapolation mit ausreichender Genauigkeit ermittelt werden.	

- 2017: $\varepsilon = 1.1887 \cdot \varepsilon_\mathrm{n} - 0.4967 \cdot \varepsilon_\mathrm{n}^2 + 0.2452 \cdot \varepsilon_\mathrm{n}^3$

ASTM E 1585 – 93

Measurement of spectral normal (near-normal) specular (directional-directional) reflectance $R_n(\lambda)$ in the wavelength range λ = 5 µm … ≥ 25 µm at 1 µm intervals at T = 294 K

→

Calculation of total normal emissivity ε_n

$$\varepsilon_\mathrm{n} = \frac{\sum_{i=1}^{i=N}[1 - R_\mathrm{n}(\lambda_i)] \cdot i_\mathrm{bb}(\lambda_i, T) \cdot \Delta\lambda_i}{\sum_{i=1}^{i=N} i_\mathrm{bb}(\lambda_i, T) \cdot \Delta\lambda_i}$$

ASTM E 1585 – 93

→ Cacluation of the total hemispherical emissivity ε

- $\boldsymbol{\varepsilon_n < 0.5}$**:** electrically conducting materials

$$\varepsilon = 1.3217 \cdot \varepsilon_\mathrm{n} - 1.8766 \cdot \varepsilon_\mathrm{n}^2 + 4.6586 \cdot \varepsilon_\mathrm{n}^3 - 5.8349 \cdot \varepsilon_\mathrm{n}^4 + 2.7406 \cdot \varepsilon_\mathrm{n}^5$$

- $\boldsymbol{\varepsilon_n > 0.5}$**:** electrically non-conducting materials

$$\varepsilon = 0.1569 \cdot \varepsilon_\mathrm{n} + 3.7669 \cdot \varepsilon_\mathrm{n}^2 - 5.4398 \cdot \varepsilon_\mathrm{n}^3 + 2.4733 \cdot \varepsilon_\mathrm{n}^4$$

Conclusions and Outlook

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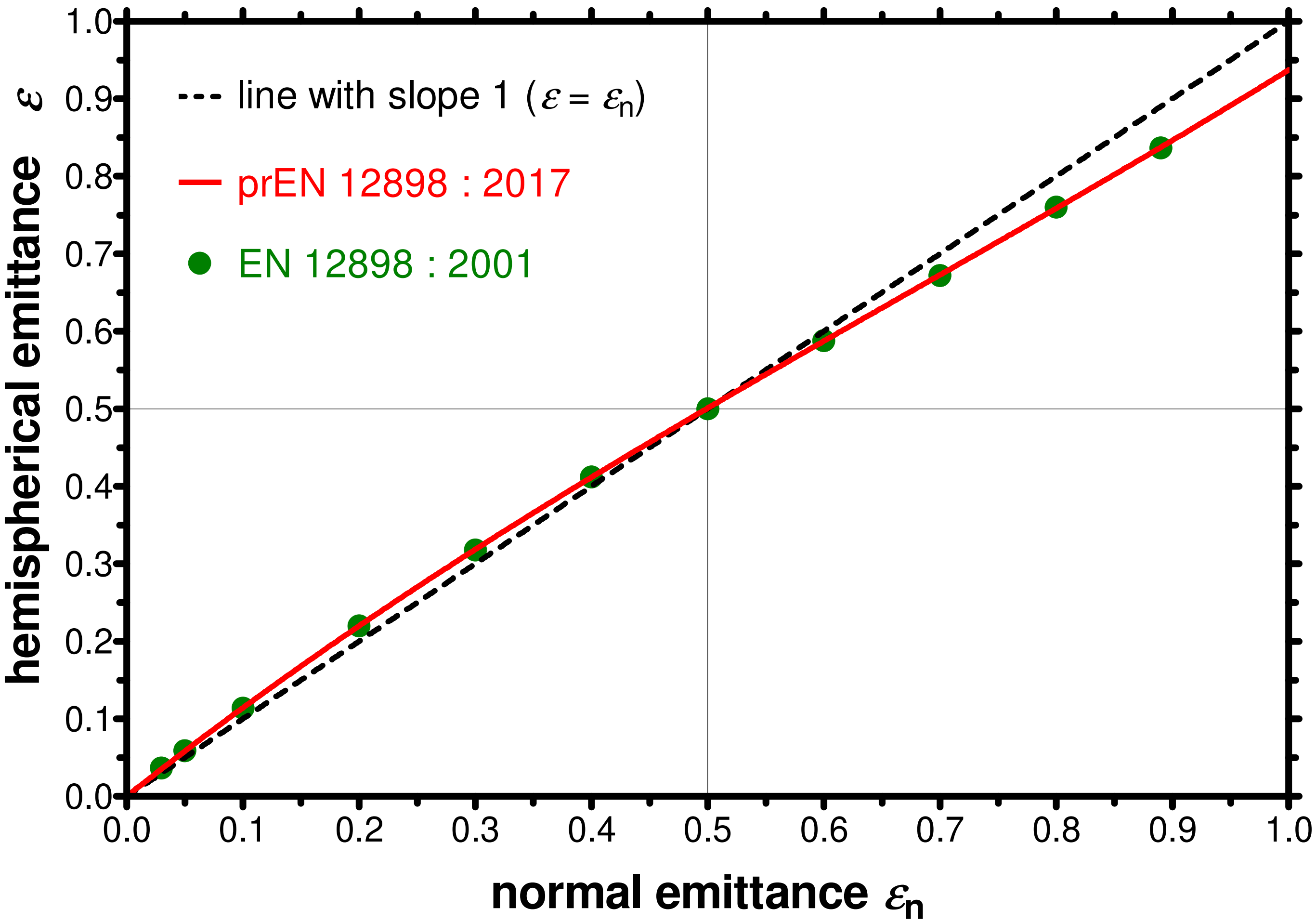
Correlation between normal and hemispherical emittance



Conclusions and Outlook

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Calculation of the total emissivity from the spectral emissivity

- Black body fraction $F_{2\mu m - \lambda_{max}}$: ratio of the intensity of a black body which is emitted between $\lambda = 2\ \mu m$ and $\lambda = \lambda_{max}$

$$F_{2\mu m - \lambda_{max}} = \frac{\int_{\lambda = 2\mu m}^{\lambda = \lambda_{max}} i_{bb}(\lambda, T) \cdot d\lambda}{\sigma \cdot T^4}$$

λ_{max}	15 µm	20 µm	25 µm	30 µm	35 µm	40 µm	45 µm	50 µm
***T* = 280 K**	51.6 %	70.1 %	80.8 %	87.1 %	91.0 %	93.5 %	95.1 %	96.3 %
***T* = 290 K**	54.1 %	72.0 %	82.2 %	88.1 %	91.7 %	94.0 %	95.5 %	96.6 %
***T* = 300 K**	56.3 %	73.8 %	83.4 %	89.0 %	92.4 %	94.5 %	95.9 %	96.9 %

Conclusions and Outlook

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- **determination of total hemispherical emissivity from**
  - spectral near-normal emissivity (EN 12898 and ASTM E 1585)
  - total near-normal emissivity (EN 16012 and EN 15976)

- **measurement principles**
  - spectrometric technique
  - TIR-principle (TIR = thermal infrared)

- **suggestions for further development of the standards**
  - activities within EMIRIM
  - …

Thank you!

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