WORKSHOP/TRAINING SESSION FOR STAKEHOLDERS AND END-USERS FROM INDUSTRY - 26TH NOVEMBER 2018

WHAT EMISSIVITY ?

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What emissivity should be measured for the application in thermal insulation ?

$$\Phi_{rad\ air\ space} = \frac{\sigma\left(T_{board}^{4} - T_{insul.}^{4}\right)}{\frac{1}{\varepsilon_{board}} + \frac{1}{\varepsilon_{insul.}} - 1}$$

$$R_{rad} = \frac{\left(T_{board} - T_{insul.}\right)\left(\frac{1}{\varepsilon_{board}} + \frac{1}{\varepsilon_{insul.}} - 1\right)}{\sigma\left(T_{board}^{4} - T_{insul.}^{4}\right)}$$

The heat flux density depends on the temperatures of the surfaces limiting the air space.

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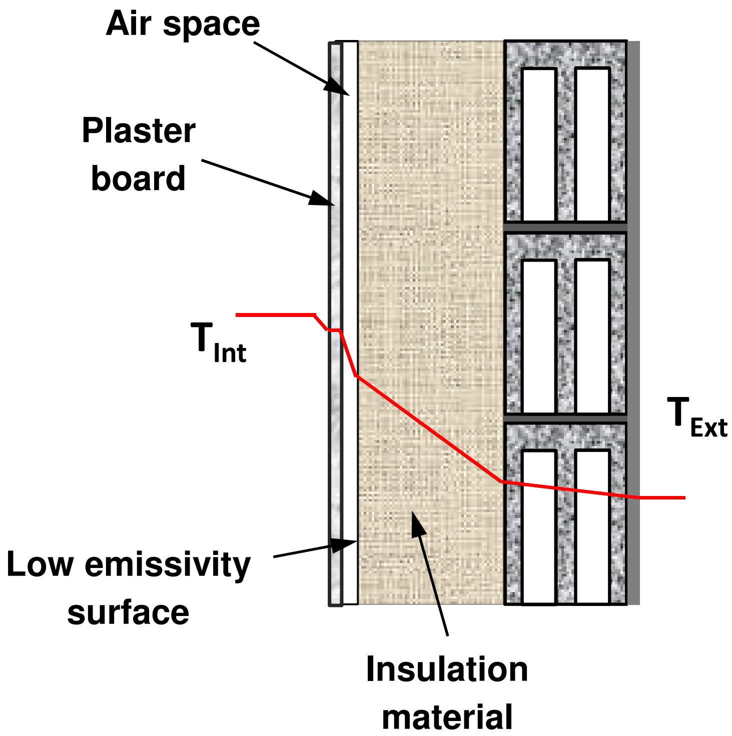

Air space not too wide to not induce thermal convection in the space

Definition of the total hemispherical emissivity used for modelling radiation heat exchanges in an air space

$$\varepsilon_{board} = 1$$

Radiation heat flux densities :

$$\Phi_{emitted\ by\ insulation\ surface} = \int_0^{\infty} \left[\int_0^{2\pi\ sr} \varepsilon_\lambda(\theta) \,.\, l^{\circ}\left(T_{insul\ surf}, \lambda\right) . \cos(\theta) \,.\, d\Omega \right] d\lambda$$

$$\Phi_{absorbed\ by\ insulation\ surface} = \int_0^{\infty} \left[\int_0^{2\pi\ sr} \varepsilon_\lambda(\theta) \,.\, l^{\circ}(T_{board}, \lambda) . \cos(\theta) \,.\, d\Omega \right] d\lambda$$

Net radiation flux density gained by insulation surface :

$$\Phi_{net\ insulation\ surf} = \Phi_{absorbed\ by\ insulation\ surface} - \Phi_{emitted\ by\ insulation\ surface}$$

$$\Phi_{net\ insulation\ surf} = \int_0^{\infty} \left[\int_0^{2\pi\ sr} \varepsilon_\lambda(\theta) . \cos(\theta) \,.\, d\Omega \right] . \left[l^{\circ}(T_{board}, \lambda) - l^{\circ}\left(T_{insul\ surf}, \lambda\right) \right] . d\lambda$$

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Definition of the total hemispherical emissivity used for modelling radiation heat exchanges in an air space

$\Phi_{net\ insulation\ surf} = \varepsilon_{hem\ total} \cdot \sigma \cdot \left(T^4_{board} - T^4_{insul\ surf}\right)$ → model usually used.

The emissivity used in the model is defined by :

$$\varepsilon_{hem\ total} = \frac{\int_0^{\infty} \left[\int_0^{2\pi\ sr} \varepsilon_{\lambda}(\theta).\cos(\theta).d\Omega\ \right].\left[l^{\circ}(T_{board}, \lambda) - l^{\circ}(T_{insul\ surf}, \lambda)\right].d}{\lambda\sigma\ .\left(T^4_{board} - T^4_{insul\ surf}\right)}$$

Wall : thermal resistance = 5, air space 0.02 m, conductivity air = 0.026 W m^{-1} K^{-1} → $T_{board} - T_{insul}$ = 3.1 K.

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Total hemispherical emissivity measured

Emissivity measured using the calorimetric technique from LNE :

$$\varepsilon_{hem\ total} = \frac{\int_0^\infty \left[\int_0^{2\pi\ sr} \varepsilon_\lambda(\theta).\cos(\theta).d\Omega\ \right].\ [l^\circ(78K,\lambda) - l^\circ(T_{samp},\lambda)].d\lambda}{\int_0^\infty \left[\int_0^{2\pi\ sr} \cos(\theta).d\Omega\ \right].\ [l^\circ(78K,\lambda) - l^\circ(T_{samp},\lambda)].d\lambda}$$

T_{samp} = temperature of the sample when measuring total hemispherical emissivity

Emissivity usually measured using an integrating sphere associated to a FTIR spectrometer :

$$\varepsilon_{hem\ total} = \left[\frac{\varepsilon_{hem\ total}}{\varepsilon_{normal\ \ total}}\right]_{theoretical} \frac{\int_0^\infty \varepsilon_\lambda(near - normal).l^\circ(T_{insul},\lambda).d\lambda}{{}^1/_\pi\ .\sigma\ .T_{insul}^4}$$

T_{insul} = any value can be selected for calculation of $\varepsilon_{hem\ total}$

$\left[\frac{\varepsilon_{hem\ total}}{\varepsilon_{normal\ \ total}}\right]_{theoretical}$ is found in literature or standards (calculated from Fresnel's équations).

Emissivity measured using the TIR100-2 reflectometer/emissometer :

Signal due to the near normal spectral radiance reflected by the sample (coming from the hemisphere)

$$U_{reflection} = \int_0^\infty sens_{TIR}(\lambda) . (1 - \varepsilon_{\lambda nn}) . l^\circ(T_{TIR}, \lambda) . d\lambda$$

Signal due to the near normal spectral radiance emitted by the sample (coming from the sample)

$$U_{emission} = \int_0^\infty sens_{TIR}(\lambda) . \varepsilon_{\lambda nn} . l^\circ(T_{samp}, \lambda) . d\lambda$$

Signal measured by TIR100-2:

$$U_{samp} = \int_0^\infty sens_{TIR}(\lambda) . \{l^\circ(T_{TIR100}, \lambda) - \varepsilon_\lambda [l^\circ(T_{TIR}, \lambda) - l^\circ(T_{samp}, \lambda)]\} . d\lambda$$

Emissivity measured using the TIR100-2 reflectometer/emissometer :

Calibration :

$$U_N = \int_0^{\infty} sens_{TIR}(\lambda) \,.\, \{l^{\circ}(T_{TIR100}, \lambda) - \varepsilon_N \,[l^{\circ}(T_{TIR}, \lambda) - l^{\circ}(T_{samp}, \lambda)]\} \,.\, d\lambda$$ → low ε ref sample

$$U_H = \int_0^{\infty} sens_{TIR}(\lambda) \,.\, \{l^{\circ}(T_{TIR100}, \lambda) - \varepsilon_H \,[l^{\circ}(T_{TIR}, \lambda) - l^{\circ}(T_{samp}, \lambda)]\} \,.\, d\lambda$$ → high ε ref sample

Sensitivity of TIR 100-2 (assumed to be independent on wavelength) :

$$sens_{TIR} = \frac{U_N - U_H}{\int_0^{\infty} (\varepsilon_H - \varepsilon_N)\,[l^{\circ}(T_{TIR}, \lambda) - l^{\circ}(T_{samp}, \lambda)] \,.\, d\lambda}$$

Definition of emissivity measured by TIR 100-2 :

$\varepsilon_{samp} = \varepsilon_H + (\varepsilon_H - \varepsilon_N)\,\frac{U_H - U_{samp}}{U_N - U_H}$ → model based on the assumption of linearity of response.

What emissivity should be measured for the application in thermal insulation ?

Emissivity actually measured by TIR 100-2

$$\varepsilon_{samp} = \varepsilon_H + (\varepsilon_H - \varepsilon_N)\ \frac{\int_0^{\infty}(\varepsilon_{\lambda} - \varepsilon_H)\left[l^{\circ}(T_{TIR}, \lambda) - l^{\circ}(T_{samp}, \lambda)\right].d\lambda}{\int_0^{\infty}(\varepsilon_H - \varepsilon_N)\left[l^{\circ}(T_{TIR}, \lambda) - l^{\circ}(T_{samp}, \lambda)\right].d\lambda}$$

T_{TIR} = 100 °C (fixed value**)**

T_{samp} = room temperature

Conclusion : The total hemispherical emissivities are not measured or calculated with the same ”temperature conditions”.

What is the influence of the temperature conditions?

Influence of the temperature conditions in measurements or for calculation

Foil	Total hemispherical emissivity (by calculation from spectrum measured at LNE)			
	FTIR (290K)	TIR100	ETOT LNE	application
PE 80 µm copper front	0.096	0.111	0.097	0.105
Bare alu foil front	0.053	0.059	0.053	0.053
PE 80 µm copper back	0.273	0.315	0.274	0.274

Conclusions :

- Total hemispherical emissivity is not really an absolute parameter.
- The total hemispherical emissivity used, measured or calculated from spectral data depends on the conditions of temperature for the application or when measuring or calculating.
- When spectral curves are flat, there is no effect of temperature conditions. The influence of temperature conditions depends on the shape of the spectral curve.
- The temperature conditions should be considered when comparing results from different techniques of measurement for materials with non-flat spectral emissivity curves.

Thank you for attention