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Experimental testing of correlations to calculate the atmospheric "transparency window" emissivity coefficient

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Abstract

An experimental verification of the correlations existing in literature for the calculation of the coefficient of emissivity inside the atmospheric transparency window, situated in the wavelength band 8–14 μm, has been performed. In addition, the authors propose a new correlation for the calculation of the coefficient ε_{in}, easily applicable since it presupposes the knowledge of the global emissivity of the sky, for which there are a lot of correlations in literature.

Keywords: Atmosphere; Transparency window; Emissivity

1. Introduction

The knowledge of radiative thermal exchanges happening in the atmosphere is of fundamental importance for the study of passive cooling of bodies exposed to the sky. The atmosphere, for purposes of radiative thermal exchange is, in general, considered to be a black body at the equivalent temperature of T_{sky}, or else as a "grey" body at outdoor air temperature measured at ground level.

In reality the atmosphere behaves like a black body across all the infrared spectrum with the exception of the wavelength interval included between 8 and 14 μm (Kondratjev, 1969). Located between the two extremes indicated is the so-called *Atmospheric Transparency Window*, characterised by high transparency to infrared thermal radiation and therefore by low energy emission (Fig. 1).

In building energy problems the radiative thermal exchange at a high wavelength takes on an important role for the purposes of thermal exchange. The presence of the atmospheric transparency window means that in the balance (in the infrared field) between the thermal radiation emitted by the building shell and the thermal radiation emitted by the atmosphere, there will be a net loss of energy on the part of the building.

It can be observed, by calculations, that for ordinary temperatures about 30% of the power is emitted by a body within the transparency window; this data can also be visualised graphically representing the emissivity curves of a black body, as shown in Fig. 2.

The quantity of infrared energy sent to the ground by the atmosphere depends on various: spectral emissivities of the constituents of the atmosphere, vertical distribution of the temperatures, vertical composition of the

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Nomenclature

ε	global atmospheric emissivity	$f_{\lambda 1-\lambda 2}$	energy fraction in the wavelength interval $\lambda_1 - \lambda_2$ (μm)
ε_{in}	atmospheric emissivity in the transparency window	T_r	dew temperature (°C)
ε_h	hourly emissivity	$\overline{T}_r$	mean daily dew temperature (°C)
T_a	outdoor air temperature (K)	σ	Stefan–Boltzmann constant (5.669×10^{-8} W/m^2 K^4)
p_v	outdoor air vapour pressure (mbar)	E_n	black body energy (W/m^2)
G_{mis}	infrared radiation measured in the interval 3.5–50 μm (W/m^2)	$G_{\lambda 1-\lambda 2}$	energy in wavelength interval $\lambda_1 - \lambda_2$ (W/m^2 μm)
G_{tot}	radiation in all the infrared (W/m^2)	λ	wavelength (μm)
G_ℓ	radiation with high wavelength (W/m^2)	t	time (h)
$G_{\ell\lambda}$	spectral radiation with high wavelength (W/m^2 μm)		

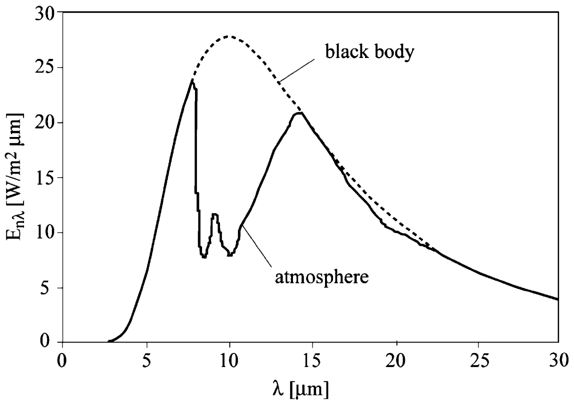

Fig. 1. Emissivity curve of the atmosphere with a ground air temperature of 20 °C.

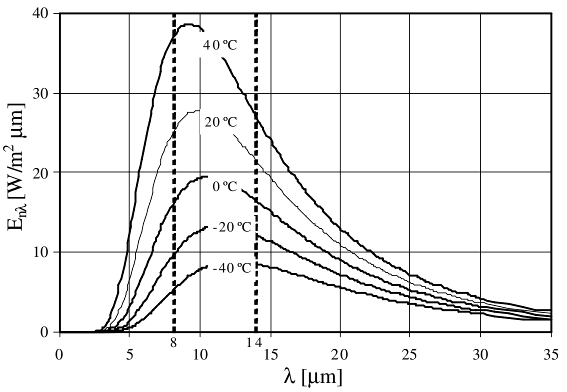

Fig. 2. Emissivity curves of a black body.

atmosphere, absorption and re-emission phenomena, which would require measurements at various altitudes carried out using aerostatic balloons or satellite measurements (Kondratjev, 1969).

In recent years, on the basis of these measurements, calculation codes have been set up of spectral thermal radiation $G_{\ell\lambda}$ in the infrared field. In general, to solve engineering problems, simpler models are relied on based on the measurement, at ground level, of more easily recorded meteorological-climatic parameters (Aubinet, 1994) such as outdoor temperature, relative humidity, etc.

In the literature the following formulations are proposed for the determination of thermal radiation at high wavelengths ($\lambda > 3.5$ μm):

$$G_\ell = \varepsilon\sigma T_a^4 \quad (1)$$

$$G_\ell = \sigma T_{sky}^4 \quad (2)$$

$$G_\ell = \varepsilon_{in} f_{in}\sigma T_a^4 + f_{out}\sigma T_a^4 \quad (3)$$

Eq. (1) considers the atmosphere as a grey body (Kamada and Flocchini, 1984) at outdoor air temperature measured at the ground, whereas Eq. (2) considers the atmosphere as a black body at equivalent temperature T_{sky}.

In the literature it is possible to find various correlations for the calculation of ε (Swinbank, 1963; Idso and Jackson, 1969; Llbot and Jorge, 1984) and T_{sky} (Unsworth and Monteith, 1975; Berger et al., 1984).

Eq. (3) instead subdivides the atmospheric emissivity curve into two wavelength intervals indicated with the subscripts in and out: a part of the energy emitted inside the transparency window (in), and a part emitted outside of the transparency window (out). In this way the sky is characterised by an emissivity ε_{in} within the window and by a unitary emissivity outside of it; f_{in} and f_{out} are the energy fractions of the black body inside and outside of the transparency window (Kimball, 1985). This formulation is the most suitable for the representation of the physical phenomenon (Kimball, 1985) qualitatively shown in Fig. 1, above all in prospective, for future developments of the problem, to be able to write the energy balances of selective surfaces exposed to the sky.