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Assessment of the thermal emissivity value of building materials using an infrared thermovision technique emissometer

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ABSTRACT

Following international standards concerning energy performance of buildings, in absence of reliable data on the envelope characteristics, thermal transmittance of building elements should be measured *in situ*. The method commonly used, based on ISO recommendations, is the heat flow meter measurement method. An alternative approach is based on the infrared thermovision technique (ITT). In this case, actual thermal emissivity value of the surface finishing material is paramount to obtain the true value of the surface temperature. Several methods and instrumentations are available for laboratory measurement of emissivity of materials, whose values can be even retrieved in databases. In this study a novel method for a direct evaluation of the emissivity of common building finishing materials by means of ITT is presented, using a portable instrument affording a comparatively fast but still quite accurate procedure. The laboratory experimental results, referring to six different building materials, provide promising indications on the possibility of applying the methodology to on site tests, so taking into account real material conditions, like environmental pollution, aging, laying mode.

1. Introduction

Thermal transmittance of outer building shells is one of the key parameters for the assessment of the energy sustainability of the whole building structure. This parameters can be evaluated, out of theoretical models, once the stratigraphy of the walls and the relevant properties of the constituent materials are known [1]. However, the experimental thermal transmittance measured on real buildings can be rather different from that estimated through modeling and calculations. In particular, since lower transmittance values are usually obtained, this leads to underestimate heat losses and, therefore, primary energy demand for indoor space heating. Indeed, thermal conductivity building elements is not constant over the years and may actually change as a consequence of several factors, like the natural aging of the materials, exposure and servicing conditions, like humidity, temperature and temperature gradients; eventually, even the correct construction procedures can have an important role, although are to be taken as occasional factors and, as such, difficult to be accounted for.

According to recent European Community guidelines [2] it is now compulsory to proceed with a complete energy efficiency certification of building structures. In this respect, the correct evaluation of thermal leakage and dispersion across the building shell is very important indeed. For the effective and reliable certification of the existing real estate, the availability of an experimental methodology for the direct measure of the actual features of the building envelope is definitely crucial. For this reason, the standard EN 15603: 2008 [3] specifies and describes in detail the methods and test parameters, including environmental conditions, to be used for *in situ* measurements of the thermal transmittance of the building envelope, for which the thermal flow meter measurement method is expressly mentioned in the ISO 9869:1994 [4].

Recently, an alternative approach has been proposed, the so-called infrared thermovision technique (ITT), affording the possibility to acquire quantitative real thermal transmittance data of the building envelope in a quasi-steady state condition by means of a non-destructive and no-contact testing technology [5]. One of the key point for the correct and reliable application of the method is the determination of the true surface temperature of opaque building elements. Temperature can be directly recorded with an infrared thermal camera, that can even reproduce the surface temperature distribution. Temperature is calculated from the infrared emission from the analyzed surface, that is a function of the environmental conditions and of the emissivity of the surface. Therefore, it is fundamental to estimate the emissivity of the surface to calculate its actual temperature correctly.

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Nomenclature

d	distance from sample surface and emissometer (mm)
E	energy (W/m^2)
N	heat power (W)
T	temperature (K)

Greek symbols

ε	thermal emissivity or hemispherical emittance of the surface (the two terms are considered synonymous in the manuscript)
λ	thermal conductivity (W/mK)
ν	wavelength range (μm)
ρ	thermal reflectivity
σ	Stefan–Boltzman constant equal to 5.67×10^{-8} (W/m^2 K^4)
τ	thermal transmissivity
Φ	diameter (mm)

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i	surface
max	maximum
out	environment
r	reflected
s	source

Infrared thermal emissivity can be defined as the fraction of energy emitted from the surface of a material at a finite temperature following an hemispherical flux geometry, as compared to an ideal black body emission [6]. For this reason, thermal emissivity can be even called hemispherical emittance. Emissivity is zero for a perfect reflector (mirror) and one for a perfect emitter (black body).

Emissivity depends on the material and on other parameters, such as temperature, surface conditions and radiation wavelength. In most common building materials, tested by Avdelidis and Moropoulou [7], the emissivity value increases with temperature in the wavelength range 3.0/5.4 μm, whereas experiments show that it is rather constant with temperature over the wavelength interval 8.0/12.0 μm. Ibos et al. [8] studied the influence of the average surface roughness, R_a, *via* thermal modulation method, and calculated emissivity equal to 0.42 for a semi-granular pavement with smooth surface (0.25 mm < R_a < 0.73 mm), while a value of 0.69 was found for the same pavement with a rough surface (0.26 mm < R_a < 1.95 mm). Emissivity increases with increasing surface roughness, an aspect not always taken into the right consideration. Indeed, most common building materials (*i.e.*, plaster, stone, concrete) are reported to have high emissivity values (usually higher than 0.8 [6]), although no specific reference to the actual surface roughness is made [9–13]. Therefore, the estimation of the surface temperature using such reference tables may be not sufficiently accurate and not always applicable to real structures.

Many methods have been proposed over the last two decades to calculate emissivity. Smetana and Reicher [14] suggest a laser irradiation system with variable wavelength. Ianiro and Cardone [15] estimated the emissivity using two thermal cameras in a stereo arrangement, with detectors sensitive to different wavelength bands. Berini et al. [16] used a thermal camera to analyze irradiation during a red-ox treatments observing *in situ* and contactless changes from metallic to insulator behavior and *vice versa.* Ono [17], Gallet et al. [18] suggested an hemispherical mirror to evaluate the surface temperature of those materials, having a diffuse reflection and isotropic emission. Similarly, Gaussorgues [19] measured the contribution of spurious radiation coming from laboratory environment, concluding, on the basis of such results, that this energy contribution could be neglected. Papini and Gallet [20] used an opaque object surface of known emissivity, a contact sensor for measuring its true surface temperature. Thus, the blackbody equivalent temperature can be obtained using infrared sensing.

However, these methods are not only expensive an time-consuming, but, above all, are difficult to be used for *in situ* evaluation of emissivity, a prerequisite to measure the real emissivity of a material, once it has been put into operation and it is exposed to the specific environmental conditions of the site and relevant aging mechanisms.

1.1. Aim of the paper

In this paper a novel instrumentation: the infrared thermovision technique emissometer (ITT-emissometer) for the measurement of thermal emissivity of materials, with particular reference for building materials, is proposed. Indeed, the equipment and relevant methodology have been developed in view of their profitable use for on site measurement of emissivity of common building finishing materials. Additional positive aspects of this technique, in relation to other methods, is that not only it can be used on-site, but it is also fully non-invasive. A simplified version of the method has been already proposed by the authors [5]. However, a complete and self-consistent protocol to verify the correctness of the results and to define a standard procedure had never been proposed as yet.

Owing to the lack of any specific instrumentation, this has been actually designed and assembled in the framework of the present research, with particular attention to the emissivity standard probe. This issue has required a specific study on the emissivity properties, considering several building materials, that have been selected starting from a wider investigation, not detailed herewith, that has confirmed the central role of a correct material choice for this application.

2. The measurement of emissivity ε_ν

Thermal emissivity of an outer surface of a building element under real working conditions and in the energy sensitivity range of the used thermal camera, is necessary in order to determine the actual surface temperature, T_i, from the radiant temperature provided by thermographic images. This temperature, together with other thermophysical parameters, is paramount for a correct characterization of the performances of building structures, as concerns particularly their energy sustainability and efficiency. The evaluation of thermal emissivity can be pursued according to two main methods: comparison with a reference material (for example, special adhesive tape with known and calibrated emissivity) or the direct measurement of the radiation reflected by the material. In fact, if N_ν is the power falling in the range ν in which the thermography equipment works, Kirchhoff's Law states that:

$$N_\nu = \varepsilon_\nu N_\nu + \rho_\nu N_\nu + \tau_\nu N_\nu \quad (1)$$

where ρ_ν is the reflectivity and τ_ν is the transmissivity.

It expresses the principle of energy conservation: a radiant power N_ν is partly absorbed ($\varepsilon_\nu N_\nu$), partly reflected ($\rho_\nu N_\nu$) and partly transmitted ($\tau_\nu N_\nu$). Thus, for opaque surfaces, it is

$$N_\nu = \varepsilon_\nu N_\nu + \rho_\nu N_\nu \quad (2)$$

so

$$\frac{\rho_\nu N_\nu}{N_\nu} = 1 - \varepsilon_\nu \quad (3)$$