DETERMINATION OF RADIATIVE PROPERTIES OF COMMERCIAL GLASS

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ABSTRACT: Spectral radiative properties of commercial glass are determined, including the index of refraction and the absorption coefficient. Such determination takes place in the visible and near infrared range of the electromagnetic spectrum. The property determination is performed with transmittances and reflectances measurements in different wavelengths from 400 to 4000 nm. Total visible and solar transmittances can be calculated, based on these data. The complete experimental set-up, the numerical models, as well as some results are presented and discussed in the paper.

Conference Topic: Building Physics.

1. INTRODUCTION

Different types of glass and other semitransparent materials have been used in buildings. New materials have been incorporated, some time following aesthetic reasons, sometimes based on economic aspects. To estimate the effect of such materials in the indoor conditions, the thermal properties, including conductive and radiative properties must be known. Properties of glass have been presented for a specified sample thickness and incidence angle, restraining the generalization of the results to another practical application.

Pursuing this goal some works have been accomplished, including the experimental set-up assembling and the development of identification methods. The results of the identification method, applied to a commercial clear glass slab, have been compared with another results with a satisfactory performance [2]. The same method was used with different sample thickness, and the same property values were obtained [4].

Some recent works deal with intrinsic properties, others analyse the complete glazing system. For example, Arasteh [5], presents a complete paper about the advances in window technology, including different aspects related to its thermal performance. New materials have been introduced and new designs have been adopted in order to reduce the U-value (global coefficient of heat transfer), of composed windows. Ismail and Henríquez [6], have modelled the heat transfer through composite windows and have also investigated the behaviour of a pcm-filled one. Caram [7], has characterised some semi-transparent materials relatively to the optical properties and has analysed its influence on building thermal comfort. Pfrommer et al [8], have developed a simulation program to calculate global properties like transmittances and reflectances of composed windows. Coated and tinted glazings are used and data for several materials and incident angle are presented. Hsieh and Su [9] has presented some equations in an attempt to help in the bulk properties calculation like absorptance, reflectance and transmittance of one or more sheets of glass. Rubin [10] uses a Fourier transform spectrometer to measure reflectances and transmittances of different kind of window glasses. The Kramers-Krönig relations are adopted to calculate the real and imaginary parts of the index of refraction. The data are provided from 0.3μm to 90 μm. Transmittance, absorptance and reflectance data are also provided.

In this paper glass of different composition are measured and the results are compared, including the bulk properties of a sample and the intrinsic properties of the constitution materials.

Several nomenclatures have been used to represent the interaction between incident beam and a surface, and between incident beam and the complete slab. In this paper the ending “ivity” is used for a single event (reflectivity, transmittivity) and the ending “ance”, for the global event (reflectance, absorptance, transmittance).

2. FORMULATION

Reflection of the thermal radiation on a specular surface, as presented in Fig. 1, is governed by Fresnel´s equation, represented in Eq. (1), [1].

$$r(q)=\frac{1}{2}\frac{\sin^2(q-c)}{\sin^2(q+c)}\left[1+\frac{\cos^2(q+c)}{\cos^2(q-c)}\right], \qquad (1)$$

where θ is the incidence angle and χ is the refraction angle. The refraction angle depends on the incidence angle and on the medium; this one represented by the index of refraction, following the Snell's Law, Eq. (2):

$$\frac{senq}{senc}=n \qquad (2)$$

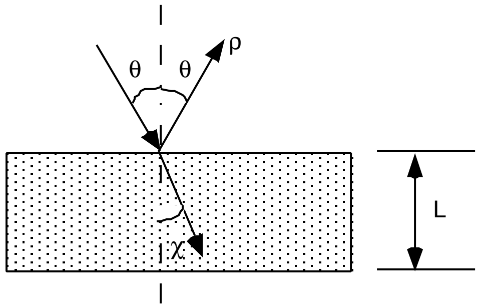

Figure 1: Interaction beam-surface.

When the incidence beam is normal to the surface, θ=0º, the reflectivity is calculated using Eq. (3):

$$r=\left(\frac{n-1}{n+1}\right)^2 \qquad (3)$$

Inside the medium, the radiation is progressively attenuated and the transmitted radiation is modeled by Beer's Law [1], Eq. (4). After a distance L/cosχ, the transmittivity τ is:

$$t=\exp(-aL/\cos c) \qquad (4)$$

where *a* is the absorption coefficient of the medium. When no homogenous medium is considered, a scattering coefficient can also be used.

Following the beam, as depicted in Fig. 2, additional reflections are observed on each interface, and each reflection can be calculated using Eq. (1) or Eq. (3). Computing all the outcoming beams from the incident surface, the result is the reflectance, given by Eq. (4), [1]. The sum of the outcoming fractions in the opposite surface is the transmittance, Eq. (5). The reflectance and the transmittance are, in fact, bulk properties, because of the dependence on the sample thickness, the incidence angle and on the intrinsic material's properties, as the index of refraction and the absorption coefficient.

$$R=r\left[1+\frac{(1-r)^2t^2}{1-r^2t^2}\right]=r(1+tT) \qquad (5)$$

$$T=\frac{t(1-r)^2}{1-r^2t^2} \qquad (6)$$

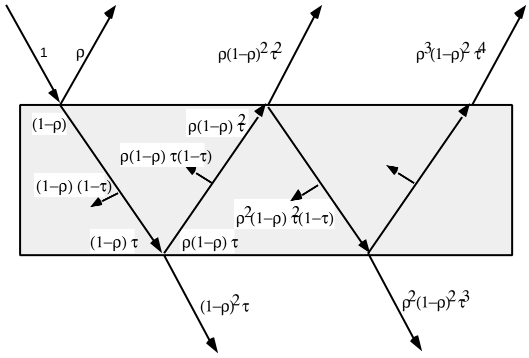

Figure 2. Interfaces' multiple reflections.

Computing all the fractions of absorbed energy inside the sample, one can obtain the sample absorptance. Therefore, absorptance can be summed with the reflectance and transmittance to obtain the unitary value. Then Eq. (7) can express this energy balance as:

$$1=A+R+T \qquad (7)$$

All the preceding equations are based on a monochromatic beam; they are associated to a particular wavelength. As a consequence, the intrinsic properties index of refraction (*n*) and absorption coefficient (*a*) are spectral properties and a dependence on the wavelength can exist (the spectral dependence is not specified in order to simplify the notations).

Properties related to a wavelength range, like visible, infrared or solar range can be obtained from the spectral distribution, using integration like Eq. (8), in such a case applied for transmittance calculation in the visible range (400 nm to 780 nm). Similar expressions can be used to reflectance and absortance and to another spectral range. G(λ) is the solar irradiation incident on the earth's surface.

$$T_{vis}=\int_{400}^{780}T(l)G(l)dl \,/\, \int_{400}^{780}G(l)dl \qquad (8)$$

When the described properties are known, the specified model can be used to calculate the interaction between the incident beam and the slab of glass or another semitransparent homogeneous materials.

3. PROPERTIES IDENTIFICATION

The mentioned properties (*n* and *a*), cannot be directly measured and an identification process takes place. An experimental setup based on a monochromator and some different gratings is used and sketched in Fig. 3.

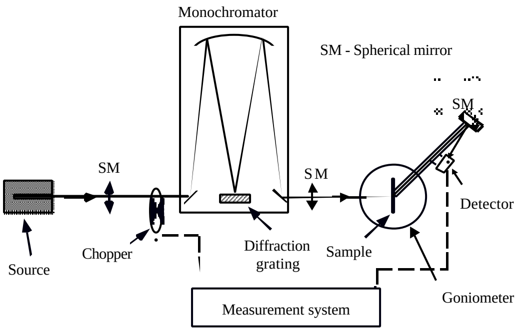

Figure 3. Experimental apparatus.

The radiation source is a tungsten lamp that allows covers the visible and the infrared wavelength range up to 4000 nm. The beam is projected into the monochromator and by interference, promoted by the grating, only a chosen wavelength band is send to the exit window and strikes the sample. The incident flux is measured with the detector aligned to the incident beam and without sample in the respective place. The transmitted flux is measured in the same way, putting the sample in its special holder. To measure the reflected flux, the goniometer is turned around the sample, placing the detector in the specular direction of reflection. An angle θ=5° between sample and incident beam is used to measure all the quantities.

In this kind of apparatus the measurement is performed step by step, using a wavelength band each time. To cover the visible, the near and middle infrared ranges up to 4000 nm, four different gratings and some longwave pass filters are necessary.

After all the measurement, covering the specified wavelength range, spectral transmittance and reflectance data are available using the ratio, respectively, transmitted/incident signals, and reflected/incident signals. The identification method, described in [2], allows obtain the spectral distribution of the index of refraction and of the absorption coefficient.

4. RESULTS

Three different glass compositions are used in the measurement and in the property identification. The spectral transmittance and reflectance are measured using the respective samples. The sample thickness is not mandatory in such a case.

Results concerning the spectral absorption coefficient are presented in the Fig. 4. All the samples have the same general behavior in the measured spectral range. The absorption increases strongly after 2900 nm - the glass becomes opaque for longwave radiation. In the visible range the clear glass has a very low absorption, followed by the bronze and the gray glass. Clear glass has a more uniform absorption in the visible. More transparence is observed around a wavelength of 550 nm, the yellow color. Gray and bronze glasses have more transparency around 700 nm (red color).

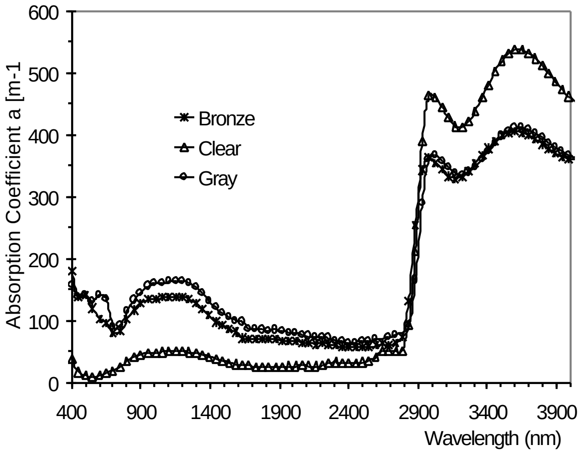

Figure 4: Spectral absorption coefficient.

In the Fig. 5, the results of the index of refraction are presented. The same pattern is observed for the three different types of glass: a decreasing index of refraction for increasing wavelength. Such variation is the reason that one can separate different colors from a beam using prisms. Clear glass has a lower value in the visible and near infrared spectrum.

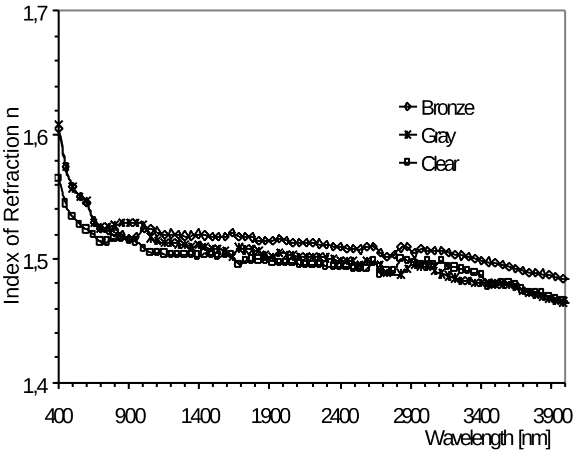

Figure 5: Spectral index of refraction.

Using the properties presented in the Fig. 4 and 5, and the model from Section 2, the normal spectral transmittance for a 4 mm slab of glass can be calculated (Fig. 6). The behavior is quite similar to the observed in the Fig. 4, in an opposite way. The clear glass has a good transmittance in the visible and near infrared and a strong reduction takes place after 2900 nm. The gray and bronze slabs have a lower transmittance in the visible and near infrared. Curiously, the clear glass transmits less than others after 2900 nm, but this region is not significant in the solar spectrum, as will be observed in the Fig. 9.

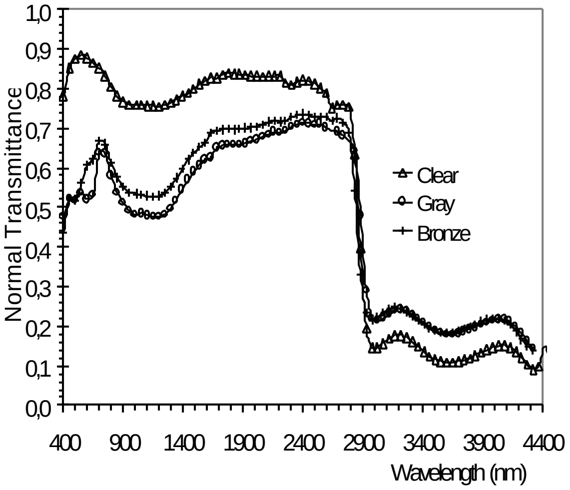

Figure 6: Normal spectral transmittance (L=4mm).

Similar to the last one, Fig. 7 and 8 present, respectively, the results to normal spectral reflectance and absortance, for the same slab thickness and angle. Clear glass reflectance up to 2900 nm is lower than others in spite of having a lower index of refraction. In such a case the preponderant effect is not on the first reflection (Fig. 2), but on the second, where the beam has traversed the slab two times (subsequent reflections are not significant [1]). The results to the spectral absorption are logically quite similar to the absorption coefficient results presented in the Fig. 4.

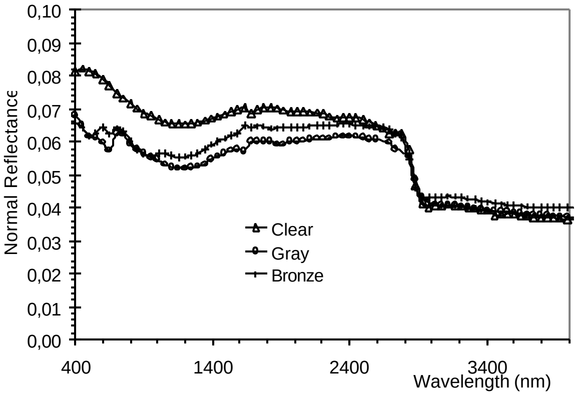

Figure 7: Normal spectral reflectance (L=4mm).

When thermal balances and luminance calculations are performed for a particular window, the visible, infrared and solar properties are necessary. In such a case the spectral properties distributions must be correlated with the spectral solar irradiation. The spectral solar radiation is modeled firstly, taking a distribution proportional to an emission from a blackbody at 5800K (Fig. 9). Extraterrestrial measurements show small differences from this model. However, on the earth' surface some significant differences are observed and these differences are due to absorption and scattering promoted by atmosphere components (Fig. 9). Taking the lower curve as a pattern to the spectral irradiation and the distribution from Fig. 6 to 8, the results are presented in Table 1. Clear glass presents a small absortance and a high transmittance, while bronze and gray glasses have more absorption. The reflectance suffers only a small variation comparing glass type and spectral region.

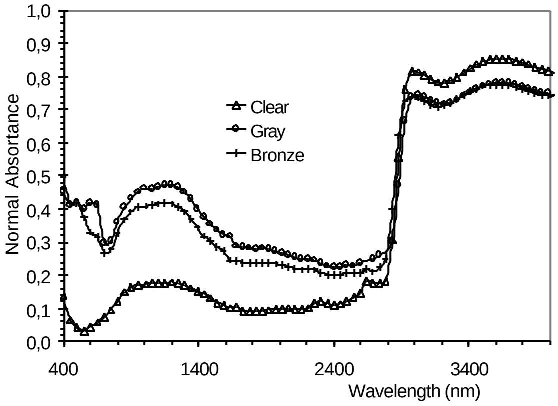

Figure 8: Normal spectral absortance (L=4mm).

Table I: Properties of glass slabs of 4 mm thick.

Glass	$T_{visible}$	$R_{visible}$	$A_{visible}$
Clear	0.86	0.08	0.06
Gray	0.55	0.06	0.39
Bronze	0.58	0.06	0.36
	$T_{infrared}$	$R_{infrared}$	$A_{infrared}$
Clear	0.78	0.07	0.15
Gray	0.54	0.06	0.40
Bronze	0.58	0.06	0.36
	T_{vis+ir}	R_{vis+ir}	A_{vis+ir}
Clear	0.82	0.07	0.11
Gray	0.55	0.06	0.39
Bronze	0.58	0.06	0.36

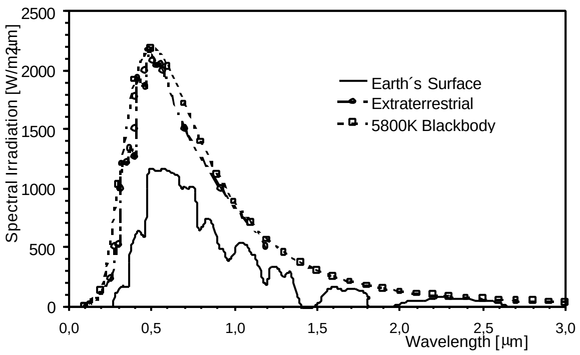

Figure 9: Spectral solar irradiation [3].

5 CONCLUSION

An identification method have been presented, allowing obtain the material intrinsic properties, the index of refraction and the absorption coefficient. With these properties, bulk properties like transmittance, reflectance and absortance can be calculated to different incidence angle and slab thickness. The model necessary is also presented.

Spectral information about properties is also very interesting in order to calculate total properties based on the solar spectrum and in order to understand the influence of a particular wavelength in the material behavior. This spectral information can still be used in ligthing evaluation, total light flux as well as color influence (monochromatic flux). In such a case measurements with more resolution in the visible spectral range must be done.

ACKNOWLEDGEMENTS: The research reported herein was conducted thanks to the financial support of CNPq (National Council of Research and Development). The authors also would like to acknowledge Mr. Mauro Lucio Nascimento Luiz from CEBRACE, who kindly has furnished the glass samples.

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