Evaluation of Solar Radiation Transmission Through Transparent Facades

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ABSTRACT

In this work we discuss the optical behavior of transparent materials, such as colored and colorless glass, as well as the sputtered and pyrolitic reflective glass types, used in building facades. The optical evaluation of these materials is carried out in different solar spectrum intervals: ultraviolet, visible-light, and near infrared, and the obtained data are related to thermal and visual comfort. This approach leads to the identification of the ideal glass for warm climates, as in Brazil, which should transmit visible light but not near infrared radiation. Spectrophotometric analysis of the transmitted radiation is performed for different incidence angles, varying from 0° to 80°, and by scanning the solar spectrum, from 300 nm to 2000 nm. At the value of 60° of the incidence angle, the transmission of the solar spectrum is significantly attenuated. These results are important for applications in architecture because data commonly found in the literature are usually related to normal incidence, which very rarely occurs in real situations. The results of this work complement available technical information, allowing a more adequate analysis of the use of the tested glasses.

INTRODUCTION

Frequently, when designing glazing facades, architects hardly find specific technical data related to radiation transmission for different regions of the solar spectrum and different incidence angles. The data found are usually given for normal incidence of radiation, which is seldom the case for building facades. This work brings up new technical contributions to better evaluate buildings in terms of illumination and solar gain.

The solar spectrum, which comprises radiation in a range of wavelengths from the near ultraviolet region (wavelength from 300 nm to 380 nm), through visible light (380 nm to 780 nm), to near infrared (780 nm to 2000 nm), is partially transmitted through glasses. Transmission can be further attenuated with the addition of oxides to the glass composition or with the application of solar control films, resulting in larger absorption and reflection of the solar radiation.

Effective solar control can also be achieved by the use of reflective coatings. Increased reflection implies a reduction of transmission. Reduced heat gain can be obtained with low emissivity, or low-e, coatings. A lower emissivity raises reflection of far infrared radiation, which increases the thermal insulation. Any surface with an emissivity at or below 0.20 is considered a low-e surface (Johnson 1991).

The spectral transmission through glass depends on the chemical composition, color, internal optical absorption coatings, and surface characteristics. Usually the available data for light transmission, reflection, and absorption in glasses are given for normal incidence measurements. The amount of energy directly transmitted through transparent materials decreases as the angle of incidence becomes larger than 45°. At 60° the transmitted radiation is significantly reduced and reflection is increased, as shown in Figure 1 (ASHRAE 1997).

One of the reasons for the use of glass in windows is to allow the passage of daylight, but glasses are also the cause of heat gain. The glasses used in civil construction may be divided into groups, classified by their transmission, absorption, and reflection coefficients. All types of glass absorb, reflect, and transmit portions of the incident solar radiation.

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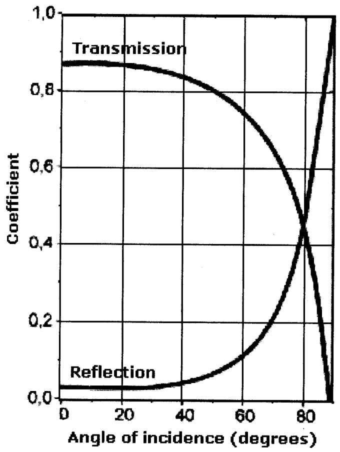

Figure 1 *Transmission and reflection coefficient as function of angle of incidence.*

Reflection depends directly on the incidence angle and on the refraction index of the material (n), which for glasses is about 1.5. It also depends upon the application of coatings and of thin films. Coatings can modify the radiative surface properties of glass and thereby affect energy efficiency. Two techniques are widely used for applying such coatings: sputter deposition and spray pyrolisis (Granqvist 1991).

Note that attenuation in the transmission of solar radiation can also result from absorption by the glass, which increases its temperature, thereby causing an increase in the emission of thermal radiation.

An "ideal" glass, for the Brazilian climatic conditions, would present optical characteristics similar to those in Figure 2 (ASHRAE 1993). What is habitually sought in relation to environmental comfort in areas with warm climates is good solar light transmission as well as a considerable attenuation in the near infrared region (Labaki et al. 1999). That attenuation would ideally come from high near-infrared reflection, as with low-e films, and not from near-infrared absorption, which would add to the thermal load of the building.

MATERIALS AND METHODS

Measurements were done on commercial glasses. All samples were cut to a standard size of 20 × 20 mm and consisted of: float colorless, bronze, and blue glass; sputtered reflective glasses, bronze and blue colors; pyrolitic reflective bronze glass.

The transmission measurements were carried out with a spectrophotometer with an angle accessory to vary the angle of light incidence. No depolarization device was used. Polarization in the spectrophotometer was partial and for this reason was not considered.

Measurements were performed in the following conditions:

- Wavelength range: 2000 nm to 300 nm, with steps of 1 nm, which yields 1700 measurements in the whole interval.
- Range of angle of incidence with the normal: 0º to 80º.

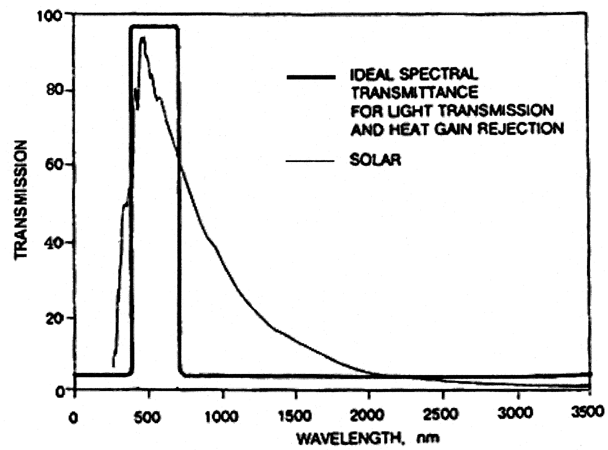

Figure 2 *Ideal spectral transmittance for warm climates.*

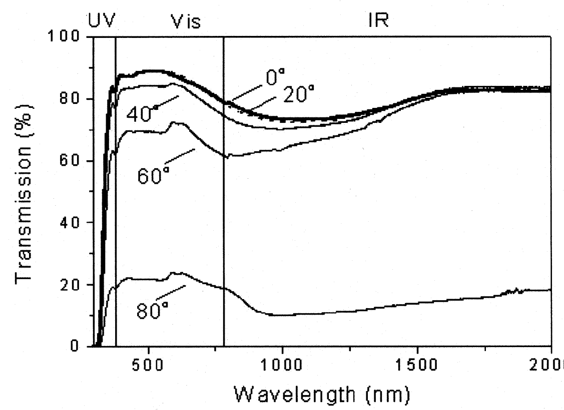

Figure 3 *Spectral transmission curves of 6 mm colorless glass.*

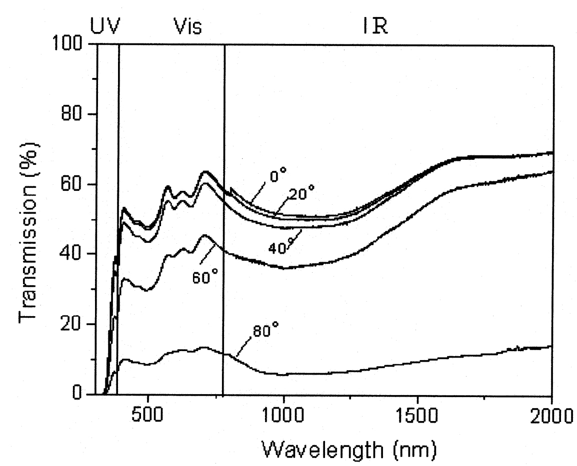

Figure 4 *Spectral transmission curves of 6 mm bronze glass.*

RESULTS AND DISCUSSION.

The results obtained confirmed that increasing the incidence angle above 60º causes the amount of radiation directly transmitted to decrease significantly. This may be attributed to

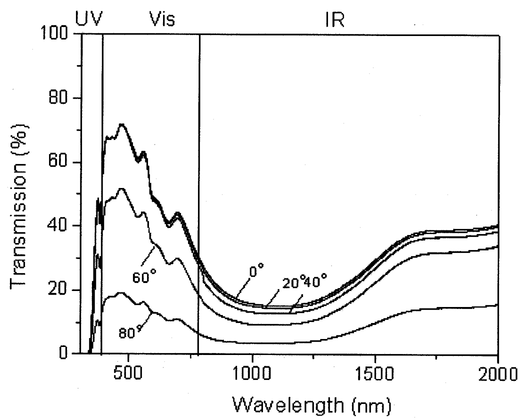

Figure 5 *Spectral transmission curves of 6 mm blue grass.*

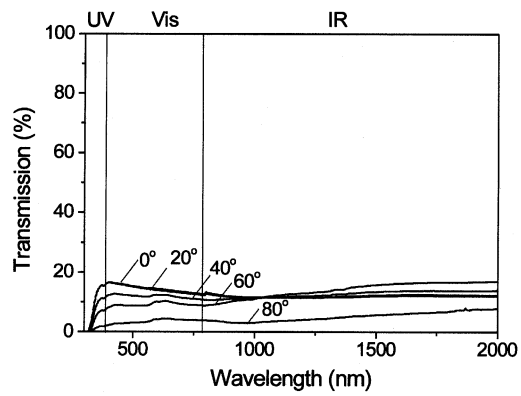

Figure 6 *Spectral transmission curves of bronze sputtered reflective glass.*

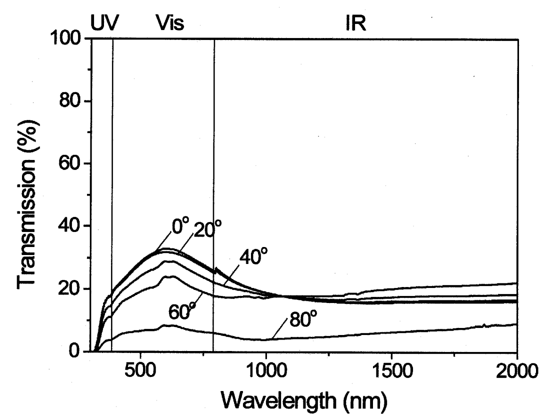

Figure 7 *Spectral transmission curves of blue sputtered reflective glass.*

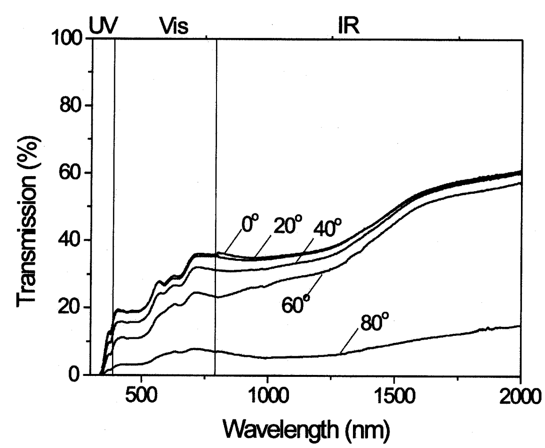

Figure 8 *Spectral transmission curves of bronze pyrolitic reflective glass.*

the reflection coefficient of the glass, which starts increasing from this angle, as seen in Figure 1. This is true for all samples tested. This reduction is observed for all regions of the solar spectrum.

Figures 3 to 8 give the transmission curves for incidences varying from 0° to 80°. The results are summarized in Table 1.

For colorless and colored glasses, the attenuation of transmission for incidence angles up to 40° is not significant. Colored glasses have a significant attenuation for incidence angles above 60°. At 80°, the attenuation is large, varying from 70% to 85% for all samples.

For the reflective sputtered glass, incidence angles up to 60° present significant attenuation in the infrared region. Nevertheless, in the visible light and ultraviolet regions, a considerable attenuation occurs as the incidence angle increases (see Figures 6 and 7 and the data in Table1). This kind of glass presents a very low transmission in the infrared, being therefore suitable for hot climatic regions. However, its transmission of visible light is also low.

For the reflective pyrolitic bronze glass, the attenuation measured above 60° is significant for the whole spectrum, as can be seen in Figure 8 and Table 1. Besides, it can be verified in Figure 8 that the pyrolitic glasses present good transmission of infrared radiation and a low one for visible light. This type of glass is not recommended for buildings in hot climatic regions there since glasses should transmit well visible light and little near infrared radiation.

Generally, it can be stated that for incidences larger than 60° a significant attenuation of solar radiation is observed. For an incidence of 80°, on the average, the glasses attenuate significantly the incident radiation by an amount varying from 50% to 80%.

For facades where the incidence of sunlight is almost tangent to the transparent surface, the penetration of radiation decreases greatly, resulting in a reduction of heat gain, due to the incidence angle. It is observed from the measurements that this attenuation may reach about 80%, quite significant therefore.

For regions of hot climate, the "ideal" glass should admit light but reject near infrared radiation. Of all types of glasses that were investigated, the blue glass can be singled out as the fenestration that best fulfills these conditions. It should be

TABLE 1
Transmission Through the Glasses for Different Incidence Angles

Sample	Angle (°)	UV (%)	Vis (%)	IR (%)	Overall (%)
Colorless Glass	0	43	85	78	78
	20	43	86	78	78
	40	40	81	77	76
	60	31	68	73	70
	80	9	21	14	15
Bronze Glass	0	12	55	60	56
	20	12	55	59	55
	40	11	51	57	54
	60	7	37	48	44
	80	2	11	9	9
Blue Glass	0	15	53	27	32
	20	15	53	26	31
	40	14	52	24	30
	60	9	37	20	23
	80	3	13	9	10
Bronze Sputtered Reflective Glass	0	8	14	12	12
	20	8	14	12	12
	40	5	11	12	12
	60	3	9	12	12
	80	1	4	5	5
Blue Sputtered Reflective Glass	0	9	28	17	19
	20	8	28	17	19
	40	7	24	18	19
	60	5	19	19	18
	80	2	7	6	6
Bronze Pyrolitic Reflective Glass	0	4	26	45	39
	20	4	26	45	39
	40	3	23	44	37
	60	2	17	40	32
	80	1	5	9	8

remembered that attenuation is not only due to reflection but also to absorption.

Figures 9 and 10 present the transmission as a function of the incidence angle. The transmission considered in these figures is the total one, with no subdivision into ultraviolet, visible and infrared regions.

CONCLUSIONS

Two fundamental points can be answered from the results obtained in this work: the first concerns the variation of the transmission in the infrared region as the incidence angle changes. It was observed that the attenuation, due to the variation of the incidence angle, generally takes place in the infrared in the same proportions found for visible light. The second point is related to the reflective sputtered and pyrolitic glasses. The results indicate that for reflective glasses there is a "vertical shift down" of the transmission curves. The same behavior is shown proportionally in all the regions of the solar spectrum, as can be confirmed by the experimental evaluation. The transmission attenuation is also due to the absorption characteristics of the material.

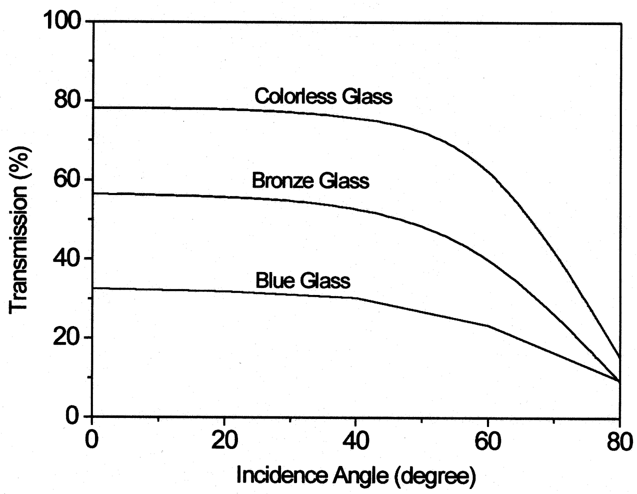

Figure 9 *Transmission of float glasses versus incidence angle.*

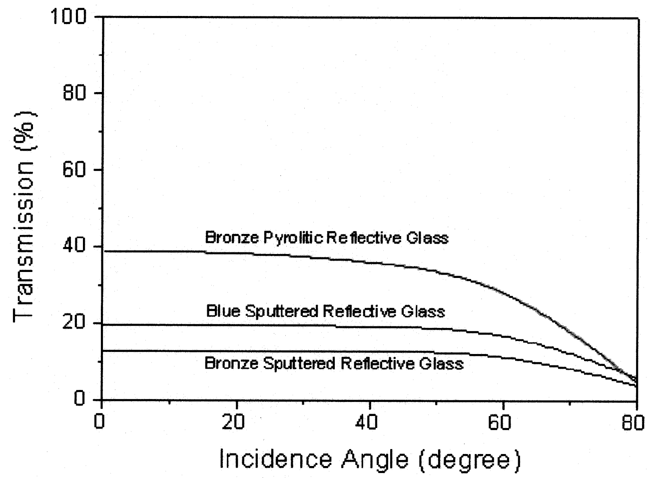

Figure 10 *Transmission of sputtered reflective glasses versus incidence angle.*

The sputtered reflective glasses generally transmit weakly infrared radiation, but this also occurs with visible light. As the incidence angle increases, the transmission of solar radiation becomes still smaller. Design specification for these glasses should be made very carefully because it can significantly impair natural illumination.

The bronze reflective pyrolitic glass shows the opposite behavior as to what is desirable, i.e., it transmits more infrared than visible light.

A good option in hot climates could be the use of blue and colorless glass in a double-pane window. The blue glass pane should be placed on the external side with the colorless float glass pane on the internal side. Blue glass allows the transmission of a great portion of the visible light but attenuates the infrared due to its absorption. This absorbed energy is reradiated in the far infrared to the exterior and interior of the window. As the inner glass is opaque to the far infrared, there will be attenuation in the solar gain when this system is considered. However, the common glass possesses an emissivity of 0.84 for the longwave radiation. If it is substituted by glass with low-e coating, with an emissivity of 0.04, the transmitted heat could be reduced from about 80% to near 4%.

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