Accurate Transmittance Measurements on Hollow Glass Blocks

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ABSTRACT

Hollow glass blocks are square shaped double glazing units available in different sizes and used for building applications. Several kinds of hollow glass blocks are commercially produced in different thickness (of the single panes and of the component), in the surface processing (obtained by acid or sand treatment), in the internal shape of the component panes and in the color. There are some intrinsic difficulties when performing optical measurements on glass block. The information available is not sufficient for a proper use of these hollow glass blocks. This work, which tries to supplement this lack of information, consists of three main experimental sections: 1) a comparison of the luminous transmittance measurements on three selected samples using two integrating spheres, 2) the mean transmittance of these samples, obtained as an interpolation of the measurements performed on several points of each block, 3) an evaluation of the bi-directional function of the luminous transmittance, by means of gonioreflectometric investigations. From an accurate knowledge of the properties of the components, the performance for the assigned application can properly be predicted.

Introduction

Hollow glass blocks are widely used in architecture for different functions. They are used in structural applications (skylights and transparent coverings), to divide different spaces in the case of interior designs (while allowing the natural light to reach the inner part of the room). More over, they are useful when large transparent surfaces are required (this is the case for atria, gyms, conference halls and so on). Figure 1 shows an example of a glass block application. As can be seen in the picture, these components are suitable for complex surfaces, which are generally difficult for ordinary windows.

Each application has a particular requirement and, as a consequence, different kinds of blocks must be used. Differences can be found in the dimensions (from 18x18 cm^2 up to 30x30 cm^2); in the internal shape of the panes: flat, prisms (parallel and crossed), complex geometry; in the external surface treatment: (clear, acid treated, sand blasted) and in the color. As a consequence different objectives can be achieved: diffusing, redirecting and accentuating the natural light are some of these.

The more accurate is the optical characterization of the glass block, the more appropriate will be their application. The aim of the paper is, after selecting three samples, to discover all the aspects regarding the optical transmittance, which is a fundamental parameter for daylighting applications parameters.

Figure 1. Application of glass blocks in architecture

Methodology

A proper lighting characterization of hollow glass blocks is difficult to obtain, due to the complex luminous behavior of such components. A collimated solar or artificial radiation, incident on one surface of the block, gives rise to regular and diffuse transmitted light and reflected components with different optical paths.

The instruments often used to perform transmittance and reflectance measurements on hollow glass blocks are large integrating spheres. The sample port should be large enough to collect the whole beam transmitted (reflected) by the sample. However, this is a difficult condition to reach because of the large dimensions of the normal hollow blocks and sample port. Other problems arise: the measurements differ from the real situation, because, when a single unit is tested, the discontinuity of the transparent system due to the presence of a spacing boarder between two adjacent blocks is not taken into account. Moreover, the border effect must be considered: usually a transparent material is characterized by measurements with the beam hitting the center of the sample. In this case, for more accurate results, it is important to evaluate the optical parameters close to the edge of the block. As an example, the ratio of the length of a window to its thickness is typically 40 (for a double glazing unit). In the case of hollow glass blocks, the ratio becomes lower than 4. In these conditions, the border effect strongly influences the overall optical parameters. The use of a center value can lead to significant errors in the evaluation of the lighting, as well as the thermal, properties of such components.

In order to perform accurate normal and directional transmittance measurements on different types of hollow glass blocks, three experimental investigations were performed:

1. Two large integrating spheres, with a large sample port, were used for the determination of the directional light transmittance, τ_V, in the central zone of the hollow glass blocks.

2. Transmittance measurements at different points of the sample surface, in order to establish a more appropriate mean value for the sample transmittance.
3. A Gonioreflectometric investigation, in order to evaluate in which direction the light is transmitted by the sample, and to estimate the regular and diffuse components of the radiation.

By means of these measurements, the hollow glass block is accurately characterized for both global and directional solar radiation The chosen blocks, 30 cm wide, 30 cm high, 8 cm thick and with single panes, 1 cm thick, are:

S1 Clear hollow glass block.
S2 Hollow glass block with a prismatic shape on inner surfaces, parallel faced.
S3 Hollow glass block with a prismatic shape on inner surfaces, cross-faced.

Integrating sphere measurements, part 1

Measurements on hollow glass blocks cannot be performed with spectrophotometers because of the thickness and geometric complexity of the sample. Integrating spheres are more suitable, but some precautions must be taken so that the beam striking the block on the outer surface and then transmitted can be completely collected inside the sphere.

Table 1. Angular Light Transmittance of S1, S2 and S3, Comparison between two Integrating Spheres

θ [°]	τ (SSV) [%]	τ (TML) [%]	Δτ [%]
		S1	
0	78.8	78.4	0.5
20	78.8	78.1	0.9
40	76.3	76.2	0.1
		S2	
0	77.5	78.7	2.1
20	78.6	78.6	0.0
40	74.2	75.2	1.3
		S3	
0	78.9	79.5	0.7
20	78.5	78.5	0.0
40	74.2	73.8	0.5

Two spheres were used in order to verify the accuracy of the results and the reproducibility of the two systems. The Stazione Sperimentale del Vetro in Murano, Venice, has a 50 cm wide sphere, and a sample port with a diameter of 20 cm (Polato et al. 1995). The sphere at the Transparent Materials Laboratory at CR-Casaccia, ENEA in Rome, is 100 cm wide and has a sample port of 30 cm in diameter (Maccari et al. 1998). Figure 2 shows the spectral transmittance curves of the three samples measured in the normal incidence configuration at TML. Table 1 reports the broad band transmittance results from the two laboratories, weighted with the Illuminant A and the V(λ) observer curve, and their relative differences Δτ (%). As expected, the spectral curves are very similar since all the blocks are made with the same clear glass. The broad band comparison shows good agreement between the two instruments. The relative discrepancies were always lower than 1%, except in the case of the normal transmittance of S2, which was found to have a difference of 2%.

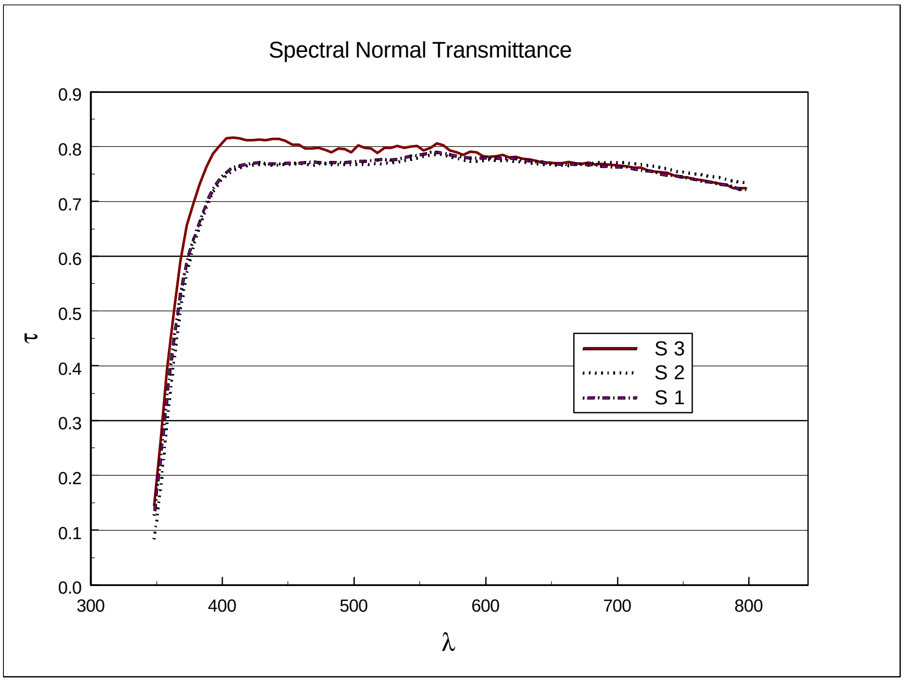

Figure 2. Normal-Hemispherical Spectral Transmittance

Integrating sphere measurements, part 2

For the hollow glass blocks, as a consequence of their dimensions, which did not exceed 30×30 cm^2, furthermore, the thickness of the component and the variability of the incidence angle of the solar radiation give rise to problems concerning the border effect. The beam, regularly transmitted by the glass pane, strikes the internal wall of the block and is diffusely reflected, with a reduction in transmittance in the second pane and, as a result, in the all block. Hence, assigning the transmittance of its central point to the block, an overestimation of this parameter, will result. Consequently the transparent area will not perform as predicted.

This error can be partially avoided by means of the following consideration: if the transmittance is measured at different points on the glass surface, a mean transmittance value of the sample can be obtained by the interpolation of the defined matrix. Thus results, which adhere more closely to real performances, are achieved. Figure 3 indicates the nine points (black circles) hit by the beam. As a result of the symmetry of the system, the measured values can be extended to other points (white circles). By moving the light source and the sample in suitable directions, it was possible to measure the non-central points. In this way the transmitted beam was always collected inside the sphere. These measurements, performed at TML, cannot be compared with those in the previous paragraph, since the different methodologies, obviously lead to different results.

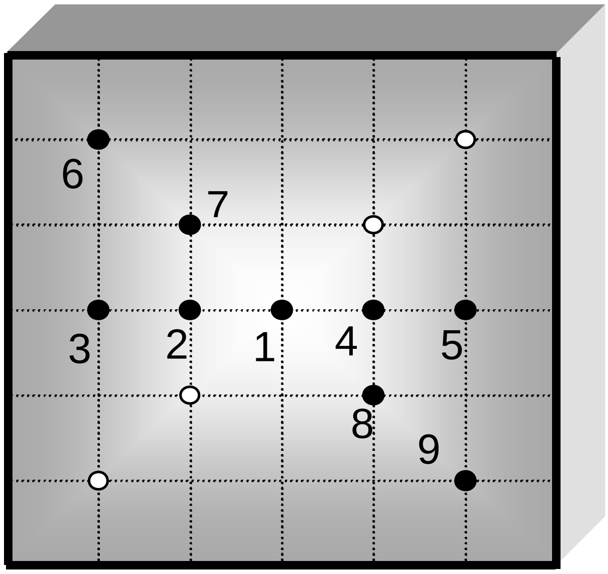

Figure 3. Measurement Points on the Glass Block

The interpolating surface of experimental results and the mean value of the light transmittance of the selected samples were found using a non-linear technique (Marquardt 1963). These results, compared with the central values, are reported in Table 2. The discrepancies were small in the case of normal radiation and increase with the angle of incidence. The relative differences were higher than 10% at 40°. Figure 4 reports the S2 graph. As expected the interpolation surface was quite flat. The S2 and S3 graphs are reported in figures 5-8 at incident angles of 20° and 40°. The shapes of such surfaces stress how the transmittance steeply decreases, when the off-normal incident radiationstrikes the edge area of the sample.

Table 2. Comparison between Central and Averaged Transmittances of S1, S2 and S3

θ [°]	τ_c [%]	τ_m [%]	$\Delta\tau$ [%]
		S1	
0	79.1	77.1	2.5
20	76.4	73.5	3.8
40	69.4	61.8	11.0
		S2	
0	77.5	77.7	-0.3
20	77.7	76.2	1.9
40	75.5	67.2	11.0
		S3	
0	78.0	77.9	0.1
20	78.2	75.5	3.5
40	74.4	64.9	12.8

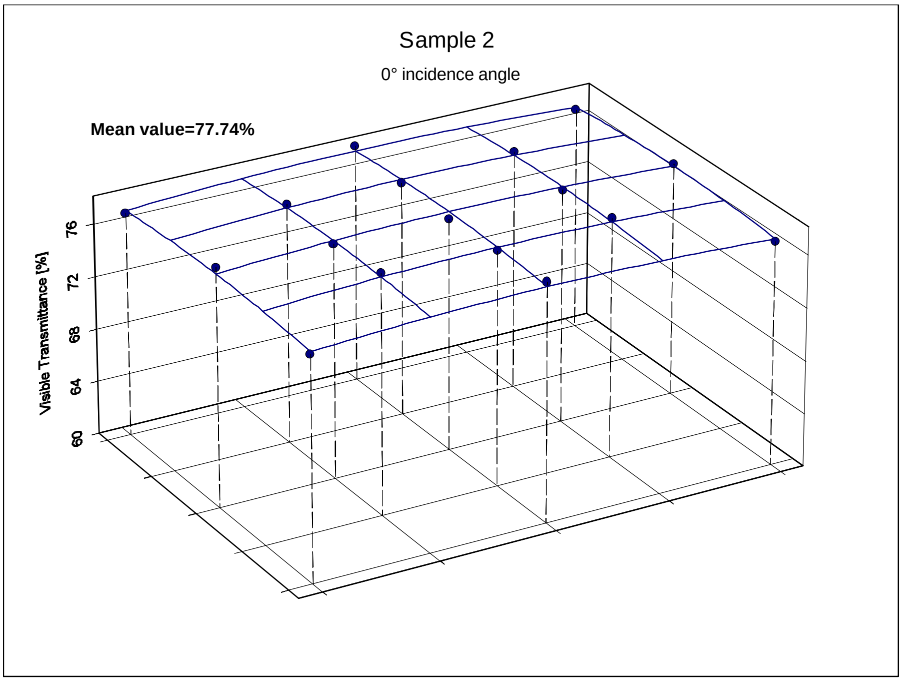

Figure 4. Interpolation Surface of S2 Light Transmittance Measurements at 0°

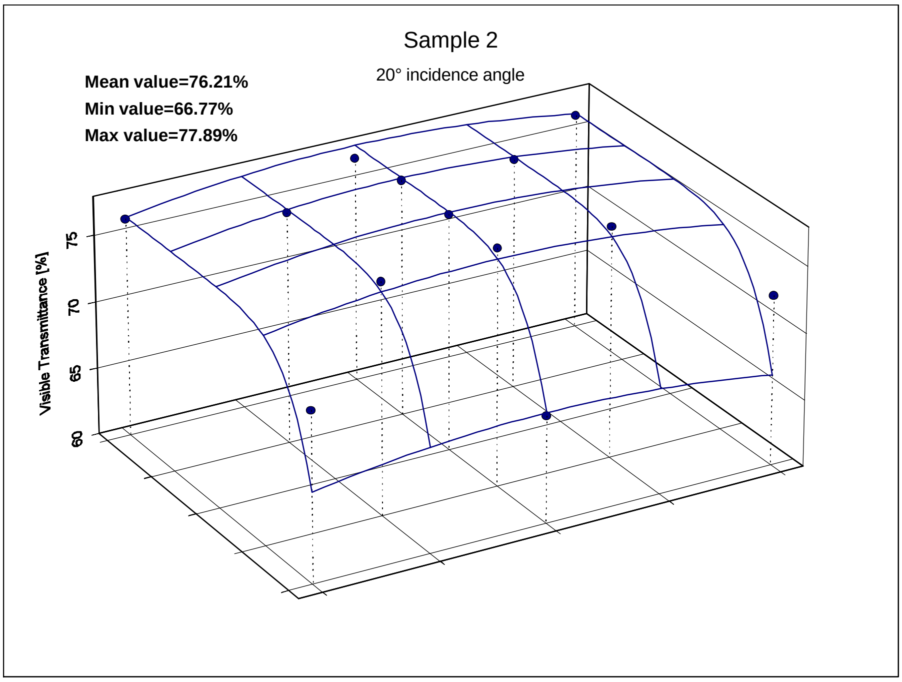

Figure 5. Interpolation surface of S2 Light Transmittance Measurements at 20°

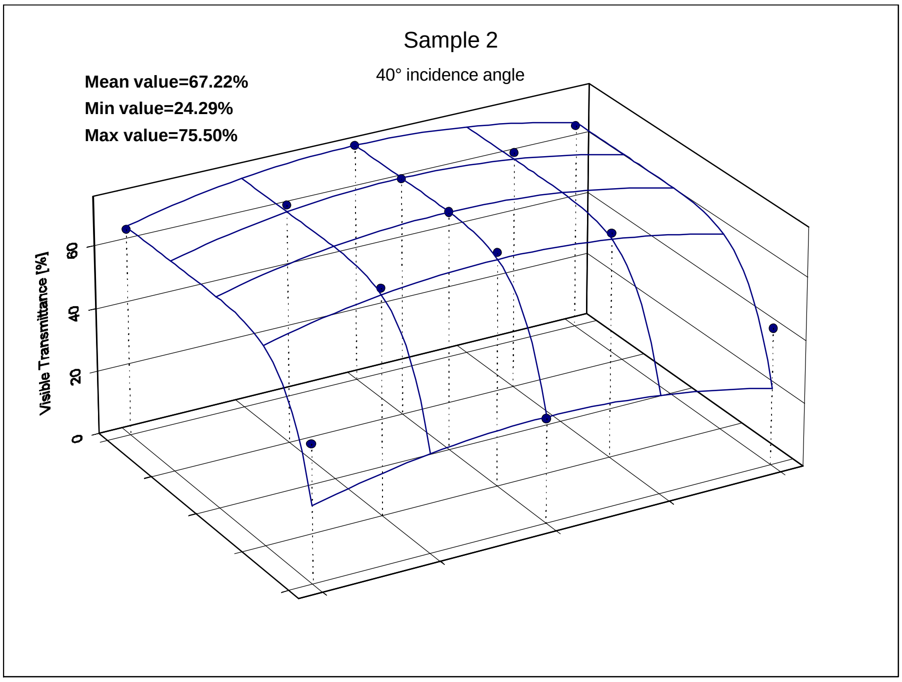

Figure 6. Interpolation surface of S2 Light Transmittance Measurements at 40°

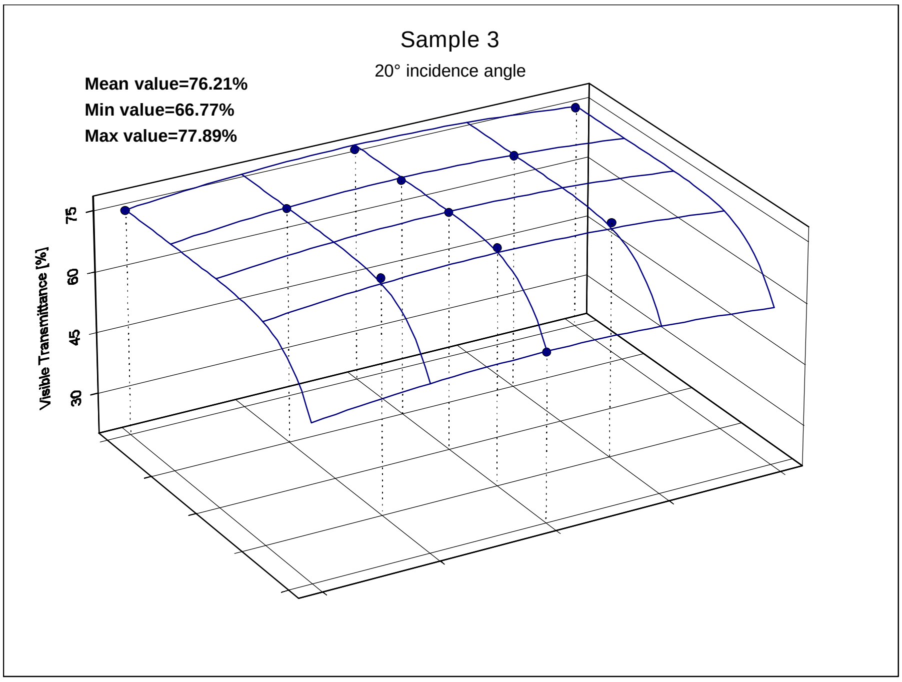

Figure 7. Interpolation surface of S3 Light Transmittance Measurements at 20°

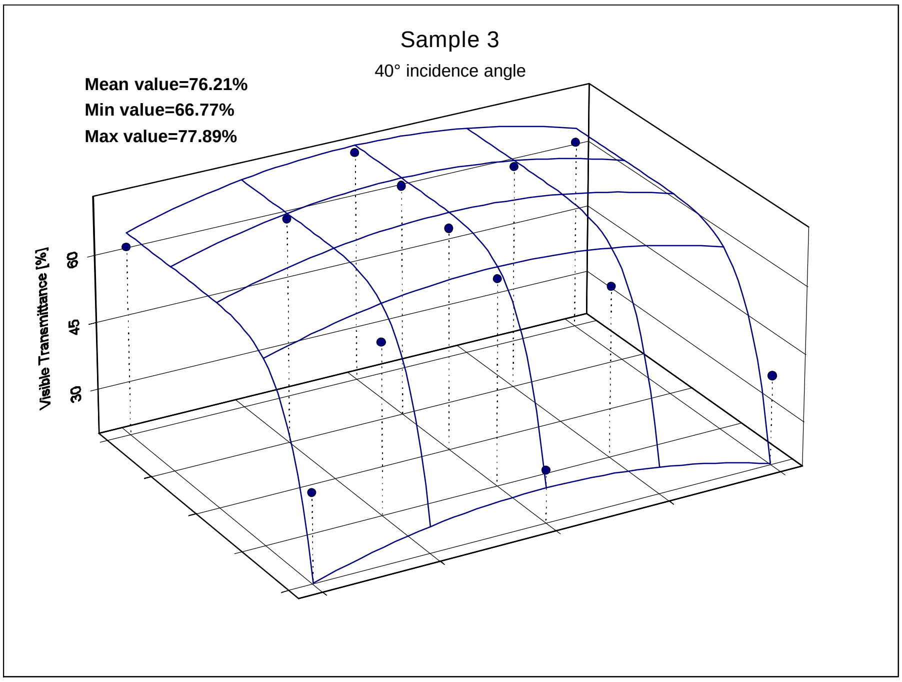

Figure 8. Interpolation surface Light Transmittance Measurements of S3 at 40°

Gonioreflectometric Measurements

These measurements give interesting details about the way the radiation is transmitted by the sample. When dealing with a complex geometry, it is important to predict how the luminous intensity and illuminance will be distributed in different directions, avoiding glare phenomena or dark areas. The measurements were performed at IEN-Galileo Ferraris in Turin(Rossi, Fusco & Soardo 1995).

The complexity of the samples suggested that we should assess the transmitted luminous intensity as the parameter to be measured. This parameter was calculated starting from the illumination data, which were the data measured by the instrument. For the purpose of this analysis a luxmeter was used. This detector allowed us to move behind the sample, along a hemisphere with a radius of 900 mm. The light source was on the opposing side, 2200 mm away from the sample. Some precautions were necessary in order to obtain accurate results. To avoid an excess of reflection phenomena, a black cloth shielded the external surface of the block from the light source. The beam passed through a hole in the cloth. This hole had a diameter of 100 mm, which was narrower than the diameter of the incident beam. Moreover, a black cone was used to force the responsive element of the luxmeter to measure only the light passing through the block. The normalized normal-directional transmittances of the selected samples were evaluated from the measurements at a normal incidence. In figure 9, the normalization refers to the normal intensity of the single block in order to stress its qualitative behavior. It is obvious that a higher redistribution of the light leads to a lower directional response.

Different behaviors were stressed among the three samples. The cross prisms block behaved in an interesting way: in figure 9 it can be seen that the transmittance reached its maximum at ±20° instead of at normal incidence, as usually happens. A high value was always obtained between - 20° and + 20° (with a good redistribution of the light). The behavior of the parallel prisms sample was different. It presented a very good directional transmittance, but at higher angles it increased its diffusing behavior, especially when compared to the clear block. This fact suggests same interesting applications whenever direct solar radiation distribution has to be modified.

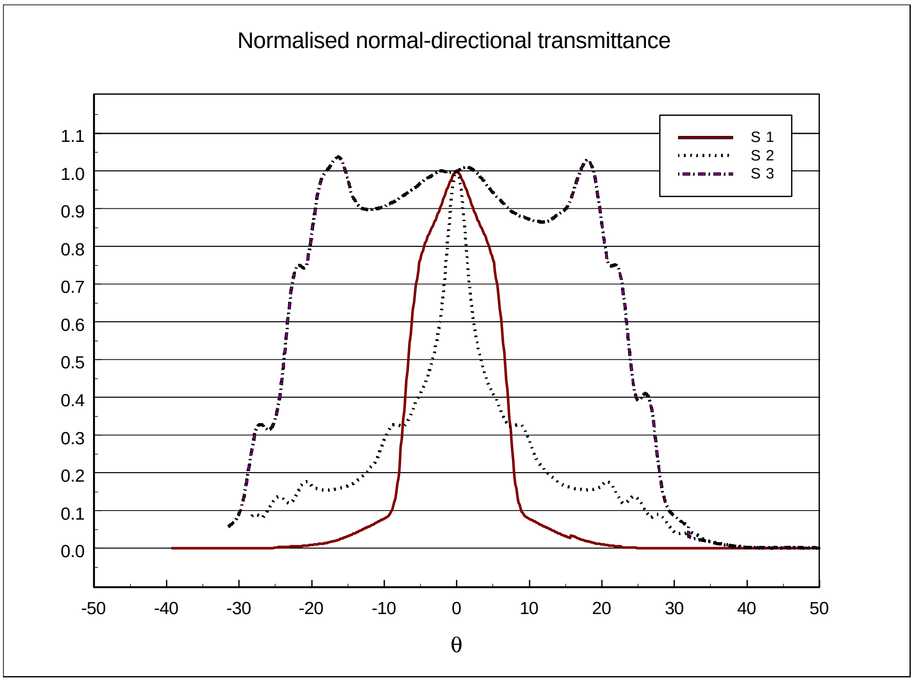

Figure 9. Normalised Normal-Directional Transmittance of S1, S2 and S3

Conclusions

Hollow glass blocks are suitable for many applications in architecture, but accurate information must be provided about their optical behavior. Transmittance measurements performed only on the center of glazing lead to incorrect results, which can seriously affect the performances of the glazing system. A light transmittance reduction of 10% at 40° was found. This suggests the importance of more accurate measurements in order to characterize hollow blocks, instead of ordinary glazings.

It must be noted that such a situation influences not only the luminous environment,with lower illuminance levels than the expected ones, but the energy balance of the whole building, since similar reductions are supposed for the solar factor as well. Less solar gain is welcome in a hot climate, but in a cold one the only thermal input coming from the environmentis reduced. Furthermore, it is widely known that the luminous environment of a built space does not depend on the amount of light achieving a visual task only, but on its quality. Hence, the bi-directional function of the transmitted light is necessaryto choose the most suitable kind of component for an assigned application. In order to obtain a uniform illuminance in a work place, analysis suggests the application of the S3 hollow block. By contrast, in order to highlight the light coming straight from the sun the S2 block would be better.

Finally, it is possible to state that integrating spheres and gonioreflectometers provide accurate characterizations of these particular components, which adequately support daylighting and the architectural design.

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