313: Experimental and Numerical Determination of Radiative Properties of Fenestration Systems

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Abstract

The increasing presence of glazed areas in building envelope can lead to high solar gains that can strongly influence the entire building energy consumption, peak loads and indoor comfort. An important strategy in sustainable building design for controlling solar heat gains through windows is the use of shading devices. Therefore, it is recommended to use detailed models that can accurately simulate the radiative properties of each type of shading device (such as roller blinds and venetian blinds) and especially to include its effect in glazing system analysis. This paper describes a net radiation method for determining solar optical properties of glazing with shading devices. Some numerical results were compared with experimental measurements carried out in an outdoor test cell. These included the measurement of the visible and solar transmission properties of the fenestration systems.

Keywords: solar optical properties, net radiation method, multilayer glazing/shading systems

1. Introduction

Large glazed building façades are architectural solutions widely used in building envelope design for their lightness, aesthetic and transparency properties but that can lead to high cooling demand and visual and thermal comfort problems. An important strategy in sustainable building design for reducing the potentially large heat gains through windows is the use of shading devices [1].

The detailed knowledge of the shading device solar optical properties is particularly important in any strategy attempting to improve the fenestration system daylighting and thermal performance and to prevent overheating problems in buildings.

This paper describes a net radiation method for determining solar optical properties of glazing with shading devices. These can be either roller blinds or venetian blinds. Unlike roller blinds, venetian blinds' radiative properties are strongly dependent on slat angle and on solar incident angle. Thus, some prior calculations are necessary to determine the overall radiative properties of venetian blinds so that they can be treated as an additional layer of the fenestration system [2]. There are some models for analyzing radiative characteristics of slat-type blinds. The first attempt was probably made by Parmelee and Aubelee [3] based on the 2-D ray tracing technique. Other models use the net radiation method to estimate such properties [4].

There are also some methods to model the multilayer solar optical properties of glazing systems when composed of any number of specular glazing layers. Usually a one-dimensional center-glass analysis is used and applied to the view area of the window as the solar gain of the frame can be safely ignored in most of the cases [5]. One of the most popular methods is the Edwards' recursion algorithm [6]. However, it can not be applied when a shading layer is present because the reflectance and transmittance of this layer is not specular.

An algorithm for the determination of all illuminance and irradiance fluxes transmitted, reflected and absorbed within a multilayered glazing/shading system is presented considering its usefulness for either daylighting or thermal purposes. The algorithm will also be used as the standard daylighting transmission model in a methodology for the quantification of energetic impacts of daylight in buildings [7]. In addition, a method for determining radiative properties of venetian blinds is also described.

The numerical results were compared with experimental measurements carried out in an outdoor test cell. These included the measurement of the solar and visible transmission properties of the fenestration systems.

2. Experimental Set-up

Fig. 1 shows an outdoor test cell at the National Laboratory of Civil Engineering (LNEC), Lisbon, Portugal (Lat.: 38.7ºN, Long.: 9.1ºW). The glazing/shading system used in the experimental study is approximately South oriented (deviated from South 22^o in East direction). The test cell is 2.5m height and 3.5m in length, the total gap depth is 0.20m. The glazing/shading system consists of (from outdoor to indoor): a single clear glass (5mm; U=5.7W/m^2/K; visible transmittance Tv=87%; solar transmittance Te=75%; solar absorptance Ae=18%; solar heat gain coefficient g=0.80); an outer air gap; a white venetian blind with horizontal movable slats (slat width=50 mm, visible reflectance Rv=0.80, solar reflectance Re=0.55); an inner air gap; and a double glazing unit, the outer pane having a low-emissivity coating (6-16-5mm; U=1.4W/m^2/K; Tv=69%; Te=36%; Ae=34%+3%; g=0.41). The gap can be ventilated through eight sets of movable horizontal louvers (allowing for different ventilation schemes), four of them located in the outer pane and four in the inner one.

Fig. 1- Test cell used in the experimental study

The test cell is fully instrumented with illuminance and irradiance sensors (LI-COR cosine corrected LI-210 illuminance sensors and LI-200 irradiance sensors) allowing for the measurement of the relevant quantities for a complete solar optical characterization of the façade system.

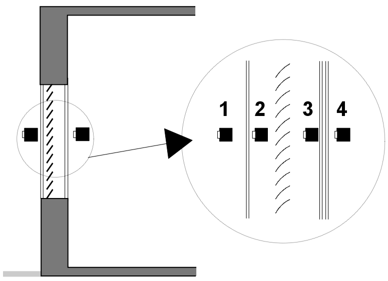

Fig. 2 – Measurement positions of vertical irradiances – W/m^2 and illuminances – lux within the glazing system.

The complete set of measurements includes (see Fig. 2): exterior global horizontal illuminance and irradiance; exterior vertical global ($E_{v1}^{D+d}, I_{v1}^{D+d}$) and diffuse ($E_{v1}^{d}, I_{v1}^{d}$) illuminance and irradiance on the plane of the façade; interpane vertical illuminances and irradiances (E_{vi}^{D+d} and I_{vi}^{D+d} with i=2, 3); interior vertical illuminance and irradiance ($E_{v4}^{D+d}, I_{v4}^{D+d}$). The measurements are made under overcast (OCS) and clear sky (CSC) conditions for four different shading system configurations: no shading, shading fully closed, shading with slats at 45^o and slats horizontal (0^o). The measured quantities are considered sufficient for a full characterization of the glazing/shading system in terms of daylighting and solar transmission characteristics for validation of the numerical model. All the measurement positions are schematically illustrated in Fig. 2.

2. Numerical model

2.1 Glazing/Shading System

As stated before, the net radiation method is used for solving the radiative energy exchange within a glazing/shading system. The radiosity of surface i (J_i) can be defined as the total radiation energy leaving a surface per unit time and area and the irradiation at surface i (G_i) as the total radiation incident upon a surface per unit time and area. The irradiation at surface i can be expressed in terms of the radiosities of all (n) surfaces and respective radiative view factors from surface i to each surface j (eq. 1 and 2).

$$G_i = \sum_{j=1}^{n} F_{ij} J_j \qquad (1)$$

The radiative view factor (F_{ij}) is the fraction of thermal energy leaving the surface of object i and reaching the surface of object j, determined entirely from geometrical considerations. The view factor from surface i to j was determined using Hottel's crossed string method [8]:

$$F_{ij} = \frac{\sum(\text{crossed strings}) - \sum(\text{uncrossed strings})}{2\,(\text{string on surface i})} \qquad (2)$$

Since all surfaces are considered as flat, the self-viewing factor F_{ii} will be zero and only the view factor between each gap adjacent surfaces (for instance the back surface of layer i and the front surface of layer i+1) will be unitary.
The radiant flux leaving a surface i (J_i) can be written as the sum of the reflected portion of G_i, the radiant flux emitted by surface i ($\varepsilon_i \sigma T_i^4$) and the transmitted irradiation from the opposite side of the element (eq. 3 and 4):

$$J_{i,f} = \varepsilon_{i,f}\sigma T_{i,f}^4 + \rho_{i,f} G_{i,f} + \tau_i G_{i,b} \qquad (3)$$

$$J_{i,b} = \varepsilon_{i,b}\sigma T_{i,b}^4 + \rho_{i,b} G_{i,b} + \tau_i G_{i,f} \qquad (4)$$

where τ_i, ε_i and ρ_i are the transmittance, emittance and reflectance of surface i (subscripts f and b refer to front and back sides) and σ is the Stefan-Boltzmann constant.
The radiative properties of a fenestration system are calculated by eq. (3) and (4) but the first term in its right-hand side – the radiant flux emitted by surface i ($\varepsilon_i \sigma T_i^4$) – was set to zero and replaced by a source term (S_i), which takes into account the external radiation flux. Thus, the system of equations can be defined as follows:

$$J_{i,f} - \rho_{i,f} \sum_{j=1}^{n} \left(F_{i,f\to j,f} J_{j,f} + F_{i,f\to j,b} J_{j,b} \right) - \tau_{i,b} \sum_{j=1}^{n} \left(F_{i,b\to j,f} J_{j,f} + F_{i,b\to j,b} J_{j,b} \right) = S_{i,f} \qquad (5)$$

$$J_{i,b} - \rho_{i,b} \sum_{j=1}^{n} \left(F_{i,b\to j,f} J_{j,f} + F_{i,b\to j,b} J_{j,b} \right) - \tau_{i,f} \sum_{j=1}^{n} \left(F_{i,f\to j,f} J_{j,f} + F_{i,f\to j,b} J_{j,b} \right) = S_{i,b} \qquad (6)$$

Since view factors $F_{i,f\to i-1,b} = F_{i,b\to i+1,f} = 1$ and the remaining are zero, eq. 5 and 6 can be re-written as:

$$J_{i,f} - \rho_{i,f} J_{i-1,b} - \tau_{i,b} J_{i+1,f} = S_{i,f} \quad (7)$$

$$J_{i,b} - \rho_{i,b} J_{i+1,f} - \tau_{i,f} J_{i-1,b} = S_{i,b} \quad (8)$$

where the source flux is equal to one for the incident solar radiation ($S_{0,b}$=1), and equal to zero for the remaining elements.

Solar radiation is divided into its direct and diffuse components. One part of the direct solar radiation incident at a given layer passes directly through it without being scattered and the related direct-to-direct (DD) solar optical properties of the layer will be: front and back transmittances $\tau^{DD}_{i,f}$ and $\tau^{DD}_{i,b}$; and reflectances $\rho^{DD}_{i,f}$ and $\rho^{DD}_{i,b}$. For specular glazing layers, as glass, front and back transmittances can be usually considered equal ($\tau^{DD}_{i,f} = \tau^{DD}_{i,b}$). However, for shading layers this may not be true, as for example a venetian blind where clearly $\tau^{DD}_{i,f} \neq \tau^{DD}_{i,b}$.

Diffuse solar radiation is diffused transmitted and reflected at each layer, and the associated diffuse-to-diffuse (dd) solar optical properties are: front and back transmittances $\tau^{dd}_{i,f}$ and $\tau^{dd}_{i,b}$; and front and back reflectances $\rho^{dd}_{i,f}$ and $\rho^{dd}_{i,b}$.

In the case of all layers being glasses, direct-to-direct and diffuse-to-diffuse solar optical properties of each layer are enough to characterize the fenestration system and to calculate, for instance using Edward's method [6], both layer absorptance within a system and the overall transmittance.

The problem becomes much more complex when a shading layer is added because part of direct solar radiation can also be converted to diffuse radiation (direct-to-diffuse radiative properties - $\tau^{Dd}_{i,f}$, $\tau^{Dd}_{i,b}$, $\rho^{Dd}_{i,f}$, $\rho^{Dd}_{i,b}$), when it passes through a roller blind or hits the slats surface of a venetian blind.

Fig.3 shows a multilayer glazing/shading system along with the direct (D) and diffuse (d) radiant fluxes leaving the front and back facing surfaces (i.e., the radiosities $J_{i,f}$, $J_{i,b}$).

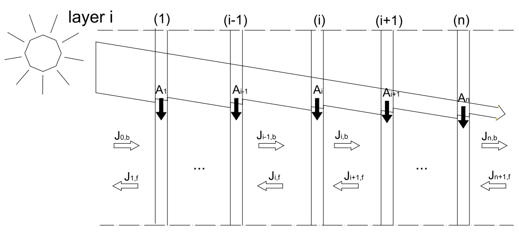

Fig 3. Direct and diffuse flux components in a multilayer glazing/ shading system.

A glazing/shading system consisting of n layers separated by non-absorbing gas layers can be treated as an n+2 element array: n glass/shading layers; outdoor (i=0); and indoor (i=n+1). The front and back radiosities of a generic layer i can be re-written from eq. (7) and (8), respectively for the direct (D) and diffuse (d) radiation, as follows:

$$J^{D}_{i,f} = \tau^{DD}_{i,b} J^{D}_{i+1,f} + \rho^{DD}_{i,f} J^{D}_{i-1,b} \quad (9)$$

$$J^{d}_{i,f} = \tau^{Dd}_{i,b} J^{D}_{i+1,f} + \tau^{dd}_{i,b} J^{d}_{i+1,f} + \rho^{Dd}_{i,f} J^{D}_{i-1,b} + \rho^{dd}_{i,f} J^{d}_{i,-1,b} \quad (10)$$

$$J^{D}_{i,b} = \tau^{DD}_{i,f} J^{D}_{i-1,b} + \rho^{DD}_{i,b} J^{D}_{i,f} \quad (11)$$

$$J^{d}_{i,b} = \tau^{Dd}_{i,f} J^{D}_{i-1,b} + \tau^{dd}_{i,f} J^{d}_{i-1,b} + \rho^{Dd}_{i,b} J^{D}_{i+1,f} + \rho^{dd}_{i,b} J^{d}_{i+1,f} \quad (12)$$

It is worth noting that $J^{D}_{0,b}$ and $J^{d}_{0,b}$ are respectively equal to the direct and diffuse components of incident radiation (I^{D}_{V1} and I^{d}_{V1}) that could be assumed as unitary for calculations. Note that this is equal to the source flux of eq. (8) ($S_{0,b}$=1). Reflectance and transmittance of the conditioned space were set to zero (and thus $J^{D}_{n+1,f} = J^{d}_{n+1,f}$ =0).

Note that, while for an unshading glazing system eq. (9) and (11) can be used either for direct (D) or diffuse (d) radiant fluxes, because glass is a specular layer, for a glazing/shading system different equations should be written for direct (D) and diffuse (d) fluxes, as diffuse flux arises from both the interaction of direct radiation with the shading and the diffuse incident radiation itself.

After solving a resulting system given by [A][J]=[S] and all of the $J^{D}_{i,f}$, $J^{D}_{i,b}$, $J^{d}_{i,f}$, $J^{d}_{i,b}$ fluxes being determined, one can calculate for each layer, the absorptance as the difference between the energy that enters and the energy that emanates from the layer surfaces:

$$A^{D}_{i} = \frac{J^{D}_{i-1,b} - J^{D}_{i,f} + J^{D}_{i+1,f} - J^{D}_{i,b}}{I^{D}_{V1}} \quad (13)$$

and the portion which is transmitted to the conditioned space can be written as:

$$T^{D}_{sys} = \frac{J^{D}_{n,b}}{I^{D}_{V1}} \quad (14)$$

The same can be done for diffuse A^{d}_{i} and T^{d}_{sys}.

It is worth emphasizing that the described algorithm is not only applied to determine solar but also luminous characteristics of glazing/shading systems. In fact, visible light is only a portion (wavelength range of 380-780nm) of the solar spectrum (wavelength range of 300-2500nm), and since the model input properties of each layer are wavelength-integrated values (see EN410 [9]), the algorithm can be used. It should be noted that photometric quantities can be derived from radiometric quantities and, for example, the radiosity, expressed in units of W/m^2, has an equivalent photometric counterpart of luminosity (as illuminance is equivalent of irradiance) expressed in lux (lm/m^2).

2.2 Venetian Blind

Unlike roller blinds, venetian blinds' radiative properties are strongly dependent on slat angle and on solar incident angle. The knowledge of the radiative properties of a venetian blind allows it to be treated as an additional layer in a series of glazing layers, making the study of complex fenestration systems easier. The radiant analysis of the venetian blind is based on the assumptions that each slat surface segment is flat, of negligible thickness, gray, isothermal, uniformly irradiated, perfect diffuser and with non-temperature dependent properties. It is also assumed that the slats are long enough such that the problem can be treated as two-dimensional.

Venetian blinds radiative properties are performed by considering (Fig.4) only a fictive cavity area between two adjacent slats. For modelling purposes the blind fictive cavity is split into: (a) two fictitious surfaces representing the openings of the cavity; (b) and N segments per each slat surface (2xN segments in total). In this study each slat surface is divided into five equal segments, as recommended by ISO15099 [4]. Other discretization schemes are used and discussed in [2].

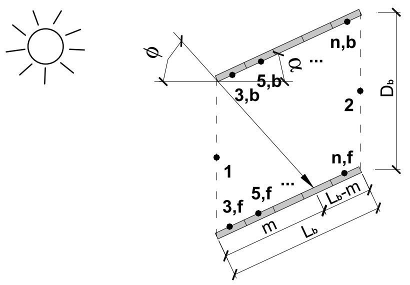

Fig 4. Venetian blind fictive cavity.

As mentioned before, one part of the direct solar radiation passes directly through the blind assembly without hitting the slats (direct-to-direct) and the remaining part passes indirectly by reflections between and transmissions through the slats (direct-to-diffuse). Finally, the diffuse solar radiation passes also directly and indirectly through the blind assembly (diffuse-to-diffuse).

2.2.1 Direct-to-direct blind transmittance

Direct-to-direct (DD) transmittance is defined as the fraction of direct solar radiation passing directly through the blind assembly without hitting the slats, and is purely a geometry problem. It can be obtained from eq. 15 (see Fig.4):

$$\tau^{DD}_{blind,f} = 1 - \frac{L_b}{m} = 1 - \frac{L_b}{D_b}\left|\frac{\sin\alpha\cos\phi + \cos\alpha\sin\phi}{\cos\phi}\right| \tag{15}$$

where L_b is the slat width, D_b the slat spacing, m the portion of slat illuminated by direct radiation, α the slat angle and ϕ the profile angle of the incident solar beam radiation.

2.2.2 Direct-to-diffuse blind properties

The direct solar radiation which does not pass directly through the blind assembly and hits the slat surfaces is diffusely reflected and transmitted (since slats are assumed to be pure diffusers) and the remaining part is absorbed by the slats (direct-to-diffuse properties). Depending on the incident profile angle of sun (ϕ) and the slat angle (α), certain parts of the slat (with length m, see Fig.4) can receive direct radiation while others only diffuse radiation. For the latter, if the direct radiation hits in the middle of a segment, all the segment is considered as illuminated.

The venetian blind's direct-to-diffuse (Dd) transmittance and reflectance are calculated using the net radiation method as described above (eq. 5 and 6). Since all surfaces are considered as flat, the self-viewing factor F_{ii} will be zero and view factors from and to segments of a same slat surface will be also zero. The source term (S_i), takes into account the external radiation flux. For the direct-to-diffuse case, direct radiation illuminates one part (or even all width) of the slat. On this illuminated extent the source flux is proportional to the slat diffuse reflectance and on the segment opposite side the source flux is proportional to the slat diffuse transmittance. Thus, depending on the slat angle and profile angle relation, the source flux of the directly illuminated segments will take the values:

- If direct radiation hits front of slats ($\phi \geq -\alpha$):

$$S_{i,f} = \rho^{Dd}_{slat,f}(1-\tau^{DD}_{blind,f})\frac{D_b}{m} \tag{16}$$

$$S_{i,b} = \tau^{Dd}_{slat}(1-\tau^{DD}_{blind,f})\frac{D_b}{m} \tag{17}$$

- If direct radiation hits back of slats ($\phi < -\alpha$):

$$S_{i,f} = \tau^{Dd}_{slat}(1-\tau^{DD}_{blind,f})\frac{D_b}{m} \tag{18}$$

$$S_{i,b} = \rho^{Dd}_{slat,b}(1-\tau^{DD}_{blind,f})\frac{D_b}{m} \tag{19}$$

The factor $(1-\tau^{DD}_{blind,f})\frac{D_b}{m}$ accounts for the portion of the direct incident radiation, I, that actually hits normally to the slats ($I\sin(\phi+\alpha)(1-\tau^{DD}_{blind,f})$), as the unit incident direct flux is considered to be the component normal to the window ($I^D_V = I\cos\phi = 1$).

The source flux, on the remaining parts of the slats which receive only diffuse radiation and on the openings of the blind fictive cavity (S_1 and S_2), is set to zero.

The front direct-to-diffuse transmittance and reflectance of the venetian blind are:

$$\tau^{Dd}_{blind,f} = G_2 \qquad \rho^{Dd}_{blind,f} = G_1 \tag{20}$$

The part that is neither directly or indirectly transmitted nor reflected is the one which is absorbed at the slat surfaces. This can be obtained from the energy balance equation:

$$\alpha^{Dd}_{blind,f} I\cos\phi D_b = I\cos\phi D_b - (G_1+G_2)D_b - \tau^{DD}_{blind,f} I\cos\phi$$

$$\Leftrightarrow \alpha^{Dd}_{blind,f} = 1 - \frac{G_1+G_2}{I\cos\phi} - \tau^{DD}_{blind,f} \tag{21}$$

giving the following relationship between radiative properties:

$$\alpha^{Dd}_{blind,f} = 1 - \tau^{DD}_{blind,f} - \tau^{Dd}_{blind,f} - \rho^{Dd}_{blind,f} \tag{22}$$

2.2.3 Diffuse-to-diffuse solar blind properties

The same methodology described above for direct-to-diffuse properties is applied to calculate the diffuse-to-diffuse solar blind properties. However, the source flux term will be different. For front-side diffuse-to-diffuse solar properties

the source flux is equal to one for the opening 1 of the fictive cavity (S_1=1) and equal to zero for the remaining elements (all slat segments and back opening 2).
Solving a system of equations similar to the described above (eq. 5 and 6), the following solar diffuse-to-diffuse (dd) blind properties can be obtained as follows:

$$\tau^{dd}_{blind,f} = G_2 \qquad \rho^{dd}_{blind,f} = G_1 \tag{23}$$

The front diffuse-to-diffuse absorptance of the blind is then:

$$\alpha^{dd}_{blind,f} = 1 - \tau^{dd}_{blind,f} - \rho^{dd}_{blind,f} \tag{24}$$

Again, it should be noted that radiative properties (transmittance, reflectance and absorptance) are independent of the magnitude of incident flux (I^d_V), for the same reasons previously explained.

2. Results

Table 1 gives the experimental, numerical and analytical overall solar (Te_{sys}) and visible (Tv_{sys}) transmittance for the glazing system without shading and under overcast sky conditions (OSC) (12:00, 07.05.2008). The analytical results were obtained from the following relationship deduced for a simple double glazing system [9]:

$$T_{sys} = \frac{\tau_1\,\tau_2}{1-\rho_{1,b}\rho_{2,f}} \tag{25}$$

Note that, in this particular case, there were only diffuse components as the sky was overcast. Otherwise, T_{sys} should be calculated from direct and diffuse overall transmittances as follows:

$$T_{sys} = \frac{T^D_{sys}\,I^D + T^d_{sys}\,I^d}{(I^D_{V1} + I^d_{V1})} \tag{26}$$

where I^D_{V1} and I^d_{V1} are the actual exterior vertical incident solar radiation components.
It can be observed that the numerical and analytical results match perfectly but are higher than the experimental results when the glass manufacturer transmittances (T) are used. This can be due to the cleanliness conditions of the glass surfaces. The numerical and experimental results show a good agreement when a cleanliness factor of 0.75 is used, which should correspond to the actual experimental conditions.

Table 1: Overall solar (Te_{sys}) and visible (Tv_{sys}) transmittance, without blinds, under OCS. Experimental, analytical and numerical results for T and 0.75T.

	Te_{sys}	Tv_{sys}
Experimental (07.05.2008)	0.15	0.35
Numerical (T)	0.28	0.61
Analytical (T)	0.28	0.61
Numerical (0.75T)	0.15	0.34
Analytical (0.75T)	0.15	0.34

Fig. 5 and 6 show respectively the vertical irradiances and illuminances, at the measurement positions of Fig.2, for different venetian blind slat angles (0º, 45º and 90º) under clear sky conditions (CSC) (14:30, 12.06.2008, $\phi = 70.6º$). Although the numerical model captures the general tendency of irradiances and illuminances at different positions (Fig.2), it is noticed again that the agreement with the experimental results is much better when 0.75T was used for both glasses. As expected, as the slat angle increases the irradiance and illuminance behind the blind decreases. Even for a fully closed position (90º) the measurements were not null, which was not found numerically. This might be attributed to: (1) the almost inexistent adjacent slats overlapping, allowing for some radiation to pass through the blind even when it is fully closed; (2) the not fully lowered blind, allowing for some radiation, especially the diffuse component from the ground, to pass; and (3) the eventual diffuse flux incident on the system indoor side, which is not taken into account by the model.

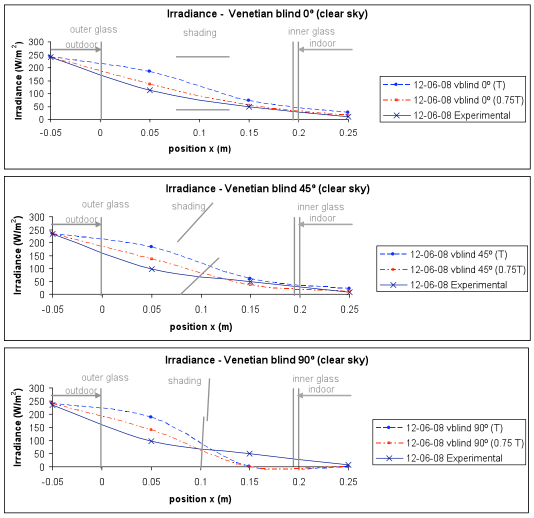

Fig 5. Irradiance for different slat angles under CSC. Experimental and numerical results for T and 0.75T.

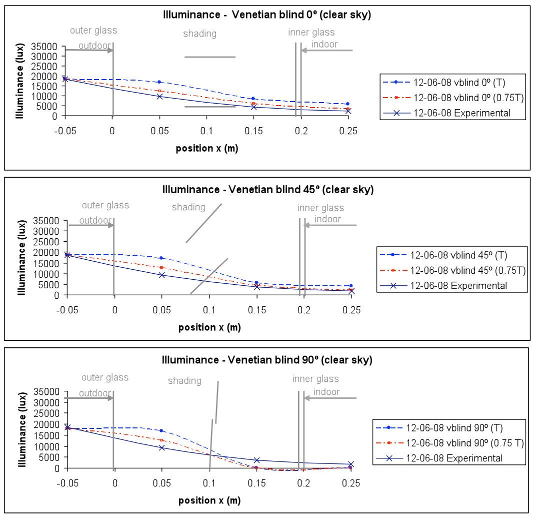

Fig 6. Illuminance for different slat angles under CSC. Experimental and numerical results for T and 0.75T.

In Fig. 7 and 8 the vertical irradiance and illuminance, with and without venetian blind, were plotted. These measurements were carried out on 7th of May 2008 at 12:00 and under OSC. Once again, the use of 0.75T makes the numerical results to fit better with the experimental ones. Even though, under OSC the agreement is better than under CSC. In fact, a higher degree of complexity is added when both diffuse and direct components are present, besides the difficulty of considering the actual DD and Dd optical properties of glass and slat, which varies with the incidence angle. It should be referred that in this study the hemispherical properties are used for both DD and dd optical properties.

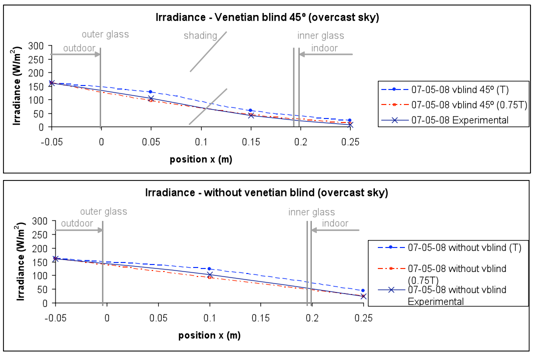

Fig 7. Irradiance with and without blind under OSC. Experimental and numerical results for T and 0.75T.

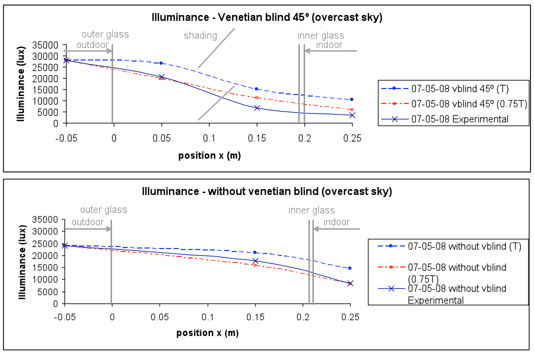

Fig 8. Illuminance with and without blind under OSC. Experimental and numerical results for T and 0.75T.

Finally, the numerical results of the system overall solar and visible transmittance for different slats' angles have also been compared with the experimental data under CSC (Fig. 9). As expected, they decrease as the slats' angle increases because of the higher obstruction of the blind. The numerical results with 0.75T were again closer to the experimental data than that using the given glass T.

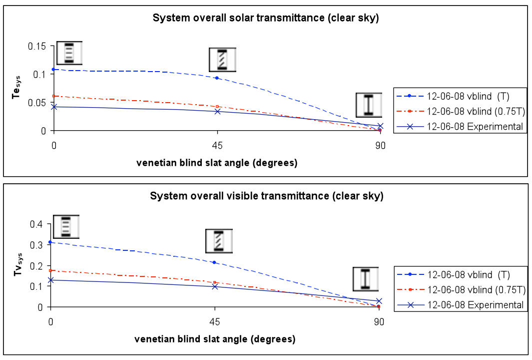

Fig 9.System overall solar and visible transmittance for different slat angles under CSC. Experimental and numerical results for T and 0.75T.

3. Conclusions

This paper presented a methodology for calculating both direct and diffuse fluxes of transmitted, reflected and absorbed irradiance and illuminance within a multilayer of a glazing/shading system. An algorithm for determining radiative properties of venetian blinds were also described so as it can be treated as an additional layer of the fenestration system.

The numerical results were compared with experimental measurements carried out in an outdoor test cell. A general good agreement was found between experimental and numerical results, especially when a reduced value of the transmittance of the glasses (0.75T) was used, which denotes the importance of the glass surfaces' cleanliness conditions in this study.

This is an ongoing study and some immediate research efforts will concentrate on obtaining more realistic optical properties of glasses, carrying out more experiments in particular under clear sky conditions and comparing with available standard numerical applications to validate the proposed model for reliable daylighting and thermal applications in building design.

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7. References

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