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# A METHOD FOR CALCULATION OF BI-DIRECTIONAL SOLAR PROPERTIES OF A VENETIAN BLIND

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## ABSTRACT

Venetian blinds are widely used as shading devices for windows. Methods for simulation of blinds are needed because measurements of their properties are expensive and quite involved. This paper presents novel method (named "directional diffuse method") for calculation of bidirectional properties of a venetian blind. The shadowing of blind slat surfaces is taken into account during the calculation of the diffuse portion, resulting in a more realistic, non-uniform distribution of the scattered (diffuse) component. The method is applicable to devices with flat or curved slats. The resulting BTDF/BRDF can be used with the glazing layers BTDF/BRDF and full matrix calculation can be performed to get system performance with full spatial resolution. This methodology has been developed and implemented in the new version 6.0 of WINDOW program and has been successfully validated against limited amount of measurements and ray tracing simulations.

## INTRODUCTION

Venetian blinds are widely used as shading devices for windows. Their purpose is to control solar heat gain, glare and privacy. There were number of studies where their performance had been measured, primarily in solar calorimeters and some with photogoniometers. Because of the need to do measurements at the real size, these measurements are expensive and quite involved.

Lately, there have been attempts to develop simulation methods, both simplified and with full complexity. Simplified method, involving diffuse reflection assumptions of the blind slats, has been developed and documented in ISO 15099 standard. While this method provides reasonable integrated performance for slats that are essentially diffusing, this methodology fails to provide spatial resolution that would be useful in daylighting and comfort applications. Also, treatment of diffuse reflections between venetian blind and layers of a glazing system is done in the same way as if they were specular reflections, which may introduce relatively larger errors when venetian blinds are calculated in conjunction with the attached glazing system.

## CALCULATION METHOD

Directional diffuse method represents a novel approach in simulation of Venetian blind performance (DBS, 2006). Bidirectional properties of a venetian blind (BTDF and BRDF – Bi-directional Transmittance/Reflectance Distribution Function) are calculated. The blind slats are treated as purely diffusing surfaces, however, depending on the angle of the blind, the diffuse component is not constant in all directions, because of the shadowing of neighboring blind surfaces. This results in a better spatial resolution for daylighting and comfort calculations. The method is applicable to devices with flat or curved slats, and can be used for calculation of properties in any band of the solar spectrum.

Geometry of the Venetian blind is described in this model using following properties: Width of the slat (without curvature) [m], Distance between adjacent slats [m], Slat tilt angle [º], Radius of slat curvature [m] and number of slat segments. Slat material properties are: solar transmittance and front/back reflectances, and IR transmittance and front/back emissivities.
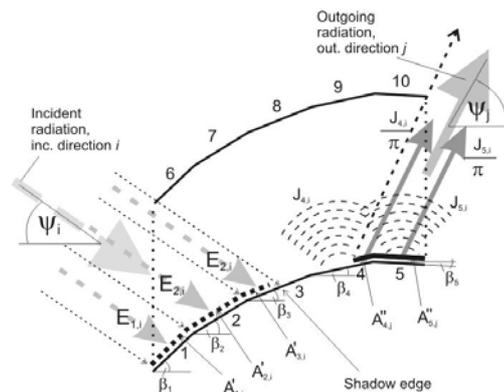


**Figure 1.** *Diffuse Reflections in Venetian Blinds*

Figure 1 shows the diffuse reflections and angles in the calculation of bi-directional transmittance of a venetian blind with curved slats. Each slat is divided into n number of linear segments. Incident beam radiation is coming from direction $i$, and is scattered along outgoing direction $j$. Unit irradiance at the front

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surface of the blind (dotted vertical line on the left-hand side in Figure 1) is assumed. It is also assumed that incident radiation is repeatedly reflected in a diffuse manner off both slats, allowing the use of view factor based, gray body radiation calculation model (Siegel and Howell 1992). Calculation is performed in 2-D space, because incident irradiances at slat segments ($E$) and outgoing radiance of the blind essentially depend on the profile angles ($\psi$) of incident and ougoing directions. Diffuse radiosity leaving each slat segment ($J$) is calculated based on the geometry of the system and incident irradiance on irradiated segments ($E$). Radiation exchange between different slat segments is calculated using view factors between segments. The two imaginary surfaces on the left and right allow the use of enclosure radiation model, in which view factors are calculated using simple cross-string rule.

Outgoing radiance of the blind is calculated by summing up contributions from each slat segment visible from the outgoing direction of interest. Contribution of partially visible segments is proportinal to the length of the visible part of the segment with respect to total segment length.

These calculations are performed for each incident and outgoing angle. In this model, also referred to as "Extended Basis", there are 145 incident and outgoing directions (Klems 2004). These results are placed in bi-directional transmittance function matrix (BTDF matrix), as ($i, j$) element. Directly transmitted part of incident radiation (which passes the blind without interaction with slat material) is calculated based on the geometry of the blind and incident profile angle, and it is added to element of the transmittance matrix which corresponds to that particular incident direction, and a collinear outgoing direction. Directly transmitted components are placed in the diagonal of the BTDF matrix. The reflected component is calculated in a similar manner, except that radiances are summed up on the same side as incident radiation**.** The results of reflectance calculations are placed in bi-directional reflectance Distribution Function (BRDF) matrix.

A total of 4 BTDF and BRFD matrices are obtained (2 for each side of the blind). The resulting BTDF/BRDF matrices can be used with the glazing layers bi-direction functions and full matrix calculation can be performed to get system performance with full spatial resolution. This methodology has been developed and implemented in the new version 6.0 of WINDOW program. Integrated (directional-to-hemispherical and diffuse) properties for a given Venetian blind are also calculated as one of by-products of this methodology.

## SIMULATION RESULTS

A series of test simulations was run and compared to existing results. For these simulations, three types of materials for Venetian blinds, described in Annex C of ISO 15099 standard were used; A, B and C from Table 1.

A total of 4 blind configurations were used, with different tilt angle of flat slats: A45, B45, C45 and C80. Letters A, B and C indicate material used, followed by the slat tilt angle expressed in degrees. Simulation results were compared against two sources; 1) average results from ISO15099 and 2) results of detailed ray trace simulations. Directional-diffuse calculations were carried out for a set of 145 incident/outgoing directions (full basis in WINDOW 6.0 program).

***Table 1.*** *Solar properties of slat meterials used*

| PROPERTY | A | B | C |
|---|---|---|---|
| Solar transmittance, $\tau_s$ | 0.00 | 0.00 | 0.00 |
| Solar reflectance outdoor (front) side, $\rho_s^f$ | 0.70 | 0.55 | 0.70 |
| Solar reflectance indoor (back) side, $\rho_s^b$ | 0.70 | 0.55 | 0.40 |

**Directional-diffuse calculation vs ISO15099**

Table 2 presents results of these simulations, namely integrated, directional-to-diffuse solar transmittances and reflectances at normal incidence. *Ref* indicates reference values from ISO15099 and *DD* indicates resutls of directional-diffuse calculations.

***Table 2.*** *Selected calculated dir-dif properties at normal incidence*

| BLIND | | A45 | B45 | C45 | C80 |
|---|---|---|---|---|---|
| Front transmittance | Ref | 0.073 | 0.047 | 0.051 | 0.005 |
| | DD | 0.0730 | 0.0472 | 0.0508 | 0.0048 |
| Back transmittance | Ref | 0.288 | 0.216 | 0.271 | 0.027 |
| | DD | 0.2882 | 0.2161 | 0.2714 | 0.0268 |
| Front reflectance | Ref | 0.558 | 0.430 | 0.544 | 0.678 |
| | DD | 0.5587 | 0.4308 | 0.5454 | 0.6788 |
| Back reflectance | Ref | 0.103 | 0.066 | 0.070 | 0.273 |
| | DD | 0.1030 | 0.0661 | 0.0701 | 0.2735 |

Results of simulations show excellent agreement with results from ISO15099.

**Directional-diffuse calculation vs TRACEPRO**

A series of ray trace simulations for the four selected blind configurations were performed by LBNL (2006b) using TracePro program. In these simulations, a total of 200.000 rays per configurations were used, and thickness of the slat material was set to 0.01 mm.

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Figures 2 to 4 present comparisons between directional-diffuse results (labeled Venetian) and ray trace results (labeled TracePro), for different profile angles of incident directions. Front and back transmittances and reflectances were compared for all test configurtations, and they all show excellent agreement.
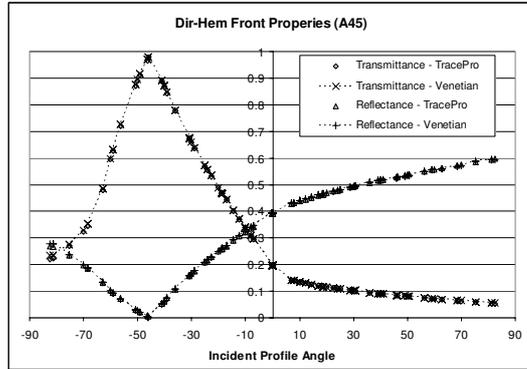


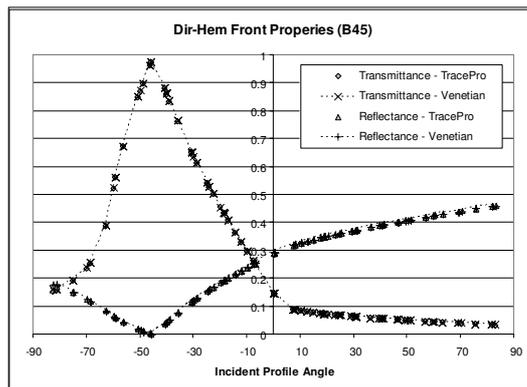*Figure 2 Front direct-to-hemispherical properties for configuration A45*



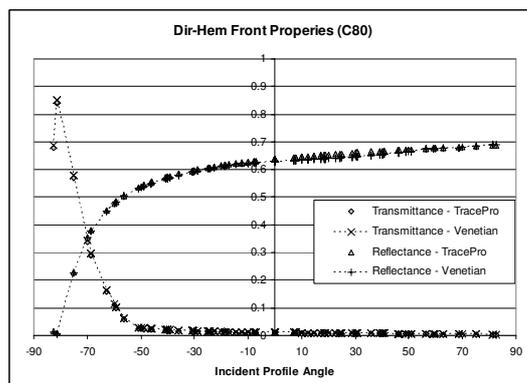*Figure 3 Front direct-to-hemispherical properties for configuration B45*



*Figure 4 Front direct-to-hemispherical properties for configuration C80*

## CONCLUSION

Directional diffuse calculatioan method can be reliably used for predicting both integrated and localized perforamance of venetian blinds, for those materials that do not show substantial specularity.

Further work is needed to extend this methodology for specular surfaces.

## ACKNOWLEDGEMENT

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