A SIMPLIFIED METHOD FOR CALCULATING THE EFFECTIVE SOLAR OPTICAL PROPERTIES OF A DRAPERY

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ABSTRACT

The use of draperies to control solar gain through windows is common in residential and commercial buildings and their potential for reduction of building peak load and annual energy consumption is recognized to be large. Thus, there is a strong need for models that allow a drapery to be included in glazing system analysis. As an approximation, the drapery is modelled as a series of uniformly arranged rectangular pleats with fabric transmitting and reflecting diffusely any incident radiation. The "effective" solar optical properties of the drapery are then determined by considering an enclosure which is representative of the entire series of pleats. The optical properties of the drapery are functions of the pleat geometry and the optical properties of the fabric. Optical properties are also influenced by the directional nature of the incident radiation. In the case of incident beam radiation, the results are presented as a function of the solar profile angle for a folding ratio corresponding to 100% fullness. The results for incident diffuse radiation on the other hand are presented in terms of fabric properties and the folding ratio of the drapery.

INTRODUCTION

Draperies provide privacy, reduce glare and improve aesthetics. They should also reduce solar gain and increase thermal resistance. The reduction in solar gain and the increase in thermal resistance can noticeably influence building peak load and annual energy consumption. Using computer simulation, Rudoy and Duran (1975), for example, reported an annual reduction in the cooling load of an office space in the range of 5-20% when draperies were attached to a window that occupied only 25% of the exterior wall. Their study also showed a reduction of annual heating load of approximately 10%.

The influence of a drapery on the solar gain through a window is strongly dependent on the solar optical properties of the drapery. Several studies have been carried out to determine the solar optical properties of draperies as well as the reduction of solar gain when draperies are used. The current study focuses on the reduction of solar gain by characterising the solar optical properties of draperies.

By visual inspection, Keyes (1967) characterised fabrics by yarn colour (yarn reflectance) as dark (D), medium (M) and light (L) and by weave as open (I), semi-open (II) and closed (III). Keyes then developed a chart that expressed measured shading coefficient (defined as the ratio of solar gain through a window to the solar gain through a standard clear single-pane glass) as a function of yarn reflectance and weave openness when a drapery was combined with both regular plate and heating absorbing glass. Whenever the solar optical properties of the fabrics are unknown, Keyes method gives an approximate value of the shading coefficient of glass-drapery combination.

Having acknowledged that fabric colour and weave openness alone were not sufficient to determine accurately the shading coefficient of glass-drapery combination, Moore and Pennington (1967) developed a chart that expressed the shading coefficient as a function of fabric reflectance and transmittance. They measured the solar optical properties of fabrics, draperies, and glass-drapery combinations using various techniques. They also measured the shading coefficient for various glass-drapery combinations using a solar calorimeter. Furthermore, they developed equations to calculate the shading coefficient for glass-drapery combinations using drapery and glass solar optical properties as inputs. The optical properties of the drapery were estimated by applying a multiplicative factor to the optical properties of the fabric at normal incidence. The proposed multiplicative factor accounted for the effect of folding and the variation of the incidence angle of beam radiation. Their calculated shading coefficients agreed quite well with experimentally determined shading coefficients.

By careful analysis of fabric transmittance and reflectance, yarn reflectance and openness factor, Keyes (1967) was able to reconcile the yarn reflectance-openness chart with the fabric reflectance-transmittance chart. Keyes (1967) universal chart (Figure 1) is the basis of the interior attenuation coefficient (IAC) data for glass-drapery combination found in ASHRAE Handbook-Fundamentals (2005). This chart conveniently correlates measured optical properties with eyeobserved values to determine the shading coefficient of glass-drapery combination thus making it a practical tool for designers in the field. However, optical properties measurements carried out by Moore and Pennington (1967) with a spectrophotometer revealed that for spectrally selective fabrics, the optical properties in the visible spectrum could be much different from the properties in the near infrared spectrum. Consequently, the solar averaged properties differ from the average in the visible spectrum. In such situations, using visual judgement to predict shading effects could give inaccurate results.

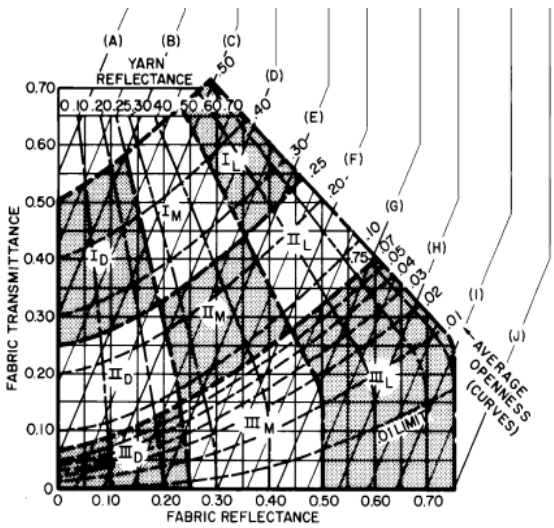

Figure 1. Fabric classification (reproduced from ASHRAE, 2005).

The first attempt to quantify the cumulative effect of folding (or pleating) and the directional nature of incident radiation on the solar gain through draperies was carried out by Ozisik and Schutrum (1960). To determine the effectiveness of 100% fullness draperies in reducing the solar gain through a sunlit window, Ozisik and Schutrum (1960) tested draperies of different fabrics in combination with regular and heat absorbing glass using a solar calorimeter. They presented their results in terms of the solar heat transfer factor, *K*, defined as the ratio of the solar gain to the insolation. Note that the *K* value is identical to the Solar Heat Gain Coefficient (SHGC) defined in ASHRAE (2005).

Ozisik and Schutrum (1960) results showed that the *K* values were independent of incidence angle for incidence angles ranging from 0^0 to 50^0. For incidence angles greater than 50^0, they suggested a decrease in *K* values by 10% for each 10^0 increase in incidence angle. They also proposed a reduction of 10% in *K* values for incident diffuse radiation. Furthermore, they presented a variation of *K* values with respect to solar optical properties of the fabric at normal incidence and observed that the reflectance was the dominant property influencing the solar gain.

In addition to the solar gain tests, Ozisik and Schutrum (1960) performed a series of tests to investigate the effect of pleating on the solar optical properties of draperies. They measured the angular transmittance and reflectance of both fabrics and draperies with a pyrheliometer. Their results showed that the transmittance of the drapery at normal incidence was almost the same as that of the corresponding fabric. However, at an incidence angle of 45^0, the transmittance of the drapery was 20% less than that of the fabric. For incident diffuse radiation, the transmittance of the drapery was also 20% less than that of the fabric. The reflectance of the drapery, on the other hand, was about 20% less than that of the fabric at normal incidence and about 10% less at 45^0 incidence.

Yellot (1965) experimentally determined the solar heat gain factor (defined as solar gain through a standard clear glass for a given insolation) and the shading coefficient of draperies in combination with clear and heat absorbing glass for a wide variety of fabrics using an outdoor solar calorimeter. He also measured the solar optical properties of fabrics as well as glass-fabric combinations at various angles of incidence using a custom-made instrument. The measurements were taken at varying incidence angles ranging from 26^0 to 90^0. His experiments showed that the solar heat gain factor for a typical glass-fabric combination decreases as the incidence angle increases although the shading coefficient remained fairly constant. To explore the effects of varying wall-solar azimuth on the reflectance of fabrics and draperies, Yellot (1965) used a reflectometer to measure reflectance of a typical light coloured fabric and a drapery in a solar calorimeter. His results showed that although the reflectance of both fabric and drapery varied with wall-solar azimuth, there was very little difference between the reflectance of the fabric and the drapery for a given wall-solar azimuth.

The results of the preceding studies (Keyes, 1967, Moore and Pennington, 1967, Ozisik and Schutrum, 1960 and Yellot, 1965) could be very useful in predicting the solar gain through windows with indoor draperies. However, they were limited to single glazed windows. Given that a significant number of double glazed windows are installed in practice, an in-depth theoretical analysis was carried out by Farber et al. (1963) to ascertain the reduction of solar gain through double glazed windows with indoor-side shading. More specifically, they considered venetian blinds as well as draperies installed at the indoor-side of the double glazed window by theoretically estimating the solar gain. Of particular interest was the determination of the apparent (effective) solar optical properties of the drapery using a simplified rectangular configuration that is representative of the drapery. The calculated apparent optical properties were based on the solar optical properties of the fabric and the assumed geometry. Farber et al. (1963) assumed that the fabric is diffusely reflecting and diffusely transmitting although the reflectance and transmittance for beam radiation vary with incidence angle. Their calculation involved a separate treatment of the front and the cavity portions of the drapery with the front portion having the same optical properties as the fabric. However, the determination of the apparent optical properties of the cavity portion involved angle factors leading to simultaneous integral-differential equations with formidable solution techniques. Nonetheless, the solution of the cavity portion was added to the front portion and the results averaged to give the apparent optical property of the drapery.

To validate the theoretical analysis carried out by Farber et al. (1963), Pennington et al. (1964) performed a series of experiments using an outdoor solar calorimeter to measure the solar gain of complex fenestration systems at various angles of incidence (or profile angles). Furthermore, they used the pyrheliometer installed in the calorimeter to measure the solar optical properties of fabrics, draperies and glass-drapery combinations at various angles of incidence. Within the range of incidence angles considered, the experimentally determined solar optical properties and solar gain compared favourably with the theoretical results.

Little research has been conducted on the solar optical characteristics of drapery fabrics in recent times. To complement the effort of past researchers on the characterisation of drapery fabrics, Hunn et al. (1991) designed an apparatus to measure the bidirectional transmittance and reflectance distribution of beam radiation incident on both fabrics and draperies. The measurements revealed the effect of textile properties (openness of weave, fibre cross section and fabric structure) on the distribution of sunlight. Such information is particularly useful in the context of daylighting simulation through windows with drapery attachments. However, this experimental method is not only time consuming but also limited in its capabilities. The bidirectional solar optical properties obtained by measurements can be incorporated into a matrix layer calculation method like the one developed by Klems (1994a and 1994b) to predict the solar gain of complex fenestration systems.

In the current study, normal-hemispherical solar optical properties of fabrics were measured using a UV/VIS/NIR spectrophotometer. The spectrophotometer is a double beam, direct ratio recording, rapid scanning high performance instrument with a scan rate of 2000nm/min for UV-Vis and 8000nm/min for NIR, a resolution of <0.05nm for UV-Vis and <0.2nm for NIR, and repeatability characteristics of <0.025nm for UV-Vis and <0.1nm for NIR. It has an extended spectral range allowing it to scan between 0.17 and 3.30μm. Having obtained the solar optical properties of a typical fabric, the effective solar optical properties of the drapery were determined as functions of the optical properties of the fabric and the geometry of the drapery. More specifically, the fabric is assumed to transmit and reflect beam radiation diffusely. In addition, the fabric optical properties are assumed to be independent of the angle of incidence. This simplified approach significantly reduces computational time. The effective optical property models developed in this study provide useful input to the multi-layer glazing/shading layer models previously developed for building energy simulation (Wright and Kotey, 2006). It is therefore anticipated that the simplified models will be highly valuable in building energy simulation.

MODEL DEVELOPMENT

Solar optical properties of a drapery are determined by considering an enclosure which is representative of the drapery. Figure 2a shows a representative geometry of the drapery where *s* is the pleat spacing and *w* is the pleat width. The optical properties are functions of the drapery geometry and the fabric optical properties as well as profile angle, Ω. Drapery optical properties are modelled based on the following assumptions and simplifications:

- The geometric configuration of the drapery is a series of uniformly arranged rectangular pleats
- The thickness of the fabric is negligible
- The surfaces of the pleats are perfectly flat
- Incident diffuse radiation is uniformly distributed
- The fabric transmits and reflects diffusely any incident beam radiation. More recent undocumented measurements show that most fabrics exhibit such optical characteristics

The optical property models for the drapery pertaining to beam radiation require the beam-diffuse reflectance of the forward-facing and backward-facing surfaces of the fabric ($\rho^m_{ff,bd}$ and $\rho^m_{bf,bd}$) as well as the beam-diffuse transmittance of the fabric (τ^m_{bd}). The superscript "*m*" is attached to the solar optical properties of fabric to distinguish them from the effective solar optical properties of the drapery. Furthermore, the optical property models for the drapery require the diffuse-diffuse reflectance of the forward-facing and backward-facing surfaces ($\rho^m_{ff,dd}$ and $\rho^m_{bf,dd}$) as well as the diffuse-diffuse transmittance of the fabric (τ^m_{dd}). From the assumption that fabric is a perfect diffuser, it follows that $\rho^m_{ff,bd}$, $\rho^m_{bf,bd}$ and τ^m_{bd} are independent of the angle of incidence and hence $\rho^m_{ff,bd} = \rho^m_{ff,dd} = \rho^m_{ff}$, $\rho^m_{bf,bd} = \rho^m_{bf,dd} = \rho^m_{bf}$ and $\tau^m_{bd} = \tau^m_{dd} = \tau^m$. Moreover,

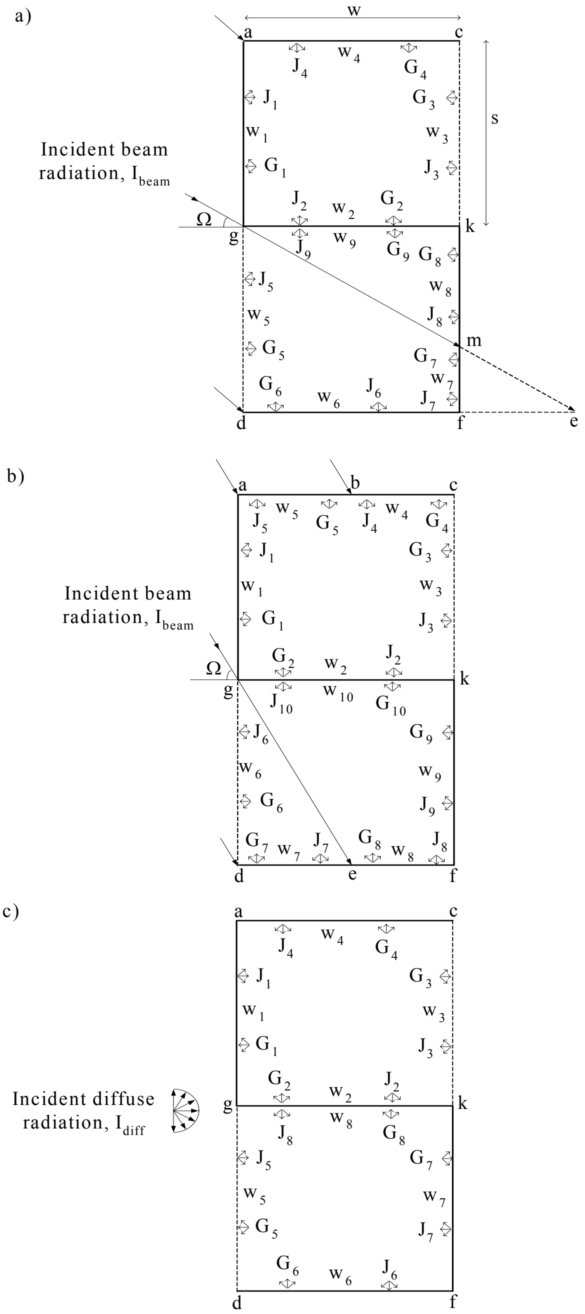

Figure 2. Enclosure Geometry for Calculating Drapery Optical Properties a) Incident Beam Radiation (nine-surface model) b) Incident Beam Radiation (ten-surface model) c) Incident Diffuse Radiation

since beam-beam transmission and reflection are negligibly small (perfectly diffusing fabric), $\tau^m_{bb} = 0$, $\rho^m_{ff,bb} = 0$ and $\rho^m_{bf,bb} = 0$. Consequently, only ρ^m_{ff}, ρ^m_{bf} and τ^m are required as inputs to the model.

The folding ratio, defined as the total width of the fabric divided by the width of the drapery, gives an indication of the percentage fullness of the drapery. For example, a 100% fullness corresponds to a folding ratio of 2. From Figure 2a, it can be seen that the folding ratio equals 1 + w/s.

Beam-Diffuse Solar Optical Properties

The calculation is subdivided into two categories depending on whether the horizontal surface of the bottom half of the enclosure (as shown in Figures 2a and 2b) is fully or partially illuminated. For a fully illuminated horizontal surface, the line segment $de \geq w$**.** The corresponding nine-surface model is shown in Figure 2a. A partially illuminated horizontal surface gives rise to a ten-surface model with $de < w$ as shown in Figure 2b. The following subsections describe the nine- and ten-surface models.

Nine-Surface Model

As shown in Figure 2a, beam radiation incident on surfaces w_6 and w_7 is reflected diffusely into the enclosure. A portion of the beam radiation incident on surfaces w_6 and w_7 is diffusely transmitted. Diffuse radiation in the enclosure will also be transmitted and reflected diffusely by all surfaces. The following definitions apply:

- J_i is the radiosity of surface i,
- G_i is the irradiance on surface i,
- Z_i is the diffuse source term due to incident beam radiation on surface i.

From the definitions of J, G and Z, the following equations can be written:

$$J_1 = Z_1 + \rho^m_{bf} G_1 \qquad (1)$$

$$J_2 = \tau^m G_9 + \rho^m_{bf} G_2 \qquad (2)$$

$$J_4 = Z_4 + \tau^m G_6 + \rho^m_{bf} G_4 \qquad (3)$$

$$J_6 = Z_6 + \tau^m G_4 + \rho^m_{ff} G_6 \qquad (4)$$

$$J_7 = Z_7 + \rho^m_{ff} G_7 \qquad (5)$$

$$J_8 = \rho^m_{ff} G_8 \qquad (6)$$

$$J_9 = \tau^m G_2 + \rho^m_{ff} G_9 \qquad (7)$$

Also, the diffuse source terms can be calculated as:

$$Z_1 = \tau^m I_{beam} \qquad (8)$$

$$Z_4 = \tau^m \frac{s}{de} I_{beam} \qquad (9)$$

$$Z_6 = \rho^m_{ff} \frac{s}{de} I_{beam} \qquad (10)$$

$$Z_7 = \rho^m_{ff} I_{beam} \qquad (11)$$

where

$$de = s\left|\frac{\cos(\Omega)}{\sin(\Omega)}\right| \qquad (12)$$

The irradiance on each surface of the top half of the enclosure is given by:

$$G_i = \sum_{j=1}^{4} F_{ij} J_j \qquad i = 1, 4 \quad (13)$$

while the irradiance on each surface of the bottom half of the enclosure is given by:

$$G_i = \sum_{j=5}^{9} F_{ij} J_j \qquad i = 5, 9 \quad (14)$$

The view factor, F_{ij}, is the fraction of diffuse radiation leaving surface i that is intercepted by surface j. The view factors can be determined by Hottel's crossed string rule (e.g., Hollands 2004).
Since there is no incident diffuse radiation on surfaces w_3 and w_5, $J_3 = J_5 = 0$. Equations (1)-(7) are linear and can be solved by matrix reduction with I_{beam} set to unity. The front beam-diffuse transmittance and reflectance are:

$$\tau_{f,bd} = \frac{s\ G_3 + \tau^m (w_8 G_8 + w_7 G_7 + w_7)}{2s} \quad (15)$$

$$\rho_{f,bd} = \frac{\rho_{ff}^m + \tau^m G_1 + G_5}{2} \quad (16)$$

where

$$w_8 = w \left| \frac{\sin(\Omega)}{\cos(\Omega)} \right| \quad (17)$$

and

$$w_7 = s - w_8 \quad (18)$$

Ten-Surface Model

The following equations are written (see Figure 2b):

$$J_1 = Z_1 + \rho_{bf}^m G_1 \quad (19)$$

$$J_2 = \tau^m G_{10} + \rho_{bf}^m G_2 \quad (20)$$

$$J_4 = \tau^m G_8 + \rho_{bf}^m G_4 \quad (21)$$

$$J_5 = Z_5 + \tau^m G_7 + \rho_{bf}^m G_5 \quad (22)$$

$$J_7 = Z_7 + \tau^m G_5 + \rho_{ff}^m G_7 \quad (23)$$

$$J_8 = \tau^m G_4 + \rho_{ff}^m G_8 \quad (24)$$

$$J_9 = \rho_{ff}^m G_9 \quad (25)$$

$$J_{10} = \tau^m G_2 + \rho_{ff}^m G_{10} \quad (26)$$

The diffuse source terms Z_1, Z_5 *and* Z_7 are calculated from equations (8), (9) and (10) respectively.
The irradiance on each surface of the top half of the enclosure is:

$$G_i = \sum_{j=1}^{5} F_{ij} J_j \qquad i = 1, 5 \quad (27)$$

Similarly, the irradiance on each surface of the bottom half of the enclosure is:

$$G_i = \sum_{j=6}^{10} F_{ij} J_j \qquad i = 6, 10 \quad (28)$$

Since there is no incident diffuse radiation on surfaces w_3 and w_6, $J_3 = J_6 = 0$. Equations (19)-(26) are solved with I_{beam} set to unity and the front beam-diffuse transmittance and reflectance are:

$$\tau_{f,bd} = \frac{G_3 + \tau^m G_9}{2} \quad (29)$$

$$\rho_{f,bd} = \frac{\rho_{ff}^m + \tau^m G_1 + G_6}{2} \quad (30)$$

Diffuse-Diffuse Solar Optical Properties

The diffuse-diffuse transmittance and reflectance of the drapery are calculated using the eight-surface model shown in Figure 2c. For a uniformly distributed diffuse radiation incident on the front surface of the enclosure, I_{diff}, the following equations are written:

$$J_1 = \tau^m I_{diff} + \rho_{bf}^m G_1 \quad (31)$$

$$J_2 = \tau^m G_8 + \rho_{bf}^m G_2 \quad (32)$$

$$J_4 = \tau^m G_6 + \rho_{bf}^m G_4 \quad (33)$$

$$J_6 = \tau^m G_4 + \rho_{ff}^m G_6 \quad (34)$$

$$J_7 = \rho_{ff}^m G_7 \quad (35)$$

$$J_8 = \tau^m G_2 + \rho_{ff}^m G_8 \quad (36)$$

The irradiance on each surface of the top half of the representative enclosure is given equation (13) while the irradiance on each surface of the bottom half of the enclosure is:

$$G_i = \sum_{j=5}^{8} F_{ij} J_j \qquad i = 5, 8 \quad (37)$$

To solve equations (31)-(36), I_{diff} is set to unity and the front diffuse-diffuse transmittance and reflectance are:

$$\tau_{dd} = \frac{G_3 + \tau^m G_7}{2} \quad (38)$$

$$\rho_{f,dd} = \frac{\rho_{ff}^m + \tau^m G_1 + G_5}{2} \quad (39)$$

The back effective solar optical properties of the drapery can easily be calculated with the same set of equations described above by interchanging the reflectances of the forward-facing and the backward-facing surfaces of the fabric. Ideally, the optical property calculations for the drapery must be performed for every wavelength required by the corresponding optical properties of the fabric. However, for the sake of simplicity, the solar (spectrally-averaged) optical properties of the fabric are used.

RESULTS AND DISCUSSION

The solar optical properties of a wide variety of fabrics were measured using a UV/VIS/NIR spectrophotometer. More specifically, the spectral optical properties of each fabric ($\rho^m_{ff}(\lambda)$, $\rho^m_{bf}(\lambda)$ and $\tau^m(\lambda)$) were obtained at direct-normal incidence and the solar (spectrally-averaged) optical properties were calculated using the 50-point selected ordinate method as described in ASTM E903-96 (1996).

Nine fabric samples that fall into each classification shown in Figure 1 were selected for analysis. The fabric transmittance and reflectance of the selected samples are given in Table 1. All the samples have their reflectances on both sides to be the same and hence only one reflectance value is shown in Table 1.

Table 1. Solar Optical Properties and Classification of Fabrics

Fabric Transmittance	Fabric Reflectance	ASHRAE Classification	Symbol
0.32	0.15	Open weave, dark-coloured	I_D
0.23	0.21	Semi-open weave, dark-coloured	II_D
0.07	0.19	Closed weave, dark-coloured	III_D
0.64	0.23	Open weave, medium-coloured	I_M
0.28	0.31	Semi-open weave, medium-coloured	II_M
0.19	0.36	Closed weave, medium-coloured	III_M
0.54	0.41	Open weave, light-coloured	I_L
0.51	0.48	Semi-open weave, light-coloured	II_L
0.29	0.67	Closed weave, light-coloured	III_L

Given the solar transmittance and reflectance of each fabric, the effective solar optical properties of the drapery were calculated. For the purpose of discussion, three fabric samples, i.e., open weave, medium-coloured fabric (I_M), closed weave, medium-coloured fabric (III_M) and closed weave, light-coloured fabric (III_L) are chosen. Figure 3 shows the effective diffuse-diffuse optical properties plotted against the folding ratio for the three selected fabrics. As seen in Figures 3a and 3b, the effective diffuse-diffuse transmittance of the drapery decreases with increasing folding ratio for fabrics classified as I_M and III_M. In contrast, the transmittance of the drapery for fabric classification III_L increases slightly, remains essentially constant before decreasing as the folding ratio increases (see Figure 3c). The effective diffuse-diffuse reflectance of the drapery in each fabric classification shows a rather interesting trend. While the reflectance increases sharply to a maximum value before remaining essentially constant with increasing folding ratio for fabric classification I_M (see Figure 3a), there exists a general decrease in the reflectance with an increase in folding ratio for fabric classification III_M and III_L (see Figures 3b and 3c). Note that for $w = 0$, when there are no folds at all, the effective optical properties of the drapery corresponds to the solar optical properties of the fabric.

Consideration will now turn to the effect of profile angle of incident beam radiation on the solar optical properties of a drapery. A folding ratio of 2 (100% fullness) is chosen in this study. Clearly, the effective beam-diffuse transmittance of the drapery always decreases with increasing profile angle as seen in Figure 4 for all three fabric classifications. For fabrics classified as III_M and III_L, the effective beam-diffuse reflectance of the drapery remains approximately constant as the profile angle increases from 0^0 to 40^0; a further increase in the profile angle results in a weak increase in the reflectance of the drapery (see Figures 4b and 4c). Fabrics classified as I_M on the other hand show a marked increase in the effective beam-diffuse reflectance of the drapery as the profile angle increases from 0^0 to 90^0. Note that the profile angle for a drapery configuration is equal to the wall-solar azimuth angle.

On a more general note, Pennington and Moore (1967) acknowledged the difficulty in measuring the solar optical properties of draperies. Given the solar optical properties of the fabric at normal incidence, they proposed multiplicative constants that could be used to scale down the optical properties of fabric in order to obtain the corresponding optical properties of the drapery. Their deduced scaling constants were based on experiments performed on several fabrics. The present results however show that the solar optical properties of a drapery do not always decrease by a constant factor with respect to folding and/or incidence angle. In fact, the optical properties of a drapery can actually increase with folding ratio as seen in Figure 3.

CONCLUSIONS

The importance of modelling solar optical properties of shading devices lies in the need to predict their energy savings potential. In the current study, simplified models were used to calculate the effective solar optical properties of a drapery for both incident beam and diffuse radiation. The drapery was modelled as a series of uniformly arranged rectangular pleats with optical properties dependent on the geometry, the optical properties of the fabric and the profile angle of incident radiation. The fabric is assumed to transmit and reflect diffusely any incident beam radiation. Given the solar optical properties of the fabric, the drapery models enable us to explore the effect of folding as well as the variation of the profile angle on the effective optical properties. The results show that the solar optical properties of a drapery do not always decrease by a constant factor with respect to folding and/or incidence angle as proclaimed by previous researchers. The simplified solar optical models can therefore produce results that can serve as useful input to building load and annual energy calculation tools. Furthermore, simplified models have advantages especially in the design stages when one wishes to compare the performance of various draperies that could be installed on windows.

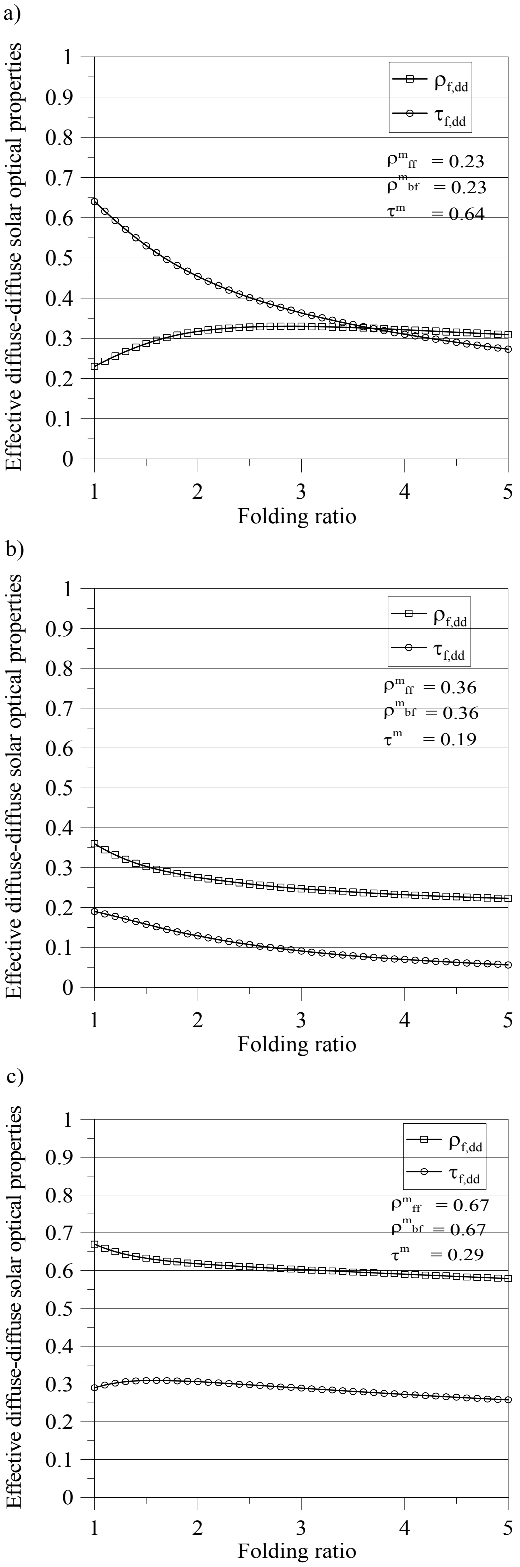

Figure 3. Effective solar optical properties of a drapery versus folding ratio for incident diffuse radiation a) I_M b) III_M c) III_L.

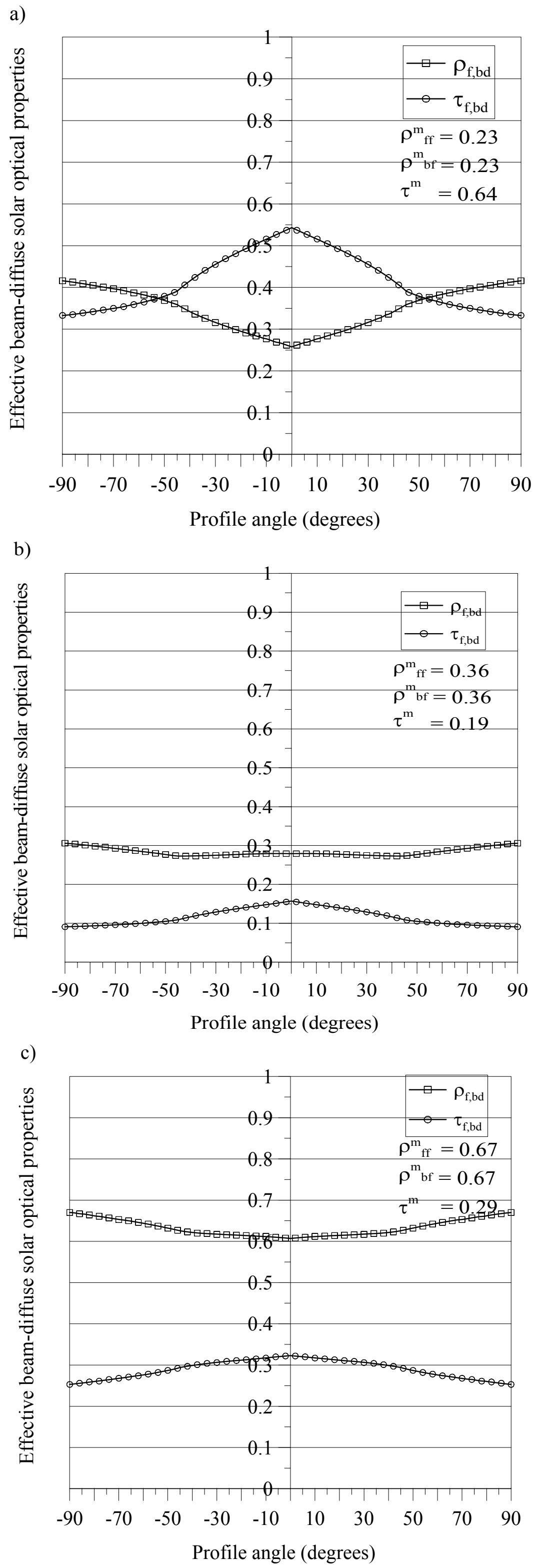

Figure 4. Effective solar optical properties of a drapery (100% fullness) versus profile angle of incident beam radiation a) I_M b) III_M c) III_L.

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NOMENCLATURE

Symbols

de	length of illuminated surface (m)
F	view factor (dimensionless)
G	irradiance (W/m^2)
I	incident flux (W/m^2)
J	radiosity (W/m^2)
K	solar heat transfer factor (dimensionless)
s	pleat spacing (m)
w	pleat width (m)
Z	diffuse source term due to incident beam radiation (W/m^2)

Greek Letters

λ	wavelength (m)
ρ	reflectance (dimensionless)
τ	transmittance (dimensionless)
Ω	profile angle

Subscripts

b	related to back surface of drapery
bb	related to beam-beam optical property
beam	related to beam flux
bd	related to beam-diffuse optical property
bf	related to backward facing surface of fabric
dd	related to diffuse-diffuse optical property
diff	related to diffuse flux
f	related to front surface of drapery
ff	related to forward facing surface of fabric
i	related to ith surface of the enclosure
j	related to jth surface of the enclosure

Superscripts

m	related to fabric solar optical property

Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ASTM	American Society for Testing and Materials
IAC	Interior Attenuation Coefficient (dimensionless)
NIR	Near infrared
SHGC	Solar Heat Gain Coefficient (dimensionless)
UV	Ultraviolet
VIS	Visible

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