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AN ALGORITHM TO DETERMINE RADIATIVE PROPERTIES OF GLAZING SYSTEMS USING SIMPLE WINDOW PERFORMANCE INDICATORS

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Abstract. An algorithm has been developed for the determination of incidence-angle dependent radiative properties and averaged properties of glazing systems based on simple performance indicators. First, the results are obtained using a computer code that applies statistical methods, multiple correlations for data treatment, and a mathematical approach to obtain the directional optical properties from the spectral values. Then, simulations are carried out using the comparative test described in ANSI/ASHRAE Standard 140/2011 (Judkoff and Neymark, 1995) for a base case, showing the adequacy of the algorithm for different glazing systems.

Keywords: Glazing systems, optical properties, building simulation, energy efficiency

1. INTRODUCTION

The trend to reduce energy losses through enclosures as walls and windows is an increasingly important part of improving the energy efficiency of a building. Adequate window design, selection and orientation can reduce the heating power in cold climates and cooling requirements of a building in hot climates. Windows are thermally critical elements of the building envelope because they are difficult to insulate and produce much greater conductive gains and losses than corresponding wall areas. A very important characteristic of windows is the transmission of light (short wavelength thermal radiation) directly into the thermal zone because provides natural lighting inside the building. This transmitted light is usually a desirable heat gain in the winter and an undesirable gain in the summer. Windows play a key role in the energy efficiency of both residential and commercial buildings. At least one-fourth of domestic heating requirements in OECD countries (Muneer *et al.*, 2001) are considered to be the result of energy losses through windows. In recent years, major efforts have been made to improve the thermal behavior of windows using various technologies, such as low-emissivity coatings, inert gas fill, insulating edge spacers, low-conductivity frames, etc. This approach has led to windows with a thermal transmittance as good as a wall (Urbikain *et al.*, 2007). Adequate windows design, selection and orientation can strongly reduce heating and cooling loads predicted by building simulation tools. In order to improve the accuracy of those tools, this work proposes an algorithm for the determination of optical properties and spectral averaged properties of glazing systems using as input parameters three simple performance indicators (overall heat transfer coefficient, solar heat gain coefficient and visible transmittance). Numerical results are first obtained for the determination of the optical variables using the input data needed to model different glazing systems such as single, double and triple glazing system. Then the simulation tools DOMUS (Mendes *et al.*, 2008) and EnergyPlus (Crawley *et al.*, 2000) are used to determine the building thermal performance and energy savings according to the non-opaque building envelope.

2. THEORETICAL BACKGROUND

A theoretical background for radiative properties of transparent media is presented along with mathematical approach for multi-glazing systems.

2.1 Radiative properties

The radiative properties that are of concern for glazings are normally transmittance, reflectance and absorptance, which correspond to the fraction of the impinging radiation that is transmitted, reflected or absorbed, respectively. These properties are wavelength dependent and can in many well-defined cases be theoretically analysed or measured. Both for theoretical calculations and measurements, sample geometry, homogeneity, scattering etc., have to be taken into account.

2.1.1 Spectral average of radiative properties

At each wavelength, energy conservation demands that the sum of the absorptance, reflectance and transmittance. The values of the total optical properties displayed are normalized weighted averages calculated by the following integration with a general equation as:

$$P_x = \frac{\int_a^b P(\lambda)\phi_x(\lambda)\Gamma_x(\lambda)d\lambda}{\int_a^b P(\lambda)\Gamma_x(\lambda)d\lambda}, \quad (1)$$

with parameters defined as Property Type in Table 1. The integrated parameters represent the average transmittance, reflectance, absorptance or emittance within the specified region, denoted T_{sol} , T_{vis} , ϵ_{th} etc. at any angle of incidence. Spectral averages for colour rendering within the visible and for skin protection factor and damage to fabrics within the ultraviolet region also exist (Karlsson, 2001). The source weighting functions are graphically shown in Figure 1.

Table 1. Property type (T, R, A or ϵ), wavelength integration limits and weighting functions used to calculate the integrated solar, visual and thermal properties.

Property type, x	Lower wavelength, a (μm)	Upper wavelength, b (μm)	Source weighting function, ϕ_x	Detector weighting function, Γ_x
Solar, P_{sol}	0.3	2.5	AM 1.5 Global Irradiance (ISO 9845)	1.0
Light, P_{vis}	0.38	0.78	CIE D65 Illuminant	CIE 1968 Observer
Thermal, P_{th}	5	50	Blackbody	1.0

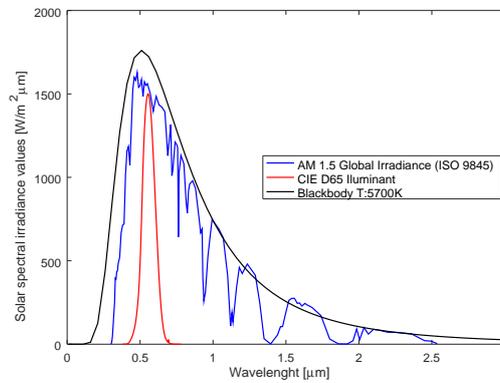


Figure 1. Spectral source-weight function

2.1.2 Directional Averages

The general formula for a conical average on an azimuthally symmetric material (properties depend only on θ) is:

$$P = \frac{\int_{\phi} \int_{\theta} P(\theta)\cos\theta\sin\theta d\theta d\phi}{\int_{\phi} \int_{\theta} \cos\theta\sin\theta d\theta d\phi}. \quad (2)$$

Ideally directional averages would be taken over the specific angular field of view. Such averages could be in building energy simulation programs to account for limited view of ground or sky. Nevertheless, lack of information about the surroundings of the glazing usually confines the calculated averages to the hemispherical quantity. Integrating over the hemisphere from $\theta=0$ to $\pi/2$ and $\phi=0$ to 2π :

$$P_{\Omega} = 2 \int_0^{2\pi} P(\theta)\cos\theta d\theta. \quad (3)$$

2.1.3 Synthesis of Window Systems

The absorptance and transmittance of a window depend on the type and thickness of the glass on whether the window is single or double or triple glazed as shown in Fig. 2 and 3 respectively, on the angle that the incident beam of light makes with the normal to the surface and on the degree of polarization of the incident beam. When a beam of radiant energy strikes an interface between air and glass some of the energy is reflected. The ratio of the intensity of the reflected beam to the incident beam is given by Fresnel's formulae (Mitalas and Stephenson, 1962).

$$r_{\parallel} = \frac{\tan^2(\theta_1 - \theta_2)}{\tan^2(\theta_1 + \theta_2)}, \quad (4)$$

$$r_{\perp} = \frac{\sin^2(\theta_1 - \theta_2)}{\sin^2(\theta_1 + \theta_2)}, \quad (5)$$

where r_{\parallel} and r_{\perp} are the reflectivity of the interface for radiation that is polarized with the electric vector parallel and perpendicular respectively to the plane that contains the incident beam and normal to the interface and θ_1 and θ_2 are the angles that the beam makes with the normal to the interface in the air and in the glass, respectively. They are related to the refraction index of the glass by Snell's law:

$$\sin\theta_1 = n \sin\theta_2. \quad (6)$$

For normal incidence, one can write:

$$\theta_1 = \theta_2 \text{ and } r_{\parallel} = r_{\perp} = \left(\frac{n-1}{n+1}\right)^2. \quad (7)$$

The energy that is not reflected at the air-glass interface enters the glass, where it is partially absorbed as it passes through. The absorption may be described by

$$\frac{dI}{dx} = -kI, \quad (8)$$

where: I is the intensity of the beam, x is distance measured in the direction of the beam, and k is an absorption coefficient. Thus, if the intensity of a beam incident on the surface of a sheet of glass is unity, the intensity of the beam that penetrates to a depth L measured along a normal to the surface is:

$$I_L = (1-r)e^{\frac{-nkL}{\sqrt{n^2 - \sin^2\theta_1}}}. \quad (9)$$

The fraction of the energy that is absorbed is

$$a = (1-r) \left(1 - e^{\frac{-nkL}{\sqrt{n^2 - \sin^2\theta_1}}}\right). \quad (10)$$

Since r depends on the polarization a does also.

The beam that reaches the second glass-air interface has the intensity I_L . A fraction r of this is reflected back into the glass and the rest passes out of the glass into the room. The internally reflected beam is again partially absorbed before reaching the outside glass-air interface where it is again partially reflected. The transmitted portion of this beam goes into the outside air and adds to the beam that was reflected back into the air initially at that interface, The over-all effect of the multiple reflections in the glass is that the over-all reflectivity, absorptivity and transmissivity are related to the parameters defined above as

$$R = r + \frac{r(1-r)^2(1-a)^2}{(1-r^2(1-a)^2)}, \quad (11)$$

$$A = \frac{a(1-r)[1+r(1-a)]}{1-r^2(1-a)^2}, \quad (12)$$

$$T = \frac{(1-r)^2(1-a)}{1-r^2(1-a)^2}, \quad (13)$$

where r is the reflectivity, and a is the absorptivity of glazing.

When the incident beam is not polarized (i.e., the parallel and perpendicular components are equal) the over-all absorption and transmission are given by the A and T values.

2.1.4 Multiple glazing

The simplest case is that of a complete window system consisting of multiple elements separated by gas gaps. The most common is to calculate window system properties wavelength-by-wavelength at normal incidence, but they are equally valid if angle-dependent or polarization-dependent properties are available. A recursive procedure is carried out until the transmittance and reflectance of the entire glazing system has been determined. Simply determination the properties τ_i (transmissivity), r_i^f (frontal reflectivity), r_i^b (back reflectivity) of each element in the system as a function of wavelength is the standard practice (Rubin *et al.*, 1998) (ISO9050, 2003). Then for two elements i and j the net transmittance $T_{i,j}$, the front reflectance $R_{i,j}^f$ and back reflectance $R_{i,j}^b$ for the subunit are given by:

$$T_{i,j} = \frac{T_{i,j-1}T_j}{1 - R_{j-1,i}^b R_j^f} \quad R_{i,j}^f = R_{i,j-1}^f + \frac{T_{i,j-1}^2 R_j^f}{1 - R_{j-1,i}^b R_j^f} \quad R_{i,j}^b = R_j^b + \frac{T_j^2 R_{j-1,i}^b}{1 - R_{j-1,i}^b R_j^f}. \quad (14)$$

In the above equations, a single subscript refers to the property of a single glazing element whose properties have to be measured. By convention, the first element is outermost toward the Sun. Similarly, for triple glazing, the system properties can be calculated starting with the properties calculated for double-glazing above and the measured properties of the added third layer. The absorption \tilde{A}_j^f of each element as part of the stack can be calculated from values for the transmittance and reflectance of the surroundings substacks obtained from the Eq. (14) and from the external absorptance of the isolated elements A_j as follows:

$$\tilde{A}_j^f = \frac{T_{i,j-1}A_j^f}{1 - R_{j-1,i}^b R_{j,n}^f} + \frac{T_{i,j}R_{j+1,n}^f A_j^b}{1 - R_{j,i}^b R_{j+1,n}^f}, \quad (15)$$

where:

$$A_j^f = 1 - T_f - R_j^f \quad A_j^b = 1 - T_f - R_j^b. \quad (16)$$

The formulation can be extended to any multi layered glazing system. For example, to progress to triple and quadruple glazing. In all cases, one should calculate the absorption in each layer using the T and R values calculated in the previous steps. The final step should always be to calculate the relevant spectral and/or directional average properties as explained before in the section about the spectral average of optical properties. Figure 2 presents a typical multiple glazing.

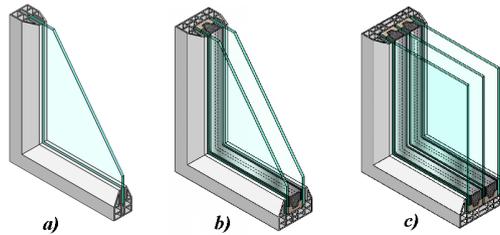


Figure 2. Typical single(a), double(b), and triple(c) pane glazing

3. METHODOLOGY

The aim of this study is to determine the angular optical properties for glazing systems using simple descriptors or windows performance indicators. The necessary steps to reach the target will be detailed.

3.1 The window descriptors or Simple window performance indicators

The window descriptors or windows performance indicators were introduced and operates by the National Fenestration Rating Council (NFRC) in United States as a voluntary program that tests, certifies, and labels windows, doors, and skylights based on their energy efficiency performance ratings. The code is used by the manufacturers and presented in the respective brochures to help to make a smarter selection of glazing systems.

3.1.1 Window overall heat transfer coefficient (U-value)

The U-value is the standard way to quantify overall heat flux. It expresses the total heat transfer coefficient of the system, and includes conductive, convective, and radiative heat transfer.

3.1.2 Window Solar Heat Gain Coefficient (SHGC)

It is defined as the fraction of incident solar radiation that actually enters a building through the entire window assembly as a heat gain.

3.1.3 Visible Transmittance (T_{vis})

It is the amount of light in the visible portion of the spectrum that passes through a glazing material. From those three performance indicators, it is possible obtain optical properties at normal incidence angle (Arasteh *et al.*, 2009). As normalized transmittance and reflectance can be determined as a function of incidence angle (Karlsson, 2001), it is possible obtain integrated radiative properties at all angle of incidence from the performance indicators. This process will be detailed in the next section.

3.2 Determine Angular Performance

The angular radiative properties of windows are important because during energy modeling, the solar incidence angles are usually fairly high. Angles of incidence are defined as angles from the normal direction extending out from the window. In general, angular radiative properties of a glazing system vary with the angle of incidence, and then with the number of layers and type of glazing, as shown in Fig. 3. The method developed for this procedure uses the window descriptors to determine the most probable composition of the window whether it is single, double, or triple glazed.

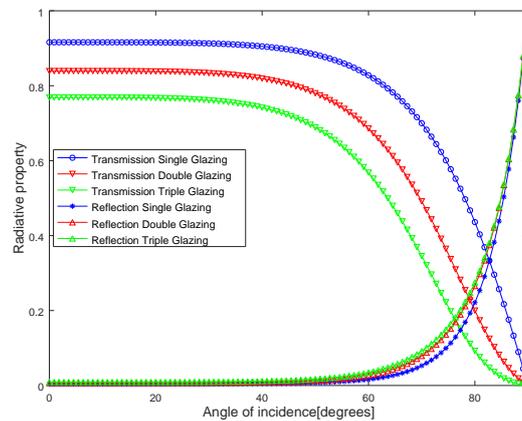


Figure 3. Radiative properties multiple glass

3.3 Computational procedure

In general, angular radiative properties of a glazing system vary with angle of incidence, and then with number of layers and type of glazing. The method developed for this procedure uses the windows descriptors to determine the most probable composition of the window: whether the window is single, double, or triple glazed. From this information, normalized transmission and reflectance are determined as a function of incidence angle (Karlsson, 2001). It is defined a normalized transmittance factor and a normalized reflectance factor. As noted in the beginning, all the angular correlations presented here were developed based on generic product solar transmission and reflection data available in The International Glazing Database (IGBD, 2017). For this work is used the same correlations for the angular correlations for visible transmittance and reflectance due to the fact that they are inherently similar (Arasteh *et al.*, 2009). In Fig. 4, it is shown a flow chart of the algorithm developed where the windows descriptors (U , SHGC, and T_{vis}) are the primal data to obtain the integrated optical properties at normal incident direction for the whole window $P_x(0)$, p is the number of panes and q the glazing category to define the angular profile for the whole window, $P_x(\theta)$ is the integrated radiative properties at all angles of incidence.

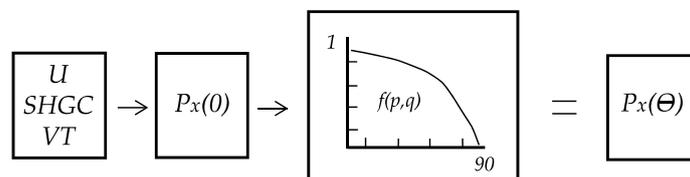


Figure 4. Algorithm flow chart

3.4 Preliminary results for clear glass

For this part, a 3 mm monolithic clear glass case denoted Type 1, illustrated in Fig. 2a, has the properties described in Tables 2 and 3.

Table 2. Type of Glazing.

	Number of panes	Glass Thickness (mm)	Coating position	Coating	Gas fill
Type 1	Single	3	none	None	None

Table 3. Single glazing system using windows descriptors.

Properties	U (W/m ² K)	SHGC	T _{vis}
Type 1	5.913	0.859	0.897

The calculated radiative properties at normal incident direction for this Type 1 glazing system are shown in Tab. 4.

Table 4. Radiative properties of glazing system at normal incidence angle, P_x(0).

	T _{sol}	R _{sol} ^f	R _{sol} ^b	T _{vis}
Type 1	0.835	0.072	0.072	0.897

Now the angular profile is determined using the radiative properties for normal angle of incidence P_x(0).

Table 5. Radiative properties of Type 1 glazing system at all incidence angle, P_x(θ).

Rad. Prop.	Angle of incidence [°]										
	0	10	20	30	40	50	60	70	80	90	Hemis.
T _{sol}	0.836	0.834	0.830	0.825	0.819	0.802	0.751	0.630	0.394	0.000	0.753
A ₁	0.088	0.090	0.094	0.097	0.097	0.098	0.106	0.115	0.099	0.000	0.100
R _{sol} ^f	0.074	0.074	0.074	0.0767	0.082	0.098	0.142	0.254	0.505	1.000	0.136
R _{sol} ^b	0.074	0.074	0.074	0.0767	0.082	0.098	0.142	0.254	0.505	1.000	0.136
T _{vis}	0.898	0.896	0.891	0.886	0.880	0.861	0.807	0.677	0.424	0.000	0.821

A comparison for a similar glazing system obtained with the LBNL software Windows 7.4 is provided in Table 6.

Table 6. Type 1 glazing system angular data.

Rad. Prop.	Angle of incidence [°]										
	0	10	20	30	40	50	60	70	80	90	Hemis.
T _{sol}	0.834	0.833	0.831	0.827	0.818	0.797	0.749	0.637	0.389	0.000	0.753
A ₁	0.091	0.092	0.094	0.096	0.100	0.104	0.108	0.110	0.105	0.000	0.101
R _{sol} ^f	0.075	0.075	0.075	0.077	0.082	0.099	0.143	0.253	0.506	1.000	0.136
R _{sol} ^b	0.075	0.075	0.075	0.077	0.082	0.099	0.143	0.253	0.506	1.000	0.136
T _{vis}	0.899	0.899	0.898	0.896	0.889	0.870	0.822	0.705	0.441	0.000	0.822

Source: LBNL WINDOW 7.4

Figure 5 clearly shows a good correlation of the results. Also it is presented the percentage error in Fig. 6, illustrating a maximal value for absorption of 5%, which is acceptable since this value is obtained from the difference of the sum of transmission and reflection and the error is propagated. Another important point is the good correlation between the hemispherical results, that is important because these values are widely used in energy modeling because they represent the overall angular behavior of radiative properties.

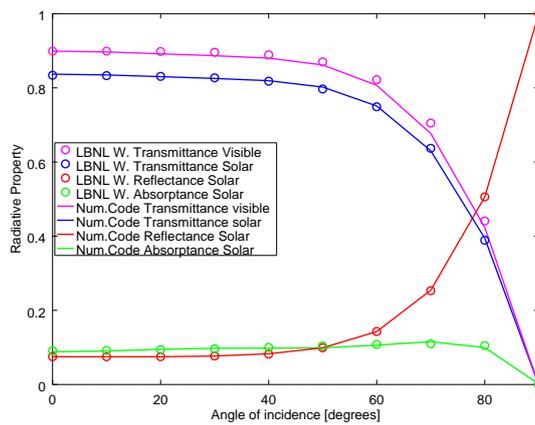


Figure 5. Results for radiative properties - Type 1

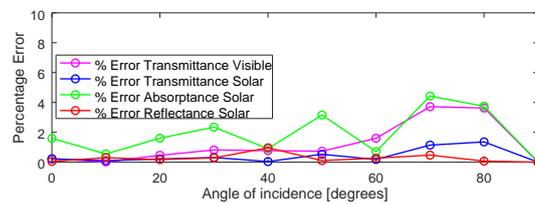
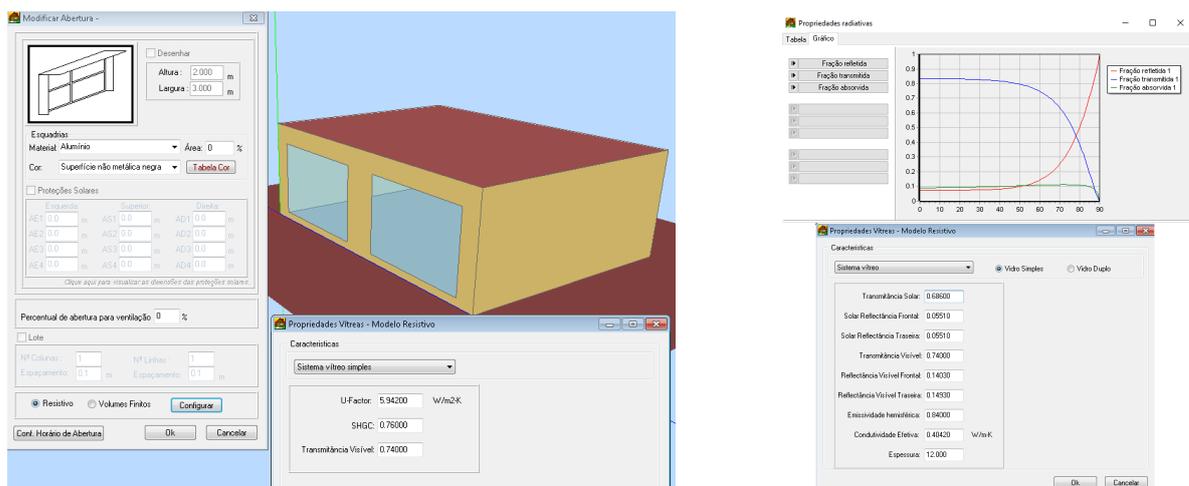


Figure 6. Percentage error - Type 1

3.5 Implementation in DOMUS

The algorithm was implemented in the software DOMUS using programming language C++ as is shown in the Figure 7. The graphic interface is nowadays in development for this reason the complete results will be presented as graphical using GNU Octave ver.4.0.0 (Eaton *et al.*, 2016) for the comparison with the data available in Windows and Daylighting Software (LBNL, 2017). The complete revision will be presented in the Results and discussion Section 5. It is also presented the building energy modeling using the software EnergyPlus 8.6.0 (Crawley *et al.*, 2000) to determine the thermal performance of window systems and to simulate the indoor conditions and energy savings because the building envelope and modeled glazing systems.



(a) Glazing system in DOMUS

(b) Optical properties in DOMUS

Figure 7. Screen view of Software DOMUS

4. DESCRIPTION OF BUILDING ENVELOPE AND GLAZING SYSTEMS FOR ENERGY MODELING

The basic test building (Fig. 8) is a rectangular single zone (8 m wide x 6 m long x 2.7 m high) with no interior partitions and 12m² of windows on the south exposure. The building is of lightweight construction with characteristics

as described below. For further details refer to Section 5.2.1 of ANSI/ASHRAE Standard 140-2011. The thermophysical properties of the materials used for the model are listed in Table 8, which correspond to the configuration of the low-mass enclosure described in the ANSI/ASHRAE Standard 140/2011 mentioned above.

4.1 Case 600 Test for Base Case Low Mass Building

This case was selected because the low mass building with extensive glazing has a high impact of the glazing systems. The glazing system proposed is defined as Type 1 to Type 4, where Type 1 is the monolithic clear glass with thickness of 3 mm, previously shown. Type 2 is double pane monolithic clear glass with thickness of 3 mm and air gap of 12.7 mm, which is similar to the glazing proposed in the Case 600; the Type 3 is also double pane monolithic clear glass with thickness of 3 mm and air gap of 12.7 mm but the surface 3 presents low-e coating of 0.137. Finally, the Type 4 is a triple pane monolithic clear glass with thickness of 3 mm and argon gap of 12.7 mm; the surface 2 and 5 present low-e coating of 0.033. The type of glazing system is presented in Table 11. Table 12 shows the same configuration of glazing using the windows descriptors or windows performance indicators. Tables 7 to 10 show the physical properties for enclosures, windows, and the other parameters as air infiltration and soil temperature.

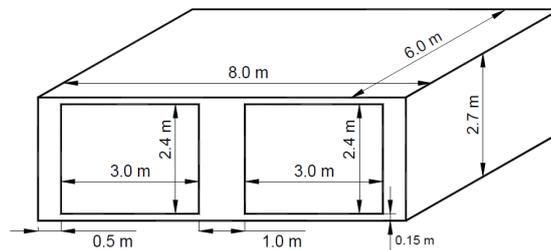


Figure 8. Base Building Case 600 - Isometric View of Southeast Corner with Windows on South Wall

Table 7. Case Description.

Case	Building structure	Heating and cooling
600	Plasterboard, insulation, wood	Heating if $T_{int} < 20^{\circ}\text{C}$, Cooling if $T_{int} > 27^{\circ}\text{C}$

Table 8. Specifications of opaque surfaces.

Surfaces	Thickness (m)	U-value ($\text{W}/\text{m}^2\text{K}$)
Wall	0.087	0.514
Roof	0.141	0.318
Floor	1.208	0.039

Table 9. Others parameters.

Infiltration	0.5 ACH
Internal load	200W continuous. 60% rad. 40% conv. 100% sens.
Mechanical system	100% convective air system. 100% efficiency.
Soil temperature	10°C. Continuous.

Table 10. Type of Glazings.

	Number of panes	Glass/air-gap Thickness (mm)	Coating position	Coating	Gas fill
Type 1	Single	3	None	None	None
Type 2	Double	3/12.7/3	None	None	Air
Type 3	Double	3/12.7/3	Surface 3	Low-E 0.137	Air
Type 4	Triple	3/12.7/3/12.7/3	Surface2/Surface5	Low-E 0.033	Argon

Table 11. Selected glazing systems using windows descriptors.

Properties	U (W/m ² K)	SHGC	T _{vis}
Type 1	5.913	0.861	0.861
Type 2	2.744	0.763	0.814
Type 3	1.863	0.717	0.752
Type 4	0.678	0.256	0.438

5. RESULTS AND DISCUSSION

This section is divided into two parts. The first one presents the results obtained using the algorithm developed for obtain the integrated angular radiative properties for glazing systems. The second part presents the results for the energy modeling and a comparison between the energy performance for annual heating and cooling loads due to the different glazing type.

5.1 Results for Radiative Properties

This section presents the comparison between the results obtained using the algorithm developed for obtain the angular radiative properties for glazing systems and the data available in the LBNL software Windows 7.4. The integrated radiative properties for Type 1, the monolithic 3mm clear glass were presented in the previous section Computational Procedure. Figure 9 presents the results for the Type 1 and Type 2 glazing systems; the continuous line is the developed numerical model and the circles are the discrete values obtained by the program LBNL Windows, which clearly shows a good match between the values in general. The increasing of the absorption in Type 2 is strongly influenced by the descend of transmission more than the little increasing of reflection. An interesting point is the comparison between the Type 2 and Type 3 because the two glazing have 2 panes with the same air gap. The coating surface affects directly all the radiative properties, improving the solar transmission performance. The absorption as expected is increasing. Finally, as expected, the window with triple glass and low-e coating presents the best performance because it allows a good transmission in the visual spectrum and an important decay in the solar transmission. The reflection is strongly affected by the coating. It can be observed that the numerical model allows to represent this property of high reflection. As expected to strongly dismantle the solar transmission and increase the reflection, the increase of the window's absorption is the greater, compared to the previous models. In the next sub section, it will be reviewed the energy behavior due to the use of each window and there should exist a certain correlation between the energy performance and the reduction of solar transmission. An important point to keep in mind is that the increase in absorption implies an increase in long-wave radiation heat transfer with both the interior and exterior environments. The reflected solar energy add an extra component of heat at the neighborhood and the increase of heat island effect. Meanwhile the increase of heating of the glazing clearly affect in the heat transfer by long-wave transmission in the interior, contributing to increase the zone average radiant temperature.

Table 12. Results for radiative properties of glazing system at normal incidence angle.

	T _{sol}	R _{sol} ^f	R _{sol} ^b	T _{vis}	A _{sol}
Type 1	0.834	0.075	0.075	0.899	0.083
Type 2	0.703	0.128	0.128	0.814	0.149
Type 3	0.596	0.159	0.149	0.752	0.168
Type 4	0.165	0.426	0.426	0.438	0.150

Table 13. Radiative properties of glazing system at normal incidence angle.

	T _{sol}	R _{sol} ^f	R _{sol} ^b	T _{vis}	R _{vis} ^f	R _{vis} ^b	A ₁	A ₂	A ₃	T _{UV}
Type 1	0.834	0.075	0.075	0.899	0.083	0.083	0.091			0.841
Type 2	0.703	0.128	0.128	0.814	0.149	0.149	0.096	0.072		0.738
Type 3	0.596	0.159	0.149	0.752	0.168	0.154	0.099	0.144		0.654
Type 4	0.165	0.426	0.426	0.438	0.150	0.150	0.310	0.020	0.076	0.299

Source: LBNL WINDOW 7.4

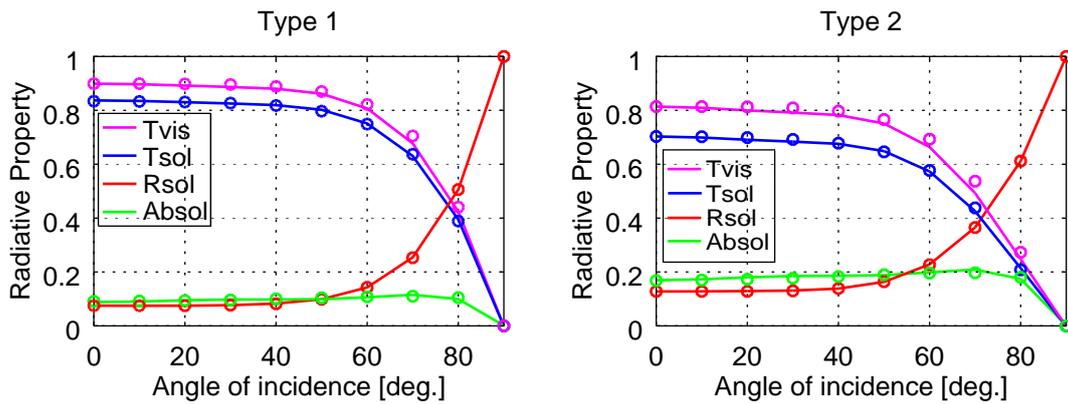


Figure 9. Results for angular radiative properties - Type 1 and Type 2

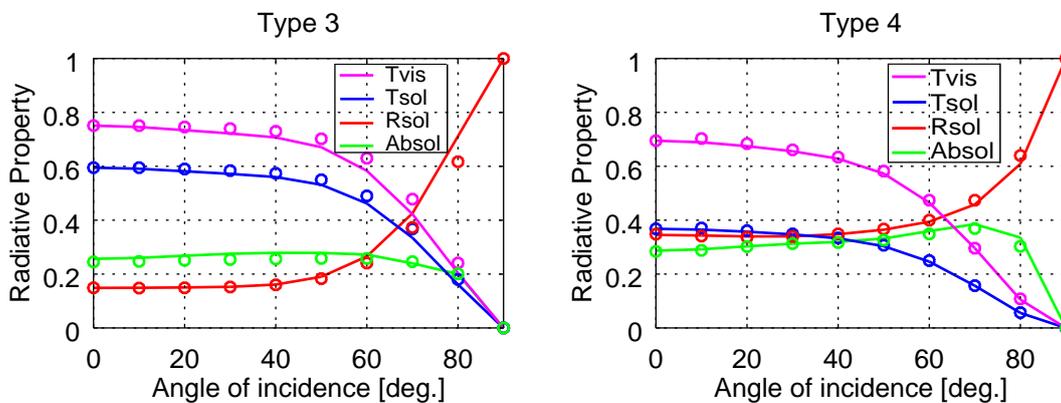


Figure 10. Results for angular radiative properties - Type 3 and Type 4

5.2 Results for Energy Modeling

In this second part, results for the energy modeling during a year using the methodology available in BESTest (Judkoff and Neymark, 1995) for the Case 600 are presented. As shown in the first part of this section, there is a clear improvement on the radiative properties that would imply better thermal performance of each glazing system. Now, it will be presented a comparison between the energy performance for annual heating and cooling loads due to different glazing types. Figure 11(a) presents the annual heating and cooling for the building defined as the case 600. In this figure, it is possible to observe the improvement of the saving energy both for heating and cooling. Figure 11(b) presents the percentage of heating and cooling saving for the simplest base case Type 1.

5.2.1 Results for Energy Modeling - Heating

For annual heating load the results present a consistent decreasing in the values, which is a clear improvement in terms of energy saving during the winter and cold days. In Figure 11(b) the comparison between the types of glazing using a base case Type 1 glazing is presented, showing how the percentage of saving is increased, but in Type 4 glazing (Triple pane) the difference between Heating and Cooling is not as marked as in the previous cases. For Type 2 (double pane with no coating), the annual heating saving is about 25%, while for Type 3, the saving is about 32%, and, for Type 4 43%.

5.2.2 Results for Energy Modeling - Cooling

For annual cooling load the behavior of the respective glazing systems is consistent with the results for heating, with a decrease of annual load, is shown in the Fig. 11(a), while the percentage of cooling load has an important improvement. The most relevant result is the low difference to percentage of saving between heating and cooling. The savings in cooling for the Type 2 glazing is a about 7%, while the savings for Type 3 is almost 16%. Finally, the main increase is showed by the Type 4, with 47% of savings.

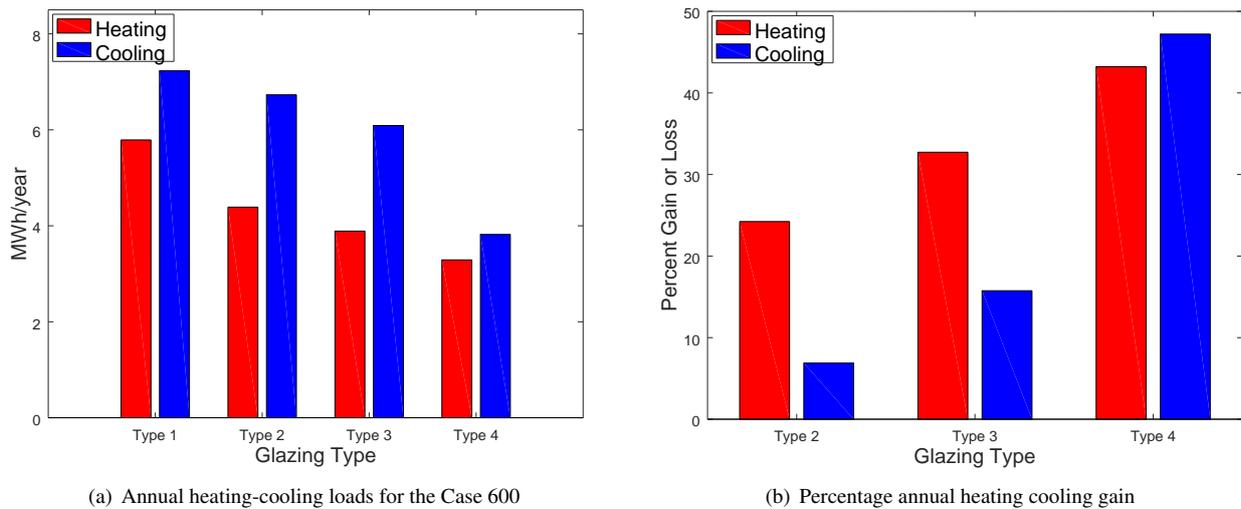


Figure 11. Results for annual heating-cooling loads for the Case 600 ANSI/ASHRAE Standard 140-2011

5.2.3 Final comments

The presented results for the optical modeling of complex glazing systems using simple descriptors have good agreement with the data with which they were compared. It is good to take into account that the methodology used is based on algorithms and programming present in the base of comparison (LBNL, 2017) so it is possible to affirm that the numerical modeling represents the physical phenomenon presented based on a program referenced as state of the art in vitreous systems.

6. CONCLUSIONS

The energy modeling for glazing systems is a complex task, but if the optical behavior of vitreous systems is directly related to energy modeling it is possible to obtain a physically consistent model. This was the motivation for this work. The windows descriptors sometimes are the only thing that is known about a window and it is necessary to develop a good methodology to use this data with the respective accuracy to input data in building simulation. Nowadays, the use of the windows descriptor to define glazing systems is generalized so that an approach to evaluate the use of this simple performance indicators is proposed in this work. The results clearly showed a good match between the numerical results and the available information recognized as reference in glazing evaluations. This work is part of an initial idea for the implementation of a program for energy evaluation of glazing systems in the software DOMUS, which uses a layer-by-layer window description format with a very detailed model with parameters with angular dependence of optical properties. Presently, DOMUS does not accept the use of these standard windows performance indicators and this could be an interesting improvement. In addition, to have a continuous algorithm to compute the angular dependence and not rely on discrete data that involves interpolation for inter-media values is also a substantial improvement. One important thing to take into account is that for a non-rigorous simulation it might be not imperative to know in details the spectral and the angular dependence of each optical parameter and it is complex to fill out the total data set for defined wavelength, angle of incidence and hemispherical values. Therefore the main purpose was simplifying the input of data for glazing systems keeping the accuracy in the results of each simulation as the correct use of the windows descriptors could minimize the error in case of unknowing about the radiative properties of glazing systems or wrong data filling for each radiative property as a function of wavelength interval and angular dependence. Finally, this work is based on a statistical approach and multi variable regression, and it is not totally equivalent to a detailed evaluation of a glazing system.

7. ACKNOWLEDGEMENTS

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