Solar Energy 141 (2017) 159–165

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Brief Note

Correlations for glazing properties and representation of glazing types with continuous variables for daylight and energy simulations

Louis Gosselin *, Jean-Michel Dussault

Department of Mechanical Engineering, Université Laval, Quebec City, Quebec, Canada

ARTICLE INFO

Article history:
Received 29 July 2016
Received in revised form 16 November 2016
Accepted 17 November 2016

Keywords:
Building design
Window
Energy simulation
Daylight

ABSTRACT

In daylight and energy simulations, fenestration products are characterized by their visible transmittance (VT) and solar heat gain coefficient (SHGC) that are both dependant on the angle of incidence, as well as by their U-value. In this work, 18 typical fenestration products suitable for the Canadian context were chosen and correlations between their actual properties were developed. First, it is shown that variations from a "standard" angular dependency curve for VT and SHGC are relatively small in such a way that the angular dependency can be approximated either by an average relation for all fenestration types, or by more precise correlations involving a linear combination of solutions with the use of a weigh coefficients. Then, relationships between values of normal VT, U-value and normal SHGC are established. In the end, it was possible to deduce the detailed behavior of all insulated glazing units (IGU) from only one continuous variable. A more precise approach with three continuous variables was also developed. A test case is presented to illustrate how to use the correlations to generate different types of IGUs in simulations.

1. Introduction

Choosing the best fenestration system for a given building façade can be quite challengeable. Windows provide the occupants with an access to daylighting, which has been shown to be beneficial for their productivity and well-being (Altomonte, 2009). On the other hand, too much daylight can cause visual discomfort (Altomonte et al., 2016). Furthermore, windows are often the weakest component of the envelope thermally speaking and managing solar heat gains is an essential aspect of building design. Choosing the best fenestration ratio and selecting the appropriate type of window requires a good balance between all these aspects. Literature shows that fenestration strongly influences building performance and that a good fenestration design can yield to significant savings (Florides et al., 2002).

Different studies have been performed to find the best window system for a given façade. Often, this work is done by considering only one type of glazing. For example, Goia (2016) optimized window-to-wall ratios (WWR) for an office building, but only one type of glazing was used. Similarly, Acosta et al. (2016) analyzed the impact of window size and position on building performance for one window type. The impact of WWR for a house was studied in Persson et al. (2006) for a fixed window. Sensitivity analysis and multi-objective optimization of windows were performed by Mangkuto et al. (2016) but the type of window was not varied. Catalina et al. developed a metamodel to predict monthly energy consumption of a building based on its architectural features, but window type was not included as a variable (Catalina et al., 2008).

The type of glazing can also be included as a parameter in design optimization, sensitivity analysis or metamodeling. Typically, this is done by selecting different IGUs among a predefined list, i.e. that the window type becomes a discrete variable. However, using discrete variables can complicate the sensitivity analysis and optimization, depending on the techniques that are used. Raji et al. tested the sensitivity of energy consumption with respect to glazing type and found that it was the second most influential parameter (Raji et al., 2016). A multi-objective optimization was performed by Delgarm et al. (2016) with the PSO technique. The type of glazing was optimized in that case. The design variables were the conductivity of the glazing, its solar transmittance and its visible transmittance, the first being continuous and the two latter, discrete. Discrete window types were used to optimize the building design with genetic algorithms (GA) by Tuhus-Dubrow and Krarti (2010).

Different ways to determine the detailed performance of fenestration from a small number of easily accessible parameters have been proposed, in particular when only limited information is available. LBNL introduced in 2009 the "Simple Glazing System"

* Corresponding author.
E-mail address: Louis.Gosselin@gmc.ulaval.ca (L. Gosselin).

http://dx.doi.org/10.1016/j.solener.2016.11.031
0038-092X/© 2016 Published by Elsevier Ltd.

Nomenclature

COG	center-of-glazing
G	solar radiation [W/m^2]
IGU	insulated glazing unit
q''	heat flux [W/m^2]
Q	net energy flux [kW h/m^2]
SHGC	solar heat gain coefficient
U	overall thermal transmittance [W/m^2 K]
VT	visible transmittance
x	weighting coefficient

Greek symbols

θ	incidence angle

Subscripts

D	direct
d	diffuse
hemis	hemispherical
n	normal incidence
net	net
VT	relative to visible transmittance
SHGC	relative to the solar heat gain coefficient

approach or "Block" model for Energy Plus simulations (Arasteh et al., 2009): based solely on U and SHGC values (and VT is needed), "fictitious" windows are generated. The U-value is used to assign an effective conductivity and thickness to a single layer representing the window in the simulation. Based on existing products, correlations between the solar transmittance and normal SHGC were found for different families of products. The angular dependency of SHGC and VT is deduced from normalized curves. Lyons et al. (2010) showed that this method provided satisfactory energy simulation results compared to the full spectral model. A study on the impact of windows on energy consumption is reported in Skarning et al. (2016) relying on this approach. Furthermore, the angular variation of fenestration properties was extensively studied by Karlsson and Roos (2000) and relations were proposed for the angular dependency of the solar energy transmittance.

The purpose of this paper is to develop correlations between center-of-glazing (COG) IGU properties and establish a way to represent existing IGUs with a small set of continuous variables. A total of 18 commercially available IGUs have been selected to include a broad range of products covering wide range of situations (i.e. different façade orientations, heating/cooling dominated buildings, etc.), while respecting today's expected level of performance and target price. Based on discussions with practice fenestration experts, they were considered as plausible IGUs for new Canadian buildings. Seven (7) IGUs are double glazing units, and eleven (11) are triple glazing. All glass panels are clear glass with a 6 mm thickness, and all gaps are 13.4 mm thick for the double glazing and 10.05 mm for the triple glazing. The gaps are filled with an air/argon mixture (10–90% respectively). A summary of the 18 IGUs is presented in Table 1. The main difference between them is the low-E films that are different and not necessarily applied on the same surface (faces are counted from the outside to the inside). The COG visible transmittance (VT) and the solar heat gain coefficient (SHGC) were extracted from the International Glazing Database (a well-known online database on properties of glazing products), as a function of the incidence angle. Similarly, the COG U-value of each IGU was also found in that database. Sections 2 and 3 present an analysis of the angular dependency of VT and SHGC, respectively, which is in line with the work in Arasteh et al. (2009) and Karlsson and Roos (2000). The empirical relation between $SHGC_n$ and VT_n is studied in Section 4. Next, these parameters are correlated with the U-value in Section 5. Finally, Section 6 presents a simple case study to illustrate how to use the correlations developed in this paper.

It should be mentioned that the message behind this paper is not that energy simulations should necessarily be performed with approximate window properties based on statistical correlations. Whenever the choice of IGU is already made in a project and that detailed data on its properties is available, it makes much more sense to use this data to calculate the exact building energy consumption or daylight illuminance. However, as explained above, there is a number of other situations (e.g., sensitivity analysis and design optimization during predesign) in which a convenient way to represent IGUs with continuous variables can prove to be useful.

Table 1
Composition of the IGUs considered in this study and main properties.

Id #	Number of glass panes	Face of low-E	Low-E emissivity	$SHGC_n$	VT_n	U [W/m^2 K]
1	2	3	0.148	0.694	0.736	1.65
2	2	3	0.068	0.592	0.762	1.48
3	2	3	0.034	0.47	0.694	1.42
4	2	2	0.034	0.383	0.694	1.42
5	2	2	0.029	0.646	0.646	1.36
6	2	2	0.019	0.277	0.616	1.36
7	2	2	0.021	0.226	0.502	1.36
8	3	5	0.148	0.603	0.658	1.19
9	3	5	0.068	0.529	0.679	1.14
10	3	5	0.034	0.439	0.619	1.08
11	3	2	0.034	0.353	0.619	1.08
12	3	2	0.029	0.33	0.578	1.08
13	3	2	0.019	0.257	0.551	1.08
14	3	2	0.021	0.211	0.451	1.08
15	3	2/5	0.334 /0.148	0.334	0.582	0.85
16	3	2/5	0.312/0.148	0.312	0.544	0.85
17	3	2/5	0.243/0.148	0.243	0.518	0.85
18	3	2/5	0.199	0.199	0.426	0.85