THERMAL AND OPTICAL ANALYSIS OF GLAZING SYSTEMS MANUFACTURED IN CYPRUS

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ABSTRACT

For the accurate determination of the building thermal load, it is very important to be able to determine the characteristics of fenestration products correctly. These are usually determined from handbooks without considering the size of the glass and the characteristics of the frame. In the present paper a survey of the available products, manufactured in Cyprus, is presented from which 14 typical glazing systems are obtained (7 windows and 7 doors). These glazing systems are analyzed with Therm v.5.2 and Window v.5.2 software and the thermal and optical characteristics are presented. Both programs are considered very accurate in performing this type of estimations. Thus with the present methodology, a more accurate estimation of the glazing coefficients is obtained. The results indicate that the new values calculated are 3-39% higher than the handbook values depending on the size of the glass. Also investigated are the effects of window size and use of wooden frames on the U-value.

Keywords: Thermal analysis, optical analysis, glazing systems

1. INTRODUCTION

Building fenestration is responsible for a major part of a building thermal (heating and cooling) load. For example for a typical house of 196 m^2 in area, the glazing is responsible for about 20-25% of the cooling and heating loads for a non insulated house, with single 20cm brick walls and 15cm concrete flat slab. Significant savings can result when low conductance and low transmittance window glazing is used. A saving in the annual cooling load of between 3000 and 5000 kWh can result on the same construction depending on the glazing type. The saving in annual cooling load for a well-insulated house may be as much as 24% when low-emissivity double-glazing windows are used. [1]. For the cooling load both the optical (solar heat gain coefficient and visual transmittance) and thermal (U-value) behaviour of fenestration are significant. It is therefore very important to be able to estimate the thermal load resulting from the fenestration products accurately.

2. SURVEY OF FENESTRATION SYSTEMS USED IN CYPRUS

In Cyprus most of the glazing systems are either single-glazed or double-glazed and are manufactured locally with imported glasses and aluminium sections. The optical characteristics and the U-value of these glazing systems are often obtained from information contained in handbooks but these values do not necessarily correspond to the locally produced products. In this case usually the frame of the windows is not taken into account, often resulting in a lower U-value. Also a single U-value is used depending on the type of glass, irrespective of its size and type of frame used. From a survey the available products, usually constructed in Cyprus, it was found that the most usual dimension for windows is 1200mm in width and 1500mm in height. For the doors the respective dimensions are 1000mm and 2000mm. With respect to the type of fenestration products, 7 typical glazing systems are identified. These include single clear glass, double clear glass with air in between, the same system with dividers and various types of double windows with reflective external glass and a mixture of two different gasses. The same construction types are considered for both windows and doors. These types are shown in Table 1.

Table 1 Window and door types considered

Type	Number of glasses	Type of glass, thickness (mm)	Frame	Dividers	Gas, thickness (mm)	Overall thickness (mm)
1	1	Clear, 6	No break	No	-	6
2	2	Both clear, 6	No break	No	Air, 12	24
3	2	Both clear, 6	No break	3H, 2V	Air, 12	24
4	2	Both clear, 3	No break	No	Argon, 12.7	18.7
5	2	Both clear, 6	No break	No	Mixture, 12.7	24.7
6	2	Inside clear Outside reflective	Break	No	Mixture, 12.7	24.7
7	2	Both clear, 6	Break	No	Air, 12	24

Notes: 1. Glass dimensions for windows: Width 1200mm, height 1500mm, double view
2. Glass dimensions for doors: Width 1000mm, height 2000mm, single view
3. Mixture composition: Air 5%, Argon 95%
4. For the dividers H=horizontal and V=vertical

3. ANALYSIS

The U-values of the fenestration products are usually obtained from handbooks. These values however are estimated by considering only the window type and do not take into account the size of the glass and the type of frame. Therefore the values obtained do not necessarily represent accurately the locally manufactured products. The U-values obtained for the products listed in Table 1 as obtained for the ASHRAE H/B of fundamentals [2] are shown in Tables 2 and 3 for windows and doors respectively. The general convention used in this paper is to symbolise the various window types with the letter "W" and the various doors with the letter "D" followed by a number corresponding to the various types of Table 1. As the usual type of windows encountered in Cyprus is of the sliding type, for the windows the values for fixed windows are used, whereas for the doors the openable type was used. The problem faced when using values from handbooks is that the exact product cannot be found from the H/B tables. For example, instead of 6mm glass for type 1, the values for 3mm were used and instead of 12mm air gap for type 2 the values for 12.7mm was used.

Table 2 Window properties as obtained from Ref. [2]

Type	Number of glasses	U-value (W/m^2K)	SHGC	VT
W1	1	6.42	0.74	0.79
W2	2	3.61	0.63	0.69
W3	2	3.61	0.63	0.69
W4	2	3.47	0.69	0.72
W5	2	3.47	0.63	0.69
W6	2	3.08	0.46	0.42
W7	2	3.22	0.63	0.69

Notes: 1. SHGC=solar heat gain coefficient
2. VT=visual transmittance

Table 3 Door properties as obtained from Ref. [2]

Type	Number of glasses	U-value (W/m^2K)	SHGC	VT
D1	1	7.24	0.71	0.75
D2	2	4.62	0.61	0.66
D3	2	4.62	0.61	0.66
D4	2	4.49	0.67	0.69
D5	2	4.49	0.61	0.66
D6	2	3.30	0.44	0.40
D7	2	3.42	0.61	0.66
Notes: 1. SHGC=solar heat gain coefficient 2. VT=visual transmittance				

For the present work the glazing systems shown in Table 1 are also analyzed with Therm v.5.2 [3] and Window v.5.2 [4] software both thermally and optically. Both programs are developed by the Lawrence Berkeley Laboratory for the Department of Energy (USA) and are considered very accurate in performing this type of estimations. A finite element method is used by the Therm program to evaluate the heat transfer through the frame and an area-weighted method is used for the optical and thermal characteristics of glass by the Window program, dividing the glass into areas such as centre-of-glazing, divider edge and edge-of-glazing.

The following equation is given in Ref. [2] for calculating the energy flow through a fenestration product (assuming no humidity difference):

$$q = U_t A_{pf}(t_{out} - t_{in}) + (SHGC_t * A_{pf} * E_t) + \left(60(AI.A_{pf})\rho c_p (t_{out} - t_{in})\right) \quad (1)$$

Where:
q = instantaneous energy flow, W/m^2
U_t = overall coefficient of heat transfer (U-factor), W/m^2-°C
t_{in} = interior air temperature, °C
t_{out} = exterior air temperature, °C
A_{pf} = Total projected area of fenestration, m^2
$SHGC_t$ = overall solar heat gain coefficient, non-dimensional
E_t = incident total irradiance, W/m^2
AI = Air infiltration rate at current conditions in l/s-m^2, not test conditions
ρ = Air density, kg/m^3
c_p = Specific heat of air, kJ/kg-°C

In Window v.5.2 software the total fenestration product properties for U-factor, solar heat gain coefficient (SHGC) and visual transmittance (VT) are based on an area-weighted average of the product's components properties which are:

- The centre-of-glazing properties of the glazing system
- The frame
- The edge-of-glazing
- Divider
- Divider edge-of-glazing

These are shown schematically in Fig. 1.

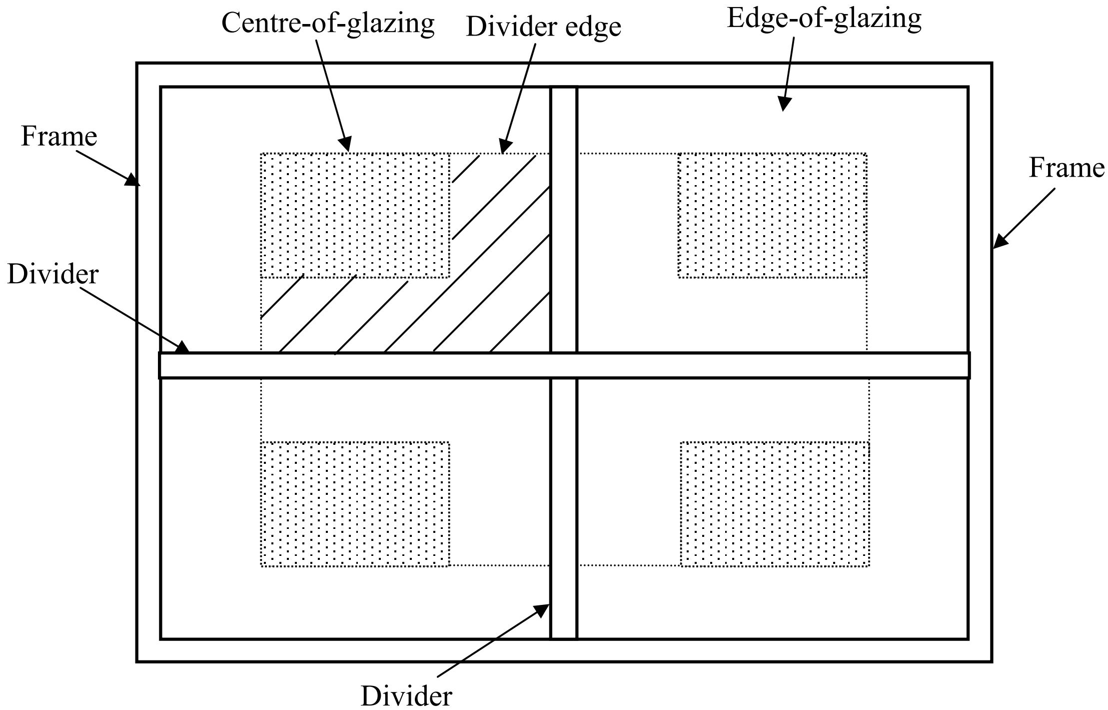

Fig. 1 Components for the whole product area-weighted calculation

This procedure is according to NFRC 100 [5]. The equation for the U-value is given by:

$$U_t = \frac{\left[\sum(U_f A_f) + \sum(U_d A_d) + \sum(U_e A_e) + \sum(U_{de} A_{de}) + \sum(U_c A_c)\right]}{A_{pf}} \qquad (2)$$

Where:
U_t = Total product U-factor, W/m^2-°C
U_f = Frame U-factor, W/m^2-°C
A_f = Frame area, m^2
U_d = Divider U-factor, W/m^2-°C
A_d = Divider area, m^2
U_e = Edge-of-glazing U-factor, W/m^2-°C
A_e = Edge-of-glazing area, m^2
U_{de} = Divider edge U-factor, W/m^2-°C
A_{de} = Divider Edge Area, m^2
U_c = Center-of-glazing U-factor, W/m^2-°C
A_c = Center-of-glazing area in m^2

All the transparent regions (center-of-glazing, edge-of-glazing, and divider edge) have the same solar heat gain coefficient (SHGC). Once the SHGC of the opaque elements is determined the total SHGC is calculated as the area-weighted average of the SHGC through the transparent and the opaque portions of the fenestration product as:

$$SHGC_t = \frac{\left[(SHGC_f A_f) + (SHGC_d A_d) + (SHGC_e A_e) + (SHGC_{de} A_{de}) + (SHGC_c A_c)\right]}{A_{pf}} \qquad (3)$$

Where:
$SHGC_t$ = Total product SHGC, dimensionless
$SHGC_f$ = Frame SHGC, dimensionless
$SHGC_d$ = Divider SHGC, dimensionless
$SHGC_e$ = Edge-of-glazing SHGC, dimensionless
$SHGC_{de}$ = Divider edge SHGC, dimensionless
$SHGC_c$ = Center-of-glazing SHGC, dimensionless

The whole-product area weighted visible transmittance (VT) calculation is:

$$VT_t = \frac{\left[(VT_f A_f) + (VT_d A_d) + (VT_e A_e) + (VT_{de} A_{de}) + (VT_c A_c)\right]}{A_{pf}} \quad (4)$$

Where:
VT_t = Total product VT (dimensionless)
VT_f = Frame VT (dimensionless)
VT_d = Divider VT (dimensionless)
VT_e = Edge-of-glazing VT (dimensionless)
VT_{de} = Divider edge VT (dimensionless)
VT_c = Center-of-glazing VT (dimensionless)

It should be noted that for opaque components the component visible transmittance (VT_f , VT_d) is zero. In this category belong all known frames and dividers.

Thus with the present methodology, a more accurate estimation of the glazing coefficients is obtained. The results are presented in Tables 4 and 5 for windows and doors respectively.

Table 4 Window properties obtained by the Window 5.2 program

Type	U-value (W/m^2K)	SHGC	VT	% difference
W1	6.764	0.730	0.700	5.3
W2	4.583	0.638	0.622	26.9
W3	5.021	0.602	0.564	39.1
W4	4.480	0.688	0.645	29.1
W5	4.381	0.640	0.622	26.3
W6	3.392	0.434	0.374	10.1
W7	3.519	0.598	0.622	9.3

Table 5 Door properties obtained by the Window 5.2 program

Type	U-value (W/m^2K)	SHGC	VT	% difference
D1	6.445	0.746	0.738	3.9
D2	4.167	0.650	0.656	15.4
D3	3.641	0.560	0.551	8.6
D4	4.057	0.702	0.680	16.9
D5	3.950	0.652	0.656	13.8
D6	3.188	0.443	0.395	3.5
D7	3.324	0.618	0.656	3.2

The results indicate that the new values calculated are 3-39% higher than the handbook values depending on the size of the glass. Also investigated are the effects of the use of wooden frames and window size and on U-values. The effect of the wooden frame is shown in Table 6. As can be seen the use of wood instead of aluminium frames employed in the cases above decrease the U-value considerably by as much as 39%. The effect of window size is shown in Table 7. As can be seen the effect of the window size on U-value is minimal with U-values increasing slightly when the area decreases.

Table 6 Effect of wood frame

Type	U-value (W/m^2K)	SHGC	VT	% difference
Window	2.784	0.544	0.588	39.2
Door	2.744	0.575	0.629	34.1
Notes: 1. In both cases glazing #2 is considered 2. % difference with respect to U-values shown in Tables 5 and 6				

Table 7 Effect of window size

Width (mm)	Height (mm)	Area (m^2)	U-value (W/m^2K)	SHGC	VT	% difference
1200	1500	1.8	4.583	0.638	0.622	-
1000	1500	1.5	4.815	0.631	0.602	+5.1
1500	1500	2.25	4.352	0.646	0.643	-5.1
1200	2000	2.4	4.428	0.642	0.635	-3.4
Notes: 1. Window #2 is considered in analysis 2. % difference with respect to U-value shown in Table 5						

4. CONCLUSIONS

The characteristics of fenestration products are usually determined from handbooks without considering the size of the glass and the characteristics of the frame. In the present paper a survey of the available products manufactured in Cyprus is presented and 14 typical glazing systems are examined (7 windows and 7 doors). These glazing systems are analyzed with Therm v.5.2 and Window v.5.2 software and the thermal and optical characteristics are presented. Both programs are considered very accurate in performing this type of estimations. Thus with the present methodology, a more accurate estimation of the glazing coefficients is obtained. The results indicate that the values calculated are 3-39% higher than the handbook values depending on the size of the glass. Also investigated are the effects of the use of wooden frames and window size on the U-value. Wooden frames decrease the U-value considerably by as much as 39%. The effect of the window area on the U-value is minimal with values increasing when the area decreases.

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