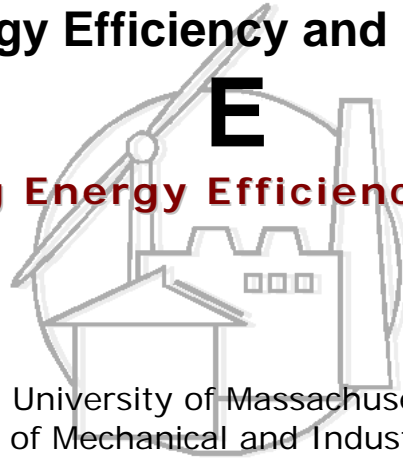


Center for Energy Efficiency and Renewable Energy

C E E R E

Building Energy Efficiency Program



University of Massachusetts
Department of Mechanical and Industrial Engineering
160 Governor's Dr.
Amherst, MA 01003-9265

COMPONENT MODEL APPROACH IN MODELING NON-RESIDENTIAL FENESTRATION PRODUCTS

Prepared by: Dr. Charlie Curcija

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INTRODUCTION

The model presented in this document enables the rating of components, as well as rapid generation of total product thermal performance from arbitrary selection of frame, spacer and glazing components. The performance is calculated for arbitrary size, allowing for generation of accurate information for annual energy analysis and peak load prediction. Using this procedure, thermal transmittance (U-factor), solar heat gain coefficient (SHGC) and visible transmittance (VT) can be determined.

DESCRIPTION OF THE METHOD

Component model approach is based on the assumption that the performance of the frame components, and IGU, including spacer variations, can be modeled separately and then “put” together using interpolating curves. Investigation of the relations for glazing system (i.e., center of glass performance) and size of the product, indicate nearly linear relationship, which enables determination of the overall U-factor (or SHGC and VT) for an arbitrary size of the product using linear interpolation. Also, the performance of the overall product with different glazing systems can be described with linear relationship, which enables determination of the overall product performance for an arbitrary glazing system, by knowing its performance with two glazing options at the opposite end of the thermal performance (i.e., “Best” and “Worst” IGU). In addition, spacer effects on the overall indices show logarithmic relationship when considered in terms of the effective conductivity of spacers, so the spacer effects can be calculated by modeling spacer options at the opposite end of the thermal performance (i.e., “Best” and “Worst” spacers). These options can be modeled in conjunction with each other, creating the total of four “Best/Worst” or “B/W” options (i.e., if using b and w for glazing and 1 and 2 for spacers, we have the following four options: b1, b2, w1, w2)

Figures 1 to 3 show relationship of center of glass performance (i.e., denoted by 100% vision area) to the total product performance, and it is evident that the curves are nearly linear. The largest departure from the linear relationship can be seen for U-Factors, however, these departures are still very small as can also be seen from the Figure 4, which show linear fit and regression coefficients being around 0.997.

Further on, to accomplish true component based approach, the methodology has been scaled down to a most common denominator, which is single cross-section assembly. In this approach, individual cross section assemblies are rated and this information is later used to assemble finished product, which may be simple fixed, single lite window, or it can be complex composite window consisting of several basic window shapes (e.g., two casement windows side by side with fixed window over them). This approach allows manufacturers to individually rate thermal performance of their basic assemblies and to re-use them in any combination that may occur. It is common practice by non-residential manufacturers to use some of their assemblies not only in various composite and combination windows, but also in different product lines. In this way, the rating of their products is simplified and streamlined.

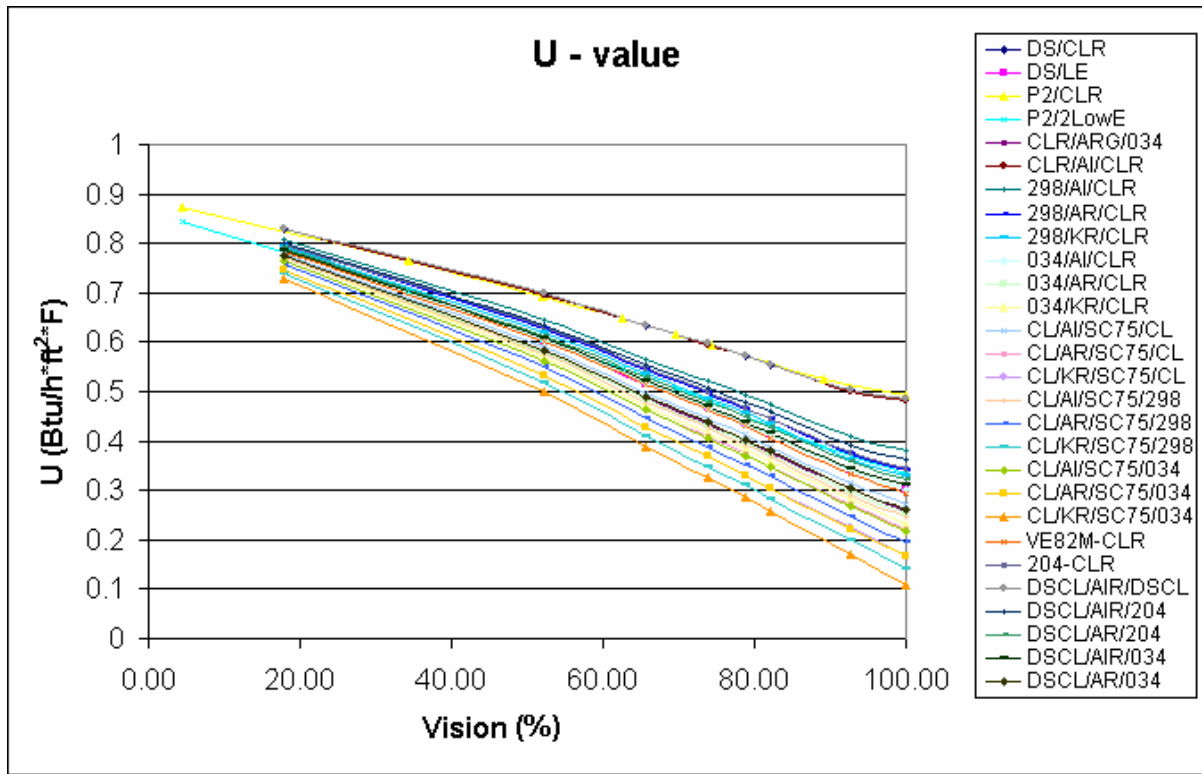


Figure 1: Variation of U - value with Vision Percentage

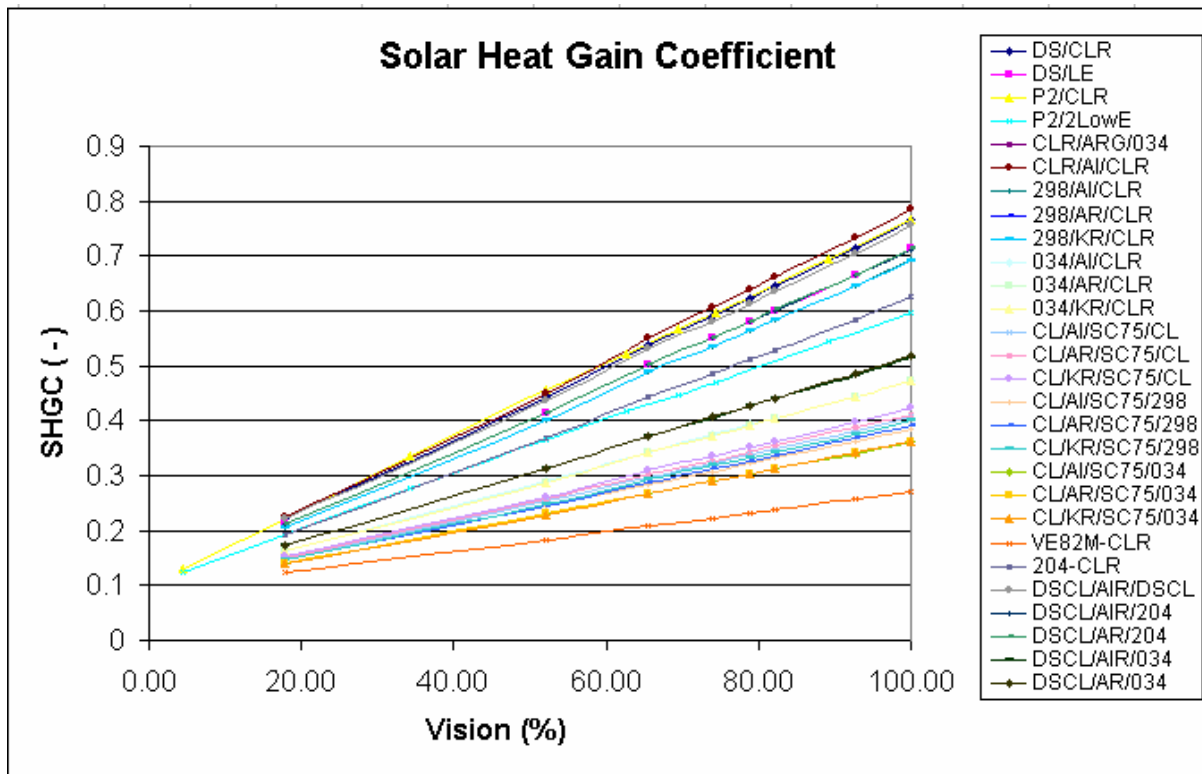


Figure 2: Variation of Solar Heat Gain Coefficient with Vision Percentage

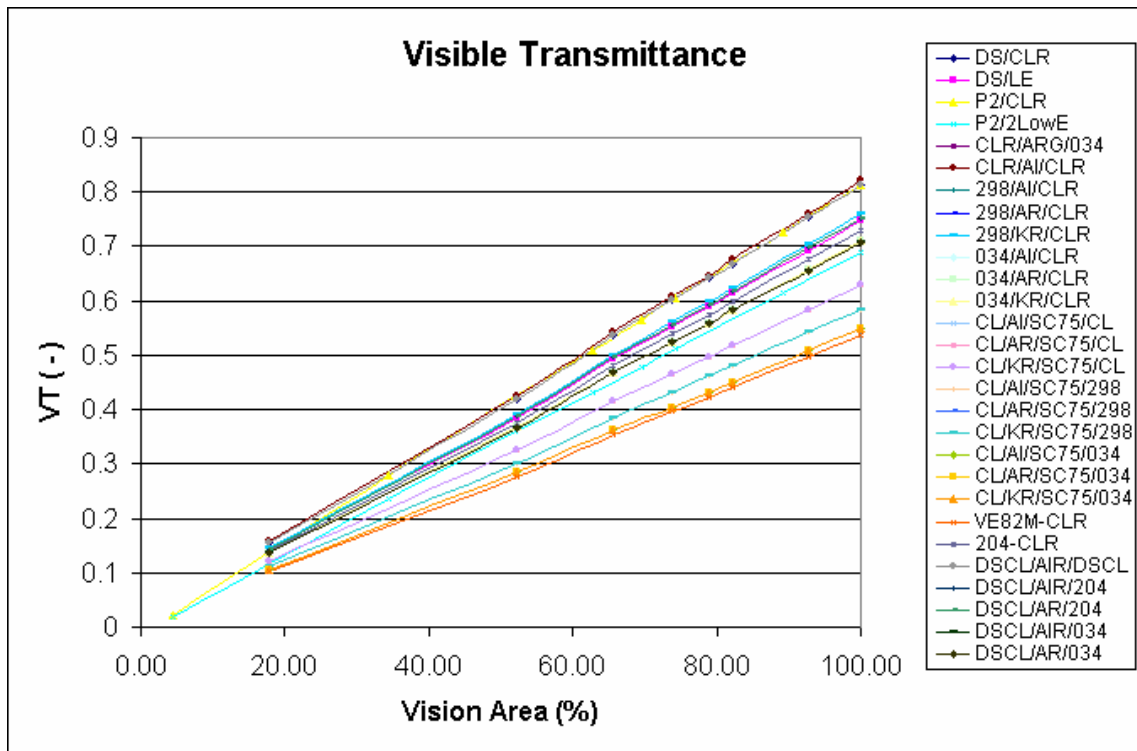


Figure 3: Variation of Visible Transmittance with Vision Percentage

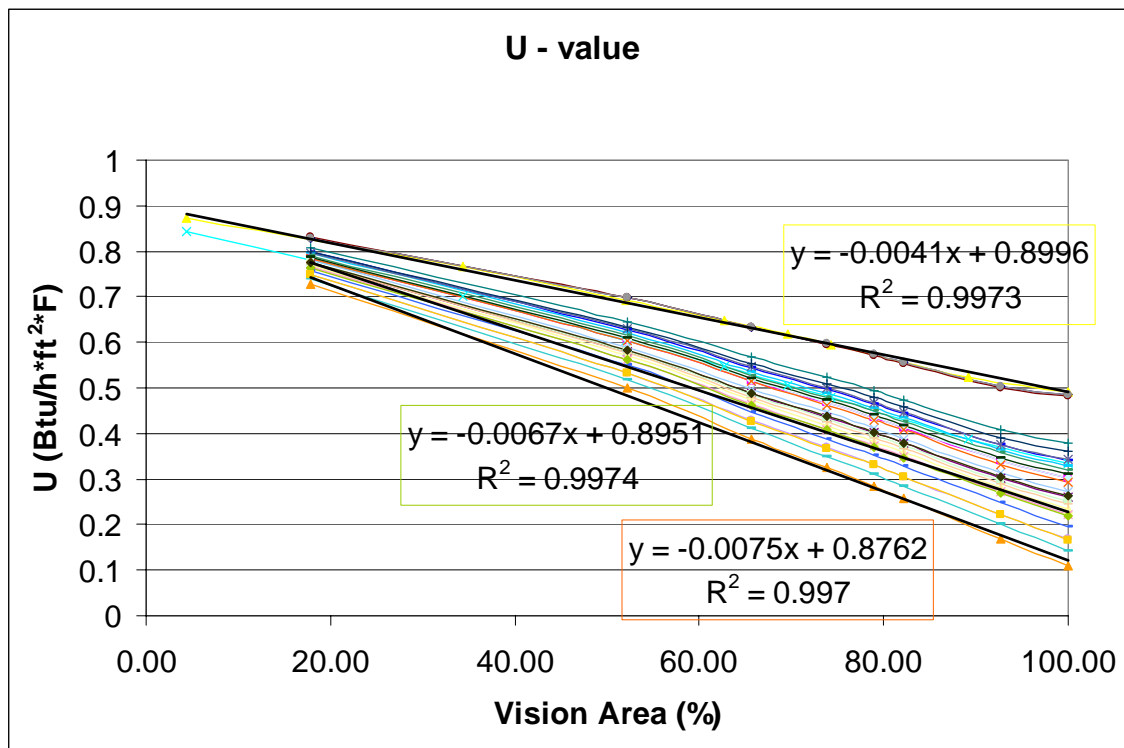


Figure 4. Linear fit and regression coefficients for U-factor curves

In order to analyze spacers, it was necessary to calculate their effective conductivity, k_{eff} , and to use that number to express their thermal performance. The calculation of k_{eff} of the spacer assembly was done according to the following procedure:

1. Overall U – value of individual spacer was calculated using THERM 5, using the standard NFRC boundary conditions

Exterior surface

NFRC 100-2002 Exterior (t = - 0 F, $h_o = 4.578 \text{ Btu/h} \cdot \text{ft}^2 \cdot \text{F}$, blackbody radiation)

Interior surface

Default interior (combined) (t = 70 F, $h_i = 1.408 \text{ Btu/h} \cdot \text{ft}^2 \cdot \text{F}$)

2. From the electrical analogy of heat transfer mechanism :

$$R_{tot} = \frac{1}{U} = \frac{1}{h_o} + \frac{L}{k_{eff}} + \frac{1}{h_i} \quad (1)$$

k_{eff} can be determined as :

$$k_{eff} = \frac{L}{R_{tot} - \frac{1}{h_o} - \frac{1}{h_i}} \quad (2)$$

where :

- $L =$ spacer length,
- $R_{tot} =$ overall thermal resistance of considered spacer,
- $h_o =$ outside heat transfer coefficient,
- $h_i =$ inside heat transfer coefficient,

Figure 5 show the example of possible spacer configurations, including two fictitious entries, representing low-end (high thermal conductance) and high-end limit (low thermal conductance). Figures 6 to 8 show relationship of major indices to the k_{eff} of spacer configurations.

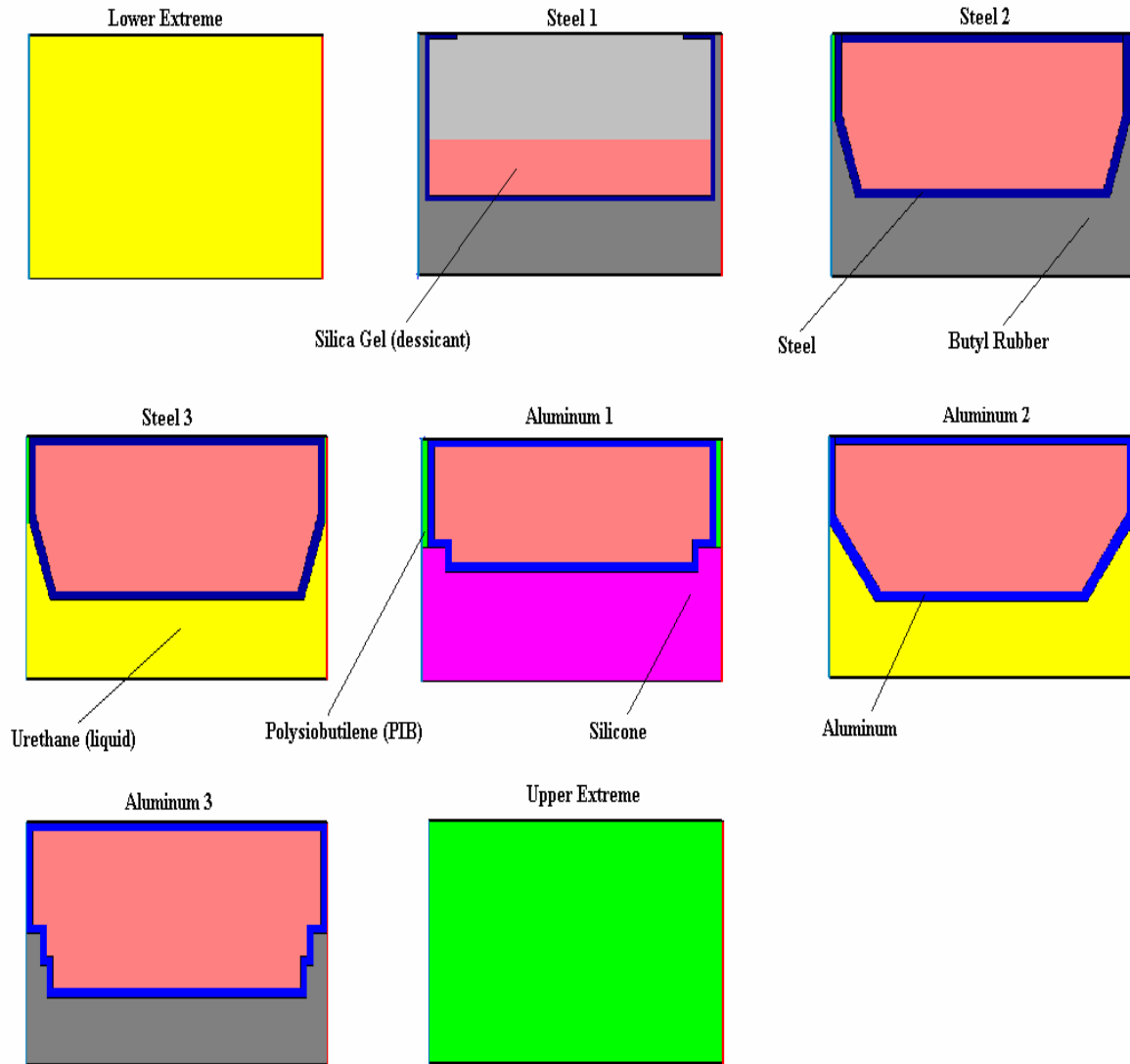


Figure 5. Example of spacer configurations

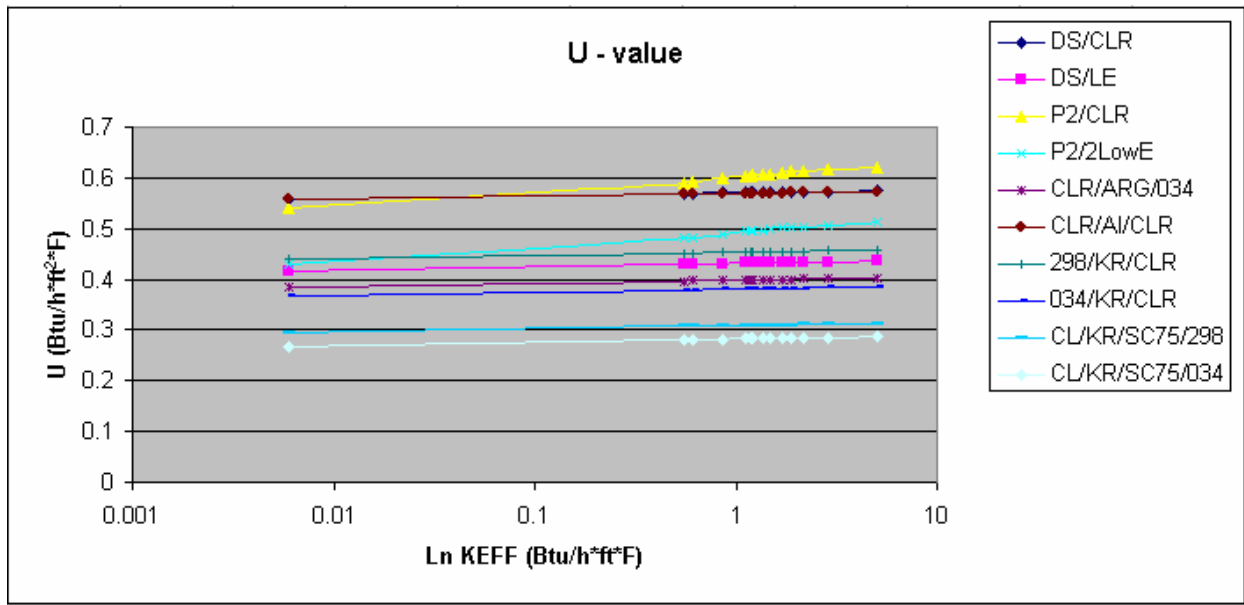


Figure 6: Variation of U-factor with k_{eff}

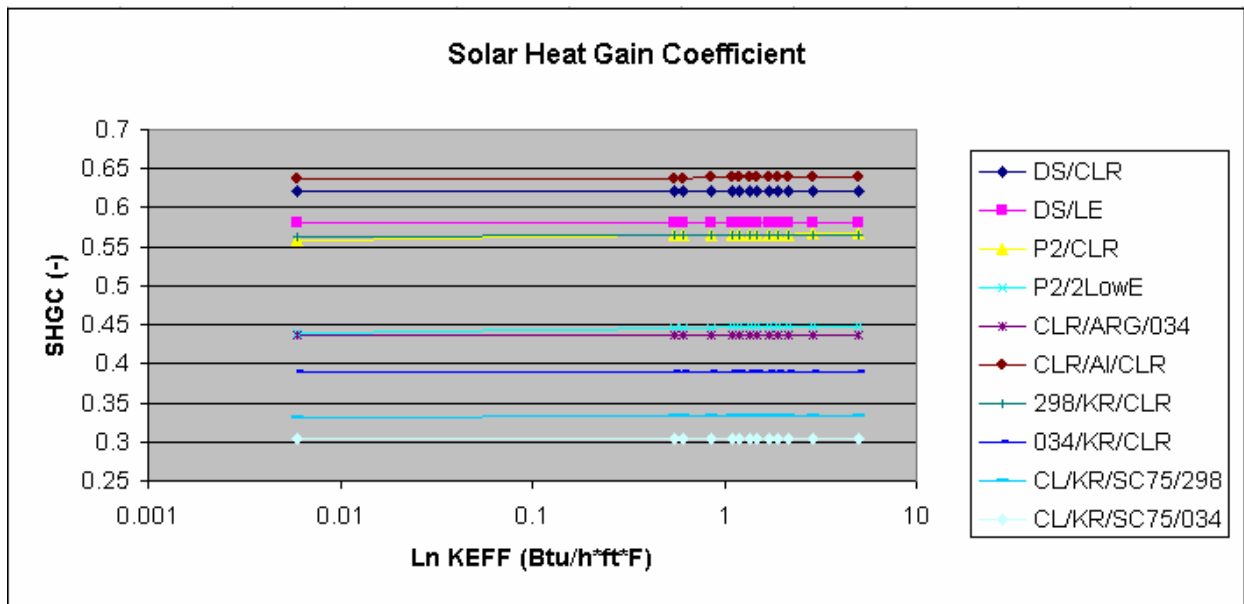


Figure 7: Variation of Solar Heat Gain Coefficient with k_{eff}

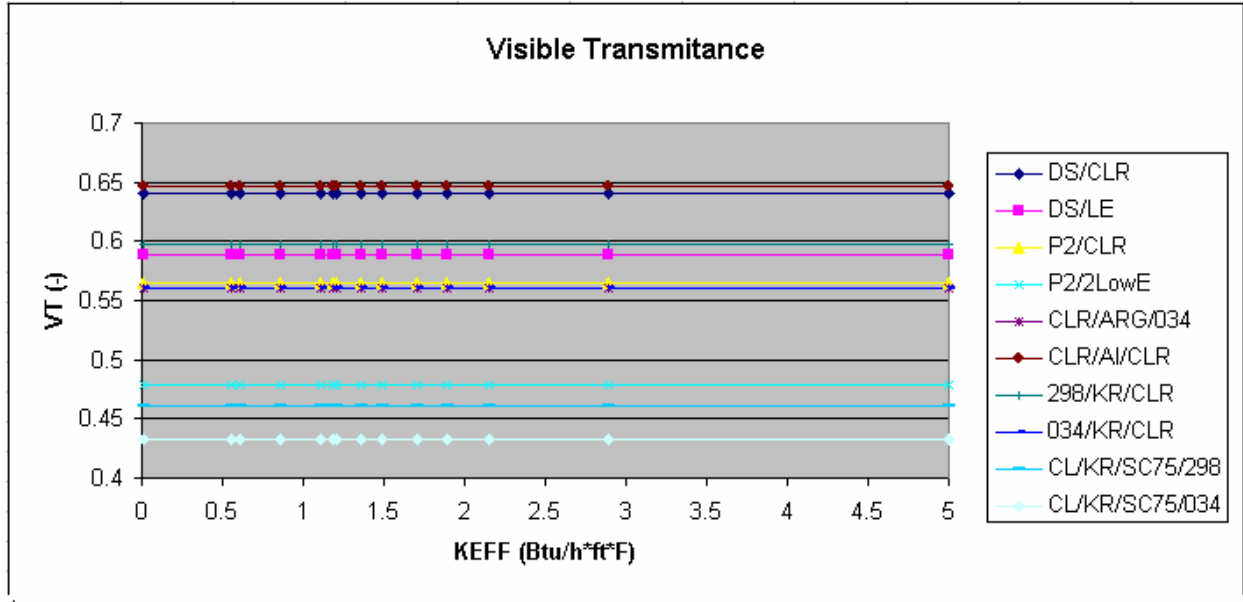


Figure 8: Variation of VT (Visible Transmittance) with k_{eff}

With the exception of VT, the relationship between spacer type and width on the overall product performance can be described with the logarithmic function. For VT, this relationship is linear.

MATHEMATICAL APPROACH

Based on the relationships shown above, U-factor of a particular window, U , (defined by a unique frame cross section and spacer type), is calculated as a function of four parameters; 1) center of glass U-factor, U_c of a window for which the U-factor is being sought; 2) U-factor of a window with the “worst” IGU, U_w ; 3) U-factor of a window with the “best” IGU, U_b ; and 4) size of a window for which U-factor is being sought, being determined by a vision percentage, V , which in turn is calculated from the overall width and height of the window. The following equation describes this relationship:

$$U = U_b + \frac{(U_w - U_b) \cdot (U_c - U_{c,b})}{U_{c,w} - U_{c,b}} + \frac{\left(U_c - U_b + \frac{(U_w - U_b) \cdot (U_c - U_{c,b})}{U_{c,w} - U_{c,b}} \right) \cdot (V - V_1)}{100 - V_1} \quad (3)$$

where:

- U_w = U factor of a window with standardized dimensions, (i.e., 24 in. x 24 in.), incorporating “worst” IGU, determined from equations that follow
- U_b = U factor of a window with standardized dimensions, incorporating “best” IGU, determined from equations that follow
- $U_{c,w}$ = center of glass U value for the “worst” IGU,
- $U_{c,b}$ = center of glass” U value for the “best” IGU,

- $U_c =$ “center of glass” U value for requested IGU,
- $V_I =$ Vision percentage of a window with standardized dimensions,
- $V =$ Vision percentage of a window with requested dimensions. Vision percentage is calculated from the following equation:

$$V = \frac{A_v}{A} \cdot 100 \quad (4)$$

where:

- $A_v =$ Vision area, calculated as:

$$A_v = A - \sum_i A_{f,i} \quad (5)$$

- $A_{f,i} =$ Individual frame areas:
- $A =$ Total product area

$$A = a \cdot b \quad (6)$$

where:

- $a =$ total window width
- $b =$ total window height

Note: “Worst” and “best” IGUs are the two extreme glazing options

SHGC i VT of a particular window with standardized dimensions, are calculated in the same manner as U-factor above.

U, SHGC, and VT vs. vision percentage for three arbitrary glazing options are compared with correspondent graphs obtained from interpolation algorithm and results are plotted in Figures 9 to 11.

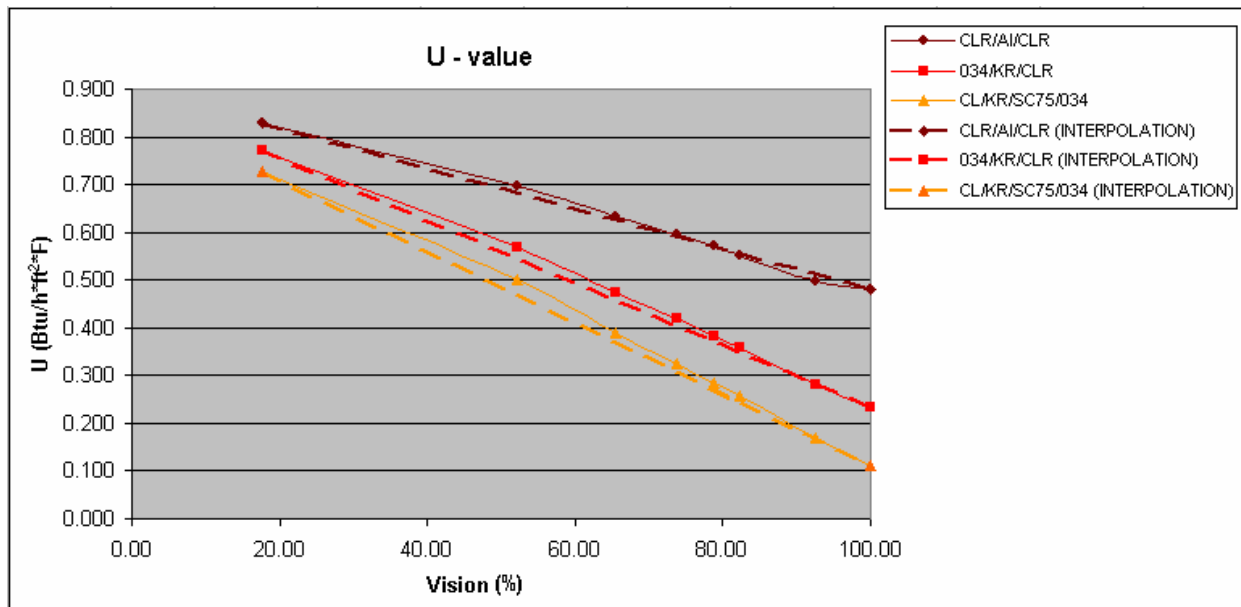


Figure 9: Variation of U factor with Vision Percentage

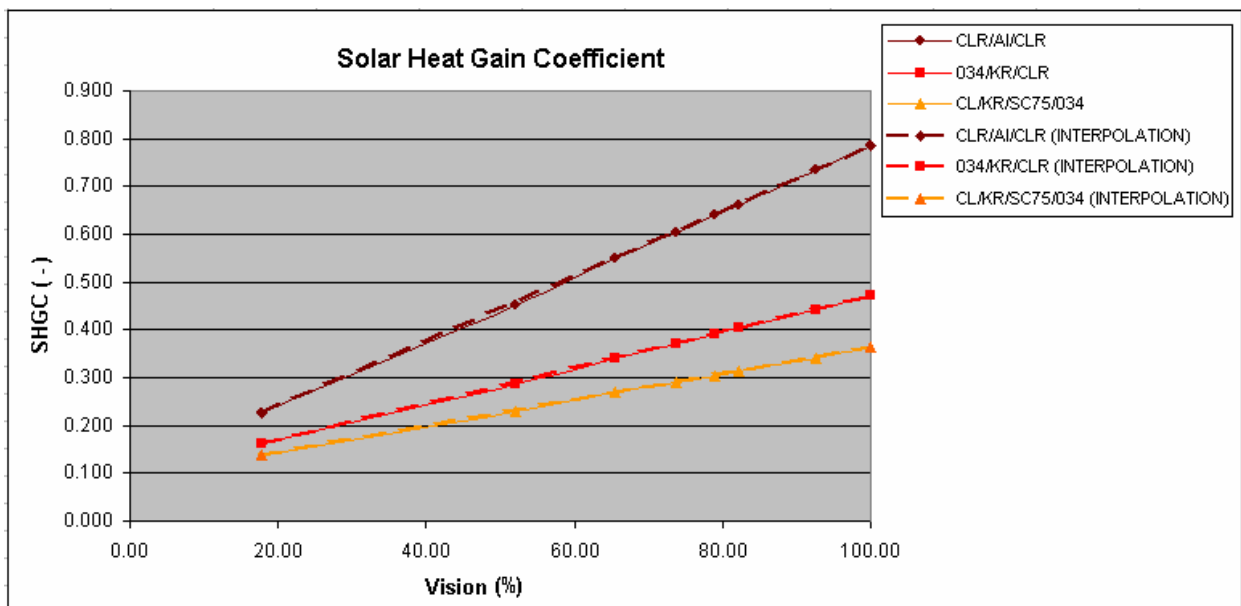


Figure 10: Variation of SHGC with Vision Percentage

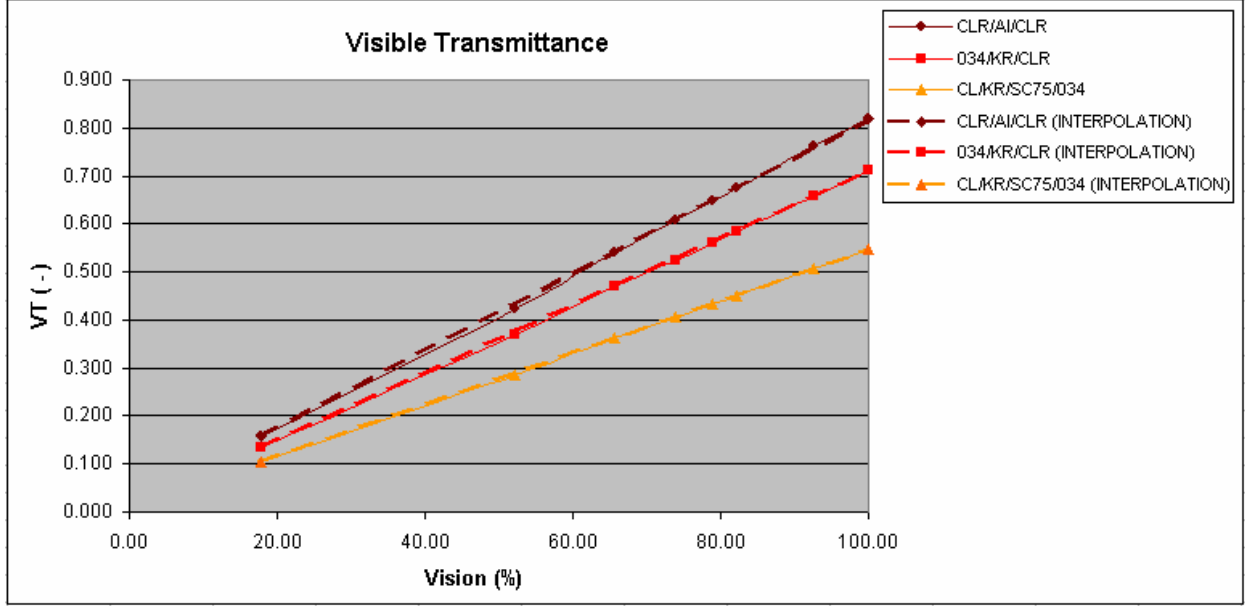


Figure 11: Variation of VT with Vision Percentage

The total window indices for the window with given spacer assembly are calculated from the calculated performance of the same window with the low and high end spacer and IGU configurations, using the following two formulas:

$$U_w = U_{w1} + \frac{(U_{w2} - U_{w1}) \cdot [\ln(k_{eff}) - \ln(k_{eff1})]}{\ln(k_{eff2}) - \ln(k_{eff1})} \quad (7)$$

$$U_b = U_{b1} + \frac{(U_{b2} - U_{b1}) \cdot [\ln(k_{eff}) - \ln(k_{eff1})]}{\ln(k_{eff2}) - \ln(k_{eff1})} \quad (8)$$

where:

- U_{w1} = U-factor of window with standardized dimensions, “worst IGU” and “best spacer” (i.e., lowest conducting spacer assembly or lowest k_{eff}),
- U_{w2} = U-factor of window with standardized dimensions, “worst IGU” and “worst spacer” (i.e., highest conducting spacer assembly or highest k_{eff}),
- U_{b1} = U-factor of window with standardized dimensions, “best IGU” and “best spacer” (i.e., lowest conducting spacer assembly or lowest k_{eff}),
- U_{b2} = U-factor of window with standardized dimensions, “best IGU” and “worst spacer” (i.e., highest conducting spacer assembly or highest k_{eff}),
- k_{eff1} = effective conductivity of the “best spacer”
- k_{eff2} = effective conductivity of the “worst spacer”
- k_{eff} = effective conductivity of the requested spacer.

U_w and U_b are variables from equation (1).

In order to calculate U_{w1} , U_{w2} , U_{b1} , and U_{b2} , component U-factors (i.e., frame U-factors, U_f , and edge-of-glass U-factors, U_e) for each individual assembly are calculated for the four “B/W” options. These component U-factors, along with SHGC and VT, are the basic information that is put on a label for each cross-section assembly. The following table summarizes information for a label:

	Frame				Spacer	Glazing
	w1	w2	b1	b2		
U_f [W/m ² K]						
U_e [W/m ² K]						
Pdf [m]						
U_c [W/m ² K]						
K_{eff} [W/mK]						
$SHGC$ [-]						
VT [-]						

Where pdf is projected frame depth.

This information is provided for each cross-section assembly and the overall U-factors are then calculated using standard area weighting method:

$$U_{w1} = \frac{\sum A_{fi-w1} \cdot U_{fi-w1} + \sum A_{ei-w1} \cdot U_{ei-w1} + A_{c,w} \cdot U_{c,w}}{A} \quad (9)$$

where i denotes cross-section (i.e., sill, jamb, head, meeting rail, etc.)

similarly,

$$U_{w2} = \frac{\sum A_{fi-w2} \cdot U_{fi-w2} + \sum A_{ei-w2} \cdot U_{ei-w2} + A_{c,w} \cdot U_{c,w}}{A} \quad (10)$$

$$U_{b1} = \frac{\sum A_{fi-b1} \cdot U_{fi-b1} + \sum A_{ei-b1} \cdot U_{ei-b1} + A_{c,b} \cdot U_{c,b}}{A} \quad (11)$$

$$U_{b2} = \frac{\sum A_{fi-b2} \cdot U_{fi-b2} + \sum A_{ei-b2} \cdot U_{ei-b2} + A_{c,b} \cdot U_{c,b}}{A} \quad (11)$$

Solar heat gain coefficient of the window with standardized dimensions, incorporating “worst” IGU and requested spacer, $SHGC_w$, and Solar heat gain coefficient of the window with standardized dimensions, incorporating “best” IGU and requested spacer, $SHGC_b$ are calculated in the same way as U-factors, presented in equations (7) through (12).

Visible Transmittance of windows with “best” IGU, VT_b and “worst” IGU, VT_w doesn’t depend on spacer assembly k_{eff} because same values are obtained both for “worst spacer” and “best spacer”. Therefore, there is no need for interpolation calculations for different spacers.

These equations have been programmed in the draft version of the program FENSIZE, which has been provided for testing and evaluation at the web site:

<http://www.fenestration.com/fensize.html>.

VALIDATION

In order to prove presumption about nearly logarithmic relationship between U – value, Solar Heat Gain Coefficient and vision percentage, graphs of U and SHGC vs. spacer assembly k_{eff} for three chosen glazing options are compared with correspondent graphs obtained from interpolation algorithm and results are plotted in Figures 13 and 14.

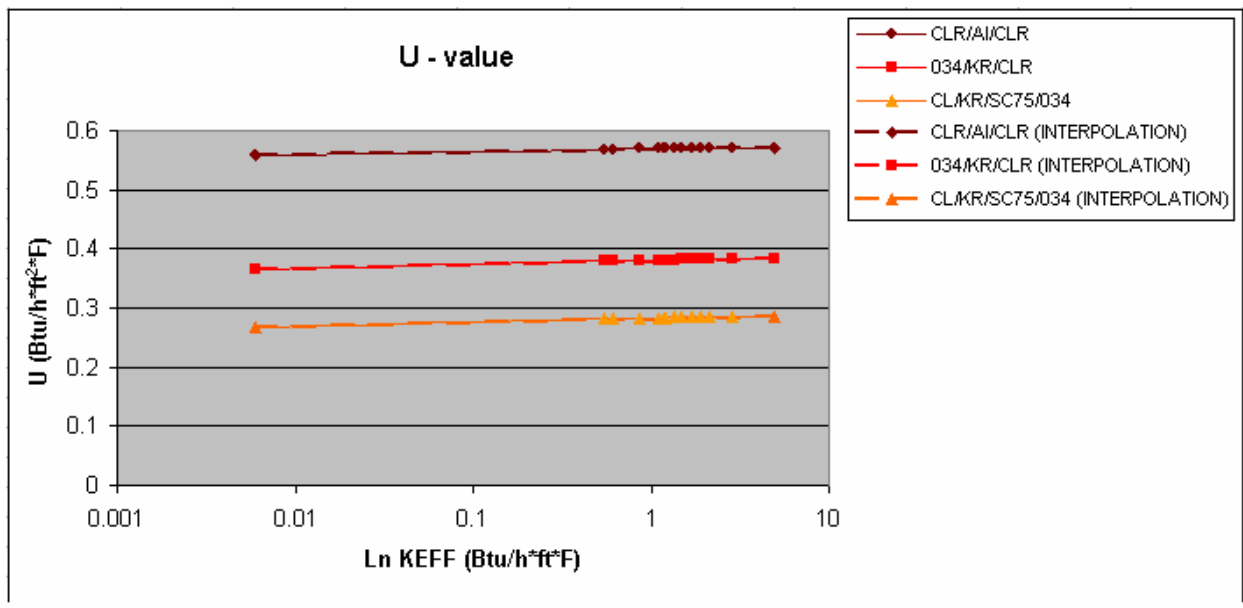


Figure 12: Variation of U factor with Spacer Assembly k_{eff}

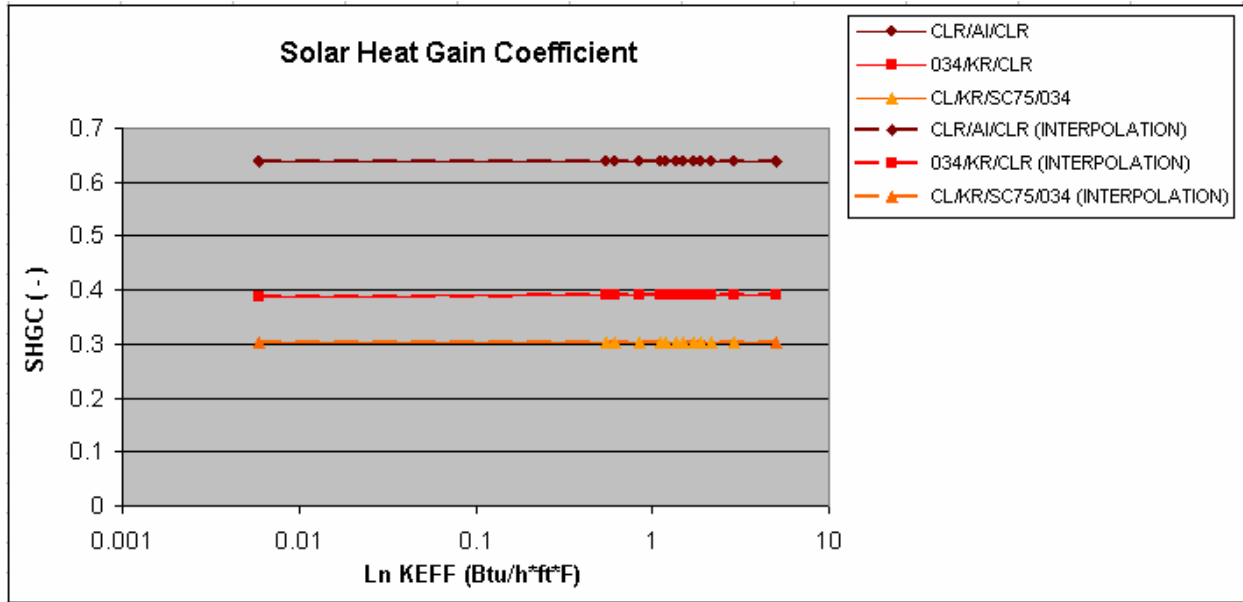


Figure 13: Variation of SHGC with Spacer Assembly k_{eff}

SUMMARY OF STEPS IN COMPONENT APPROACH:

- 1) Obtain Frame Cross Sections:

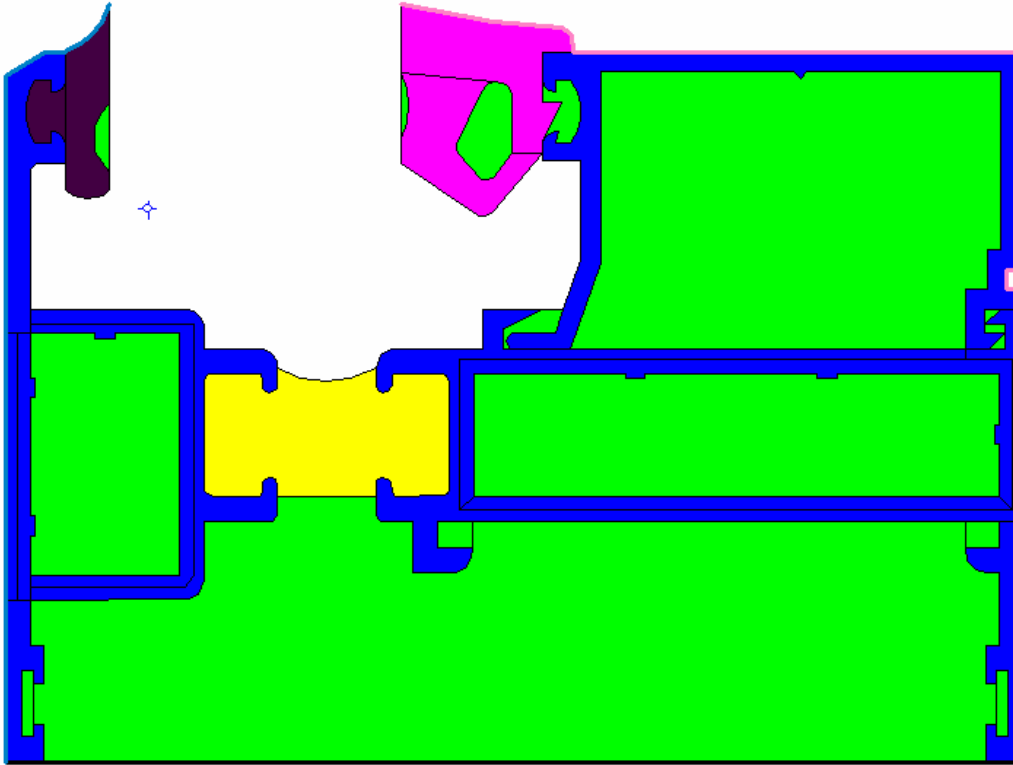


Figure 14. Example of Sill Cross Section of a Non-Residential Window

- 2) Model thermal performance of this frame cross section coupled with four options; 1) “worst” IGU and “best” spacer (w1), 2) “worst” IGU and “worst” spacer (w2), 3) “best” IGU and “best” spacer (b1), and 4) “best” IGU and “worst” spacer (b2). The analysis should be done using THERM program and reported U_f , U_e , and $SHGC_f$ should be recorded for each option. Figure 15 shows example of one of the options inserted in a frame cross-section.
- 3) For the known fenestration configuration, calculate U_{w1} , U_{w2} , U_{b1} , and U_{b2} using equations (9) through (12)
- 4)

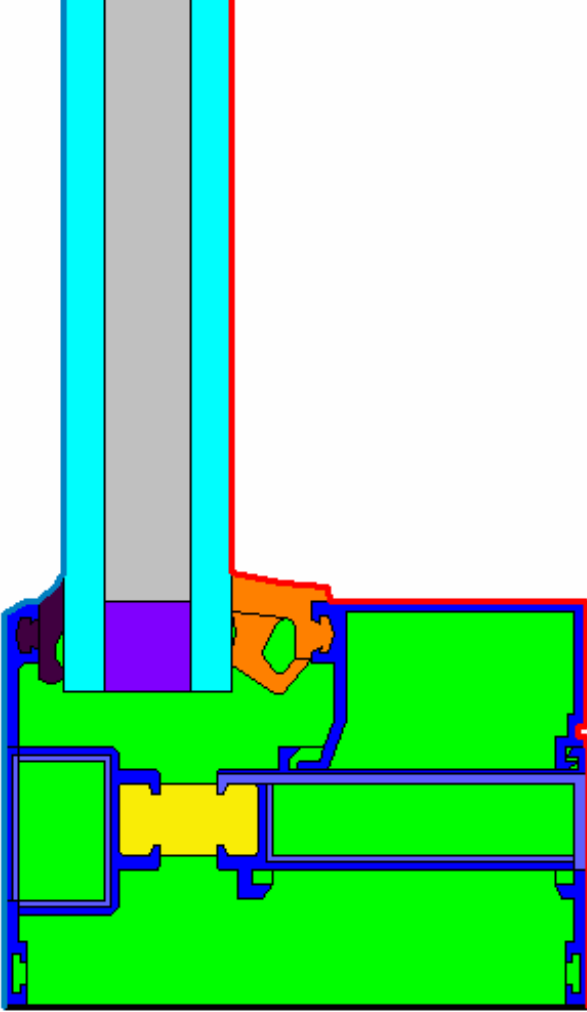


Figure 15. Example of a frame cross-section with one of the “best-worst” options

3) Model center of glass performance of the actual glazing system in the product.

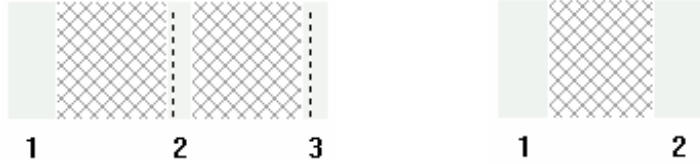


Figure 16. Schematics of the best and worst center of glass options

4) Determine spacer assembly k_{eff}

5) For the given size (including NFRC standard commercial size of 80" x 80"), calculate total product performance using equations 3, 7, and 8.