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 SITE BUILT PRODUCTS

Prepared by: **Dr. Charlie Curcija**

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INTRODUCTION:

One of the difficulties in modeling site built products is that the framing system and insulated glazing unit (IGU) are purchased separately and then put together by a glazing contractor on site. This makes the process disconnected and it is difficult to identify "responsible party", as it is case with residential or punched opening commercial windows. In addition, for commercial buildings, for whom the site built products are intended, it is important to know size specific thermal performance, rather than standard size indices.

The model presented in this document enables the rating of components, which can than be used for rating the product at standard size or for accurate energy and peak load analysis by Architects or mechanical contractors. The following thermal performance indices can be rated using this procedure, thermal transmittance (U-factor), solar heat gain coefficient (SHGC) and visible transmittance (VT).

DESCRIPTION OF THE APROACH:

Component model approach is based in 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. Preliminary investigation of the relations for glazing system (i.e., center of glass performance) and size of the product, indicate nearly linear relationship of the performance of center of glass to the overall product. In addition, spacer effects on the overall indices show logarithmic relationship when considered in terms of the effective conductivity of spacers.

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.

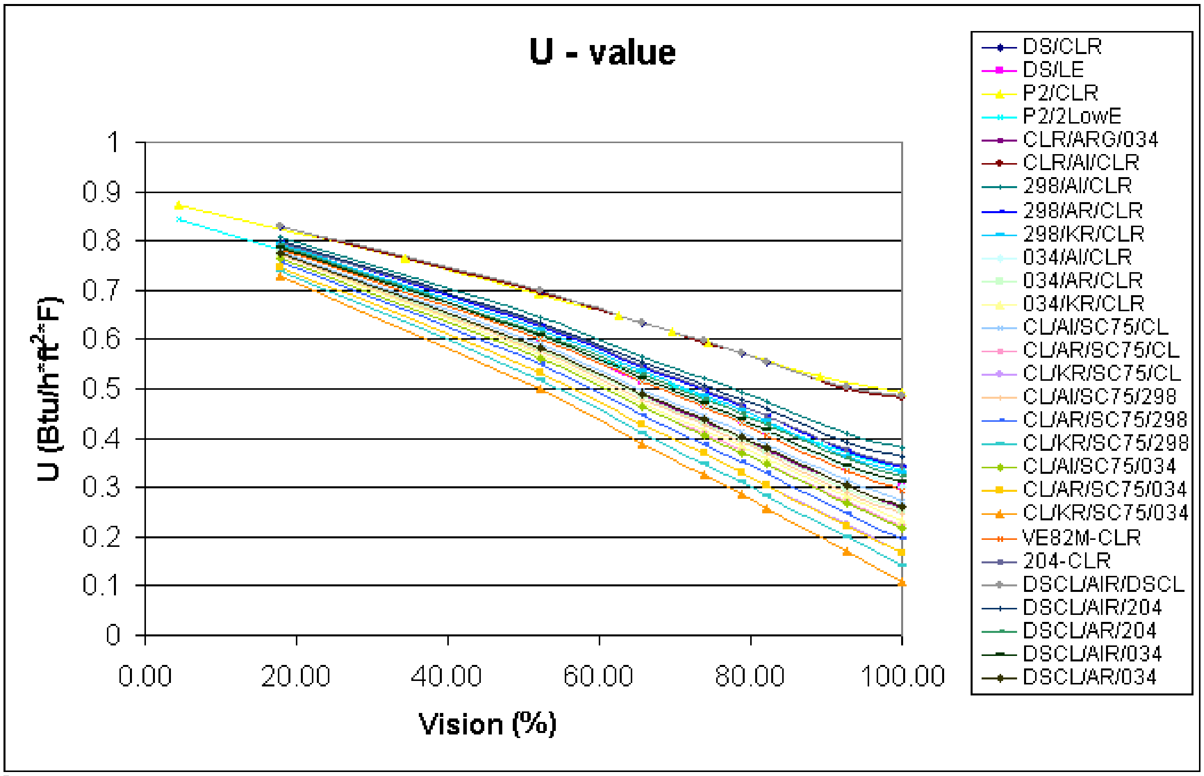

Figure 1: Variation of U - value with Vision Percentage

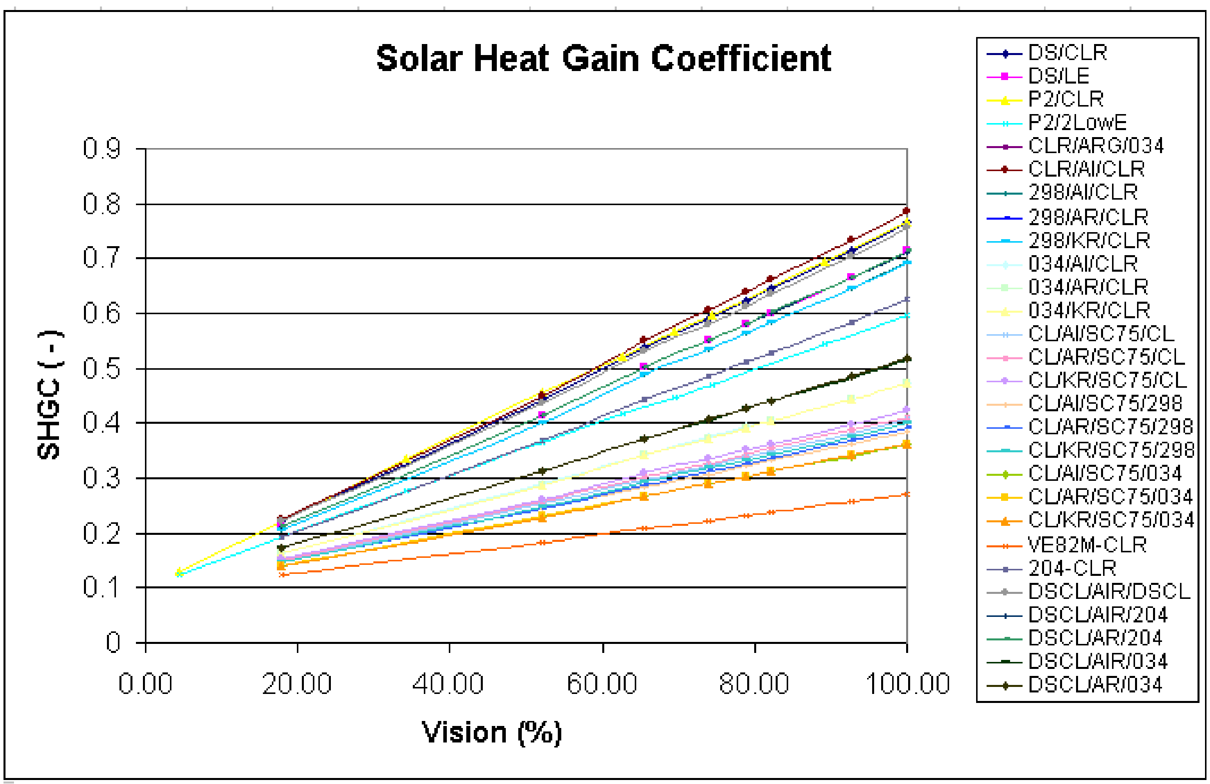

Figure 2: Variation of Solar Heat Gain Coefficient with Vision Percentage

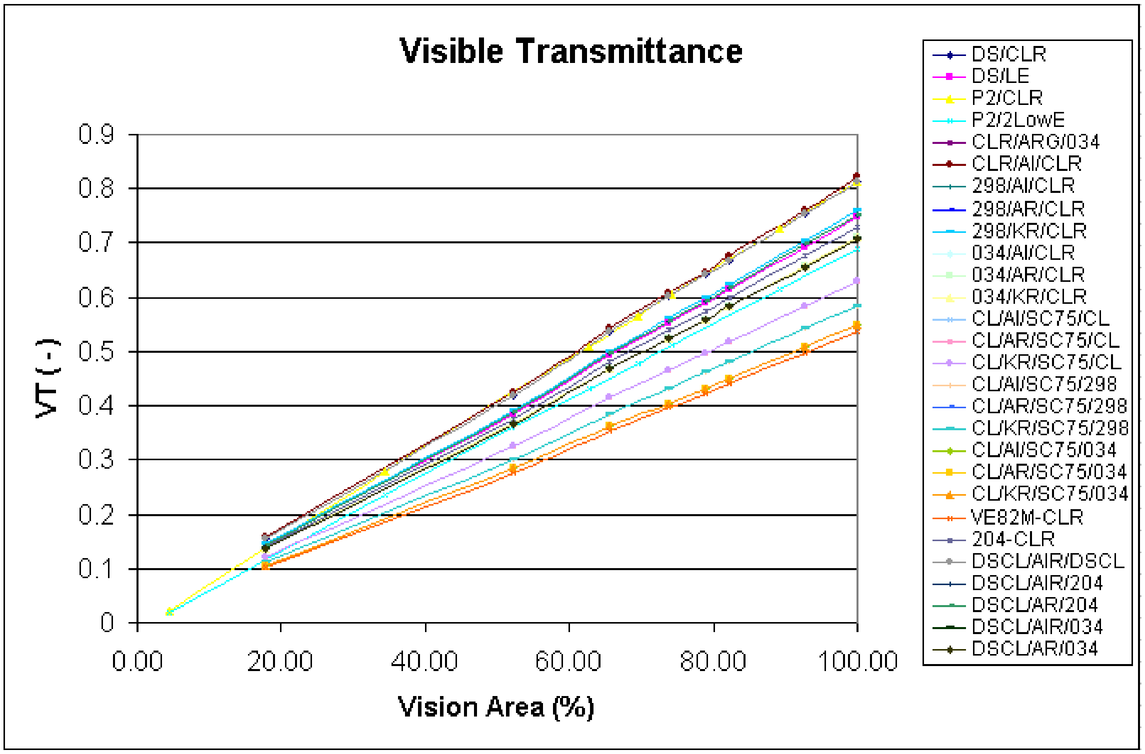

Figure 3: Variation of Visible Transmittance with Vision Percentage

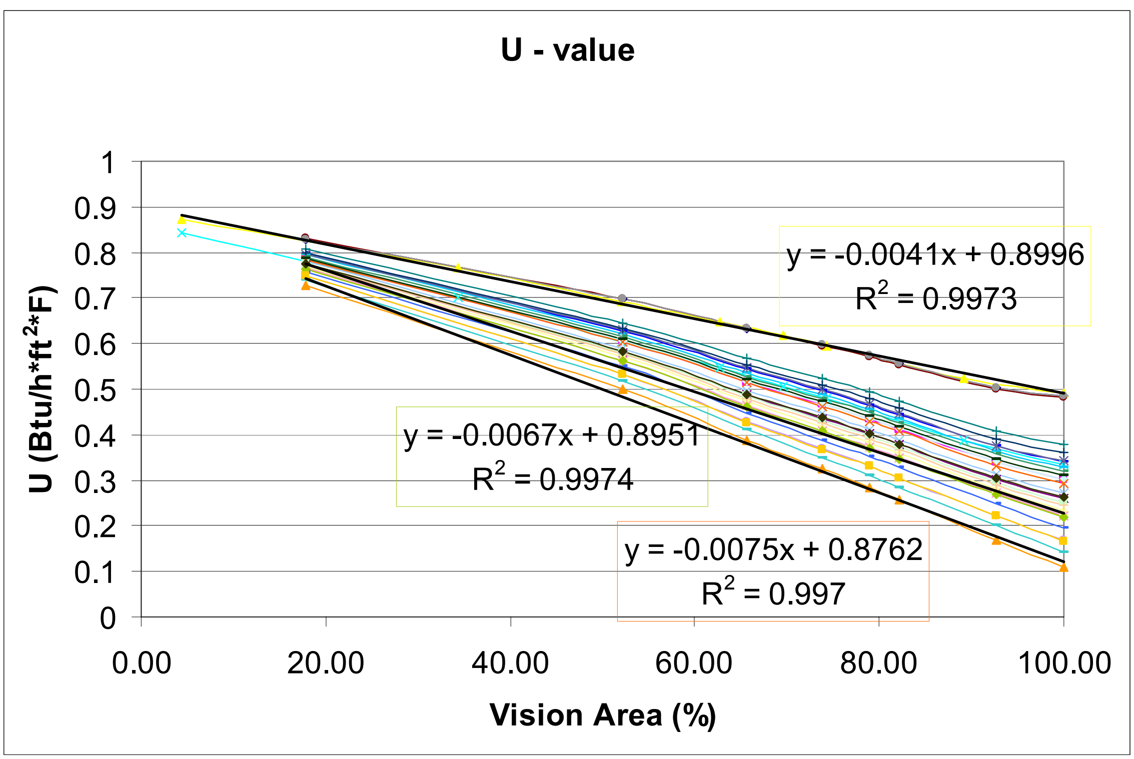

Figure 4. Linear fit and regression coefficients for U-factor curves

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 Btu/h*ft^2*F, blackbody radiation)

   Interior surface

   Default interior (combined) (t = 70 F, h_i = 1.408 Btu/h*ft^2*F)

2. From the electrical analogy of heat transfer mechanism :

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

   keff can be determined as :

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

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.

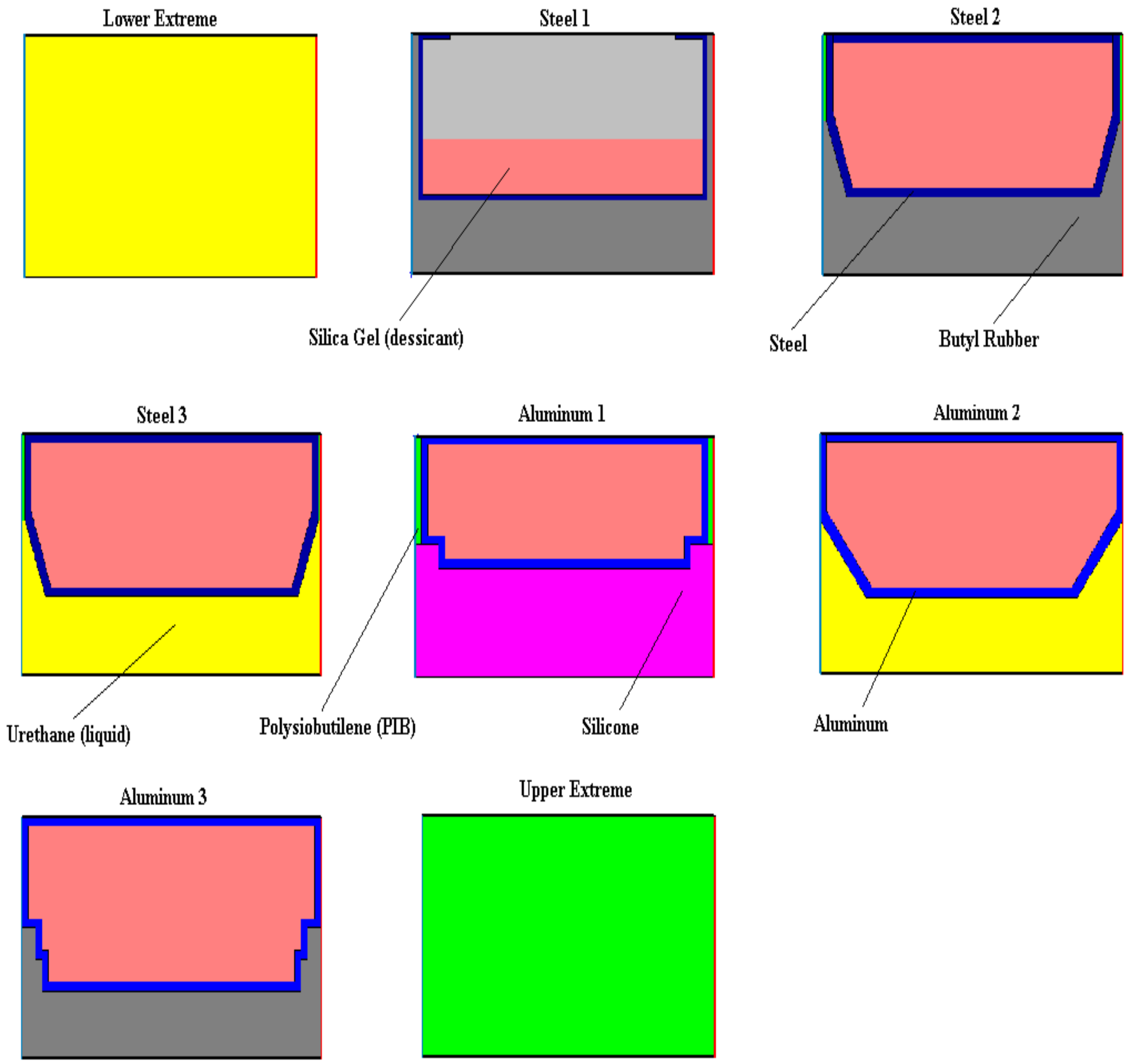

Figure 5. Example of spacer configurations

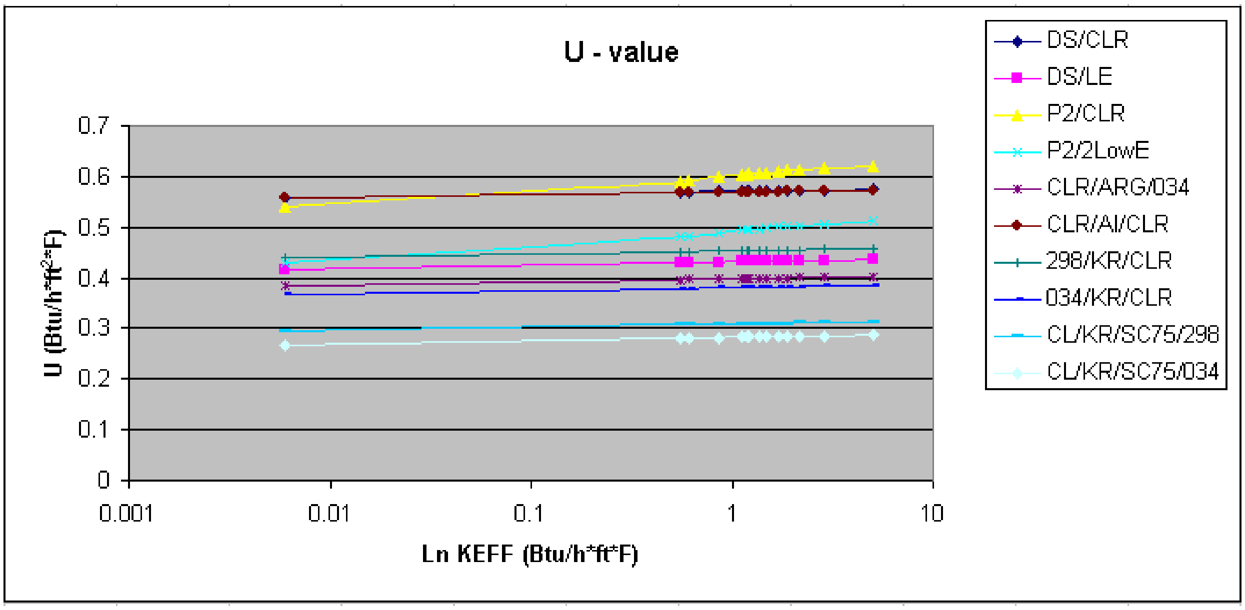

Figure 6: Variation of U-factor with k_{eff}

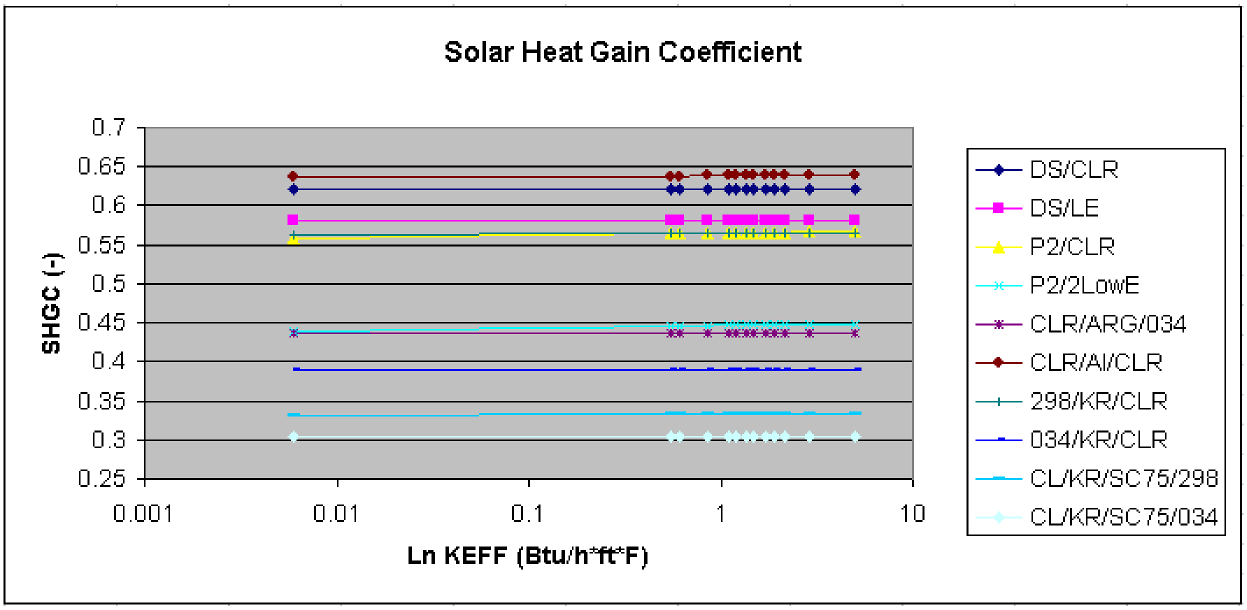

Figure 7: Variation of Solar Heat Gain Coefficient with k_{eff}

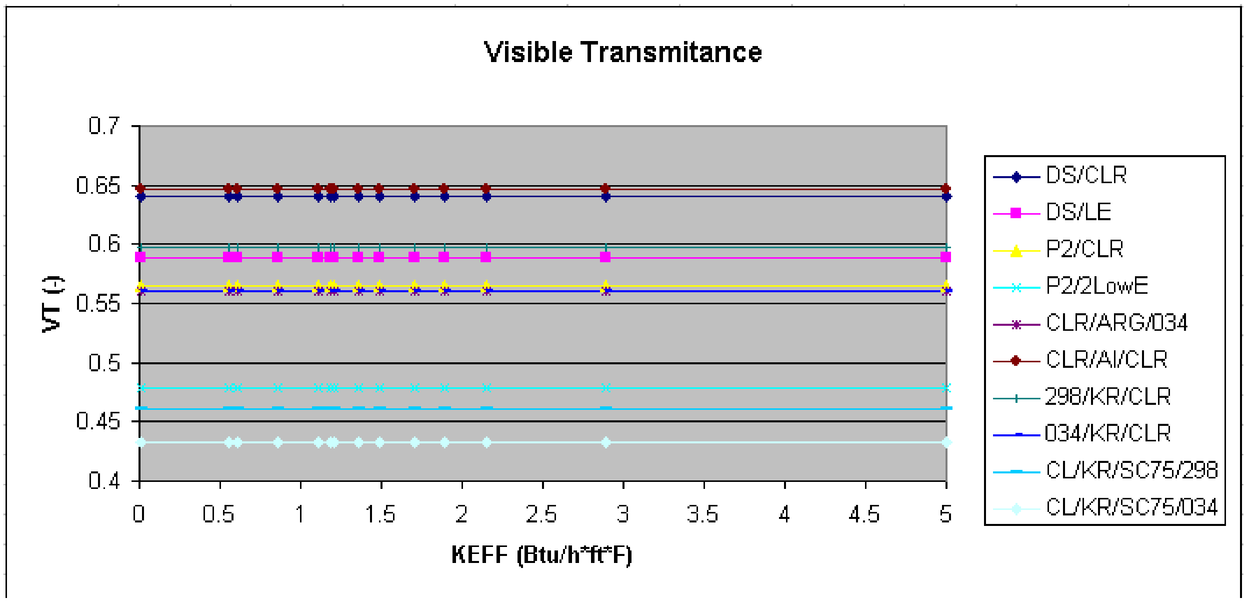

Figure 8: Variation of VT (Visible Transmittance) with k_{eff}

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.

RECOMMENDED EQUATIONS

Based on this analysis, U-factor of a particular window, U, (defined by a unique frame cross section and spacer type), is calculated as a function of center of glass U-factor, U_c, and requested dimensions, width and height, using the following equation:

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

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,
- $V_1 =$ 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:

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

where:

- $A_v =$ Vision area, calculated as:

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

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

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

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.

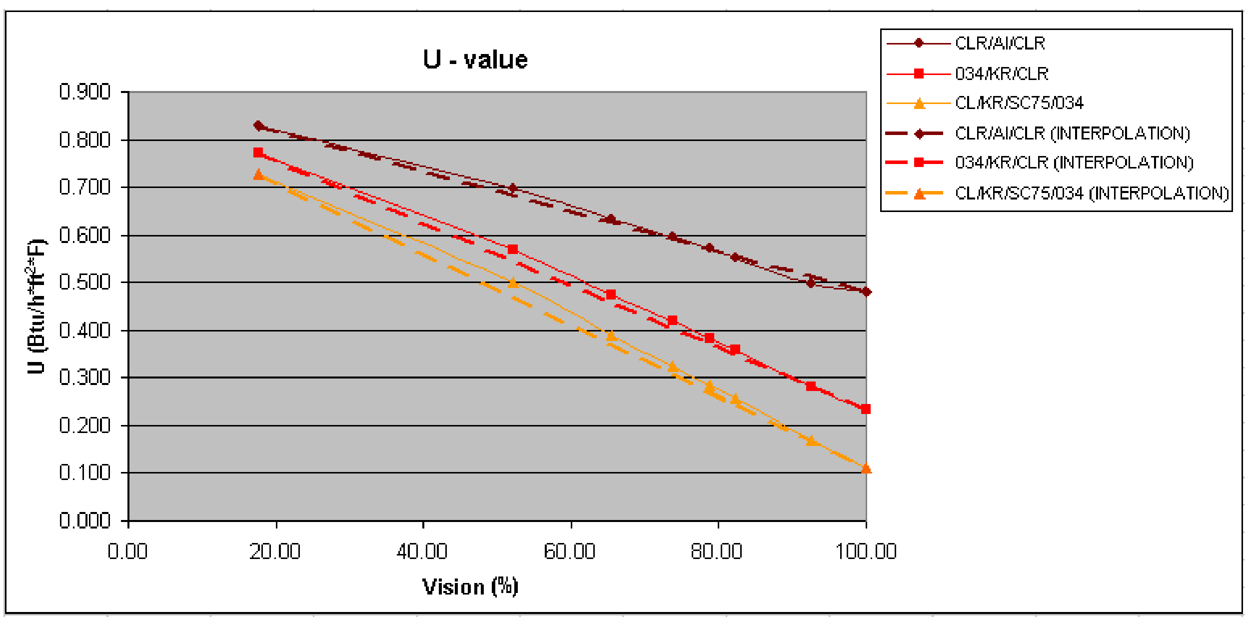

Figure 9: Variation of U factor with Vision Percentage

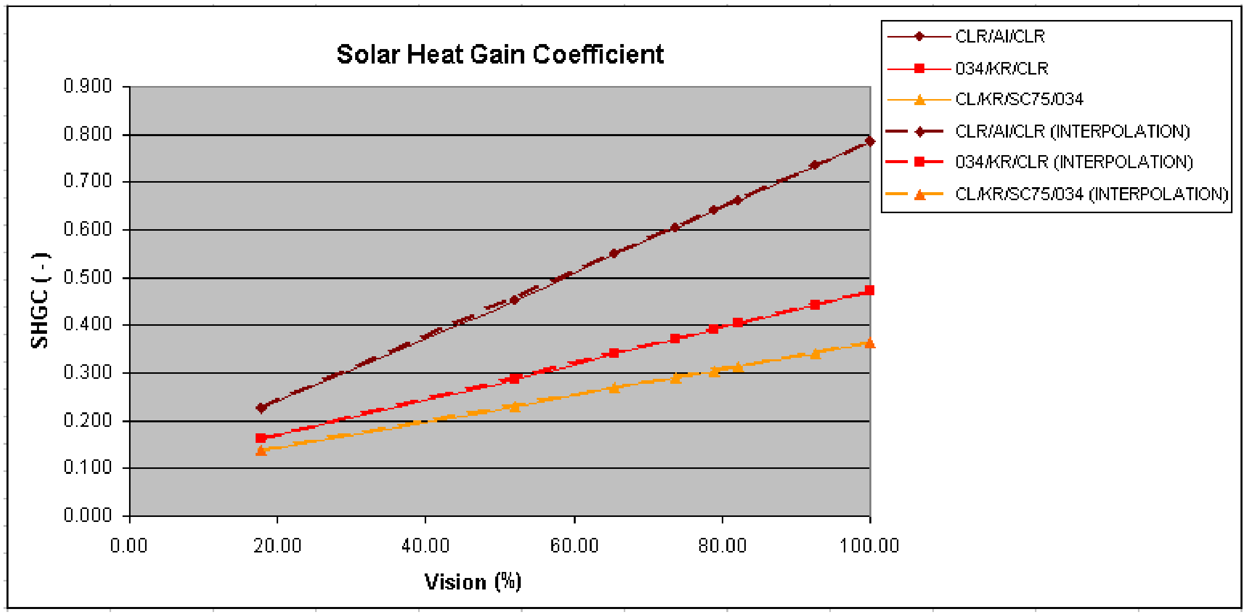

Figure 10: Variation of SHGC with Vision Percentage

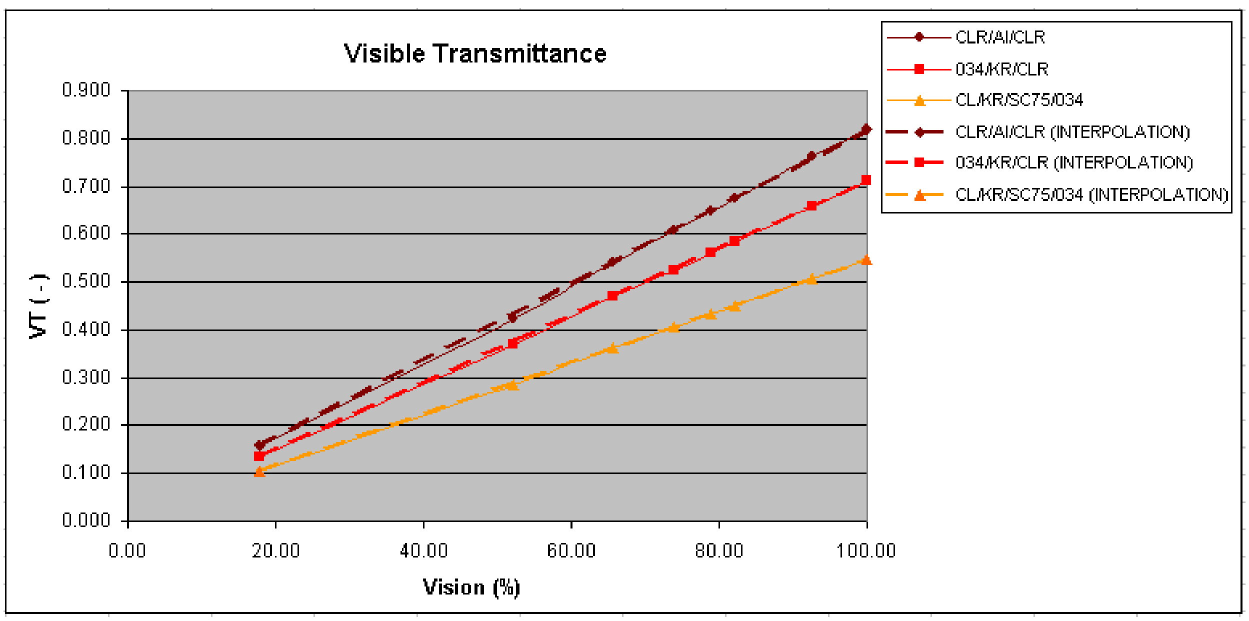

Figure 11: Variation of VT with Vision Percentage

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 to following two formulas:

$$U_w = U_{w1} + \frac{(U_{w2} - U_{w1}) \cdot [\ln(keff) - \ln(keff_1)]}{\ln(keff_2) - \ln(keff_1)} \qquad (7)$$

$$U_b = U_{b1} + \frac{(U_{b2} - U_{b1}) \cdot [\ln(keff) - \ln(keff_1)]}{\ln(keff_2) - \ln(keff_1)} \qquad (8)$$

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).

Solar heat gain coefficient of the window with standardized dimensions, incorporating "worst" IGU and reqested 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-factor, presented in equations (7) and (8).

Visible Transmittance of windows with "best" IGU, VT_b and "worst" IGU, VT_w don'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.

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 assmembly 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.

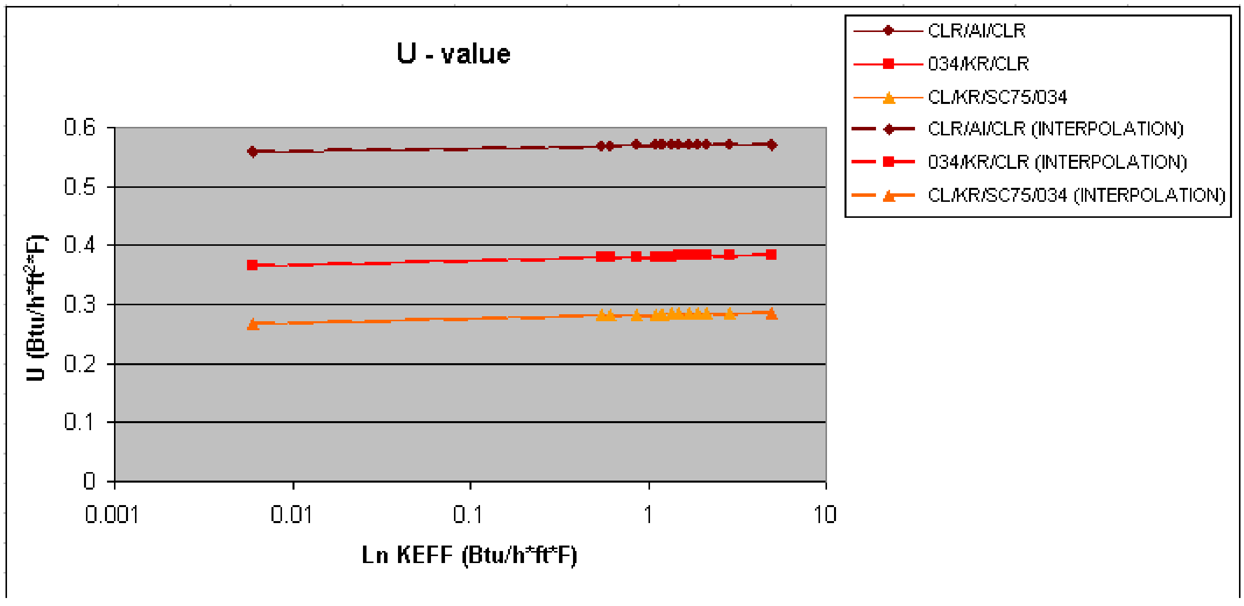

Figure 12: Variation of U factor with Spacer Assembly k_{eff}

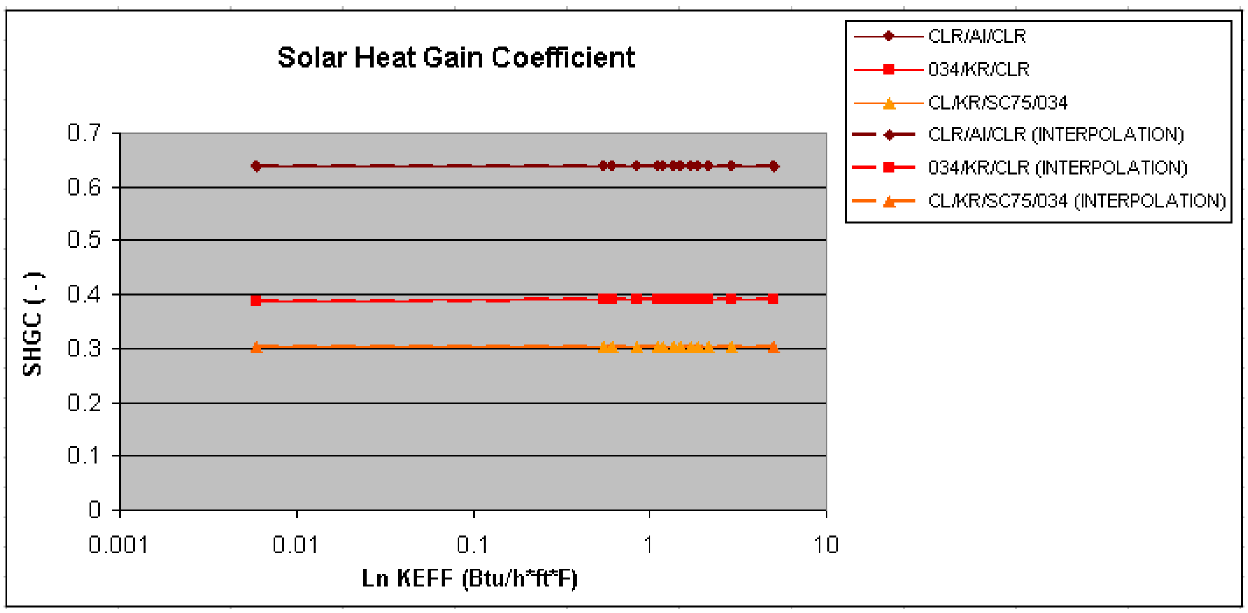

Figure 13: Variation of SHGC with Spacer Assembly k_{eff}

SUMMARY OF STEPS IN COMPONENT APPROACH:

1) Obtain Frame Cross Sections:

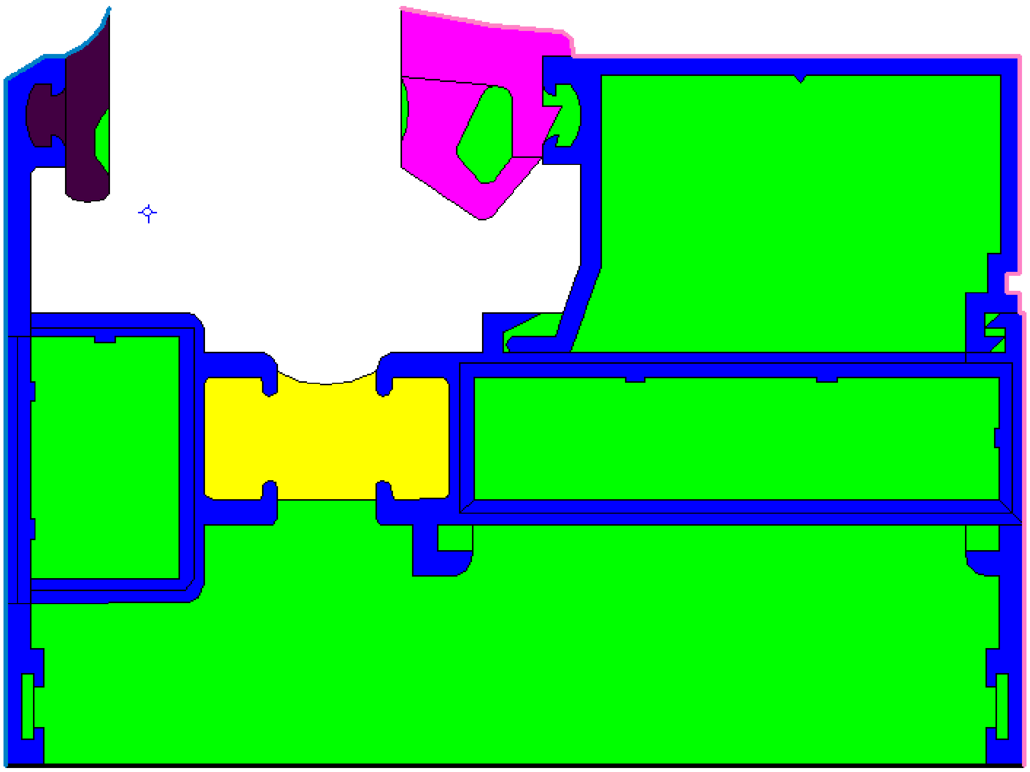

Figure 14. Example of Sill Cross Section of a Non-Residential Window

2) Model this product line defined by the frame design using two pre-defined glazing systems, incorporating two pre-defined spacer designs, giving total of four options. The glazing systems would be representative of "best" and "worst" glazing system, denoted by subscripts *b* and *w*. Spacers would be representative of "bad" and "good" spacers, denoted by subscripts 1 and 2. Therefore, the four glazing systems would be denoted with subscripts *w*1, *w*2, *b*1, *b*2. For the purpose of identifying this step, we will call it "best-worst options". Figure 15 shows example of one of the options inserted in a frame cross-section.

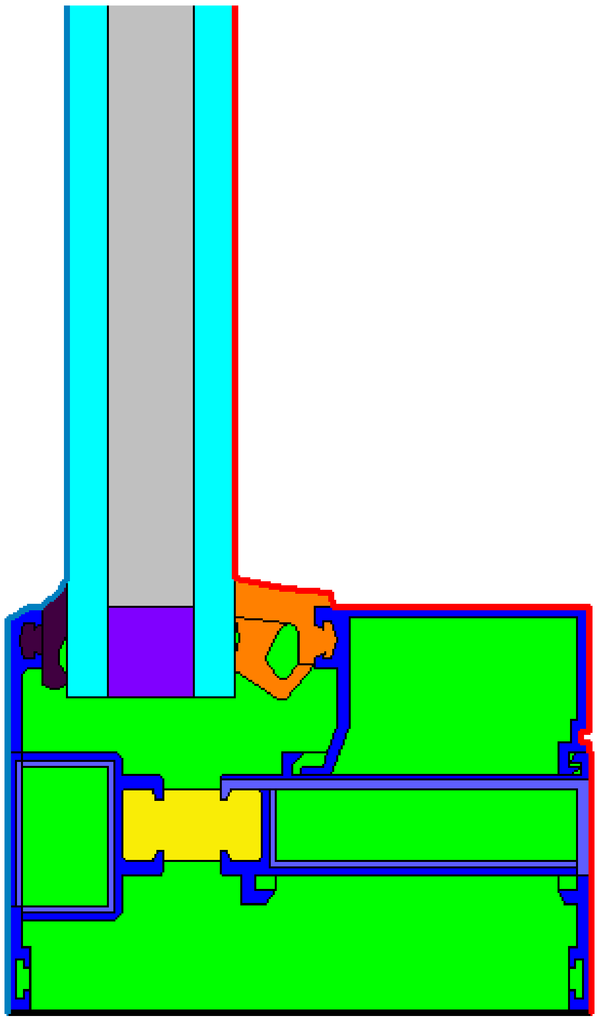

Figure 15. Example of a frame cross-section with one of the "best-worst" options

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

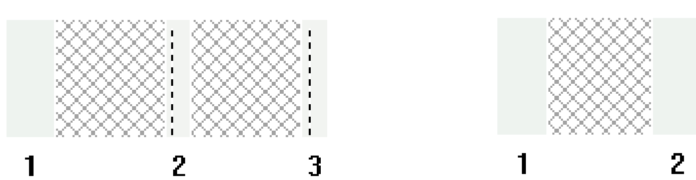

Figure 16. Schematics of the best and worst center of glass options

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.