Component Modeling Methodology for Predicting Thermal Performance of Non-Residential Fenestration Systems

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ABSTRACT

Non-Residential fenestration systems have different characteristics from residential products and therefore require different treatment. The component modeling methodology has been developed and is presented in this paper to specifically address non-residential fenestration products, from punched openings to site-built and assembled products. The basic premise of this methodology is that the manufacturer of each fenestration component (i.e., framing, glazing and spacer manufacturer) is responsible for its own product, for which the performance is published in NFRC certified product directory (CPD), while the overall performance of the fenestration system is determined using functions developed from number of actual runs with the real glazing and spacer systems. The methodology is based on four generic runs, incorporating high and low end of performance (i.e., best/worst or B/W options). This methodology can be implemented in a software tool, which would pull component information from the CPD into its own database and would calculate thermal and solar-optical performance at the standard size as well as the actual product size. This way, not only responsibility for component performance is clearly defined, but also the input data about fenestration systems for building energy simulation is accurate and will lead to more precise prediction of peak loads and annual energy use. Implementation of this methodology within nationally recognized rating program will allow for uniform and accurate representation of non-residential fenestration systems, for both site-built and punched opening type of fenestration products, while still providing data for prescriptive path in energy codes (e.g., performance at standard NFRC size).

INTRODUCTION:

Non-Residential products have been included in NFRC rating system within the framework of residential windows (NFRC 2001 procedures), with one notable exception, the site-built products. Recognizing that site-built products are manufactured by several parties (i.e., frame component are manufactured separately from IGU) and often put together by an independent party (i.e., "glazing contractor" or "glazer"), NFRC has established separate procedure for these products and has developed separate certification process for buildings having more than 10,000 sq. feet of fenestration. However, this process is still very similar to residential windows in that it requires single responsible party, which is often fulfilled by framing system manufacturer. This places undue burden on one side, as their role in reality is limited to selling and delivering frame lineals that are then put together at the site and IGU manufactured by another party is put into the framing system.

AAMA procedure for non-residential products (AAMA 507- 2003) introduced the concept of separate treatment of framing and IGU units, which was a step in the right direction. AAMA 2003 procedure uses simulation method to determine U-factors, SHGC and VT of products with different glazing systems and spacers. Using different glazing systems, with U-factors in increments of 0.12 $W/m^2{\cdot}K$ (0.02 $Btu/hr{\cdot}ft^2{\cdot}{}^oF$), the frame cross-sections are modeled using NFRC approved software. Once all cross-sections were analyzed, overall U-factors, SHGC and VT are calculated and plotted on a graph with vision area percentage on x axis and performance index (i.e., U-factor, SHGC, or VT) on y axis. For 100% vision area, the U-factor is simply center of glass value. The graphs incorporate linear distributions and in order to draw a line for each glazing system, one other point at 70% vision area is calculated. For each spacer, the performance is re-calculated and graph is constructed. This method is somewhat cumbersome, as it requires block of simulations for 15 different glazing options for each product line and separate blocks of simulations for each spacer design.

Within the last year, updated versions of software tools THERM and WINDOW had been released. THERM 5.2 (LBNL 2003) and WINDOW 5.2 (LBNL 2003) fully incorporate ISO 15099 methodology, which has been published in 2003. NFRC program and new standards specify use of THERM 5.2 and WINDOW 5.2 as the only approved software tools. Advanced radiation modeling is now required for all fenestration products that are certified through NFRC system. Advanced, view factor based, radiation modeling produces more accurate results for all products, but the difference is largest for higher conducting products, like ordinary glazing, or/and Aluminum frames. Testing standardization of results (NFRC 102- 2001) have also been modified and limited to CTS method only, in order to reflect more accurate simulation results.

COMPONENT METHODOLOGY

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 best worst and 1 and 2 for spacers best worst cases, 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 simulated and this information is later used to "assemble" finished product, which may be simple fixed, single lite window, or it can be complex combination window consisting of several basic window shapes (e.g., two casement windows side by side with fixed window over them), incorporated in common frame.

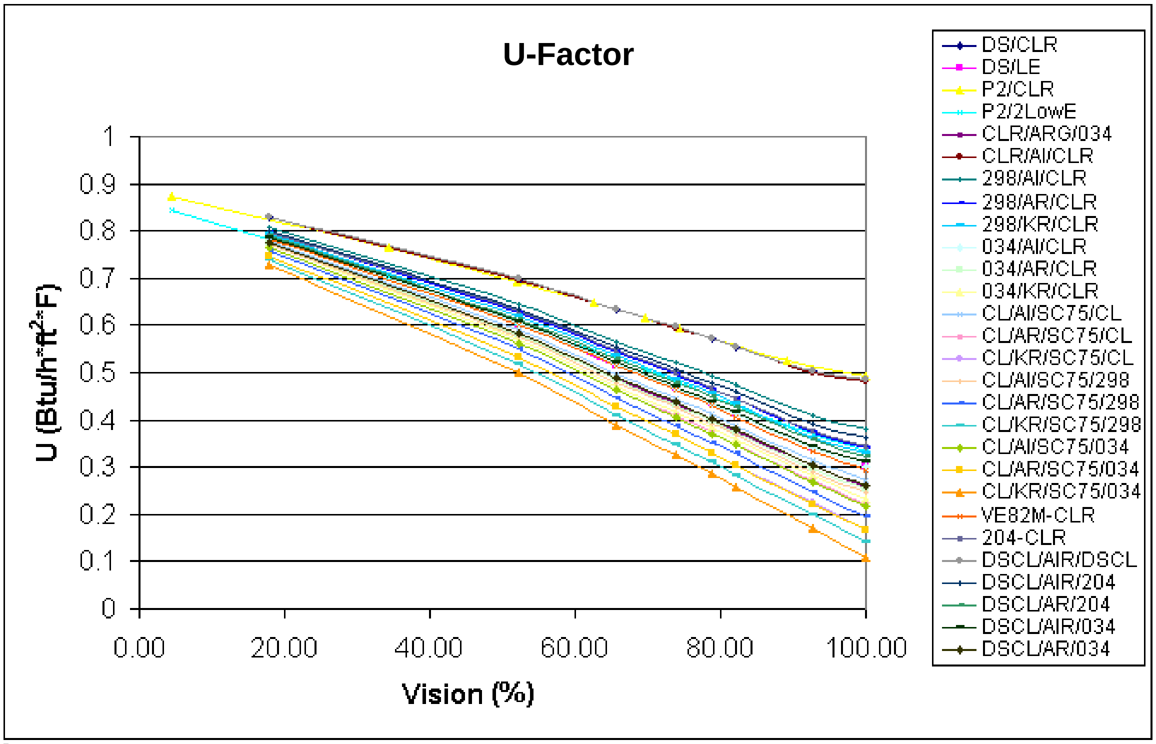

Figure 1: Variation of U - factor with Vision Percentage

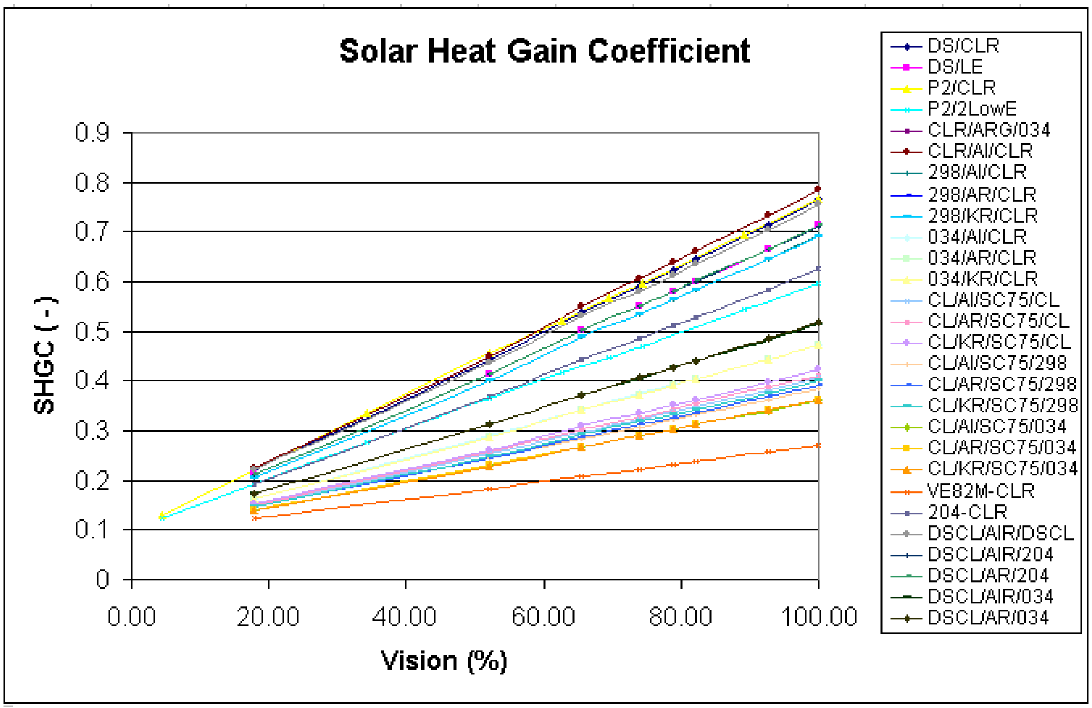

Figure 2: Variation of Solar Heat Gain Coefficient with Vision Percentage

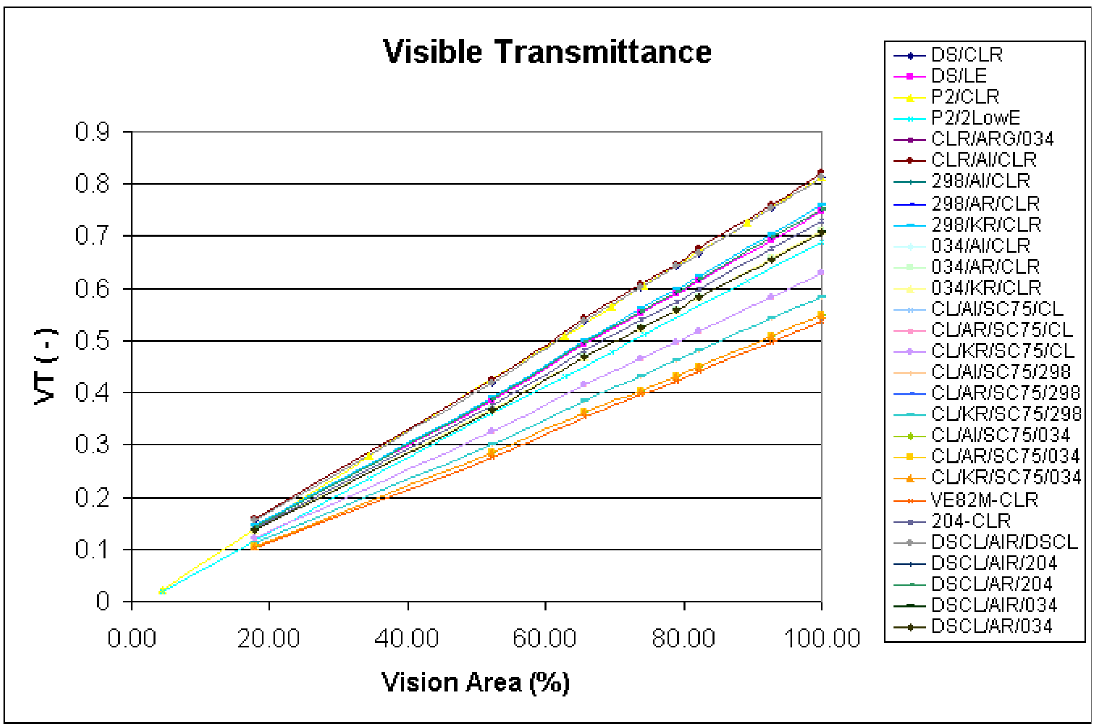

Figure 3: Variation of Visible Transmittance with Vision Percentage

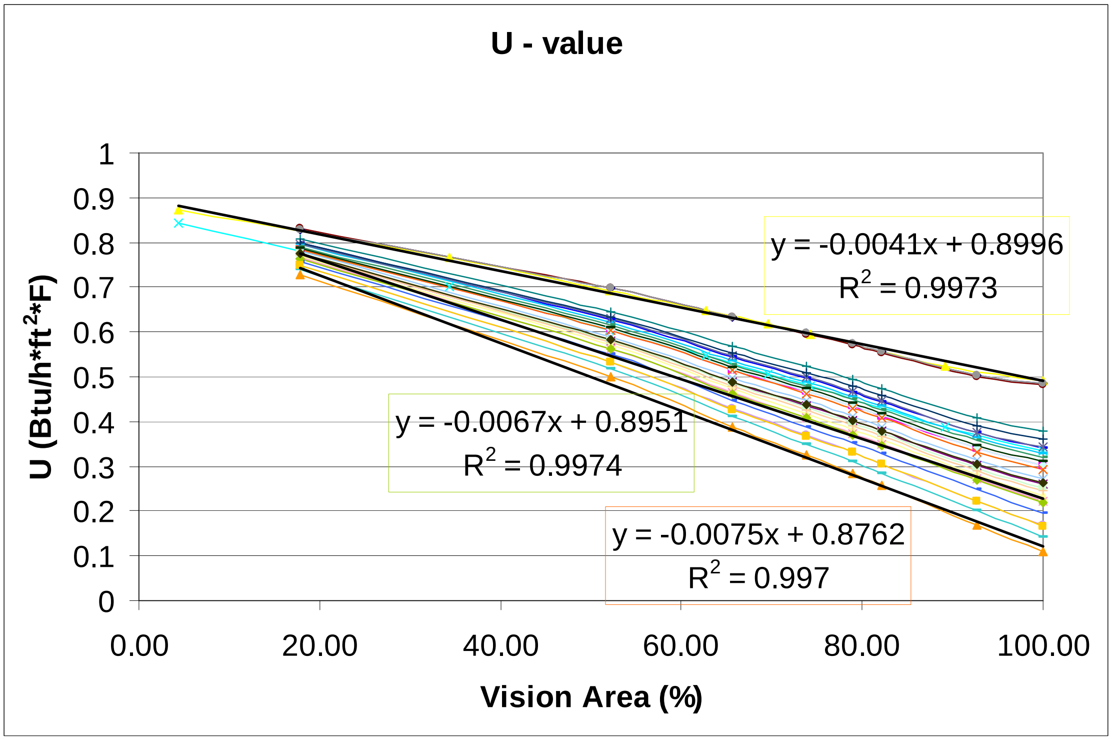

Figure 4. Linear fit and regression coefficients for U-factor curves

Spacer Analysis

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 5.2 and using the following standard NFRC boundary conditions

   Exterior surface: T_o = -18.00 °C (-0.40 °F), h_o = 30.00 W/m²K (5.28 Btu/h·ft²·°F)

   Interior surface: T_i = 21.00 °C (69.80 °F), h_i = 8.00 W/m²K (1.41 Btu/h·ft²·°F)

2. From the electrical analogy of resistances, the total heat flow resistance is:

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

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 a given 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).

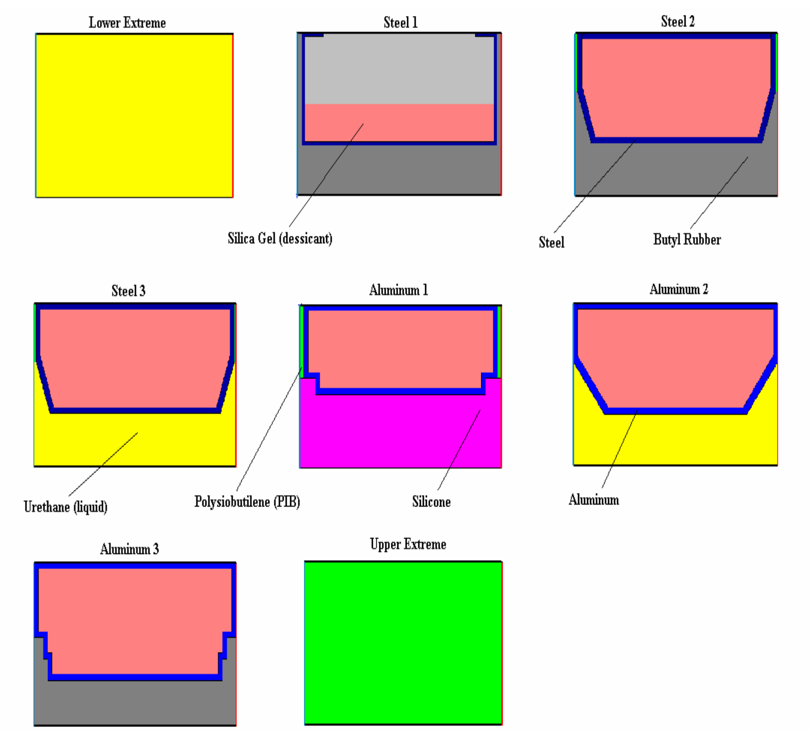

Figure 5. Example of spacer configurations

Using *keff* of a given spacer for *x* axis and overall product U-factor, SHGC and VT, incorporating this spacer on *y* axis, the logarithmic relationship results. Using logarithmic scale for *x* axis, the curves have nearly linear distribution, confirming logarithmic distribution. Figures

6, 7, and 8 show U-factor, SHGC and VT distributions for selected glazing systems. Note that for VT, the relationship is linear, so the *x* axis in the graph in Figure 8 is linear rather than logarithmic.

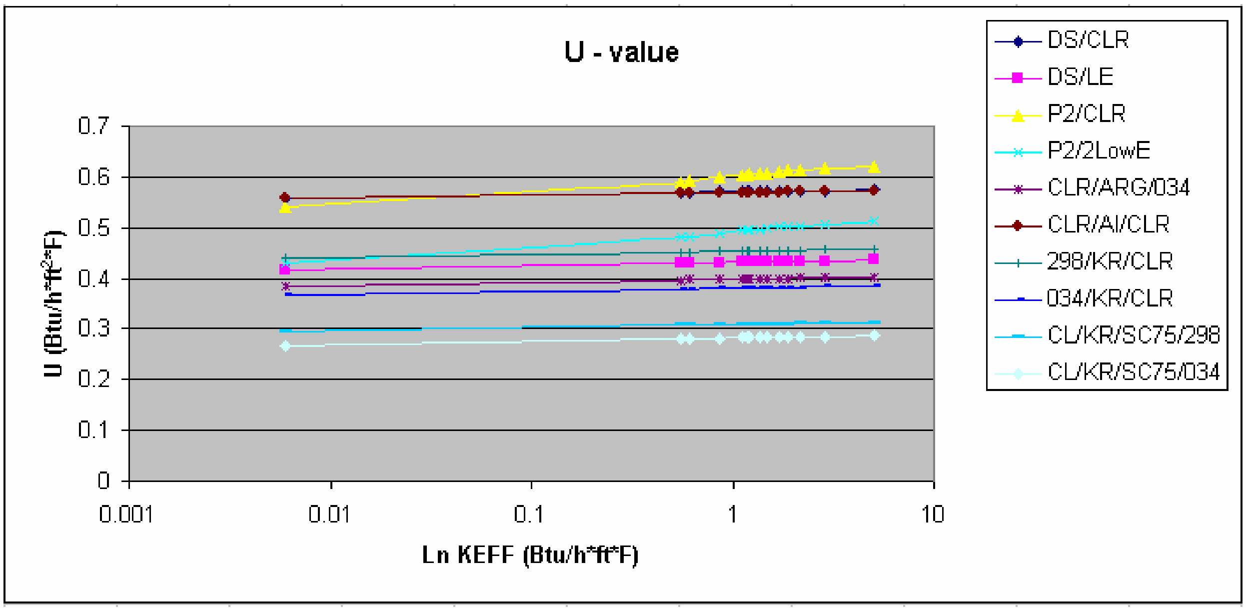

Figure 6: Variation of U-factor with k_{eff}

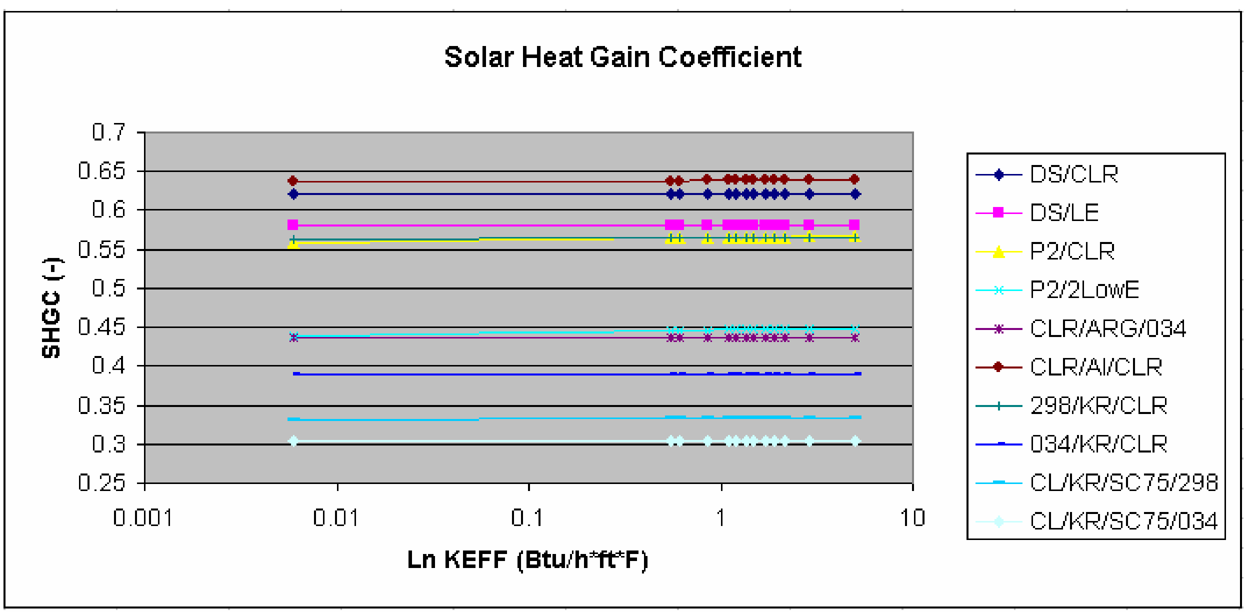

Figure 7: Variation of Solar Heat Gain Coefficient with k_{eff}

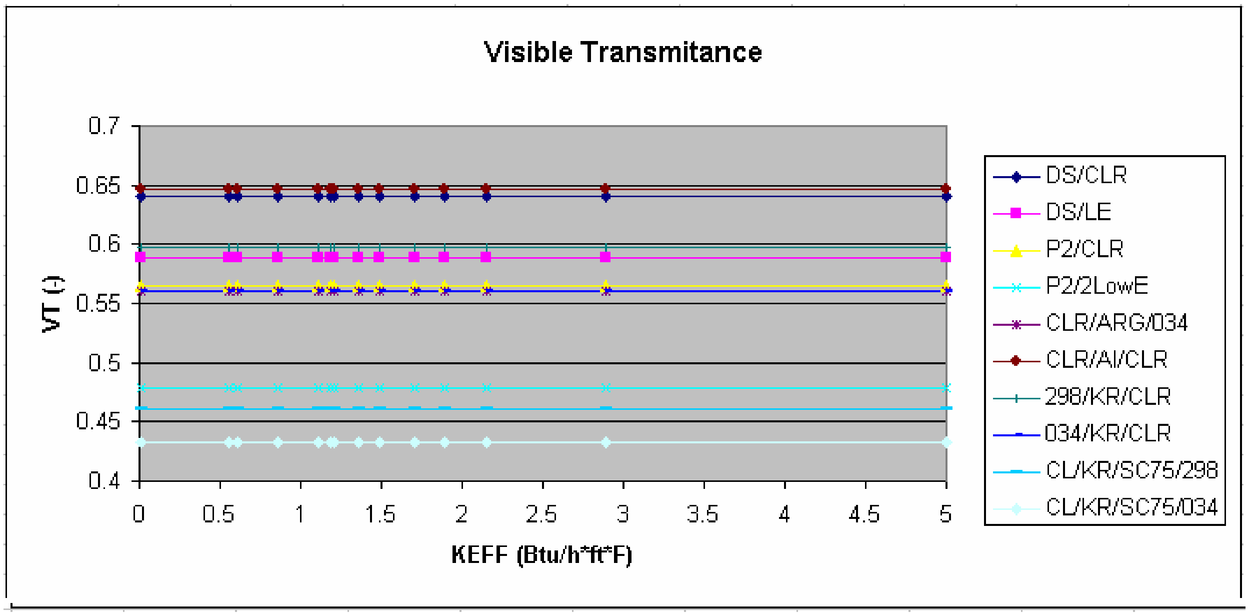

Figure 8: Variation of VT (Visible Transmittance) with k_{eff}

ALGORITHM DEVELOPMENT

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.

Having linear relationship for the performance indices and having one point at the 100% vision area, it was important to select the second point at the lower vision percentage. It was decided that 24 in. x 24 in. window represents reasonable lower size limit and corresponding vision percentage area was developed for each of unique window operator types. These dimensions (24 in. x 24 in.) are labeled "Base dimensions"

The following equation gives U-factor of a fenestration system in terms of "Best" and "Worst" glazing and spacers, denoted here as "B/W options":

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

where:

- U_w = U factor of a window with base dimensions, incorporating "worst" IGU, determined from equations that follow
- U_b = U factor of a window with base 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 of a window for which the U-factor is being calculated,
- V_1 = Vision percentage of a window with base dimensions,
- V = Vision percentage of a window for which the U-factor is being calculated,

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

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” IGU was chosen to be double, clear, air filled IGU, and “Best” IGUs was chosen to be triple glazed, double low-e, Argon filled IGU.

- Base window dimensions are: 24 in. x 24 in.

The U-factors for a window incorporating “worst” IGU, U_w, and the U-factor for a window incorporating “best” IGU, U_b, is calculated using the following procedure:

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

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

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}),

where:

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

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

- U_{w2} = U-factor of window with standardized dimensions, “worst IGU” and “worst spacer” (i.e., highest conducting spacer assembly or highest k_{eff}),

where:

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

- U_{b1} = U-factor of window with standardized dimensions, “best IGU” and “best spacer” (i.e., lowest conducting spacer assembly or lowest k_{eff}),

where:

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

- U_{b2} = U-factor of window with standardized dimensions, "best IGU" and "worst spacer" (i.e., highest conducting spacer assembly or highest k_{eff}),

where:

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

- k_{eff1} = effective conductivity of the "best spacer"
- k_{eff2} = effective conductivity of the "worst spacer"
- k_{eff} = effective conductivity of the spacer in a window for which the U-factor is being calculated.

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.

SHGC and VT of a particular window with base dimensions, are calculated in the same manner as U-factors detailed in the equations above.

PERFORMANCE LABELING

The four B/W performance numbers for U-factors, SHGC, and VT, as well as center of glass indices and projected frame dimension (useful in determining vision percentage area), and effective conductivity of spacer can be tabulated in a table as shown in Table 1. From this information, performance at any size can be calculated. However, the more effective and rational approach in rating and labeling would be to have manufacturer of each "component" provide the rating for their individual components, where components here are divided into three groups:

- Framing system
- Glazing system
- Spacer system

Note: Dividers are treated in the same manner as frame systems.

Labels with information for each of these component groups can be provided by a manufacturer and the performance of the overall product can be performed by a third party (i.e., glazing contractor, architect, building official, Independent agency, etc.) using computer tool that incorporate these algorithms and area weighting for different fenestration operator types (i.e., casement window, fixed window, horizontal slider, sliding doors, swinging doors, curtain wall, combination window, etc.). Table 2 show example of a rating label for the framing system. Table 3 shows example of a label for glazing system and Table 4 shows example of a label for spacer system.

Table 1. Required information for calculating overall product indices

	Frame Cross Section				**Spacer**	**Glazing**
	w1	w2	b1	b2		
U_f [W/m^{2}K]						
U_e [W/m^{2}K]						
Pdf [m]						
Uc [W/m^{2}K]						
Keff [W/mK]						
SHGC [-]						
VT [-]						

Note: pdf is projected frame depth.

Table 2. Example of Label for Framing Cross Section System

	w1			w2			b1			b2		
	U	SHGC	VT	U	SHGC	VT	U	SHGC	VT	U	SHGC	VT
Frame												
Edge of glass												
Pdf [m]												

Note: U-factor units are: $W/m^2 \cdot K$ (SI) and $Btu/hr \cdot ft^2 \cdot {}^oF$ (IP)

Table 3. Example of Label for Glazing System

	U	SHGC	VT
Center of Glass			

Note: U-factor units are: $W/m^2 \cdot K$ (SI) and $Btu/hr \cdot ft^2 \cdot {}^oF$ (IP)

Table 4. Example of Label for Spacer System

	k_{eff}
Spacer	

Note: k_{eff} units are: $W/m \cdot K$ (SI) and $Btu/h \cdot ft \cdot {}^oF$ or $Btu \cdot in./hr \cdot ft^2 \cdot {}^oF$ (IP)

VALIDATION

U, SHGC, and VT, calculated for three representative glazing options using detailed modeling approach using THERM and WINDOW are compared with corresponding values obtained from interpolation algorithm and plotted vs. vision percentage, and results are shown in Figures 9 to 11. It is evident from comparisons that the results obtained from interpolation compare very well with those obtained from detailed modeling. More comprehensive validation was done for three different window materials (Aluminum, Thermally Broken Aluminum, Fiber-glass and Vinyl-reinforced frames) and two different spacer materials and results were presented in tabular form in Tables 5 to 10. These tables present the total product indices, U-factor, SHGC and VT determined using current NFRC approved THERM/WINDOW programs and component modeling algorithm described here. The results of component modeling approach are labeled as FENSIZE and presented in series of tables with corresponding results obtained from simulation using current THERM5/WINDOW5 procedure. TRR-97, TRR-99, TRR-01, and TRR-02 are NFRC testing round robin specimens for year 1997 and 1998, 1999 and 2000, 2001, and 2002, respectively. Fiberglass and TR-4600 are additional products provided by manufacturers to cover all of available products and materials. The difference between the results of two approaches is shown in these tables with reference to FENSIZE results.

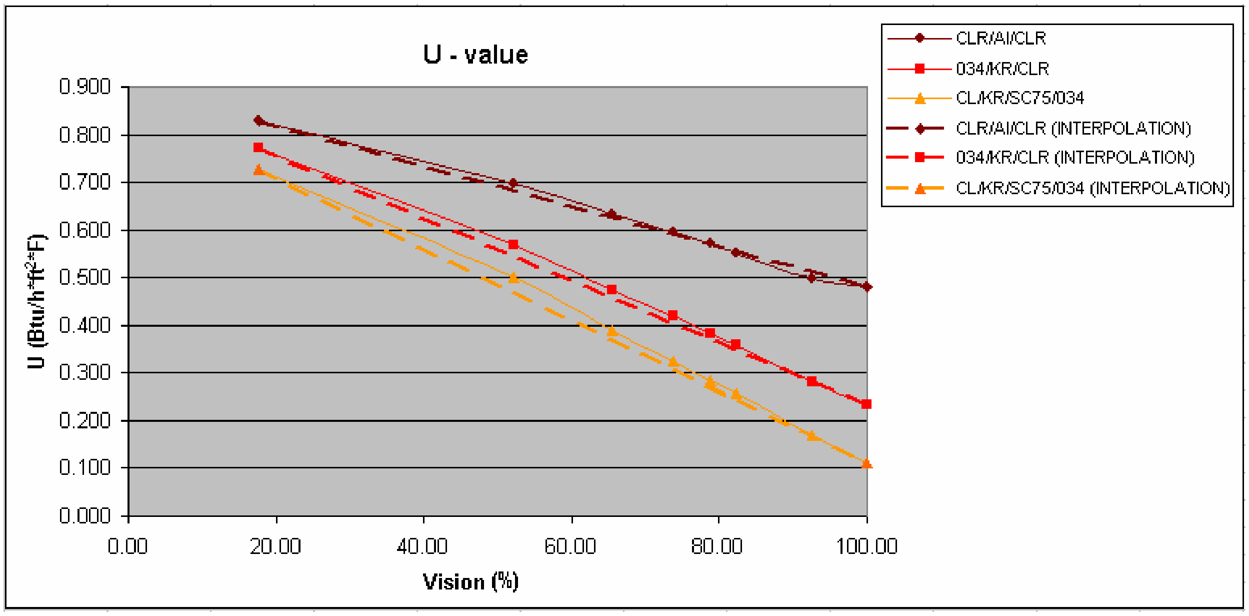

Figure 9: Variation of U factor with Vision Percentage

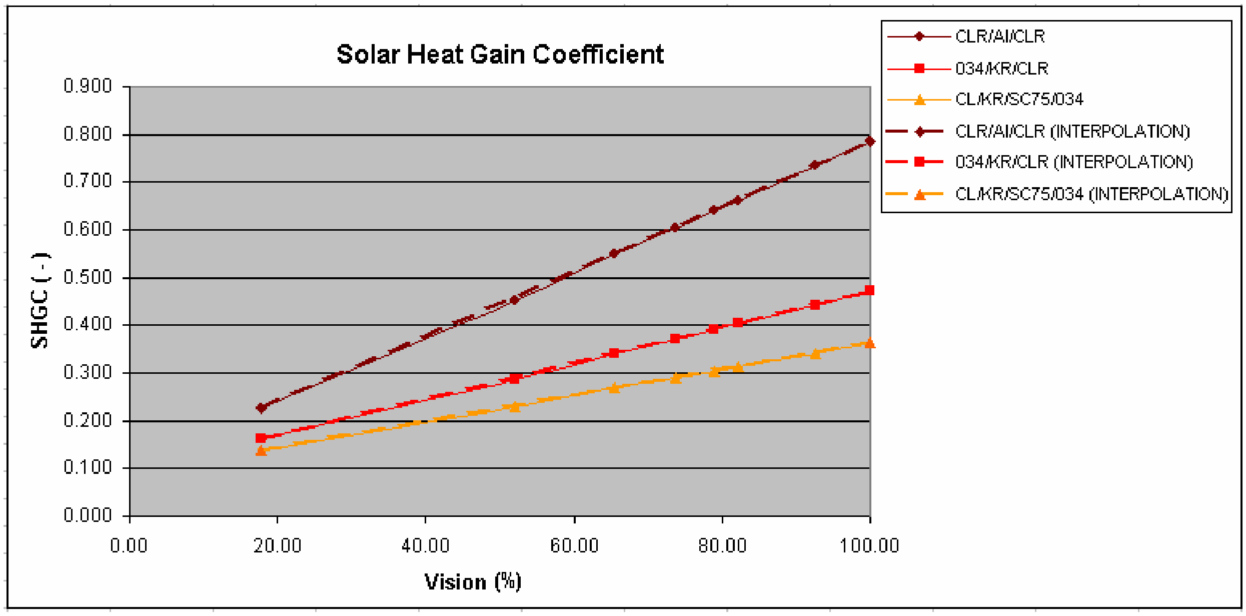

Figure 10: Variation of SHGC with Vision Percentage

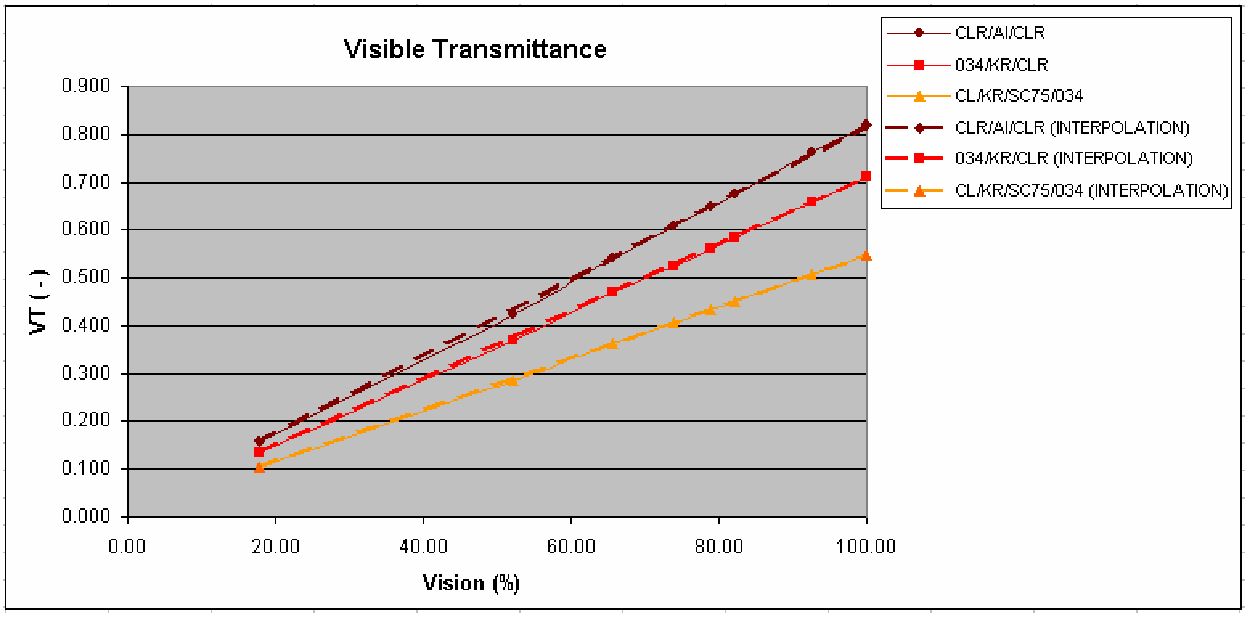

Figure 11: Variation of VT with Vision Percentage

Table 5: TRR-01 - Thermally Broken frame Fix window-(Comparison Results)

Model	Glazing System	Spacer	Size (in)	U (Btu/h*ft^2*F)			SHGC (-)			VT (-)		
				T5/W5	FENSIZE		T5/W5	FENSIZE		T5/W5	FENSIZE	
TRR-01	clr/ar/clr (7/8")	Standard Aluminum (5/8")	36x24	0.532	0.527	-0.005	0.561	0.561	0.000	0.569	0.569	0.000
			48x36	0.510	0.507	-0.003	0.624	0.625	0.001	0.640	0.640	0.000
			47.244x59.055	0.494	0.497	0.003	0.657	0.658	0.001	0.678	0.678	0.000
			72x54	0.489	0.491	0.002	0.676	0.676	0.000	0.698	0.698	0.000
			96x72	0.476	0.483	0.007	0.702	0.703	0.001	0.728	0.728	0.000
		Insulating Foam (5/8")	36x24	0.511	0.515	0.004	0.560	0.560	0.000	0.569	0.569	0.000
			48x36	0.494	0.498	0.004	0.624	0.624	0.000	0.640	0.640	0.000
			47.244x59.055	0.482	0.490	0.008	0.657	0.658	0.001	0.678	0.678	0.000
			72x54	0.478	0.485	0.007	0.675	0.676	0.001	0.698	0.698	0.000
			96x72	0.468	0.478	0.010	0.702	0.703	0.001	0.728	0.728	0.000
	034/ar/clr (7/8")	Standard Aluminum (5/8")	36x24	0.391	0.394	0.003	0.342	0.343	0.001	0.493	0.493	0.000
			48x36	0.352	0.354	0.002	0.379	0.379	0.000	0.555	0.555	0.000
			47.244x59.055	0.332	0.333	0.001	0.398	0.399	0.001	0.587	0.587	0.000
			72x54	0.320	0.321	0.001	0.409	0.409	0.000	0.605	0.605	0.000
			96x72	0.302	0.304	0.002	0.424	0.425	0.001	0.631	0.631	0.000
		Insulating Foam (5/8")	36x24	0.373	0.378	0.005	0.342	0.342	0.000	0.493	0.493	0.000
			48x36	0.339	0.342	0.003	0.379	0.379	0.000	0.555	0.555	0.000
			47.244x59.055	0.320	0.323	0.003	0.398	0.398	0.000	0.587	0.587	0.000
			72x54	0.310	0.313	0.003	0.408	0.409	0.001	0.605	0.605	0.000
			96x72	0.295	0.298	0.003	0.424	0.424	0.000	0.631	0.631	0.000

Note: NFRC standardized dimensions are marked yellow.

Table 6: TRR-97 - Aluminum Clad Fix Window-(Comparison Results)

Model	Glazing System	Spacer	Size (in)	U (Btu/h*ft^2*F)			SHGC (-)			VT (-)		
				T5/W5	FENSIZE		T5/W5	FENSIZE		T5/W5	FENSIZE	
TRR-97	Clr/ar/clr (7/8")	Standard Aluminum (5/8")	36x24	0.490	0.485	-0.005	0.591	0.591	0.000	0.612	0.612	0.000
			48x36	0.480	0.477	-0.003	0.647	0.647	0.000	0.672	0.672	0.000
			47.244x59.055	0.470	0.473	0.003	0.676	0.676	0.000	0.703	0.703	0.000
			72x54	0.468	0.470	0.002	0.692	0.692	0.000	0.720	0.720	0.000
			96x72	0.461	0.467	0.006	0.714	0.715	0.001	0.745	0.745	0.000
		Insulating Foam (5/8")	36x24	0.450	0.463	0.013	0.590	0.591	0.001	0.612	0.612	0.000
			48x36	0.450	0.461	0.011	0.646	0.647	0.001	0.672	0.672	0.000
			47.244x59.055	0.447	0.460	0.013	0.675	0.676	0.001	0.703	0.703	0.000
			72x54	0.448	0.460	0.012	0.691	0.692	0.001	0.720	0.720	0.000
			96x72	0.445	0.459	0.014	0.714	0.715	0.001	0.745	0.745	0.000
	034/ar/clr (7/8")	Standard Aluminum (5/8")	36x24	0.348	0.341	-0.007	0.357	0.357	0.000	0.530	0.530	0.000
			48x36	0.322	0.316	-0.006	0.390	0.390	0.000	0.582	0.582	0.000
			47.244x59.055	0.306	0.303	-0.003	0.407	0.407	0.000	0.609	0.609	0.000
			72x54	0.299	0.295	-0.004	0.417	0.417	0.000	0.623	0.623	0.000
			96x72	0.286	0.285	-0.001	0.430	0.430	0.000	0.645	0.645	0.000
		Insulating Foam (5/8")	36x24	0.302	0.313	0.011	0.356	0.356	0.000	0.530	0.530	0.000
			48x36	0.288	0.296	0.008	0.389	0.390	0.001	0.582	0.582	0.000
			47.244x59.055	0.279	0.287	0.008	0.406	0.407	0.001	0.609	0.609	0.000
			72x54	0.275	0.282	0.007	0.416	0.416	0.000	0.623	0.623	0.000
			96x72	0.268	0.274	0.006	0.430	0.430	0.000	0.645	0.645	0.000

Note: NFRC standardized dimensions are marked yellow.

Table 7: TRR-99 - Aluminum Horizontal Slider-(Comparison Results)

Model	Glazing System	Spacer	Size (in)	U (Btu/h*ft^2*F)			SHGC (-)			VT (-)		
				T5/W5	FENSIZE		T5/W5	FENSIZE		T5/W5	FENSIZE	
TRR-99	clr/ar/clr (3/4”)	Standard Aluminum (1/2”)	36x24	0.687	0.682	-0.005	0.630	0.630	0.000	0.643	0.643	0.000
			48x36	0.621	0.618	-0.003	0.674	0.674	0.000	0.693	0.693	0.000
			59.055x47.244	0.585	0.584	-0.001	0.697	0.697	0.000	0.720	0.720	0.000
			72x54	0.564	0.565	0.001	0.710	0.710	0.000	0.735	0.735	0.000
			96x72	0.532	0.537	0.005	0.728	0.729	0.001	0.756	0.756	0.000
		Insulating Foam (1/2”)	36x24	0.676	0.677	0.001	0.630	0.630	0.000	0.643	0.643	0.000
			48x36	0.613	0.614	0.001	0.674	0.674	0.000	0.693	0.693	0.000
			59.055x47.244	0.578	0.581	0.003	0.697	0.697	0.000	0.720	0.720	0.000
			72x54	0.558	0.562	0.004	0.710	0.710	0.000	0.735	0.735	0.000
			96x72	0.528	0.535	0.007	0.728	0.729	0.001	0.756	0.756	0.000
	034/ar/clr (3/4”)	Standard Aluminum (1/2”)	36x24	0.540	0.536	-0.004	0.384	0.385	0.001	0.557	0.557	0.000
			48x36	0.459	0.454	-0.005	0.409	0.410	0.001	0.600	0.600	0.000
			59.055x47.244	0.416	0.411	-0.005	0.423	0.423	0.000	0.623	0.623	0.000
			72x54	0.390	0.386	-0.004	0.430	0.430	0.000	0.636	0.636	0.000
			96x72	0.353	0.351	-0.002	0.441	0.441	0.000	0.655	0.655	0.000
		Insulating Foam (1/2”)	36x24	0.526	0.529	0.003	0.384	0.384	0.000	0.557	0.557	0.000
			48x36	0.449	0.449	0.000	0.409	0.410	0.001	0.600	0.600	0.000
			59.055x47.244	0.407	0.407	0.000	0.422	0.423	0.001	0.623	0.623	0.000
			72x54	0.382	0.382	0.000	0.430	0.430	0.000	0.636	0.636	0.000
			96x72	0.347	0.348	0.001	0.440	0.441	0.001	0.655	0.655	0.000

Note: NFRC standardized dimensions are marked yellow.

Table 8: TRR-02 - Thermally improved with bolts -Curtain wall -(Comparison Results)

Model	Glazing System	Spacer	Size (in)	U (Btu/h*ft^2*F)			SHGC (-)			VT (-)		
				T5/W5	FENSIZE		T5/W5	FENSIZE		T5/W5	FENSIZE	
Curtain wall	clr/ar/clr (1")	Standard Aluminum (3/4")										
			48x36	0.763	0.768	0.005	0.588	0.588	0.000	0.585	0.585	0.000
			59.055x47.244	0.702	0.708	0.006	0.627	0.627	0.000	0.631	0.631	0.000
			72x54	0.664	0.671	0.007	0.650	0.651	0.001	0.659	0.659	0.000
			96x72	0.611	0.621	0.010	0.683	0.683	0.000	0.698	0.698	0.000
		Insulating Foam (3/4")										
			48x36	0.737	0.751	0.014	0.587	0.588	0.001	0.585	0.585	0.000
			59.055x47.244	0.681	0.694	0.013	0.626	0.627	0.001	0.631	0.631	0.000
			72x54	0.646	0.659	0.013	0.649	0.650	0.001	0.659	0.659	0.000
			96x72	0.597	0.612	0.015	0.682	0.683	0.001	0.698	0.698	0.000
	034/ar/clr (1")	Standard Aluminum (3/4")										
			48x36	0.634	0.638	0.004	0.364	0.364	0.000	0.506	0.506	0.000
			59.055x47.244	0.561	0.564	0.003	0.385	0.386	0.001	0.547	0.547	0.000
			72x54	0.516	0.519	0.003	0.398	0.398	0.000	0.571	0.571	0.000
			96x72	0.453	0.457	0.004	0.416	0.416	0.000	0.605	0.605	0.000
		Insulating Foam (3/4")										
			48x36	0.604	0.618	0.014	0.363	0.363	0.000	0.506	0.506	0.000
			59.055x47.244	0.536	0.548	0.012	0.384	0.385	0.001	0.547	0.547	0.000
			72x54	0.495	0.505	0.010	0.397	0.398	0.001	0.571	0.571	0.000
			96x72	0.437	0.446	0.009	0.415	0.416	0.001	0.605	0.605	0.000

Note: NFRC standardized dimensions are marked yellow.

Table 9: Fiberglass Casement -(Comparison Results)

Model	Glazing System	Spacer	Size (in)	U (Btu/h*ft^2*F)			SHGC (-)			VT (-)		
				T5/W5	FENSIZE		T5/W5	FENSIZE		T5/W5	FENSIZE	
Fiberglass	clr/ar/clr (1”)	Standard Aluminum (3/4”)	36x24	0.452	0.448	-0.004	0.521	0.521	0.000	0.534	0.534	0.000
			23.622x59.055	0.452	0.449	-0.003	0.553	0.553	0.000	0.569	0.569	0.000
			48x36	0.454	0.451	-0.003	0.595	0.595	0.000	0.614	0.614	0.000
			72x54	0.452	0.454	0.002	0.655	0.656	0.001	0.680	0.680	0.000
			96x72	0.449	0.456	0.007	0.687	0.687	0.000	0.714	0.714	0.000
		Insulating Foam (3/4”)	36x24	0.428	0.435	0.007	0.520	0.520	0.000	0.534	0.534	0.000
			23.622x59.055	0.430	0.438	0.008	0.552	0.553	0.001	0.569	0.569	0.000
			48x36	0.436	0.442	0.006	0.594	0.595	0.001	0.614	0.614	0.000
			72x54	0.440	0.448	0.008	0.655	0.656	0.001	0.680	0.680	0.000
			96x72	0.440	0.451	0.011	0.686	0.687	0.001	0.714	0.714	0.000
	034/ar/clr (1”)	Standard Aluminum (3/4”)	36x24	0.332	0.324	-0.008	0.316	0.316	0.000	0.462	0.462	0.000
			23.622x59.055	0.326	0.316	-0.010	0.335	0.335	0.000	0.493	0.493	0.000
			48x36	0.313	0.306	-0.007	0.360	0.360	0.000	0.532	0.532	0.000
			72x54	0.295	0.291	-0.004	0.395	0.395	0.000	0.589	0.589	0.000
			96x72	0.285	0.283	-0.002	0.414	0.414	0.000	0.618	0.618	0.000
		Insulating Foam (3/4”)	36x24	0.302	0.308	0.006	0.315	0.315	0.000	0.462	0.462	0.000
			23.622x59.055	0.299	0.302	0.003	0.334	0.335	0.001	0.493	0.493	0.000
			48x36	0.290	0.294	0.004	0.359	0.359	0.000	0.532	0.532	0.000
			72x54	0.279	0.283	0.004	0.395	0.395	0.000	0.589	0.589	0.000
			96x72	0.273	0.277	0.004	0.413	0.414	0.001	0.618	0.618	0.000

Note: NFRC standardized dimensions are marked yellow.

Table 10: TR-4600 – Vinyl with Reinforcement Vertical Double hung -(Comparison Results)

Model	Glazing System	Spacer	Size (in)	U (Btu/h*ft^2*F)			SHGC (-)			VT (-)		
				T5/W5	FENSIZE		T5/W5	FENSIZE		T5/W5	FENSIZE	
TR-4600	clr/ar/clr (7/8")	Standard Aluminum (5/8")	36x24	0.471	0.457	-0.014	0.487	0.486	-0.001	0.500	0.500	0.000
			48x36	0.466	0.457	-0.009	0.570	0.570	0.000	0.589	0.589	0.000
			47.244x59.055	0.459	0.457	-0.002	0.615	0.615	0.000	0.638	0.638	0.000
			72x54	0.461	0.457	-0.004	0.638	0.638	0.000	0.663	0.663	0.000
			96x72	0.456	0.457	0.001	0.673	0.674	0.001	0.701	0.701	0.000
		Insulating Foam (5/8")	36x24	0.433	0.436	0.003	0.486	0.486	0.000	0.500	0.500	0.000
			48x36	0.438	0.442	0.004	0.569	0.570	0.001	0.589	0.589	0.000
			47.244x59.055	0.438	0.445	0.007	0.614	0.615	0.001	0.638	0.638	0.000
			72x54	0.441	0.446	0.005	0.638	0.638	0.000	0.663	0.663	0.000
			96x72	0.441	0.449	0.008	0.673	0.674	0.001	0.701	0.701	0.000
	034/ar/clr (7/8")	Standard Aluminum (5/8")	36x24	0.363	0.344	-0.019	0.295	0.295	0.000	0.433	0.433	0.000
			48x36	0.333	0.318	-0.015	0.344	0.344	0.000	0.510	0.510	0.000
			47.244x59.055	0.312	0.304	-0.008	0.371	0.371	0.000	0.552	0.552	0.000
			72x54	0.308	0.297	-0.011	0.385	0.385	0.000	0.574	0.574	0.000
			96x72	0.294	0.287	-0.007	0.406	0.406	0.000	0.607	0.607	0.000
		Insulating Foam (5/8")	36x24	0.316	0.316	0.000	0.294	0.294	0.000	0.433	0.433	0.000
			48x36	0.298	0.298	0.000	0.344	0.344	0.000	0.510	0.510	0.000
			47.244x59.055	0.286	0.289	0.003	0.371	0.371	0.000	0.552	0.552	0.000
			72x54	0.283	0.284	0.001	0.384	0.385	0.001	0.574	0.574	0.000
			96x72	0.275	0.276	0.001	0.405	0.406	0.001	0.607	0.607	0.000

Note: NFRC standardized dimensions are marked yellow.

Tables 5-10 above show that the results obtained from the two approaches are very close to each other. The maximum difference for different NFRC sizes is not more than 3% and 0.5% respectively for U-factor and SHGC and there is no difference for VT while for non-standard NFRC sizes the differences respectively for U-factor and SHGC are not larger than 5% and 1%. In absolute terms, for NFRC size differences in U-factor calculated from both approaches are no greater than 0.01 Btu/hr-ft^2-F, for SHGC no greater than 0.001 and for VT there is no difference. For sizes other than NFRC standard sizes the differences in U-factor are no greater than 0.02 Btu/hr-ft^2-F, for SHGC no greater than 0.001 and for VT there is no difference.

This component modeling procedure has been incorporated into the computer tool FENSIZE (Carli 2003). For more information about the tool and for demonstration copy, the following web site can be visited: http://www.fenestration.com/fensize.htm).

CONCLUSIONS:

The approach for modeling non-residential products, described in this paper, offers simple and effective means for determining overall thermal and solar-optical performance of fenestration products. Comprehensive validation study, covering a wide range of framing materials and spacer types that was carried out in this work, show that the performance indices calculated from this approach compare well with detailed traditional modeling procedures, which requires full numerical modeling of each glazing and spacer option, as incorporated into the window. Because this methodology requires only four generic glazing and spacer options to be modeled for any fenestration product that may incorporate arbitrary number of glazing and spacers, it saves money and preserves simplicity for the manufacturer.

This methodology is equally suitable for the rating of the non-residential products, as well as for the calculation of data that can be used in detailed building energy analysis. The component performance indices are easily assembled into the overall performance for the actual product size and configuration and utilized in building simulation programs.

This approach allows each component manufacturer to provide performance information only for its own products, calculated independently from other components. Also, the component-rating responsibility lies with each component manufacturer, where labels with information for each individual component groups (i.e., framing, glazing and spacer systems) can be provided by a manufacturer, while the performance of the overall product can be performed by a third party (i.e., glazing contractor, architect, building official, Independent agency, etc.)

This methodology can be incorporated into the computer tool, which would provide uniform and credible environment for determining overall product performance. This tool would incorporate algorithms presented in this paper and area weighting for different fenestration operator types (i.e., casement window, fixed window, horizontal slider, sliding doors, swinging doors, curtain wall, combination window, etc.).

This simplified and yet accurate approach can easily be adopted by rating organizations and the certification process can be web-based, utilizing database structure and therefore be easily accessed by users.

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