WINDOW-WALL INTERFACE CORRECTION FACTORS: THERMAL MODELING OF INTEGRATED FENESTRATION AND OPAQUE ENVELOPE SYSTEMS FOR IMPROVED PREDICTION OF ENERGY USE

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ABSTRACT

The boundary conditions for thermal modeling of fenestration systems assume an adiabatic condition between the fenestration system installed and the opaque envelope system. This theoretical adiabatic boundary condition may not be appropriate owing to heat transfer at the interfaces, particularly for aluminum-framed windows affixed to metal-framed walls. In such scenarios, the heat transfer at the interface may increase the discrepancy between real world thermal indices and laboratory measured or calculated indices based on NFRC Rating System.This paper discusses the development of Window-Wall Interface (WWI) Correction Factors to improve energy impacts of building envelope systems.

INTRODUCTION

Thermal modeling to determine thermal indices of fenestration systems for rating purposes or to be used in whole building energy analysis program is well documented. The boundary conditions for this modeling are applied assuming that the fenestration systems are installed in the test chambers where there is negligible heat transfer (i.e. adiabatic condition) between the fenestration system installed and the walls of chamber in which the fenestration system is installed. Modern building envelope systems include various thermal bridging elements. In terms of fenestration system modeling, it is assumed that frame two-dimensional heat transfer affects 63.5 mm on the glazing beyond which the heat transfer is one-dimensional (NFRC100, 2010). However, in reality, when these fenestration systems are installed in buildings, heat transfer at the window-wall interface may be significant.

A theoretical adiabatic boundary condition may not be appropriate and the heat transfer at the interface may increase the discrepancy between laboratory determined and real world thermal indices. Although several researches have focused on fenestration and opaque envelope systems separately, there is a lack of research documentation related to the heat transfer impacts at the interface of window-wall systems. Among others, the interface between the aluminum-framed window and metal-framed opaque envelope construction is more susceptible for heat transfer. Curcija et al (2001) discussed the importance of window-wall interfaces to develop correlations or correction factors taking into consideration the real world effects of heat transfer that happens at the intersections of window-wall systems. In spite of several advancements in the research and development of NFRC rating system, the heat transfer issues at the interfaces of window-wall systems have been largely ignored.

ASHRAE 1365-RP (ASHRAE, 2011) attempted to catalogue the thermal performance data of common building envelope details for mid- and high- rise construction, particularly those that were not addressed in other ASHRAE publications. Both analytical solutions and guarded hot box tests were conducted to validate heat transfer models. For intersections, ASHRAE 1365-RP quantified the linear and point transmittances for easier inclusion for energy use analysis. In the ASHRAE study, two details ("#7-exterior insulated steel stud wall with insulated flush slab intersection" and "#34-precast sandwich panel w/out cavity insulation with curtain wall transition") that corresponds to glazing and wall intersections were studied. Although such an approach improves thermal performance data of opaque envelope constructions, i.e. offers an alternate method to the series, parallel path, and zonal method in Chapter 25, "Heat, Air, and Moisture Control in Building Assemblies – Fundamentals" of 2009 ASHRAE Handbook – Fundamentals (ASHRAE Handbook, 2009), one of the limiting factor is the lack of thermal transmittances due to changes in window size. Currently, the point transmittance related to window transition is specific to the window size used in the experiment. Changes to window size will change point transmittance values (ASHRAE, 2011).

This paper discusses the development of WWI Correction Factors for two specific combinations of aluminum- framed windows and metal- framed opaque envelope constructions in order to improve energy impacts of building envelope systems. The total fenestration product U-factor of the envelope system is updated with the estimated WWI Correction Factors developed in this paper to include the effects of window-wall intersections. WWI Correction Factors improve prediction of heat transfer between the fenestration system and opaque envelope. The development of WWI Correction Factors is the first step toward aiding the process of integrating fenestration systems in opaque envelope systems. For this paper, lab tests were not conducted for comparison purposes.

MODEL DEVELOPMENT

For this project, two types of window-wall constructions were used. Although both the window-wall constructions used for this project comprised of a combination of aluminum-framed fenestration system and metal-framed opaque envelope constructions, they differ in their intrinsic design details as developed by the architects. These window-wall constructions were selected from actual construction documents. In order to determine heat transfer between window-wall constructions, sill has been included in the model. Future studies will include headers. To evaluate the impact of glazing system types, for each of these window-wall constructions, three types of double glazed systems were modeled. They are double clear (CL), hard coat low-emissivity (HC), and soft coat low-emissivity. In hard coat low-e type, the coating is covalently bonded to the glass using Chemical Vapor Deposition technology. This type is also referred to as “pyrolytic.” The soft coat low-e type or “sputtered” is manufactured using Magnetron Sputtering Vacuum Deposition technology. Sputtered type is not durable when compared to hard coat type.

To compute the WWI Correction Factors, two modeling approaches were used to determine total fenestration product U-factors of the above-mentioned glazing system type. While the first approach did not include the effects of adjacent opaque envelope constructions, the second approach included the modeling of opaque envelope constructions. In other words, the first set of models were based on NFRC modeling methodology, i.e. excludes any modeling of adjacent opaque envelope constructions to represent a theoretical adiabatic boundary condition, and the second set of models include adjacent opaque envelope constructions. In all, 12 models were developed that represented fenestration systems – with and without adjacent opaque envelope constructions, table 1.

From table 1, models #1 to #6 use typical NFRC modeling approach that excludes adjacent opaque envelope constructions in thermal modeling of fenestration systems irrespective of the types and combinations of fenestration frames and envelope construction types. NFRC 100-2010 (NFRC100, 2010) assumes a theoretical adiabatic boundary condition between fenestration system’s frame (aluminum) and adjacent opaque envelope construction (metal- framed). On the other hand, models #7 to #12 uses a unique modeling approach that recognizes the heat transfer between the box beams (tube steel structures placed to structurally hold the windows in place) and fenestration system.

Table 1. List of models.

Model. No.	Name	Constr. Type		Glazing System		
		Frame	Wall	CL	HC	SC
1	A1-CL	A1	-	✓		
2	A1-HC	A1	-		✓	
3	A1-SC	A1	-			✓
4	A2-CL	A2	-	✓		
5	A2-HC	A2	-		✓	
6	A2-SC	A2	-			✓
7	A1W1-CL	A1	W1	✓		
8	A1W1-HC	A1	W1		✓	
9	A1W1-SC	A1	W1			✓
10	A2W2-CL	A2	W2	✓		
11	A2W2-HC	A2	W2		✓	
12	A2W2-SC	A2	W2			✓

A fenestration system type “Casement – Single” of size 600 mm x 1,500 mm (24 in x 59 in) was assessed for total fenestration product U-factor. It was assumed that space between the glass panes are filled with air. The glazing system comprised of glazing, spacer, and desiccant. The typical glazing system (CL type) is a double 6mm (1/4 in) clear 6 mm (1/4 in) with 12.7 mm (1/2 in) air gap with metal spacer. Both HC and SC types use low-e coatings with emissivities of 0.202 and 0.043 respectively. As a first step, the glazing systems were modeled in WINDOW 6 (LBNL, 2011). The center-of-glass U-factors were calculated using NFRC 100-2010 environmental conditions. The center-of-glass U-factors are 2.69 W/m2K (0.47 Btu/hr-ft2F), 1.73 W/m2K (0.31 Btu/hr-ft2F), and 1.41 W/m2K (0.25 Btu/hr-ft2F) for double clear, HC, and SC respectively. The fenestration system was simulated in a vertical position. Environmental conditions for the experiment were based on Section 8.2, NFRC-100 2010. Using THERM (LBNL, 2011), the frame and edge-of-glass conductivities were calculated, table 2; figures 1-6.

Results show an increase in frame and edge-of-glass U-factors when adjacent opaque envelope construction is included in modeling heat transfer. For example, in a double clear glazing system placed in type 1 of envelope construction, frame and edge-of-glass U-factors increased by 20.8% and 2.5% when adjacent envelope constructions were included. Similarly, for type 2 envelope constructions, U-factors increased when opaque envelope constructions were included in modeling. For low-e glazing systems, these changes were even greater.

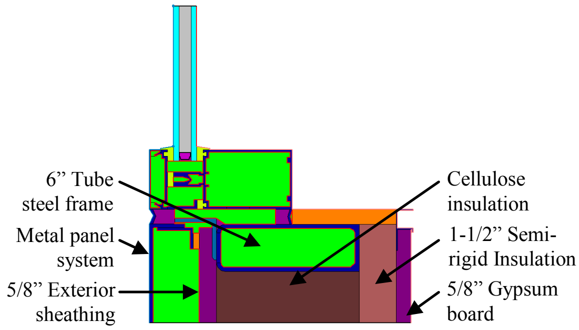
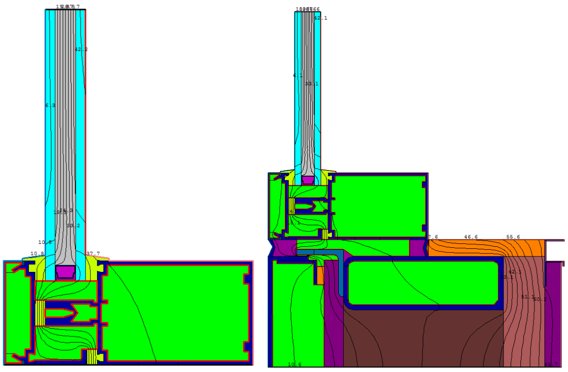


Figure 1. Model A1-CL showing wall construction.



Figures 2 & 3. A1-CL (left) and A1W1-CL (right).

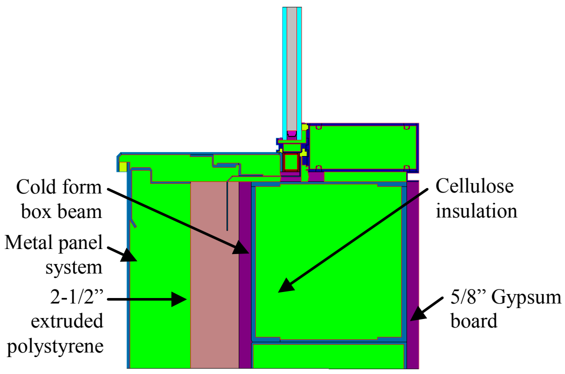
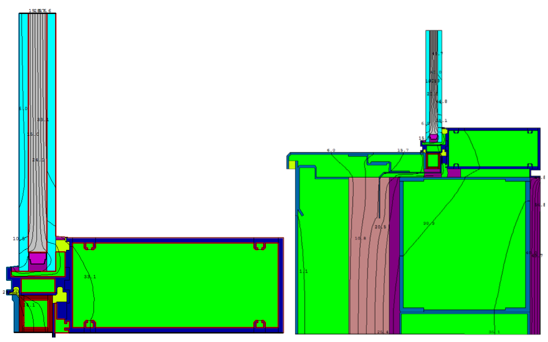


Figure 4. Model A2-CL showing wall construction.



Figures 5 & 6. THERM models: A2-CL (left) and A2W2-CL (right).

Table 2. Frame and edge-of-glass U-factors.

Name	Frame		Edge-of-Glass	
	W/m^2.K	% Diff	W/m^2.K	% Diff
A1-CL	1.36	20.8%	0.46	2.5%
A1W1-CL	1.64		0.47	
A1-HC	1.36	21.5%	0.34	4.2%
A1W1-HC	1.66		0.36	
A1-SC	1.36	21.8%	0.31	5.0%
A1W1-SC	1.66		0.32	
A2-CL	2.03	11.8%	0..46	1.9%
A2W2-CL	2.27		0.47	
A2-HC	2.03	12.5%	0.34	3.3%
A2W2-HC	2.29		0.35	
A2-SC	2.03	12.7%	0.30	4.0%
A2W2-SC	2.29		0.32	

RESULTS AND DISCUSSION

Finally, the THERM results were imported in WINDOW software (THERM 6.3/WINDOW 6.3, 2011) to calculate total fenestration product U-factor, table 3. The total fenestration product U-factor was determined based on the requirements of Reference 2 and Section 4.3.2.1, NFRC Simulation Manual (THERM 6.3/WINDOW 6.3, 2011). Area-weighted method as described in Section 4.1.3 of ISO 15099 was used to calculate overall fenestration U-factor. Thermo-physical properties of materials used in fenestration system were determined in accordance with NFRC 101-2010 (NFRC 101, 2010).

Table 3. Total fenestration product U-factors.

Name	Fenestration U-factor	
	W/m^2.K	% Diff
A1-CL	4.13	11.8%
A1W1-CL	4.61	
A1-HC	3.54	14.4%
A1W1-HC	4.04	
A1-SC	3.34	15.4%
A1W1-SC	3.85	
A2-CL	5.15	7.7%
A2W2-CL	5.55	
A2-HC	4.56	9.3%
A2W2-HC	4.99	
A2-SC	4.36	9.9%
A2W2-SC	4.80	

From table 3, it is evident that the total fenestration product U-factors increased when opaque envelope constructions were included in modeling. For example, for type 1 envelope construction, on average, an increase of 14.9% can be noticed for low-e glazing system. Likewise, for type 2 envelope construction, the average increase for low-e glazing system is 9.6%. These changes in heat transfer characteristics of fenestration systems will results in changes to envelope loads and, thereby, energy use. In other words, for certain fenestration – opaque envelope system configurations such as aluminum-framed windows and metal-framed walls, the current modeling approach, particularly NFRC recommended theoretical adiabatic condition, to determine total fenestration product U-factor may be deemed incorrect. However, through the inclusion of a Correction Factor (WWI Correction Factor, in this case), the total fenestration product U-factors may be improved to reflect real world phenomenon. For example, WWI Correction Factors, 14.9% and 9.6% may be used for envelope construction types 1 and 2 respectively.

CONCLUSION

This paper discussed the development of WWI Correction Factors for two combinations of aluminum-framed window and metal- framed envelope constructions to improve energy impacts of building envelope systems. WWI Correction Factors improve prediction of heat transfer between the fenestration system and opaque envelope. The development of WWI Correction Factors will aid in standardizing the process of integrating fenestration systems in opaque envelope systems. These fenestration indices may be passed into whole building energy modeling tools for accurate prediction of energy use. It is to be noted that the current example uses a specific window type. Besides, two-dimensional heat transfer software program has been used for this experiment and lab tests were not conducted.

In order to develop WWI Correction Factors at a more generic- level for easy inclusion in building energy use calculations, additional simulations would have to be performed. Future study will include changes to window type, dimensions, insulation material, other combinations of aluminum- framed window and metal-framed envelope construction types, and types of glass treatments to determine more generic range of WWI Correction Factors for easy implementation in existing energy simulation software. None of the current building energy modeling software has the potential to calculate WWI Correction Factors. However, the generic range of WWI Correction Factors, once developed, can be implemented within the energy modeling software. For example, in EnergyPlus™, a modified WWI Correction Factor can be implemented to the frame section of fenestration such that the frame U-factor is corrected. Alternatively, the corrected U-factor may be input in the "simple glazing method" of EnergyPlus.

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