Evaluation of the Condensation Index Rating as Determined using the Proposed Simulation Method in the NFRC 500 Draft Procedure

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ABSTRACT

This paper presents a comprehensive and detailed assessment of the proposed NFRC 500 Procedure currently under development in the NFRC Technical Committee, as developed by the NFRC Condensation Subcommittee. The proposed NFRC 500 Procedure contains a new element in the evaluation of condensation, that being the utilization of computer software in analyzing and calculating the condensation index for comparative purposes. For those products that can=t be simulated, a test only option is also offered.

The primary focus for this paper is the analysis of the simulation portion of the proposed NFRC 500 procedure, emphasizing the simulation calculations as defined in the procedure. NFRC annual test round robins are analyzed, from 1997 to 2000. The 1997 and 1998 NFRC test round robins utilized two identically constructed nominal 4040 aluminum-wood composite fixed windows with high performance glazing, one for each year. Similarly, the 1999 and 2000 NFRC test round robins employed a nominal 5030 non-thermal aluminum horizontal sliding window with high performance glazing. The simulated results will be used as a benchmark for the analysis of the testing data.

Each round robin test specimen was tested at the NFRC-accredited Testing Laboratories. The tested fenestration thermal performance ratings (U-factors) were acquired in accordance with *NFRC 100 (1997): Procedures for Determining Fenestration Product U-factors* and *NFRC Test Procedure for Measuring the Steady-State Thermal Transmittance of Fenestration Systems (April 1997)*.

Simulation results are compiled for both products, used in the 1997-1998 and 1999-2000. The simulations were done using the computer software tools WINDOW 4.1 and THERM 2.1. Specific data regarding various measured and calculated performance values as required by the NFRC Procedures and Program Documents are presented in the companion paper detailing the testing results.

Overview

NFRC 500 provides two methods of determining a condensation index rating for fenestration products, including windows, entrance doors, sliding glass doors, skylights, door-lite, and curtain wall. Fenestration products include residential, commercial and site-built applications. For the purposes of rating, the product is modeled and rated at a net zero air leakage, meaning that product is sealed and air leakage effects on condensation index rating are not accounted.

The total product is evaluated for condensation, and the rating is a total product rating. Manufacturers can now, effectively and efficiently, obtain condensation index ratings for their fenestration products by using NFRC-approved software tools used to model and calculate a CI rating in concurrence with U-factor, SHGC and VT. In essence four ratings, by using simulation software, can be obtained simultaneously.

Definitions

Condensation Index - The resistance of the a product to the formation of condensation in any form.

Conduction - the method by which heat is transferred due to free valence electrons moving through the metallic crystalline lattice or due to agitation of atoms vibrating about their equilibrium points in the lattice.

Convection - the method by which heat is transferred by the bulk, or macroscopic, motion of the fluid.

Radiation - the heat transferred process as a consequence of energy-carrying electromagnetic waves, emitted by atoms and molecules resulting from changes in their energy content. Simply, energy transfered due to propagation of electromagnetic waves.

Ambient Temperature - Temperature at a given set of environmental condition. For condensation resistance, the surrounding localized air temperatures would be considered the ambient air temperatures.

Relative Humidity - the ratio of the amount of water vapor in the air compared to the maximum amount of water vapor that the air could hold at that particular temperature. When the air is holding all of the moisture possible at a particular temperature, the air is said to be saturated.

Dew Point Temperature - the temperature to which air would have to be cooled for saturation to occur. On the surface of the window, this is the surface temperature at which condensation would first begin to form when the surface temperature, for given relative humidity conditions, are at or below the dew point temperature. If conditions are such that condensation forms when the surface temperature is above 32 F (0 C), condensation would be in the form of water droplets; and if the temperature is at or below 32 F (O C), the condensation would be in the form of frost or ice.

Simulation requirements for Condensation Index

Since both temperature and surface film coefficient affect the results, standardized conditions are used for the evaluation and rating of the condensation index.

Interior ambient temperature of 21.1°C (70°F).
Exterior ambient temperature of -17.8°C (0°F).
Relative Humidities of 30%, 50%, and 70% RH providing dew point temperatures of approximately 2.9°C (37.2°F), 10.3°C (50.5°F) and 15.4°C (59.7°F)
Wind speed of 6.7 m/s (15 mph)
Sky condition of 100% cloud cover.

Current NFRC procedure provides allowance for the use of computer simulation tools capable of 2-D conduction and radiation heat transfer analysis, and convection heat transfer analysis in glazing cavities. THERM 2.1 computer program meets the requirements of this standard and in companion of WINDOW program, capable of analyzing 1-D center of glass heat transfer, was utilized in this study.

Calculation of Condensation Index (CI)

The determination of a condensation index rating for a fenestration product is performed by analyzing each section of the fenestration system i.e frame and sash, edge-of-glass, dividers, divider-edge-of-glass and center-of-glass. For a cross-section the indoor surface is subdivided into smaller segments, no larger than the size of mesh or grid used by the simulation program. These segments are then used to compute the product of segment lengths and temperature difference used in the Condensation Index rating calculation. In addition, the total length of each 2-D cross-section is calculated. Continuing, identify the segment area that have the temperatures which are less than or equal to the dew point temperatures and than calculate the frame areas and glazing areas that have surface temperatures at or below the three prescribed dew point temperatures at 30%, 50% and 70% relative humidities. (see equation 1 for illustration of this concept)

$$S = \frac{\sum_i \left(t_{dpp} - t_i\right)^+ * \Delta L_i}{\left(t_{dpp} - t_o\right) * L} \quad (1)$$

where:

- t_{dpp} = dew point temperature + 0.5 F
- t_i = temperature of the surface segment, i
- ΔL_i = length of the surface segment, i
- L = total length of the surface

$$SS = \frac{\sum_j (S)_{j=RH\,@\,30\%,50\%,70\%}}{3} \quad (2)$$

Finally, determine the condensation index of the frame, CI_f, center-of-glazing, CI_{cog}, and edge-of-glazing, CI_{eog} by using the equivalent of equation 3:

$$CI = \left\{1 - \left\{\frac{\sum_k SS_k * A_k}{A}\right\}^{1/3}\right\} * 100 \quad (3)$$

where:

- A_k = area of each fenestration section
- A = total area of frame, center-of-glazing, or edge-of-glazing

Details on how to determine each CI for each section and the whole product are given in *NFRC 500*. When the computer modeling is performed with NFRC-approved software, the temperature measurement at locations, measurement of segment areas at or below the dew-point temperature, and subsequent CI calculations are an automatic routine of the software.

NFRC 500 is designed to provide a range of relative humidities and uses three pre-defined relative humidities, 30%, 50% and 70% for evaluation and rating purposes. 30% and 70% are the extreme ends of the relative humidity beyond which human comfort is affected, while 50% is the optimal humidity level for a home or workplace. The final condensation resistance rating is minimum value of the CI_f, CI_{cog}, and CI_{eog}.

Ratings and Sizes

NFRC provides a fair, accurate, and credible rating system for thermal performance properties such as U-factor, Solar Heat Gain Coefficient (SHGC), Visible Transmittance (VT) and Condensation Index (CI). Size is an important characteristic when considering comparison of these ratings from product to product. Size is an important parameter because of the area ratios of the frame, edge-of-glass, and center-of-glass. These same areas are used in determining U-factor of a fenestration product. However, the difference between U-factor and CI is that the former is average indice and later is the minimum of the three. This is because of the local nature of condensation, which will start forming in areas that are bellow dew point. An average rating for CI would be therefore meaningless, because if one had two extremes in the same product (e.g., low performance frame and high performance glazing, or vice versa, the average number would indicate acceptable performance, while in reality, one significant part of the window could be under condensation or even frost, potentially damaging the window and/or surrounding wall structure.

NFRC has addressed the size issue for each operator type and provides referenced sizes for comparison purposes. The current sizes can be found in *NFRC 100*, Table 1. Proposed revisions to the sizes are currently being considered, which would basically provide standard operator sizes for the following general categories: windows, entrance doors, double doors/glazed wall systems/sloped glazing, and sidelites/transoms. The same product size will be utilized for all reported indices, including CI.

Analysis of the 1997-98 and 1999-2000 Test Round Robin

The proposed condensation index equations, as found in the NFRC 500, have been used to analyze the two round robin products. The first product, tested in 1997 and 1998 is composite Aluminum/wood frame window, incorporating high performance double glazing (see Figure 1). The second product, tested in 1999 and 2000 is Aluminum (no thermal break) frame horizontal slider window with very high performance triple glazing, also known as HeatMirror product (see Figure 2). WINDOW 4.1 computer program (Ref.) was utilized to calculate center-of-glass thermal performance for both windows. These center of glass models were then imported into two-dimensional finite element computer program THERM 2.1 (Ref.) for analysis of thermal performance of frame and edge-of-glass cross sections. THERM program incorporates detailed multi-element radiation heat transfer model, which was utilized on indoor window surfaces. This was done because on indoor side, radiation heat transfer makes almost 2/3 of the total surface heat transfer coefficient, while on the outdoor side, radiation heat transfer is only a small fraction of the total surface heat transfer coefficient. Condensation Index model in THERM also incorporates convection heat transfer model in glazing cavities, as well as multi-element radiation heat transfer model. Figures 3 and 4 show sill cross section and temperature distribution for Aluminum/Wood composite frame fixed window and Aluminum frame horizontal slider window, respectively.

Table 1 summarizes calculated CI values from the two tests and one simulation run for each window. Testing CI's are the result of averaging 8 laboratories that participated in the round robin. Even though, it is evident that the tests, done in different years on the identical unit, produce different results. For 1997/1998 round robin, CI for edge-of-glass (reported value, in this case) shows the difference of almost 8 points! The simulation values have the advantage that they produce very consistent results, even when run by different simulators. When compared to test results, simulation results show reasonably good agreement, except for frame and edge-of-glass for 1999/2000 round robin. This is attributable to the fact that simulation accounts for every segment on the cross section of frame and edge of glass, while testing relies on pre-determined single point thermocouple locations, which may or may not capture an average performance of that region. Therefore, it may be concluded with certainly that simulation method produces more consistent and more accurate CI than testing does.

Table 1 Condensation Index Values

Round Robin Year	**1997-1998**			**1999-2000**		
	CI_f	**CI_{cog}**	**CI_{eog}**	**CI_f**	**CI_{cog}**	**CI_{eog}**
First Year	69.9	**68.9**	**50.9**	**18.3**	**67.9**	**31.9**
Second Year	**71.0**	**68.7**	**43.1**	**18.8**	**68.9**	**32.0**
Simulated Value	**71.8**	**67.9**	**52.2**	**6.7**	**66.7**	**48.2**

Reference material:

NFRC 500
NFRC 100
LBL Ref. 1
LBL Ref. 2

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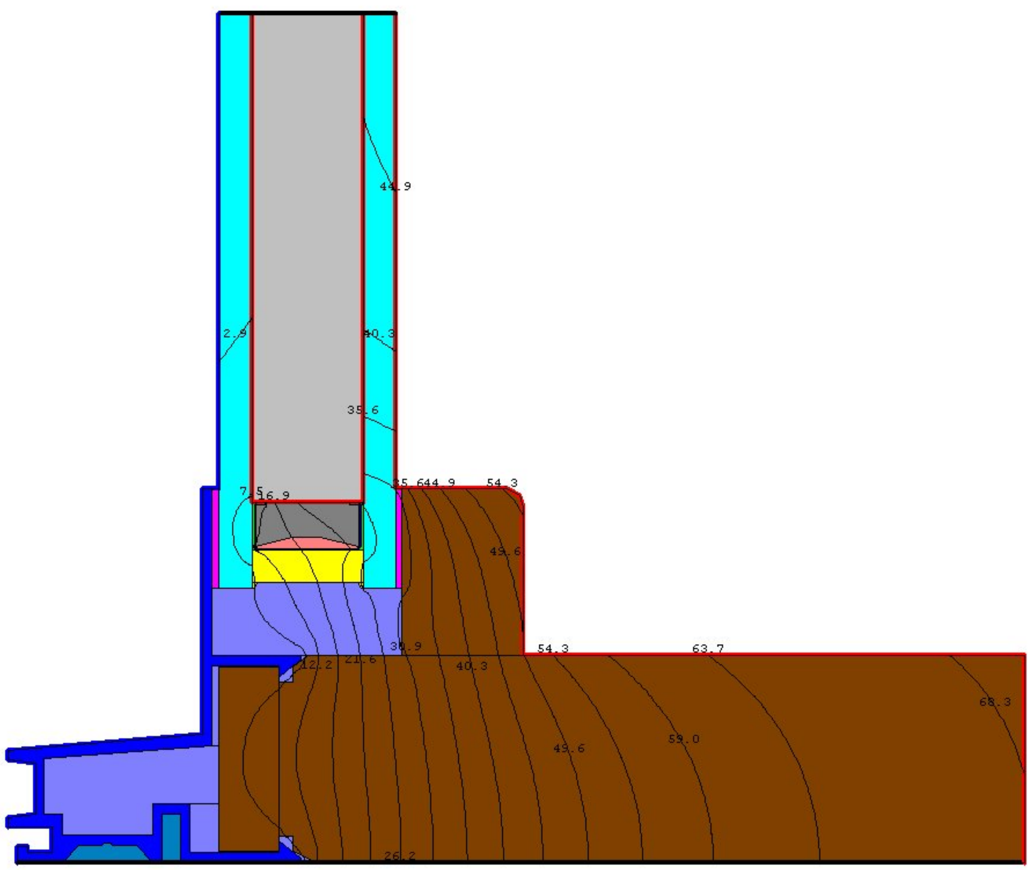

Figure 3. Heat Transfer Results for 1997/1998 Round Robin Window (Sill cross section)

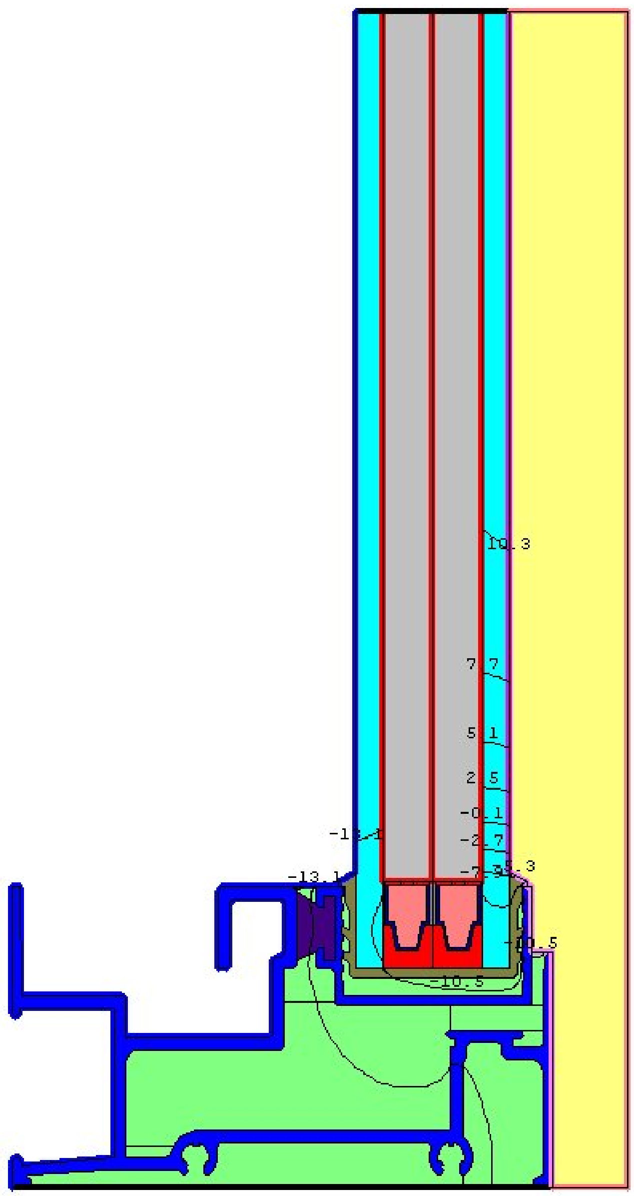

Figure 4. Heat Transfer Results for 1999/2000 Round Robin Window (Sill cross section of vented side)

APPENDICES