National Fenestration Rating Council Incorporated

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User Guide to NFRC 500: Procedure for Determining Fenestration Product Condensation Resistance Rating Values

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FOREWORD

Questions on the use of this procedure should be addressed to:

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Table of Contents

1. UNDERSTANDING CONDENSATION PERFORMANCE

1.1 Purpose

NFRC 500 provides a method of determining a condensation resistance rating for fenestration products by simulation and testing. Condensation Resistance ratings can be determined for windows, doors, skylights, storefronts, site-built products and curtain wall systems. These products are included in the definition of fenestration products. For the purposes of rating, a product is modeled and rated at a specified set of environmental conditions and at a specific size depending on the product type. The procedure rates the product at net zero air leakage, meaning that product air leakage is not considered.

The total product, comprised of all fenestration system components (such as frame, glazing and dividers), is evaluated for condensation resistance, and a rating is established for the total product. Manufacturers are able to obtain condensation resistance ratings for all fenestration products specified in NFRC 500. These include individual product designs using different combinations of glazing options, spacers and other components. NFRC-approved software tools are used to model and calculate a Condensation Resistance rating concurrently with U-factor, Solar Heat Gain Coefficient (SHGC) and Visible Transmittance (VT). In essence, four ratings can be obtained simultaneously by using the simulation software.

The use of NFRC-approved simulation tools also provides the user additional capabilities such as the ability to:

A. Evaluate the fenestration product condensation resistance for different environmental parameters specific to job conditions (such as interior and/or exterior ambient temperatures and individual relative humidity).

B. Evaluate actual specified sizes.

C. Generate a colorized version of a thermo-graphic image that can provide better understanding of the product’s performance; and

D. Obtain comparison of product performance by changing one or more components such as the glazing or a spacer in the model.

With the speed of today's computers, these tasks can be accomplished in a very short period of time.

NFRC 500 currently only addresses condensation, and the potential for formation of condensation, on the interior surfaces of a fenestration product. Condensation on the exterior of a product, or condensation that forms between glazing layers, is not considered and is not a part of the procedure.

1.2 Understanding Condensation Resistance Rating

The indicated resistance of a fenestration product to the formation of objectionable condensation in either liquid or solid form at the specified environmental conditions per NFRC 500.

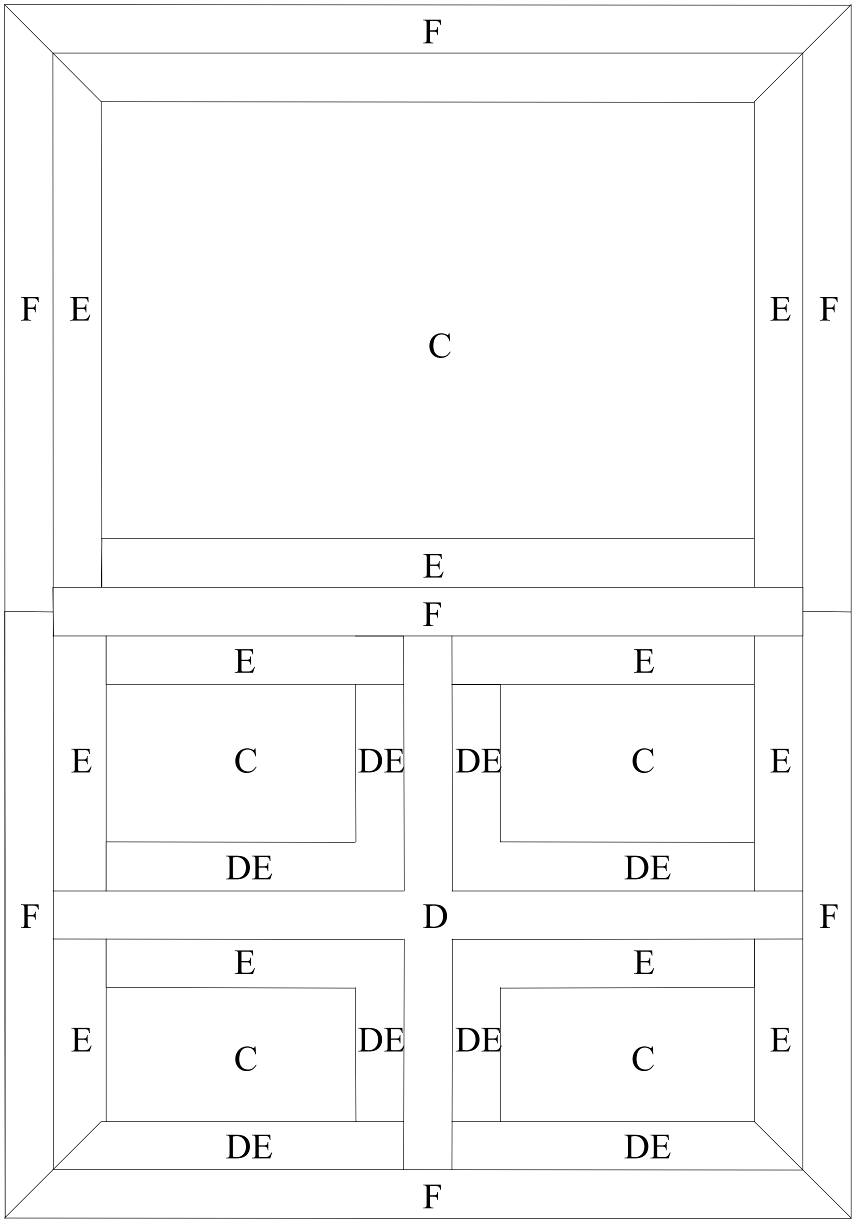
Condensation forms when the surface temperature is at or below the dew point temperature of the surrounding air. To assist in preventing the formation of condensation, fenestration product manufacturers have to design their products with components having improved thermal performance. The purpose of this design effort is to raise the interior surface temperature above the dew point and, therefore, reduce the possibility of condensation forming on the interior of a product. Some of the components to be considered by a manufacturer while designing a fenestration product in order to get a condensation resistive product are as follows: frame systems fabricated from materials of low thermal conductivity and/or having thermal barriers (material of high resistance put in the path of heat transfer); warm-edge technology spacer systems that improve the resistance to heat flow; and high performance glazing.

Frame material properties, spacer systems and designs, and glazing types will, separately or in combination, affect the product's resistance to the formation of condensation. The ability of manufacturers to design and modify fenestration products has been enhanced with the use of simulation software tools. Designers and simulators can readily change component materials and designs, and then calculate the resultant changes quickly and efficiently. Optimization of a particular design is enhanced by using the computer-assisted software tools.

A fenestration product typically has three distinct areas, or zones, that can be evaluated for the formation of condensation. Those areas are the frame area, the edge-of-glazing area and the center-of-glazing area. The frame is evaluated as one component, as is the center-of-glazing. The edge-of-glazing is the third area, and is described in more detail below. Divider and divider edge-of-glazing areas are considered part of the center-of-glazing area (see Figure 1-1).

The area that acts as an interface between the frame and center-of-glazing region is termed the edge-of-glazing. For the purpose of a Condensation Resistance calculation, the edge-of-glazing area is a 63mm (2 1/2 in.) band from the frame sightline towards the center-of-glazing region, which is the same area utilized for the calculation of an edge-of-glazing U-factor.

Figure 1-1 Fenestration Product Schematic Vertical



LEGEND

C	Center-of-glazing
E	Edge-of-glazing
F	Frame
D	Divider
DE	Edge-of-divider

Because of the design and sometimes-complex nature of this edge-of-glazing area, as well as apparent differences in the rate of heat loss and interior surface temperatures, the edge-of-glazing area is considered separately.

Condensation will form first at the surface locations that exhibit the coldest surface temperatures. In most thermally efficient designs, condensation formation will occur at some location along the perimeter of the glazing before it will occur in the center-of-glazing region (condensation will form on the frame first on a product that has a metal frame without a thermal barrier and a thermally efficient insulating glass (IG) unit). If condensation is occurring in the center-of-glazing region before it appears at the perimeter, the air gap in the IG unit may be partially or totally collapsed at the center. An important component of this edge-of-glazing area is the spacer system. A spacer system, which is designed to be thermally efficient, will improve the resistance to condensation by allowing less heat transfer, and thus increasing the interior surface temperatures around the perimeter of the glazing. A spacer system that has a higher conductance may result in lower perimeter edge temperatures and thus may cause condensation to form.

Other design features which must be considered if applicable are dividers (internal grids or muntins) and true divided lites. The composition, location, and pattern, singularly or in combination, may have an effect on the formation of condensation. If the muntins are internal, the distance from the internal surfaces of the glazing may have an influence on the interior surface temperature of the glazing.

NFRC 500 provides for the calculation of separate condensation resistance ratings for each of these three areas. The lower of the three values is used as the condensation resistance rating of the total product.

1.3 General

In the realm of thermal performance of fenestration products, reducing or eliminating condensation is one of several fenestration product selection criteria that become increasingly important in cold climates. In addition to the aesthetic issue of reduced visibility or view, condensation can cause damage to curtains, carpets and wall finishes, cause mold and wood rot, lift paint and plaster, and eventually result in significant damage to other building materials and the fenestration product itself. Water contact with IG unit sealant may result in premature failure of the edge seals and thus result in reducing the overall product thermal performance.

The formation of condensation on the interior surfaces of fenestration products is dependent on a number of factors, which include environmental parameters such as the indoor air temperature, outdoor air temperature, and the relative humidity inside the building. As the outside temperature falls, areas of the fenestration product's interior surfaces may fall below the dew point temperature. The dew point temperature is a function of the relative humidity of the air. The higher the relative humidity, the higher the dew point temperature. This means that with the same fenestration product surface temperature conditions, condensation will occur sooner in a space with a higher indoor relative humidity. Measured winter relative humidity levels in buildings typically vary between 20 and 70 percent.

The NFRC Condensation Resistance scale is 1-100, with a higher number representing more resistance to the formation of condensation. The Condensation Resistance rating is determined based on outside conditions of approximately -18ºC (-0.4ºF) with a 6m/s (15mph) wind, and inside conditions of approximately 21ºC (69.8ºF) with relative humidities of 30 percent, 50 percent, and 70 percent taken into consideration. The Condensation Resistance rating is a value that considers the relative area under condensation at these three humidity levels, which are then normalized, and the degree to which the surface temperatures are below the dew point for the frame and for the glazing are taken into account. The Condensation Resistance rating specified in the NFRC rating is based on the lower of the frame, center-of-glazing, or edge-of-glazing values.

The Condensation Resistance rating is determined for very specific environmental conditions. When installed in a building, there are numerous uncontrolled, site specific factors that may affect the formation of condensation on the fenestration product, including installation details, site geometry, wind speed and direction, and fenestration product coverings, to name a few. In this procedure, the Condensation Resistance rating is meant to apply only to the exposed interior fenestration product surfaces under cold winter conditions. The procedure does not address the issue of condensation on the exterior fenestration product surface as can occur during seasons other than winter.

To increase the resistance of fenestration products to the formation of condensation, it is important to maintain the surface temperature of the fenestration products above the dew point. To accomplish this, fenestration product manufacturers must reduce the amount of heat that passes through a fenestration product in the form of *thermal transmittance* (U-factor). Heat from inside the building will conduct its way through the parts of the fenestration product that are the least energy efficient (i.e., are highly conductive), causing those parts to have lower indoor surface temperatures. This increases the potential for condensation on and around these less energy efficient parts of the fenestration product.

Other ways to improve the resistance to condensation on fenestration products are controlling the indoor temperature, relative humidity and air circulation. Individually, or in combination, these factors can reduce the possible formation of condensation. Increasing the indoor air temperature would increase the dew point, however, there are potential adverse affects in increased heating bills. Reducing the relative humidity in a living space to slightly above or at 30 percent, the lower limit of human comfort, would lower the dew point. The movement of air over the surface of a fenestration product increases the evaporation rate of moisture, and thus slows the formation of moisture on the surface. Many homes and offices have some type of interior window treatment, such as blinds or drapes. While blinds and drapes are typically beneficial in the reduction of heat loss, they can adversely affect the resistance to condensation. In the closed or partially closed position, the interior surface temperatures of the fenestration product could be decreased, and if they are decreased below the dew point temperature, condensation formation takes place.

2. PHYSICAL FACTORS AFFECTING CONDENSATION

2.1 Environmental Factors

NFRC uses specific conditions for the purpose of rating and comparing products. However, real world environmental conditions are not constant, and are a function of the surroundings to which the product is exposed. There are a number of environmental variables, singularly or in combination, which can have a significant influence on the performance of a fenestration product as it pertains to the resistance to the formation of condensation.

Environmental factors that can influence the resistance to condensation formation are exterior wind, interior air movement, relative humidity, localized interior and exterior ambient temperatures at the product surfaces, and the temperatures the product is radiating to (e.g., during night time conditions and a clear sky, the radiant temperature will be lower than the localized air temperature at the exterior of the product). Specific rooms within a building can be influenced by the activities occurring in those rooms. Bathrooms and the kitchen are two rooms that may experience high humidity levels as a result of bathing or cooking. Rooms with large numbers of plants such as conservatories or sun rooms may also experience both higher humidities and higher than normal temperatures. High occupancy buildings, such as dormitories, may experience high humidity due to the concentration of people in those buildings. Special treatment rooms such as natatoriums or burn recovery rooms may be designed for high relative humidities. When selecting a Condensation Resistance rating it is important to review and understand the environmental factors to which the fenestration product(s) will be exposed. A detailed analysis that addresses the required environmental factors may be required.

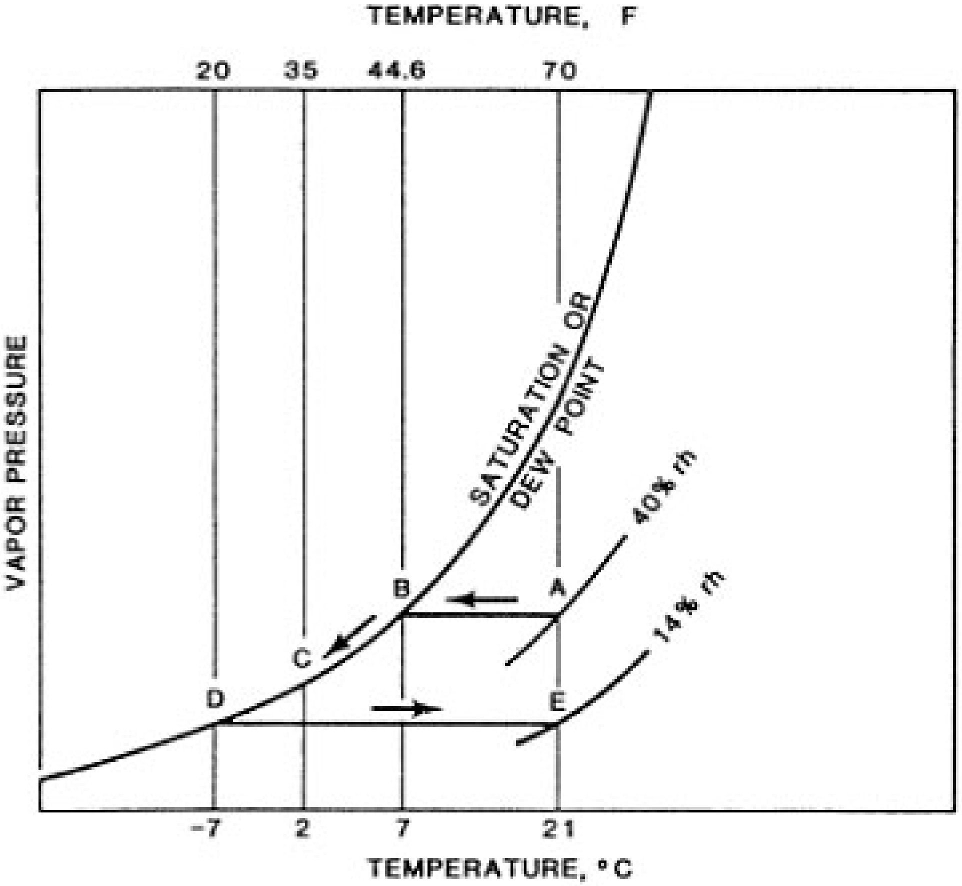
2.2 Effect of Change in Temperature:

The properties of air and water vapor mixtures are relatively well known. Changes in these properties with heating and cooling can be followed readily with the aid of a psychrometric chart, represented in Figure 2-1. The saturation line represents the limiting concentrations of water vapor, which can exist as vapor at various temperatures.

The indoor condition of 21ºC (69.8ºF) and 40 percent relative humidity (RH) is represented by point A. This is a condition of partial saturation; i.e., less than 100 percent RH. The actual vapor pressure of the water present in the air, although not shown in the chart, can be calculated readily from the vapor pressure at saturation and the RH, since RH is approximately the ratio of the actual vapor pressure to the saturation pressure at the existing temperature, expressed as a percentage.

The increased RH accompanying cooling from condition A on the chart to point B can be readily followed. At B, 7ºC (45ºF), the RH becomes 100 percent and the air/vapor mixture is said to be saturated. On further cooling to 2ºC (35ºF), the original amount of water vapor can no longer be retained and is reduced by condensation to condition C. The process illustrated by ABC is typically that which an air/vapor mixture experiences when in contact with a cool fenestration product surface. Cooling from B to C results in visible condensation on the fenestration product components. If point C were below 0ºC (32ºF), the condensate would be frost, and in more severe conditions, ice.

Figure 2-1 Psychometric Chart of Dew Point Curve



Once the temperature drops below the dew point, or frost point if below 0ºC (32ºF), the vapor pressure at the condensing surface is also reduced, establishing a gradient of vapor pressure from room air to the fenestration product surface. This gradient with convective action within the room will move water vapor continuously to the fenestration product surface, causing it to be condensed, so long as the concentration of water vapor in the room is maintained. NFRC 500 considers this effect by considering the temperature difference between the dew point and the surface temperatures. The procedure also accounts for the area which is affected by the surface temperature at or below the dew point temperature. This method of evaluation is important to fenestration product designers.

2.3 Fenestration Product Design Factors

Fenestration product manufacturers and the designers responsible for improving the energy efficiency of fenestration products have many new or improved technologies that are now available to them that ten years ago were either not developed or were still in developmental stages. The use of lower conductivity frame materials reduces the possibility of the formation of condensation. Improvements in glazing technology with the advent of low emissivity coatings, inert gas-fills used in the air space cavities, tints/coatings/films, and low conductivity spacer systems (warm edge technology) have all added to the selection of components and materials that the manufacturer has at their disposal to improve the energy performance, and reduction in the potential for condensation formation, of their products.

3. DEFINITIONS

Ambient temperature: temperature at a given set of environmental conditions. For condensation resistance, the surrounding localized air temperature would be considered the ambient air temperature.

Dew point temperature: the temperature to which air would have to be cooled for saturation to occur. On the surface of a fenestration product, this is the surface temperature at which condensation would first begin to form. If conditions were such that condensation forms when the surface temperature is above 0ºC (32ºF), condensation would be in the form of water droplets. If the temperature were at or below 0ºC (32ºF), the condensation would be in the form of frost or ice.

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

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

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

Relative humidity, RH: 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 a particular temperature. When the air is holding all of the moisture possible at a particular temperature, the air becomes 'saturated', or is in a state of 'saturation'.

4. DETERMINATION OF CONDENSATION RESISTANCE RATING

The first and primary method is using NFRC-approved simulation tools for the determination of the condensation resistance rating. The fenestration product shall be simulated in accordance with an NFRC-approved software tool that includes a multi-element gray-body diffuse radiation model and detailed convection modeling inside all glazing cavities.

A second method, that of physical testing, shall be used only in the case where a fenestration product cannot be accurately simulated using currently approved NFRC software tools. In this instance, physical testing is the only alternative offered to obtain condensation resistance ratings. The test can be performed simultaneously during the U-factor test using NFRC 102. For condensation resistance evaluation, additional thermocouples are attached to the interior surface of the test specimen in pre-specified locations.

4.1 Simulation Requirements for Condensation Resistance Rating

Since both temperature and surface film coefficients affect the results, standardized conditions are used for calculation of the condensation resistance rating.

A. Interior ambient temperature of 21.0ºC (69.8ºF).

B. Exterior ambient temperature of -18ºC (-0.4ºF).

C. Relative Humidity levels of 30 percent, 50 percent and 70 percent RH providing dew point temperatures of approximately 2.9ºC, 10.3ºC and 15.4ºC (37.2ºF, 50.5ºF and 59.7ºF).

D. Exterior wind speed of 6.7 m/s (15 mph).

E. Sky condition of 100 percent cloud cover.

Current NFRC procedures provide allowances 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.

4.2 Calculation of the Condensation Rating

The calculation of a condensation resistance rating for a fenestration product is performed by analyzing each section of the fenestration product; i.e. frame and sash, edge-of-glazing, dividers, edge-of-divider and center-of-glazing. For a cross-section, the indoor surface is subdivided into smaller segments no larger than the size of the mesh or grid used by the simulation program. These segments are then used to compute the product of segment lengths and temperature differences used in the Condensation Resistance rating calculation. In addition, the total length of each 2-D cross-section is calculated. Additionally, the segment areas that have the temperatures which are less than or equal to the dew point temperatures are identified. The final determination is calculating the frame areas and glazing areas that have surface temperatures at or below the three prescribed dew point temperatures at 30 percent, 50 percent and 70 percent relative humidity (see Equation 4-1 for illustration of this concept).

$$S = \frac{\sum_i \left(t_{dpp} - t_i\right)^+ \cdot \Delta L_i}{\left(t_{dpp} - t_o\right) L} \qquad \text{Equation 4-1}$$

Where

t_{dpp} = dew point temperature + 0.3ºC (0.5ºF)
t_i = temperature of the surface segment, *i*
ΔL_i = length of the surface segment, *i*
L = total length of the surface
t_o = exterior weather side temperature
$(\,)^+$ = the $^+$ indicates positive values only

The value of *S*, at a given relative humidity, provides information about the severity of condensation formed and the area of the cross-section that is influenced by condensation. The higher the value of *S*, the more the severe the condensation. This value is helpful for plotting the thermo-graphic picture of the cross-section modeled.

Critical design temperature, T^*, for the condensation can be defined as:

$$T^* = \frac{\left(t_{dpp} - t_i^*\right)^+}{\left(t_{dpp} - t_o\right)} \qquad \text{Equation 4-2}$$

Where

T_I^* = coldest temperature of all the surface segments under consideration, *i*

By having the value of T^* positive or if t_i^* is less than or equal to the t_{dpp} temperature, there is a likelihood of condensation formation for the specified humidity under consideration. The higher the value of T^*, the more severe the condensation.

NFRC provides the condensation resistance rating for fenestration products with the objective of providing methodology to differentiate products in the market place. By considering the three relative humidity levels of 30 percent, 50 percent and 70 percent to calculate *S*, and then averaging the sum of the value to be used in the calculation of CI, the procedure is sensitive to any variation in the surface temperatures (see Equation 4-3). This helps to differentiate similar products in the market place, which have very little difference in terms of design criteria.

$$SS = \frac{\sum_{j} (S)_{j=RH\,@\,30\%,50\%,70\%}}{3} \qquad \text{Equation 4-3}$$

As a result of the previous calculations, the user can determine the condensation resistance rating of the frame, center-of-glazing, and edge-of-glazing, by using the equivalent of Equation 4-4:

$$Condensation\,Re\,sistence = \left\{ 1 - \left\{ \frac{\sum_{k} SS_{k} A_{k}}{A} \right\}^{1/3} \right\} \times 100 \qquad \text{Equation 4-4}$$

Where

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

Details on how to evaluate each cross section and determine their corresponding surface temperatures for use in calculating Condensation Rating frame, Condensation Rating center-of-glazing, and Condensation Rating edge-of-glazing for the whole fenestration product are stipulated in NFRC 500. When the computer modeling is performed with NFRC-approved software, the temperature measurement locations, measurement of segment areas at or below the dew-point temperature, and subsequent Condensation Resistance calculations are an automatic routine of the software.

NFRC 500 uses three pre-defined relative humidity levels, 30 percent, 50 percent and 70 percent for evaluation and rating purposes. 30 percent and 70 percent are the extreme ends of the relative humidity beyond which human comfort is typically affected, while 50 percent is considered the midpoint of the referenced range of humidities. The final condensation resistance rating is the minimum value of the Condensation Rating frame, Condensation Rating center-of-glazing, and Condensation Resistance edge-of-glazing values.

The condensation resistance ratings determined using NFRC 500 are for comparison purposes only. As the Condensation Resistance rating number increases, the fenestration product’s ability to resist the formation of condensation increases.

5. CALCULATION OF CONDENSATION RESISTANCE RATING USING THE PHYSICAL TEST PROCEDURE

In the case of physical testing, temperature sensors known as thermocouples are attached to the interior of the specimen. The temperatures are configured in a pre-specified arrangement so as to adequately area-weight specific area segments of the specimen with a measured temperature. Calculations are then performed to determine area-weighted temperatures for each defined area of the specimen. Additional calculations are then performed in accordance with the NFRC 500 procedure to determine the Condensation Resistance rating for each of the three designated regions: the frame, the center-of-glazing, and the edge-of-glazing.

Standardized test conditions are used for the evaluation and rating of the Condensation Resistance rating, which are defined in the NFRC 102 document.

The determination of a condensation resistance rating for a particular fenestration product is performed using the same calculation methods, whether the simulation or test only method is used. However, when the computer modeling is performed with NFRC-approved software, the temperature location and area calculations are performed for each element defined by the finite element meshing at the boundary, and are an automatic routine of the software. For the physical test procedure, this level of temperature determination is not possible; therefore the area segment considered during testing is larger than the segment considered for simulation. The area segment considered may have temperature variations, and therefore an area-weighted temperature calculation is performed by measuring the temperature using a thermocouple placed at the center of a representative area and then calculating the average representative temperature for the segment. These measured area-weighted temperatures are then used in the equations specified in NFRC 500 to calculate separate condensation resistance ratings of the frame, the center-of-glazing, and the edge-of-glazing.

When determining a condensation resistance rating, the user of the NFRC 500 procedure first calculates the average interior ambient surface temperature for each individual thermocouple location. The next step is to calculate the wetted area assigned to each individual surface thermocouple sensor as described in Section 6.2.2 of NFRC 500. Next, the percentage areas are determined by calculating the percent area for each individual surface thermocouple based on the total calculated wetted surface area of all centerline pre-determined thermocouple locations. Thermocouple temperatures are identified that are less than the dew point temperatures and used to calculate the frame areas and glazing areas that have surface temperatures at or below the three prescribed dew point temperatures at 30 percent, 50 percent and 70 percent relative humidity. Finally, a determination is made of the condensation resistance rating of the frame, the center-of-glazing and the edge-of-glazing using the equations as defined in NFRC 500.

6. 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 Resistance (CR). Size is an important characteristic of the product when considering comparison of these ratings from product to product. Variation in the size of the product can be important when any of these ratings are considered because size affects the area ratios of the frame, edge-of-glazing and center-of-glazing. The condensation resistance rating is a total product rating and is evaluated using three distinct areas: the center glazing area (comprised of the center-of-glazing, divider, and edge-of-divider), the edge glazing area (comprised of the edge-of-glazing) and the frame area (frame and sash components) for specific sizes of a fenestration product. Differing sizes of the same product may have different ratings.

NFRC has addressed the size issue for each operator type and provides referenced sizes for comparison purposes. The current sizes can be found in Table 4-3 of NFRC 100. Table 4-3 provides standardized sizes for the following general categories: windows, doors, glazed wall systems/sloped glazing, and sidelites/transoms.

NFRC 500 provides ratings at specific environmental conditions for comparative purposes only. The procedure is not intended to predict or evaluate the formation of condensation; the amount of, or locations of, the condensation; the severity of the condensation; or the performance characteristics at varying environmental conditions.

7. ADDITIONAL INFORMATION AND READING MATERIAL

[1] *Residential Windows: A guide to new technologies and energy performance.* Second Edition. John Carmody, Steven Selkowitz, Dariush Arasteh, and Lisa Heschong. W.W.Norton and Company. New York. 2000.

[2] Special Publication, A440.3-98, User Guide to CSA Standard A440.2-98, Energy Performance of Windows and Other Fenestration Systems, pages 39 - 55.

[3] *Window Systems for High Performance Buildings.* John Carmody, Stephen Selkowitz, Eleanor S. Lee, Dariush Arasteh, and Todd Willmert. W.W. Norton and Company. New York. 2004.

Index