# CONSIDERATIONS FOR THE CONDENSATION RESISTANCE OF FENESTRATION ASSEMBLIES

**Tracy G. Rogers**[1]

***KEYWORDS***

1 = condensation 2 = Condensation Resistance 3 = Condensation Resistance Factor 4 = CRF

5 = U-factor 6 = thermal transmittance 7 = mold 8 = moisture damage

***ABSTRACT***

The ever stringent focus on the thermal performance of fenestration products for thermal transmittance (U-factor) and solar heat gain (SHGC) ignores the third thermal performance parameter of these systems; condensation resistance. While U-factor and SHGC are area-weighted performance averages of the fenestration system, condensation resistance is a localized condition that relies on performance characteristics of discrete locations in the fenestration system. Performance factors that may have a minimal impact on U-factor and/or SHGC may be critical in the prevention of condensation formation that may, if not controlled, lead to health concerns and building component/system damage. Tighter buildings with reduced fresh air exchanges may exacerbate the problems and concerns with condensation formation on interior fenestration surfaces. This paper compares the differences between the performance of fenestration products relative to U-factor and condensation resistance and outlines principal design features to improve the latter.

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## *INTRODUCTION: U-FACTOR VS. CONDENSATION RESISTANCE – THE BASICS*

### **U-Factor Basics**

U-factor is a measure of the heat flux (quantity of heat energy) that is transmitted from the air on the warm side of a fenestration system to the air on the cold side. It is, therefore, also known as air-to-air transmittance through a window, door or skylight. U-factor is represented in imperial units as BTU/hr-ft$^2$-°F and in metric units as W/m$^2$-K. Functionally, these represent the amount of heat energy transmitted through a product per hour, per degree temperature difference from the hot side to the cold side as averaged over the entire projected area of the system. While certain sections of a fenestration product may transmit more heat energy than others, the U-factor value represents the heat flux averaged over the entire area of the system.

This "area-weighted average U-factor" characterizes the impact of each component of the fenestration system based on the respective area percentage that the component represents relative to the projected area of the entire fenestration product as represented in the following simplified formula:

$$U_w = \frac{U_f * A_f + U_{cog} * A_{cog} + U_{eog} * A_{eog}}{A_w}$$

Where:

*Uw = total window U-factor*

*Uf = frame components U-factor*

*Af = frame components projected area*

*Ucog = center-of-glass components U-factor*

*Acog = center-of-glass components projected area*

*Ueog = edge-of-glass components U-factor*

*Aeog = edge-of-glass components projected area*

*Aw = total window project area*

Obviously in most window products, the glazing area, particularly the center-of-glass area, has the most significant influence on the product as it has the greatest percentage of projected area (Figure 1). The next area of greatest influence becomes dependent on a number of variables including type of window (e.g., casement, fixed, hung, etc.), frame material, frame reinforcement, frame cross-section, spacer/sealant system, location of spacer system in frame, etc.. Each of these may have multiple components of varying size and thermal conductivity and the individual effect of each on the overall U-factor can be marginalized as the relative projected area of the individual component relative to the entire window system becomes less and less.

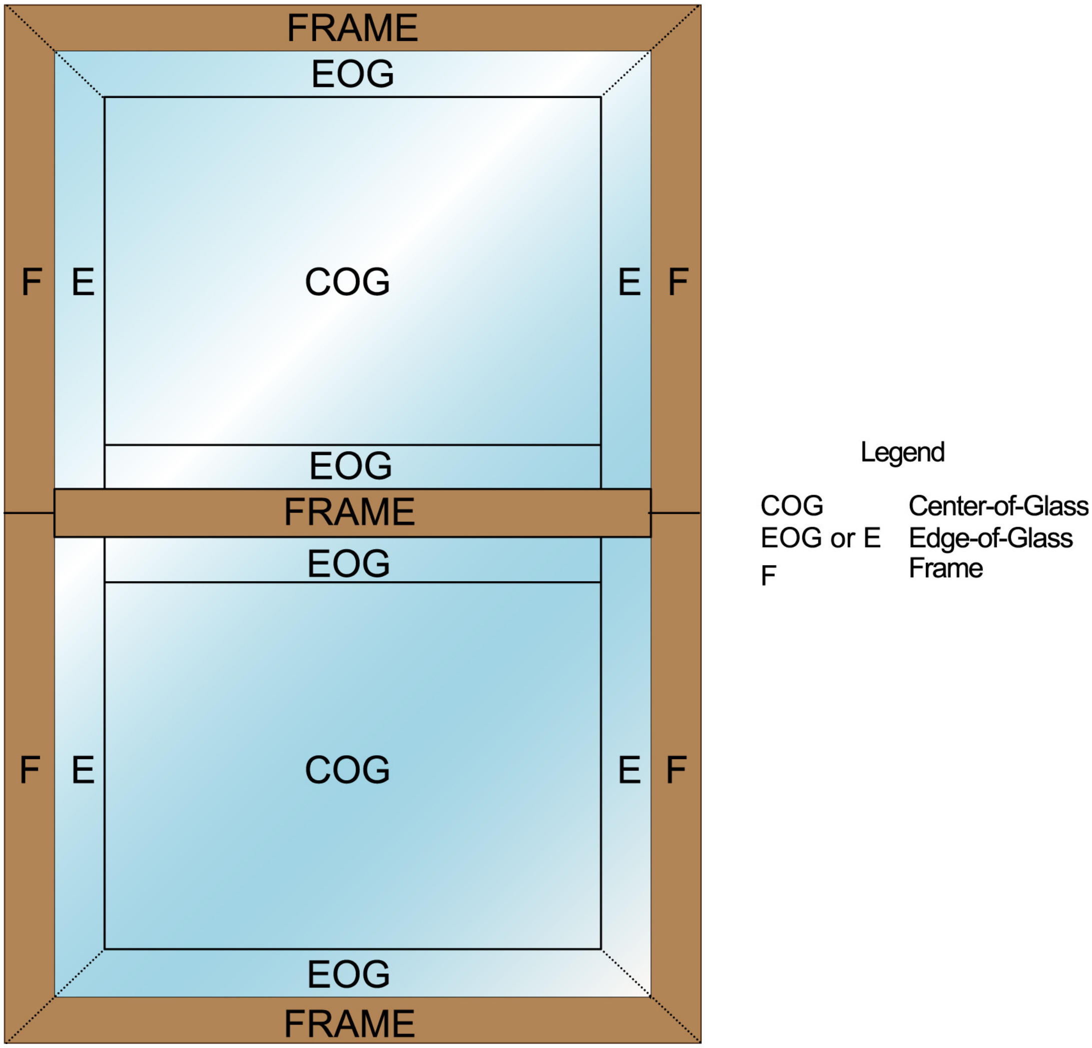



Figure 1: Area weighted sections for thermal analysis

**Condensation Resistance Basics**

As compared to U-factor, condensation resistance has far less to do with system performance than with component performance. The determination of a fenestration system's ability to resist the formation of moisture condensation on interior surfaces, whether physically measured or computer simulated, is an evaluation of localized effects due to thermal conductivity differences of discrete components. A highly conductive material that 'reaches' from the warm side surface to the cold side surface will create a localized heat flux significantly greater than lower conductivity, insulating materials around it. Regardless of the component's projected area percentage relative to the overall window unit a thermal 'short-circuit' will be introduced that, while perhaps having minimal influence on the system U-factor, may create significant problems concerning condensation.

Such thermal short-circuits can have a detrimental effect on the ability of a fenestration system to resist moisture condensation. In many cases, the impact can be so severe that frost and/or ice can form on the interior surfaces of the window. This can lead to a variety of problems including water damage and poor indoor air quality.

### *SYSTEMS FOR RATING PERFORMANCE*

There are two primary organizations that rate the thermal performance of fenestration systems: the National Fenestration Rating Council (NFRC) and the American Architectural Manufacturers Association (AAMA). As thermal transmittance (U-factor) is a quantitative, measurable characteristic of fenestration systems the mechanisms under each the NFRC and AAMA for measuring this value are virtually identical and result in the same performance number. Resistance to condensation formation, however, is a relative rating and each organization has independent criteria for determining performance. Accordingly, **there is <u>no correlation</u> between NFRC and AAMA condensation resistance values.**

The following is a general comparison of the rating systems under each organization and is not intended to provide technical direction for product evaluation or comparison. Refer to the appropriate organizations for more information.

**<u>NFRC</u>**

<u>U-factor</u>: The NFRC uses computer simulation software under NFRC 100 to calculate the U-factor of fenestration systems exposed to exterior conditions of approximately -18°C (0°F) with a 6 m/s (15 mph) wind and interior conditions of approximately 21°C (70°F). Fenestration systems and all represented glazing options are modeled in the most current version of the Therm and Window software. A representative unit from the product line glazing matrix is then physically tested to validate the simulated U-factors. The simulation matrix is validated if the tested unit U-factor is within 10% of the simulated value for units have U-factors greater than 1.7 W/$m^2$-K (0.3 Btu/h·$ft^2$·ºF) or within .17 W/$m^2$-K (0.03 Btu/h·$ft^2$·ºF) for units having U-factor ≤ 1.7 W/$m^2$-K (0.3 Btu/h·$ft^2$·ºF).

<u>Condensation Resistance</u>: NFRC 500 also uses computer simulation through the same software to identify the Condensation Resistance of a fenestration product under the same exposure conditions. Condensation Resistance is based on a dimensionless scale of 1 - 100 with a higher number representing a greater resistance to condensation formation.

Condensation values are calculated for each the frame, COG and EOG at representative dew points correlating to interior relative humidities of 30%, 50% and 70%, respectively. The Condensation Resistance for each area section is then derived from the average of the three relative humidity values and the fenestration system Condensation Resistance is the lowest of the frame, COG and EOG value.

**<u>AAMA</u>**

<u>U-factor</u>: AAMA uses physical testing under AAMA 1503 to measure the U-factor of a baseline fenestration system exposed to exterior conditions of approximately -18°C (0°F) with a 6 m/s (15 mph) wind and interior conditions of approximately 21°C (70°F). Data from this baseline test is combined under AAMA 1505 with test data from ASTM C518 measuring the thermal conductivity of the system components to obtain the U-factor for each of the fenestration system glazing options.

<u>Condensation Resistance</u>: known as the Condensation Resistance Factor or CRF under AAMA it is based on a dimensionless scale generally in the range of 30 – 80 with a higher number representing a greater resistance to condensation formation. Physical testing under AAMA 1503 is performed on a baseline fenestration system exposed to exterior conditions of approximately -18°C (0°F) with a 6 m/s (15 mph) wind and interior conditions of approximately 21°C (70°F). Data from this baseline test is combined under AAMA 1505 with test data from ASTM C518 measuring the thermal conductivity of the system components to obtain the CRF for each of the fenestration system glazing options.

### *COMPARING U-FACTOR AND CONDENSATION RESISTANCE*

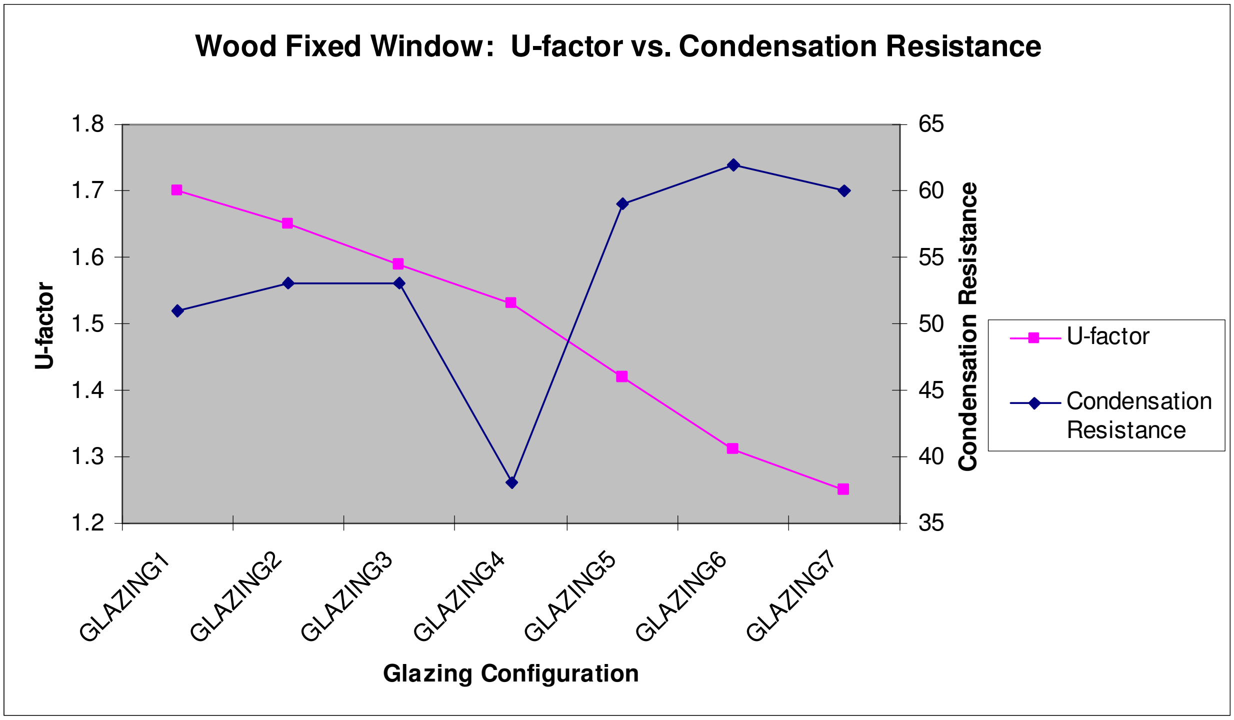
There is frequent confusion that U-factor and Condensation Resistance performance are linearly related; i.e., improvement in one will have a comparable improvement in the other. As discussed above, this may or may not be the case due to localized heat flux effects of the component(s) being improved.

The NFRC's Certified Products Directory (CPD) is a listing of all products by manufacturer and fenestration type that are certified under the NFRC for thermal performance. Tables A.1 and A.2 (Appendix) represent subsets of window performance data taken directly from the NFRC's CPD for two different fixed window systems of differing framing materials; aluminum clad wood and PVC, respectively. The data represents different glazing configurations for the same respective windows having U-factor ranges from 1.87 - 1.25 $W/m^2$-K (0.33 - 0.22 BTU/hr-$ft^2$-°F). Note in each the inconsistent change in Condensation Resistance rating between certain glazing configurations even though the U-factors improve for each. These are not small changes but significant and sometimes large reductions as illustrated in Table 1:

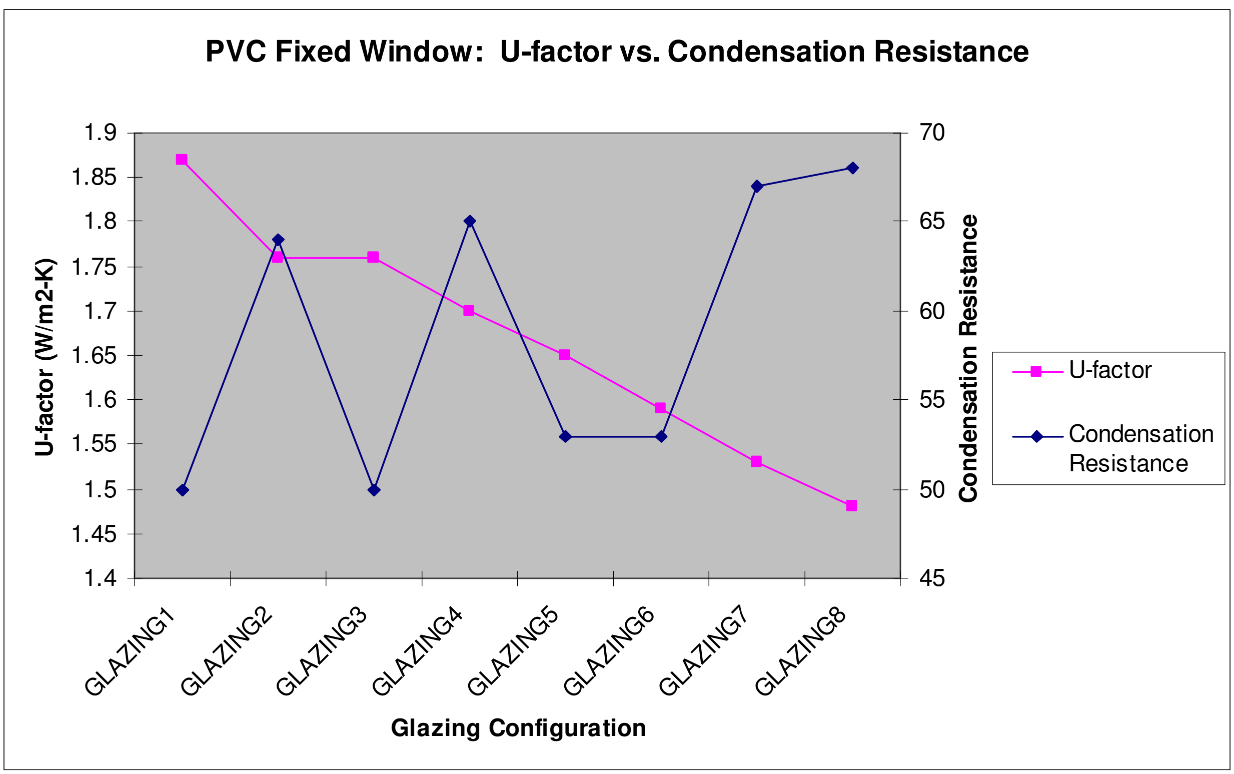
| Product | Glazing Configuration | U-factor ($W/m^2$-K)) | Condensation Resistance | CR Variation from Previous |
|---|---|---|---|---|
| Al Clad Wood Fixed | N-21-00139-00001 | **1.70** | **51** | **-** |
| | N-21-00137-00001 | **1.65** | **52** | **+1** |
| | N-21-00133-00001 | **1.59** | **53** | **0** |
| | N-21-00179-00001 | **1.53** | **38** | **-15** |
| | N-21-00151-00001 | **1.42** | **59** | **+21** |
| | N-21-00175-00001 | **1.31** | **62** | **+3** |
| | N-21-00152-00001 | **1.25** | **60** | **-2** |
| PVC Fixed | A-12-00016-00001 | **1.87** | **50** | **-** |
| | A-12-00025-00001 | **1.76** | **64** | **+14** |
| | A-12-00015-00001 | **1.76** | **50** | **-14** |
| | A-12-00023-00001 | **1.70** | **65** | **+15** |
| | A-12-00019-00001 | **1.65** | **53** | **-12** |
| | A-12-00018-00001 | **1.59** | **53** | **0** |
| | A-12-00028-00001 | **1.53** | **67** | **+14** |
| | A-12-00026-00001 | **1.48** | **68** | **+1** |

Table 1: U-factor vs. Condensation Resistance comparison

Graphs 1 and 2 provide graphical representation of this data for each of these respective windows and glazing configurations.




Graph 1: U-factor vs. Condensation Resistance for an aluminum clad wood, fixed window

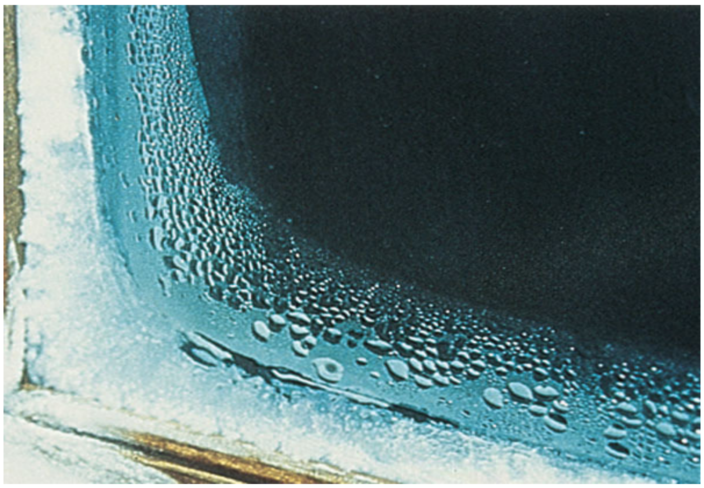



Graph 2: U-factor vs. Condensation Resistance for a PVC fixed window

The differences in each of these glazing options are varied. While some had changes to low-e coatings and others had spacer changes the key point is that there is neither a direct nor a linear relationship between U-Factor and Condensation Resistance. As concerns about condensation on the interior surfaces of fenestration products continue to grow it is imperative that this lack of direct correlation between these performance characteristics is understood.

### *EFFECTS OF CONDENSATION*

Anyone who's lived in a temperate climate has experienced condensation on the interior surfaces of windows at one time or another. Whether due to over-humidification in a bathroom or old, single glazed aluminum window construction, moisture, water and sometimes even frost and ice on the sill or glass of a window were quite common at one time.



Ice formation on window sash

The significant improvements in fenestration design and construction for thermal performance have significantly improved the ability of fenestration products to resist condensation formation. Hand-in-hand with these improvements, however, have also been improvements in the construction of the building envelope and the tightening of the shell to resist air leakage. Tightening of the building envelope can exacerbate the effects of interior moisture as it has no way to easily escape the structure. While past fenestration products were highly conductive, the buildings in which they were installed leaked so much air a natural air exchange took place to keep interior relative humidity in check (fortunately heating fuels were cheaper back then too…).

As the nature of man hasn't changed much over these years, we still take showers that are too long and too hot, design kitchens with windows over the sink and fail to consider humidity control and air exchange systems when designing new residences. These, inevitably lead to interior relative humidity levels that are too high for the design of the building envelope.

**<u>Lower Relative Humidity Isn't Always The Answer</u>**

As many might assume, the answer lies in keeping the interior relative humidity of the structure as low as possible. Everyone is familiar with the factors that accelerate mold growth; food, darkness and, of course, <u>moisture</u>. Mold control is an important concern for several reasons:

i. Molds and moisture can cause damage to window frames and wall surrounds that may accelerate the degradation of the building envelope.

ii. Tighter building envelope construction not only keeps moisture in but it reduces the air quality inside a structure if not properly ventilated. Molds release spores as they propagate that are also trapped in this environment. Many people can have allergic reactions to these spores that can create breathing problems and general discomfort.

iii. It's nasty to look at.

Moisture and mold damage to a wood window sash and frame

Condensation damage to wall surround (Building Envelope Forum – S. O'Brien)

As molds need moisture to grow and survive, the obvious answer might be "make it drier". Unfortunately, molds aren't the only culprit when concerns are raised regarding indoor air quality. There are a variety of air borne pathogens that can affect humans and not all like it wet. Some even prefer very dry air.

As illustrated in Figure 2, there is a range of indoor relative humidity that is most conducive to optimal indoor air quality relative to the propagation of a variety of pathogens. Some such as bacteria and viruses actually prefer either the moist or the dry extreme environments with generally reduced activity in a relatively narrow band of target indoor relative humidity. The "Optimum Zone" of relative humidity for indoor air quality is in a range of 30% - 55%. While optimal for the reduction of pathogen growth and air-borne irritant propagation this range of relative humidity can be a challenge for the prevention of moisture condensation on interior fenestration surfaces.

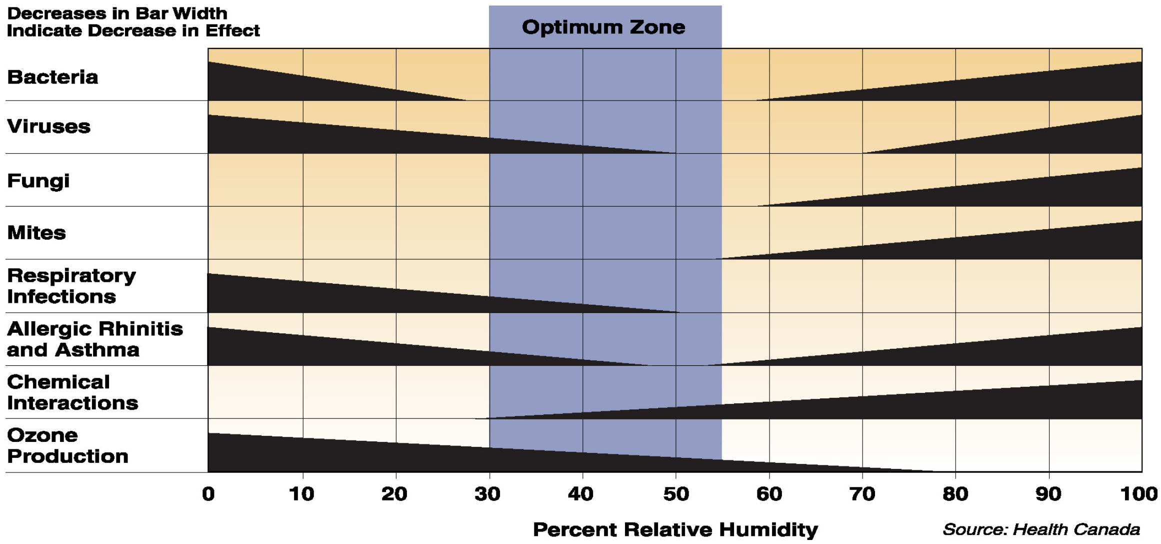
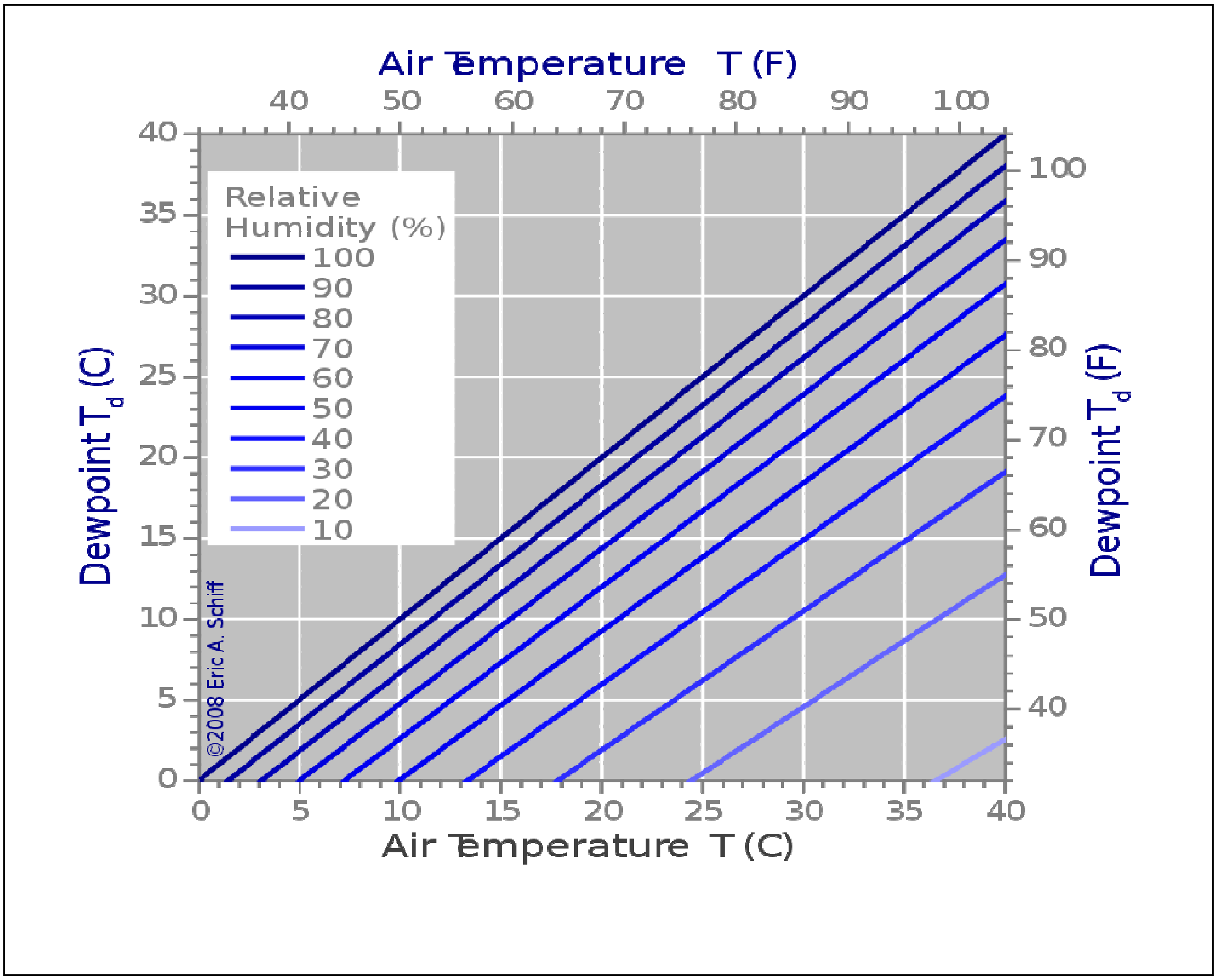



Figure 2: Optimal Indoor Relative Humidity

Graph 3 illustrates the relationship between air temperature, moisture dewpoint and relative humidity. The sloped lines represent varying percentages of relative humidity vs. coordinates of air temperature and dewpoint; being the point at which moisture will form. For an average indoor winter air temperature of 22°C (72°F) and relative humidity of 30%, the coldest point on any interior fenestration surface must be at least 8°C (46°F). At a relative humidity of 55% the coldest point on any interior fenestration surface must be at least **13°C (56°F)** to prevent condensation. This is only 9°C (16°F) less than the ambient air temperature and requires a fenestration system and relative components that have very low thermal conductivity. At these relative humidities it is imperative that a fenestration system utilize components of minimal thermal conductivity to prevent isolated 'cold spots' that may hasten condensation formation.




Graph 3: Dewpoint vs. Air Temperature at Varying Relative Humidities. Based on the Magnus-Tetens approximation (Schiff, E. A. 2008. Wikimedia Commons file Dewpoint-RH.svg)

Lastly regarding moisture condensation on fenestration products, it conveys a perception of poor quality. When someone purchases a high-end fenestration system that has claims of excellent thermal performance (U-factor) only to find pools of water on the window sill when it gets cold outside it inevitably raises questions and concerns about the quality of the product.

### ***DESIGN CONSIDERATION FOR CONTROL OF CONDENSATION***

Proper design for condensation resistance concerns the isolation of all components that may create a localized thermal 'short-circuit' or 'thermal bridge' across the fenestration system. This isn't simply with regards to material characteristics but must also consider design of insulating glass units for optimal performance and the elimination of air leakage effects.

#### **Break The Frame**

Any framing system must be thermally broken to reduce heat flux around the insulating glass unit. Not only must the frame be thermally broken but the thermal breaks must be properly designed and located to avoid thermal bridging. This occurs when the thermal break is located such that an exterior frame component is allowed toward the interior beyond the plane of conditioned space.

Figures 3 and 4 present a thermally broken aluminum curtainwall and an aluminum clad wood window with properly positioned thermal breaks and cladding, respectively.

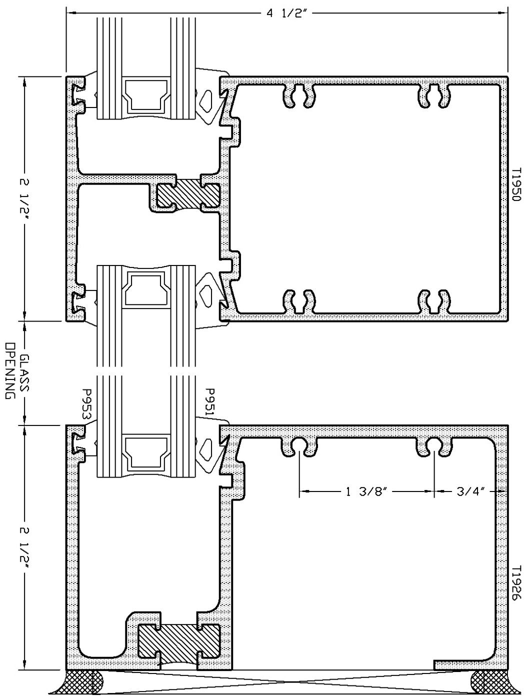



Figure 3: Thermally broken aluminum curtainwall (courtesy Tubelite Inc., www.tubeliteinc.com)

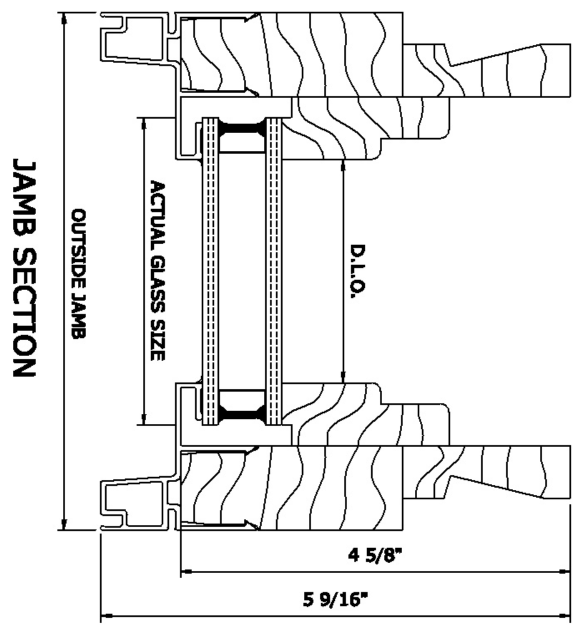



Figure 4: Aluminum clad wood window (courtesy Manko Windows, www.mankowindows.com)

## Control the Air

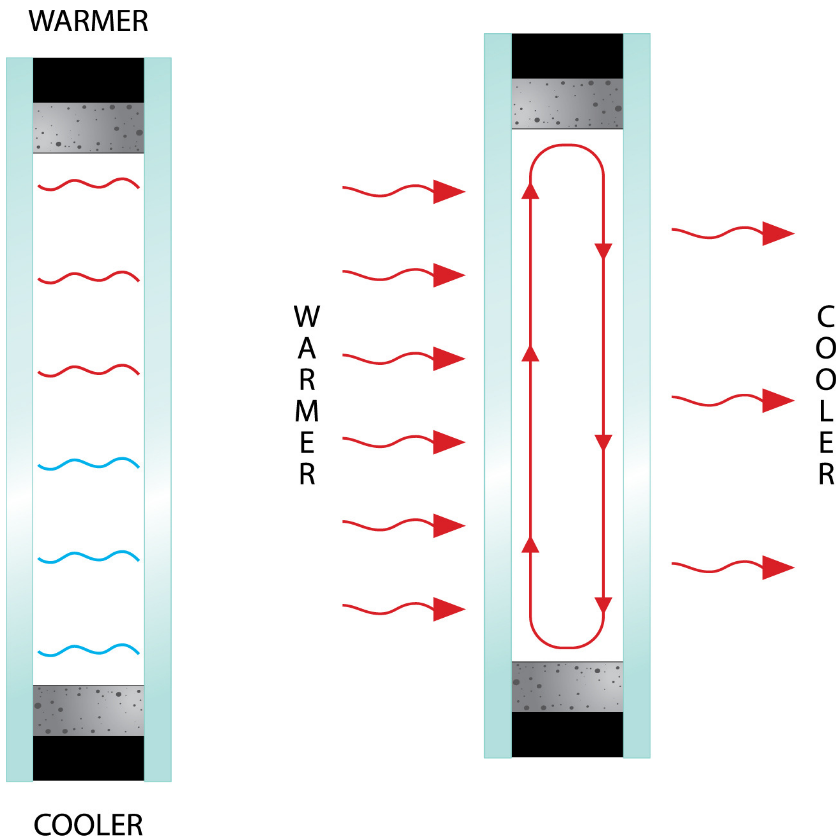
Air leakage doesn't immediately come to mind in regards to condensation resistance but it is one of the most common reasons for localized cooling in operable fenestration products. Air leakage around weatherseals and through openings in frame joints can focus cold area onto very isolated regions of a window frame or sash and significantly lower the surface temperature relative to the rest of the window unit.

## Optimize the Glazing System

As the center of glass of an insulating glass unit (IGU) is typically the warmest spot in a fenestration product principal design focus is placed on the edge-of-glass (EOG) area that consists of a 63.5 mm (2-1/2 in.) area around the perimeter of the IGU. The EOG consists of the glazing and gas infills in this area and the spacer/sealant system.

A key to proper IG design for insulating gases is to optimize the space dimension between the glazing layers for the gas being used. While the typical understanding is 'bigger is better,' this isn't the case with an IG glazing space. Glazing gap dimensions that are too small will allow for higher thermal conductivity across the IG unit. Gaps that are too large, however, will allow for convection inside the IGU, which will degrade the thermal performance of the unit.

An IGU should be designed to prevent movement of gas within the glazing space and create a condition known as “stratification”.  The stratified glazing space is small enough that the gas within it cannot move within the unit and create ‘convection loops’ (Figure 5).  The gas within the glazing space becomes stratified or layered within the IGU with the warmer air at the top and the cooler air at the bottom and little/no movement between them.




Stratified IGU    Convecting IGU

Figure 5

Different gases have different optimal glazing space gaps based on their respective densities to prevent convection inside the IGU while having the greatest possible distance to reduce conduction.  The optimal glazing space dimension for air and argon is between 12.7 mm (0.5 in.) and 15.9 mm (0.625 in.) while the optimal dimension for krypton is closer to 6.4 mm (0.25 in.).  Anything greater will allow convection inside the IGU, decreasing thermal performance.

Proper design to eliminate convection within the IGU goes hand-in-hand with the proper selection of the spacer/sealant system.  Traditional aluminum spacers are very effective for structural integrity but extremely poor for thermal resistance.  In the mid-80’s products known as “warm-edge” spacers were introduced to the market.  Warm-edge essentially refers to anything that is warmer than aluminum and there is a broad range of products that are available as illustrated in Figure 6.

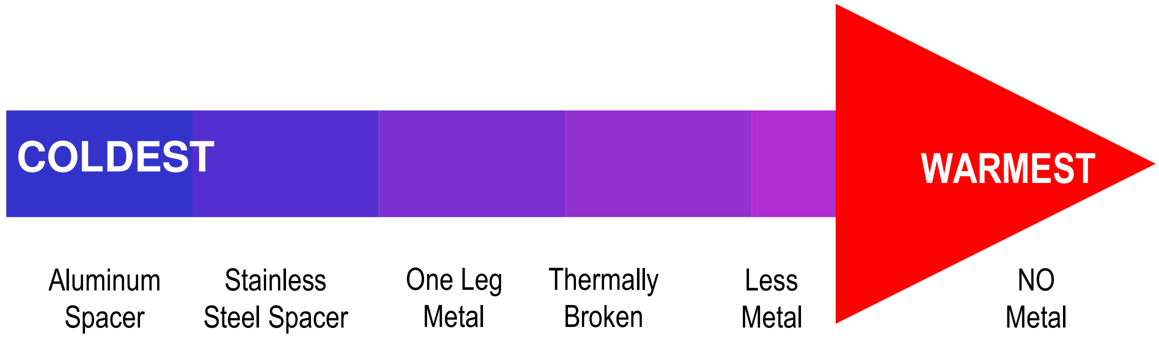
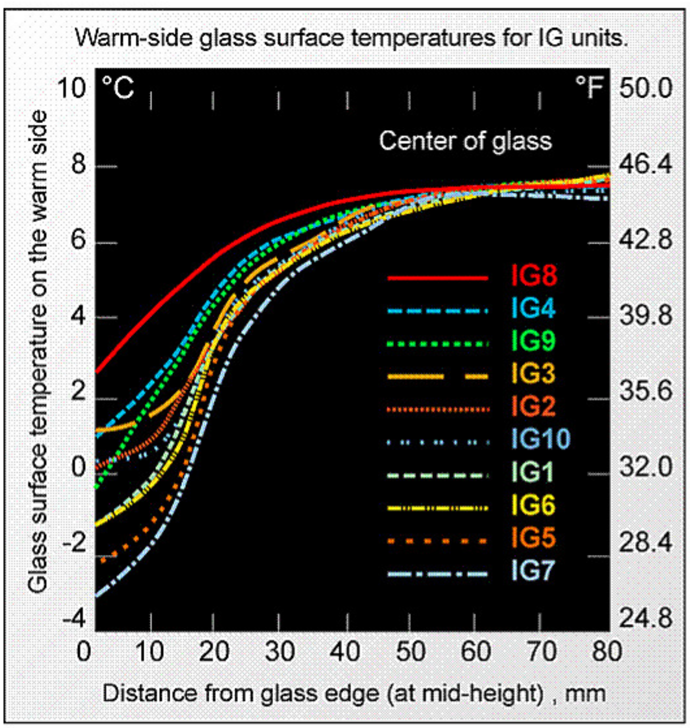
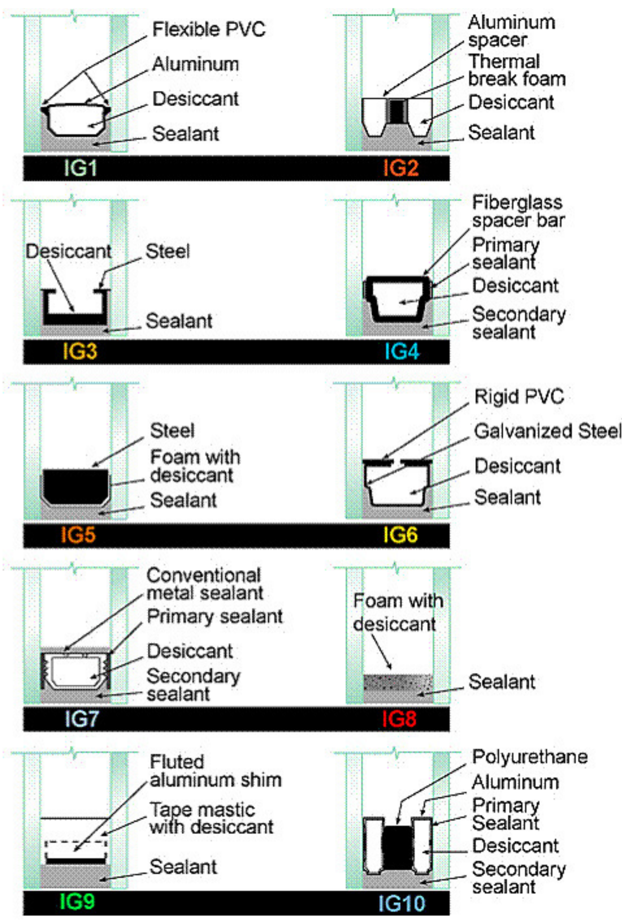



Figure 6: Warm Edge Spacers

Warm edge spacer systems are designed to reduce the heat flux at the EOG. Figure 7 illustrates the effect of different spacer constructions at the EOG on interior glass temperature. As is illustrated, once beyond the 63.5 mm (2-1/2 in.) EOG area all spacer systems are effectively the same. The nearer to the actual glass edge the greater the segregation between spacer types with a difference of up to 6℃ (11℉) in surface temperature.




Information: A.H. Elmahdy, Institute for Research in Construction(IRC), National Research Council of Canada (NRC) 2004.

Figure 7: Glass edge temperatures of various warm edge spacer systems

In conjunction with the thermal stratification of gas within an IGU, the effects on localized cooling of the IGU at the lower corners can be quite dramatic. Figure 8 is a thermogram of two IG systems having identical construction but with the unit on the left having clear glass and an aluminum spacer and the unit on the right having low-e glass and a warm edge spacer system. The 'exterior' of each unit is held at -18°C (0°F). The impact of the low-e glass on the COG is quite obvious but note the edge temperatures of the left unit. Virtually the entire perimeter of the unit is at or below 0°C (32°F). Additionally, due to the stratification of the air within each unit, colder air has sunk to the bottom of the unit to amplify the thermal bridging through the EOG. Regardless of the interior relative humidity (as long as there is some) the left unit will experience condensation around much of the IGU perimeter.

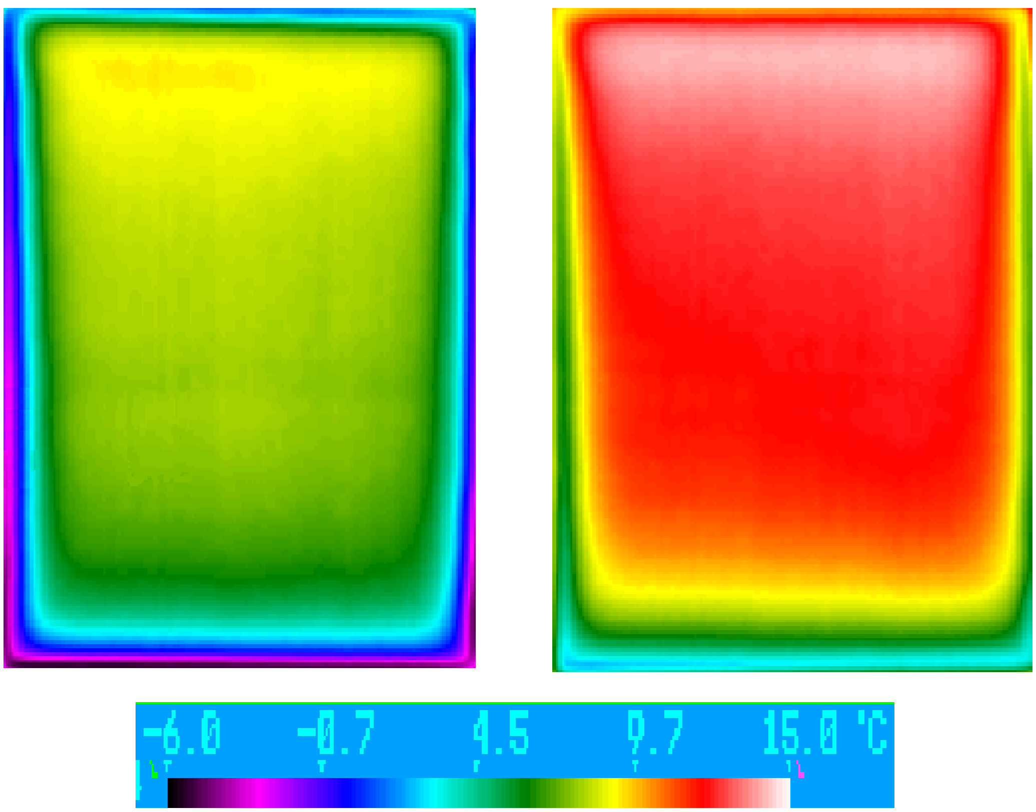



Figure 8: IGU Thermograms (courtesy Lawrence Berkley Laboratories, www.lbl.gov)

A final representation of the importance of optimizing the spacer system to reduce condensation formation is illustrated in Figure 9 which presents three fixed PVC windows having identical construction but for the type of spacer system tested under the exact same conditions within the same test chamber. The full metal spacer system acts as an aggressive thermal bridge and interior condensation is readily evident. The system with a thermally broken metal spacer demonstrates significant reduction in surface condensation while the spacer having no metal has but a minute amount of condensation in one corner.

Full Metal Less Metal No Metal

Figure 9: Condensation resistance of different spacer systems

***CONCLUSION***

While the primary focus on the thermal performance of fenestration products is and will continue to be thermal transmittance or U-factor due to building envelope energy conservation, the continued tightening of the envelope will further highlight problems and concerns with condensation on fenestration surfaces. Condensation resistance is a localized heat flux evaluation due to the conductivity of specific fenestration system components. The factors influencing the ability of fenestration products to resist condensation formation are not, necessarily, the same or of the same magnitude as those that affect U-factor rating. The relationship between condensation resistance and U-factor performance of fenestration systems is neither direct nor linear and may, at times, be inversely influenced by specific component modifications.

Efforts to improve fenestration system performance to improve condensation resistance include optimization of framing materials and thermal breaks, control of air leakage through weatherseals and frame joints and the optimization of the insulating glass unit package.

## REFERENCES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**APPENDIX: Table A.1 - Aluminum Clad Wood Fixed Window** (NFRC CPD, 2009)

| CPD # | U-factor (BTU/hr-ft$^2$-°F) | SHGC | Condensation Resistance | Glazing Layers | Low-E | Gap Widths | Spacer | Gap Fill |
|---|---|---|---|---|---|---|---|---|
| SIE-N-21-00139 | 0.3 | 0.23 | 51 | 2 | 0.057 (2) | 0.5 | SS-D | Argon |
| SIE-N-21-00139-00001 | 0.3 | 0.21 | 51 | 2 | 0.057 (2) | 0.5 | SS-D | Argon |
| SIE-N-21-00139-00002 | 0.3 | 0.19 | 51 | 2 | 0.057 (2) | 0.5 | SS-D | Argon |
| SIE-N-21-00129 | 0.29 | 0.38 | 53 | 2 | 0.042 (2) | 0.5 | ZF-S | Argon |
| SIE-N-21-00131-00001 | 0.29 | 0.21 | 53 | 2 | 0.057 (2) | 0.5 | ZF-S | Argon |
| SIE-N-21-00137 | 0.29 | 0.38 | 52 | 2 | 0.042 (2) | 0.5 | SS-D | Argon |
| SIE-N-21-00137-00001 | 0.29 | 0.34 | 52 | 2 | 0.042 (2) | 0.5 | SS-D | Argon |
| SIE-N-21-00133 | 0.28 | 0.25 | 53 | 2 | 0.022 (2) | 0.5 | ZF-S | Argon |
| SIE-N-21-00133-00001 | 0.28 | 0.23 | 53 | 2 | 0.022 (2) | 0.5 | ZF-S | Argon |
| SIE-N-21-00141 | 0.28 | 0.25 | 52 | 2 | 0.022 (2) | 0.5 | SS-D | Argon |
| SIE-N-21-00141-00001 | 0.28 | 0.23 | 52 | 2 | 0.022 (2) | 0.5 | SS-D | Argon |
| SIE-N-21-00179-00001 | 0.27 | 0.24 | 38 | 2 | 0.022(2),0.156(4) | 0.5 | SS-D | AIR (100) |
| SIE-N-21-00179-00002 | 0.27 | 0.22 | 38 | 2 | 0.022(2),0.156(4) | 0.5 | SS-D | AIR (100) |
| SIE-N-21-00179-00003 | 0.27 | 0.2 | 38 | 2 | 0.022(2),0.156(4) | 0.5 | SS-D | AIR (100) |
| SIE-N-21-00180-00001 | 0.27 | 0.24 | 40 | 2 | 0.022(2),0.156(4) | 0.5 | ZF-S | AIR (100) |
| SIE-N-21-00180-00002 | 0.27 | 0.22 | 40 | 2 | 0.022(2),0.156(4) | 0.5 | ZF-S | AIR (100) |
| SIE-N-21-00180-00003 | 0.27 | 0.2 | 40 | 2 | 0.022(2),0.156(4) | 0.5 | ZF-S | AIR (100) |
| SIE-N-21-00151-00001 | 0.25 | 0.35 | 59 | 3 | 0.042(2) | 0.5,0.5 | SS-D | AIR (100)/AIR (100) |
| SIE-N-21-00151-00003 | 0.25 | 0.29 | 59 | 3 | 0.042(2) | 0.5,0.5 | SS-D | AIR (100)/AIR (100) |
| SIE-N-21-00155-00001 | 0.25 | 0.23 | 59 | 3 | 0.022(2) | 0.5,0.5 | SS-D | AIR (100)/AIR (100) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SIE-N-21-00155-00003 | 0.25 | 0.19 | 59 | 3 | 0.022(2) | 0.5,0.5 | SS-D | AIR (100)/AIR (100) |
| SIE-N-21-00159-00001 | 0.25 | 0.21 | 58 | 3 | 0.057(2) | 0.5,0.5 | SS-D | AIR (100)/AIR (100) |
| SIE-N-21-00159-00002 | 0.25 | 0.19 | 58 | 3 | 0.057(2) | 0.5,0.5 | SS-D | AIR (100)/AIR (100) |
| SIE-N-21-00169-00001 | 0.25 | 0.35 | 60 | 3 | 0.042(2) | 0.5,0.5 | ZF-S | AIR (100)/AIR (100) |
| SIE-N-21-00169-00002 | 0.25 | 0.32 | 60 | 3 | 0.042(2) | 0.5,0.5 | ZF-S | AIR (100)/AIR (100) |
| SIE-N-21-00177-00001 | 0.25 | 0.21 | 60 | 3 | 0.057(2) | 0.5,0.5 | ZF-S | AIR (100)/AIR (100) |
| SIE-N-21-00177-00003 | 0.25 | 0.18 | 60 | 3 | 0.057(2) | 0.5,0.5 | ZF-S | AIR (100)/AIR (100) |
| SIE-N-21-00153-00001 | 0.24 | 0.38 | 59 | 3 | 0.042(4) | 0.5,0.5 | SS-D | AIR (100)/AIR (100) |
| SIE-N-21-00153-00003 | 0.24 | 0.31 | 59 | 3 | 0.042(4) | 0.5,0.5 | SS-D | AIR (100)/AIR (100) |
| SIE-N-21-00173-00003 | 0.24 | 0.19 | 61 | 3 | 0.022(2) | 0.5,0.5 | ZF-S | AIR (100)/AIR (100) |
| SIE-N-21-00178-00001 | 0.24 | 0.28 | 61 | 3 | 0.057(4) | 0.5,0.5 | ZF-S | AIR (100)/AIR (100) |
| SIE-N-21-00178-00003 | 0.24 | 0.23 | 61 | 3 | 0.057(4) | 0.5,0.5 | ZF-S | AIR (100)/AIR (100) |
| SIE-N-21-00175-00001 | 0.23 | 0.27 | 62 | 3 | 0.022(4) | 0.5,0.5 | ZF-S | AIR (100)/AIR (100) |
| SIE-N-21-00175-00003 | 0.23 | 0.23 | 62 | 3 | 0.022(4) | 0.5,0.5 | ZF-S | AIR (100)/AIR (100) |
| SIE-N-21-00152-00001 | 0.22 | 0.35 | 60 | 3 | 0.042(2) | 0.5,0.5 | SS-D | ARG/AIR (90/10)/ ARG/AIR (90/10) |
| SIE-N-21-00152-00003 | 0.22 | 0.28 | 60 | 3 | 0.042(2) | 0.5,0.5 | SS-D | ARG/AIR (90/10)/ ARG/AIR (90/10) |
| SIE-N-21-00170-00002 | 0.22 | 0.31 | 62 | 3 | 0.042(2) | 0.5,0.5 | ZF-S | ARG/AIR (90/10)/ ARG/AIR (90/10) |
| SIE-N-21-00170-00003 | 0.22 | 0.28 | 62 | 3 | 0.042(2) | 0.5,0.5 | ZF-S | ARG/AIR (90/10)/ ARG/AIR (90/10) |
| SIE-N-21-00154-00001 | 0.21 | 0.37 | 62 | 3 | 0.042(4) | 0.5,0.5 | SS-D | ARG/AIR (90/10)/ ARG/AIR |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | (90/10) |
| SIE-N-21-00154-00002 | 0.21 | 0.34 | 62 | 3 | 0.042(4) | 0.5,0.5 | SS-D | ARG/AIR (90/10)/ ARG/AIR (90/10) |
| SIE-N-21-00172-00001 | 0.21 | 0.37 | 64 | 3 | 0.042(4) | 0.5,0.5 | ZF-S | ARG/AIR (90/10)/ ARG/AIR (90/10) |
| SIE-N-21-00172-00003 | 0.21 | 0.3 | 64 | 3 | 0.042(4) | 0.5,0.5 | ZF-S | ARG/AIR (90/10)/ ARG/AIR (90/10) |
| SIE-N-21-00174-00003 | 0.21 | 0.19 | 63 | 3 | 0.022(2) | 0.5,0.5 | ZF-S | ARG/AIR (90/10)/ ARG/AIR (90/10) |
| SIE-N-21-00143-00001 | 0.2 | 0.3 | 63 | 3 | 0.042(2),0.042(4) | 0.5,0.5 | SS-D | AIR (100)/AIR (100) |
| SIE-N-21-00143-00002 | 0.2 | 0.27 | 63 | 3 | 0.042(2),0.042(4) | 0.5,0.5 | SS-D | AIR (100)/AIR (100) |
| SIE-N-21-00143-00003 | 0.2 | 0.24 | 63 | 3 | 0.042(2),0.042(4) | 0.5,0.5 | SS-D | AIR (100)/AIR (100) |

**APPENDIX: Table A.2 - PVC Fixed Window** (NFRC CPD, 2009)

| CPD # | U-factor | SHGC | Condensation Resistance | Glazing Layers | Low-E | Gap Widths | Spacer | GapFill |
|---|---|---|---|---|---|---|---|---|
| AWD-A-12-00006 | 0.33 | 0.35 | 50 | 2 | 0.027 (3) | 0.5 | A1-D | Air |
| AWD-A-12-00016-00001 | 0.33 | 0.35 | 50 | 2 | 0.027(3) | 0.5 | A1-D | AIR (100) |
| AWD-A-12-00016-00002 | 0.33 | 0.29 | 50 | 2 | 0.027(2) | 0.5 | A1-D | AIR (100) |
| AWD-A-12-00004 | 0.32 | 0.4 | 51 | 2 | 0.027 (3) | 0.563 | A1-D | Air |
| AWD-A-12-00004-00001 | 0.32 | 0.36 | 51 | 2 | 0.027 (3) | 0.563 | A1-D | Air |
| AWD-A-12-00014-00001 | 0.32 | 0.4 | 51 | 2 | 0.027(3) | 0.563 | A1-D | AIR (100) |
| AWD-A-12-00014-00002 | 0.32 | 0.36 | 51 | 2 | 0.027(3) | 0.563 | A1-D | AIR (100) |
| AWD-A-12-00014-00003 | 0.32 | 0.32 | 51 | 2 | 0.027(2) | 0.563 | A1-D | AIR (100) |
| AWD-A-12-00014-00004 | 0.32 | 0.29 | 51 | 2 | 0.027(2) | 0.563 | A1-D | AIR (100) |
| AWD-A-12-00005 | 0.31 | 0.39 | 50 | 2 | 0.027 (3) | 0.5 | A1-D | Air |
| AWD-A-12-00015-00001 | 0.31 | 0.39 | 50 | 2 | 0.027(3) | 0.5 | A1-D | AIR (100) |
| AWD-A-12-00015-00002 | 0.31 | 0.32 | 50 | 2 | 0.027(2) | 0.5 | A1-D | AIR (100) |
| AWD-A-12-00025-00001 | 0.31 | 0.35 | 64 | 2 | 0.027(3) | 0.5 | P1-S | AIR (100) |
| AWD-A-12-00025-00002 | 0.31 | 0.29 | 64 | 2 | 0.027(2) | 0.5 | P1-S | AIR (100) |
| AWD-A-12-00023-00001 | 0.3 | 0.4 | 65 | 2 | 0.027(3) | 0.563 | P1-S | AIR (100) |
| AWD-A-12-00023-00002 | 0.3 | 0.36 | 65 | 2 | 0.027(3) | 0.563 | P1-S | AIR (100) |
| AWD-A-12-00023-00003 | 0.3 | 0.32 | 65 | 2 | 0.027(2) | 0.563 | P1-S | AIR (100) |
| AWD-A-12-00023-00004 | 0.3 | 0.29 | 65 | 2 | 0.027(2) | 0.563 | P1-S | AIR (100) |
| AWD-A-12-00024-00001 | 0.3 | 0.39 | 64 | 2 | 0.027(3) | 0.5 | P1-S | AIR (100) |
| AWD-A-12-00024-00002 | 0.3 | 0.32 | 64 | 2 | 0.027(2) | 0.5 | P1-S | AIR (100) |
| AWD-A-12-00023-00001 | 0.3 | 0.4 | 65 | 2 | 0.027(3) | 0.563 | P1-S | AIR (100) |
| AWD-A-12-00023-00002 | 0.3 | 0.36 | 65 | 2 | 0.027(3) | 0.563 | P1-S | AIR (100) |
| AWD-A-12-00023-00003 | 0.3 | 0.32 | 65 | 2 | 0.027(2) | 0.563 | P1-S | AIR (100) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| AWD-A-12-00023-00004 | 0.3 | 0.29 | 65 | 2 | 0.027(2) | 0.563 | P1-S | AIR (100) |
| AWD-A-12-00024-00001 | 0.3 | 0.39 | 64 | 2 | 0.027(3) | 0.5 | P1-S | AIR (100) |
| AWD-A-12-00024-00002 | 0.3 | 0.32 | 64 | 2 | 0.027(2) | 0.5 | P1-S | AIR (100) |
| AWD-A-12-00009 | 0.29 | 0.36 | 53 | 2 | 0.027 (3) | 0.5 | A1-D | Argon |
| AWD-A-12-00019-00001 | 0.29 | 0.36 | 53 | 2 | 0.027(3) | 0.5 | A1-D | ARG/AIR (95/5) |
| AWD-A-12-00019-00002 | 0.29 | 0.29 | 53 | 2 | 0.027(2) | 0.5 | A1-D | ARG/AIR (95/5) |
| AWD-A-12-00007 | 0.28 | 0.4 | 54 | 2 | 0.027 (3) | 0.563 | A1-D | Argon |
| AWD-A-12-00007-00001 | 0.28 | 0.36 | 54 | 2 | 0.027 (3) | 0.563 | A1-D | Argon |
| AWD-A-12-00008 | 0.28 | 0.39 | 53 | 2 | 0.027 (3) | 0.5 | A1-D | Argon |
| AWD-A-12-00017-00001 | 0.28 | 0.4 | 54 | 2 | 0.027(3) | 0.563 | A1-D | ARG/AIR (95/5) |
| AWD-A-12-00017-00002 | 0.28 | 0.36 | 54 | 2 | 0.027(3) | 0.563 | A1-D | ARG/AIR (95/5) |
| AWD-A-12-00017-00003 | 0.28 | 0.32 | 54 | 2 | 0.027(2) | 0.563 | A1-D | ARG/AIR (95/5) |
| AWD-A-12-00017-00004 | 0.28 | 0.29 | 54 | 2 | 0.027(2) | 0.563 | A1-D | ARG/AIR (95/5) |
| AWD-A-12-00018-00001 | 0.28 | 0.39 | 53 | 2 | 0.027(3) | 0.5 | A1-D | ARG/AIR (95/5) |
| AWD-A-12-00018-00002 | 0.28 | 0.32 | 53 | 2 | 0.027(2) | 0.5 | A1-D | ARG/AIR (95/5) |
| AWD-A-12-00028-00001 | 0.27 | 0.36 | 67 | 2 | 0.027(3) | 0.5 | P1-S | ARG/AIR (95/5) |
| AWD-A-12-00028-00002 | 0.27 | 0.29 | 67 | 2 | 0.027(2) | 0.5 | P1-S | ARG/AIR (95/5) |
| AWD-A-12-00026-00001 | 0.26 | 0.4 | 68 | 2 | 0.027(3) | 0.563 | P1-S | ARG/AIR (95/5) |
| AWD-A-12-00026-00002 | 0.26 | 0.36 | 68 | 2 | 0.027(3) | 0.563 | P1-S | ARG/AIR (95/5) |
| AWD-A-12-00026-00003 | 0.26 | 0.32 | 68 | 2 | 0.027(2) | 0.563 | P1-S | ARG/AIR (95/5) |
| AWD-A-12-00026-00004 | 0.26 | 0.29 | 68 | 2 | 0.027(2) | 0.563 | P1-S | ARG/AIR (95/5) |
| AWD-A-12-00027-00001 | 0.26 | 0.39 | 67 | 2 | 0.027(3) | 0.5 | P1-S | ARG/AIR (95/5) |
| AWD-A-12-00027-00002 | 0.26 | 0.32 | 67 | 2 | 0.027(2) | 0.5 | P1-S | ARG/AIR (95/5) |