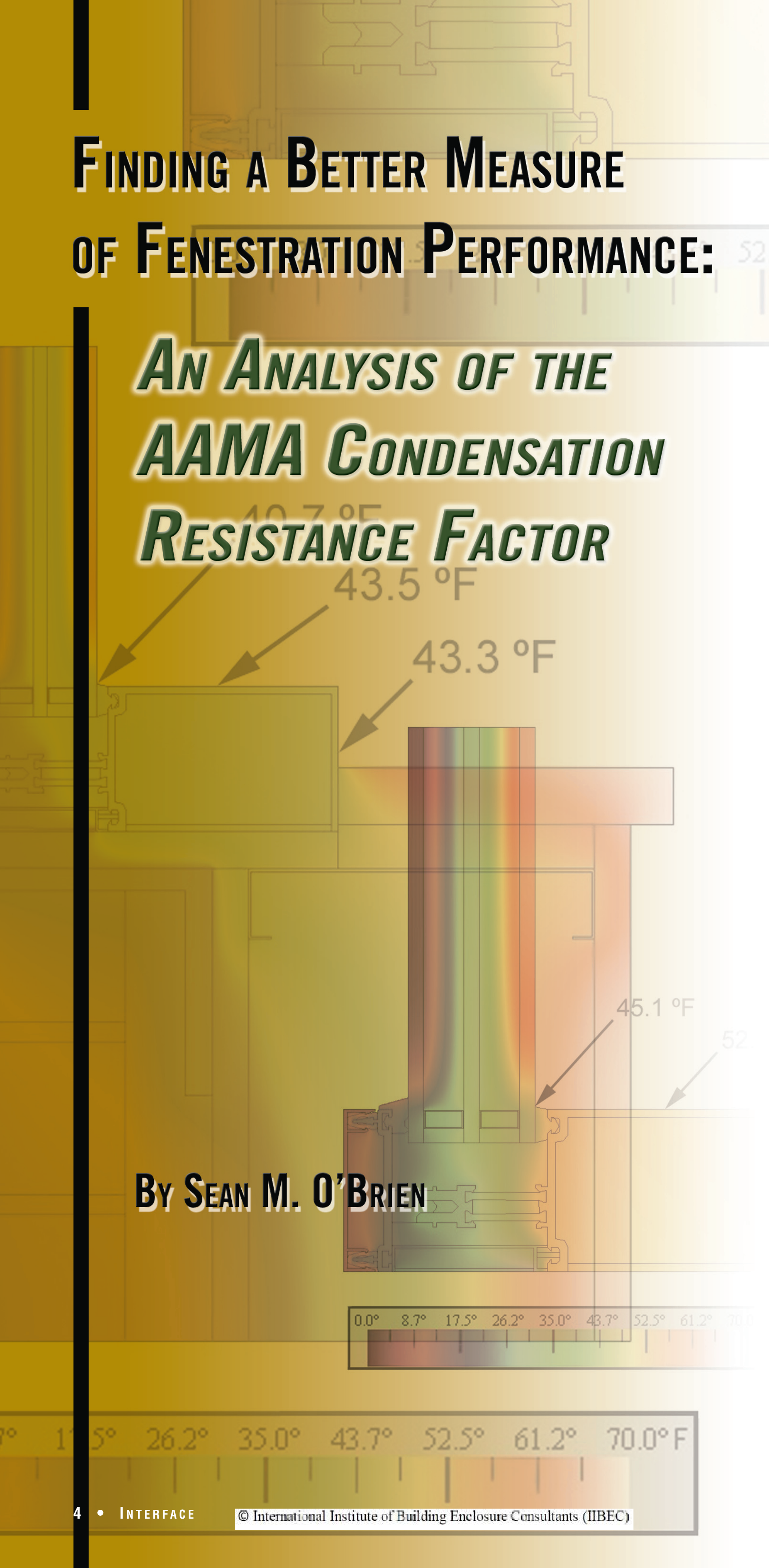
Finding a Better Measure of Fenestration Performance:

An Analysis of the AAMA Condensation Resistance Factor



By Sean M. O'Brien

INTRODUCTION

As architectural products become more advanced, making comparisons between them becomes more difficult for designers. This is especially true in the case of fenestration products (e.g., windows, skylights, and curtain walls). The significant variety of commercially available fenestration products has created a great challenge for designers and specifiers. The days of specifying an "aluminum-framed skylight" are long gone, replaced in recent times by specifying a "high-performance, thermally–broken, aluminum-framed skylight with triple pane insulating glass units and a low-e coating on surface #5." Unfortunately, this detailed description tells us little about the actual thermal performance and resistance of the product to condensation. In an effort to create a simple way for architects and designers to rate and compare the condensation resistance of different fenestration products, the American Architectural Manufacturer's Association (AAMA) created the "Condensation Resistance Factor," or CRF.

A Brief History of the CRF

In 1972, AAMA (at that time, the Architectural Aluminum Manufacturer's Association) published Standard 1502.3[1]. This was the first test standard designed specifically to measure the condensation resistance of thermally-improved aluminum insulating windows and sliding doors for use in residential construction. This standard was developed in response to the popularity of aluminum as a framing material for windows and sliding glass doors.

Aluminum has many desirable qualities, such its strength-to-weight ratio and design versatility, which made it a natural choice for use as a framing material. The high thermal conductivity of aluminum, however, meant that it was more prone to condensation at low exterior temperatures than traditional materials such as wood and vinyl.

In 1980, in response to concerns over heat loss and energy efficiency, AAMA developed Standard 1503.1[2], which described a procedure for measuring the overall thermal transmittance of fenestration products. A year later, Standard 1502.7-81[3] was released to update Standard 1502.3-72 and include all types of windows, doors, and glazed wall sections. In 1988, procedures for measuring condensation resistance and thermal transmittance were combined into a single standard, AAMA 1503.1.[4] The current version of that standard, 1503-98[5], includes updated calibration and test techniques and environmental conditions modified to be consistent with those used by the National Fenestration Rating Council (NFRC).

CRF Formula for the Glass

$$CRF_{glass} = \frac{\text{Average glass temperature - Cold side temperature}}{\text{Cold side temperature - warm side temperature}} \times 100$$

CRF Formula for the Frame

$$CRF_{frame} = \frac{\text{Weighted frame temperature - Cold side temperature}}{\text{Cold side temperature - warm side temperature}} \times 100$$

Determining the CRF of Fenestration Products

The procedure for determining the CRF of a particular fenestration product is relatively simple. The specimen is placed in a test chamber designed to maintain a constant temperature differential. The test chamber is similar to the “hot box apparatus” described in ASTM C1363-97[6]. An air flow of 15 miles per hour is directed at the specimen (perpendicular to its face) on the cold side of the assembly. The test conditions are 70˚F and 15% maximum RH warm side; 0˚F cold side for AAMA 1503-98. After the specimen reaches equilibrium with the surroundings, a series of surface temperature measurements are taken on the warm side of the specimen. These include 14 fixed points on the frame, four “roving” points designed to find the coldest points on the frame, and six fixed points on the glazing. The overall thermal transmittance of the specimen is also measured during this procedure. (That measurement is not discussed in this article.)

Once the surface temperatures on the frame and glass are measured, the data are manipulated to generate a CRF for both the frame and the glass areas of the specimen. The CRF for the glass is computed using the top formula in the box on this page.

A similar calculation (see the second formula) is performed to produce the CRF for the frame, with the exception that a weighted frame temperature is used in the calculation (as opposed to the straight numerical average).

The weighted frame temperature is calculated taking into account temperature data from the roving thermocouples. Since the roving thermocouples are intended to locate the coldest points on the frame, the intent of the weighting factor is to lower the CRF of fenestration products with areas of significantly lower temperature than the average temperature on the frame. After computing the CRF of the glass and of the frame, the overall CRF of the specimen is taken to be the lower of those two numbers. At the conclusion of the test, the standard does not require the testing agency to report on whether or not condensation was observed on the interior surfaces of the glass and frame – something that would appear to be inherent in the nature of a condensation resistance test.

Photo 1 – Although selected for its high CRF, the installation method for this curtain wall caused significant thermal bridging around the frame, leading to condensation and even frost buildup on its interior surfaces.

How the CRF is Used

As AAMA intended, designers generally use the CRF in construction specifications to prescribe a level of condensation resistance for fenestration products. If a designer wants to reduce the chances of condensation occurring on the windows in a building, he or she will specify a high CRF. In warmer climates, a designer may specify a lower CRF, as the risk of condensation on windows is reduced, and the cost savings associated with buying windows with lower CRFs is more attractive.

Despite the number of projects that use the CRF as the measure of performance for fenestration products, surprisingly few designers stop to ask themselves a very simple question: “What exactly does a CRF number mean?” The following sections present an explanation of why the CRF is not an effective measure of condensation resistance, despite years of use and industry-wide acceptance, and why designers need to account for a variety of complicating factors when evaluating condensation resistance.

Calculation

Before examining how the CRF is used in practice, it is important to look at the calculation method itself. The use of average glass temperatures and weighted frame temperatures in calculating the CRF for a specimen presents an inherent problem. In typical fenestration products (especially those with complicated frame geometries), the majority of the frame area is in the same general temperature range, with only a small area being significantly colder than the rest of the frame. This area (generally, but not always near the sill) will govern the condensation resistance of the specimen. These cold spots are used to produce a weighting factor that will be applied to the average frame temperature. As a result of this calculation method, the effect of low frame temperatures on the CRF of a specimen is much less significant than the actual effect that they have on condensation resistance.

To illustrate this point, consider the following example, based on an actual AAMA 1503-98 report for a typical aluminum curtain wall system. The system in question has an overall CRF of 60 (CRF_{glass} = 60, CRF_{frame} = 66). At the test conditions of 0°F exterior and 70°F interior, condensation will occur on the specimen at an interior relative humidity (RH) of 33% or greater (based on a tested frame low temperature of 39.3°F).

Now consider a hypothetical curtain wall system that is exactly the same as our test specimen, with the exception that the thermal breaks are constructed differently at the sill, producing 30°F cold spots at the frame corners. If we include these temperatures in the original CRF calculation (all other values remaining constant), the CRF for the frame only drops to 64 (a change of -2), with a corresponding drop in the allowable RH to 23% (a change of -10%).

The previous example considered the CRF of the frame only. The calculation for the CRF of the glass is even simpler, as it uses a numerical average of the glass temperatures as opposed to a weighted average for the frame. Since the thermocouples on the glass are placed in pre-determined locations, as opposed to roving locations to determine the coldest points on the glass, it is possible for the effects of cold spots on the glass to be misreported by the CRF. It also makes it possible for a piece of glazing with a CRF of 60 to have lower interior surface temperatures than glazing with a CRF of 58 (based on actual AAMA 1503-98 test reports).

Boundary Conditions

The boundary conditions used by AAMA to evaluate condensation resistance are 0°F exterior and 70°F interior, with appropriate exterior and interior airflows to simulate the effects of wind and natural convection on surface heat transfer coefficients. Because of the difference in surface heat transfer coefficients for non-vertical fenestration, AAMA 1503-98 is not applicable to skylights or sloped glazing (although this does not necessarily prevent designers from specifying skylights with a particular CRF, or skylight manufacturers from publishing CRF values for their products). 70°F is an appropriate temperature to assume for the interior of most typical buildings. Zero degrees Fahrenheit, while appropriate for a location such as Portland, Maine (99% exterior design temperature[7] of 2°F), it is not appropriate for Miami, Florida (exterior design: 50°F), or Fargo, North Dakota (exterior design: -17°F).

AAMA has attempted to compensate for this limitation by providing a supplemental chart in 1503-98 containing its recommendations for maximum interior RH levels for several different cities (design temperatures) and CRFs. Although a wide range of exterior temperatures (other than the standard test condition) is shown on the chart, the basis for the effects of exterior temperature on the CRF curves is not stated.

To determine the effectiveness of this chart in selecting window systems based on condensation resistance, we reviewed five AAMA 1503-98 test reports and one AAMA 1503.1-88 test report and compared the data on condensation resistance from those reports to the data in the chart. The reports covered a range of products, including windows, curtain walls, and sliding glass doors. The results of these comparisons are presented in *Table 1*, which shows the interior RH at which condensation occurs (based on measured surface temperatures) and the reported CRF for each product, as well as the recommended maximum RH taken from the AAMA chart. *Table 1* also shows the CRF that we obtained from the AAMA chart, based on the actual maximum RH and exterior temperature. For example, for specimen 1, the AAMA table would recommend a CRF of 45 if the maximum interior RH were 24% at an exterior temperature of 0°F. Since the test reports contain data based on a fixed exterior temperature of 0°F, we made comparisons to the AAMA table at that temperature (with the exception of the horizontal sliding window, which was tested at an exterior temperature of 18°F under AAMA 1503.1-88).

TABLE 1

	Based on 1503-98 test report		Predicted from AAMA 1503-98 table	
Specimen	**Maximum RH**	**CRF**	**Maximum RH**	**CRF**
1. Curtain wall	24%	60	37%	45
2. Curtain wall	27%	58	35%	49
3. Curtain wall[a]	31%	69	> 37%[b]	53
4. Single-hung window	15%	54	24%	32
5. Sliding glass door	10%	54	23%	< 25[c]
6. Horizontal sliding window	31%	57	46%	37

a) For this specimen, the frame CRF was lower than the glass, even though the lowest temperature on the frame was higher than the lowest temperature on the glass.
b) Maximum CRF shown on AAMA table is 60.
c) Minimum CRF shown on AAMA table is 25.

The comparison presented in *Table 1* shows that the recommendations chart in AAMA 1503-98 consistently overestimates the interior RH at which condensation occurs and underestimates the CRF required to avoid condensation, making it a poor tool for selecting fenestration products. Furthermore, the chart is based on an interior temperature of 68°F, which limits its application to typical interior environments (offices, residences, etc.) and excludes specialty buildings such as natatoriums.

Practice and Application

A wider problem than CRF calculation methods is the way in which the number is often used in design practice. Many designers will confidently specify that all fenestration for a particular building have a CRF of 70 to prevent condensation, but fail to account for a number of complicating factors.

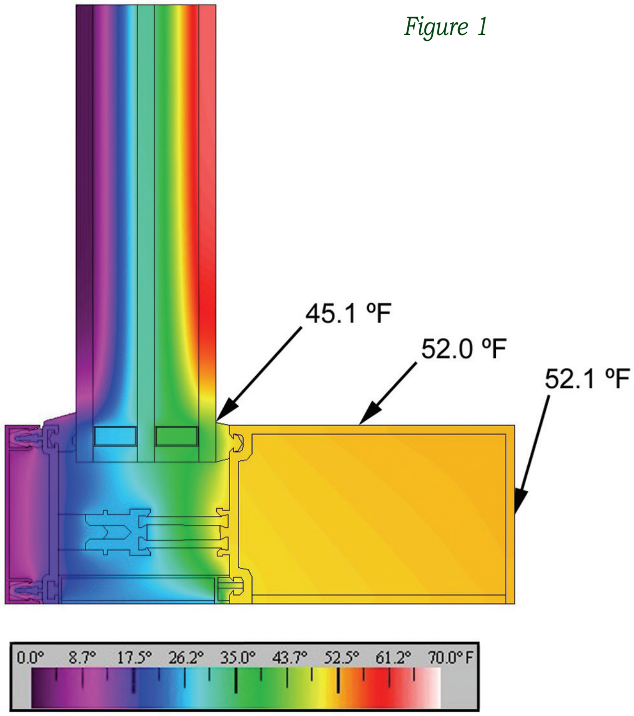


Figure 1

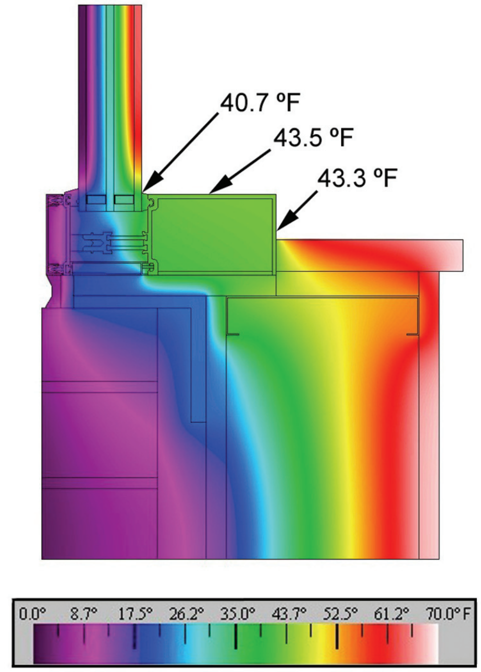


Figure 2

The most commonly overlooked factor is the difference between the test conditions and the installed conditions. During the thermal test, a specimen is placed in a "surround panel" consisting of facing material on either side of thermal insulation (R-3.6/inch, minimum). The intent of the surround panel is to limit heat flow through the perimeter of the specimen.

Real fenestration products will, however, be placed into a wide variety of openings in building walls, the vast majority of which involve clips, anchors, and framing materials to secure the product in place. Wall insulation may or may not be aligned with the specimen, which can have a significant effect on the surface temperatures of a window or curtain wall. *Figure 1* shows the results of a 2-dimensional, steady-state heat transfer calculation[8] through a high performance curtain wall sill. This type of system is often specified for high humidity buildings due to its increased thermal performance. The model simulates the environmental conditions during a standard AAMA 1503-98 test (0°F exterior, 70°F interior), with no heat transfer though the perimeter of the frame. If the building for which this system is selected has interior conditions of 70°F and 50% RH (dewpoint = 50.6°F), the simulation results indicate that no condensation will occur on the frame, and only a small area of condensation will occur on the glass, at an exterior temperature of 0°F.

The "installed" condensation resistance of the system, however, may be significantly different, depending on the method of installation. *Figure 2* shows the simulation results for one method of installation for the system. These results show that predicted interior surface temperatures on the glass and frame are up to 9°F lower than those in the "tested" system. Condensation will occur on part of the glass and entire frame under the design conditions. This simulation shows that a curtain wall that looks good on paper (i.e., has a high CRF) may fail to provide the desired condensation resistance if installed in an assembly where the wall insulation is misaligned with the curtain wall and glazing.

Another common installation problem occurs when draperies or curtains are installed inboard of windows (typical in residential construction). When closed, these finishes can act as insulators by creating a relatively still airspace between the window and the interior. This insulating airspace reduces the amount of heat that the windows receive from the interior, lowering surface temperatures on the frame and glass and causing increased amounts of condensation. Just as the installation method for a

Left: Photo 2 – The installation of curtains (not shown) over this window led to significant condensation on the frame; the same window without interior curtains did not experience condensation.

Below: Photo 3 – Failure to provide sufficient condensation resistance on fenestration in high humidity spaces can lead to problems ranging from mold growth on interior surfaces to premature failure of the product.

curtain wall can reduce its actual resistance to condensation, installing some types of interior finishes can lead to condensation on windows that would otherwise perform satisfactorily. In both of these cases, the tested CRF does not provide an accurate portrayal of the installed condensation resistance of the products.

Potential Solutions to the CRF Dilemma

To benefit from an AAMA 1503-98 report, designers need to look beyond the CRF number to the test method and raw data used to produce it. A typical CRF report will contain drawings of the specimen showing the location of all temperature measurements, as well as a table showing the actual values measured. These data, before being averaged and manipulated into the CRF, are a much better source of information on condensation resistance. The overall temperature distribution is clear, high and low temperatures on the glass and frame are easily located, and the maximum allowable RH (for the specimen under test conditions) can be calculated based on the surface temperature data. The maximum allowable RH is a much better point of comparison for similar products; a higher number will always indicate greater condensation resistance. By reviewing the actual data contained in the test report and specifying a level of performance based on interior RH rather than a specific CRF, designers can exercise greater control over the final product.

The problem of tested vs. installed performance is a more complicated issue, as is the problem of extrapolating test data to account for interior and exterior conditions that differ from the standard 0°F/70°F. While a basic understanding of heat transfer and psychrometrics (calculating the properties of moist air) can steer a designer in the right direction, they are often not sufficient to predict the installed performance of fenestration systems. Calculation of the heat transfer through complex shapes consisting of multiple materials is extremely difficult (and in some cases, impossible) to perform by hand. These calculations must be done with the aid of computers.

There are several commercially available software packages that are capable of calculating the 2- and 3-dimensional heat flow through all types of building constructions, particularly fenestration products. Testing and development of these programs has created software tools that are powerful and highly accurate (when properly used). Ge and Fazio (2004)[9] showed that for a typical curtain wall system, they could calculate the surface temperatures on the frame and glass to within +/-0.9°F of the values obtained for the same system through experimental testing. The discrepancy between simulated and tested values was slightly higher for a highly insulated curtain wall (+/-3.6°F), but work is currently underway to reduce the discrepancy by applying experimental test data to the computer model to fine-tune the calculation.

The benefits of computer simulation are numerous, and when combined with experimental test results, can be of great use to designers. Consider a designer who is specifying windows for a museum in North Dakota. The exterior temperature is much lower than the standard 0°F test condition, and the interior RH will be much higher than a typical building, making condensation resistance a critical factor in the design. Rather than specifying a high CRF and hoping for the best, the designer should simulate the performance of potential products, using the experimental data from an AAMA 1503-98 report to validate the results. Once the model is "up and running," changes can be made to the interior and exterior boundary conditions, the type of glass, the installation method, or any other design parameters being considered. The time and expense of creating thermal models of a system and simulating a range of options is small compared to the time and expense to run full-scale lab tests to evaluate the same options.

As computer simulations become more advanced and more accurate, there will be less need to compare the simulation results to physical test results, making simulations a more powerful tool for evaluating products for which no thermal performance data exist. A computer simulation based on good assumptions, accurate material, construction data (e.g., geometry and dimensions), and sound engineering judgment has the potential to save both time and expense, as well as prevent the headaches and negative publicity associated with performance failures.

Conclusions

The AAMA condensation resistance factor, while widely used by designers, offers insufficient information on the installed condensation resistance of fenestration products. However, the information contained in an AAMA 1503-98 test report, combined with good engineering judgment, can still be useful for determining the condensation resistance of a product. Designers seeking to specify products that are "resistant to condensation" must first determine what "resistant" really means. Specifying that a window shall not experience condensation under specific interior and exterior design conditions leaves little room for error, as opposed to specifying a minimum CRF. The surface temperature data in an AAMA 1503-98 test report can be reviewed to estimate condensation (at set boundary conditions) potential. These data can also help a designer select products in a compromise situation, such as when dealing with a building owner who is not willing to pay for condensation-free windows but does want to limit condensation to the greatest extent possible under his budget. The test data will help the designer identify the extent of cold spots on the frame and glass of potential products and then determine which products will produce the smallest amount of condensation to meet the satisfaction of the owner.

Computer simulations can be of great help in both selecting products to specify and verifying the performance of products submitted for approval. A well-designed computer model can be used to evaluate the performance of a fenestration product under varying interior and exterior conditions, multiple methods of installation, or alternate options for frame and glass materials. The ability to evaluate a wide range of options via simulation can produce significant time and cost savings over traditional full-scale testing.

The wide range of fenestration products, building details, and interior and exterior environments found in modern construction projects makes selecting fenestration products a complicated task. While the CRF has some merit for comparing the generic (good, not-so-good, etc...) performance of similar products installed in similar constructions and climates, it fails to provide a true, physical measure of condensation resistance. Designers seeking to specify fenestration must become aware of these limitations and begin making use of the actual test data and modern computer simulations to accurately specify and verify the performance of fenestration products.

FOOTNOTES

1. *AAMA Publication 1502.3-1972: Voluntary Test Method for Condensation Resistance of Windows, Doors, and Glazed Wall Sections.*
2. *AAMA Publication 1503.1-1980: Voluntary Test Method for Thermal Transmittance of Windows, Doors, and Glazed Wall Sections.*
3. *AAMA Publication 1502.7-1981: Voluntary Test Method for Condensation Resistance of Windows, Doors, and Glazed Wall Sections.*
4. *AAMA Publication 1503.1-88: Voluntary Test Method for Thermal Transmittance and Condensation Resistance of Windows, Doors, and Glazed Wall Sections.*
5. *AAMA Publication 1503-98: Voluntary Test Method for Thermal Transmittance and Condensation Resistance of Windows, Doors and Glazed Wall Sections* (including May 4, 1998 Errata and December 1, 1999 Addendum).
6. ASTM 1997. *ASTM C1363, Standard Test Method for the Thermal Performance of Building Assemblies by Means of a Hot Box Apparatus.* Philadelphia, American Society for Testing and Materials.
7. ASHRAE 2001 *Handbook of Fundamentals.* Atlanta: The American Society of Heating, Refrigerating, and Air-Conditioning Engineers.
8. Simulation performed using Therm 5.2 and Window 5.2, developed by the Lawrence Berkeley National Laboratory.
9. Ge, H., and Fazio, P. 2004. *Effect of Boundary Conditions on the Prediction of Temperature Distribution for Curtain Walls.* Atlanta: The American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

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Polyiso Study Touts More Insulation

A study performed by the Energy Service Provider Group and EBL Engineers and released by the Polyisocyanurate Insulation Manufacturers Association (PIMA) claims that using additional thicknesses of polyiso insulation on a roof deck over the minimum code requirements resulted in:

- Significant rate of return for users for the financial investment of installing additional polyiso insulation.
- Reduction in the costs to facilities on average per year.
- Reduction in CO_2 emission by thousands of pounds, SO_2 emissions by thousands of grams, and NO_x emissions by thousands of rams per year.

Record production of more than 5.4 billion board feet of polyiso was reported in 2004. The following table shows results procured from retail buildings in the study.

City	ASHRAE 90.1-2001	Thickness of polyiso in inches Energy cost savings/IRR% internal rate of return		
Atlanta	R-15, 2.5"	3" $1,601/7.1	3.5" $3,007/14	4.8" $5,155/7.1
Boston	R-15, 2.5"	3" $2,660/10.9	3.5" $4,639/17.9	4.8" $8,210/10.3
Chicago	R-15, 2.5"	3" $3,273/14.3	3.5" $5,592/22.2	4.8" $9,774/13.2
Dallas	R-15, 2.5"	3" $1,451/6.1	3.5" $2,537/11.7	4.8" $4,158/4.8
Denver	R-15, 2.5"	3" $2,433/12.2	3.5" $4,078/18.9	4.8" $7,397/11.3
Los Angeles	R-15, 2"	2.5" $538/14.6	3" $1,249/1.2	4.8" $1,571/>0.0