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FENESTRATION AIR TIGHTNESS LIMITATIONS: SERVICEABILITY/DURABILITY

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ABSTRACT

Current design strategies for fenestration products and their ability to resist heat and mass transfer (air leakage) do not adequately account for serviceability concepts, state of the art design methods, and materials utilization.

The design life of fenestration products, as it relates to air leakage performance, is not fully understood and addressed by designers and manufacturers. Performance serviceability is a new concept that is being implemented by standards/specifications development organizations. These groups are working on new standards that will address these issues.

This paper will deal with selection criteria for fenestration systems based on requirements for long term air leakage performance of these products in field service applications.

The effects of thermal cycling on fenestration durability as it relates to air tightness standards will be addressed and air tightness standards will be evaluated for their appropriateness within the overall design schemes of the building thermal envelope.

INTRODUCTION

The thermal envelope and its components (windows, doors, skylights) interact with the environment by means of convection, conduction, radiation and air leakage. These components also provide visual, esthetics, safety and security aspects to the thermal envelope.

Manufacturers of fenestration systems have many performance requirements that must be met if they are to successfully gain a competitive edge in the marketplace. These performance requirements are based on the needs of the building occupants. Various test parameters and performance rating systems are, however, largely governed by manufacturers trade associations. These associations write specifications for products and components that are prescriptive in nature.

These product specifications are very specific to function and material of construction. The major materials of which fenestration products are constructed are aluminum, wood, vinyl or aluminum clad wood, vinyl and steel. Other materials that are beginning to see inroads into the marketplace are fiberglass pultrusions and composites. Fenestration performance specifications that are currently in use have been designed around the materials from which these products have been manufactured rather than performance.

The National Wood Window and Door Association (NWWDA), the American Architectural Manufacturers Association (AAMA), the California Association of Window Manufacturers (CAWM), the Society for the Plastics Industry (SPI), Insulated Steel Door Systems Institute (ISDSI) and the American Society for Testing and Materials (ASTM) are some of the associations that are writing and promulgating testing and performance standards for fenestration products. Air leakage, heat transfer, structural loading, water resistance, and economic requirements have allowable performance levels, in these standards, that have been deemed appropriate or safe for specific applications. The fenestration industry has dozens of performance specifications, for as many types of windows and doors, manufactured from many types of materials.

In 1975 the ASTM E6 Committee on Building Materials and Performance, published what was to be the industries first generic performance specification for residential windows; ASTM E1017. This specification is based solely on performance with no requirements for the type of material from which the window is manufactured. Window systems that meet minimum performance levels will qualify under the specification regardless of the material of construction. The elegance of this specification is obvious. Architects can choose from any window type manufactured from any material based on performance needs of buildings and budgetary constraints. In no other specification for fenestration systems is this possible. ASTM is to be commended for the development of such an important standard. In fact the promulgation of this standard has raised many eyebrows in various trade associations. AAMA is currently in the process of developing a generic window standard. It is possible we will see other fenestration associations follow suit.

PERFORMANCE CRITERIA

Of all the performance aspects that can be attributable to windows and doors none is more vulnerable to fluctuations in environmental temperatures than the overall heat transfer rate. This energy transfer descriptor has four components: radiation, convection, conduction and air leakage. The air leakage component has been simplified in heat loss/gain calculation procedures, negated during conductive heat transfer tests, and for the most part assumed negligible by persons performing energy audits; compared with the glazing effects. Test temperatures used for measuring air leakage rates of fenestration products are room temperatures; approximately 70 F. This ASTM procedure, E283, was developed as a comparative rating system. It does not provide the user with methodology to measure air leakage rates at elevated or depressed exterior ambient air temperatures which fenestration systems are exposed to in the field. The overall coefficient of heat transfer (U-value) test is performed with a differential air temperature across the specimen. Air leakage measurements, however, are performed with no differential air temperatures across them. A very unnatural state for fenestration systems.

An assumption is made that air leakage rates for windows and doors will not change for varying exterior ambient air temperatures. Fenestration air leakage rates are vulnerable to seasonal and diurnal ambient air temperature swings. These changes are attributable to coefficient of expansion and contraction of materials and thermal bow. Also a major contributor to the problem are compression set characteristics of weather seals.

Materials from which weather seals are manufactured play a major role in fenestration air leakage maintenance. Weather seal performance is highly interactive with the type of material from which windows and doors are manufactured and ambient air temperatures.

If air leakage rates can vary with exterior ambient air temperatures, what relevance do current allowable air leakage levels found in industry performance specifications have? If the air leakage rate of a window or door is at or below the allowable threshold when the product is certified at an independent laboratory using E283; with laboratory temperature on the interior and exterior sides of the specimen, what happens to the air leakage characteristics when the product is five years old and the ambient air temperature is 0 F.?

More than likely the weather seals have taken a compression set and have shrunk. The products air leakage rate has increased. It is very possible that the leakage has increased to the point where the window or door no longer meets the industry requirement for allowable air leakage of new products. The chart in figure 1 illustrates changes in field air leakage rates of windows that were one year old. Researchers (Weidt/Weidt/Selkowitz) concluded that weather seal location and fit was a major factor in the reduction of field air leakage performance.

It seems that fenestration manufacturers are always in the testing laboratory evaluating their designs or certifying their products. How then, is it possible for fenestration products to lose performance in such a short time span after installation? The answer lies in the fact that weather seals, used in windows and doors, are manufactured from materials that have a propensity for shrinkage and compression set.

Table 1 lists some of the various tests that fenestration manufacturers and their suppliers use in evaluating their products (ASTM, AAMA). These tests are not interactive. They are not performed simultaneously, nor were they designed to provide a wholeistic performance rating. Each test is performed with a specified set of parameters and a single performance rating is obtained.

These tests were designed as an aid to the designer and the specifier. The designer uses the test data to determine if the product will meet architectural performance specifications that are required for a specific geographic location; weather conditions being the predominant influencing factors that designers must contend with. Specifiers use the test data to ensure that manufacturers have designed their products to meet minimum performance levels which will provide adequate performance for building occupant comfort, system performance and interaction with the building thermal envelope.

These tests are also used in another very important way. That is, as a rating system to compare manufacturers products on the open marketplace. Test data are usually condensed into a single number that gives an interpretation as to how well a product performs to specified test parameters that represent very specific environmental conditions. This condensation process can be very misleading and has the potential for high liability. Test data, when condensed an used as a marketing tool, can become a "numbers game". Manufacturers sell and promote their products based on single figure ratings. The thinking goes like this: If the rating system is a 0 to 10 and manufacturer A rates 6 and manufacturer B rates 7, then manufacturer B has the better product! This may not be the case because of the data condensation process. A good example of this would be the sound transmission loss test for partitions. A fenestration product may have good high frequency attenuation properties but poor low frequency properties. Another product may be manufactured differently and the sound transmission loss characteristics may be opposite the first product. The sound transmission class (STC), however, may be the same for both products because of the procedure used to calculate STC.

Architects, specifiers, designers and code officials have been trained to think about test results in this manner. Test data usually describes performance of new products or prototypes. Tests are performed in a laboratory under ideal conditions. Tests are also static in nature in that they do not allow for multivariate interaction.

A test which the industry does not have available to it at this time, is one that will allow design engineers and specifiers the freedom to evaluate fenestration system performance over time. This is an accelerated aging test that would be performed in the laboratory in a short time span. Accelerated aging data could then be used to determine defects or shortcomings in materials or components before products are manufactured and installed in the envelope. This accelerated aging test falls under the heading of performance durability. Durability is the maintenance of serviceability over a specified time. Serviceability, as defined by ASTM, is the capability of a building product, component, assembly or construction to perform the functions for which it is designed and constructed.

FENESTRATION AIR LEAKAGE METHODOLOGIES

The current method for measuring fenestration air leakage is ASTM E283-86 "Standard Method of Test to Determine the Rate of Air Leakage of Windows, Curtain Walls and Doors." It does not provide proper information for the design professional who has to make energy analysis decisions and product or system performance evaluations. This test method does not simulate environmental factors that these products are exposed to in the field. The method and the developers of the methodology are not to blame however. Recent data on fenestration air leakage performance at various temperature conditions was not available until relatively recent advances in thermal test methods and apparatuses. These advances have stimulated applied research into material performance and fenestration system dynamics.

The methodologies developed and promulgated by ASTM and AAMA for the determination of heat transfer of window systems do not allow for air leakage effects during the test. The air leakage effect on the heat transfer function is negated altogether. The overall coefficient of heat transfer; U-value, has been reduced to conductive, convective and radiative functions. Mass transfer effects (air leakage) must be calculated from equations 2, 3 and 4 using the air leakage rate obtained at room temperatures and added to the heat loss/gain portion obtained at differential temperatures using equation 1; 18 F exterior side and 68 F interior side of the test specimen (AAMA).

$$Q_T = Q_C + Q_R + Q_C + Q_I \qquad (1)$$

where: Q_T = Total heat loss/gain, Btu/Hr
Q_C = Conductive heat loss/gain, Btu/hr
Q_R = Radiative heat loss/gain, Btu/hr
Q_C = Convective heat loss/gain, Btu/hr
Q_I = Infiltration heat loss/gain, Btu/hr

$$Q_I = Q_{LATENT} + Q_{SENSIBLE} \qquad (2)$$

$$Q_{SENSIBLE} = 1.10 \times Q_i \times T \qquad (3)$$

$$Q_{LATENT} = 4840 \times Q_i \times W \qquad (4)$$

Q_i = Fenestration air leakage rate, SCFM/sq. ft.

ASTM Committee E6 on Building Materials and Performance is developing a test method to measure air leakage rates of windows and doors with differential air temperatures across test specimens. Ambient air temperatures used in this test could be the same as those specified in the AAMA or ASTM heat transfer tests. Air leakage rates of fenestration products could then be obtained during the conductive heat loss test; before or after the test period proper and not during.

Air leakage rates of various types of windows at differential ambient air temperatures are illustrated in figure 2. The data was obtained using the proposed test method that is being developed in the ASTM E6.51.04 Task Group. Figure 3 illustrates the effect of differential air temperatures on air leakage rates of steel entrance doors. The data indicate an increase in air leakage as the specimens exterior ambient air temperature is lowered. This occurs for both windows and doors. When exterior ambient air temperature is increased, window air leakage decreases. The door air leakage, however, increases similar to the cold air temperature data. This is due to the method of functional operation of the two types of systems. Figure 4 illustrates crack width variation of a double hung window. The change in sealing profile is directly proportional with exterior ambient air temperature. Figure 5 illustrates the thermal bow of a steel entrance door at hot and cold exterior ambient air temperatures. This bowing effect causes the door to move into and away from the sealing system located in the jamb. The door and seal are at different contact points at various temperatures. The interior ambient air temperature was maintained at approximately room temperature throughout all tests; 68-72 F.

The thermal bow of the steel entrance door was measured by placing electronic deflection transducers at the positions indicated on the interior side of the door; figure 5. The corners of the door, on the strike plate side, had the greatest amount of movement. The steel door had both interior and exterior movement with respect to the frame. This movement into and away from the frame adversely effects the performance of the perimeter sealing system by altering the compression ratio on the seal.

Window air leakage can also be adversely effected by exterior ambient temperature cycling. The movement of window sills and rails relative to frame members can be great enough to effect seal compression ratios. The alteration of weather seal compression ratios will effect air leakage characteristics in a similar manner as the door systems. The style of the window system will greatly determine the amount of weather seal compression change during the temperature cycling (Weidt, et. al.). Construction and assembly techniques also have an effect; i.e. miter or butt corners, screw or thermal weld.

Air leakage rates of weather seals can significantly change with very small changes in seal compression. The data in figure 6 indicate weather seal air leakage as a function of compression ratio and compression set.

When this data is correlated with the changes in window and door mounting distance due to thermal cycling it becomes very clear why fenestration systems will undergo changes in air leakage characteristics at varying ambient air temperatures over the life span of these systems.

FENESTRATION SELECTION CRITERIA

The process by which architects and component specifiers select windows and doors must be modified to account for real world environmental conditions that can have a dramatic impact on the installed air leakage performance of these products.

A manufacturers' guarantee on the air tightness of a fenestration product in the field and over time is not probable in the foreseeable future. These products, when installed in the thermal envelope, are exposed to environmental factors which were not simulated in the laboratory during prototype testing; i.e. thermal and physical cycle tests. Consequently, the interaction of weather sealing systems and frame/sash members of windows and doors is unknown and until recently unpredictable. This interaction is critical and should be known by fenestration design engineers as well as architects and specifiers.

The selection of fenestration products should not be based solely in laboratory test data. Field verification tests are the only tools that architects have at their disposal; until ASTM accelerated aging and differential air leakage tests are developed and adopted, to insure that the installed performance of fenestration products meet manufacturers published data. Laboratory performance should be verified in the field and be required by the architect as one of the contractual agreements. Field performance should not be less than that obtained in the laboratory. If it is, it should be by an amount that is agreed upon by the architect and the window or door manufacturer before installation.

Table 2 lists fenestration performance characteristics that architects and specifiers should be looking for when specifying fenestration systems for long term field performance. If a manufacturer of a fenestration system is unable to supply differential temperature air leakage or accelerated aging tests they would supply weather seal performance data. This data will indicate the seals ability to maintain its functional and performance integrity which will allow the fenestration system to maintain good air leakage performance.

The major cause of fenestration air leakage failures are the sealing systems. The materials that were chosen in the manufacture of the weather seals, more often than not, are inadequate to meet real world environmental conditions that fenestration products are exposed to. Performance standards for windows and sliding glass doors have allowable maximum air leakage rates of 0.370 SCFM/FCP. These standards apply to aluminum, vinyl and wood windows and doors. This allowable air leakage rate requires that fenestration products maintain very tight manufacturing tolerances and tightly defined dimensions for the crack perimeter. Crack perimeters of windows and doors are where weather seals perform. This in-turn means higher compression ratios on the weather seals. This fact coupled with extreme environmental ambient and surface temperatures on these window and door products can cause weather seals to succumb to irreversible compression set. This will result in increased field air leakage of installed windows and doors.1

There is currently no consensus for field failure criteria as it relates to fenestration air leakage. If we assume that if field air leakage rates of fenestration products increase above allowable industry thresholds of 0.370 SCFM/FCP, then a failure of the product has occurred, then a starting point will have then been defined to deal with the problem of material failure causing system or component failure. This is where the weather seals material of construction becomes so important.

The proper selection of weather seals for windows and doors is often over looked by designers of such products. The oversight is not out of ignorance but from a lack of knowledge about material characteristics under the influence of environmental factors. Fenestration engineers place a high responsibility on the designers of weather seals. They require the sealing industry to provide them with state of the art in seal technology. This includes high performance materials, special profiles that cater to uniquely styled window and door products, and testing. Not only profile testing for performance and material characteristics but system tests. How well seals perform in fenestration products when interacting with other components under adverse weather conditions is a major issue. The means by which this type of interactive performance testing can be achieved is currently being developed at AAMA and ASTM. It is, however, the first time that fenestration and sealing engineers are coming together in a combined methodology development effort.

It is safe to say that if fenestration systems are exposed to heat, cold, moisture, UV, ozone, chemicals, environmental and uses stresses, their components will also be exposed. The chart in figure 7 illustrates weather seal requirements based on in-service conditions that fenestration products are exposed to. Performance trade-offs will be required as it would be very difficult to have a single material meet all in-service requirements. It is very important for fenestration designers to realize that weather seals, if not designed properly with the right materials and profiles, will deteriorate and consequently the installed field performance of fenestration systems will degrade. This can mean increased air leakage which will cause occupant discomfort, condensation, heat loss/gain, noise, dust and water penetration and premature wear and possible failure of other components in the system.

Weather seals used in windows and doors that are certified to a trade association specification must allow for east of operation by the user. This means a material with a low coefficient of friction and suitable profile geometry. The seal must be highly compressible to obtain very low air leakage rates. The seal must be resilient and flexible. It ideally should have almost 100% memory retention. Operable windows require high wear resistance properties. Color and strength retention are important as well. All of these factors will have an impact on the ability of weather seals to maintain required air tightness of fenestration systems.

Seals that are manufactured from materials that can be reshaped by the application of heat and pressure are vulnerable to premature field failure in fenestration products. These materials are known as thermoplastics. Materials that resist change when heat and pressure are applied are known as thermosets. Fenestration weather seals that are manufactured from thermoset materials will help windows and doors maintain their laboratory rated air leakage performance in the field.

FENESTRATION AIR TIGHTNESS (LEAKAGE) STANDARDS

Given all that has been discussed about fenestration air leakage and environmental conditions that can effect performance, what can the fenestration industry realistically expect from these products as they age? Is it enough to continually lower the allowable air leakage rates found in industry performance specifications every 5 to 7 years to compensate for the aging process of materials that ultimately effect air leakage performance of windows and doors in the field? This process has led to severe problems with users of windows not being able to open or close them. The ability of fenestration products to perform adequately, that is to maintain their air leakage ratings at or below the nationally acceptable standards after they leave the production line; or testing laboratory, depends on materials of construction, fundamentally proper designs, and the expectations of architects, building owners, occupants and consumers.

Fenestration products, like all other products, undergo a process of change, both in physical integrity and performance as they age. Designers knowledge of the components that go into fenestration systems and their materials will prove to be the overriding factor in the longevity of fenestration performance in the thermal envelope.

Architects and fenestration specifiers must realize that the current stock of fenestration industry specifications for air leakage provide a means to rate products under ideal conditions in the laboratory. The test method is static and idealistic in design. Performance specifications provide low level threshold limitations for compliance to standards. Laboratory and field test data may or may not show correlations. This is due to installation practices, differential air temperatures, and measurement techniques. The bottom line is, if the industry expects to improve fenestration air leakage durability, it is going to require improved test methodologies, materials, and designs. It will also require the efforts of trade associations and their members to promulgate these practices.

CONCLUSION

Fenestration products have come along way in sophistication. They are constructed from state of the art materials and components. Some are designed on CAD/CAM systems. They are manufactured to exacting standards. The toughest that have every been on the books. They are required to meet exacting demands of architects and buildings for structures located in all types of climates. In fact, it is the fenestration component of a building that gives it its uniqueness and beauty. It is the fenestration component that allows the building occupant to interact with the outside world. It is the fenestration component that allows the world to per into the sole of buildings and the people that occupy them.

Windows, doors, curtain walls, store fronts, and skylights give beauty and strength to buildings. Fenestration designers give form and function to them. Fenestration components, if not designed properly, will fail, causing premature failure of fenestration systems.

From a users standpoint, fenestration products will always seem to be functional and intact. Performance however, may not. Air leakage can increase. Water resistance may decrease. And operating forces may increases. Building occupants rarely know of system failures and their causes. They do know that the windows are drafty, that the carpet is wet or the walls are water damaged, and that the windows cannot be opened. The ability of weather seals to maintain their form and function throughout the life of fenestration products will ultimately determine the success of such products in the eyes of people who use them.

It is understandable that architects do not want to get involved in the design process of fenestration systems given all else that they have to contend with. Proper selection of sealing systems for windows and doors, however, must not be under rated by fenestration designers or architects. The performance of the system increases beyond an acceptable level whereby retrofit and/or replacement is warranted.

With ASTM developing two new test methods for the determination of real world air leakage characteristics and the measurement of performance longevity, architects may not have to get involved. But until these standards are in place and extensively used by the fenestration industry, architects and fenestration specifiers should take an active role and request that high performance weather seals are designed into these systems.

Figure 8 illustrates air leakage data that is supplied to the marketplace today by the fenestration industry. Air leakage measured at one test pressure with no differential air temperature across the specimen. Figure 9 illustrates a European air leakage specification. Air leakage is measured at 6 differential test pressures.

This specification provides the designer and specifier grater knowledge about the system and how it will perform in the field under a variety of wind load conditions. Figure 10 illustrates test data that will be generated from the proposed ASTM differential temperature air leakage test. This test will provide air leakage data on multiple differential pressures and temperatures. This type of system performance data will enable architects to perform highly accurate heat loss/gain calculations when used in conjunction with conductive heat transfer data. Fenestration specifiers will be able to select windows and doors based on the ability to perform under a wide range of environmental conditions. Not merely at one test pressure.

<u>REFERENCE</u>

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