

# Vinyl Windows: Designed for Performance



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Vinyl (PVC) windows have been around longer than you might think. The first were manufactured in Germany in 1954 as vinyl began to come to the forefront for construction applications in the face of post-war wood shortages and high prices for aluminum. This led to spectacular growth worldwide. According to the Vinyl Institute ([www.vinylbydesign.com](http://www.vinylbydesign.com)), of the 15 billion pounds of vinyl produced worldwide today, about two thirds is used in the construction industry.

Vinyl building products first found favor in the U.S. market in the early 1960s, initially in the form of pipe and then siding. The first PVC window in the U.S., a single-glazed side-load double hung product for replacement application, was introduced in the U.S. in 1964 by Thermal Industries. General acceptance of this new product was spurred by the inherent benefits of vinyl windows: low maintenance, economy and, in particular, energy efficiency — a concern that gained prominence during the “energy crisis” of the early 1970s.

Today, vinyl building products are widely accepted and make up 58% of the market share of residential window sales, according to 2005 research\* jointly sponsored by the American Architectural Manufacturers Association (AAMA) and the Window and Door Manufacturers Association (WDMA). In the U.S., over 40 million vinyl windows are sold each year. Vinyl windows and doors are expected to claim a 53% market share (in terms of unit sales) for new residential construction applications in the U.S. by 2009. In residential remodeling, vinyl products are projected to command more than 65% of the market.

In addition, the use of vinyl is expanding beyond windows and doors to include skylights, decking and fencing products. Vinyl siding has also recently become the dominant residential cladding, overtaking wood, brick and aluminum.

Why this degree of acceptance? Primarily because vinyl has proven itself to be a well-performing, cost effective building material.

But vinyl had to overcome some misconceptions and competitive “spins” to attain this level of acceptance. Contractors and consumers initially regarded vinyl building products with skepticism when they first appeared on the U.S. market. After all, structures should be built with solid, robust “traditional” materials, shouldn’t they? How can “plastic”—perceived early on as the same “cheap” stuff used to make kids’ toys—be acceptable for construction?

Perhaps this initial concern was understandable, given the limited use of rudimentary plastics half a century ago. But, things have changed, thanks to advances in materials engineering. Once the technology was better understood, the material-oriented competitive claims began to blur. While some of the old misconceptions may still ring true to some people, today’s vinyl, highly engineered specifically for construction applications, is as different from early “toy” plastic as stainless steel is from cast iron.

## So, What is Vinyl Anyway?

Vinyl, more technically known as Poly Vinyl Chloride, or PVC, was first synthesized in 1872, but wasn’t investigated seriously for practical applications until 1926 at B.F. Goodrich by Dr. Waldo Lonsbury Semon. Among its first practical uses was jacketing for electrical wiring on naval ships during World War II, where it replaced increasingly

### Case Study

**Location:** Saratoga Springs, NY

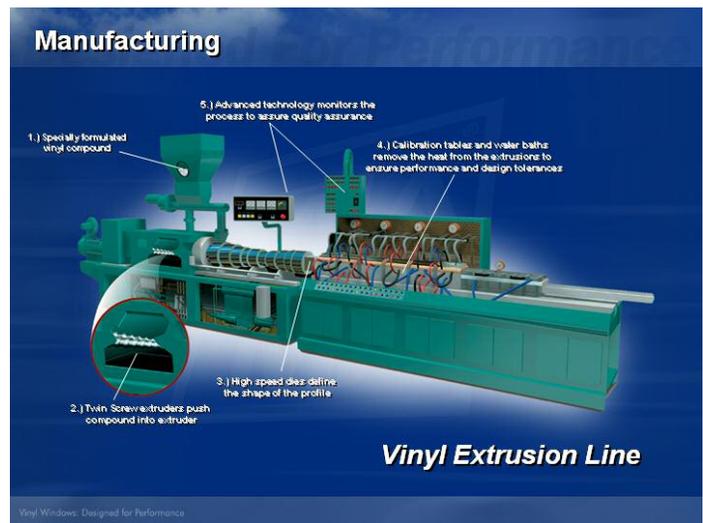
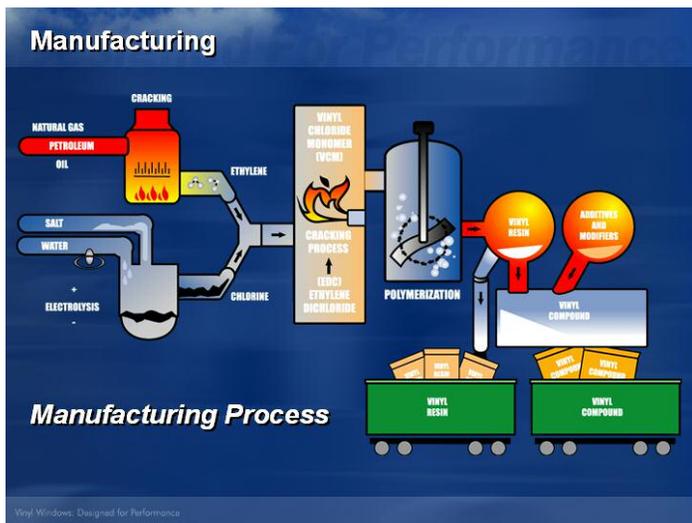
**Challenge:** Save energy in a large atrium of a retirement community where utilities are included

**Solution:** Energy efficient vinyl windows and patio doors



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\* 2006 AAMA/WDMA U.S. Industry Market Studies



scarce rubber insulation and flammable cloth jacketing. Shortly after the war, material shortages led to experimentation with vinyl window frames, flooring and wallpaper coating. The advent of PVC pipe proved critical to maintaining clean water delivery all around the globe.

Salt, which is abundant in supply, is actually the primary ingredient of vinyl. Chlorine derived from the electrolysis of salt water is combined with ethylene (a petroleum derivative) in a clean, automated closed-loop process that yields ethylene dichloride (EDC). EDC is then "cracked" under heat to produce vinyl chlorine monomer (VCM). Vinyl resin, typically in powder or granular form, is produced when the VCM is subjected to polymerization to produce polyvinyl chloride, or PVC. Polymerization is the process by which smaller organic molecules (monomers) are bonded together chemically into a much larger, chainlike repeating molecule called a polymer. The polymer is typically engineered to have very different physical properties than the constituent monomer(s). The primary constituents of PVC, for example, ethylene and chlorine, have very different properties than the final PVC polymer.

The resulting PVC resin can be mixed with a variety of additives and modifiers to improve the impact resistance, thermal stability, UV resistance and weathering characteristics. Such high-tech compounding and unique processing techniques are the keys to vinyl's versatility.

Physical property specifications for PVC compounds used for windows can be found in American Society for Testing and Materials (ASTM) standard ASTM D4216 *Specification for Rigid PVC and Related Plastic Building Product Compounds*. It provides minimum values and ranges for tensile, flexural, and impact strength, coefficient of expansion, and heat deflection temperature.

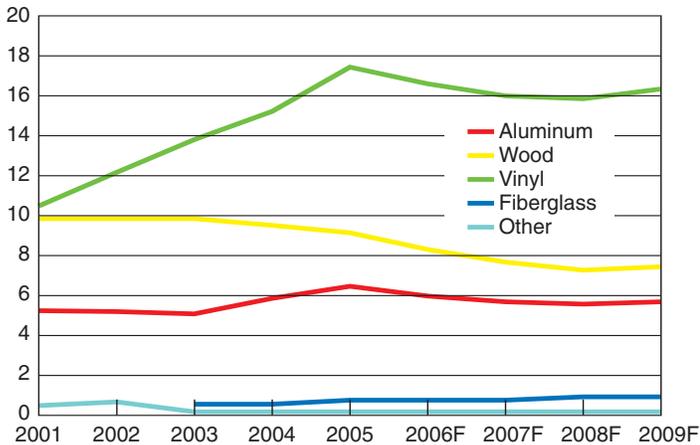
For use as window profiles, the specially-formulated resin, augmented with processing additives and pigments, must be processed into final form through an extrusion process. In this step, the resin is melted and the resulting soft mass is forced through dies that give it its final shape. The extrusions are cooled under carefully controlled conditions to ensure that intended shapes and tolerances are maintained.

ASTM D4726 *Specification for Rigid PVC Exterior Profiles Used for Assembled Windows and Doors* concentrates on the extrusion process quality. It outlines the testing protocol for dimensional stability, weathering, color hold and impact strength before and after weathering, and weight tolerance.

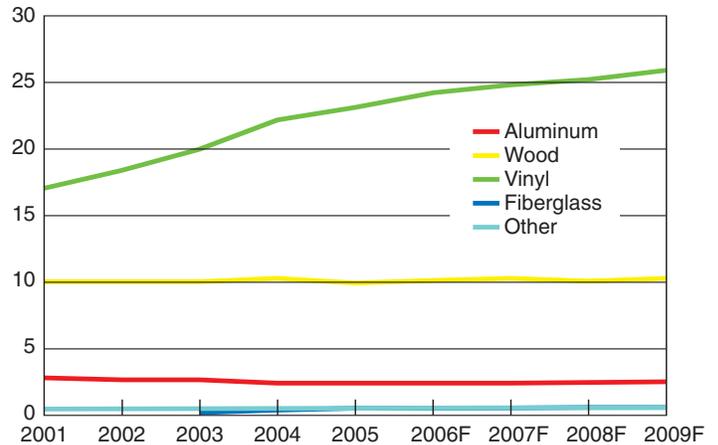
These extrusions, which form the basis for a vinyl window assembly, are shipped to a window fabricator in bulk lengths. The window fabricator, using manual or automated equipment, then cuts the bulk lengths to the specified dimensions of the window. The profiles are then tooled or machined to accept the appropriate hardware and components for assembly. The mitered corners of frame and sash members are most often fusion-welded together, but in some instances mechanical fasteners or corner keys can also be used to complete the corner connection. Automated corner-cleaners precisely remove the weld sprue (waste material) to ensure a smooth appearance. The remainder of the assembly entails installation of hardware components (locks, keepers, balances, operators), weatherstripping and in most cases an insulating glass unit is preferred because it provides better thermal performance. The completed window is cleaned and inspected, then labeled appropriately before packaging, making it ready for shipment to the customer.

## Growth of Vinyl Windows (United States)

New Construction (millions of units)

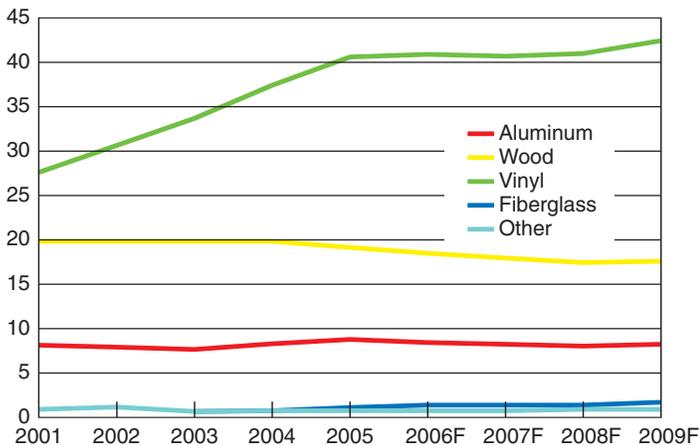


Remodeling & Replacement (millions of units)



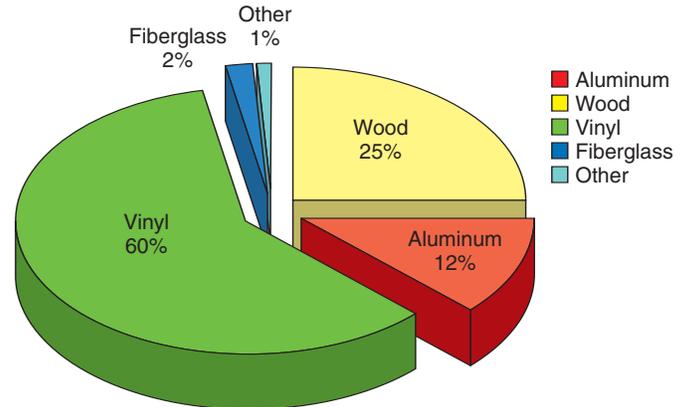
Please note that the categories of "Fiberglass" and "Other" had very similar numbers, which may be difficult to decipher in the graph above.

Total Construction (millions of units)



## 2009 Projected United States Market Share

2009 Projected Residential Windows



Source: 2005 AAMA/WDMA U.S. Industry Statistical Review and Forecast

## Why Specify Vinyl Windows?

### An Amazing Success Story

Used in hundreds of industries, vinyl is now the second largest volume plastic produced worldwide and the largest volume plastic for building and construction products. Vinyl products have revolutionized the building industry because, as a building material, vinyl offers remarkable versatility. It can be flexible, rigid, customized for application and produced in nearly any color, pattern and texture. Vinyl combines many characteristics of traditional materials with advanced technologies.

A look at the fenestration segment of the vast building products market reveals the amazing speed at which vinyl-framed windows and glass doors have penetrated residential and light commercial applications, with annual growth rates in the neighborhood of 20%.

While vinyl windows were first aimed at the replacement and remodeling market, passing aluminum in preference for that application in 1988 and wood by 1996, they first became visible on the radar screen for new construction only as recently as 1987. Driven by their advantages of low cost and ease of maintenance, vinyl products entered a strong growth period in the 1990s, in 1999 capturing the leadership position in the overall market share race, and tallying 58% by 2005. By 2009, they are projected to be the leader in residential applications, accounting for 60% of all windows sold, according to the *AAMA/WDMA 2006 U.S. Industry Statistical Review and Forecast*.

Vinyl windows are used on all types of housing (high-end custom, high-volume tract, manufactured housing and multi-unit housing), so they are projected to continue gaining market share before maturing in about 20 years.

# The Proof Is In the Performance

The simple reason for this revolution is cost-effective performance, which is the primary reason for specifying vinyl windows for residential and light commercial projects. In addition to well-promoted consumer benefits of economy and ease of maintenance, that performance is well documented in several key areas of particular interest to architects and specifiers, which are listed below and described in further detail later in this article:

- Low Maintenance
- Energy Efficiency
- Structural Strength
- Weatherability
- Chemical Resistance
- Fire Resistance
- Impact Resistance
- Dimensional Stability
- Thermal Expansion
- Heat Build-Up Characteristics
- Long-Term Durability
- Green Building
- Lead Content
- Dioxin Releases
- Solid Waste and Recyclability
- Design Flexibility
- Exterior Colors and Interior Finishes

## Low Maintenance

Perhaps the original benefit of vinyl windows that was heavily promoted to the homeowner, low maintenance has been a prime factor in the exploding market share that vinyl products have enjoyed – including floors and wall coverings as well as windows and doors. With vinyl windows, color can be integral to vinyl frames through the addition of pigments to the vinyl formulation, not a surface coating, so there is never a need for touch-up due to scratches. Extremely durable, vinyl products resist rotting, chipping, peeling and corrosion, are not susceptible to insect or fungus attack, and can be easily cleaned with a solution of mild soap and warm water. In fact, vinyl's ability to be cleaned easily and thoroughly makes it a popular material for use in hospitals and other health care environments.

The economic, durability and low maintenance attributes of vinyl windows and doors led Habitat for Humanity International to choose them for its volunteer-built homes for families in need. Due to ease of installation, vinyl windows are ideally suited to the varying skill levels of the thousands of workers involved in Habitat builds each year. Vinyl building products are a cornerstone of affordable housing.

## Energy Efficiency

Vinyl's popularity in the U.S. is largely due to energy efficiency. Because it is such an effective thermal insulator (having a low U-factor, also known as U-value), vinyl is well recognized as an excellent frame material for energy-efficient windows. Currently, 43% of the windows listed in the National Fenestration Rating Council (NFRC)

Certified Products Directory are framed with vinyl. Many utilities are offering incentives to builders who install energy-efficient windows in homes. Federal and state tax incentives also offer rebates or special deductions for the use of these products. Vinyl windows are commonly used to meet these requirements. The Department of Energy's (DOE) Energy Star® program sets forth climate-dependent criteria for window performance which are easily met by vinyl products.

All energy-saving glazing options are of course available in vinyl windows: double or triple pane insulating glazing, with air or gas (argon or krypton) infills, or low emissivity ("low-E") coatings. The latter are composed of an extremely thin layer of metal applied to glass to maximize beneficial solar heat gain and reflect heat back into the house. When applied to the outer pane (typically for use in hot climates), low-E coating minimizes heat gain and reflects heat back outdoors.

The chart compares vinyl's legendary energy efficient characteristics.

THERMAL PERFORMANCE	
<i>U-Factor* Range for Vinyl Framing Material</i>	
Frame Material	U-Factor
Vinyl	0.3 – 0.5
Insulating vinyl	0.2 – 0.4

Source: Residential Windows: A Guide to New Technologies and Energy Performance, Third Edition

\* A measure of the rate of non-solar heat loss or gain through a material or assembly. The lower the U-factor, the greater a window's resistance to heat flow and the better its insulating value. U-factor is equivalent to 1/R-value.

For example, the typical U-factor of vinyl window frames ranges from 0.3 to 0.5, with lower numbers meaning less heat flow and better thermal performance.

The ultimate goal – expressed in the U.S. Department of Energy's "2020 R&D Roadmap" – is to develop windows that have zero annual energy cost. The industry already envisions "super windows" that will use spectrally selective and automated electrochromatic glazing to admit solar heat gain in winter to supplant heat loss and reflect heat back outside in summer. The multi-chambered vinyl product frames are designed to trap air, known to provide optimal insulating characteristics against heat transfer year-round.

In addition to saving on home heating and cooling bills, the manufacture of vinyl products takes relatively little energy. Production of all vinyl products worldwide accounts for less than 0.3% of all oil and gas consumption, with windows and doors accounting for a small fraction of that. Vinyl Institute figures show that the use of vinyl as a construction material actually saves more than 40 million barrels of oil per year compared to other building and construction alternatives. Vinyl products in general have

low embodied energy, which is the amount of energy used to convert raw material into a final product. A lifecycle study by Franklin Associates has shown that the use of vinyl over alternatives in window frames saves the United States nearly two trillion BTUs of energy per year, enough to meet the yearly electrical needs of 20,000 single-family homes.

### **Structural Strength**

Vinyl serves admirably within the massive residential and light commercial markets. This is because most vinyl window profiles are engineered with a multi-chambered design that can actually be stronger than a solid frame. The network of baffles and chambers, like those of a honeycomb structure, creates a favorable weight-to-strength ratio. For larger windows, the strength of vinyl frames is often bolstered by inserting metal reinforcing members into the chambers. Corners of the frames are fused together using an advanced heat welding process, providing even more strength and ensuring that the windows are air- and water-resistant. Automated equipment ensures precision and quality throughout the manufacturing process.

As we will discuss shortly, using performance-based standards as the basis for specifying levels the playing field and removes any concern about structural performance of any framing material for given job-site conditions.

### **Weatherability**

Weatherability is the ability to retain impact strength, color, and other physical properties (e.g., gloss, texture, etc.) over a period of time despite exposure to the elements, such as ultraviolet (UV) rays in the solar spectrum, extreme temperatures, wind, rain, snow and ice. Weathering studies at test sites in various climates and commercial applications around the globe prove that appropriate additives such as Titanium Dioxide (TiO<sub>2</sub>) and specially-formulated pigments can effectively make vinyl products very resist to weathering while requiring low or no maintenance during the service life of the products.

TiO<sub>2</sub> is well recognized for its ability to enhance the weatherability of vinyl products—so much so that most vinyl siding, windows and doors contain anywhere from 5% to 10% TiO<sub>2</sub> by weight. Because of its chemical

properties, TiO<sub>2</sub> reflects about 95% of the visible light, making it an effective bright white pigment. It also absorbs much of the incident solar UV light, which protects the polymer matrix from photochemical degradation, the cause of discoloration and loss of impact strength over time. There are two types of crystal structure of TiO<sub>2</sub>: Rutile and Anatase. Because of the higher UV light absorbing property of the rutile-type of TiO<sub>2</sub>, it is the preferred TiO<sub>2</sub> for achieving weather resistance in vinyl products.

Commercially available TiO<sub>2</sub> is typically surface-treated, and depending on the surface treatment, is categorized as a "chalking" (i.e. "non-durable") or a "non-chalking" (i.e. "durable") TiO<sub>2</sub>. Both chalking and non-chalking TiO<sub>2</sub> provide the same level of weatherability to vinyl products in terms of impact retention, while chalking grade promotes chalking on the surface of the product when exposed to UV light and moisture. Surface

chalking is preferred when gloss retention is not required and a long-lasting white color surface is desirable. On the other hand, a non-chalking TiO<sub>2</sub> should be used when gloss retention is required and/or when the vinyl product is tinted (non-white).

### **Chemical Resistance**

Vinyl window profiles are formulated to resist the effects of moisture, household chemicals and cleaning

agents, pesticides and corrosive conditions (such as near the sea coast or heavy industrial areas). This is one reason that PVC has found popular use as water piping.

### **Fire Resistance**

The fire hazard of a product is defined by several factors, including its ignitability or flammability, the amount of heat released when it burns, the rate at which this heat is released, the flame spread, smoke production, and the toxicity of the smoke.

Being a plastic, PVC might be suspected of hazardous behavior in some of these categories. However, it in truth has excellent fire properties due to its chlorine content. In particular, PVC not only has a high flash ignition point (736°F [391°C] per ASTM D 1929 test methods), it is actually self-extinguishing once the source of heat or flame is removed (i.e., it will not support combustion), according to the Vinyl Institute's brochure entitled "Fire and Polyvinyl Chloride."



Generally, a distinction must be made between plasticized vinyl—used to make flexible products such as wire coatings, upholstery or wall coverings—which has less favorable fire properties than the unplasticized (rigid) PVC used in pipe, siding or window profiles. The latter products, in fact, have higher ignition temperatures, lower flame spread and lower heat release rates in a fire than similar samples of wood, according to the Vinyl Institute.

- Flame spread indicates the tendency of a material to spread flame. With a flame spread index of 10 as determined per the ASTM E 162 radiant panel test (compared, for example, to plywood at 143), PVC will not spread flame on its own.
- Heat release indicates the ability of a burning object to spread fire to nearby objects by giving off enough heat to ignite them. In addition, this heat has to be released fast enough not to be dissipated while traveling through the air to the object. In terms of overall fire hazard, the rate of heat release (RHR) has in fact been shown to be much more important than ease of ignition, flame spread or smoke toxicity. This is reflected in the fact that fire fatalities most often occur when the rate of heat release is sufficiently large to cause most of the items in a room to burn. When measured in a variety of ways in the lab, very few materials have lower rates of heat release than PVC. In full scale room tests (e.g., ASTM E 1537, E 1590, etc.), considered most representative of actual fires, rigid PVC released 38 kW of heat energy over the 13 minute test period, while oak wood released 109 kW.

Dense smoke obscures light and hinders escape from a fire, and can be quite toxic. This is why smoke inhalation is by far the greatest cause of fire injury or fatality. Smoke production figures from tests of PVC show it to be among the lowest smoke producers of all polymers. In full scale room tests, measurements taken at the door to the test room showed that peak smoke generation from rigid PVC was only 24% that of oak wood. In terms of smoke toxicity, the smoke from virtually all organic materials falls within a very narrow range. Within that range, the toxicity of PVC smoke ranks between that of wood and ABS plastic.

Vinyl also produces less carbon monoxide than most organic materials. By comparison, nicotine is considered to be about 70 times as toxic as smoke from burning PVC.

However, relative performance in isolated structure fires is not the whole issue when it comes to fire resistance. Windows are considered to be one of the most vulnerable portions of structures located in the “Wildland-Urban Interface” (WUI)—boundary areas where suburban residential developments meet fire prone open grasslands, forests or brushy areas. Regulatory action, mostly at local levels in California, Arizona and Colorado—well-publicized sites for wildfires, initially sought to essentially ban vinyl windows under the assumption that the PVC framing members would soften and sag when exposed to exterior fires, allowing the glass to fall out, exposing the building to the entry of flames.

As a result of discussions between the window industry and fire officials, FEMA-sponsored fire performance tests of exterior building components conducted by the University of California Forest Products Laboratory (UCFPL), showed that the glass was the weakest link in windows, failing first in each and every test, with tempered double-pane glass outlasting single-pane significantly. Also, none of the framing materials sustained combustion. Even where frames did fail, there

**Case Study**

**Location:** Pinnacle Lofts and Condominiums - Portland, OR

**Challenges:**

1. Design a sleek and modern mixed-use building that celebrates the views of Portland's Pearl District
2. Match anodized finish of other products used in the building
3. Achieve energy efficiency

**Solution:** Commercially-rated vinyl windows with co-extruded capstock

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was no discernable difference among vinyl or clad wood. Researchers also pointed out that, with regard to the possible softening and sagging of vinyl frames under exposure to radiant heating, steel- or aluminum-reinforced members were likely to protect against such failures. Fire protection officials additionally recommended that, for maximum protection against WUI fires, vinyl window frame and sash profiles should be certified under the AAMA Profile Certification Program, while complete window units should be certified and labeled as conforming to current window performance standards.

### **Impact Resistance**

Impact resistance is a very important property for PVC extrusions. Consider that, before assembly, a PVC profile is punched, routed, and sawed. During assembly it is welded, the corners cleaned and hardware installed. Shipment entails bouncing around in a trailer truck, moving several times in a warehouse or retail outlet with an

unforgiving forklift truck and finally riding in the back of a pickup to the job site. Additives such as impact modifiers (i.e., acrylic and CPE), enhance the ability of PVC to resist impact, and—as we will see shortly—testing for impact resistance is a requirement for certification of vinyl profiles for use in AAMA-certified windows.

One area that standard test methods have addressed more zealously – spurred by recent brutal hurricane seasons of 2004 and 2005 along the southeastern United States coastal regions, Atlantic and Gulf coasts specifically – is that of impact resistance of the entire window assembly.

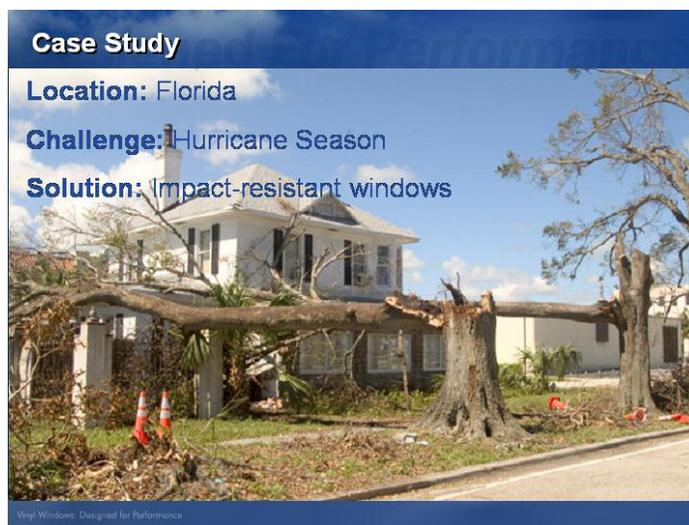
Led by the understandably stringent requirements of Florida’s Miami-Dade County (as expressed in their TAS201 and 203 standards), products are rigorously tested for resistance to the impact of flying debris. This has been shown to be the leading cause of window failure during severe storms, not wind pressure alone.

These tests are not trivial.

An air cannon shoots a two-by-four stud weighing 9.25 pounds directly at a window at a speed of 50 feet per second (37 mph). Each test specimen is impacted twice, and all mullioned assemblies must be impacted additionally on the mullion, where the separate units are joined. Then, the window is subjected to 9,000 cycles of combined positive and negative pressure. Dade County-approved

products must withstand 146 mph wind speed (equivalent to a strong Category 4 hurricane). However, each county or city has its own wind speed requirement, based on proximity to coastline. To achieve Dade County approval, each window must continue to be operable after running this gauntlet of tests. Other coastal jurisdictions require testing to ASTM E 1886, *Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials* and ASTM E 1996, *Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors and Impact Protective Systems Impacted by Windborne Debris in Hurricanes*, which form the basis of AAMA 506, *Voluntary Specifications for Hurricane Impact and Cycle Testing of Fenestration Products*.

Vinyl impact-resistant windows, typically with steel-reinforced frames and laminated glass, regularly pass these tests.



## ***Dimensional Stability***

Dimensional stability – the ability to retain size and shape over a product’s service life – is one of the most important requirements for building products. Problems such as warping, bowing and other changes may occur when they are excessively heated by the sun.

Polymeric materials, such as vinyl and ABS, expand and contract (have a higher coefficient of thermal expansion) to a greater degree than other building materials. Heat buildup, or infrared energy absorption upon exposure to the sun, will determine the thermal stability of a colored vinyl.

## ***Thermal Expansion***

Under identical conditions of elevated heat exposure, vinyl and other polymeric materials such as ABS expand more than four times as much as glass due to their greater thermal expansion. Vinyl expands at a rate anywhere from 4.4 to 8.8 times that of glass, although heat-stabilized compounds perform at the lower end of this range.

Of course, real-world conditions (such as the fact that only small portions of the exterior surface of a window frame are subjected to extreme solar heating at any given time and are restrained from excessive expansion by the wall opening) and proper window profile design (such as providing adequate glass bite) accommodate these differences in properties between basic raw materials.

## ***Heat Build-Up Characteristics***

Because dark-colored surfaces absorb heat more readily than light-colored surfaces, heat build-up in framing material due to solar radiation is very color-dependent and is controlled by the pigment system used. The same color with different pigment systems can have widely varying heat build-up numbers. The ASTM D 4803 *Standard Test Method for Predicting Heat Build-up in PVC Building Products* measures the increase in heat within a product. Different areas of the United States receive different amounts of solar radiation and have different high ambient temperatures. These two climate characteristics along with heat build-up can be used to evaluate various environments throughout the country.

## **Long-Term Durability and Green Building**

Builders are finding that in addition to the environmental allure of "sustainable" (renewable or recyclable) or "green" buildings (those with low life-cycle environmental impact), they are also more economical over the long run because of better energy efficiency. However, they are also realizing that "green" is long-lasting and appealing to occupants due to abundant windows and skylightings that bring in fresh air and natural light, fostering fewer "sick days" and greater productivity. An environmentally sensible approach to building considers the building's impact from "cradle to grave" – from design, siting and construction to operation of the building through its lifetime to final disposition of the building and its materials at the end of their useful life.

Despite some activists' claims to the contrary, vinyl building products are increasingly included on lists of "green" building products. For example, a study by life cycle assessment experts Greg Norris and Peter Yost of MIT and Yale Universities shows the use phase is the most important in terms of a material's life cycle impact, and counterbalances over time the environmental impact stemming from a product's manufacture. Vinyl, because of energy efficiency, thermal-insulating value, low contribution to greenhouse gases, easy maintenance and excellent durability of products made from it, provides extensive life cycle benefits.

Because vinyl windows and doors will be in service for many years with minimal maintenance, which requires no periodic use of stripping chemicals, paints or stains, and no associated clean-up and disposal, use of vinyl tends to reduce air and groundwater pollution.

Vinyl's ease of recyclability also lends itself to use as a green material.

## **Recyclability**

Due to the thermoplastic nature of vinyl, products and materials can be processed and reprocessed using heat without loss of properties.

According to a 1999 study by Principia Partners, more than one billion pounds of vinyl were recovered and recycled into useful products in North America in 1997. About 18 million pounds of that was post-consumer vinyl diverted from landfills and recycled into second-generation

products. Overall, more than 99% of all manufactured vinyl compound ends up in a finished product, due to widespread post-industrial recycling.

A 2002 Principia Report found that of the 3.2 billion pounds of vinyl compound consumed in the manufacture of new siding and windows, only 201 million pounds of scrap is generated, such as when window manufacturers cut mitered corners from extrusions. The majority of this is reclaimed for use in the same or similar applications, such as pipe, conduit, siding, fencing and garden lumber. For example, some manufacturers have produced vinyl window frames containing up to 25% recycle content. In total, less than 20 million pounds of scrap is discarded resulting in a 99% efficient process.

Due to vinyl's durability, the vast majority of vinyl windows installed over the past 25 years are still in use and, therefore, are not candidates for end-of-life or post-consumer recycling. Their estimated service life of more than 50 years means few older ones are being replaced (although there is a growing trend for older vinyl windows to be replaced with newer, more efficient vinyl units).

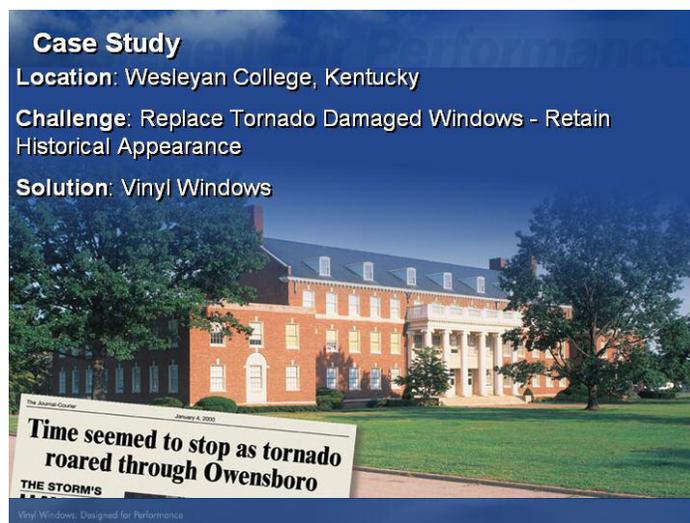
When the time for final disposal comes, however, vinyl windows—like all vinyl—can be recycled. The low contribution to the solid waste stream is primarily a result of vinyl's use in long-lived applications,

such as windows. The vinyl that is discarded is so stable that it degrades very slowly in a landfill and is thus not a source of groundwater pollution.

As with any building product, the key to greater post-consumer vinyl window recycling is to find more cost-effective ways to collect, separate, process and transport used materials to a manufacturer for use in new products.

## **Lead Content**

Linking vinyl windows and doors to lead-laced PVC products is erroneous. The simple truth is that no lead is added to the vast majority of vinyl sash and frames used in windows and glass doors. All of the 12,601 vinyl profiles certified in the AAMA Profile Certification Program must have no lead added during processing and must contain less than 0.02% by weight of lead, a level that meets California's stringent requirements (more rigorous than the Consumer Product Safety Commission level of 0.06%). All coatings and laminates must also meet this requirement if applied on AAMA-certified PVC window profiles.



## ***Dioxin Releases***

Dioxin is a persistent and toxic substance that is produced when chlorine-containing compounds are burned in the presence of hydrocarbons. In addition to being a known carcinogen, dioxin exposure has been linked to reproductive and hormonal disorders, diabetes, learning disabilities, immune system suppression, lung problems and skin ailments.

Because chlorine can be found almost everywhere on earth (e.g., in salt), dioxin will be formed when most things burn. Because chlorine is so pervasive in the environment, dioxin is a byproduct of natural events like forest fires, lightning and volcanoes, as well as manmade activities such as burning wood and backyard trash, diesel vehicle emissions and various manufacturing processes including vinyl production.

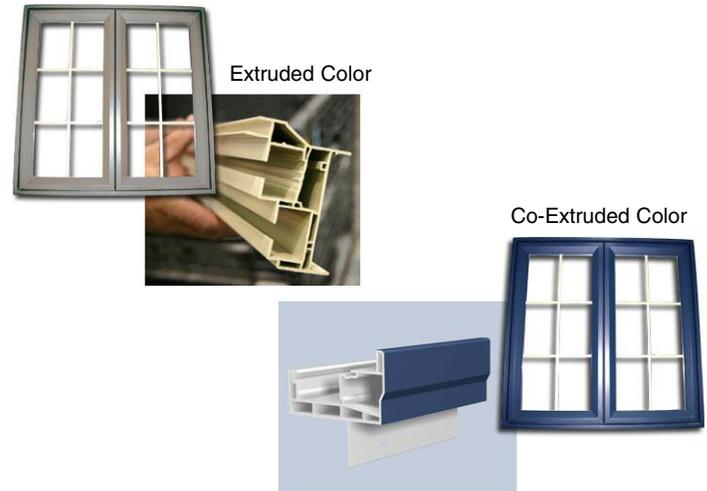
The good news is that dioxin emissions and levels in the environment are declining, according to data from the U.S. Environmental Protection Agency (EPA). Dioxin emissions from human sources in particular have declined by more than 90% in recent decades, and further declines continue to be documented. This has occurred even as production of vinyl has soared, proving that vinyl production and disposal are not significant contributors to dioxin levels, accounting for less than 1% of total dioxin releases to the environment. This simple fact indicates that there is no significant relationship between vinyl use and aggregate dioxin releases to the environment. Interestingly, EPA statistics also show that the biggest manmade sources of dioxin today by far are backyard trash burning and residential wood burning (i.e., fireplaces).

With respect to the incineration of vinyl, scientific studies indicate that the most important variable affecting dioxin emissions from incinerators is the design and operation of the incinerator unit, not the feedstock. When burning is well controlled, as it is in modern incinerators, very little dioxin is made or emitted. However, in uncontrolled burning (e.g., volcanoes, forest fires, old incinerators, backyard burn barrels and accidental building fires), dioxin can be formed in larger amounts.

## ***Design Flexibility***

Of definite appeal to architects and designers, vinyl windows permit wide latitude of creative expression. Because vinyl is a thermoplastic material, it can be bent when sufficiently heated to create innovative shapes such as half and full rounds. Custom colors and textures — gloss, matte or wood-grain — offer a wide variety of combinations. Ease of fabrication affords special sizes and configurations without high cost.

## **Exterior Colors / Interior Finishes**



## ***Exterior Colors and Interior Finishes***

As noted earlier, basic colors can be integrated homogeneously into the frame material by adding pigments to the vinyl formulation. However, the range and depth of colors that can be practically integrated in this manner is limited — traditionally to the familiar choices of white, gray, beige, dark brown, and light brown. To offer a virtually unlimited variety of interior and exterior colors and finishes, layers of color may also be added to selected surfaces by the coextrusion process, in which a capstock (thin layer of surface color) is bonded to the substrate. Color options can also be obtained through embossed laminates in solid or wood-grain patterns and finishes. Factory-applied organic coatings further expand on color choices available.

Adherence to AAMA standards for these coextruded, laminated or coated finishes ensures that they will perform well in terms of film integrity, exterior weatherability and general appearance over many years of service.

## **The Range of Vinyl Window and Door Products**

Vinyl windows, doors and skylights are readily available in all traditional product types (hung, sliding, casement, picture, awning, bay, bow, patio door, etc.).

The most popular configurations in use today are mulled-together window assemblies featuring combinations of fixed and operable units plus non-rectangular shapes such as full rounds, half rounds, hexagons, trapezoids, quarter rounds, ellipticals, triangles, etc. Art glass types feature beveled, V-grooved and stained glass. In addition, composite products utilize laminated foils, veneers and stainable wood fiber composites to provide the look of wood on the inside, combined with the maintenance-free vinyl on the exterior.

## Cellular PVC

Relative newcomers to the marketplace, windows made of cellular PVC are being well received as an alternative to those made of either rigid vinyl or wood.

Cellular PVC is created by a foaming extrusion process, known as "celuka," that creates tiny air bubbles within the shape, resulting in a density less than half that of regular PVC. When the extruded material is cooled, it forms a smooth, hard skin that doesn't absorb stains or bleed. Cellular PVC is not quite as strong as solid PVC, having a tensile strength of 2,000 to 5,000 psi where solid vinyl has a tensile strength of about 6,400 psi. Cellular PVC resists heat deflection up to 150°F and has a coefficient of thermal expansion similar to that of rigid PVC. It weighs about the same as soft wood, and has superior U-values. Cellular PVC formulations include UV protectors and impact modifiers as with solid PVC, and extrusions can be welded like solid vinyl to fabricate window assemblies.

Its benefit is that while it can be economically extruded into intricate profile shapes like solid vinyl, it can be cut, milled and fastened like wood, yet avoids undesirable problems, such as rot, split, water absorption, peeling paint and termites. It can be surface-textured and/or laminated with a surface film to accurately simulate the look of real wood grain and painted to match any color specification. This makes it a good alternative for historical renovation projects.

In addition to windows, cellular PVC is used as lumber, interior and exterior trim, paneling, blinds and furniture. It does become brittle below 40°F, which is more of an installation issue (pre-drilling recommended during cold weather) than an in-service concern.

## Rely on Industry Standards and Certification for Specifications

Material pros and cons aside, all window profile materials offer special advantages for dealing with the performance challenges posed by climate, building design or consumer preference for various applications. Material evaluations are rendered virtually immaterial when one stops comparing the basic characteristics of flat pieces of unsupported material and instead concentrates on the performance of the completely fabricated window unit.

Any given window product, regardless of material, can be well designed and competently made, or it can be poorly designed and defectively made. The distinction between "high end" and "low end" products is based not on its framing material, but on the performance level that the products are designed to meet – something that goes beyond clever advertising or competitive claims. The issue is performance quality, not material.

Performance-based standards, a concept pioneered for windows and doors by AAMA, rate completely fabricated windows, doors and skylights according to their structural performance under wind loading and their level of resistance to air leakage and water penetration. In addition, forced entry resistance is also required. These standards provide a uniform basis for comparing these key performance attributes of different manufacturers' products of the same type and grade, thereby taking into account the

unique properties and comparative strengths and weaknesses of all profile materials.

The product designer determines the level of performance desired under specified conditions, such as wind loading. Then, factoring the well-understood characteristics of the material and components into the equation, the designer builds a window that meets the specified performance level. In general, the required performance drives



the design.

It is the buyer's task to first determine the tradeoff between performance levels and cost that is acceptable for the job at hand. Given equal performance requirements, the choice of material basically reduces to one of preference with regard to operating features, appearance, brand name or manufacturer's reputation and other factors for the specific application, rather than determining which is "better" than another at some absolute level.

The task is more straightforward with the material neutral, performance-based standards that the industry has developed over the last decade: AAMA/NWDA 101/I.S. 2-97, ANSI/AAMA/WDMA 101/I.S. 2/NAFS-02 and the newest, AAMA/WDMA/CSA 101/I.S. 2/A440-05.

The latter is the first fenestration standard jointly published by U.S. (AAMA/WDMA) and Canadian (CSA) Associations. This standard, or an updated version of it, will eventually replace the pre-existing standards. Like the others, it identifies the requirements for windows, glass

doors and skylights for R, LC, C, HC and AW Performance Classes, but for the first time adds side-hinged exterior doors.

These standards provide a uniform basis by which all materials and products can be tested and compared on a level playing field. All are currently referenced by the International Building Code (IBC) and International Residential Code (IRC) as criteria for compliance of windows and sliding glass doors, regardless of framing material.

These standards and AAMA product certification go beyond basic quality assurance for completed window units by recognizing that a window is a complex system of components—extrusions, as well as finishes, glass, screening, weatherstrip, sealants and hardware—that must perform properly and continuously over a long service life. Therefore, any effective definition of window quality must encompass the performance of these components as well as the way they interact to make a completed window unit.

### ***PVC Profile Certification***

Producers of PVC profiles who wish to sell to manufacturers of vinyl windows that are certified under the AAMA Certification Programs must certify their extrusions under the AAMA Profile Certification Program.

Under the Profile Certification Program, samples of vinyl extrusions are tested by an accredited third-party laboratory for conformance with AAMA 303, *Voluntary Specification for Poly (Vinyl Chloride) (PVC) Exterior Profile Extrusions* or AAMA 308, *Voluntary Specification for Cellular Poly Vinyl Chloride (PVC) Exterior Profiles* for cellular PVC.

Vinyl windows must be made from extrusions which comply with AAMA 303 in order to be eligible for authorization for certification under the AAMA Certification Program. The requirements for completed extrusions include extensive physical testing by an independent laboratory to verify impact resistance, dimensional stability, heat resistance, weight tolerance and color fastness.

Impact resistance of the PVC profile is verified with a dropped-dart test for resistance to cracking or breaking.

The profile is also subjected to temperature extremes to verify dimensional stability. A 180°F water bath test ensures that the extrusion processing did not induce resid-

ual stresses that would result in excessive part shrinkage during exposure to elevated temperatures. The part is also exposed to a 300°F hot air oven to uncover any surface imperfections such as chipping, blistering and cracks.

Adherence to established color-hold guidelines are assured through actual exposures for two years at three sites—South Florida, Arizona and Ohio. These three sites represent the typical U.S. climatic extremes of temperature cycling, humidity, and acid rain.

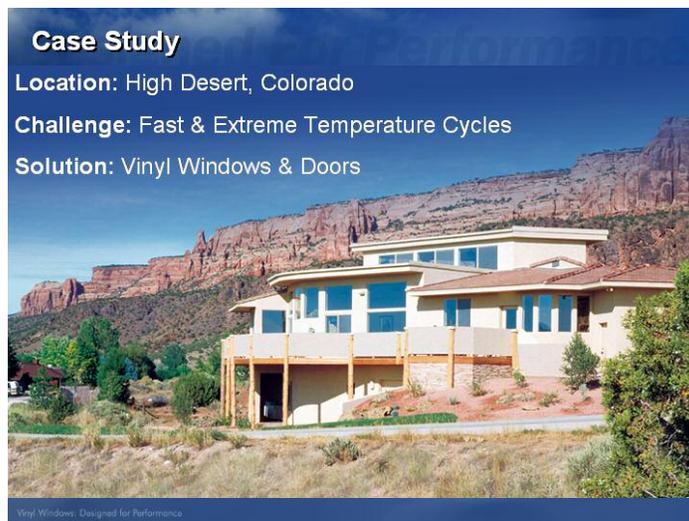
Surface treatments are tested extensively and are also exposed outdoors to ensure long term bond integrity and color retention. Lamination tests include a pull-off test following immersion in boiling water to determine adhesion.

Other testing requirements for laminates include resistance to abrasion, mortar, muriatic acid, detergents and sealant compatibility. Coatings are also tested to evaluate adhesion, stain resistance, chemical resistance, color uniformity, gloss, hardness, detergent resistance and weatherability. In-plant quality control sampling frequency, test requirements and record keeping are spelled out for both coated and laminated window profiles.

Once all tests are passed, the extruder must also prepare a Quality Control Manual setting forth the procedures used to assure ongoing conformance of the product with the AAMA 303 specification. At least two unannounced in-plant inspections are conducted annually by third-party inspectors to determine continued compliance with the program and includes the random selection of production line samples for testing. AAMA 308 sets forth performance requirements for cellular PVC extrusions, which include dimensional stability, weatherability, heat resistance, hardness and weight tolerance. Cellular PVC profiles must meet AAMA 308 requirements to be approved under the Profile Certification Program and eligible for use in products that are certified under the AAMA Window & Door Certification Program.

### ***Laminates and Coatings***

As noted earlier, laminates and factory-applied organic coatings expand on the color choices available as compared to integral colors achieved through the addition of pigments to the vinyl material. AAMA standards for these laminates



and coatings on vinyl profiles define tests (per ASTM methods) and performance requirements that they must meet if the profiles are to be approved for use in AAMA-certified windows and doors.

AAMA 307, *Voluntary Performance Requirements and Test Procedures for Laminates Intended for Use on AAMA Certified Plastic Profiles*, establishes performance requirements for decorative laminate materials intended for application to either the interior or exterior surfaces of the profiles.

AAMA 613, AAMA 614 and AAMA 615 offer three performance levels for organic coatings: basic performance, high-performance and superior performance, respectively. The table on the following page shows where these standards differ in terms of performance requirements.

Additionally, all three coatings standards set forth equal performance requirements for the following:

- Color uniformity (no variation outside of established limits)
- Dry film hardness (no rupture when tested per ASTM D 3363)
- Dry and wet film adhesion (pass per ASTM D 3359)
- Cold crack cycle (15 cycles of exposure to 100°F followed by exposure to -10°F, with no change in performance)
- Oven aging (verifies hardness and adhesion after exposure to 125°F for seven days then 100% humidity for 4 days)
- Heat build-up due to solar radiation (per ASTM D 4803)

### ***Certifying the Completed Window***

Windows fabricated from certified extrusions are then tested for conformance to the same structural, air leakage and water penetration requirements for residential and commercial rating as those imposed on windows with other framing materials. Vinyl products are also tested for specific quality factors such as strength of the corner welds of the fabricated frames.

Fenestration products that have passed these tests and are therefore authorized for certification under the AAMA

Certification Program are listed in the online AAMA Certified Products Directory, a valuable resource for architects and specifiers. However, products are not actually certified until the manufacturer applies the AAMA Gold Label.

### ***Energy Efficiency Certification***

For verification of thermal performance, windows, doors and skylights are voluntarily tested for conformance to the NFRC specifications. U-factor and solar heat gain coefficient (SHGC) are reported for each product tested. Vinyl's unique characteristics provide excellent U-factor ratings, which translates into energy savings for the consumer. Because AAMA is also one (in fact the largest) of NFRC's four Licensed Independent Certification and Inspection Agencies, authorized to validate tests and simulations and conduct in-plant inspections, windows can be certified and labeled as NFRC-compliant under the AAMA Certification Program.

Code bodies in some regions of the country now require that windows meet certain U-factor and SHGC requirements depending on the climatic zone. The DOE's EnergyStar™ program specifies maximum U-factors and SHGCs for four specifically delineated geographical regions in the continental United States. Vinyl windows typically meet Energy Star requirements in all regions of the country.

## **A Proven Material**

While all architects are very much aware of the particular characteristics of the wide array of building materials available and how those characteristics make a given material appropriate for a given application, use of today's performance standards validates the selection by ensuring the particular product performs as anticipated. For applications where energy efficiency ranks high on the list, and where economy, low maintenance, long-term durability and environmental compatibility are important, vinyl windows are an excellent choice.

Attribute	AAMA Standards for Organic Coatings on Plastic Profiles		
	AAMA 613 (Basic Pigmented Coatings)	AAMA 614 (High-Performance)	AAMA 615 (Superior)
Minimum initial dry film thickness	20 microns (0.8 mil)	30 microns (1.2 mil); 25 micron (1.0 mil) topcoat where primer is used	30 microns (1.2 mil); 25 micron (1.0 mil) topcoat if primer is used
Specular gloss (per ASTM D 523)	Within manufacturer's recommended values	Gloss values within $\pm 5$ units of manufacturer's specification	
Outdoor Weathering Exposure Time (south Florida)	6 months, 1 year and 2 years	5 years	10 years
Chalking (after weathering exposure)	1 year: Slight chalk	5 years: Chalk: $\leq 8$ rating (per ASTM D 4214)	10 years Chalk: $\leq 8$ rating (per ASTM D 4214)
Color Retention (after weathering exposure)	White: Per ASTM D 4726 guidelines at 6 months and 1 year of outdoor weathering exposure. Other colors: $\Delta E \leq 5$ at 6 months, 1 year and 2 years	5 year fade: $\Delta E \leq 5$	10 year fade: $\Delta E \leq 5$
Gloss Retention after weathering exposure	No specification	5 years: $\geq 30\%$ retention	10 years: $\geq 50\%$ retention
Erosion Resistance after weathering exposure	No specification	5 years: $\leq 10\%$ loss	10 years: $\leq 10\%$ loss
Impact Resistance	No film removal at initial test and after impact test at 6 months, 1 year and 2 years of outdoor weathering exposure	No film removal from substrate at initial test (not subject to weathering exposure)	
Humidity Resistance (test per ASTM D 2247 or D 4585; no visually apparent change and "few" blisters " size 8 per ASTM D 714)	1500 hours at 100°F and 100% humidity	3000 hours at 100°F and 100% humidity	4000 hours at 100°F and 100% humidity
Abrasion Resistance (per ASTM D 968)	No specification	Abrasion coefficient $\geq 20$	Abrasion coefficient $\geq 40$
Chemical Resistance	No loss of adhesion, blistering or visually apparent change after exposure to muriatic acid, mortar and detergent.	No loss of adhesion, blistering or visually apparent change after exposure to muriatic acid, mortar, detergent, window cleaner and nitric acid.	
Sealant compatibility	No specification	Sealant must meet AAMA 800 and have no effect on coating	
Boiling water film adhesion	No specification	No loss of adhesion after 20 minutes in 212°F water	
Color Uniformity	No variation outside of limits established by range sample approval		
Dry Film Hardness	No rupture when tested per ASTM D 3363		
Dry and Wet Adhesion	Meet requirements of ASTM D 3359		
Resistance to Cold Cracking	15 cycles of exposure to 100°F followed by exposure to -10°F, with no change in performance		
Oven Aging	Verify hardness and adhesion after exposure to 140°F for 7 days and then 100% humidity for 4 days		
Heat Build-up	Record heat build-up due to solar radiation per ASTM D 4803		

Please [click here](#) to request a subscription to the Vinyl Material Council (VMC) Newsletter to stay apprised of activities and developments in the vinyl fenestration market.



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