Architects have many choices when it comes to specifying and designing windows and fenestration systems into buildings. Understanding the basic attributes of the available choices contributes to better design and specification writing. Therefore, architects who take the time to understand the differences and similarities between fenestration systems will make the best informed choice for energy efficiency, sustainability, durability, aesthetics, and cost effectiveness.

**PERFORMANCE OF FENESTRATION SYSTEMS**

Incorporating windows and fenestration into a building design is a fundamental and integrated design activity. Decisions about the size, shape, type, and characteristics of such fenestration are increasingly driven not just by aesthetic concerns, but by demands for energy efficiency as defined by building codes, green design standards, or even the building owner.

The International Energy Conservation Construction Code (IECCC), the emerging International Green Construction Code (IGCC), and many state energy codes recognize that there are not one, but multiple individual components of windows and fenestration systems that determine their true performance. Hence, in order to show compliance with these codes, each component must be considered as part of a truly holistic assessment.

Most people tend to think first of the thermal performance of the fenestration as identified by U-Factor or the inverse R-Value. However, it is no longer acceptable under the codes to simply look at the thermal performance of just the glazing.

**LEARNING OBJECTIVES**

After reading this article, you will be able to:

- Identify and recognize the energy rating and certification process of window and fenestration systems as defined by national standards and codes.
- Assess and compare the energy performance and other attributes of preglazed windows with frames made from different but commonly available materials.
- Investigate the differences between storefront systems and curtain wall window systems related to energy performance and other weathering criteria.
- Explore case study applications where each type of window and fenestration system may be the preferred choice for optimizing energy savings and overall performance in new buildings.

Turquoise Place Condominiums, Orange Beach, AL
Architect: Forest Daniell Associates, Daphne, AL
(Photography Courtesy of Pella EFCO Commercial Solutions.)
Rather, the entire assembly including the frame, the insulated glass spacers, and the glass are all brought into play. This means that the choice of a frame material, such as aluminum, wood, fiberglass, or vinyl, can be every bit as important, if not more so, than the specification for the glazing.

The National Fenestration Rating Council (NFRC) is a not-for-profit trade association dedicated to identifying true performance of fenestration systems and products. Since 1989 they have championed the process of fairly and comprehensively rating windows, doors, skylights, and similar products. They have developed a uniform testing and rating process that quantifies the key elements of fenestration performance including:

- A procedure for determining the total product thermal transmittance ("U-Factor"), not just the U-Factor of the glazing
- Solar Heat Gain Coefficient ("solar heat gain" or "SHGC")
- Visible Transmittance ("VT")
- Air Leakage ("AL") in residential window units
- Condensation Resistance ("CR")

Together, these individual rating procedures are simply known as the NFRC Rating System which employs both computer simulation and physical testing by NFRC-accredited laboratories. The Rating System is supplemented by two separate product certification programs, one for residential products and one for commercial (nonresidential) products, where fenestration manufacturers or responsible parties may certify and label fenestration products to indicate the performance ratings achieved. Both of these product certification programs have been updated as of May of 2012.

For residential fenestration products, NFRC’s Product Certification Program (NFRC 700, PCP) sets forth the specific requirements for rating, certification, and labeling of a residential manufactured product. For windows, it essentially requires a preglazed, manufactured window unit to be tested as a total product. Any given manufacturer will have multiple manufactured window types, sizes, and shapes, and each significant variation needs to be tested and rated. When complete, a standard label can be applied to the finished product that identifies the key elements of performance, much the way mileage rating stickers are applied to cars or nutrition labels are applied to food.

For commercial (nonresidential) projects, the NFRC’s new Component Modeling Approach (CMA) Product Certification Program enables whole product energy performance ratings for fenestration systems of all types. This program recognizes that commercial buildings often employ custom fenestration systems where architects can select from a myriad of choices related to glazing, frame material, configuration, size, and shape. Therefore, the concept behind component modeling is based on performance data from the three primary components that make up a fenestration system of any type:

- Glazing: Glazing manufacturers do their own testing and identify optical spectral and thermal data for the glazing that they produce. This data is submitted and recorded in the International Glazing Database (IGDB). The NFRC CMA program uses this data as it applies to a specific glazing and incorporates it into the overall rating determination of a specific commercial fenestration system.
- Frame: Manufacturers of window frames provide the thermal performance data of frame cross-sections based on testing and computer simulation as appropriate.
- Spacer: The efficiency of different glass spacer components is identified based on geometry and materials.
Using the basic data above, the NFRC has also made available the Component Modeling Approach Software Tool (CMAST), which establishes a set of performance libraries of approved components (frames, glass, and spacer). These libraries can be accessed for configuring fenestration products for a project, and obtaining a U-Factor, Solar Heat Gain Coefficient (SHGC), and Visible Transmittance (VT) rating for those products. All of this can then be reflected in a CMA Label Certificate for indications of performance and code compliance.

Beyond direct thermal transfer through materials, codes and standards, along with the NFRC, have increasingly recognized air infiltration as a very significant factor in fenestration performance. Therefore, it is becoming required for all residential fenestration systems to meet minimum standards for air infiltration and be tested, certified and labeled as such. Energy Codes also look at other overall performance characteristics including the well-established Solar Heat Gain Coefficient (SHGC), which measures how much heat passes through a particular glazing. This is usually adjusted by coatings applied to the glass to allow more light (and resulting solar heat) where it may be desired in cold climates, or to allow less where it is not wanted in hot climates. Green building standards assign value to Visible Light Transmittance (VLT) for daylighting, so finding the right balance between how much solar heat is brought in versus how much to exclude needs to be looked at on a project-by-project basis.

The rationale for this benchmark seems to rely on the fact that a well-insulated wall will inherently perform better thermally than any type of fenestration. Nonetheless, they also recognize that only fenestration allows the natural daylight and potentially beneficial solar heat gain into buildings. Simple energy modeling of different scenarios during the earliest stages of design will help to determine the most appropriate balance of opaque wall to fenestration. This is particularly important when different façade orientations (i.e. north, south, east, west) are taken into account since the best performing buildings usually do not treat all facades equally. The talent, experience and skill of the architect used in finding this appropriate balance will determine not only design quality and code compliance, but in a very real way the overall energy performance and utility costs experienced by the owner and users of the building.

Beyond energy performance of fenestration, they need to address other environmental concerns as well. The total system must be able to withstand wind pressures associated with their location. Water penetration cannot occur, which means that water must either be sealed out completely or managed so that if it does penetrate a part of the system, it will drain away harmlessly. Air infiltration must be similarly controlled not only for energy performance as discussed, but for occupant comfort and long-term durability of the fenestration system.

With all of that in mind, we will explore the fundamental choices available to architects and others in fenestration types. These include: 1) preglazed windows manufactured out of different frame materials, 2) aluminum storefront systems, and 3) aluminum curtain wall systems.
PREGLAZED MANUFACTURED WINDOW UNITS

Individually manufactured preglazed windows are commonly used as single units that fit into “punched openings” in the wall. While this may be quite desirable aesthetically with good thermal performance and light distribution, it is not the only choice. Ganging windows together horizontally with concealed intermediate support as required yields the “ribbon window” look that has been popular in schools and office buildings for some time. Similarly, they can be stacked vertically to create the appearance of a large vertical opening. By combining them in both directions, with intermediate concealed support as required, a full window wall can be created. This produces the appearance of large expanses of fenestration consistent with the look of many commercial and institutional buildings.

By selectively creating various sizes and shapes of ganged windows, individual preglazed window units can successfully be used in all types of commercial and institutional buildings, including retail storefront applications, although aluminum storefront systems are most often used.

Within the realm of preglazed window units, there are at least four material types used for the frames that can be considered as follows:

**Wood and Aluminum-Clad Wood Windows**

Wood is one of the best thermal performing materials to use in a window frame system with high thermal resistance and excellent insulating ability. As a result, thermal bridging through the frame is reduced compared to other frame materials. The wood used in the manufacture of window units is strong and also has a low coefficient of thermal expansion. But perhaps the most dominating advantage of wood is its aesthetic appeal, particularly on interiors. Windows made entirely of wood may be preferred in regions where wood construction prevails and exposed wood finish materials are popular. However, this will require ongoing care and maintenance to protect the wood from environmental or insect damage. Hence, wood windows clad on the exterior with low-maintenance aluminum are more commonly specified, particularly on nonresidential projects. This creates a virtually maintenance-free condition on the outside while retaining the appeal of the look of wood on the inside.

The best design applications for wood windows include situations where design flexibility is desired since virtually unlimited interior and exterior color options and wood types are available; buildings where the warmth of wood windows will complement other interior woodwork; when low-maintenance interiors and exteriors are important; or in older buildings that require an authentic look. Wood windows can readily be used in singular punched openings or ganged together in horizontal ribbons, vertical stacks, storefronts, or window walls.

![Building: The Peabody Hotel](image1)

Customer: Pitman Glass Company

(Photo Courtesy of Pella EFCO Commercial Solutions.)

Building: The Peabody Hotel
Location: Memphis, TN
The clubhouse at the prestigious Journey at Pechanga Golf Course was designed to be as breathtaking and unforgettable as the awe-inspiring beauty of the surrounding Temecula Valley. The Frank Lloyd Wright-inspired three-story, 62,000-square-foot building is the centerpiece of the world-class Journey course.

The philosophy behind the clubhouse’s design was to work with nature. The concept was brought into fruition with the use of stones indigenous to the area, the use of natural light flowing in from more than 500 individual windows, the incorporation of wood, as well as numerous fire pits and fireplaces. A cascading 30-foot waterfall is a dramatic focal point just inside the oversize lobby doors.

From the large ribbon windows to the soaring three-story window walls, aluminum-clad wood windows play a major role in the clubhouse’s aesthetic impact. Their custom-color aluminum-clad wood exteriors and stained alder interiors enhance the other natural construction materials, allowing the building to beautifully reflect its majestic landscape. The window manufacturer offered the building team turnkey services and value-added capabilities such as creative installation solutions. In conjunction with the local product representative, the manufacturer worked closely with the clubhouse’s architect, contractor and owner, resulting in a construction process as impressive as the building itself – the local team installed more than 500 windows in only five weeks.
CLAD WOOD RIBBON WINDOWS CASE STUDY
GREENSBORO PUBLIC LIBRARY

The construction of public buildings is often a budget-driven process, and the Greensboro Library was no exception. The architects, J. Hyatt Hammond and Associates, were able to find cost-effective solutions, while still remaining true to their design objective — creating a welcoming environment where visitors could relax, read, and study.

Located in the downtown cultural district of Greensboro, NC, the city’s main library facility is a sprawling, 100,000-square-foot brick and precast concrete structure that filled its available site. Focal points of the design include curved walls on the right and left sides of the building punctuated with horizontal ribbons of windows, and a 300’ loggia with arched windows on the front façade of the building. On the interior, terrazzo floors, coffered ceilings and wood trim create a warm, inviting atmosphere. And it’s made even more welcoming by the abundance of natural light — and energy-efficient comfort — provided by wood windows clad with aluminum. Construction came in under budget, and the building is a source of great pride for the community of Greensboro. In fact, the number of library visitors has more than doubled since the new facility opened — proof positive of its user appeal.

The manufacturer produced single and multiple windows to fit specified masonry openings without special upcharges — which allowed the windows to meet the budget criteria and streamlined the installation process. The aluminum-clad wood windows also provided the benefits of low-maintenance aluminum exteriors and the warmth and design flexibility of wood interiors. To maximize the amount of wood interior trim, ribbon and masonry openings are divided into 8’ x 8’ segments with mullion connections that create interior details evocative of traditional library architecture. And if one module gets broken, the entire window does not have to be replaced. The manufacturer factory-built and shipped the window assembly — consisting of more than 1,000 windows — within six weeks, and provided turnkey installation. In order to minimize solar heat gain in Greensboro’s warm, southern climate, the windows use clear, low-emissivity (Low-E) glass. The Low-E coating also helps protect the library’s books and interior against fading caused by UV light, while allowing in an abundance of daylight.
CLAD WOOD STOREFRONT CASE STUDY
PHILLIPS PLACE

When the Charlotte-based architecture firm, LS3P Associates LTD., began designing the Phillips Place project, the team faced two challenges – integrating retail, residential, and entertainment spaces within a single development and creating a pedestrian-scaled environment on a site adjacent to a heavily traveled six-lane highway bordered by high-tension power lines.

In keeping with the streetscape imagery of the development, storefront windows were deeply recessed in their openings and sit on stone bases. Preglazed windows, with boldly articulated aluminum-clad wood fixed frames, create shadow lines inside and out that fit with the architecture. A more economical solution than aluminum, the aluminum-clad wood windows also offer a variety of exterior frame cladding color options.

Interior design flexibility was a major project objective, so the design team specified windows and doors with wood interiors that can be repainted or restained for compatibility with any tenant’s decor requirements. Window openings varied in size, so the windows were fabricated to fit brick and block dimensions without special additional charges. The manufacturer provided technical support from design through construction and beyond, including ongoing custom window and door alterations for tenants.
Vinyl Windows

Solid vinyl framed windows have gained in popularity in recent years since they are comparatively lightweight, are as thermally efficient as wood, and are often the least expensive option available. Further, vinyl windows do not corrode or rust and the integral homogeneous color does not wear away, blister, crack, peel, or pit. The colors are usually limited to lighter ones such as white or almond since darker colors can promote heat buildup in hot climates that can warp or damage the vinyl. The latest generation of vinyl windows offers darker colors along with deeper frames, more insulating air chambers, optional foam insulation in the frame, triple glazing, and optional blinds or shades between the panes of glass. These enhancements will provide greater structural performance, more design flexibility, and better energy efficiency with total window U-Factors as low as 0.15.

The best applications for using vinyl windows are buildings where individual punched openings are desired, although next-generation systems will make it easier to create larger expanses of ganged windows. They are particularly well suited to situations where excellent energy efficiency and low-maintenance is needed but budget restrictions require a lower cost product.

VINYL WINDOW CASE STUDY
PRAIRIE POINTE TOWNHOMES

Vinyl windows and doors are an option for many nonresidential and multifamily projects like Prairie Pointe Townhomes. They can be used in new construction or renovation projects and are available in a wide variety of sizes, styles and frame types. At Prairie Pointe Townhomes, low-maintenance vinyl single-hung windows, sliding windows, fixed windows, and sliding patio doors were included in the building design to provide ample daylight and natural ventilation while offering a competitive price point and outstanding energy efficiency. Superior insulating properties are achieved through a multichambered, fully welded frame and sash that reduce sound transmission and heat loss. Strong performance comes from steel-reinforced interlocking sash that helps seal out drafts and improves energy efficiency while providing excellent structural integrity and resistance to wind. Frames are available with an optional integral brickmould for a more traditional aesthetic, while sliding patio doors feature a narrow panel sightline that provides a contemporary look that maximizes glass and views to the outside.
Fiberglass Windows

A fairly recent addition to the window market, fiberglass framed windows consist of glass fibers and a resin that binds those fibers together. The well-known tensile strength of fiberglass gives these windows high levels of durability and impact resistance.

They are better suited than vinyl to handle a wide range of temperature extremes from -40 degrees F up to 200 degrees F. The frames tend to be very energy-efficient and in some cases, additional insulation can be added inside the frames. Finishes are available that resist chalking, fading and chipping and are suitable for use in harsh environments.

Fiberglass framed windows are mostly used in buildings where price, durability and low-maintenance are important and where higher performance aluminum windows are too expensive. Common building types include dormitories, hotels, condos, apartments, low-income housing, and assisted-living facilities. They can be used in punched openings, horizontal ribbons, vertical stacks, and storefronts where extreme heat, cold, or sea air conditions are encountered.

FIBERGLASS WINDOWS CASE STUDY
FRED AND SARA MACHELANZ ELEMENTARY SCHOOL

Fred and Sara Machetanz Elementary School is a K-5 school that opened in 2009. Located in Alaska’s Matanuska Susitna Borough, the school received Silver LEED® Certification in the U.S. Green Building Council’s Leadership in Energy and Environmental Design (LEED) program. It was the first LEED-certified school in Alaska. To help achieve this superior level of energy efficiency, McCool Carlson Green Architects chose fiberglass composite single-hung and fixed frame windows. The particular windows selected are made from a patented five-layer fiberglass composite that is virtually impervious to all weather conditions – protecting the school from harsh Alaska winters. Plus, these windows offered the energy-efficient options that meet or exceed ENERGY STAR® guidelines in all 50 states.

The placement of the fiberglass windows also provides classrooms with abundant daylight — reducing the school’s dependency on electric lighting and improving students’ ability to focus. And the classrooms’ built-in window seats serve as intimate spaces in which students can work. The manufacturer was proud to help McCool Carlson Green Architects achieve their design vision, and enhance the learning environment at Fred and Sara Machetanz Elementary School.
Aluminum Windows

Aluminum has been a popular choice of window manufacturers for quite a while due to its light weight and superior strength. It can readily be formed into complex extruded sections that are strong and can efficiently achieve desirable weathering and operating characteristics. These aluminum extrusions easily provide tracks, drips, baffles, and grooves for weather stripping and sealants. These pieces can then be cut and fabricated into window units of many different shapes and sizes. Further, the appearance of aluminum can be varied by selecting from a wide range of commonly available anodized and painted finishes. When complete, the final product can be decorative, be strong enough to be used in large openings, and provide a low-maintenance solution.

Aluminum does have a higher coefficient of expansion compared to other materials so that needs to be allowed for in the detailing. Its high rate of conductivity also makes it prone to thermal bridging and unwanted heat transfer. However, the current focus on energy efficiency has prompted manufacturers to increase the energy efficiency of aluminum frames through enhanced polyamide thermal breaks and fiberglass pressure plates to limit or reduce thermal bridging.

Buildings where added strength, durability and design flexibility are needed are usually the most suitable application for aluminum windows. They are also popular where low-maintenance is desired in moderate environments and in buildings where function and performance are important. In selecting particular aluminum windows, it should be noted that they are classified by the American Architectural Manufacturers Association (AAMA), which is a non-profit trade association of manufacturers and others in the fenestration industry. There are four AAMA performance classifications as follows:

- **R class** - commonly used in one- and two-family dwellings and designed to withstand pressures of at least 15 psf

- **LC class** - commonly used in low- and mid-rise multifamily dwellings or other buildings where larger sizes and higher loading requirements are expected and designed to withstand pressures of at least 25 psf

- **CW class** - commonly used in low- and mid-rise buildings where larger sizes, higher loading requirements, limits on deflection and heavier use are expected and designed to withstand pressures of at least 30 psf

- **AW class** - commonly used in high-rise and mid-rise buildings to meet increased loading requirements and limits on deflection and in buildings where frequent and extreme use of the fenestration products is expected and designed to withstand pressures of at least 40 psf

Aluminum Windows: The products used on this school were required to meet the large missile impact test because the school is a designated hurricane shelter in Pinellas County. The manufacturer was able to meet the impact requirement with the fenestration systems provided.

Building: Gibbs High School
Location: Saint Petersburg, FL
Architect: Renker-Eich Parks
Erector: Tab Glass & Window Corp.
Contractor: Ajax Building

(Photo Courtesy of Pella EFCC Commercial Solutions)
STOREFRONT SYSTEMS

Storefront systems take their name from retail settings, where they are commonly used for large, single floor height openings of glass. These systems were designed for light commercial single-story retail viewing and readily incorporate entrances for quick access to interior product displays. They are often used on interior applications such as shopping malls or schools as well as exterior light commercial applications. They typically span a floor-to-floor or a floor to head condition without passing in front of any intermediate anchorage conditions.

Storefront system strengths include convenience for contractors who normally have access to multiple local suppliers/installers who are able to shop fabricate a system within a relatively short lead time. Field installation of these systems is commonly done with a dry gasket system which means that fabrication is readily available and subsequent re-glazing or replacement is easy. These systems are typically the least expensive when compared to curtain walls or preglazed aluminum window systems. However, storefront systems are restricted to a single-floor installation since there are very limited provisions for a supplemental structure within the frames. From a design standpoint, they also offer limited customization of mullions and accessories, limited anchorage options, and limited opening configurations. Storefront systems are best suited for low-rise applications typically on the ground floor. However, they may be used on upper floors as long as the code and environmental conditions don’t require higher structural and/or water management performance than is possible with these inherently limited systems. Storefront systems are not intended to be stacked directly on top of each other and should not be used in upper stories of mid to high-rise buildings since they are not rated for higher winds that may be present there. Storefront systems are also quite appropriately used for interior applications such as shopping malls, schools, etc. where simple separation of conditioned space is sought.

Aluminum Storefront System: The photo on the left shows a typical lower-level storefront solution while the photo on the right shows an appropriate upper-level use of storefront system. (Photos courtesy of Pella EFCO Commercial Solutions)

Left building: Canyon Creek Elementary School
Location: Bothell, Washington
Architect: Studio Meng Strazzara

Right building: Fort Lee Soldier Support Center
Location: Fort Lee, Virginia
Architect: Wiley and Wilson Architects - Richmond, Virginia
Contractor: Rocky Hill Contracting Inc. - Kenbridge, Virginia
Provided by:

COMMERCIAL SOLUTIONS

ALUMINUM STOREFRONT SYSTEM CASE STUDY
FIRE STATION #10

Location: Seattle, WA
Architect: Weinstein A/U Architects - Seattle, WA

Project Category: Other Government Service
Project Location: Seattle, WA
Finish: Black Anodized Aluminum
Contractor: Hoffman Construction - Seattle, WA
Erector: Kenco Construction Inc - Seattle, WA

(Image courtesy of Pella EFCO Commercial Solutions)
A curtain wall system is a complete exterior envelope facade system that provides a non-structural, relatively light-weight, weather-tight covering on buildings. In the case of small, low-rise projects, the system may be field fabricated or stick built and glazed using standard components similar to a storefront system. However, curtain wall components are notably different in design and performance characteristics with typically much better results compared to storefront components. Larger projects may justify full factory fabrication with panels prepared and glazed ready to be placed directly onto the building structure. Curtain wall systems are generally installed outside of the structural system of a building, running past floor slabs and other structural elements. They are then attached via tiebacks directly to the building structure at floors, columns and beams. This installation process means that all wind loads and dead loads imposed on the system are compartmentalized and transferred directly to the building structure. Hence the curtain wall system carries only its own weight and loading while the building structure absorbs all imposed loads.

The strength of curtain wall systems lies in its higher overall performance, particularly when compared to a storefront system. This is true in terms of wind resistance, water management, and thermal performance. From a design standpoint, they are easy to customize, are available with a variety of interior and exterior aesthetic appearances, and allow a virtually unlimited range of installation locations, configurations, and opportunities. Typically product design and fabrication comes from a single source, meaning that specific decisions can be made early related to anchoring options, accommodation of specified glazing thickness, and other details. Most curtain wall manufacturers also offer accessory items such as sun shades or light shelves to enhance day lighting approaches for the overall building. From a building operation standpoint, it should be noted that many curtain wall systems use dry gasket systems, which allows for simplified reglazing should it be needed for any reason in the future.

Proper scheduling and planning are required to allow for the production and delivery of curtain wall systems. Certain standardized systems are readily available, but with greater customization often comes greater lead times that need to be allowed for. Beyond the schedule, the cost of curtain wall systems is often cited as higher than other systems. However, that should be reasonably expected considering the higher quality and higher performance that are usually included in curtain walls. In some cases it may be worth doing a life-cycle analysis on the system compared to less expensive systems to identify potentially higher long-term costs for maintenance, repairs, and replacement, not to mention higher potential building energy costs compared with poorer performing systems.

Aluminum Curtain Wall System: This system is best suited to multi-story applications with a variety of performance requirements.

(Photos courtesy of Pella EFCO Commercial Solutions)

Left building: Cornell Physical Science Building
Location: Ithaca, NY
Architect: Koetter Kim & Associates

Right building: Greenpath
Location: Farmington Hills, MI
Architect: Harley Ellis Devereaux
ALUMINUM CURTAIN WALL CASE STUDY
UNIVERSITY OF WISCONSIN, HYLAND HALL

Project Category: Schools and Colleges
Finish: Clear Anodized Aluminum
Glass: Multiple colors and types

Contractor: Miron Construction Co Inc.
Erector: Mobile Glass - Waunakee, WI

Site-fabricated curtain wall systems are best suited for low-rise to mid-rise buildings where overall performance exceeds the capabilities of storefront. Unitized curtain wall systems are best suited for most mid-rise to high-rise applications that have repetition in unit sizes and require superior performance. They are also well suited to situations where customization of the system itself is desired.

CONCLUSION
Every building deserves to have the most appropriate fenestration solution designed and specified into it. It is up to the architect to determine the full extent of what is or is not most appropriate on a building-to-building basis. By understanding the attributes of individual manufactured window units, storefront systems and curtain wall systems, the best match can be determined. In the end that selection will impact the overall design, the performance of the building, and the long-term sustainability and usability of a newly created or renovated portion of the built environment.