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Journal

Energy Efficiency Considerations in Window Replacement Projects

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At some point, windows reach the end of their useful life. The question is, how does a building owner know whether it is advisable to defer a window project another year or two, or to call in a design professional right away? At what point is window replacement inevitable?

The first thing to consider is the comfort of building users. Most complaints about office environments involve thermal comfort, often originating at deteriorated windows. Leaks at window openings are obvious indicators of compromised performance, but more subtle problems may also become troublesome, such as difficult operation or drafts. To keep occupants comfortable, a certain amount of energy must be added to or removed from the building interior by the heating and air-conditioning systems. This thermal load can become much higher in buildings with inefficient windows, as HVAC systems run overtime to meet the demand of excess heat transfer through the fenestration.

Window replacement presents the opportunity to improve aesthetics, enhance daylighting and views, and reduce operating costs, provided windows are selected and detailed appropriately.

The cycling of temperatures and the migration of moisture from one day or season to the next can manifest at windows in the form of shrunken gaskets and seals; warped, faded, or displaced frames; and etched or fogged glass. As glazing becomes scratched, distorted, or clouded, building occupants may complain of compromised views, along with bothersome glare that can impact daylighting schemes.

Another factor to consider is maintenance and cost control. As windows age, it may become increasingly difficult and cost-prohibitive to find replacement parts. Keeping up with the needs of older windows is more demanding, as maintenance personnel spend hours responding to user complaints. Protecting building

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The challenge is to select windows that suit the building and perform as desired.

Building codes specify glazing requirements for solar heat gain and thermal transfer.

infrastructure from environmental infiltration and chasing after damage can become a strain, and the cost of ongoing problems begins to add up.

As with any capital improvement, aesthetics is also a driving force. New windows can add equity to a commercial property, and they present an opportunity to dramatically improve the appearance of the building.

Of all of these considerations, energy efficiency is not often a precipitating factor in the decision to replace aging windows. However, once user comfort, maintenance demands, and aesthetics conspire to make window replacement unavoidable, a window project offers the opportunity to improve energy efficiency and reduce operating costs. Whether owners pay for these expenses themselves or pass them along to tenants, energy savings can be a compelling consideration when designing new windows.

Basic Window Design

A truly energy-efficient window starts with good design. As defined by the American Architectural Manufacturers Association (AAMA) in the North American Fenestration Standard (NAFS), window types are standardized according to performance grades, distinguished by design pressures:

- **R class,** 15 psf, typically used in one- and two-family dwellings;
- **LC class,** 25 psf, usually low- and mid-rise residential buildings;
- **CW class,** 30 psf, low- and mid-rise buildings with higher loading requirements and heavier use; and
- **AW class,** 40 psf, used in high-rise and mid-rise buildings to meet increased loading requirements and limits on deflection.

Window class selection is dependent upon the application and expected use, with higher performance grades capable of withstanding greater operating force, deflection, and structural loading.

Knowing the applicable building code is critical to window specification. Requirements for structural stability typically cover frame, glass, anchorage, and substrate attachment. An architect or engineer should identify the condition of the existing substrate and determine whether it has been damaged or has decayed over time. A window's structural integrity is only as good as its attachment to the substrate, and if the substrate itself is unsound, the window could become unstable.

Building codes frequently stipulate requirements for air and water infiltration testing of new window assemblies. Even where the code does not mandate testing, it's a good idea to review test results from the manufacturer and to conduct laboratory and field performance tests. AAMA and ASTM International provide guidelines for test methods that should be followed as the industry standard.

Glass type for a given application may be mandated by code. The three most common types of commercially available glazing are:

- **Annealed glass,** raw glass that has not been heat-treated, may be limited by code due to its susceptibility to thermal shock and mechanical stress and its tendency to break into large, sharp pieces;
- **Heat-strengthened glass,** which undergoes controlled heating and cooling to improve strength and fracture resistance, is roughly twice as strong as annealed glass but still breaks into large, dangerous shards; and
- **Fully tempered glass,** which is chemically or thermally treated to improve strength and shatter resistance, breaks into tiny pieces that are less likely to cause injury.

Aside from structural and safety considerations, window options may be limited by energy code requirements, which are becoming increasingly stringent, even for existing buildings. As of this writing, the International Energy Conservation Code (IECC) is in use or adopted in 47 states, the District of Columbia, the U.S. Virgin Islands, New York City, and Puerto Rico. With each successive edition of the model code, performance criteria will likely continue to become more rigorous.

What Is an Energy-Efficient Window?

For windows, energy efficiency is broadly defined by two qualities: *solar heat gain coefficient (SHGC)* and *thermal transmittance (U-factor)*. The first of these, SHGC, is defined by ASHRAE 90.1-2013, the reference guide that has become the national

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Quantifying Window Assembly Performance

The performance of window assemblies should be assessed for structural integrity, air and water infiltration, and potential condensation issues, as well as for energy efficiency. Often, much of this information is available from the manufacturer. Before relying on published material, however, confirm that the data provided pertains to the exact assembly under consideration, and that the test specimen incorporated the same glass that will be installed in the project.

Sometimes, conditions are project-specific and cannot be anticipated in testing performed by the manufacturer. For instance, potential condensation issues that might result from the installation of a replacement window in an existing opening may need to be evaluated through thermal modeling performed by a building enclosure specialist, using software programs such as THERM. Developed by Lawrence Berkley National Laboratory (LBNL), THERM allows design professionals to model two-dimensional heat-transfer effects in building components and evaluate an assembly's energy efficiency. Although limited in its ability to assess complex real-world conditions, such as thermal massing, THERM and other computer models can help anticipate problems with thermal bridging, condensation, moisture damage, and structural integrity.

If the variables are too numerous, or there is a need to quantify performance within extremely specific parameters, physical testing of a window assembly and, ideally, of a sample of the wall into which it will be installed, can be performed in lieu of computer modeling. For energy performance, tests are typically performed at a testing facility using a *hot box*, an apparatus that aims to replicate conditions typical of what is seen in the field. The ASTM International (formerly American Society for Testing and Materials) Standard C1363-11, "Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus," is the recognized reference standard for such tests.

On-site air and water leakage testing can provide a quantitative measure of in-situ window performance.

During installation, windows should be tested for water penetration, as per ASTM Standard E1105, "Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls, by Uniform or Cyclic Static Air Pressure Difference." By establishing a pressure differential across the building envelope, this test method encourages water from a calibrated spray grid at the exterior to migrate into the building. Window assemblies and the surrounding substrate can then be evaluated for water-tightness. ■

Static and dynamic water penetration tests confirm the window assembly's conformance with design specifications.

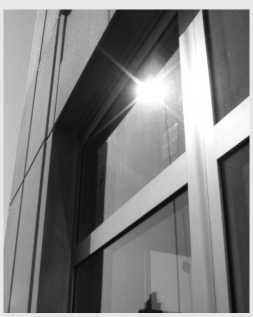
Off-site mockup ("hot box") testing of window units provides controlled conditions for thorough evaluation.

Daylighting and Views

A window replacement project may present an opportunity to improve user comfort by incorporating daylighting schemes. By introducing appropriate levels of natural light into a space, daylighting can reduce the need for artificial illumination, lowering electricity expenses and providing the health benefits of full-spectrum lighting.

Daylighting may be quantified in a number of ways, one of which is through the glazing factor, the ratio of exterior to interior illumination, expressed as a percentage. The architect or engineer may perform calculations to determine that a minimum two percent glazing factor is achieved for all daylighted spaces. Another method for determining daylighting requirements is to demonstrate through computer simulation that at least 25 foot-candles of daylight is available for illumination.

Daylighting schemes almost always require redirection or glare control devices to maintain energy efficiency and user comfort. For windows receiving direct sunlight, interior shading may be required to manage glare and limit heat gain. Automatic photocell controls for light screens, blinds, or curtains can be programmed to adjust shading depending upon incident light levels. Advanced glazing technologies, including electrochromic and photochromic "smart glass," can adapt light transmission levels in response to electric controls or sunlight.



^ Daylighting should limit undesired glare and heat.

Although it may add to project costs, increasing the window opening size may be considered as part of a window replacement project, in order to amplify natural light and expand views to the exterior. Windows that are two and a half feet at their base to seven and a half feet at their head above a finished floor are considered an optimal size, as they are most effective at distributing daylight deep into spaces.

When designing daylighting schemes, it's important to consider not only the dimensions and glazing of the window itself, but also the channeling of light within and between rooms. Interior glazing allows borrowed light from exterior windows to reach inside spaces; low partitions and open-plan office layouts are other options for distributing natural light across large areas.

While daylighting schemes may add to the up-front cost of a project, providing better-quality natural lighting can pay dividends in improved user experience. From an ROI standpoint, a pleasing daylighting design can also add value to the building. ■

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standard for energy performance, as: "The ratio of the solar heat gain entering the space through the fenestration area to the incident solar radiation." SHGC is a measure of how much of the sun's heat is transmitted into the building interior through the windows.

In the past, maximum reduction of SGHC beyond that dictated by code was not considered optimal for buildings in cold climates, since solar energy could help heat the building during the winter. However, due to inherent inefficiencies in building enclosures, the industry has largely revised its thinking on this issue, and recommendations now favor a reduction in SHGC across climate zones. There is, of course, always a trade-off; as SHGC is reduced, so is *visible light transmission (VLT)* or the transparency of the glass.

The other major determinant for energy efficiency in windows, U-factor, is defined by ASHRAE 90.1-2013 as "heat transmission in unit time through unit area of material or construction… induced by a unit temperature difference between the environments on each side." A measure of a material or assembly's propensity to transmit energy, U-factor is the inverse of *R-value,* which measures ability to resist energy transfer. Window manufacturers' data should provide *whole assembly* U-factor values, including both frame and glass, rather than *center-of-glass* U-factor values, which tend to make the window seem more efficient than it is.

In terms of the energy code, defining what constitutes an energy-efficient window often demands calculations, based upon fenestration area and the performance of other building envelope elements. The IECC and ASHRAE 90.1 provide two compliance paths, the Prescriptive Building Envelope Option, for buildings in which vertical fenestration is no more than 30 percent of gross wall area, and the Building Envelope Trade-Off Option. This number can be increased to up to 40 percent, provided that daylighting controls (methods to automatically regulate artificial lighting within *daylight zones,* defined by ASHRAE 90.1-2013 as "the floor area substantially illuminated by daylight") are used. The Prescriptive path assumes that windows are less energy-efficient than are opaque wall assemblies, and it provides maximum values for U-factor and SHGC.

Most current codes also permit adjustments in the SHGC and U-factor for a given set of conditions. For instance, the use of *dynamic glazing* (discussed in the following section) and projections on the building (such as eaves and cornices), in combination with window orientation, allows for an increase in the maximum allowable SHGC. For certain categories of fenestration, an area-weighted average, which estimates the efficiency of a whole building section, can be employed to calculate the maximum U-factor.

> "Benefits of window upgrades include reduced maintenance costs, added equity, and the possibility of increased rental rates."

The Building Envelope Trade-Off Option is intended to demonstrate that a building with greater than 40 percent vertical fenestration can function as efficiently as one with less window area, by offsetting thermal transfer across the fenestration with efficiencies in wall and roof assemblies. However, for a window replacement project, Building Envelope Trade-Off may not be an option, because it can be difficult (or even impossible) to identify efficiencies elsewhere in the building that could compensate for excess window area.

Glazing Strategies for Energy-Efficient Windows

The overarching goal of window design is to optimize visible light transmittance and exposure to natural light and exterior views for building users. To this end, glazing strategies are frequently employed to:

- Maximize energy efficiency
- Take full advantage of natural light and exterior views
- Reduce glare
- Decrease U-factor and SHGC
- Limit the need for artificial lighting

Use of window shades and other opaque blinds or screens is not optimal, because not only do such window treatments obscure daylight and limit views, they also tend to be inconsistently and incorrectly operated by building occupants. Instead, the industry has advanced a number of technologies that improve efficiency while preserving the natural light and vistas afforded by large areas of glass. These include:

Dual Glazing. Perhaps the most prevalent glazing strategy for energy efficiency, dual glazing consists of two panes of glass assembled into one integral unit by use of spacers and a perimeter seal. The space between panes is often filled with an inert gas (most often argon) to form an insulating glazing unit (IGU). Dual glazing is often used in conjunction with other strategies, such as tinting, low-emissivity coatings, fritting, etc.

Triple Glazing. Similar to dual-glazed IGUs but with three panes of glass instead of two, triple glazing has not been widely used in the United States, due to cost. However, progressively

Water infiltration field testing involves close analysis of frames and wall openings.

Sealant is applied in preparation for energy-efficient glazing installation.

Trim installation completes a custom historic window replacement.

more stringent energy codes have increased the prevalence of triple glazing in recent years, which should have the added effect of bringing down manufacturing costs.

Low-Emissivity (Low-E) Coatings. These factory-applied treatments reduce the ultraviolet and infrared light that passes through glass, limiting heat gain while preserving VLT.

Window Tinting. Like low-e coatings, tinting cuts down on solar heat gain and glare, but it may reduce VLT by blocking part of the visible spectrum. Highly reflective coatings on tinted glass can limit VLT to less than 10 percent, compared with over 90 percent transmission for uncoated clear glass.

Fritted Glass. By introducing ceramics or other materials into glazing, fritting creates a pattern (screen) that reduces glare and SHGC. Color and location of the frit is essential in maximizing results. New generations of frit glazing are experimenting with pattern organization on dual panes of glass that can vary the translucency of the assembly to maximize efficiency.

Photochromic Glazing. Also called *dynamic glass,* photochromic glazing can reduce glare and solar heat gain, as well as the need for window treatments, lighting, and shading devices, through the introduction of thin films that react to solar loads. Photochromic glazing generally falls under two major categories: *thermochromic* and *electrochromic.* Thermochromic glass

Where roof, window, and wall systems interface, custom details may be necessary.

High-performance replacement windows *(right)* resolve thermal inefficiencies and leaks that the retrofitted storm windows *(left)* at this historic building failed to adequately address.

uses a laminate comprised of organic compounds to react passively when exposed to solar loads. In the presence of such loads, the glass will go from clear to tinted and back again. Electrochromic glass, also known as *smart glass,* uses an applied electric current to affect an inorganic coating in order to alter the translucency or opacity of the glass.

By balancing desired levels of visible light with heat gain control, the design team can recommend window assemblies that achieve energy efficiency standards and improve occupant comfort.

When the Code Is Not Enough: When and Why to Exceed Basic Requirements for Energy Efficiency

If, thanks to strict energy conservation codes, code-compliant window assemblies are already energy-efficient, why would anyone bother to surpass code requirements? The answer lies in additional perks that provide value beyond that of improved sustainability.

The local governing authority may offer benefits to those who exceed baseline requirements for energy performance. In New York City, zoning laws provide a deduction from gross square footage for buildings with wall and fenestration assemblies that exceed energy code requirements. Such incentives illustrate the type of recompense that might be offered by state or local governments for energy-efficient design.

Another motivating factor in the decision to go beyond code requirements might be reduced operating expenses. Although the cost of a window replacement project is unlikely to be offset by energy savings in fewer than 20 years, incremental increases in the efficiency of a new assembly may pay for themselves in five years or less. A low-emissivity coating that reduces the SHGC, for instance, or warm spacers in frames that lower U-factor can improve efficiency enough to recuperate the extra up-front cost in a relatively short period of time.

Planned upgrades to an HVAC system also present an opportunity to realize cost savings from improved window efficiency. The building envelope and mechanical system are in a symbiotic relationship, in that as one becomes more efficient, the other need not work as hard. In theory, improving the energy efficiency of windows permits a reduction in the size of the mechanical package. However, calibrating window performance and HVAC output demands detailed analysis.

Return on investment (ROI) benefits

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representative projects

High-Performance Windows

For both existing buildings and new construction, Hoffmann Architects guides building owners, managers, and designers in the selection and detailing of window systems that are energy-efficient and cost-effective. From specifying glazing properties to evaluating as-built assemblies, our design professionals consider daylighting, maintenance, return on investment, and other factors to meet the operational and aesthetic demands of window projects.

We have developed window solutions for a variety of clients, including:

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Insulating glazing may be heavier than the original glass, requiring additional support.

of high-performance window upgrades include reduced maintenance costs, added equity, and the possibility of increased rental rates. Energy codes based on the IECC and ASHRAE 90.1 provide good benchmarks for window performance that have come a long way in a short period of time. Before undertaking a window replacement project, however, it's worthwhile to evaluate whether exceeding code requirements might be a good investment.

Realizing Design Goals

Although other factors, including user comfort, appearance, and maintainability, often initially take precedence when window replacement is under consideration, energy efficiency soon becomes part of the conversation. Energy savings alone will not pay for the cost of a typical window replacement project in a reasonable amount of time. However, ancillary factors make energy efficiency an important part of such projects. Beyond energy considerations, a window replacement project offers the opportunity to optimize the user experience through a reconsideration of daylighting and views of the exterior. By setting design goals at the outset of a window replacement, owners may be able to realize multiple objectives, from improved interior comfort to reduced operating costs, with one well-designed project. ■

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