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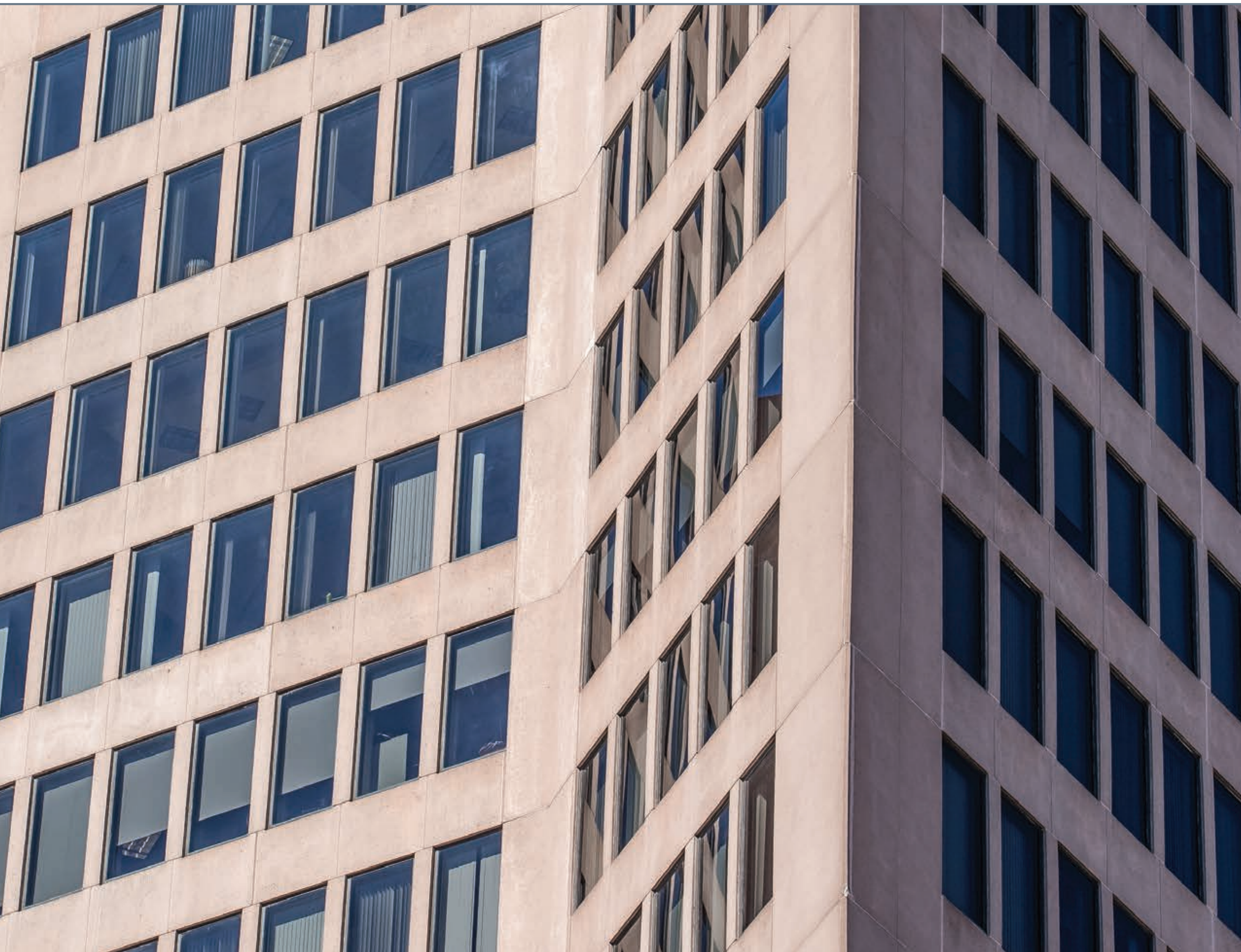
Window Replacement
Unrealized Benefits to Building Owners and Occupants



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Top Reasons for Façade Renovation

To attract and retain occupants, the top reasons for renovating the building façade are:

- Aesthetic improvement
- Energy performance
- Remediation of failure (water or air infiltration, material failure, etc.)
- Code compliance
- Green standard compliance (LEED®, ENERGY STAR®, Living Building Challenge™, WELL Certified, etc.)[1]
- Increase building value and improve occupant retention

"America's commercial building stock comprises some 6 million buildings, totaling around 90 billion square feet, almost half of which are more than 40 years old. Over the lifespan of the existing stock, standards of sustainability, particularly energy efficiency, have evolved.[2]"

– American Institute of Architects

Case Study Legend

- Acoustic optimization
- Blast mitigation
- Add usable floor space
- Reduce maintenance costs
- Improve occupant well being
- Improve appearance and views
- Save energy
- Historical renovation
- Protect property and occupants

New Windows Provide a Better Work Environment and Create Building Value

Window systems and components have evolved significantly since the 1980s. About half of all U.S. commercial and institutional buildings were constructed prior to this period, which presents a significant opportunity for owners and occupants to benefit from façade improvements and window replacement.

Many aging buildings' existing windows are leaky, single-glazed units with non-thermal framing systems. These windows may be difficult – or even dangerous – to operate. They can promote unhealthy condensation, mold or mildew formation. Occupants may prefer not to sit close to the windows due to glare, solar heat gain, drafts and noise.

In addition to the benefits in the appearance and marketability of commercial spaces, nearly every occupant desires window views, natural light and comfortable interiors.

Tall, triple-hung windows, clerestory and skylight glazing, and courtyard areas characterize turn-of-the-century buildings. These features maximize natural daylight by necessity, as available artificial lighting and climate control were unavailable or insufficient. As electric-powered lighting and HVAC systems became standard, natural light and ventilation were no longer seen as essential. Today, they are making a comeback as the cost of wasted energy, and the benefits of daylighting and views, and occupants' well being, are emphasized.

Re-cladding and renovating building exteriors with high-performance window systems can have a measurable, positive effect on the building's energy efficiency. When window replacement is timed in conjunction with an HVAC system upgrade, significant reductions in peak load can yield further savings in equipment costs. For building owners seeking enhancements in security, design criteria for façade renovation also can include blast hazard and ballistic mitigation, hurricane impact resistance, electronic eavesdropping protection and forced entry deterrence.

Most buildings currently in use will continue to be in use until 2050 and, eventually, will require renovation. Establishing clear goals and expectations for building envelope maintenance and renovation will contribute significantly to future success.

"Daylight design should aim to achieve required illuminance levels and avoid glare. It should also control solar heat gain in the summer and reduce undesirable heat losses through windows during colder seasons, while providing visual balance and a comfortable environment.[3]"

– American Institute of Architects

According to the National Institute of Building Sciences:

Indoor environments strongly affect human health and wellbeing, which in turn impact productivity, accuracy and effectiveness, as well as perceived stress, organizational commitment and job satisfaction.

To maximize the positive fiscal, physical and psychological benefits to their occupants, healthy buildings:

- Provide maximum access to natural daylight and views to the outdoors
- Provide superior ventilation
- Control sources of indoor air contamination
- Prevent unwanted moisture accumulation
- Enhance the psychological and social aspects of space[4]

Case Study:

The Woolworth Tower Residences New York

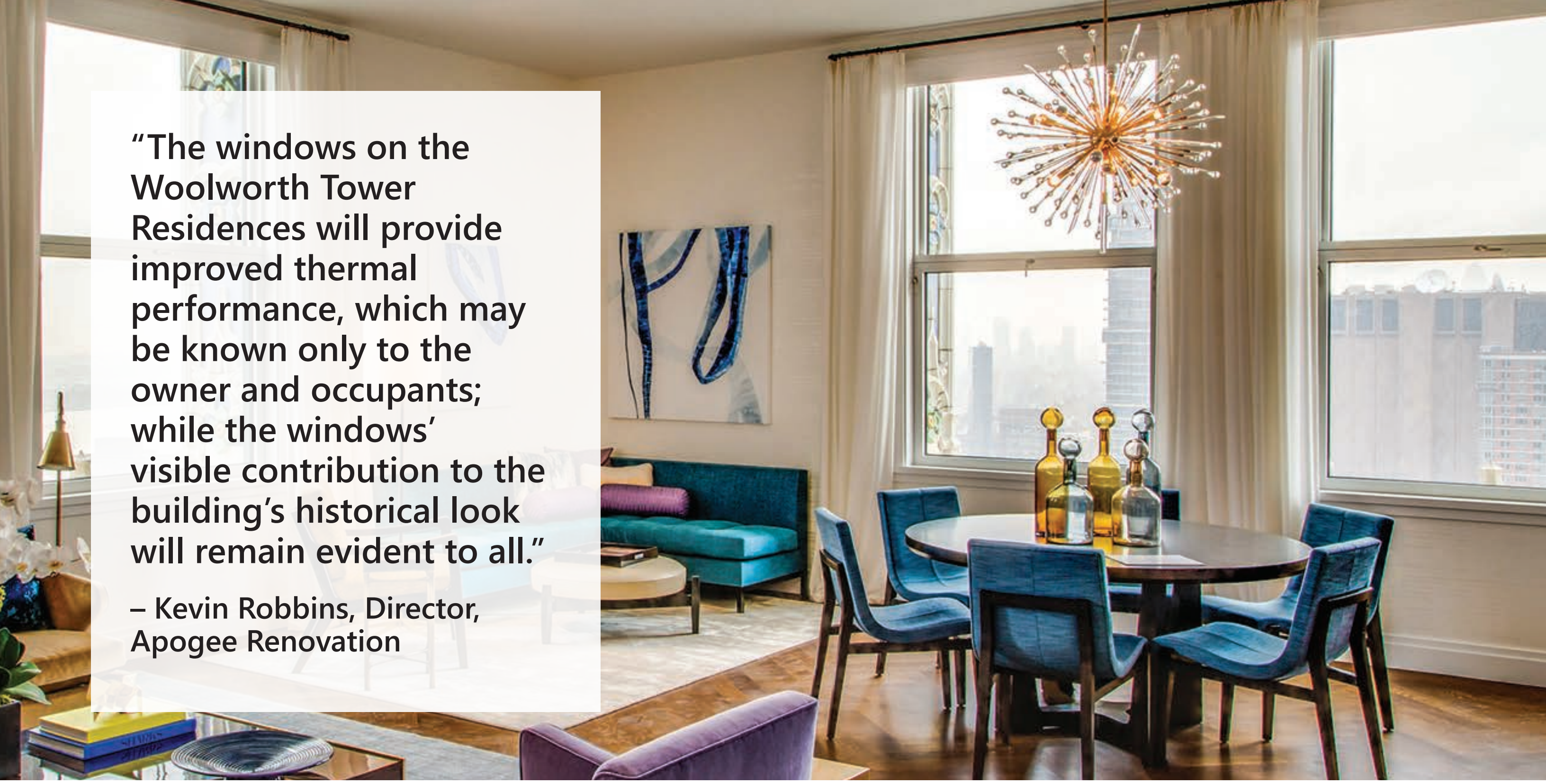
The Woolworth Tower Residences renovated its top 30 floors to feature new, high-performance windows and terrace doors with restored, exterior terra cotta surrounds. Historically inspired by the iconic building's 1913 design, the oversized windows make the connection between outside and in with breathtaking views of New York City.

Floor-by-floor, the window replacement team carefully removed the existing double-hung units. These had been manufactured using non-thermal framing and 1-inch insulating glass without the low-e coatings available today. After removing the previous unit, the rough opening was prepared using pre-assembled, extruded aluminum "panning" trim to help ensure the new windows were easily installed plumb and square. Along with using low-e, insulating glass, the aluminum framing members of the windows and doors incorporate polyamide insulating strips helping achieve high thermal performance, condensation resistance and better air infiltration performance, which support energy efficiency and comfort.

In addition to helping maintain the desired interior temperature, the windows and doors also reduce unwanted noise when closed. When the residents prefer to open their windows for natural ventilation, projected windows are easier to open than hung windows and eliminate balances, which require continual maintenance, especially in large sizes with heavy glass.

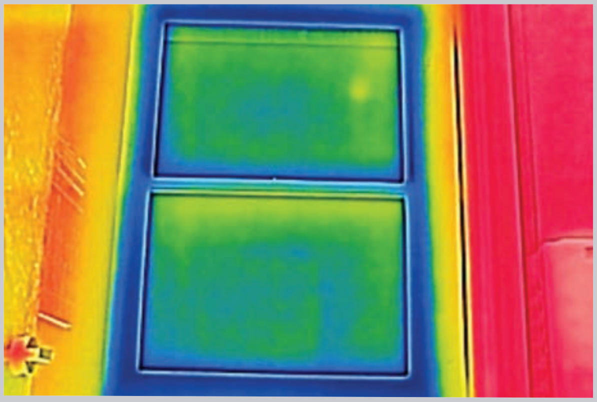
Helping extend the system's lifespan and reduce future maintenance, the aluminum framing and panning were finished using a two-coat 70% PVDF resin-based architectural painted coating in a color called "Dark as Night" to complement the buildings' historic aesthetic.

> **"Thermal bridging can occur where a building component or assembly has a higher thermal conductivity than those surrounding it. This can lead to unwanted heat transfer into or out of a conditioned space. Implications of thermal bridging include increased energy use, reduced occupant comfort, and the appearance of unwanted condensation.[2]"**
>
> **– American Institute of Architects**



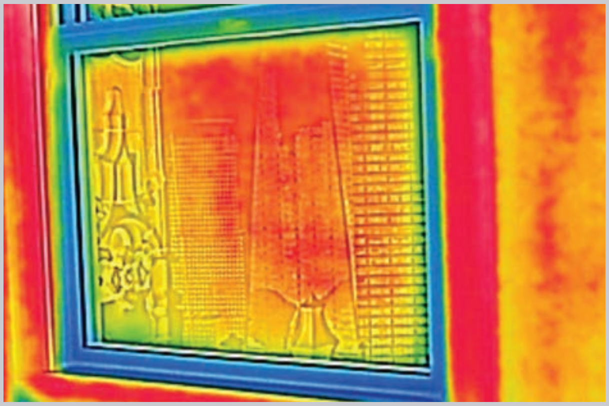
> **"The windows on the Woolworth Tower Residences will provide improved thermal performance, which may be known only to the owner and occupants; while the windows' visible contribution to the building's historical look will remain evident to all."**
>
> **– Kevin Robbins, Director, Apogee Renovation**

In these thermal images — cooler temperatures are shown in blue, while warmer temperatures are shown in red. On average, the surface temperatures of the new windows are 9°F warmer in the winter than the old windows.



OLD

1. Interior thermal imaging of the old windows shows cold glass and framing surface temperatures. This indicates that the old glass (without low-e coating) is letting the 39°F outside conditions to permeate into the interior of the building.



NEW

2. Interior thermal imaging of the new windows shows warmer glass and framing surface temperatures. This indicates that the new glass (with a low-e coating) is keeping out the 50°F outside conditions, while keeping in the warm 72°F inside conditions. The low-e coating on the new glass also is reflecting the heat back inside the space, making it more comfortable for occupants.

Case Study:
195 CHURCH
New Haven, Connecticut

Located on Connecticut's New Haven Green, 195 CHURCH completed a $6 million energy-efficient window and lighting retrofit. Tenants of the 244,000 square foot, 18-story, Class A office are enjoying more comfortable workspaces and the building owner has noticed significant annual energy savings. The property earned an estimated $589,000 rebate from its local utility provider.

Built in 1974 and largely constructed of concrete, 195 CHURCH reflected the materials and style of the era. The original windows remain functional, but were manufactured at a time before low-e insulated glass and improved thermal breaks in the aluminum framing were available. In addition to the aging windows, the property's all-electric baseboard heating and variable-air-volume system with electric reheat contributed to large utility bills.

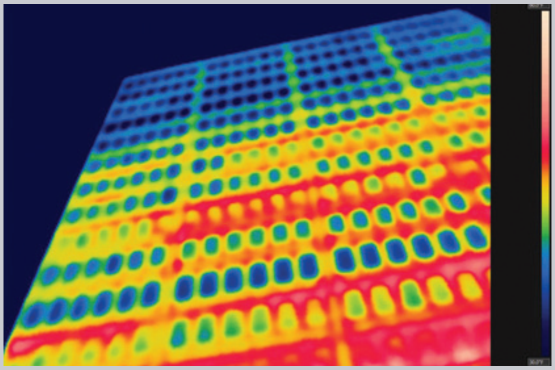
Energy modeling simulated the performance of the building on an annual basis and forecasted the level of energy savings that could be achieved by adding interior accessory windows (IAWs) with low-e glass over the existing windows, which were sealed closed to prevent air infiltration. From this data, performance predictions were provided on annual energy, peak demand and daylight energy use.

"The goal was to make this building as efficient as possible thus doing the right thing for the environment and also producing a very good return on our investment."

– Christopher Vigilante, Chief Operating Officer, Northside Development Co. property management company

Based on the energy modeling and analysis, 195 CHURCH's owner and property manager moved forward in upgrading more than 1,400 window units. Adding an IAW with low-e glass to the existing glazing also significantly improved occupant comfort because surface temperatures are much closer to room temperature. Comparing the window bays before and after the retrofit, thermal imaging shows window surface temperature differences of nearly 20°F.

After a full year of occupancy, analysis of the raw energy data showed a 15.7% measured whole-building savings when adjusted for colder than predicted winter weather and increased occupancy. The low-e glass also improved light-to-solar gain (LSG) ratio by 21%, increasing the number of hours in the year that tenants can rely on natural daylighting. These combined improvements allowed occupants to sit closer to the windows, expanding the usable floor space of the building.



Thermal imaging of the north façade shows the building with a temperature scale of 30 to 50°F. Cooler temperatures are shown in blue, while warmer temperatures are shown in red. From the blue on floors 4, 8, 9 and 14-18, it is apparent that these floors have completed their window retrofit. The new units offer improved thermal performance, which contribute to energy savings and occupants' comfort.

"Daylighting helps create a visually stimulating and productive environment for building occupants, while reducing as much as one-third of total building energy costs.[4]"

– National Institute of Building Sciences

Case Study:
ANB Bank Building Cherry Creek, Colorado

ANB Bank Building of Cherry Creek, Colorado, revitalized its 1980's exterior into a modern, high-performance glass and metal façade that better suited its 21st century tenants and those visiting this upscale destination. Along with improving the appearance, energy modeling assisted the owner in selecting high-performance glass to enhance the property's performance and comfort.

Before

After

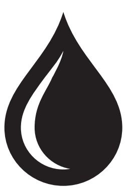
Improved Performance

Beyond the benefits of improved appearance, window systems directly affect and influence multiple areas of the whole building. In the short term, there are initial cost considerations of materials, equipment, labor and disruption to occupants. Long term, the impact is much greater when considering the cost and function of the building's operation, the marketability of available space, and the comfort and productivity of its occupants.

According to Lawrence Berkeley National Laboratory:

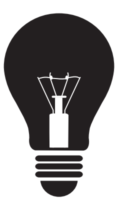
- Windows account for approximately 30% of the total heating and cooling loads in buildings, and about 4.1 quads of primary energy use in the U.S.
- 1 quad of lighting energy can be offset by daylighting through windows and skylights[5]

During the useful life of 30 years or more, a window system in a commercial building[6]:



Contributes to water infiltration

Contributes to air infiltration



Contributes to peak electricity use

- **Impacts HVAC sizing**
- **Impacts productivity**
- **Impacts occupant well being**

"Energy lost through residential and commercial windows costs U.S. consumers about $40 billion a year.[7]"

– Lawrence Berkeley National Laboratory

Energy Modeling

Whole-building energy modeling offers a detailed examination of an entire building's systems and its key parameters, including: heating and cooling, pumps and ventilation, lighting, plug and process loads, occupancy schedules and the envelope.

For a complete model, every hour of the year can be simulated along with site-specific considerations such as orientation, typical meteorological data and building geometry.

Commercial buildings are divided into thermal zones, which are served by different HVAC and lighting systems and/or controls. Each space can have a different temperature range, a different outside air ventilation requirement and even a different operating schedule.

Industry-leading, whole-building energy modeling tools currently include the U.S. Department of Energy's DOE-2 eQUEST, Integrated Environmental Solutions' Virtual Environment (IESVE) and Sefaira's software. Using these utility-grade tools and methodologies help produce calculations acceptable when building owners apply for tax deductions, credits and other rebates.

Energy modeling tools also can compare performance data between a building's existing window system and proposed, new, high-performance, replacement units to provide building performance information on annual energy, peak demand, carbon emissions, daylight, glare and condensation.

Perimeter zone modeling results may be used in subsequent whole-building modeling. A perimeter zone is defined as a 10-foot-wide office space extending 15 feet from the window with a ceiling height of 9 feet and a total floor-to-floor height of 12 feet.

Energy Study Example

Energy studies are presented as tools to aid decision-makers on whether to upgrade the windows on their buildings. These studies can analyze how newly proposed window systems may improve performance in comparison to a property's existing fenestrations.

Take, for example, a condominium building in New York City. Built in 1986, it offers 33 floors with 290 one-, two-, three- or four-bedroom units ranging from 700 square feet to 3,900 square feet. In addition, the 487,900-square-foot property contains common areas, laundry room, storage area, retail space and 12 townhomes.

The scope of this example study includes the building's existing mechanical, electrical and plumbing, so that the only variable was the proposed window system. Furthermore, savings were calculated only for the condominiums that were designated for window replacement.

The original windows were installed in 1986 and constructed with aluminum framing and two 1/4-inch clear glass lites separated by a 1/2-inch gap filled with air. It was assumed for modeling purposes, the existing windows have an air infiltration of 2.00 cfm per square foot due to wear.

The new windows modeled were Wausau Window and Wall Systems' 2250i INvent Retro™ Series windows with Viracon's 1-5/16-inch VE1-2M glass, argon fill and an extra-wide polyamide thermal barrier. It was assumed for modeling purposes, the new windows have an air infiltration of 0.030 cfm per square foot due to new construction.

Determining where, and in what quantities, energy is used throughout the building helps prioritize energy improvement efforts to maximum effectiveness. Energy modeling for this example was performed in IESVE 2018 software concerning ASHRAE 90.1, 62.1 and 55 compliance standards.

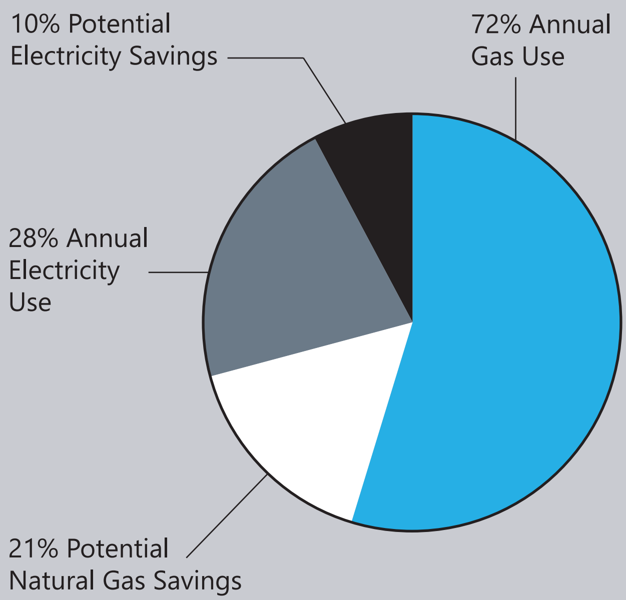
The best way to gauge total energy consumption of a given building is to run a calculated comparison using the U.S. Environmental Protection Agency (EPA) ENERGY STAR Target Finder Tool. This tool is commonly used to determine eligibility for ENERGY STAR Certification. The following energy use intensity (EUI) and energy cost intensity were calculated based on annual electric and gas bills for the year 2017 to provide an average comparative score. Buildings with a score of 75 or higher meet the ENERGY STAR Certification requirements and are considered among the nation's more dynamic properties. The EUI rating for this example is 66.1 kBTU per square foot per year with an energy cost of $1.49 per square foot per year.

Based on this model, replacing the old windows on this condominium building not only would increase thermal comfort and reduce air infiltration, it also would reduce the total carbon dioxide footprint of the building by 448 metric tons. This is equivalent to 166.2 tons of waste recycled instead of being deposited in a landfill.

The total potential annual savings, once windows are replaced, is estimated at $90,000, which is equivalent to a 31% reduction in total energy usage across the building. These savings are equivalent to about 21% energy saving in natural gas usage and about 10% energy saving in electricity usage.

By generating waste heat, electric lighting also adds to the loads on a building's mechanical and cooling systems. The energy savings from reduced electric lighting through the use of daylighting strategies can keep spaces significantly cooler in the summer, directly reducing a building's cooling energy usage by an additional 10% to 20%.

Total Annual Energy Use



Case Study:
Franklin Tower Residences Philadelphia

Franklin Tower Residences updates the Philadelphia skyline with 550 luxury apartments fashioned from a former 1980s concrete, office tower. Now a premier, modern, glass-clad residential property, the 24-story building encompasses more than 607,000 square feet. It offers generously sized floor plans, high ceilings and ample natural light with floor-to-ceiling windows, plus a rooftop deck and lounge.

Along with panoramic views from the top, residents can enjoy views, natural light and fresh air from their apartments' private patios. When the Philadelphia weather turns cold, they stay comfortable indoors thanks to the high thermal performance curtainwall, window wall, operable vents, terrace doors, sliding doors and entrance systems. These systems incorporate glass with low-e coatings and thermally improved aluminum framing members.

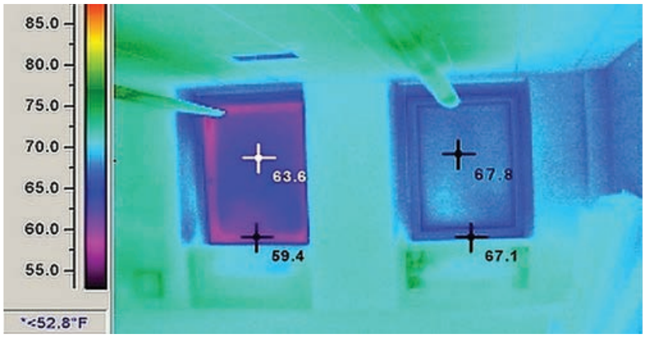
A European Cherry wood grain finish was selected for the ground level's entrance and curtainwall systems. Applied to the aluminum framing, this specialty finish simulates the look of wood without the maintenance to provide a lasting, aesthetically pleasing impression.

> **"Our challenge was to create a building that could enliven the public realm at street level, modernize and improve the functionality of its floor plates, and accommodate new homes for a growing downtown population."**
>
> **– Robert Fuller, AIA, Principal, Gensler**

Case Study:
Prudential Plaza, Prudential I Tower Chicago

More than $100 million was invested in updating Prudential Plaza, one of the most recognizable landmarks in Chicago's East Loop. Renovating the 41-story façade of this Class A, high-rise office tower from 1955 included improving exterior aesthetics, tenant comfort and leasing success.

As part of the overall project, the renovation team replaced more than 1,200 bays of existing, single-pane windows with high-performance windows featuring low-e glass. Using proprietary energy modeling tools, the team reviewed annual energy use, peak demand, carbon emissions, daylight, glare, condensation predictions and cost savings to optimize product selection. The modern windows meet the high design pressure requirements due to proximity to Lake Michigan, meet acoustic performance for improved occupant comfort, contribute to operational savings through energy efficiency, and achieve the owner's objectives for enhanced appearance and long-term value.



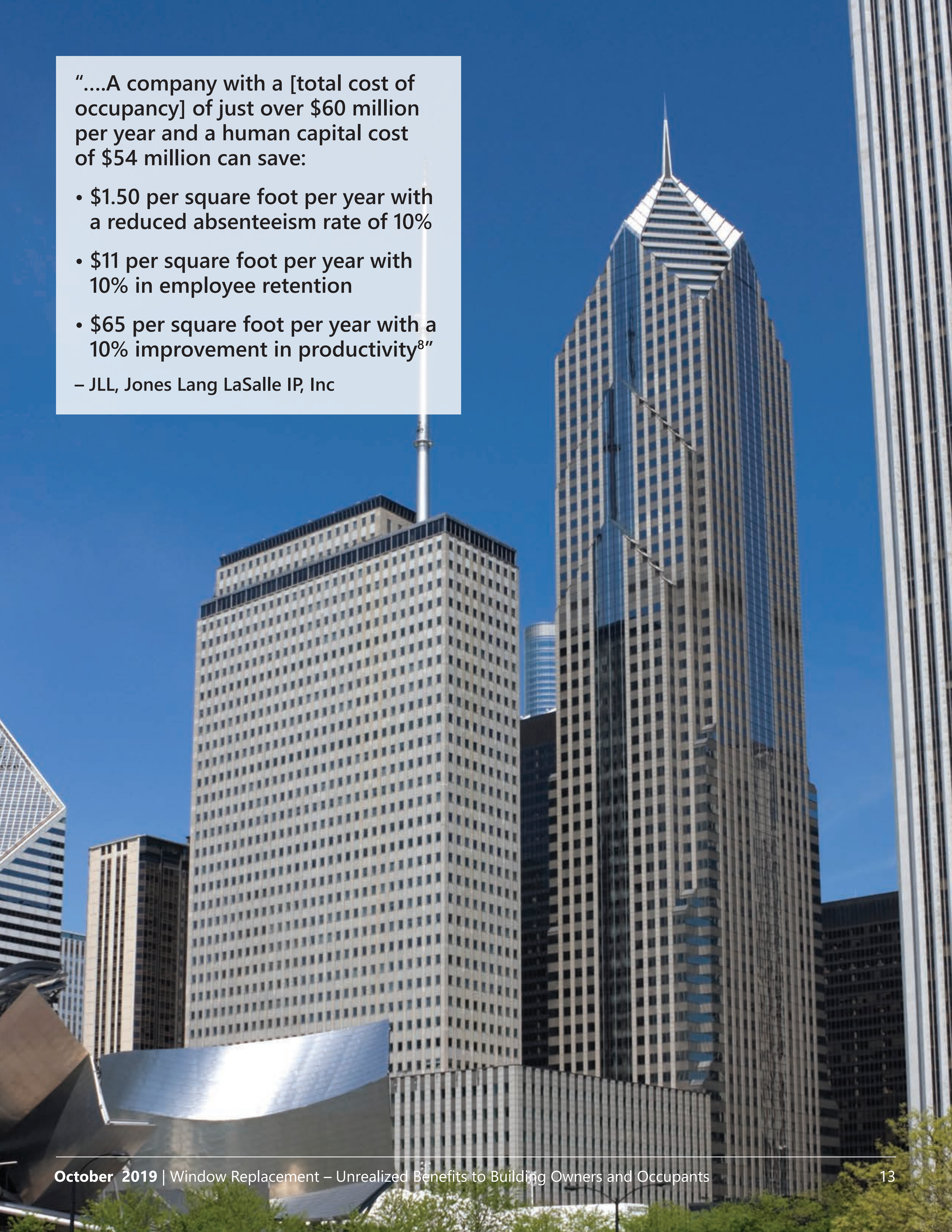
Infrared thermographic imaging can identify areas where there is air or water infiltration, as well as where thermal performance can be improved. These images for Prudential I Tower show window frame surface temperature differences of nearly 8°F between the old unit on the left and the new unit on the right. The exterior temperature was 33°F. The interior temperature was 71°F.

> "Buildings also embody the upstream energy used in all of the processes associated with their construction, including the production (mining, harvesting, and/or manufacturing) and transport of their constituent materials, as well as the erection of the structure. Energy-efficient retrofits achieve dual savings: conserving embodied energy and curtailing operations emissions.[2]"
>
> – American Institute of Architects

ROI on Window Replacement

"High-performance buildings use less energy to operate, have reduced energy costs and carbon emissions, and contribute less to climate change. ...High-performance buildings improve occupant experience, health, and productivity by providing greater visual and thermal comfort along with improved indoor air quality. These buildings also improve the local community by avoiding contributions to heat islands and stormwater runoff, while supporting resiliency by maintaining core operations and services during emergencies. They also offer additional societal benefits by supporting green economies and sustainable communities."[3]

– American Institute of Architects



"….A company with a [total cost of occupancy] of just over $60 million per year and a human capital cost of $54 million can save:

- $1.50 per square foot per year with a reduced absenteeism rate of 10%
- $11 per square foot per year with 10% in employee retention
- $65 per square foot per year with a 10% improvement in productivity[8]"

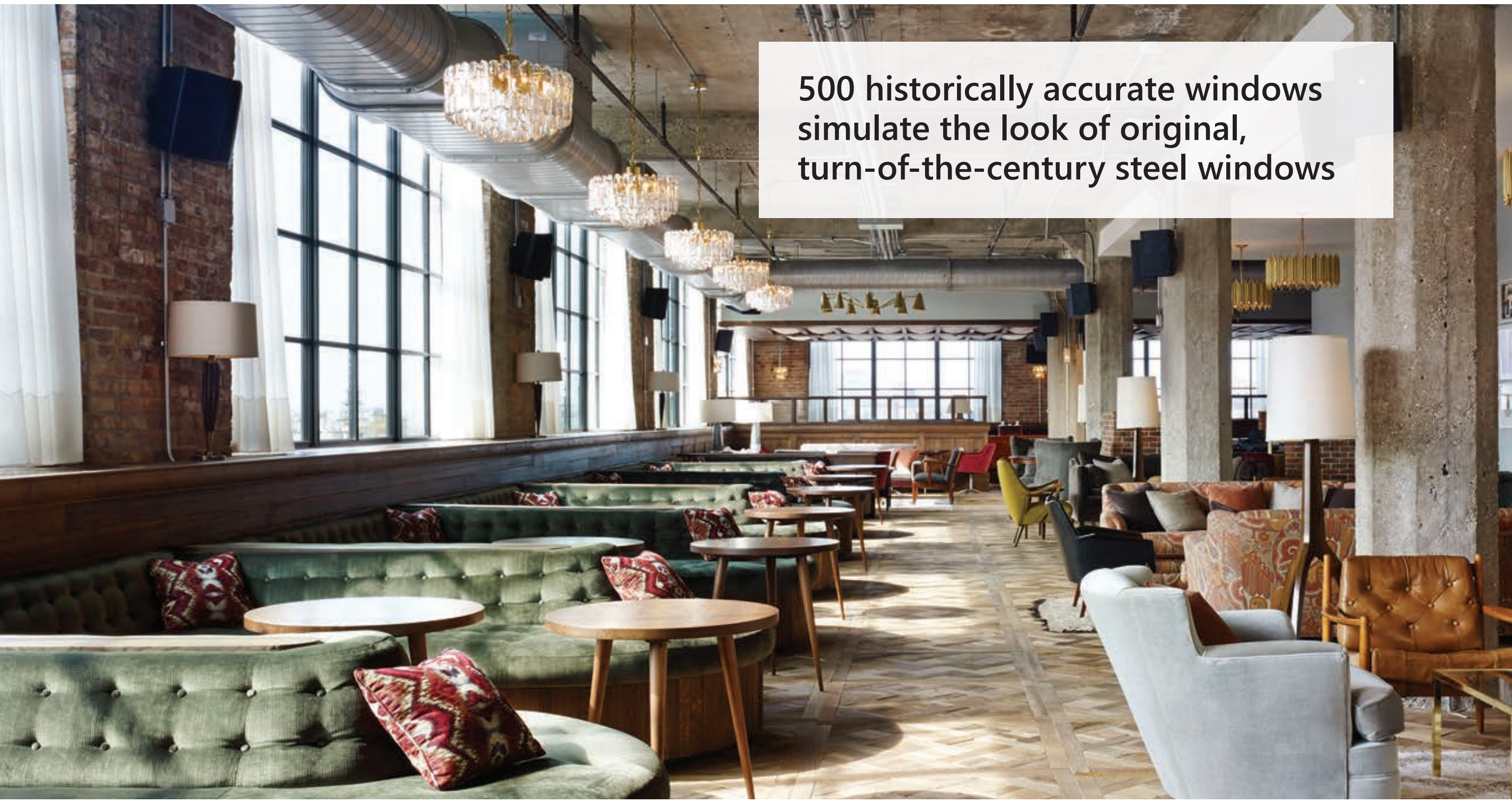
– JLL, Jones Lang LaSalle IP, Inc

Case Study:

Soho House Chicago

Transforming a 1900s factory building into a modern, 40-room hotel and private club, Soho House wanted to maintain the historic aesthetic and update performance for the comfort of its clientele. Matching the large scale and fine detail of this vintage property, 500 historically accurate windows simulate the look of original, turn-of-the-century, steel windows' true divided lites with a narrow, exterior in cove profiles. The matte Statuary Bronze finish communicates a sense of established longevity and timelessness. Along with providing large views and daylight, the new windows also meet Chicago's stringent energy codes.

> "Retrofitting buildings strengthens the local economy: Compared to new construction, a greater proportion of a retrofit's budget typically goes to labor, creating more jobs for the dollars spent. Among owners, 94% believe that their buildings are more valuable after a green retrofit.[2]"
>
> – American Institute of Architects



Look Beyond Simple Energy Payback

In the current economy, when energy cost escalation and interest rates are much more comparable, few installations show an energy-based simple payback time less than 20 years.[9] Facilities professionals are more informed these days, however, and now consider all the factors involved, including carbon footprint reduction, maintenance savings, safety and occupant productivity.

- 1-2 year payback on energy for lighting – 10% of energy use in commercial buildings
- 5-7 year payback on energy for HVAC – 49% of energy use in commercial buildings
- 15-50 year payback on energy for windows[10]

Important Factors to Consider for Return on Investment[11]

- New window systems reduce lighting and HVAC capacity requirements.
- New window systems reduce maintenance and repair expenditures due to water infiltration, condensation, caulking, painting and glass replacement.
- Employee productivity can be enhanced by improving the work environment. Even a small increase in employee productivity can have a large, positive financial impact as salary costs are generally 10 times higher than energy costs in U.S. office buildings. Energy-efficient, high-performance buildings provide occupants with access to daylight, comfortable temperatures and better air quality. These environmental characteristics are correlated with lower absenteeism and higher productivity, and can save more than $2,000 annually per employee.
- Utilization of the perimeter space of a building is becoming more important as the space per employee continues to decline and tenants are trying to be more efficient. New window system technology can keep people in a comfortable environment without experiencing extreme heat or cold, while seated next to a window.
- A building's aesthetics can be improved with new glass and aluminum framing products, which will attract new tenants and retain existing tenants. Buildings that have upgraded these components have reduced vacancies and increased lease rates. This, in turn, improves the value of a building.
- In most cases, window replacement or curtainwall re-cladding is considered to be an imperative – with energy savings characterized as an added, albeit significant, benefit.

"Buildings that are equipped with low-e glazings are estimated on average to reduce annual energy use by 5-15% over buildings with conventional glazings.[12]"

– Building Operating Management

"Office buildings from the mid-20th century offer significant opportunities for increasing value and reducing environmental impact through energy-efficient retrofits.[2]"

– American Institute of Architects

Case Study:

The University of Washington-Tacoma, McDonald-Smith Building

The University of Washington-Tacoma (UW Tacoma) completed its reconstruction and renovation of the 120-year-old, four-story McDonald-Smith Building located in the Union Station Historic District. Meeting the historic aesthetic and modern performance needs, more than 116 simulated double-hung, arched top, fixed windows were installed.

As part of an $11 million renovation project, the university has modified the existing historic building for additional office and meeting spaces.

The single-pane wood windows were original to the building and were in poor shape. The Landmarks Commission was particularly concerned that the profiles of the new window frames matched the historic windows as closely as possible.

This was the first project using extruded aluminum framed windows approved by the Commission. Given the unique arch of the McDonald-Smith windows, and that 17 different custom arched window openings exist on the building, the team was challenged to find the best product to use. The selected windows were to exemplify "superior craftsmanship, similar sightlines, closer brickmold profiles" and "fewer long-term warranty issues."

With more than 90% of 2025's building stock already standing, improving our existing buildings offers the greatest chance of reducing greenhouse gas (GHG) emissions by 26-28% below 2005 levels by 2025.[2]

The simulated double-hung fixed windows that were selected met all of these needs and match the arched openings. The windows feature curved 4-7/8-inch-deep aluminum frames painted in a Black Panther color. Using a two-coat, 70% PVDF resin-based coating helps extend the window systems' lifespan and reduce maintenance costs.

The fixed windows have offset glass planes to give the appearance of historic double-hungs. Combined with high-performing glass, extra-wide polyamide thermal barriers achieve low U-Factors, high frame condensation resistance, high acoustic performance and are American Architectural Manufacturers Association AW-100 Architectural Performance Class rated.

"More than 116 simulated double-hung, arched top, fixed windows were installed to meet the project's historic aesthetic and modern performance needs. The renovation of the McDonald-Smith Building [feels] like a natural extension of the University of Washington Tacoma campus, honoring the heritage of the Union Depot historic district by breathing new life into an aging building."

– University of Washington-Tacoma's Division of Finance & Administration's Campus Planning & Real Estate

For many historically influenced window replacement projects, or for "retro" new construction, building owners seek to replicate the look of steel sash or putty-glazed wood framed, or hung windows by using architecturally rated, aluminum windows. This historic look will reduce maintenance and overall cost without sacrificing modern performance.

Using high-performance glass and aluminum frames with thermal barriers, the exterior face of the glass is set back from the face of the frame to provide an interesting "depth" and texture to windows' surfaces. These can be beveled, ogee or cove molding shapes.

The decision on whether to do a complete tear-out of existing frames – or to use a panning to prepare the opening – is one of the most critical decisions facing a major window renovation project. Aluminum extrusions are easily customizable, opening up possibilities for enhancing ease of installation and matching original appearance.

The fidelity to which historic buildings must be preserved depends on regulations, desired tax credits and grants, and the purpose of the building.

Interior Accessory Windows

When original windows are weather-tight, and operation for ventilation is not a requirement, the addition of high-quality, custodian-operable, interior accessory windows (IAWs) can be a viable option. With appropriate caution to avoid between-glass condensation, these economical add-on units improve control of sound, energy, air and light, while leaving existing windows undisturbed.

Demonstrating the successful use of IAWs in buildings listed on the National Register of Historic Places (NRHP), "Preservation Tech Notes: Windows, Number 5 – Interior Metal Storm Windows," was developed by the U.S. National Park Service (NPS) and the Center for Architectural Conservation at Georgia Tech. It offers a case study in historical preservation of the 1887 Old Watkins National Bank in Lawrence, Kansas. The property's 102 windows included five styles and 12 sizes with many spanning 5-by-10 feet.

According to the "Tech Notes"[13]

- "The monumental [existing] windows are elegantly detailed on the interior and contribute to the grandeur of the spacious banking rooms. The original interior shutters are still being used for comfort and light control."
- "The numerous problems with exterior storm windows encountered in this project led to consideration of an interior storm system."
- "An initial cost savings of nearly $20,000 was realized over exterior storm applications."
- Furthermore, "the storm windows are reducing the energy consumption by more than 40% – a figure that exceeded the theoretical calculations. Long-term maintenance of the storm windows is expected to be low because of the quality of construction."

Case Study:
Byron Rogers Federal Office Building Denver, Colorado

Renovation of Denver's Byron G. Rogers Federal Office Building and U.S. Courthouse included modernization upgrades to meet current codes, seismic and blast hazard mitigation criteria, as well as U.S. General Services Administration (GSA) facility requirements for acoustic privacy, security and sustainability. It demonstrated a continued commitment to LEED Gold certification and earned an ENERGY STAR Rating of 99.

Constructed in the 1960s, the 18-story office tower now houses 11 federal agencies and sits perpendicular to the five-story courthouse to frame an open plaza. Today, the NRHP-listed property serves as the cornerstone of the Denver Federal District and has revitalized the eastern edge of the downtown central business district.

Preserving its Modern Formalist design style, while improving its performance and daylighting, more than 1,600 blast hazard-mitigating windows plus curtainwall and light shelves were installed on the 494,000-square-foot Byron G. Rogers Federal Office Building.

> **"The improvements are expected to create 55% overall energy reduction in the federal office. That means GSA will reduce its greenhouse gas emissions by more than 2,908 tons of CO_2, which is the equivalent of taking 612 cars off the road or providing energy to 266 average sized homes."**
>
> **– U.S. General Services Administration (GSA)**

> **"The windows were selected to maximize the amount of visible light and insulative properties and to minimize solar heat gain. The exterior window must also meet federal blast requirements, and maintain its original gray color to meet historic preservation requirements."**
>
> **– Rocky Mountain Institute**

The design-build team worked with the GSA to find ways to generate a design model targeting an aggressive savings goal of 27-30 kBTU per square foot per year. Using continuous whole-building energy modeling that compared various combinations of efficiency measures, predicted hourly energy use and annual energy costs, the team was led to a realistic evaluation of various alternatives.

In addition to selecting appropriate products, Byron Rogers Federal Building's renovation necessitated that the exterior window frames and existing precast remained intact. Working from inside the occupied buildings, the glazing contractor carefully replaced the windows and added the light shelves.

"The median lifespan of a commercial building is 70 to 75 years, and the expected lifespan of many building components ranges from 15 to 35 years.[3]"

– American Institute of Architects

"High-performing green buildings provide the best value for the taxpayer and the public because they minimize the federal footprint through efficient use of energy, water and resources, and they create healthier productive workspaces."

– Susan Damour,
GSA Regional Administrator

The top floors' existing, exterior windows were re-glazed in the field using new, insulating glass units (IGUs). More than 1,600 new, custom-designed, in-swing IAWs were glazed with 9-foot-tall, laminated IGUs. The office's successful window retrofit met the project's required performance specifications for thermal performance and blast hazard mitigation, and preserved its historical profile.

Code Compliance and Green Standards

Energy codes and other provisions of local building codes may be different for historically significant buildings, and also may depend on the extent of the retrofit. The EPA's ENERGY STAR program's methodology and data are used by the Green Building Initiative's Green Globes system, the Collaborative for High Performance Schools, the AIA 2030 Commitment, the U.S. Guiding Principles for High Performance and Sustainable Buildings, the U.S. Green Building Council's (USGBC) LEED certification and more.

Buildings that have earned EPA's ENERGY STAR are certified as performing among the top 25% of similar buildings nationwide. Participants are scored on a scale of 0-100, those with a 75 or higher are eligible to earn the ENERGY STAR certification.[14]

An ENERGY STAR score of 75 also is a prerequisite of buildings certified in LEED Operations and Maintenance, version 4, (LEED O+M v4).

Demonstrating their energy efficiency, more than 35,000 facilities have been certified by the ENERGY STAR program.[15]

More than 270,000 buildings, comprising 26 billion square feet of floorspace, used ENERGY STAR Portfolio Manager™ tool to measure and track their energy use, water use, and waste and materials.[16]

Energy use in commercial buildings and manufacturing plants accounts for nearly half of all energy consumption in the U.S. at a cost of over $400 billion per year, more than any other sector of the economy. Commercial and industrial facilities are also responsible for nearly half of U.S. GHG emissions which contribute to climate change.[14]

On average, ENERGY STAR certified buildings use 35% less energy, generate 35% fewer GHG emissions than their peers, are less expensive to operate, and are more attractive to tenants.[14]

The ENERGY STAR program for commercial buildings has contributed to cumulative energy cost savings of more than $150 billion since 1992.[16]

Other benefits include:

Up to 26% increase in property value[18]

Up to 11% increase in occupancy rates[19]

Up to 16% increase in sales prices and rental rates[16]

According to the EPA: "American communities have more options than ever for encouraging greener building and development. Many organizations have developed model codes or rating systems that communities can use to develop green building programs or revise building ordinances.[17]"

Environmental Stewardship

Improving both the performance and the appearance of existing buildings, a new energy-efficient window system is proven to enhance the building's overall value and is a clear demonstration of environmental stewardship. One of the best ways to illustrate this is by converting the energy savings determined by modeling tools into approximate fossil fuel equivalents.

The most sustainable project is one that improves on what already has been built. Energy-efficient, historically accurate replacement windows can play an important role in improving older buildings' performance and in achieving these designations, through energy savings, recycled content, regional extraction, increased natural ventilation, thermal comfort, daylight and views.

Fossil Fuel Savings Equivalents[20]

Based on a 16,200-square-foot office building's average annual energy use of 237,200 kWh = 185 tons of GHG emissions of CO_2 equivalent to:

CO_2 emissions from 18,874 gallons of gasoline consumed or 183,374 pounds of coal burned or 20.1 homes' energy use per year

Carbon sequestered by 2,774 tree seedlings for 10 years or 197 acres of U.S. forest in one year

GHG emissions from 35.6 passenger vehicles driven for one year or 410,113 miles driven by an average passenger vehicle

GHG emissions avoided by 58.5 tons or 7,319 trash bags of waste recycled instead of landfilled

"Worldwide, buildings account for

- 45% overall energy consumption
- 60% of electrical use
- 39% greenhouse gas emissions

Urban areas account for 70% global greenhouse gas emissions.[3]"

– American Institute of Architects

Incentives and Credits

Of course, every institution's method of calculating return on investment is different. Renovation design teams often provide the savings and cost information to financial professionals or energy service companies for economic analysis, so applicable rebates, subsidies, incentives, deductions and credits can be factored into the equation.

Depreciation and tax credits also are applicable, using the appropriate rates for the institution or firm in question. Maintenance savings can be considerable, and are either inflation-adjusted only or assumed to increase as existing windows age further. Using the installed budget cost per bay of new windows, and an appropriate after-tax alternative investment rate, a payback time in years is inferred.

Financial assumptions can have a more significant effect on payback time than fenestration design parameters, especially for tax-exempt institutions. Encouraging private sector investment in the rehabilitation and re-use of historic buildings, the Federal Historic Preservation Tax Incentives program has leveraged more than $96.87 billion in private investment to preserve 44,341 historic properties since 1976.[21]

The Rehabilitation Tax Credit program is administered jointly by the NPS, the U.S. Internal Revenue Service and each State Historical Preservation Office (SHPO).

For private sector buildings seeking to earn this credit, both the structure and the rehabilitation process must be certified.

- Certified structures are those that are either listed on the NRHP, are more than 50 years old or contribute to the historic significance of a registered historic district.
- A certified rehabilitation process is one consistent with the historic character of the building or district, as evidenced by the written review and approval of the SHPO and the NPS.

When window replacement is required, and using the same material is not technically or economically feasible, the referenced standards still require preserving distinctive features, finishes and construction techniques, as well as matching design, color, texture and visual quality of the original building components.

The NPS has the last word in acceptability of replacement window aesthetics. The GSA owns nearly 400 buildings listed in, or eligible for, the NRHP. Similar to private sector projects, the GSA is required to use SHPOs to assess the potential adverse impacts per the U.S. Secretary of Interior's "Standards for Rehabilitation." For GSA-owned buildings, blast hazard mitigation and hurricane impact resistance can take precedence over preservation, but other historical parameters still hold.

Case Study:
Edith Green-Wendell Wyatt Federal Building, Portland, Oregon

In Portland, Oregon, an 18-story, 1970s office tower was renovated and transformed from a former "energy hog" into a high-performing, attractive building now known as the Edith Green-Wendell Wyatt Federal Building.

To meet the GSA's aggressive energy-use-intensity target of 35 kBTU per square foot per year for the property, site-specific climate and solar analyses specified 40% vision glazing and 50% shading during summer's peak loads. Tuned to these requirements, the new curtainwall used elevation-specific shading and reflective elements.

In addition to the high thermal performance, the curtainwall also offers blast hazard mitigation. Exceeding expectations, the improved exterior reduces annual energy usage by 60% and annual operating costs by up to $400,000. The American Institute of Architects (AIA) Committee on the Environment recognized the renovated facility as a Top Ten green project.

"Adopting model codes saves $11 per $1 spent

Federal mitigation grants save $6 per $1 spent

Exceeding codes saves $4 per $1 spent[22]"

– National Institute of Building Sciences

Case Study:
2400 Market Street Philadelphia

Originally constructed in the early 1920s as a four-story Hudson Motor Car Company fabrication plant, Philadelphia's 2400 Market Street property was adaptively reused as an office building. Previously known as the Marketplace Design Center, it was reimagined and vertically expanded into a nine-story, mixed-use, Class A office building and positioned as a vibrant part of Center City's riverfront renewal. Now home to Aramark's corporate headquarters, the building's updated design incorporates innovation and sustainability features in pursuit of LEED Gold certification.

The new design was conceived by architecture firm Gensler, with Varenhorst serving as the executive architect. The old, existing structure was a concrete slab with concrete columns, sufficient to permit a five-story overbuild above the roof line to create the block-wide, 600,000-square-foot development. The renovated and expanded building was re-clad in a modern, high-performance façade. Its fresh exterior showcases high-performance, low-e glass within a thermally improved, aluminum-framed window wall system with anodize and wood grain finishes.

Among U.S. workers surveyed by the USGBC about office buildings and LEED:

93% of those who work in LEED-certified green buildings say they are satisfied on the job; 12% more than those who work in conventional buildings

85% feel their access to quality outdoor views and natural sunlight boosts their overall productivity and happiness

84% prefer to work for a company that has a strong, concrete mission and positive values

79% would choose a LEED-certified green building over a non-LEED building[23]

Glossary

AAMA is the abbreviation for the American Architectural Manufacturers Association, the fenestration industry's source of performance standards, product certification and educational programs.

Anodizing is the process of electrochemically controlling, accelerating and enhancing oxidation of an aluminum substrate. Anodized aluminum resists the ravages of time, temperature, corrosion, humidity and warping, and is 100% recyclable.

Building envelope refers to the physical separation between the interior conditioned spaces and exterior unconditioned spaces.

Carbon emissions are based on source energy. It is multiplied by the electric energy consumption to calculate the pounds of CO_2 emitted due to electricity use (lbs/kWh).

Cladding on a building refers to the application of one material over another to provide a "skin" intended for aesthetic purposes and/or to control the infiltration of air, water and weather elements.

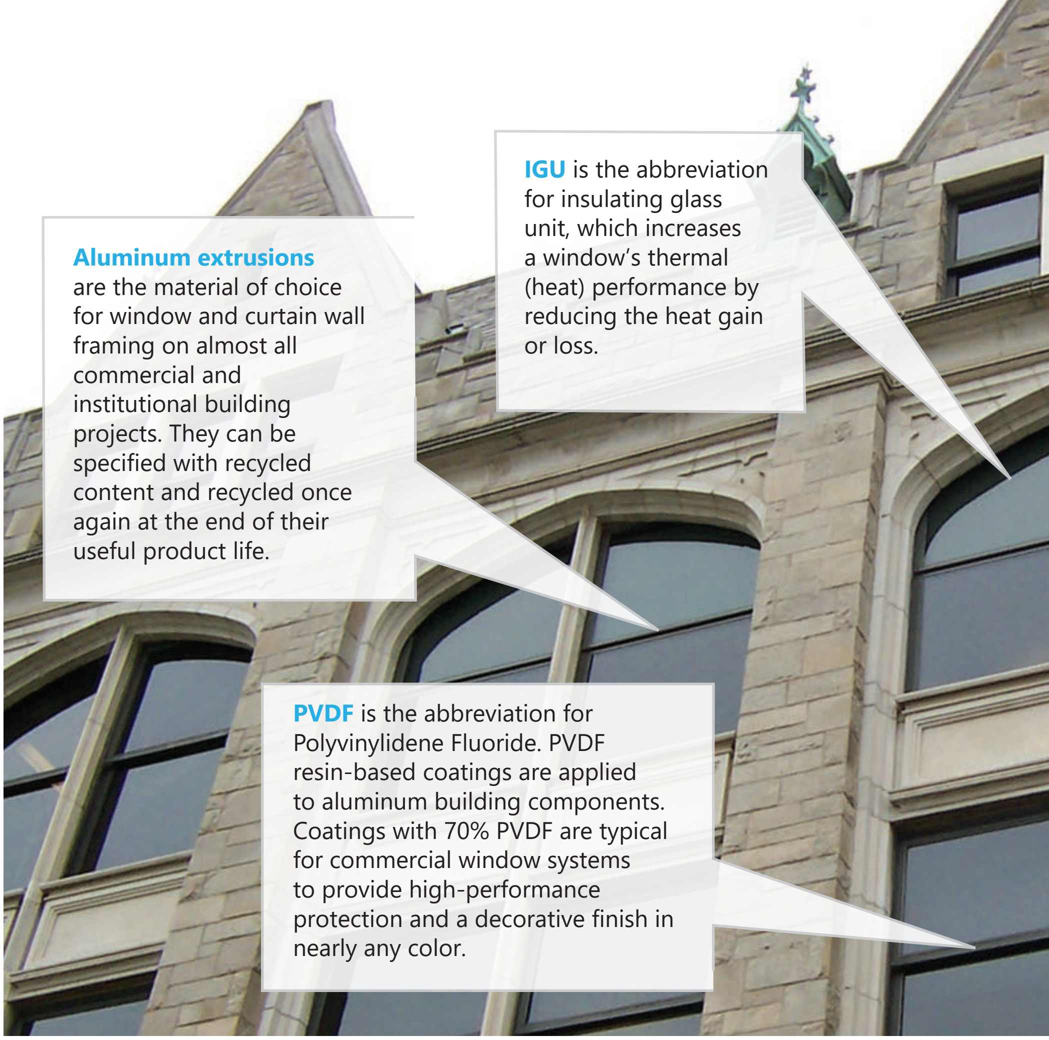
Condensation prediction is reported at "none," minimal" or "extensive." If the surface temperature is more than 3°F higher than dew point then the condensation prediction is "none."

Curtainwall refers to non-load-bearing exterior wall cladding that usually spans from floor-to-floor with vertical framing members running past the face of the floor slabs. Curtainwall systems are designed to support their own weight and wind loads.

Daylight illuminance is calculated as an annual average measured in foot-candles at a point 9 feet from the window in the center of the room.

Effective aperture is the light-admitting potential of a glazing system determined by multiplying the window-to-wall ratio (WWR) with the visible transmittance (Tvis). This can be useful in evaluating the cost effectiveness and daylighting potential of a glazing system.

ENERGY STAR® is a program of the U.S. Environmental Protection Agency (EPA) for certifying energy-efficient buildings.



Aluminum extrusions are the material of choice for window and curtain wall framing on almost all commercial and institutional building projects. They can be specified with recycled content and recycled once again at the end of their useful product life.

IGU is the abbreviation for insulating glass unit, which increases a window's thermal (heat) performance by reducing the heat gain or loss.

PVDF is the abbreviation for Polyvinylidene Fluoride. PVDF resin-based coatings are applied to aluminum building components. Coatings with 70% PVDF are typical for commercial window systems to provide high-performance protection and a decorative finish in nearly any color.

Entrance systems refer to the building components that form a building's entry, including doors and surrounding windows.

eQUEST is the abbreviation for U.S. Department of Energy's DOE-2 Quick Energy Simulation Tool.

EUI is the abbreviation for energy use intensity, typically measured as total annual energy consumption (kBTU) divided by square footage.

Fenestration refers to the openings in or on the building envelope. This includes windows, doors, curtainwall, storefront, sloped glazing and other systems that are designed to permit air, light or people to pass through them.

Glazing is an infill material, such as glass or plastic. It also is the process of installing an infill material into a prepared opening.

HVAC is the abbreviation for heating, ventilation and air conditioning.

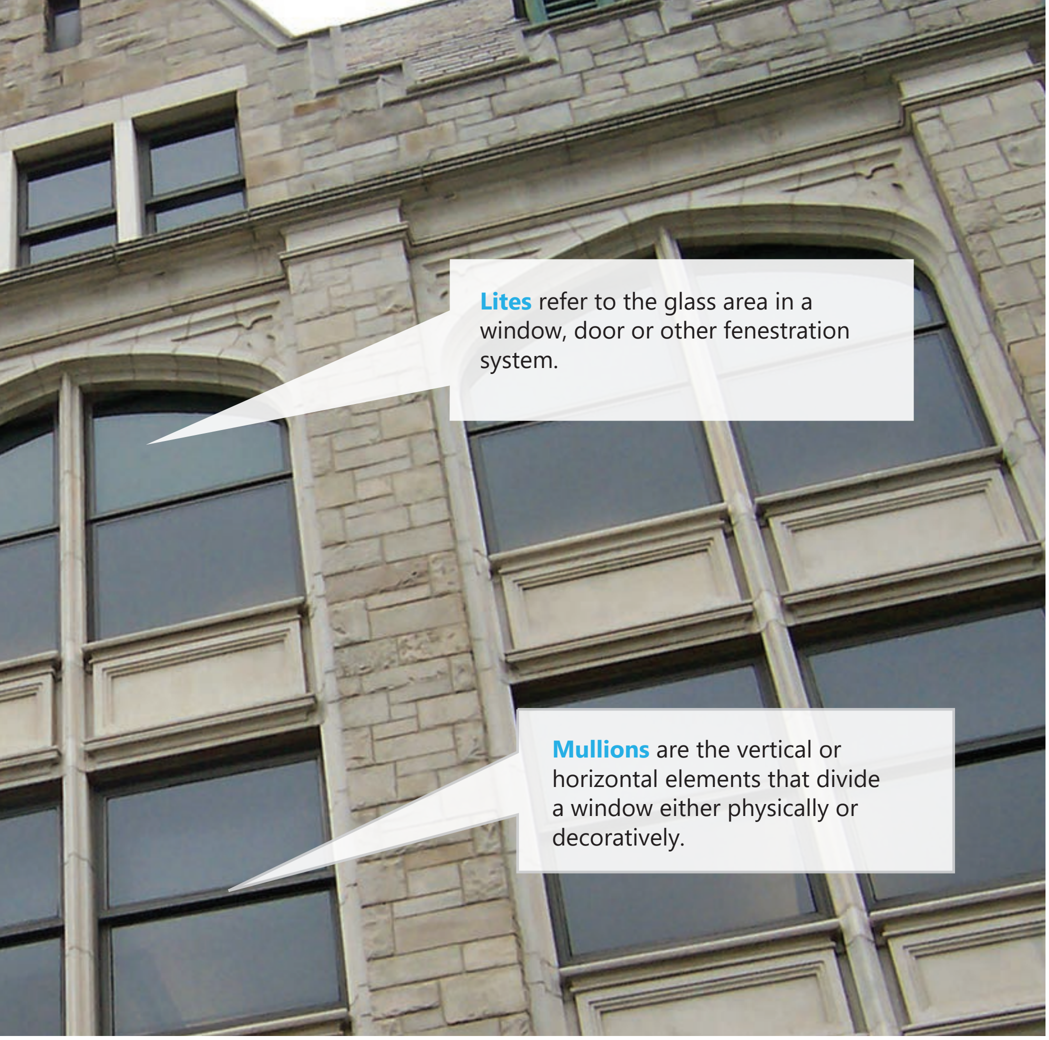
IAW is the abbreviation for interior accessory window, which is attached inboard of the existing, weather-tight windows to enhance performance for sound, energy, air leakage, light, as well as for human impact and blast hazard mitigation.

IRT imaging is the abbreviation for infrared thermographic imaging, which shows contrasting colors to indicate warm and cool areas or objects.

kWh is the abbreviation for a kilowatt hour of energy, which is the measure of how energy is sold in the U.S. A 40-watt light bulb operating continuously for 25 hours uses 1 kWh.

LEED® is the acronym for the U.S. Green Building Council (USGBC) program, which formerly was known as the Leadership in Energy and Environmental Design green rating program.

Light shelves are effective at redirecting sunlight deep into occupied spaces when positioned on a building's interior at transom height.



Low-e is the shortened form of low-emissivity, which refers to a surface condition that emits low levels of radiant thermal energy.

LSG is the light-to-solar-gain ratio between the visible transmittance (Tvis) of a glazing and its solar heat gain coefficient (SHGC). This is a measure of the ability of a glazing to provide light and exclude solar heat.

Muntins, or **muntin bars**, are strips of wood or metal that separate panes of glass in a window. Muntins can be designed to hold panes of glass in a true divided lite (TDL) or applied to the interior and exterior surfaces of glass.

NPS is an abbreviation for the U.S. National Park Service, an agency of the U.S. Department of the Interior. NPS administers the National Register of Historic Places (NRHP). NPS also jointly administers the Rehabilitation Tax Credit program with the U.S. Internal Revenue Service and State Historical Preservation Offices (SHPOs).

NRHP is an abbreviation for the National Register of Historic Places, which is the official Federal list of districts, sites, buildings, structures, and objects significant in American history, architecture, archeology, engineering and culture.

Panning is the trim used to cover the existing material in a window opening, rather than removing it and potentially exposing unwanted wall conditions.

Peak demand is based on source energy and is the greatest amount of electricity required at one point in time during the year.

Quad is a unit of energy equal to 1 quadrillion British Thermal Units (BTUs) or 10 to the 15th power.

Simulated double-hung projected windows refer to windows that look like double-hung windows, but actually project from the plane of the wall, either inward or outward. Projected windows are easier to open than hung windows, especially in large sizes with heavy glass. They also have much better air infiltration performance than hung windows.

Storefront systems literally refer to the façade of a store, but more generally describe a commercial system of doors and windows installed together on low- to mid-rise buildings or the lower floors of high-rise buildings.

Sun shades are positioned on a building's exterior and intercept unwanted solar heat gain before it can impact the HVAC system's load.

Thermal barriers are components made of a material with low thermal conductivity and are inserted between metal framing members of a fenestration system to reduce the transfer of heat or cold.

True divided lites, sometimes abbreviated as TDLs, indicate that a lite has been physically separated into smaller sections by muntins. When TDLs are not required, muntins and grids may be applied to the interior and/or exterior surface to simulate this traditional, historic aesthetic.

U-Factor is the accepted measurement to quantify a commercial window system's thermal performance. The higher the U-Factor, the more heat is transferred (lost) through the window in winter. U-Factors usually range from a high of 1.3 for a typical aluminum-framed, single-pane window to a low of around 0.16 for a multi-paned, high-performance window with low-e coatings and expanded thermal barriers in the aluminum frames.

Weighted glare index is calculated at 0.50 feet from the window for a person facing the side wall. Anything under 22 is acceptable for glare.

Window walls in commercial buildings are non-load-bearing fenestration systems that span from the top of a floor slab to the underside of the next higher floor slab.

Renovation Specification Checklist

Setting aesthetic and performance goals for a successful window replacement involves considerations for thermal transmittance, condensation resistance, acoustics, ventilation, view and solar heat gain. The window replacement project team not only can include facility management and design professionals, but also the building's mechanical engineer and the technical staff from a qualified window manufacturer.

Working with an experienced building envelope renovation team that includes the installer and manufacturers, building owners and facility managers can improve their properties' appearance to attract and retain tenants, expand their useable floor space for greater lease value, save energy and operating costs, reduce maintenance costs, enhance occupants' comfort and productivity, and ultimately, increase the value of their buildings.

> "Target your upgrades. Rather than fixing everything, look for places of major heat loss and fix those.[2]"
>
> – American Institute of Architects

To ensure complete and competitive bids from the building envelope retrofit team, consider the following:

PREWORK

Create before and after rendering images
Conduct a window assessment and performance testing on existing windows
Create comprehensive drawings, specifications and description of work
Conduct testing and quality control requirements

LOGISTICS

Research potential utility rebates and tax credits (State & Federal)
Research Historical Preservation requirements (State & Federal)
Determine physical access, working hours and protection for all interior, exterior and unoccupied spaces
Determine sequence of work and overall schedule

REQUIREMENTS

Specify minimum performance requirements for manufacturer, installer, materials, fabrication, finish, operation and window hardware
Specify minimum bonding, insurance and warranty requirements

INSTALLATION

Identify storage location (interior/exterior)
Install samples in an easily accessible on-site location
Specify instructions and sequence for deliveries
Ensure the building shell is protected from the elements during installation
Specify a plan for related repairs during the project: plaster, molding, etc.
Create instructions and sequence for disposal of materials removed

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Sources

1 International Conference on Sustainable Design, Engineering and Construction; "Fundamentals in Façade Retrofit Practice;" Andrea Martinez, Mic Patterson, Anders Carlson, Douglas Noble; University of Southern California; Aug. 2015; https://www.researchgate.net/publication/281850445_Fundamentals_in_Facade_Retrofit_Practice

2 American Institute of Architects (AIA), "Renovate, retrofit, reuse: Uncovering the hidden value in America's existing building stock;" Katharine Logan; 2019; http://content.aia.org/sites/default/files/2019-07/RES19_227853_Retrofitting_Existing_Buildings_Report_Guide_V3.pdf

3 AIA, Architect's Guide to Integrating Building Performance Simulation in the Design Process; 2019; http://content.aia.org/sites/default/files/2016-04/Energy-Modeling-Design-Process-Guide.pdf

4 Whole Building Design Guide, a program of the National Institute of Building Sciences (NIBS); accessed Oct. 2, 2019; https://www.wbdg.org/design-objectives/productive/promote-health-well-being and http://www.wbdg.org/resources/daylighting

5 Innovative Glazing Materials, Ch. 6.3, "Handbook of Energy Efficiency in Buildings – A Life Cycle Approach;" Eleanor S. Lee; Butterworth-Heinemann, Elsevier Inc.; ISBN: 978-0-12-812817-6; Jan. 2018; http://eta-publications.lbl.gov/sites/default/files/ch6.3-innovative_glazing_lbnl_2001193_eslee.pdf

6 Fannie Mae; "Instructions for Performing a Multifamily Property Condition Assessment," V.2, Appendix F: Estimated Useful Life Tables; Oct. 2014; https:/multifamily.fanniemae.com/sites/g/files/koqyhd161/files/migrated-files/content/guide_form/4099f.pdf

7 Journal of the National Institute of Building Sciences; "Retrofitting with High-Performance, Aluminum-Framed Window Systems," Aug. 2016; https://www.wje.com/assets/pdfs/articles/WJE_Windows_Walls_Wu_Reprint.pdf

8 JLL, Jones Lang LaSalle IP, Inc.; accessed Oct. 2, 2019; https://.us.jll.com/en/views/workplaces-that-work-for-your-employees-and-bottom-line

9 U.S. Department of Energy, Energy Efficiency and Renewable Energy, Pacific Northwest National Laboratories; Advanced Energy Retrofit Guides: Practical Ways to Improve Energy Performance – Office Buildings; Sept. 2011; https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-20761.pdf

10 U.S. Energy Information Administration (EIA); "2012 Commercial Buildings Energy Consumption Survey: Energy Usage Summary," (CBECS) Table 5; March 2016; https://www.eia.gov/energyexplained/index.php?page=us_energy_commercial

11 U.S. Department of Labor; 2010 annual absenteeism rate in the private sector of 3% per employee, 62.4 hours/employee/year = $2,074/employee/year, 83 hours/employee/year in the public sector = $2,502/employee/year; 2018 rates show similar numbers; https://www.bls.gov/cps/cpsaat47.htm#cps_eeann_abs_ft_occu_ind.f.1

12 Building Operating Management; "6 ways to boost building envelope performance;" April 2017; https://www.facilitiesnet.com/windowsexteriorwalls/article/3-Ways-to-Boost-Building-Envelope-Performance--17099?source=part

13 U.S. National Park Service (NPS); "Preservation Tech Notes: Windows, Number 5 – Interior Metal Storm Windows;" https://www.nps.gov/tps/how-to-preserve/tech-notes/Tech-Notes-Windows05.pdf

14 ENERGY STAR; "Media FAQs about ENERGY STAR for commercial and industrial buildings;" accessed Oct. 2, 2019; https://www.energystar.gov/buildings/about-us/press-room/media-faqs

15 ENERGY STAR; "ENERGY STAR® PortfolioManager™ DataTrends: Benchmarking and Energy Savings"; Oct. 2012; https://www.energystar.gov/sites/default/files/buildings/tools/DataTrends_Savings_20121002.pdf

16 ENERGY STAR; "Facts and Stats;" accessed Oct. 2, 2019; https://www.energystar.gov/buildings/about-us/facts-and-stats

17 U.S. Environmental Protection Agency (EPA); "Smart Growth: Green Building Standards;" accessed Oct. 2, 2019; https://www.epa.gov/smartgrowth/green-building-standards

18 AIA and Rocky Mountain Institute; "Deep Energy Retrofits: An Emerging Opportunity, An Architect's Guide to the Energy Retrofit Market;" 2013; http://www.aia.org/practicing/AIAB099249

19 Institute of Market Transformation; "Added Value of ENERGY STAR-Labeled Commercial Buidings in the U.S. Market;" 2016; https://www.imt.org/wp-content/uploads/2016/12/IMT_Premiums_ENERGY-STAR_2016.pdf

20 EPA, Greenhouse Gas Equivalencies Calculator; accessed Aug. 19, 2019; https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator; based on electricity use per 16,200-square-foot office building of 237,200 kWh per year as represented by the 2012 EIA CBECS, https://www.eia.gov/consumption/commercial/data/2012/c&e/cfm/pba4.php

21 NPS; "Tax Incentives for Preserving Historic Properties;" accessed Oct. 2, 2019; https://www.nps.gov/tps/tax-incentives.htm

22 NIBS, Natural Hazard Mitigation Saves: 2018 Interim Report; https://www.nibs.org/page/mitigationsaves

23 U.S. Green Building Council (USGBC); Employee Survey 2018; https://www.usgbc.org/sites/default/files/employee-happiness-survey-final.jpeg