Windows and Glazing

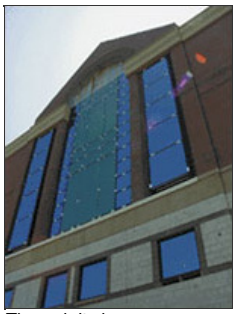
by Gregg D. Ander, FAIA
Southern California Edison(http://www.sce.com/)
Last updated: 11-04-2014

INTRODUCTION

Windows have long been used in buildings for daylighting(daylighting.php) and ventilation(naturalventilation.php). Many studies have even shown that health(/design/ensure_health.php), comfort(/design/provide_comfort.php), and productivity(/design/productive.php) are improved due to well-ventilated indoor environments and access to natural light. However, windows also represent a major source of unwanted heat loss, discomfort, and condensation problems(moisturedynamics.php). In 1990 alone, the energy used to offset unwanted heat losses and gains through windows in residential and commercial buildings cost the United States $20 billion (one-fourth of all the energy used for space heating and cooling).

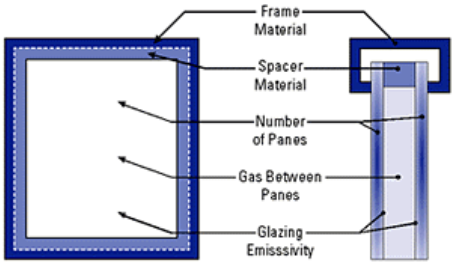
In recent years, windows have undergone a technological revolution. High-performance, energy-efficient window and glazing systems are now available that can dramatically cut energy consumption and pollution sources: they have lower heat loss, less air leakage, and warmer window surfaces that improve comfort and minimize condensation. These high-performance windows feature double or triple glazing, specialized transparent coatings, insulating gas sandwiched between panes, and improved frames. All of these features reduce heat transfer, thereby cutting the energy lost through windows.

This Resource Page covers basic concepts for specifying window and glazing systems, particularly energy-efficient windows.


Through its loan program, NYSERDA helped the Capital District Train Authority install new, energy-efficient glazing and high-efficiency heating and cooling equipment at this train station in Rensselaer, New York
(Courtesy of NYSERDA)

DESCRIPTION

Window systems are comprised of glass panes, structural frames, spacers, and sealants. In recent years, the variety of glass types, coatings, and frames available for use in window systems has increased dramatically, as has the opportunity to fine-tune and optimize window selection on a project-by-project basis.



Factors affecting window performance
(Courtesy of Energy User News)

Careful specification of window and glazing systems is essential to the energy efficiency and comfort of all buildings. In residential, skin-load dominated structures(psheating.php) (such as housing) optimum window design and glazing specification can reduce energy consumption from 10%-50% below accepted practice in most climates. In internal-load dominated(psheating.php) commercial, industrial, and institutional buildings, properly specified fenestration systems have the potential to reduce lighting and HVAC costs 10%-40%.

Window and glazing choices should be considered holistically. Once the design team and owner agree on the design problem, window and glazing options can be evaluated. Issues to consider include:

- Heat gains and losses
- Visual requirements (privacy, glare, view)(/design/provide_comfort.php)
- Shading and sun control(suncontrol.php)
- Thermal comfort(/design/provide_comfort.php)
- Condensation control(moisturedynamics.php)
- Ultraviolet control
- Acoustic control(/design/provide_comfort.php)
- Color effects
- Daylighting(daylighting.php)
- Energy requirements

Ultimately, the optimum choice of window and glazing systems will depend on many factors including the building use type(/design/buildingtypes.php), the local climate, utility rates, and building orientation(/design/site_potential.php).

A. Specifying Windows and Glazings

To fully specify a window system, it is necessary to specify the following characteristics:

- Window U-value
- Window Solar Heat Gain Coefficient (SHGC), or shading coefficient (SC)

- Glass Visible Transmittance ($T_{vis\text{-}glass}$)

For specific aesthetic and performance objectives the specifier may also wish to specify:

- Tints (colors) and Coatings

U-Value

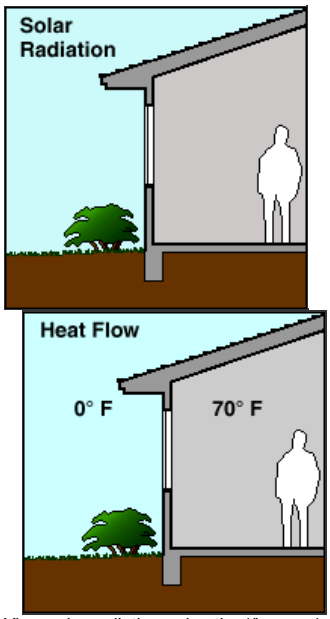
U-value indicates the rate of heat flow due to conduction, convection, and radiation through a window as a result of a temperature difference between the inside and outside. The higher the U-factor the more heat is transferred (lost) through the window in winter.

- The units of U-value are: Btus per hour per square foot per °F (Btu/hr · ft² · °F)
- U-factors usually range from a high of 1.3 (for a typical aluminum frame single glazed window) to a low of around 0.2 (for a multi-paned, high-performance window with low-emissivity coatings and insulated frames).
- A window with a U-factor of 0.6 will lose twice as much heat under the same conditions as one with a U-factor of 0.3.
- Total (or net) window U-factors can be considerably higher than the center-of-glass U-factors.

Solar Heat Gain Coefficient (SHGC)

SHGC indicates how much of the sun's energy striking the window is transmitted through the window as heat. As the SHGC increases, the solar gain potential through a given window increases.

- The SHGC is a ratio between 0 and 1. SHGC = 0 means none of the incident solar gain is transmitted through the window as heat and SHGC = 1 means all of the incident solar energy is transmitted through the window as heat.
- A window with a SHGC of 0.6 will admit twice as much solar heat gain as one with a SHGC of 0.3.
- Typically, windows with low SHGC values are desirable in buildings with high air-conditioning loads(hvac.php) while windows with high SHGC values are desirable in buildings where passive solar heating(psheating.php) is needed.
- The term "SHGC" is relatively new and is intended to replace the term "shading coefficient (SC)." While the terms are related, the shading coefficient of glass is defined as the ratio of the solar heat gain through a given glazing as compared to that of clear, 1/8 inch single pane glass.



View solar radiation animation(/images/media_img.php?m=wgshgani.gif&w=200&h=200)
(Courtesy of Efficient Windows Collaborative
View heat flow animation(/images/media_img.php?m=wguvalueani.gif&w=200&h=200)
(Courtesy of Efficient Windows Collaborative)

Visible Transmittance (Tvis-glass)

$T_{vis\text{-}glass}$ indicates the percentage of the visible portion of the solar spectrum that is transmitted through a given glass product.

- Sunlight is an electromagnetic form of energy exchange between the sun and the earth. It is composed of a range of electromagnetic wavelengths, generally categorized as ultraviolet (UV), visible, and infrared (IR) referred to collectively as the solar spectrum.
- The short, UV wavelengths are largely invisible to the naked eye, but are responsible for fabric fading and skin damage. Visible light is made up of those wavelengths detectable by the human eye. This light contains about 47% of the energy in sunlight. Longer IR wavelengths are also invisible and contain about 46% of the energy in sunlight.
- For a given glazing system, the term "Coolness index (K_e)," also called Efficacy Factor, is the ratio of the $T_{vis\text{-}glass}$ to the shading coefficient (SC).

Tints (Color) and Coatings

The properties of a given glass can be altered by tinting or by applying various coatings or films to the glass.

- Glass tints are generally the result of colorants added to the glass during production. Some tints are also produced by adhering colored films to the glass following production.
- Tints are usually selected for aesthetic purposes. Some tints also help reduce solar gains.
- Coatings, usually in the form of metal oxides, can also be applied to glass during production. Some of these coatings, called "low-emissivity" or "low-e," help reduce radiant heat transfer between panes of glass by blocking some or all of the IR wavelengths. These coatings can dramatically lower the window U-factor.
- Care should be taken in specifying tints and coatings, as their application can dramatically impact window heat loss and heat gain. Mis-specification can result in the exact opposite of the desired performance.
- From a performance perspective, specifying window U-factor, SHGC and Glass Visible Transmittance ($T_{vis\text{-}glass}$) means there is no need to specify tints and coatings.

Some recommendations for specifying windows and glazings include:

There are far more glazings available for buildings today than there were even a few years ago.

- In general cases, specify low U-factors (< 0.40) for residential applications. Even lower values may be desired in extreme heating climates.
- When specifying windows performance, take care to specify "whole product performance values" for U-factor and SHGC. Use of "glass-only" U-factors should be avoided as they can be 10% to 40% better than the whole product value.
- In climates with significant air conditioning loads, specify windows with low SHGC values (< 0.40).
- In general, high (> 70%) Glass Visible Transmittance is desired, especially for daylighting applications(daylighting.php).
- For commercial buildings in conjunction with daylighting strategies, analyze the trade-offs between standard glazing and high coolness index (also called spectrally selective) glass. Spectrally selective glass has a relatively high visible transmittance and a relatively low SHGC.
- In general, low SHGC windows should be considered for east- and west-facing glazing as a means of controlling solar heat gain and increasing occupant comfort. For large commercial and industrial structures, specify low SHGC windows on the east, south, and west facades. SHGC for north-facing windows is not critical for most latitudes in the continental United States.
- For buildings where passive solar heating energy(psheating.php) is desired, south-facing windows with high SHGC values coupled with low U-factors should be specified.
- Select windows with comfort in mind. The proper specification of windows can result in higher Mean Radiant Temperature (MRT) in winter and lower MRT in summer, improving occupant comfort and productivity(/design/provide_comfort.php). MRT represents the average temperature an occupant feels from radiant heat exchange with their surroundings.

B. Representative Glass Specifications

Glass Type (Product)	Glass Thickness (Inches)	Visible Transmittance (% Daylight)	U-factor (Winter)	Solar Heat Gain Coefficient (SHGC)
Single Pane glass (standard clear)	0.25	89	1.09	0.81
Single White Laminated w/Heat Rejecting Coating (*Southwall California Series®*)	0.25	73	1.06	0.46
Double Pane Insulated Glass (standard clear)	0.25	79	0.48	0.70
Double Bronze Reflective Glass (*LOF Eclipse®*)	0.25	21	0.48	0.35
Triple Pane Insulated Glass (standard clear)	0.125	74	0.36	0.67
Pyrolitic Low-e Double Glass (*LOF Clear Low-e®*)	0.125	75	0.33	0.71
Soft-coat Low-e Double Glass w/Argon gas fill (*PPG Sungate® 100 Clear*)	0.25	73	0.26	0.57
High Efficiency Low-e (*Solarscreen 2000 VEI-2M™*)	0.25	70	0.29	0.37
Suspended Coated Film (*Heat Mirror™ 66 Clear*)	0.125	55	0.25	0.35
Suspended Coated Film w/ Argon gas fill (*Azurlite® Heat Mirror SC75*)	0.125	53	0.19	0.27
Double Suspended Coated Films w/ Krypton (*Heat Mirror™ 77 Superglass*)	0.125	55	0.10	0.34

Performance information was calculated using Lawrence Berkeley National Laboratory WINDOW 5.2 computer analysis program(http://windows.lbl.gov/software/window/window.html)
Azurlite® and Sungate® are registered trademarks of PPG Industries(http://www.ppg.com/)
Heat Mirror™ and California Series® are trademarks of Southwall Technologies(http://www.southwall.com/)
LOF Eclipse® is a registered trademark of Pilkington/Libby-Owens-Ford Co.(http://www.pilkington.com/)

Solarscreen 2000 VEI-2M™ is a registered trademark of Viracon(http://www.viracon.com/)

C. Other Attributes

Other important attributes of window and glazing systems include:

- ***Gas Fills***—Inert gases such as argon and krypton are often injected between panes of glass to reduce conductive and convective heat transfer. These low-cost, gas fills reduce U-values without affecting shading coefficients or visible transmittance.
- ***Fritting***—Baked on ceramic coatings, or frits, can be applied to the surface of glass in many different patterns, colors, and densities.
- ***Safety and Security Glass(glazingmitigation.php)***—Visit the North American Laminated Glass Information Center(http://www.glasschange.com/assn/gl000248.html). It provides information on the applications and benefits of laminated architectural glass.
- ***Retrofit Films***—For information on the pros and cons of retrofit films, visit Florida Solar Energy Center(http://www.fsec.ucf.edu/en/consumer/buildings/homes/windows/films.htm).
- ***Switchable Optics***—A new generation of dynamic glazings are available that change optical properties through changes in light, temperature, or voltage (i.e., photochromic, thermochromic, electrochromic.) Currently, these materials are economically viable for niche markets only, such as two-way mirrors.
  - For more information on switchable glazings see Pacific Energy Center Factsheet—Switchable Glazings(http://www.pge.com/includes/docs/pdfs/about/edusafety/training/pec/inforesource/switchable_glazings.pdf) (PDF 82 KB) and DOE's Windows and Glazings Research Program(http://windows.lbl.gov/). For information on the general state of fenestration research contact Lawrence Berkeley National Laboratory's Windows & Daylighting Group(http://windows.lbl.gov/).

D. Opportunities and Cautions

Some design opportunities and cautions concerning the specification and application of window and glazing systems include:

International terminal building in Istanbul's Ataturk Airport uses laminated glass for safety and security
(Courtesy of DuPont Laminated Technologies)

Opportunities

- Using high-performance windows can dramatically reduce heating and cooling loads, and eliminate the need for perimeter heating in internal-load dominated buildings due to the effect of increased Mean Radiant Temperature (MRT) on occupant comfort (see High-Performance HVAC(hvac.php)).
- Window systems with low-e and spectrally selective coatings can filter damaging UV wavelengths and increase the life of room furnishings.
- Optimized fenestration systems for passive heating(psheating.php) in residential buildings or for daylighting(daylighting.php) in commercial/industrial buildings will reduce loads and save O&M costs(/design/optimize_om.php).

Cautions

- Always specify certified, whole product energy performance values.
- All low-e coatings are not the same! If selective coatings have been identified as a strategy to increase performance, make sure the coating is fully and properly specified for your application.
- Always consider glare control, especially in commercial and industrial applications. Limiting contrast ratios and providing visual comfort in the field of view is critical, particularly in daylighting applications.
- Avoid condensation problems(moisturedynamics.php). Condensation occurs when the glass surface temperature falls below the dew point of the room air. It can damage window and wall elements and obstruct views.
- Historic buildings often require special window detailing. The desire to achieve historical accuracy can sometimes conflict with the desire to provide energy efficiency. Fortunately, several companies are now offering high-performance products that can replicate the appearance of historical windows while maintaining energy efficiency.

APPLICATION

Case Study

The State of Iowa Facilities Improvement Corporation (SIFIC) and the Mental Health Institute in Independence, Iowa joined forces to identify and implement energy management improvements. Among several strategies, the team installed more than $300,000 worth of energy-efficient windows. To date, the Institute has saved more than $100,000 annually in energy costs.

Argonne National Laboratory, Argonne, Illinois, is one of DOE's first buildings to pursue LEED certification(http://www.leedbuilding.org/) by the U.S. Green Building Council. The design includes more than 15 building materials chosen for their recycled, renewable, or lower-emitting content. In addition, several energy conservation features, such as high-performance windows selective to west and north orientations, will reduce electric consumption by 20% and natural gas by 30%, lowering the building's greenhouse gas impact by 55 tons/year. More…(http://blogs.anl.gov/greenlab/2012/03/19/argonne-facilities-achieve-green-building-designations/)

Argonne National Laboratory—Argonne, IL

RELEVANT CODES AND STANDARDS

- Energy Policy Act of 2005(/ccb/browse_doc.php?d=1361) (PDF 1.9 MB)
- Energy Star® Windows(http://www.energystar.gov/products/certified-products/detail/residential-windows-doors-and-skylights)
- *National Fenestration Rating Council (NFRC) Certified Products Directory(http://www.nfrc.org/getratings.aspx)*—Contains performance characteristics for window assemblies from most manufacturers.

ADDITIONAL RESOURCES

WBDG

Design Objectives
Aesthetics(/design/aesthetics.php), Productive(/design/productive.php), Sustainable(/design/sustainable.php)

Products and Systems
Section 07 92 00: Joint Sealants(/design/079200.php), Building Envelope Design Guide: Wall Systems(/design/env_wall.php), Exterior Insulation and Finish System (EIFS)(/design/env_wall_eifs.php), Panelized Metal Wall Systems(/design/env_wall_panelizedmetal.php), Precast Concrete Wall Systems(/design/env_wall_precast_concrete.php), Thin Stone Wall Systems(/design/env_wall_thin_stone.php), Fenestration Systems(/design/env_fenestration.php), Glazing(/design/env_fenestration_glz.php), Windows(/design/env_fenestration_win.php), Curtain Walls(/design/env_fenestration_cw.php), Sloped Glazing(/design/env_fenestration_slpglz.php), Exterior Doors(/design/env_fenestration_doors.php), Atria Systems(/design/env_atria.php)
Federal Green Construction Guide for Specifiers:

- 08 50 00 (08500) Windows(/ccb/browse_doc.php?d=8052)

Associations and Organizations

- American Architectural Manufacturers Association (AAMA)(http://www.aamanet.org/)—Trade association of firms engaged in the manufacture and sale of building fenestration components and related products.
- Efficient Windows Collaborative(http://www.efficientwindows.org/)—Provides information on the benefits of energy-efficient windows in houses throughout the US. This site is sponsored by the U.S. Department of Energy.
- Florida Solar Energy Center—Fenestration Research Group(http://www.fsec.ucf.edu/en/research/buildings/fenestration/)—This group studies the performance of fenestration systems. The main focus is on solar heat gain and its effects on energy costs for heating and cooling.
- National Fenestration Rating Council (NFRC)(http://www.nfrc.org/)—A non-profit public/private collaboration of manufacturers, builders, designers, specifiers, code officials, consumers, utilities, and regulators working towards a national energy performance rating system for fenestration products.
- National Glass Association(http://www.glass.org/)

Design and Analysis Tools

Window Properties

- Energy Star® Windows(http://www.energystar.gov/index.cfm?c=windows_doors.pr_windows)
- Usually, the physical properties of glazing systems are easily obtained from product literature and certified by the National Fenestration Rating Council (NFRC)(http://www.nfrc.org/).
- WINDOW5.2 or latest version(http://windows.lbl.gov/software/window/window.html), a federally funded computer program developed by Lawrence Berkeley National Laboratory (LBNL), calculates U-values, SHGC, and Tvis of window systems constructed from glass and frames of known properties.

Window Design Strategies

- *Residential*—To analyze the effect of different window areas and glass properties, consider:
  - Guidelines for Home Building with BuilderGuide software—This is a simple computer software tool for evaluating the solar savings fraction of a building design. Availability: Sustainable Buildings Industry Council (SBIC)(http://www.nibs.org/?page=sbic).
- *Commercial and Institutional*—To analyze the effect of different window areas and glass properties, investigate:
  - Computational Fluid Dynamics (CFD)—This advanced computer-based analysis method can help analyze the effects of complex fenestration systems on air currents and interior ventilation patterns. For more information: CFD Online(http://www.cfd-online.com/)
  - DOE-2.1—An hourly building simulation software designed to analyze, complex, multi-zone buildings. Availability: Simulation Research Group(http://gundog.lbl.gov/), Lawrence Berkeley National Laboratory.
  - PowerDOE—Similar to DOE-2 with a Window's interface. Availability: DOE2.com(http://doe2.com/)
  - Skylight Handbook—A hand calculation method for optimum skylight design developed by Lawrence Berkeley National Laboratory (LBNL). Distributed by AAMA(http://www.aamanet.org/) (Product Code SHDG-1-88).
  - VisualDOE(http://www.eere.energy.gov/buildings/tools_directory/software.cfm/ID=59/pagename_submenu=retrofit_analysis/pagename_menu=whole_building_analysis/pagename=subjects)—Similar to DOE-2 with a Window's interface. Distributed by Charles Eley Associates.

Other

- GSA Sustainable Facilities Tool (SFTool)(http://sftool.gov/)—SFTool's immersive virtual environment addresses all your sustainability planning, designing and procurement needs.

Manufacturers of Fenestration Products

- Andersen Windows Corporation(http://www.andersenwindows.com/)—Major manufacturer of windows and patio doors.
- Cardinal Glass Industries(http://www.cardinalcorp.com/)—A national supplier of glass products to window companies.
- Certainteed Corp.(http://www.certainteed.com/)—A leading manufacturer of building materials.
- Daylighting Technologies(http://www.sun-dome.com/)—Manufacturer of tubular skylights that transmit daylight into otherwise dark spaces.
- Ecker Window Corp.(http://www.eckerwindow.com/)—Manufactures and installs windows for retrofit and new construction.
- EFCO Corp.(http://www.efcocorp.com/)—A national manufacturer of commercial aluminum windows and curtain wall systems.
- Fibertec Fiberglass Windows and Doors(http://www.fibertec.com/)—A pioneer manufacturer of fiberglass windows and doors.
- JELD-WEN Windows & Doors(http://www.doors-windows.com/)—One of the largest providers of doors, windows, and wood products.
- Kalwall(http://www.kalwall.com/)—A manufacturer of fiberglass reinforced polyester glazing.
- Marvin Windows & Doors(http://www.marvin.com/)—One of the largest manufacturers of wood windows and doors.

- Pella Corp.(http://www.pella.com/)—One of the largest manufacturers of wood windows and doors.
- Simpson Door Company(http://www.simpsondoor.com/)—One of the oldest continuously operating door plants in the U.S.
- Solatube(http://www.solatube.com/)—Manufacturer of tubular skylights that transmit daylight into otherwise dark spaces.
- Southwall Technologies(http://www.southwall.com/)—Develops and manufactures high-performance, low-e window and glass products.
- Sun Pipe Company(http://www.sunpipe.com/)—Manufacturer of tubular skylights that transmit daylight into otherwise dark spaces.
- Sun-Tek Skylights(http://www.sun-tek.com/)—Manufacturer of skylights and tubular skylights.
- Sunoptics Prismatic Skylights(http://www.sunoptics.com/)—Manufacturer of skylights.
- Traco Doors & Windows(http://www.traco.com/)—An established manufacturer of custom residential and commercial windows.
- Velux(http://www.velux.com/)—Manufacturer of roof windows and skylights.
- Viracon(http://www.viracon.com/)—Commercial curtain wall and window fabricator.
- Vistawall(http://www.vistawall.com/)—A Canadian manufacturer of high performance commercial curtain-wall systems.

Publications

- *Glazing Design Handbook for Energy Efficiency* by The American Institute of Architects (AIA)(http://www.aia.org/). Washington, DC, 1997.
- *1997 ASHRAE Handbook of Fundamentals(/references/ihs_l.php?d=ashrae%20fun%20ip)* by American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE). Atlanta, GA, 1997.
- *GSA LEED® Applications Guide(/ccb/browse_doc.php?d=238)*
- *GSA LEED® Cost Study(/ccb/browse_doc.php?d=90)*
- *Residential Windows: A Guide to New Technologies and Energy Performance(http://books.wwnorton.com/books/978-0-393-73225-2/)* by John Carmody, Stephen Selkowitz, Dariush Arasteh and Lisa Heschong. New York: W. W. Norton & Company.

Others

- EREC Fact Sheet—Energy Efficient Windows(https://www.energyguide.com/info/heat-05.asp)
- Understanding Energy-Efficient Windows(http://www.finehomebuilding.com/how-to/articles/understanding-energy-efficient-windows.aspx)
