Chapter 5 Windows and Doors

Windows are a significant source of transmission heat loss in cold climates and a significant source of solar heat gain in temperate or hot climates. Windows exist to provide natural light, ventilation, and a view to the outdoors. These functions make windows a formidable energy problem. The difficulty is limiting heat loss and gain while preserving natural light and view.

Window energy conservation measures may be expensive too; retrofit or replacement window costs commonly range from $5 to $50 per square foot of window area. Any window upgrade for energy efficiency must be designed to significantly reduce thermal transmittance, reduce solar transmittance, or reduce both. Air leakage reduction is usually a secondary benefit producing only small energy savings, unless the window has large visible air leaks.

Doors generally have a thermal transmittance higher than walls, but lower than windows. Their surface area is small and replacement cost is high, so door replacement is not usually considered a cost-effective energy conservation measure. However, doors can be a significant air leakage problem due to faulty operation or poor air seals.

This chapter outlines the most important energy characteristics of windows and doors, identifies concerns unique to older windows when improving energy performance, and defines the challenging terminology associated with window ratings. Windows and doors are also referred to as *fenestration*.

For a discussion of comfort and windows, see "Fenestration" on page 61.

Window Characteristics

Windows are composed of the following parts:

- Glass Assembly — One or more glass panes with spacers and gaskets, if needed.
- Sash — Frames the glass assembly. Sashes are either movable for ventilation, or fixed.
- Frame — Surrounds the sash and is the window part attached to the building.
- Rough Opening — Structural framing around the window to which the window frame is attached.

Energy Characteristics of Typical Window Glass Options

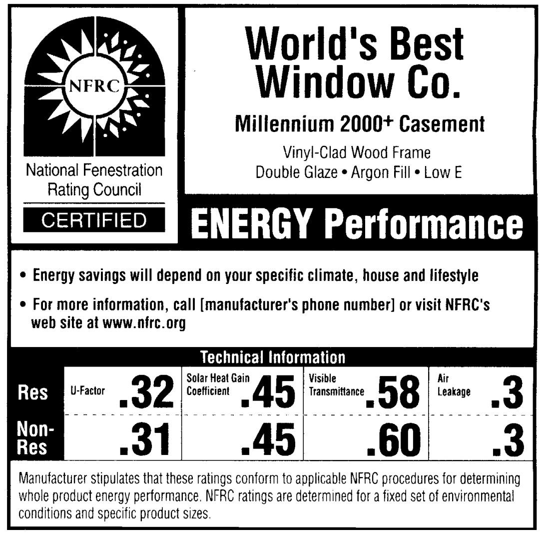
Glazing Assembly	U-factor	R-value	SHGC	VT
Single glass	1.1	0.9	0.87	0.90
Standard insulated glass	0.50	2.0	0.76	0.81
High-SHGC, low-e insulated glass	0.30	3.3	0.74	0.76
Medium-SHGC, low-e insulated glass	0.26	3.8	0.58	0.78
Low-SHGC, low-e insulated glass	0.29	3.4	0.35	0.65
Triple glazed 2 low-e insulated coatings	0.12	8.3	0.50	0.65

Understanding state-of-the-art window features is difficult because heat flow through windows is complicated, and the terminology is unnecessarily complex. Conduction, convection, and radiation are all important window heat-flow mechanisms. The high conductivity of glass is tolerated because of its other useful and unusual qualities, including the fact that glass absorbs most infrared radiation while transmitting most solar radiation.

Thermal transmittance (U-factor) and solar heat gain are the most important energy considerations for windows. The window's air leakage, optical characteristics, frame material, and type of glass assembly also enter into window selection.

Radiation, convection, and infiltration from windows reduce indoor comfort. Radiation is more complex with windows than with other building components.

NFRC Window Label



The NFRC label rates U-factor, SHGC, visible transmittance, and air leakage. Manufacturers associated with NFRC must submit their products for testing.

Window Research, Testing, and Rating

Four organizations serve as gate keepers for information about window thermal and structural characteristics. Their roles are briefly explained here to facilitate further information gathering.

National Fenestration Rating Council (NFRC): A public/private collaborative agency created to establish standardized window testing and rating. The Council simulates window performance with computers, then verifies that simulation with laboratory testing. NFRC labels are applied to windows made by member manufacturers listing thermal transmittance (U-factor), solar transmittance, visible transmittance, and air leakage. Condensation resistance is also being listed on some window models.

American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE): A professional society providing the theoretical framework for calculating heat flows through windows. ASHRAE's Handbook of the Fundamentals is the most common technical reference about window heat flows.

Lawrence Berkeley Laboratory (LBL): North America's most authoritative and prolific window research facility. LBL excels at computer simulation of window heat flows. LBL researches and develops new window technologies and distributes information about windows.

American Society for Testing and Materials (ASTM): Develops testing methodology for all types of building systems. Testing methods are specified by building codes and rating organizations like the NFRC. Windows are tested under ASTM standards for air leakage, water leakage, and structural strength.

Thermal Transmittance (U-factor)

The window industry describes and rates its products by U-factor or thermal transmittance. The U-factor includes heat transfer by conduction, convection, and radiation through the window assembly.

The U-factor is the reciprocal or inverse of R-value ($U=1/R$). U-factor is measured in units of BTUs per square foot per hour per degree Fahrenheit. As U-factor decreases, heat flow decreases. Lower U-factors are more energy-conserving than higher U-factors.

The U-factors of windows are rated using an area-weighted average of different sections of the window that have distinctly different U-factors: the frame, the edge of the glass area (a 2.5-inch band), and the central area of the glass.

Solar and Optical Characteristics

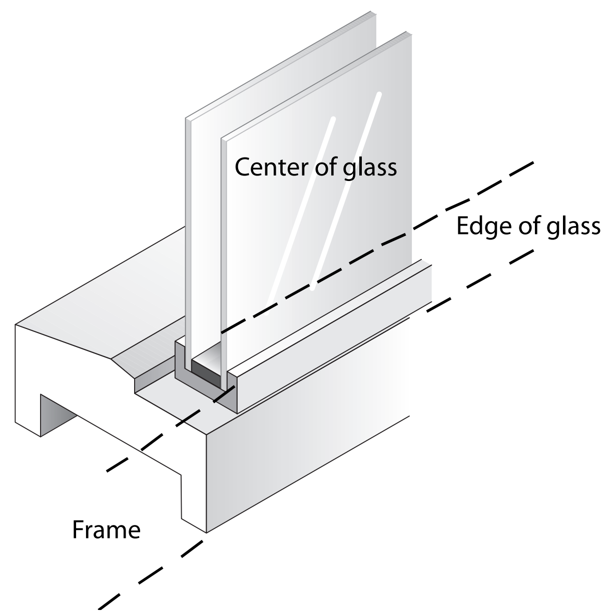
Solar heat gain shares importance with thermal transmittance as a primary window energy characteristic. Solar heat gain through windows can account for up to 40% of the total heat removed by an air conditioner. There are three common factors used to measure solar heat gain, and you are likely to encounter any of them. Each of these factors is a ratio and has no unit of measurement. Therefore, each factor may be expressed as a decimal number between 0 and 1.0 or as a percentage.

Solar Heat Gain Coefficient (SHGC): The ratio of solar heat passing through the glass to solar heat falling on the glass at a 90° angle. Includes radiant heat transmitted, and also the solar heat absorbed and re-radiated indoors. Single pane glass has a SHGC of 0.87.

Shading Coefficient (SC): Compares the solar transmittance of a glass assembly—with its interior and exterior shading devices—to that of single-pane glass, which has a shading coefficient of one. The shading coefficient is always less than one and approximately 1.15 times greater than the SHGC of the glass assembly being considered.

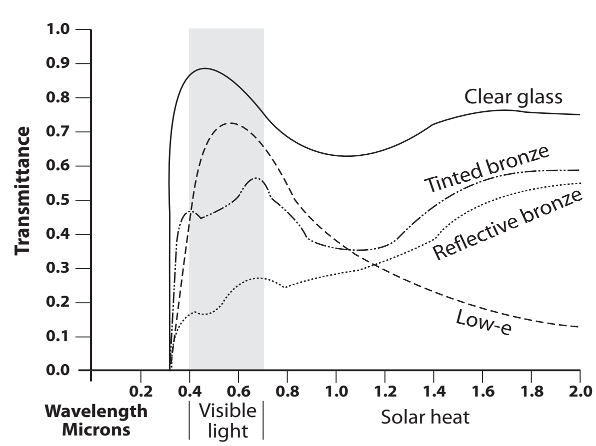
Generally, buildings in hot, sunny climates should employ window glass with SHGC of less than 0.50. South-facing windows used for passive solar heating need a SHGC of 0.70 or more.

U-Factor of Insulated Glass



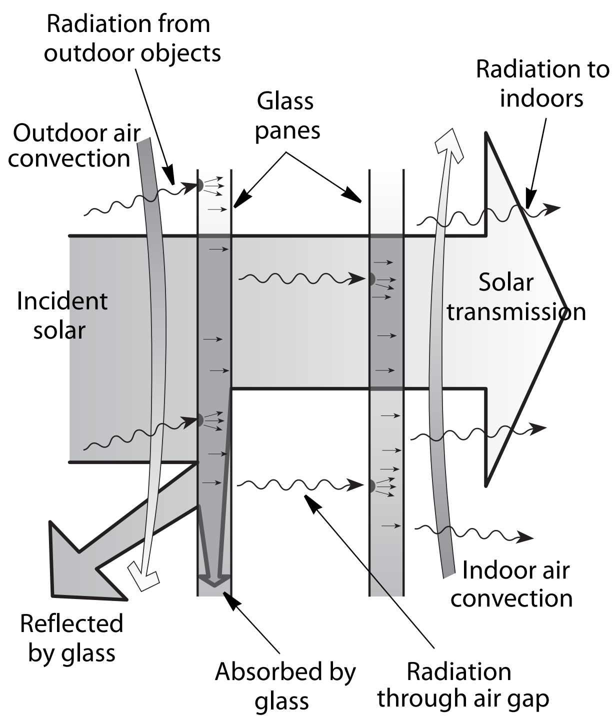
The U-factor of an insulated glass window is an area-weighted average of the window's center of glass, edge of glass, and window frame.

Transmittance Spectrum for Glass Types



Transmittance of radiant energy varies widely with the type of glass used in a window.

Heat Gain Through Insulated Glass



Most incident solar energy streams through the double-pane glass assembly, although some is absorbed and some is reflected. The glass absorbs most longer-wave infrared radiation from warm outdoor objects. Absorbed solar heat and heat from hot outdoor air conducts through the glass, then radiates across the air space and is absorbed by the second pane. Finally, radiation and convection carry that heat indoors.

Visible transmittance (VT): Measures how much visible light is admitted by the window glass. Visible transmittance is important because one of the window's main functions is to admit visible light. Reflective coatings and tints—some of which cut visible transmittance to 30%—aren't acceptable in many residential applications. A window's ultraviolet-blocking ability is important to consumers concerned about the destructive effect of ultraviolet radiation on furnishings.

Each glass type has a solar transmission chart showing the transmission percentage of solar heat and visible light. These transmission charts can be used as a guide for comparison shopping when selecting a window's optical characteristics.

See "Radiation" on page 35 for a better understanding of radiation.

Air Leakage

Window air leakage is usually a less important energy consideration than thermal transmittance during the heating season or solar heat gain during the cooling season. Exceptions to this generalization include old windows that are falling apart from neglect, or windows that are poorly installed and have significant air leakage around frame edges.

Windows and doors are less an air leakage problem than most people believe. Most existing buildings have hidden air leaks in the floor, ceiling, and wall cavities that overshadow the leaks around windows and doors. In fact, sometimes you can tightly seal all the window and door openings with duct tape and plastic without noticing a significant change in leakiness as measured by the blower door. In contrast, sealing the supply and return registers of a warm air heating system or insulating walls with dense-pack cellulose will often reduce air leakage by 15% to 30% in older homes.

Residential windows are leak-tested at a pressure roughly equaling a 25 mile-per-hour (m.p.h.) wind under controlled laboratory conditions. This test is known as ASTM E283. The test results are expressed in cubic feet per minute (CFM) of air leakage for each linear foot of crack between the sash and frame of the window. New windows vary from 0.1 CFM/linear foot (lf) to 0.5 CFM/lf. This is a very airtight range of numbers. Window air leakage is often dominated not by frame/sash cracks, but by installation flaws between the window frame and rough opening.

The NFRC air-leakage rating lists CFM-per-square-foot of window surface area. This ranges from about 1.0 all the way down to 0.06. Window air leakage varies according to the window vent's operation. Casement and awning windows have compression weatherstripping, which is more effective than the felt weatherstripping of sliding windows. Therefore, casement and awning windows have lower air leakage rates than sliding windows.

Window air leakage may help to maintain good indoor air quality in relatively airtight buildings. In fact, some manufacturers make windows with adjustable vents designed to remain permanently open.

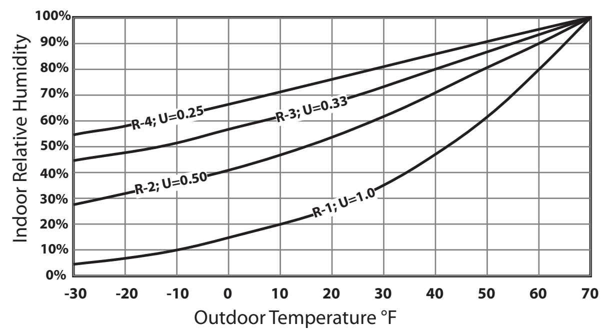
Resistance to Condensation

Water condensation on glass leads to the deterioration of the window and the opening surrounding the window. Condensation is one of the most common consumer complaints about windows. Condensation is mainly a winter problem, which gets worse as the outdoor temperature drops. The NFRC now has a window rating of condensation resistance with a scale of 1 to 100.

Mitigating condensation problems requires raising the thermal resistance of the window's interior surface or reducing the home's relative humidity, and may require both. Consumers sometimes think that condensation is leaking from the outdoors or is caused by the window's age. When the new windows they buy to fix the problem also sweat, consumers are often disappointed.

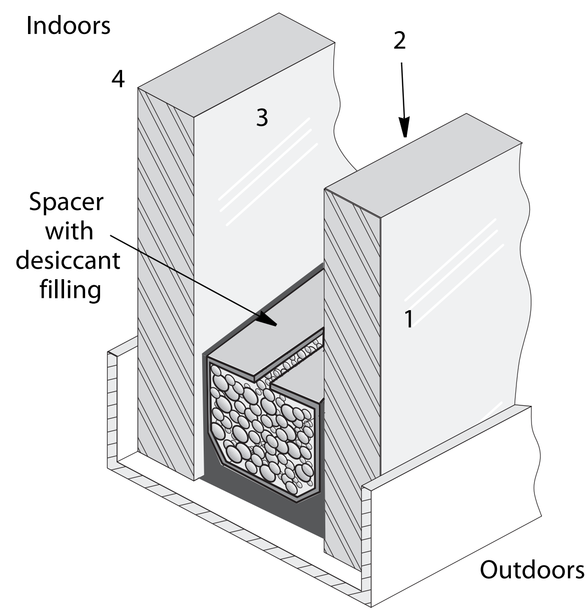
The energy specialist should know how much thermal resistance needs to increase and/or how much relative humidity needs to decrease in order to solve a window condensation problem. The chart shown here plots the outdoor temperature and relative humidity where condensation will happen for window R-values from R-1 to R-4 (U = 1.0 to 0.25).

Window Condensation Chart



The indoor relative humidity and thermal resistance of glass determines what outdoor temperature will cause condensation.

Low-e Insulated Glass Unit (IGU)



Insulated glass employs a sealed spacer between the two glass panes. A low-e coating on one pane retards emission of radiant heat from that pane. In warm climates, the coating is located on surface #2. In cold climates, the coating is located on surface #3.

Window Structure

Frame and sash materials are important for thermal performance, maintenance, and life-span. Wood frames have good thermal performance and life-span, but maintenance is an ongoing chore. Metal frames have excellent life-span and freedom from maintenance, but poor thermal performance. Vinyl frames have excellent thermal performance and freedom from maintenance. However, with the many manufacturers making vinyl windows, their formulation and resistance to heat and ultraviolet radiation differs widely.

Sash Operation and Frame Type

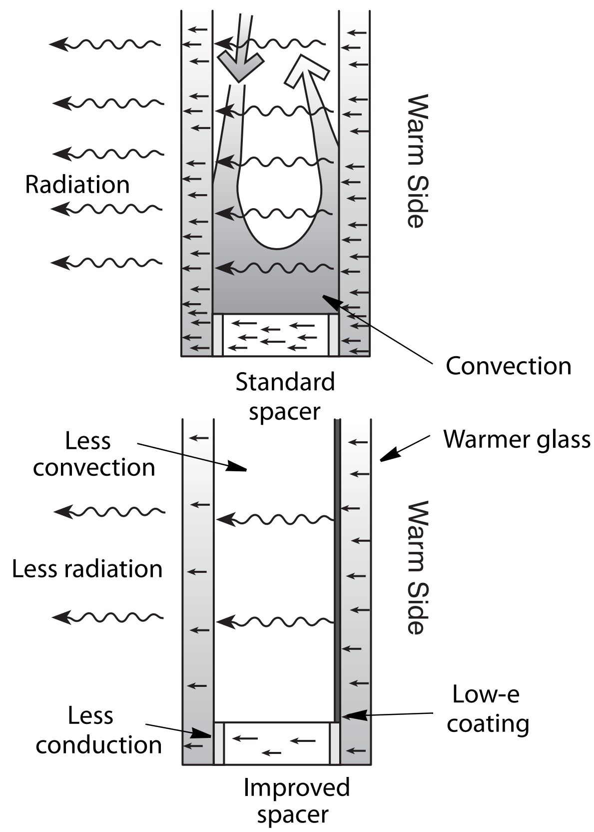
Windows have two types of sash: fixed sash and movable sash. Movable sashes either slide within their frames or open inwardly or outwardly on hinges. Vertical sliding windows include double-hung windows, where both sashes move, and single-hung, where only the bottom sash moves. Horizontal sliders usually feature only one sliding sash with one fixed sash. Sliding windows are usually less expensive than hinged windows.

Horizontally hinged windows are called hopper or awning windows. Vertically hinged windows are called casement windows. Hinged windows generally offer better ventilation and seal more tightly than sliding windows. Casement windows can be planned to project outward to catch wind, enhancing natural ventilation.

Aluminum-frame windows have been thermally improved by splitting their frames in half and then joining them back together with an insulating gasket called a thermal break. However, aluminum remains the most conductive frame and is prone to condensation problems in winter months.

Wood-frame window manufacturers have improved exterior maintenance by covering the frame's exterior with metal cladding. Metal clad wood windows are popular for custom new homes.

Standard Versus Enhanced Insulated Glass



Low-e coatings reduce radiant heat flow, increasing the temperature of the warm-side glass pane. This temperature increase reduces conduction through the glass. Improved spacers reduce conduction heat flow. Heavier gases like argon reduce convection between the glass panes.

New fiberglass-frame windows are energy efficient, strong, and low-maintenance. Fiberglass is stronger than vinyl and expands and contracts less with temperature change than aluminum or vinyl. Fiberglass comes with baked-on finishes or can be painted. Some window frames combine fiberglass with a wood interior frame. The best fiberglass windows have foam-insulated frames and sashes.

Vinyl-frame windows are the best-selling window type. Low cost and freedom from maintenance are key features accounting for vinyl windows' popularity. Vinyl windows are made by many manufacturers and vary in the quality of their vinyl formulation and assembly. Expectations of life span vary because of differences in stability and ultraviolet resistance.

Glass Characteristics and Assemblies

Energy-efficient windows use three strategies to improve the R-value of glass: multiple panes, gas fillings, and special coatings. The very best windows combine two or more of these strategies.

A wide variety of window glass assemblies is available, featuring from one to four glazing layers. Some advanced windows use flexible plastic inner glazings. The glass or plastic glazing often have a low-e coating on one side to retard the radiant heat flow. Low-e coatings are also designed to regulate solar heat gain. Low-e glass is available in high solar transmittance, medium, and low solar transmittance for use in various climates. It is now common for window customers to specify different low-e specifications for walls facing different cardinal directions.

Low-e coatings are used on only one surface of one glass pane in the standard double-pane or insulated glass window. The coating faces the air space between the panes on either the inner or the outer pane to protect the coating from damage. For heating-dominated climates, the coating is on the inner pane. In cooling-dominated climates, the coating is on the outer pane. This is because the low-e coating works best as an emittance retarder. The glass absorbs radiant heat, then the low-e coating resists the heat's reradiation.

The low-e coatings come in two varieties: soft coats and hard coats. The soft coats, made of silver, are the most effective at reflecting heat, but they are fragile and must be enclosed in a double-pane window assembly shortly after the glass is manufactured. The hard coats (of tin-oxide) reflect less heat than the soft coats. But the hard coats are more resistant to mechanical damage.

The pyrolytic, or heat-treated hard coat low-e glass is sometimes used in single-glass storm windows. The low-e surface is more difficult to clean than a standard glass surface. Therefore it's best to install the low-e surface toward a relatively airtight air space.

Gases like carbon dioxide and argon, which have a higher R-value than air, fill the space between panes in some high-tech windows. Carbon dioxide and argon weigh more than air. The greater weight of these gases reduces convection between the glass panes, compared with air.

Insulated glass manufacturers now use improved edge spacers for assembling the insulated glass units. The conventional spacers are made of aluminum, which conducts heat very rapidly. New spacers, made from dense foam plastic or plastic-steel composite materials, reduce the heat loss through the edge of the insulated glass.