Windows and doors connect the interior of a house to the outdoors, provide ventilation and daylight, and are important aesthetic elements. Windows and doors are often the architectural focal point of residential designs, yet they provide the lowest insulating value in the building envelope. Although the efficiency of windows has improved markedly, they still represent one of the major energy liabilities in new construction.

The type, size, and location of windows greatly affect heating and cooling costs. Select good quality windows, but shop wisely for the best combination of price and performance. Many house building budgets have been blown by spending thousands of additional dollars on premium windows with marginal energy savings. In general, double-paned units with low-emissivity coatings are a cost effective window choice. Well-designed homes carefully consider window location and size. In summer, unshaded windows can double the costs of keeping a house cool. Year round, poorly designed windows can cause glare, fade fabrics, and reduce comfort. Chapter 11, on passive solar design, describes how to design windows to save even more energy.
Windows lose and gain heat in the following ways:

- Conduction through the glass and frame;
- Convection across the air space in double- and triple-glazed units;
- Air leakage around the sashes and the frame; and
- Radiation through the glazing.

The goals of energy efficient windows are:

- Low U-factors;
- Moderate to high transmission rates of visible light;
- Low air leakage rates; and
- Low transmission rates of invisible radiation—ultraviolet and infrared light energy.

Few windows can meet all of these goals, but in the past several years, the window industry has unveiled an exciting array of higher efficiency products. The most notable developments include:

- Thermal breaks to reduce heat losses through highly conductive glazing systems and metal frames;
- Inert gas fills, such as argon and krypton, which help deaden the air space between layers of glazing and thus increase the insulating values of the windows;
- Tighter weatherstripping systems to lower air leakage rates; and
- Low-emissivity coatings, which hinder radiant heat flow.

**LOW-EMISSIVITY COATINGS**

Low-emissivity (low-e) coatings are primarily designed to hinder radiant heat flow through multi-glazed windows. Some surfaces, like flat black metal, used on wood stoves, have high-emissivities and radiate heat readily. However, other surfaces, such as shiny aluminum, have low-emissivities, and radiate little heat, even at elevated temperatures.

Low-e coatings are usually composed of an extremely thin layer of silver applied between two protective layers. The use of coatings is now the standard for national window manufacturers. Low-e windows (see Figures 6-1 and 6-2) also:

- Screen ultraviolet radiation, which reduces fabric fading; and
- Increase the surface temperature of the inside of the surface glass, which makes us feel warmer because we radiate less heat.
Chapter 6: Windows and Doors

Figure 6 – 1 Winter Heat Loss in a Double-Glazed Window

Figure 6 – 2 Summer Heat Gain in a Double-Glazed Window
**INERT GAS FILLS**

Inert gas fills enhance the performance of double pane windows by reducing conductive heat loss. The inert gas is heavier than air and circulates less, thereby reducing the convection currents between the window panes. Inert gas is also a better insulator than air. ENERGY STAR® rated windows, which can be used in any climate zone, are filled with an inert gas.

**SOLAR HEAT GAIN COEFFICIENT**

In climate zones of the country where cooling is the major energy use, it is important that the windows reduce the solar heat gain. The Solar Heat Gain Coefficient (SHGC) is the fraction of incident solar radiation admitted through a window. SHGC is expressed as a number between 0 and 1. The lower a window’s solar heat gain coefficient, the less solar heat it transmits. All climate zones of the country benefit from reduced solar heat gain on the east and west facing windows because the heat gain for heating reduces the heating energy requirement less than the cooling energy requirement. There is a tradeoff between solar heat gain and visible light transmission (an optical property that indicates the amount of visible light transmitted). There is also a tradeoff between the solar heat gain coefficient and the amount of passive solar heating of the house. The overall energy benefits favor windows with a lower solar heat gain coefficient for houses in Climate Zone 4.

The more layers of glass, coatings, or tints that a window has, the more sunlight it impedes and hence, the lower the SHGC. Typical values are shown in Table 6-1.

<table>
<thead>
<tr>
<th>Table 6-1  Typical Window Treatment Solar Heat Gain Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Treatment</strong></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Double-paned window</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Low-e window</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Venetian blinds</td>
</tr>
<tr>
<td>White roller blinds</td>
</tr>
<tr>
<td>Light, airy drapes</td>
</tr>
<tr>
<td>Heavy drapes</td>
</tr>
<tr>
<td>Shade screen, louvered sun screen</td>
</tr>
</tbody>
</table>

*Fraction of sunlight that passes through the glass and window treatment. Assumes that sunlight strikes perpendicular to glass.
Homes with low-e windows usually already have low SHGC. Most low-e windows have SHGC values less than 0.40. If SHGC values higher than 0.40 are desirable for certain windows, some low-e models have SHGC over 0.50. The most common application for high-SHGC windows would be on the southern exposure of passive solar homes, as described in Chapter 11.

**MULTIPLE PANES**

To further reduce the U-factor of windows, some manufacturers have introduced triple pane windows. The middle pane will typically be some type of clear plastic rather than glass to reduce weight. These windows have an additional space that enhances the window’s U-factor. Careful consideration of these windows must be done for use in Climate Zone 4.

**WINDOW RECOMMENDATIONS FOR CLIMATE ZONE 4**

**U-Factor**

U-factor is the rate at which a window, door, or skylight conducts non-solar heat flow. It is usually expressed in units of Btu/hr-ft²°F. U-factor ratings represent the entire window performance, including frame and spacer material. A lower U-factor means that the windows, doors, or skylights are more energy efficient, Figure 6-3.

Recommendation: The code minimum for windows is a U-factor of 0.40. High performance homes should have a window U-factor of 0.35 or less.

**Solar Heat Gain Coefficient (SHGC)**

The SHGC is the fraction of solar radiation admitted through a window, door, or skylight—either transmitted directly and/or absorbed, and subsequently released as heat inside a home. The lower the SHGC, the less solar heat it transmits and the greater its shading ability. A product with a high SHGC rating is more effective at collecting solar heat gain during the winter. A product with a low SHGC rating is more effective at reducing cooling loads during the summer by blocking heat gained from the sun (see Figure 6-4).
Recommendation: There is no code requirement for SHGC for Climate Zone 4; however, high performance homes should consider SHGC values of 0.40 or less. While windows with lower SHGC values reduce summer cooling and overheating, they also reduce winter solar heat gain.

Visible Transmittance (VT)

Visible transmittance (VT) is a fraction of the visible spectrum of sunlight (380 to 720 nanometers), weighted by the sensitivity of the human eye, that is transmitted through a window’s, door’s or skylight’s glass. A product with a higher VT transmits more visible light. The VT you need for a window, door, or skylight should be determined by your home’s daylighting requirements and/or whether you need to reduce interior glare in a space (Figure 6-5).

Recommendation: A window with VT glass above 0.70 (for the glass only) is desirable to maximize daylight and view. This translates into a VT window above 0.50 (for the total window including a wood or vinyl frame).

Air Leakage (AL)

Air leakage is the rate of air infiltration around a window, door, or skylight in the presence of a specific pressure difference across it. It is expressed in units of cubic feet per minute per square foot of frame area (cfm/ft²). A product with a low air leakage rating is tighter than one with a high air leakage rating (see Figure 6-6). While many think that AL is extremely important, it is not as important as U-factor and SHGC for common high performance windows.

Recommendation: The code requires an AL of 0.30 or below (cfm per square foot).
THE PROBLEM OF REPORTING WINDOW INSULATING VALUES

Window insulating values are typically reported in U-factors. This is a weighted average that includes the frame materials. Single-glazed windows generally have U-factors of 1.0. Double-glazed products have U-factors of about 0.50. Double-glazed, low-emissivity windows have U-factors of 0.40 or less.

The National Fenestration Rating Council (NFRC) offers a voluntary testing program for window and door products. The NFRC reports average whole window U-factors. Windows listed by the NFRC include a label showing test data and other information.

Occasionally, window U-factor is reported as the efficiency of the center of the glass alone. However, windows are made of more than just glass (Figure 6-7). They have a frame or sash, spacer strips, typically made of aluminum which hold the sections of glass in a double-glazed window apart, and a jamb. The claimed U-factor should reflect the overall insulating value of all of the components. New procedures coordinated by the NFRC encourage window manufacturers to report window U-factors consistently and accurately.

Figure 6 – 7  Window Anatomy
NFRC labels (Figure 6-8) provide:

- U-Factor—conductive heat loss of the assembly
- Solar Heat Gain Coefficient (SHGC)—the fraction of sunlight transmitted through the window;
- Visible Transmittance (VT)—the fraction of visible light that is transmitted; and
- Air Leakage (AL)—expressed as cfm per square foot.

When shopping for windows, find out the total U-factor, not just that for the glass. The best approach is to use the NFRC label as the objective source of information. The NFRC website lists the values of products that are NFRC certified.

*Image courtesy of NFRC
BENEFITS OF ENERGY STAR® RATED WINDOWS

National window manufacturers have begun to market windows that can be used in any Climate Zone. As a result, these windows have a U-factor of 0.35 or less in order to meet the requirements of climate zones with predominately heating loads and a solar heat gain coefficient of 0.40 or less to meet the requirements of climate zones with predominately cooling loads. These characteristics are achieved with a combination of low-e coating, inert gas fill, and coatings to reduce solar heat gain.

Table 6-2 shows the economic benefits of different types of windows compared to the minimum window requirement for Climate Zone 4, U-factor = 0.48. Some of the additional investment in higher performance windows can be offset by the reduced size of the heating and cooling system required for the home.

<table>
<thead>
<tr>
<th>Type of Window</th>
<th>Energy Savings* ($/yr)</th>
<th>Break-even Investment‡ ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U – 0.40, SHGC– 0.50</td>
<td>18</td>
<td>204</td>
</tr>
<tr>
<td>U – 0.35, SHGC– 0.40</td>
<td>52</td>
<td>591</td>
</tr>
</tbody>
</table>

*Savings are for a two-story home with 254 sq ft of windows and 2 exterior doors, located in Lexington, KY, with approximately 17 - 3x5 windows.

‡See Chapter 2 for information on break-even investment.

In addition to the economic benefit, high performance windows also improve the comfort of a home by increasing the inside surface temperature of the glass, Figure 6-9. The increased surface temperature lowers the radiant heat loss from the skin, making the room with the high performance windows feel more comfortable.
PROPER WINDOW INSTALLATION

Step 1: Make sure that the window fits in rough opening and that the sill is level.

Step 2: Install window level and plumb according to the manufacturer’s instructions.

Step 3: Use non-expanding foam sealant to seal between the jamb and the rough opening, or stuff the gap with a backer rod or insulation and cover the insulation with caulk. Remember that most fibrous insulation does not stop air leaks—it just serves as a filter.

Step 4: If using a housewrap air barrier, slide the top window flashing under the barrier and seal the barrier to the window jamb with long-life window flashing tape or other appropriate, durable sealant.

Step 5: After interior and exterior trim is installed, seal the gap between the trim and the interior or exterior finish with long-life caulk.

FUTURE WINDOW OPTIONS

ELECTROCHROMIC WINDOWS

A new genre of windows is composed of special materials that have coatings, which can darken the glazing by running electricity through the unit. Some manufacturers already have prototypes of these high technology windows in operation. At night and on sunny, summer days, an electric switch can be turned on to render the windows virtually opaque.

SOLID WINDOWS

Another new window technology uses gel-type material (aerogel), up to one inch thick, between layers of glazing. The window offers increased insulating value, but at present, this feature is not completely transparent and is extremely expensive.

WINDOWS AND NATURAL VENTILATION

A primary purpose of windows is to provide ventilation. With Kentucky’s mild climate, natural ventilation can maintain comfort for much of the spring and fall. In the mountains, natural ventilation can provide sufficient cooling for summer as well. The size and placement of the window openings affect ventilation. Casement windows open fully for ventilation, while only half of the entire area of double-hung and slider windows can open. Casement windows can also help channel breezes into the home. The optimum placement of windows for ventilation would be on each side of the house to take advantage of breezes from any direction. However, the ventilation benefits of east and west windows are overshadowed by the problems they pose by allowing summer sunlight into the home. In general, it is best to avoid east and west windows. Place the major glass areas on the south and a moderate number of windows on the north for cross ventilation.

Each room should have a window to allow air to enter (ideally located on the south or north wall) and a separate opening to enable air to exit. The outlet may be a doorway leading into another area of the home. The inlet and outlet should be located so that they create breezes in the areas most frequently occupied.
In addition to providing for cross ventilation, windows can be used to create ventilation between low and high areas. For example, in a two-story house, as air inside warms, it rises and exits through upper level windows. As the air rises, it draws outside air into the house, through the lower windows. This process is known as the stack effect. However, the force of the rising air is weak, so it is not practical to provide special design features in a house to encourage this type of ventilation. In fact, natural ventilation of any type is unpredictable. While having some operable windows is desirable, it is not usually worthwhile to increase construction costs solely to increase the window area for ventilation.

WINDOWS AND SHADING

In some cases, windows in Kentucky require additional shading; options include:

- Overhangs
- Exterior shades and shutters
- Interior shades and shutters
- Landscaping and trees

The effectiveness of different window shading options depends on the composition of the incoming sunlight. Sunlight reaches the home in three forms: direct, diffuse, and ground reflected. On a clear day, most sunlight is direct, traveling as a beam without obstruction from the sun to a home’s windows. In winter, most of the direct sunlight striking a window is transmitted through the glass; however, in summer, the sun strikes south windows at a much steeper angle, and much of the direct sunlight is reflected. The majority of the sunlight entering south-facing windows in the summer is either diffuse—bounced between the particles in the sky until it arrives as a bright haze—or is reflected off the ground.

In developing a strategy for effectively shading windows, all three forms of sunlight must be considered. Overhangs, long thought to be very effective for shading south-facing windows, are best at blocking direct sunlight and are therefore only a partial solution.

OVERHANGS

Overhangs shade direct sunlight on windows facing within 30 degrees of south. Overhangs on east and west windows are ineffective unless they are as long as the window is high. Overhangs above south-facing windows should provide complete shade for the glazing in midsummer—around July 21—yet still allow access to winter sunlight (see Table 6-3). For a standard 8-foot wall with windows, the overhang should be 2 feet in length. Make certain that there is a gap between the bottom of the overhang and the top of the glazing to prevent shading the upper portion of the glass in winter. Figure 6-10 illustrates a method for sizing overhangs above south-facing windows. Retractable awnings allow full winter sunlight, yet provide effective summer shading. Retractable awnings should have open sides or vents to prevent accumulation of hot air underneath. Awnings may be more expensive than other shading options, but they serve as an attractive design feature.
GUIDELINES FOR OVERHANGS

Size south overhangs using the diagram and these rules:

1. Draw to scale the wall to be shaded by the overhang.
2. Draw the summer sun angle upward from the bottom of the glazing.
3. Draw the overhang until it intersects the summer sun angle line.
4. Draw the line at the winter sun angle from the bottom edge of the overhang to the wall.
5. Use a solid wall above the line where winter sun hits. The portion of the wall below that line should be glazed.
EXTERIOR SHADES AND SHUTTERS

Exterior window shading treatments are effective cooling measures because they block both direct and indirect sunlight before it enters windows. Solar shade screens have a thick weave that blocks up to 70% of all incoming sunlight before it enters the windows. The screens absorb sunlight so they should be used on the outside of the windows. From the outside, they look slightly darker than regular screening, and provide greater privacy. From the inside, many people do not detect a difference. They also serve as insect screening and come in several colors. The screens should be removed in winter to allow full sunlight through the windows. Thin, louvered metal screens are a more expensive alternative to the fiberglass product.

INTERIOR SHADES AND SHUTTERS

Shutters and shades located inside the house include curtains, roll-down shades, and Venetian blinds. More sophisticated devices are also available, such as shutters that slide over the windows on a track and interior movable insulation.

Interior shutters and shades are generally the least effective shading measures because they try to block sunlight that has already entered the room. However, if east-, south-, or west-facing windows do not have exterior shading, interior measures are needed. The most effective interior treatments are solid shades with a reflective surface facing outside. In fact, simple white roller blinds keep the house cooler than more expensive louvered blinds. Louvered blinds do not provide a solid surface and allow trapped heat to migrate between the blinds into the house.

LANDSCAPING AND TREES

Kentucky’s abundant trees are wonderful for natural shading, but they must be located appropriately to provide shade in summer and not block the winter sun coming from the south. Even deciduous trees that lose their leaves during cold weather block some winter sunlight—a few bare trees can block over 50 percent of the available solar energy. Some guidelines for energy efficient landscaping are given in Chapter 1, Figure 1-1.

DOORS

Exterior wood doors have low insulating values, typically R-2.2. Storm doors increase the R-value only to about R-3.0 and are not good energy investments. The best energy-conserving alternative is a metal or fiberglass insulated door. Metal doors have a foam insulation core, which can increase the insulating value to above R-5. They usually cost no more than conventional exterior doors and come in decorative styles, complete with raised panels and insulated window panes. Insulated metal or fiberglass doors usually have excellent weatherstripping and long lifetimes. They will not warp; they offer increased security. As with windows, it is important to seal the rough openings. Thresholds should seal tightly against the bottom of the door and must be caulked underneath. After the door is installed, check it carefully, when closed, to see if there are any air leaks.
ACCESSIBLE DESIGN

Almost one out of ten people will suffer from physical disabilities during their lifetime. Designing homes to ensure accessibility for the physically impaired adds little to the cost of a home. One important feature is to ensure that both exterior and interior door openings are 3'-0" wide to allow passage of a wheelchair or walker. Ensuring that baths and kitchens have adequate room for wheelchairs is another feature that adds little to construction costs but is expensive to retrofit.