Builder's Guide to Windows

New efficient glazings can cut energy costs and improve comfort, but you have to choose the right units for your climate

by Steve Easley

There are more than 100 million homes and approximately 20 billion square feet of clear-glass residential windows in the U.S. Most of those homes are more than 30 years old, and as a result, the market is growing for replacement windows with energy-efficient insulating glass. High-performance options are now readily available in all regions of the country. Windows with U-factors and solar heat-gain coefficients less than 0.3 are now standard. And the cost of upgrading from conventional double-pane windows to double-pane low-E units with argon gas is less than $1 per square foot. Heating and cooling energy savings of 10 percent to 20 percent or more are possible, depending on the climate region and the replacement-window choice. Similar savings can be achieved in new construction by upgrading to high-performance glazing. Compared with clear glass, almost all of these new products reduce ultraviolet (UV) radiation and cut fading damage due to UV by 50 percent or more.

A Profusion of Choices

Since there are hundreds of window manufacturers, each with many different

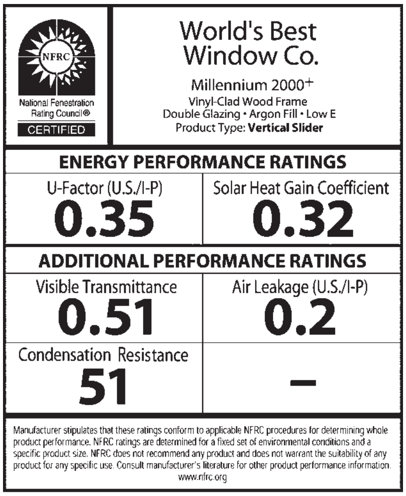


Figure 1. The NFRC label makes it easy to assess a window's energy performance. Which U-factor and solar heat-gain coefficient (SHGC) are optimal depends on climate. Optional ratings for air leakage (AL) and condensation resistance (CR) are included on this sample rating. AL indicates how many cubic feet of air leak through a square foot of window area, and generally ranges from 0.1 to 0.3. CR, which uses a scale of 1 to 100, indicates how well a window resists forming condensation on the inside of the glass. Higher numbers indicate better resistance.

product offerings, it's easy to get confused trying to sort through the trade names and marketing hype. Window options used to be limited to single-pane versus double-pane and wood frame versus aluminum frame. Today, there are three or four basic frame types, double- and triple-pane glass, and warm-edge insulating glass spacers. The low-E coatings used on most windows can be formulated for low, medium, or high solar gain. The terminology alone is enough to make your head spin, and most of this technology is hidden inside the window so it can't readily be seen.

To make matters even more challenging, consumers have grown to expect high performance from their windows even when they don't understand the technologies involved. I once received a call from a homeowner who had bought tinted windows. A few sunny days after the installation, she wanted the windows removed because she didn't feel they were doing anything to reduce heat gain, as the salesperson had so zealously promised. After a few questions, I discovered that she had a 10-foot-wide covered porch wrapping all the way around her house. She was right: Her windows never received direct sunlight, so there was no way a tinted window was going to affect her energy costs. She had been sold the wrong product.

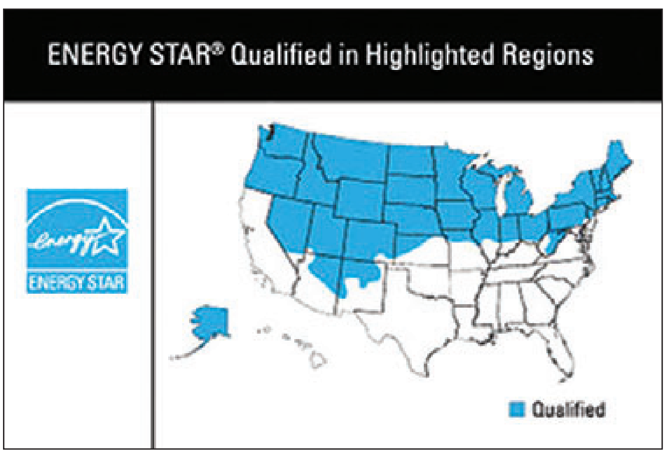


Figure 2. The Energy Star label uses color shading to show the climate zones where a particular window or skylight will perform well.

Better Labeling

Thanks to the efforts of the National Fenestration Rating Council, most building codes now require windows to be labeled. (The NFRC is a collaborative effort between manufacturers, the Department of Energy, utility companies, and others.) The NFRC label gives you specific information about the whole window performance, not just the glass or components (**see Figure 1**). For instance, a single pane of clear glass transmits about 90 percent of the visible light striking it, giving it a visible transmittance rating of 0.90. For the whole window, including sash and frame, however, that number drops to about 0.60 or less, depending on the specific window. (See below for a more complete explanation of visible transmittance ratings.)

U-factor measures how well a product prevents heat transfer; the lower the U-factor, the greater a window's resistance to heat flow and the better its insulating value. The U-factor is the inverse of the more common R-value measurement. For example, a window with a U-factor of 0.25 has an R-value of 4 (1/.25 = 4).

Solar heat-gain coefficient (SHGC) measures how well a window blocks heat from incoming sunlight. The number, from 0 to 1, is the fraction of incident solar radiation admitted through a window. The lower a window's SHGC, the less solar heat it transmits into the house.

Visible transmittance (VT) measures how much light comes through a window. It too is expressed as a number between 0 and 1. The higher the number, the more visible light gets through the window.

Air leakage (AL) is a measure of infiltration through cracks in the window assembly. The rating is expressed as the equivalent cubic feet of air passing through a square foot of window area. The lower the AL, the less air will pass through.

Matching Windows to Climate

	Windows		Skylights	
Climate Zone	Maximum U-Factor	Maximum SHGC	Maximum U-Factor	Maximum SHGC
Northern	0.30*	Any	0.55	Any
North Central	0.32	0.40	0.55	0.40
South Central	0.35	0.30	0.57	0.30
Southern	0.60	0.27	0.70	0.30

*up to 0.31 if SHGC ≥ 0.35; up to 0.32 if SHGC ≥ 0.40
Source: Energy Star Requirements for Residential Windows Version 5.0

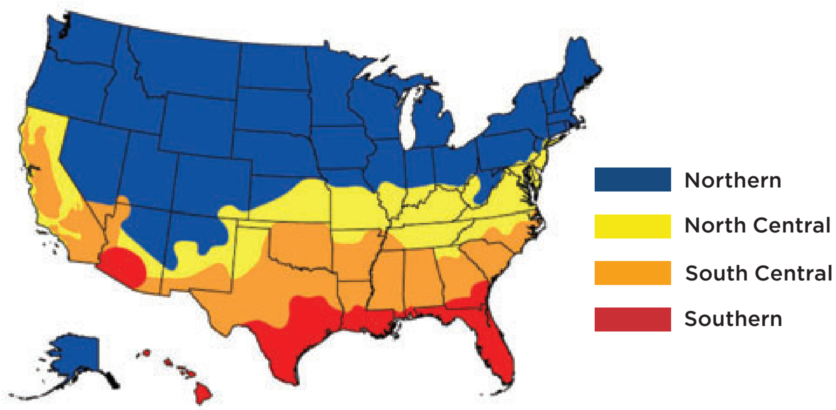


Figure 3. Builders can turn to the Energy Star program for help selecting the best windows for their climate. In northern regions, windows must be good at keeping in wintertime heat; in the south, they should be able keep heat out in the summer. Windows installed in the middle of the country must balance summer and winter performance. Note that all values in the table are based on NFRC whole-window ratings.

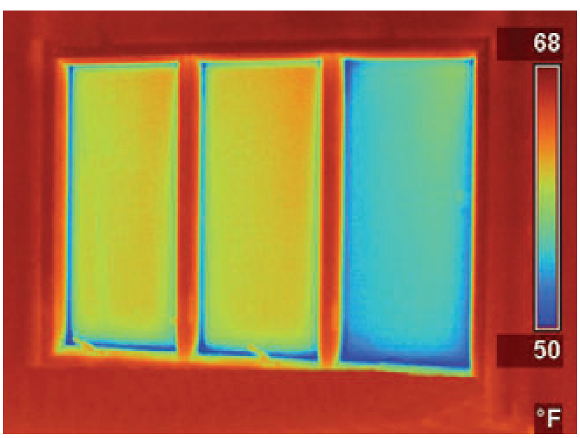


Figure 4. The inside surface of the low-E windows (left and center panes) are much warmer than that of the clear double-pane (right pane). If this window had three bays of clear double-pane glass, the room's heating thermostat would have to be 2°F to 3°F warmer to provide the same level of comfort achieved with low-E glass.

Condensation resistance (CR) measures the ability of a window to resist the formation of condensation on the interior surface during cold weather. CR is expressed as a number between 0 and 100. A higher rating indicates that the product is better at resisting condensation formation.

Matching Windows to Climate

A companion to the NFRC label is the Energy Star label (**Figure 2, page 2**), which makes it easy to tell whether a given window is right for your climate. The Energy Star rating is based on minimum Department of Energy performance specifications by region. In the absence of an Energy Star label, follow the Energy Star guidelines in **Figure 3**. The program groups window requirements according to four climate regions.

The Importance of Low-E

Of the many window technologies developed in recent years, none has had as great an effect on window energy performance as low-E (low-emittance) coatings. This microscopically thin, transparent metal layer is applied to one of the glass surfaces in the sealed space of the insulating glass unit (IGU). In an ordinary IGU (no coating), about two-thirds of the heat transfer across the gap happens via thermal radiation. Low-E coatings block most of this heat loss; double-pane glass with low-E insulates as well as uncoated triple- or quad-pane glass. This allows window manufacturers to offer high-performance windows using proven double-glazed window designs — particularly important for operable windows. All of the U-factors listed in the Energy Star criteria can be met using double glazing with low-E.

When the heat loss is reduced, the room-side glass surface temperature is warmer during cold weather. The infrared photograph in **Figure 4** provides a visual

How Spectrally Selective Low-E Works

Low-E Type (double-pane glass)	Visible Transmittance (center-of-glass VT)	Window Properties (typical)		
		U-Factor	SHGC	VT
None (clear glass)	81%	0.55	0.60	0.60
High solar gain	75%	0.33	0.52	0.56
Medium solar gain	70%	0.32	0.32	0.53
Low solar gain	66%	0.31	0.22	0.50

Window U-factor, SHGC, and VT are based on NFRC whole-window ratings, including sash and frame.

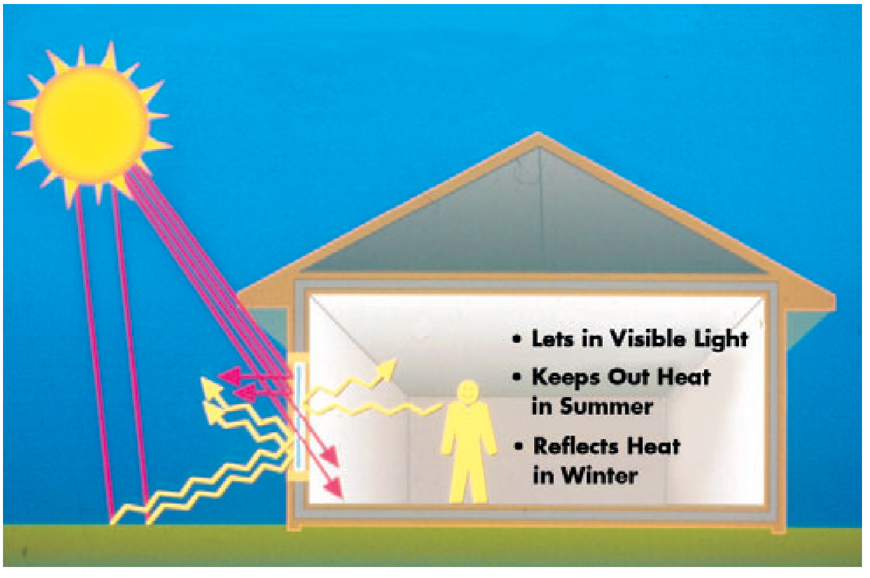


Figure 5. Spectrally selective low-E coatings do a good job of preventing winter heat loss and reducing summer heat gain while still allowing most of the visible light to enter the space (as indicated by high center-of-glass VT ratings). The chart compares the performance of standard clear glass with that of three types of low-E. Note the performance options available with advanced low-E. Going from high to low solar gain cuts the SHGC by nearly two-thirds with only a modest loss of visible light.

representation of comfort levels on a cold winter night with three different windows installed side by side; two have low-E coatings. A warmer surface on the inside of the glass also means less potential for condensation.

Spectrally Selective Low-E

Roughly half the energy in sunlight is invisible to the human eye. Low-E coating manufacturers have learned how to design coatings that let most of the visible light pass through, with little tint or coloration, while either transmitting or blocking most of the solar heat. The different glass designs can be grouped into generic categories of high, medium, and low solar-heat gain.

Spectrally selective low-E coatings do a good job of preventing winter heat loss and reducing summer heat gain while still allowing most of the visible light to enter the space (**Figure 5**).

Other Glass Technologies

Manufacturers have developed a number of technologies to improve window thermal performance in all climates. Some, like warm-edge spacers and gas fills, are widely used across the country. Others, such as tints and films, are used only for special applications.

Warm-edge IG spacer systems. The aluminum spacer bars traditionally used to separate the two panes in double glazing created a thermal short-circuit around the edge of the glass. Despite the warm center-of-glass temperatures achieved with low-E glass, the bottom edge of the glass was cold and had frequent condensation (**Figure 6, next page**). Today more than 90 percent of the residential windows sold use some form of "warm-edge" system. Instead of aluminum, the new designs use low-conductance metals (like stainless steel), foam, or plastic for the spacers. The thermal-performance improvement from warm-edge technology is reflected in the total window U-factor rating found on the NFRC label. However, be sure to pay attention to window durability, too. Compare manufacturers' warranty provisions — the best performer may lack long-term warranty support because of uncertainty about the staying power of new materials and technologies.

Gas fills. Many manufacturers put low-conductance gases, such as argon or krypton, between the glazing layers to enhance the performance gains from low-E. Without low-E, the gas will have little effect. And even with the coating, the window U-factor will typically improve by less than 10 percent. Again, it's important to read the manufacturer's warranty to understand its provisions regarding gas retention.

Triple- and quad-pane glazing. Double-pane glass is optimized with a low-E coating and gas fill. To provide even better insulating values, some new window designs are incorporating triple- and quad-pane systems with multiple low-E coatings (one coating in each air space). Concerns about weight and thickness have some manufacturers replacing the internal layers with plastic or suspended films. Many remain skeptical of the durability of plastics encapsulated in the gap and exposed to sun and thermal cycles. Some newer window designs use thicker sash to accommodate all-glass triple or quad units. Refer to installation instructions to ensure that these products are compatible with your wall system.

Tinted glass. Tinted glass is sometimes used to reduce heat gain in hot climates. However, tinted glass gets hot in sunlight (from absorption) and suffers more loss of light transmission than spectrally selective low-E coatings. Although there are some spectral tinted glasses available today — usually light blue or green in color — residential windows tend to avoid tints, given the market preference for clear glazings. Also, these tints don't improve the U-factor, so a low-E coating is still required to meet code and Energy Star standards.

Aftermarket applied films. Tint films are often retrofitted onto windows in rooms that overheat due to direct sunlight. While they can effectively address overheating, the films can be problematic because the low visible-light transmission can excessively darken interiors. There can also be problems with film adhesion, and some window manufacturers will void their warranty if tint films have been applied. When buying new or replacement windows, look for products with a low SHGC, indicating that solar control is already built into the window.

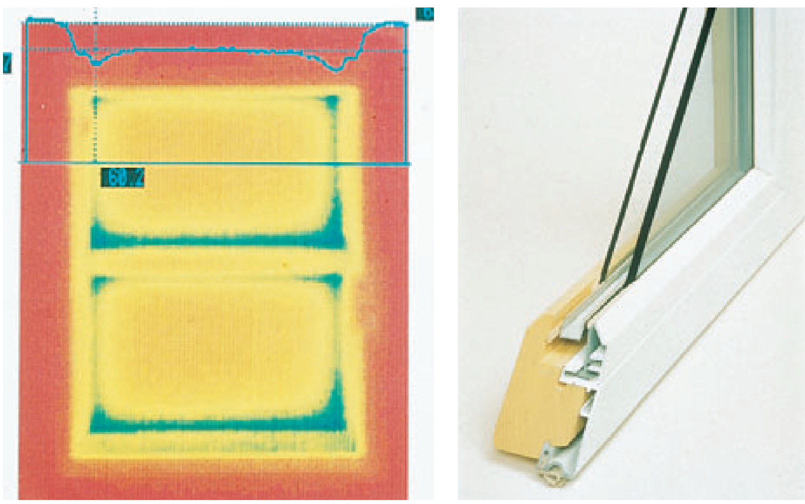


Figure 6. Conductive heat loss around the perimeter of insulated glass units (dark areas in the thermographic image, left) caused by metal edge spacers has led to recent innovations in "warm-edge" nonmetal spacers, such as the PPG Intercept (right).

Reducing Fading With Low-E

Glass Type	Tdw-ISO
Clear	0.74
High solar gain low-E	0.66
Medium solar gain low-E	0.55
Low solar gain low-E	0.43

Figure 7. Although blocking UV light is important for preventing fading, some damage is also caused by portions of the visible light spectrum. To determine the actual fading potential of light passing through a glazing system, use the total damage weighted (Tdw) values. The lower the Tdw, the less fading will occur.

Reducing Fading With Low-E

The spectral selectivity of low-E coatings allows them to block significant amounts of UV light. Research into the fading of fabrics, artwork, finishes, and home furnishings has shown that the radiant energy that affects fading includes portions of the visible light spectrum in addition to UV. The International Organization for Standardization (ISO) has proposed a damage-weighted scale called Tdw-ISO that accounts for the effects of both UV and visible light. The ratings for low-E glass (**Figure 7**) suggest that low-solar-gain low-E glass with a rating of 0.43 would reduce the rate of fading by over 40 percent compared with clear glass rated at 0.74.

It's not appropriate to claim that a glass type can "eliminate" fading altogether. If light passes through, there will always be a risk of fading. Also, the rate of fading will vary with the type of material and the exposure levels. Keeping a sensitive material out of direct sunlight is always a good idea.

Comfort Is the Issue

A study commissioned by Pacific Gas and Electric several years ago discovered that the No. 1 reason customers make energy-efficiency improvements to their homes is to increase comfort. Windows have a huge impact on comfort. When it's 40˚F outside, the inside surface temperature of a single-pane window can be 20˚F colder than room temperature. Since our bodies radiate heat to colder surfaces, a room full of poorly insulating windows can make us feel uncomfortable (by radiant cooling) even if the home is well-insulated. High-performance technologies can make windows feel warmer during cold weather by keeping the temperature of the interior glass surface higher (**Figure 8**).

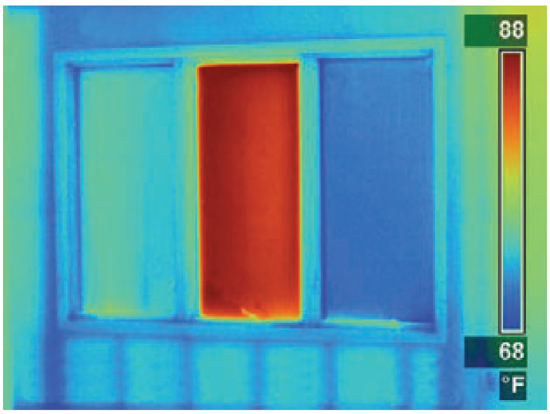


Figure 8. This infrared photo was taken on a cool (30°F) winter day. Notice how hot the high-solar-gain glass (at center) is relative to the other windows.

While winter performance is important, the right window can also have a big impact on comfort in the summer — and on air-conditioning costs. Since more than 40 percent of existing homes and 80 percent to 90 percent of new homes have air conditioning, it makes sense to pay close attention to a window's solar heat-gain properties as well (**see table below**).

In warm weather, clear glass and high-solar-gain low-E will increase cooling loads and air-conditioner size. In cold climates, solar gain can be used to offset heat losses, but this requires a system design approach. Windows should face south for best winter sun exposure, and overhangs should be designed to shade the glass in the spring and fall. If large amounts of south-facing glass are used, the building should be designed by an experienced solar designer, and it may need thermal mass to absorb solar gains, and a circulation system to distribute the stored gains. Even with all of that, many passive-solar buildings experience daily temperature swings that don't meet the comfort expectations of many homeowners.

Striking the right balance. Choosing

Glass Surface Temperature

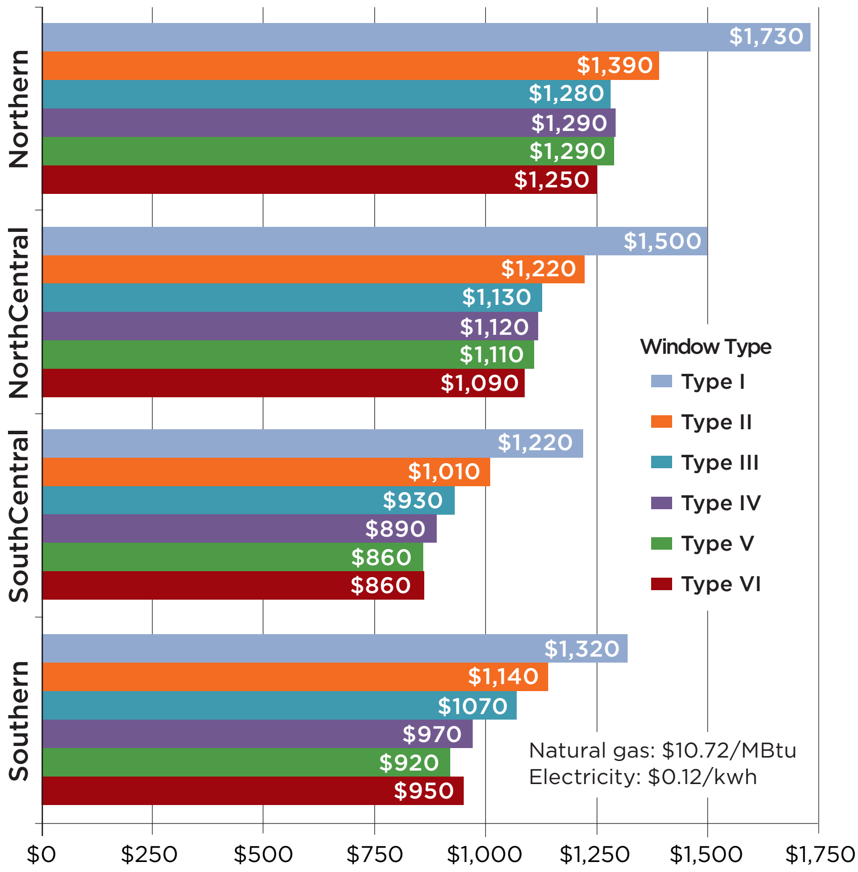
		Interior Glass Surface Temperature	
Insulated Glass Type	**Low-E Coating**	**Winter Night**	**Summer Day**
Double Pane	None	44˚F	91˚F
	High solar gain	52˚F	98˚F
	Medium solar gain	56˚F	84˚F
	Low solar gain	56˚F	82˚F
Triple Pane	None	52˚F	94˚F
	High solar gain	61˚F	94˚F
	Medium solar gain	61˚F	87˚F

Table assumes 0˚F and 15-mph wind for winter conditions and 89˚F with bright sunshine for summer conditions. Note that low solar-gain low-E glass is both warmer in winter and cooler in summer.

Energy Savings From Better Windows

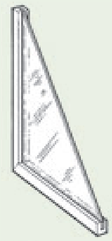
	Savings vs. Single-Pane Glass					Savings vs. Double-Pane Clear			
	Type II	Type III	Type IV	Type V	Type VI	Type III	Type IV	Type V	Type VI
Northern	20%	26%	25%	25%	28%	8%	7%	7%	10%
North Central	19%	25%	25%	26%	27%	7%	8%	9%	11%
South Central	17%	24%	27%	30%	30%	8%	12%	15%	15%
Southern	14%	19%	27%	30%	28%	6%	15%	19%	17%

How Different Windows Affect Heating and Cooling Costs in a Typical Home

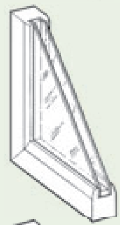


Note: Table courtesy of Jim Larsen, Cardinal Glass Industries. Energy savings were calculated using analysis performed by Lawrence Berkeley National Laboratory in support of the Energy Star window program (see windows.lbl.gov for details). Building type was assumed to be an existing two-story wood-frame house, 2,000 square feet in size. National average fuel prices of natural gas and electricity for January 2011 came from the Energy Information Agency.

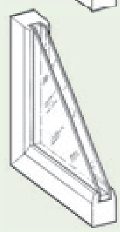
Window Guide



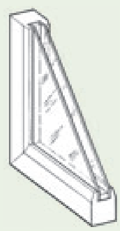
I
Single glazing
Clear glass
U = 1.20
SHGC = 0.80



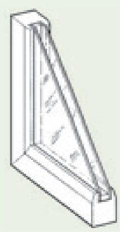
II
Double glazing
Clear glass
U = 0.55
SHGC = 0.60



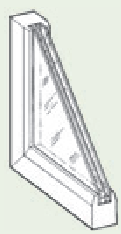
III
Double glazing
Argon gas fill
Low-E: high solar gain
U = 0.33
SHGC = 0.52



IV
Double glazing
Argon gas fill
Low-E: medium solar gain
U = 0.32
SHGC = 0.32



V
Double glazing
Argon gas fill
Low-E: low solar gain
U = 0.31
SHGC = 0.21



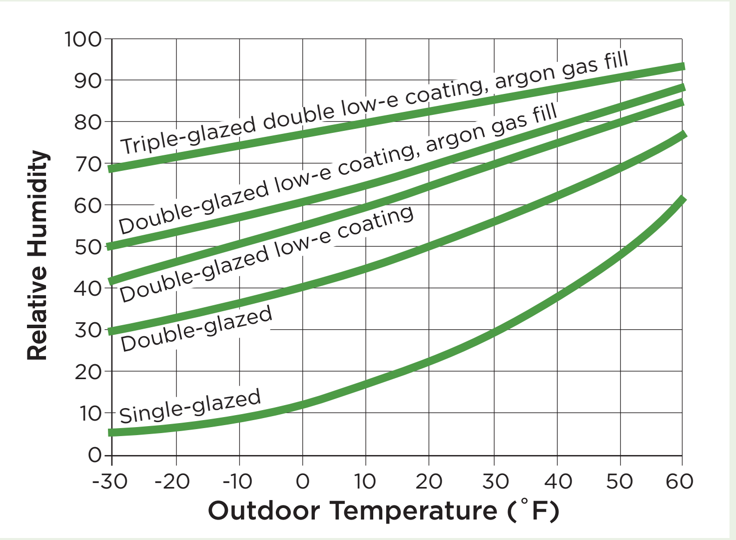
VI
Triple glazing
Argon gas fill
Low-E: medium solar gain
U = 0.25
SHGC = 0.29

All frames: wood, vinyl, or fiberglass

Figure 9. These graphs illustrate the total annual energy costs associated with several common window types. In the northern region, for example, you can reduce energy costs in an existing home by about $450 annually by switching from single glazing (Type I) to double glazing with low-E and argon (Types III, IV, or V). In the southern region, switching from single glazing to double glazing with low-solar-gain low-E with argon (Type V) would save about $400 a year. Similar savings would be realized in new construction.

Dealing With Condensation

Condensation on windows — which can lead to disappointed customers and callbacks — can be reduced with new glazing technologies. Use the chart below to predict whether condensation will form on a given window under certain conditions. Low-E windows can prevent the formation of condensation until relative humidity levels reach 65 percent at an outdoor temperature of 20°F. Relative humidity levels above 65 percent are excessive and will likely cause other problems besides dripping windows. It's a good idea for contractors to carry a digital hygrometer to measure and record indoor relative humidity while they are in customers' homes.



Given an outdoor temperature of 20°F, project up vertically to the desired glazing curve. A double-glazed clear window, for instance, corresponds to a relative humidity of 51 percent. Compare this with a double-glazed low-E argon product, which would allow almost 70 percent relative humidity before condensation would occur. This chart is for the glass only and not the frame.

For More Information

Efficient Windows Collaborative
efficientwindows.org

Building America (U.S. Department of Energy)
buildingamerica.gov

Energy Star Windows Program
energystar.gov/windows

National Fenestration Rating Council (NFRC)
nfrc.org

Lawrence Berkeley Laboratory Building Technologies Program
windows.lbl.gov

Energy Efficient Building Association (EEBA)
eeba.org

American Architectural Manufacturers Association (AAMA)
aamanet.org

the optimal glazing type for both winter and summer performance can be tricky. However, computer modeling indicates that the sweet spot for most homes in the U.S. is argon-filled double glazing with medium-solar-gain low-E (SHGC from 0.25 to 0.35, U-factor of 0.28 to 0.32). This will provide warm inside glass temperatures on cold winter nights and limit unwanted heat gain in summer. In hot southern climates, it makes sense to use the lowest SHGC available.

Reasonable Cost

As with the Energy Star program, national building codes have adopted window-efficiency requirements that basically mandate low-E everywhere in the country. Given that the cost of upgrading from clear double glass to a gas-filled low-E window is less than $1 per square foot of glass area, most studies show that the payback period for choosing low-E will be less than one year (**Figure 9, previous page**) — and this does not even take into account the cost savings of a downsized furnace and air-conditioner.

Triple glazing may be cost-effective in extremely cold climates, but with a longer payback period, this option would need to be evaluated on a case-by-case basis.

In retrofits, while it may not be cost-effective to replace old windows based on energy savings alone (depending on the new window and installation costs), once you have decided to replace the windows, upgrading from clear glass to low-E will provide a payback as quickly as in new construction.

***Steve Easley** is a consultant based in Danville, Calif., who specializes in energy-efficient construction. This article was adapted from* The JLC Guide to Energy Efficiency.