ADVANCEMENTS IN WINDOW GLAZING

Presented by:

SageGlass®

Butler County Health Care Center, Photo courtesy SAGE Electrochromics; Copyright Paul Daubmann

LEARNING OBJECTIVES

Upon completion of the article the reader will be able to:

- Identify the basic components and properties of a high performance window
- Discuss how traditional mirror or tinted glazing functions and benefits occupants
- Describe the advancements in tinting and mirrored window coatings by today's manufacturers
- Explain how electrochromic coatings on windows function and the benefits of programmable tinted windows

CONTINUING EDUCATION

CREDIT: 1 LU

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By: Andrew Hunt

While the concept of smart phones is now well-accepted, the technology of smart windows is not well known in the public awareness. Windows and glazing options have made major advancements in the past decade. By all indications, the industry is poised to keep offering new and innovative options for architects in both commercial and residential settings. In order to take full advantage of these advancements, it is important to understand the anatomy of high performance windows and how new coating, tinting and programmable windows are best implemented.

WINDOW BASICS

The evolution of windows has held a slow and steady pace until recently. Before 1900, commercial and residential windows were mostly custom-built on site with wood frames and a simple single-pane design. At the turn of the 20th century, though, some companies started to manufacture pre-framed wooden windows. While this made it a bit easier and faster during construction, these mass-produced

windows were still crude in terms of energy efficiency, and installation was inconsistent with little attention to air sealing. As the century progressed, aluminum and steel frames were introduced, allowing for more interesting and unique designs, but by and large the windows were still basic frames with glass. These early windows were initially inexpensive to purchase. As technology evolved, they became more expensive to replace or upgrade. As a result, almost half of all commercial buildings still house single-pane, poorly installed windows.

However, in the 1960s, building scientists, engineers and progressive manufacturers looking for a competitive edge started to research and develop new fenestration designs and technologies. The first upgrade came when a second pane of glass was added to improve overall insulation. Then gas was added between panes to help keep them clear of humidity and also increase thermal properties. Tinting, glazing, coatings and additional panes soon followed. By the mid-1980s, there were hundreds of glass types, styles and features with varying benefits.

Most of the improvements in window design revolved around four measurable aspects of energy efficiency and comfort. Basic insulation, heat transfer, light transfer and air sealing were classified. Each area has been measured and improved on over the years. These attributes are commonly known as:

U-factor: Also called U-value, the U-factor measures the rate of heat transfer and indicates how well a window insulates. U-factors generally range from 0.25 to 1.25 and are measured in Btu/h•ft²•°F. The U-value of a window is similar to the r-value of an insulation material except it measures the heat transfer properties of the entire window as a unit rather than just the single components such as glazing and frame. Also, unlike an r-value where the higher the rating the better the insulation properties, the higher the U-factor the worse the thermal performance of a window. A typical single-pane window with a wooden frame may have a U-factor ranging from .9 to 1.1, whereas a high performance window will perform around .3 to .4 or better.

Solar Heat Gain Coefficient (SHGC): SHGC measures the fraction of solar energy transmitted and reveals how well a product blocks heat caused by sunlight. Simply put, this measurement indicates how much incidental solar gain, or heat transfer from sunshine, is passing through the window. Again a lower rating is better. SHGC is measured on a scale of 0 to 1, so an SHGC rating of 0 means that all heat is being reflected back out and away from the inside of the building, and a SHGC rating of 1 means all solar energy in heat form is passing through the glazing to the interior. Older single-pane windows generally have a SHGC above .75, while newer double-pane windows coated to improve performance may have ratings under .3.

Visible Transmittance (VT): VT measures the amount of light the window lets through. VT is measured on a scale of 0 to 1; values generally range from 0.20 to 0.80. The higher the VT, the more light you see. The glazing type, number of panes and glass coatings influence VT. This value decreases somewhat when a low-emittance (low-e) coating is added, and it decreases substantially when a tint is added. Including another layer of glass also decreases VT.

Air Leakage (AL): AL measures the rate at which air passes through joints in the window. AL is measured in cubic feet of air passing through one square foot of window per minute. The lower the AL value, the less air leaks through the window. Most industry standards and building codes require an AL of 0.3 cfm/ft².

There are several ways window manufacturers pursue the improvement of these measurable attributes. Of note are new tinted and mirrored glazing options that combine the conventional technologies of higher performing windows with coatings specifically designed to enhance and improve an occupant's comfort. New glazing options increase curb appeal in the urban setting and also reduce solar heat gain and help control energy costs.

Taking the advancements of reflective coated glass to the next level, programmable tinting options make it possible to manage daylight, glare, energy use and color rendering based on occupancy, light levels or integration with building management systems. Zoning of glass panels is also possible, enabling occupants to control the optimized balance of light quality, visual and thermal comfort, and energy performance in a space.

But before we get to the next generation of window technology, it is important to understand how current high performance windows address energy use and comfort concerns.

IMPROVING WINDOW PERFORMANCE

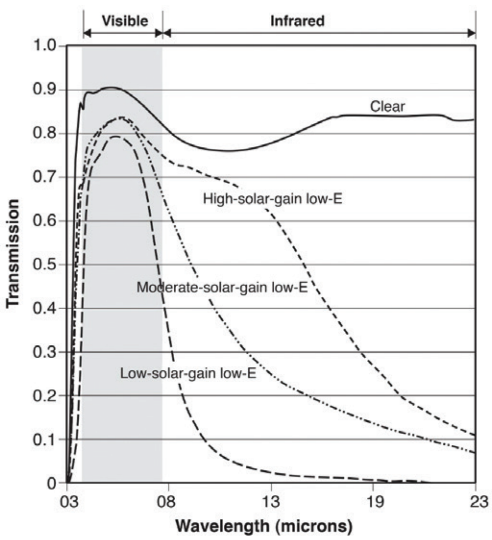
Single-pane windows do very little to reduce the amount of energy that passes between the outside environment and inside of the home. Glass alone is highly conductive, so to improve energy efficiency a second and third pane of glass were added to the window frame. The concept of creating space between panes as a thermal barrier is the same strategy used in basic fiberglass insulation; heat transfer is greatly reduced through air. To further slow the rate of heat gain, or loss, the gap between panes is filled with argon or krypton. Both gases are inert, nontoxic, nonreactive, clear and odorless. Krypton has better thermal performance than argon and is more expensive to produce. The optimal spacing for an argon-filled unit is the same as for air, about ½ inch. Krypton performs better than argon when the space between glazings is thinner than normally desired (eg: ¼ inch). A mixture of krypton and argon gases sometimes is used as a compromise of thermal performance and cost. Argon and krypton occur naturally in the atmosphere, and the gasses work to reduce heat transfer while also eliminating fog from humidity between panes. When compared to single-pane windows, double-glazing reduces heat loss by more than 50 percent (as measured by the U-factor). However, additional panes alone do little to improve solar heat gain or visibility ratings and can add significant weight to a window, making it more difficult and expensive to transport and install.

Arguably the greatest advance in window technology in the past few decades has been the use of low-e coatings. Emissivity is the ability of a material to radiate energy. All materials including windows emit (or radiate) heat in the form of long-wave, far-infrared energy depending on their temperature. When heat or light energy is absorbed by glass, it is either convected away by moving air or reradiated by the glass surface. Reducing the window's emittance can greatly improve its insulating properties.

A little understanding of basic science is helpful to appreciate how low-e coatings function to improve energy performance in windows. Visible light is a small fraction of the entire large spectrum of energy that surrounds us. Microwaves, radio waves, x-rays and ultraviolet are all forms of light we cannot see. Infrared is also on the spectrum of light, and though we cannot see it, we sense it in the form of heat energy. Different materials reflect, absorb or manipulate wave forms of light energy (like lead blocking x-ray waves) and low-e coatings have a high reflectance to long-wavelength infrared radiation. When applied to a pane of glass, the coating reduces long-wavelength radiative heat transfer between glazing layers by a factor

CLEAR AS GLASS?

We may think of glass as a perfectly transparent material, but the truth is glass really isn't all that clear. Imagine breaking an older glass soda bottle. When you look at the glass directly, it appears clear, but from the side the glass looks green. This tint is caused by impurities, mostly iron, in the glass. So it is with commercial-grade glass used in windows—when looking at the edge of the pane, the glass appears green. Today manufacturers are finding ways to remove additional materials from the glass and have created ultra-clear panes to allow maximum visible transmittance.



1. Spectral transmittance curves for glazings with low-e coatings. This graphic shows how different types of low-e coatings can reduce the amount of infrared solar radiation. Note that by choosing different types of low-e coatings, more or less heat energy is allowed to pass through the window. This is important when choosing window coatings in colder climates where additional solar heat gain may be advantageous. (image source: US DOE, EERE Building America Measure Guidelines Measuring Window Performance) http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_windows.pdf.

of 5–10, thereby reducing total heat transfer between two glazing layers. Coating a glass surface with a low-e material and facing that coating into the gap between the glazing layers blocks a significant amount of radiant heat transfer, lowering the total heat flow through the window. Low-e coatings may be applied directly to glass surfaces or to suspended films between the interior and exterior glazing layers.

There are many different types of low-e coatings but almost all are microscopically thin, virtually invisible metal or metallic oxide. Advantageously, low-e coating can lower the U-factor of the window without interfering with visibility. For example, uncoated glass has an emissivity of .84, while some advanced low-e coatings can reduce emissivity to .02.

Low-e coatings are broken down into three classifications: high, moderate and low solar gain. These have been designed to accommodate building needs. Low-e coatings can be custom-ordered to either encourage or halt solar gain, depending on a climate zone and other situational needs.

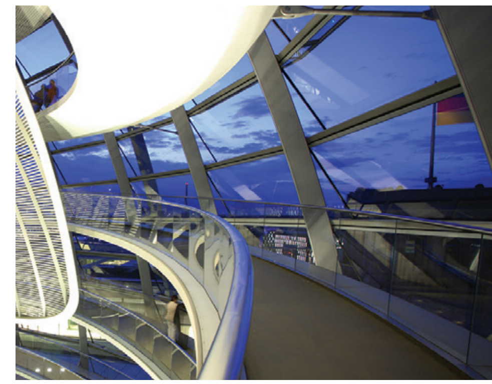
High solar gain low-e coatings typically have an SHGC value greater than 0.40 and are designed to reduce heat loss but admit solar gain. High solar gain products are best suited for buildings located in heating-dominated climates, and particularly for south-facing windows in passive solar designs. Unless properly shaded, high-solar-gain windows may result in overheating from excess solar gain in swing seasons, but the overall benefit of the additional heat during cold northern winters usually outweighs the additional cooling load during the relatively shorter summers.

Moderate solar gain low-e coatings typically have an SHGC value of 0.25–0.40. These coatings reduce heat loss, maintain high light transmittance, allow a reasonable amount of solar gain and are suitable for climates with heating and cooling concerns.

Low solar gain low-e coatings typically have an SHGC value less than 0.25. This type of low-e product, using a highly spectrally selective low-e glass, reduces heat loss in winter and reduces heat gain in summer. Compared to most tinted and reflective glazings, this low-e glass transmits visible light, but blocks a large fraction of the solar infrared energy, thus reducing cooling loads. Low solar gain low-e coatings are generally specified for hot sunny climates.

The location of a low-e coating application is also important. Placement of a low-e coating within the air gap of a double-glazed window does not affect the U-factor, but it does influence the SHGC. Thus in colder climates with higher heating demands, placing a low-e coating on the outside surface of the inner pane will maximize winter passive solar gain at the expense of a slight reduction in the ability to control summer heat gain. In cooling climates, applying a coating on the inside surface of the outer pane is generally best to reduce solar heat gain and maximize energy efficiency. Manufacturers sometimes place the coatings on surfaces for other reasons, such as minimizing the potential for thermal stress. Multiple low-e coatings also are placed on surfaces within a triple-glazed window assembly, or on the inner plastic glazing layers of multi-pane assemblies, which further improves the overall U-factor.

Some low-e coatings can be spectrally selective, filtering out 40% to 70% of the heat normally transmitted through insulated window glass or glazing while allowing the full amount of light transmission. Spectrally selective coatings are optically designed to reflect particular wavelengths, but remain transparent to others. Such coatings are commonly used to reflect the infrared (heat) portion of the solar spectrum while admitting more visible light. They help create a window with a low U-factor and SHGC, but a high VT.



A final consideration when evaluating low-e windows is the UV or ultraviolet protection the window coatings offer. Blocking UV light is important because it can protect furniture, art, carpet and décor from the fading effects of UV exposure. Low-e windows can block over 70 percent of the UV light coming through the window, but for projects such as galleries or in offices with extensive art collections, using a low-e coating with greater UV protection can be important.

Another category of window glazing that has developed in recent decades is tinting and reflective coatings. Unlike low-e coatings that generally are designed to be invisible, reflective and tinted windows are created to enhance the aesthetics of the project while also providing comfort and energy efficiency.

Reflective or mirrored coatings on window glazing or glass reduce the transmission of solar radiation, blocking more light than heat. While they improve the SGHC rating, they also greatly reduce the VT. Reflective coatings usually consist of thin, metallic layers, and come in a variety of colors including silver, gold and bronze. Because of the reduced solar heat gain, these coatings are most common in hot climates to control solar heat gain.

Tinting windows also can provide relief from solar gain, but again at the cost of visibility. Tints are added to the glass during the manufacturing process and come in a wide range of styles. Depending on the color of the tint, different wavelengths of light are manipulated to produce varying results. For instance, the most common gray- and bronze-tinted windows are not spectrally selective, so they reduce the penetration of both light and heat. Blue- and green-tinted windows offer greater penetration of visible light and slightly reduced heat transfer compared with other colors of tinted glass. In cold climates, black-tinted glass can absorb more light than heat—helping reduce energy costs in winter month. Tinted, heat-absorbing glass reflects only a small percentage of light, so it does not have the mirror-like appearance of reflective glass.

Thomas D. Culp, an energy consultant working with the Glass Association of North America and glazing industry since 1998, has witnessed considerable change in the industry as both tastes and technologies have changed. Culp has a PHD in engineering and began his career researching low-e coatings.

"Mirrored glass is pretty much gone. The trend has been to be less reflective, with Las Vegas and international places like Dubai as exceptions," he says. "If you go to Seattle and look at some of the new office buildings, they aren't the mirrored buildings of the '80s. … There's all the old tints like grays, bronzes, blues and green, and then there are new high performance tints that give more color choices but lower the solar gain. From the coating standpoint, there are hundreds of low-e coatings options from high visible transmittance, high reflective to low reflective—even new ultra-clear glass tints. Architects now can choose anything they want from daylighting to glare control to improving energy efficiency."

While many of the low-e, reflective and tinting options in glazing have been available for a number of years, Culp points out that like the rest of the building industry, updating window trends has taken a long time.

"Anything in the architectural world tends to move at slow pace, and in general the industry is pretty risk adverse," Culp says. "It's been interesting to see what is coming into popularity."

Chromogenic windows, called "smart" or "dynamic" windows, have grown in popularity in the past decade. Chromogenic windows have materials added to the glass that allow it to change tinting density depending upon the condition or stimulus. There are three main styles of chromogenic window technology available today—photochromic, thermochromic and electrochromic.

Visit http://go.hw.net/AR715Course2 to read more and complete the quiz for credit.

QUIZ

1. A window's U-Factor measures:
   a. The impact of solar panels on the building envelope
   b. The rate of heat transfer
   c. The rate of heat conduction through light beams
   d. The thermal rating of insulation

2. Which of these is not one of the measureable aspects of energy efficiency and comfort for windows?
   a. Clearness Rating (CR)
   b. Solar Heat Gain Coefficient (SHGC)
   c. Air Leakage (AL)
   d. Visible Transmittance (VT)

3. Low-e coatings reduce a window's heat:
   a. admittance
   b. omniscience
   c. emittance
   d. admissions

4. Which of the following features do reflective or tinted coatings NOT provide?
   a. Added noise protection
   b. Enhance the aesthetics of the space
   c. Provide comfort
   d. Help with energy efficiency

5. A second or third panel of glass was traditionally added to a window frame in order to do what?
   a. Added opening options
   b. Diminish mold and mildew buildup
   c. Prevent cracks
   d. Improve energy efficiency

6. Chromogenic windows are sometimes referred to as which of the following?
   a. 'Stylish' or 'Functional'
   b. 'Impressive' or 'Satisfying'
   c. 'Noteworthy or Inviting'
   d. 'Smart' or 'Dynamic'

7. Photochromic materials change their tint transparency in response to the amount of _____ they receive
   a. Care
   b. Light
   c. Titanium Dioxide (TiO2)
   d. Surface Area

8. With Electrochromic windows, the intensity of the tint is:
   a. Manually adjustable
   b. Automatic
   c. Fully calibrated
   d. Not available

9. Much like a household thermostat, Electrochomic windows are:
   a. Utilitarian
   b. Universal
   c. Dial operated
   d. Programmable

10. True or False: According to the U.S. Department of Energy, the window frame can account for over 80 percent of the energy loss through a window.
    a. True
    b. False

SPONSOR INFORMATION

Photochromic materials change their tint transparency in response to the amount of light they receive. This is a familiar technology in the form of eyeglasses. Photochromic eyewear was mostly a passing fashion phase that allowed people with prescription glasses to have a single pair of frames that worked as both regular glasses and sunglasses. When inside under normal light, the lenses would be clear or be lightly shaded, but when a person walked outside into bright light, the lenses would darken. While this seemed like a novel idea at the time, many users abandoned photochromic glasses because they had little control over when or how quickly the lenses would change. Photochromic windows can help reduce solar heat gain and glare improving comfort and lowering cooling loads, but like the prescription glasses can be problematic because occupants have no control over the intensity of the tinting.

As the name suggests, thermochromic windows are heat sensitive and adjust the intensity of tinting depending on external temperature. This technology is not new and has been used in paints and mood rings for years. In windows, the material vanadium dioxide, a metal, is added along with tungsten to allow for tint changes when the glass temperature exceeds about 85 degrees Fahrenheit. Above this temperature, the additives switch from absorbing the heat energy to reflecting it as a semiconductor. Because vanadium dioxide is "spectrally-selective" it mostly blocks the infrared light rays (that deliver heat) and allows a large portion of the visible light spectrum through. In practical terms this allows for windows to only moderately darken visually while greatly reducing the solar heat gain.

Electrochromic coatings (EC) are switchable thin-film coatings applied to glass or plastic that can tint or clear depending on the application of a small voltage. The electrochromic film is attached to the glass and usually consists of ceramic metal oxide coatings with three electrochromic layers positioned between two electrical conductors. When voltage is applied, various coloration ions like hydrogen or lithium move from the metal oxide layer to the electrochromic layer where they create a blue-grey tint. When the electrical current is stopped, the ions return to the oxide layer and visibility is completely restored. Electrochromic coatings work very much like photochromic coatings but can be adjusted depending on the amount of current sent through the layers. Windows are wired to a main control panel that sends the voltage to the units.

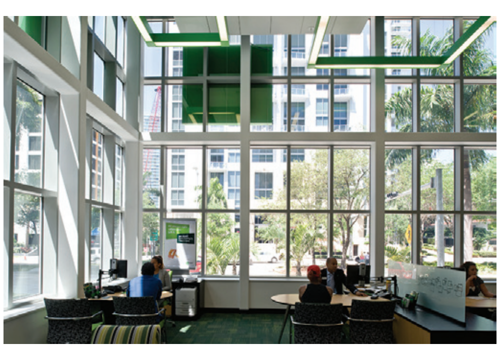
"Electrochromic windows are the next big thing, and they have been for the last 30 years," Culp says. "The Department of Energy funded research on these a long time ago, and now the industry is at the breaking point. They have been in the market for the last 10 years and are hitting the volume points where it is just about to take off."

There are several advantages to electrochromic windows over the other types of chromogenic window.

First, the intensity of the tint is manually adjustable, allowing for a much more precise match of the window's darkness to the occupants' comfort and usage needs. During winter months with overcast skies, glare can be difficult to manage, but shorter days also call for a brighter workspace to be emotionally beneficial. While photochromic tints tend to shift from either complete tint capability, or totally clear with less nuance in shading intensity, electrochromic windows can be adjusted to the exact shade required.

And electrochromic windows are programmable.

"The programmable thermostat is a good analogy for electrochromic window systems," Culp says. "You can choose the algorithm that



Electrochromic windows can be manually adjusted to change the reflective tint of windows, so occupants can allow more or less light into the work space depending on comfort and usage needs. Photos courtesy SAGE Electrochromics; Copyright Brett Drury Photography.

Kimmel Center for the Performing Arts, Photos courtesy SAGE Electrochromics; Copyright Jeffrey Totaro you want, whether it is to maximize energy efficiency or for glare control. If the sun is beating in, your solar gain is high, you can set it to darken at different times of the day depending on how the building is oriented. Set it and leave it, but at any point the user can walk over and change it for presentations or specific occupants who get glare."

New technology being rolled out by manufacturers makes electrochromic window seem almost futuristic. Besides the manual and programmable aspects, not all windows in the system need to adjust to the same darkness at the same time. Different panels or sets of windows can be adjusted individually to allow for more or less light and heat transfer. Imagine an east-facing office with a full wall of windows. Early morning times when the sun is rising can present significant glare challenges for occupants. But electrochromic windows can be set to darken along the path of the sun so that maximum light and visibility is possible in all parts of the window bay except where the direct glare is the most intense. Some new designs even allow for up to three variable tint zones within a single pane of glass. This allows for occupants to gradient shade the windows and strike the perfect balance of glare, heat gain and visible light even in small offices.

If the thought of having to hard-wire windows into the building envelope seems challenging, new electrochromic windows now can come with small and discreet photovoltaic solar panels that provide ample energy to the low-voltage needs of the window. This proves especially handy when installing skylights or during retrofits when older building designs limit access for running additional conduits. Keeping pace with the "smart" technology, these wireless windows can be remotely programmed with either wall-mounted control panels or applications for mobile devices like smart phones.

When specifying electrochromic windows, there are a few things for architects to keep in mind. Specifying the glazing is just like any other glazing, but the one difference is that the electric control system needs to be considered both in terms of installation and use. Appropriate trades are needed to ensure the wiring is connected properly. Often this can be done if the glazing contractor is familiar with the specified product, however consulting an electrician may also be prudent. Also, just as with an advanced programmable environmental control system, training and support may be required for owners and occupants in order to achieve the expected results of comfort and energy efficiency. Finally, fully engaged electrochromic and photochromic window tinting tend to be much darker than conventional reflective coatings used on windows. This can be unsettling for some occupants who are used to the light bronze or green tinting normally associated with glazing.

Modern fenestrations are nothing like the windows most of us are accustomed to in existing homes and businesses. The rapid deployment of new technologies has created more interesting aesthetics and almost exponential options in coating, features and benefits. Today architects can fine-tune glazing options to achieve maximum visible light with minimal heat gain, while allowing occupants to tint windows at whim. ■

FRAMED!

When selecting window options to improve thermal performance and increase a building's energy efficiency, coatings, tints and multiple panes are often the focus of the purchase process. However, the frame of the window is one critical aspects of new window technology that can significantly impact the overall performance of the unit.

Window frames are made from vinyl, wood, fiberglass or composite materials, yet in commercial applications over 90 percent of window frames are made from metal, primarily aluminum. Aluminum frames are very strong, durable, light-weight and inexpensive relative to other frame materials. The extrusion process used to make aluminum or metal frames also allows for the creation of unique and interesting designs, which can increase the overall aesthetics of a project at minimal cost. Aluminum frames are recyclable and can lend credits to green building programs that stress sustainability and resource conservation.

Yet metal is a very poor insulating material because it conducts heat rapidly. According to the U.S. Department of Energy, the frame can account for over 15 percent of energy loss through a window. So metal frames often become the weakest link in the building's defense against heat loss or heat intrusion. In cold climates, a metal frame can encourage condensation—moisture or frost—on the inside surface of window frames.

To address this, manufacturers have developed an improved window frame design by separating the interior and exterior pieces of the frame. Between the two parts of the frame an additional material—often polyurethane or a polyamide strip—is used for a low heat transfer capacity. This additional barrier stops the flow of heat from the inside to the outside by creating a "thermal break."

When compared to traditional aluminum framed windows, a window frame with a thermal break can significantly reduce (improve) the U-factor of the overall window unit.

WHOLE WINDOW U-FACTORS OF SAMPLE WINDOWS

	Aluminum frame w/o thermal break	Aluminum frame with thermal break	Wood or vinyl frame
Single glass	1.30	1.07	n/a
Double glass, ½" air space	0.81	0.62	0.48
Double glass, low-e, (E*=0.2), ½" air space	0.70	0.52	0.39
Double glass, low-e, (E*=0.1), ½" air space	0.67	0.49	0.37
Double glass, low-e, (E*=0.2), ½" space with argon	0.64	0.46	0.34
Triple glass, low-e, on two panes, ½" paces with argon	0.53	0.36	0.23
Quadruple glass, low-e (E=.01) on two panes, ¼" spaces with krypton	n/a	n/a	

Source: U.S. Department of Energy, "Choosing a Well-Insulated Window" https://www.energyguide.com/info/window2.asp

RESOURCES AND ADDITIONAL INFORMATION

U.S. Department of Energy, Energy Efficiency & Renewable Energy, Building Technologies Program: "Measure Guideline: Energy Efficient Window Performance and Selection" http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_windows.pdf

California Energy Commission: "Advancement of Electrochromic Windows"

http://www2.lbl.gov/Science-Articles/Archive/sabl/2007/Jan/Advance-EC-Windows.pdf

GSA Public Building Service: "Electrochromic and Thermochromic Windows: Chromogenic Windows Offer a Dynamic Approach to Energy Efficiency"

http://www.gsa.gov/portal/mediaId/188003/fileName/Smart-Windows-Findings-508.action

Energy.gov: "Energy Performance Ratings for Windows, Doors, and Skylights"

http://energy.gov/energysaver/articles/energy-performance-ratings-windows-doors-and-skylights

Energystar.gov: "Independently Tested and Certified Energy Performance"

http://www.energystar.gov/index.cfm?c=windows_doors.pr_ind_tested

Energy.gov: "Window Types"

http://energy.gov/energysaver/articles/window-types