Federal Technology Alert

A publication series designed to speed the adoption of energy-efficient and renewable technologies in the Federal sector

Prepared by the New Technology Demonstration Program

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Spectrally Selective Glazings

A well proven window technology to reduce energy costs while enhancing daylight and view

Spectrally selective glazing is window glass that permits some portions of the solar spectrum to enter a building while blocking others. This high-performance glazing admits as much daylight as possible while preventing transmission of as much solar heat as possible. By controlling solar heat gains in summer, preventing loss of interior heat in winter, and allowing occupants to reduce electric lighting use by making maximum use of daylight, spectrally selective glazing significantly reduces building energy consumption and peak demand. Because new spectrally selective glazings can have a virtually clear appearance, they admit more daylight and permit much brighter, more open views to the outside while still providing the solar control of the dark, reflective energy-efficient glass of the past.

Because of its solar heat transmission properties, spectrally selective glazing benefits both buildings in warm climates where solar heat gain can be a problem and buildings in colder climates where solar heat gains in summer and interior heat loss in winter are both of concern. In other words, these glazings are appropriate for residential and commercial buildings throughout the United States. The energy efficiency of spectrally selective glazing means that architects who use it can incorporate more glazing area than was possible in the past within the limitations of codes and standards specifying minimum energy performance. When spectrally selective glazing is used, the capacity of the building's cooling system can also be downsized because of reduced peak loads.

Spectrally selective glazings screen out or reflect heat-generating ultraviolet and infrared radiation arriving at a building's exterior surface while permitting most visible light to enter. Spectral selectivity is achieved by a microscopically thin, low-emissivity (low-E) coating on the glass or on a film applied to the glass. There are also carefully engineered types of blue- and green-tinted glass that can perform as well in a double-pane unit as some glass with a low-E coating. Conventional blue- and green-tinted glass can offer some of the same spectral properties as these special absorbers because impurities in tinted glass absorb portions of the solar spectrum. Absorption is less efficient than reflection, however, because heat absorbed by tinted glass continues to radiate to the building's interior.

This Federal Technology Alert (FTA) of the Federal Energy Management Program (FEMP) is one of a series of publications on new, energy-efficient technologies that have potential for widespread use in Federal buildings. The body of this report describes the types of spectrally selective glazings, the situations in which they are most likely to be cost-effective, and considerations for selecting and installing them. Several case studies are included.

Application

Spectrally selective glazings can be used in windows, skylights, glass doors, and atria of commercial and residential buildings.

This technology is most cost-effective for residential and nonresidential facilities that have large cooling loads, high utility rates, poorly performing existing glazing (such as single-pane clear glass or dark tinted glass), or are located in the southern United States. In the northern United States, spectrally selective low-E windows can also be cost-effective for buildings with both heating and cooling requirements.

In general, the technology pays back in 3 to 10 years for U.S. commercial buildings where it replaces clear single-pane or tinted double-pane glass and for most commercial buildings in the southern United States where it replaces conventional high-transmission, low-E, double-pane windows. Spectrally selective glazing is applicable in both new and retrofit construction.

Technology Selection

The FTA series targets new energy-efficient technologies that appear to have significant untapped potential in Federal buildings. Many of the alerts are about new technologies identified through advertisements in the Commerce Business Daily and trade journals and through direct correspondence in response to an open solicitation for technology ideas. Spectrally selective glazing is an energy efficiency technology with known energy, cost, and environmental benefits for which there is substantial, untapped potential in Federal buildings.

Case Studies

This report gives case study examples by glazing type—selective low-E glazings, selective tinted glazings, and selective window films—for residential and nonresidential facilities and new and retrofit construction. Detailed energy simulations are seldom conducted to justify the selection of window systems and monitored data cannot be obtained directly. Therefore, multiple case studies are offered to show how several users approached the selection and justified the cost of spectrally selective windows.

Implementation Barriers

There are no technological barriers to the use of spectrally selective windows. Cost-effectiveness varies by geographical area, type of use, and utility rates, but suitable applications exist in all types of buildings and parts of the country.

If decisions about window design are made based only on cost-effectiveness and greatest energy efficiency, physiological and psychological concerns of building occupants may be overlooked. The most cost-effective and energy-efficient window may be a dark, reflective window that offers building occupants little or no daylight and view. Spectrally selective glazing's incremental additional cost may be justified if its clear appearance, enhanced view, and improved comfort are taken into account.

In retrofit applications, spectrally selective glazing is often appreciated because it reduces complaints from occupants who have lived with the discomfort of poorly performing glazing, and it reduces high utility bills, particularly during peak cooling periods. Building managers may have faced high vacancy rates in spaces where non-spectrally selective glazing causes discomfort. (Retrofit examples for the Tucson and Oakland Federal Buildings later in this report address the improvement in occupants' comfort that can result from installation of spectrally selective glazing.)

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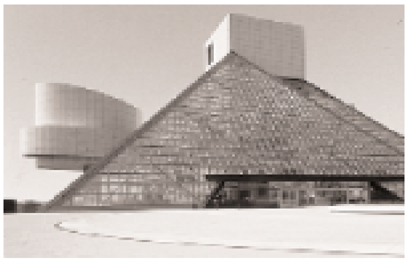


Compare the clear appearance of the spectrally selective glass used in the Rock and Roll Hall of Fame in Cleveland, Ohio (above) to appearance of the dark reflective glass used in the Piper Jaffray tower in Minneapolis, Minnesota (below). Selective coating on clear double-pane glass (above): visible transmittance (Tv)=0.70, solar heat gain coefficient (SHGC)=0.37; Double-pane, titanium coating on blue reflective glass (below): Tv=0.19, SHGC=0.21.

Photographer: Wes Thompson

Spectrally Selective Glazings

A well proven window technology to reduce energy costs while enhancing daylight and view

Abstract

Spectrally selective glazing is window glass that permits some portions of the solar spectrum to enter a building while blocking others. This high-performance glazing admits as much daylight as possible while preventing transmission of as much solar heat as possible. By controlling solar heat gains in summer, preventing loss of interior heat in winter, and allowing occupants to reduce electric lighting use by making maximum use of daylight, spectrally selective glazing significantly reduces building energy consumption and peak demand. Because new spectrally selective glazings can have a virtually clear appearance, they admit more daylight and permit much brighter, more open views to the outside while still providing the solar control of the dark, reflective energy-efficient glass of the past, as shown in the figures on the left.

Because of its solar heat transmission properties, spectrally selective glazing benefits both buildings in warm climates where solar heat gain can be a problem and buildings in colder climates where solar heat gains in summer and interior heat loss in winter are both of concern. In other words, these glazings are appropriate for residential and commercial buildings throughout the United States. The energy efficiency of spectrally selective glazing means that architects who use it can incorporate more glazing area than was possible in the past within the limitations of codes and standards specifying minimum energy performance. When spectrally selective glazing is used, the capacity of the building's cooling system can also be downsized because of reduced peak loads.

Spectrally selective glazings screen out or reflect heat-generating ultraviolet and infrared radiation arriving at a building's exterior surface while permitting most visible light to enter. Spectral selectivity is achieved by a microscopically thin, low-emissivity (low-E) coating on the glass or on a film applied to the glass. There are also carefully engineered types of blue- and green-tinted glass that can perform as well in a double-pane unit as some glass with a low-E coating. Conventional blue- and green-tinted glass can offer some of the same spectral properties as these special absorbers because impurities in tinted glass absorb portions of the solar spectrum. Absorption is less efficient than reflection, however, because heat absorbed by tinted glass continues to radiate to the building's interior.

This technology is most cost-effective for residential and non-residential facilities that have high cooling loads, high utility rates, poorly performing existing glazing (such as single-pane clear glass or dark tinted glass), or are located in the southern United States. In the northern United States, spectrally

selective low-E windows can also be cost-effective for buildings with both heating and cooling requirements.

In general, the technology pays back in 3 to 10 years for U.S. commercial buildings where it replaces clear single-pane or tinted double-pane glass and for most commercial buildings in the southern United States where it replaces low-E, double-pane windows. Spectrally selective glazing is applicable in both new and retrofit construction.

This Federal Technology Alert provides detailed information and procedures for Federal energy managers to consider spectrally selective glazings. The principle of spectrally selective glazings is explained. Benefits related to energy efficiency and other architectural criteria are delineated. Guidelines are provided for appropriate application of spectrally selective glazing, and step-by-step instructions are given for estimating energy savings. Case studies are also presented to illustrate actual costs and energy savings. Current manufacturers, technology users, and references for further reading are included for users who have questions not fully addressed here.

Contents

About the Technology

Buildings account for more than one-third of all U.S. energy consumption, 30 to 40% of which is directly attributable to cooling and lighting electricity use and heating by natural gas, coal, electricity, or oil. Energy policy has emphasized the development of new "secure" energy supply options such as offshore oil, but advanced building technologies such as spectrally selective glazings that effectively reduce energy consumption can also be viewed as a "supply" option.

Spectrally selective glazing is a glazing system that permits some portions of the solar spectrum to enter a building while blocking others. This high-performance glazing admits as much daylight as possible while preventing transmission of as much solar heat as possible. By controlling solar heat gains in summer, preventing loss of interior heat in winter, and allowing occupants to reduce electric lighting use by making maximum use of daylight, spectrally selective glazing significantly reduces building energy consumption and peak demand. Because new spectrally selective glazings can have a virtually clear appearance, they admit more daylight and permit much brighter, more open views to the outside while still providing the solar control of the dark, reflective energy-efficient glass of the past (Figure 1).

Because of its solar heat transmission properties, spectrally selective glazing benefits both buildings in warm climates where solar heat gain can be a problem and buildings in colder climates where solar heat gains in summer and interior heat loss in winter are both of concern. In other words, these glazings are appropriate for residential and commercial buildings throughout the United States. The energy efficiency of spectrally selective glazing means that architects who use it can incorporate more glazing area than was possible in the past within the limitations of codes and standards specifying minimum energy performance. When spectrally selective glazing is used, the capacity of the building's cooling system can also be downsized because of reduced peak loads.

Spectrally selective glazings screen out or reflect heat-generating ultraviolet and infrared radiation arriving at a building's exterior surface while permitting most visible light to enter. Spectral selectivity is achieved by a microscopically thin, low-emissivity

Photographer: Viracon

Figure 1. New Spectrally Selective Glazings at the Vancouver Library Atrium (The atrium offers viewers a clear connection to the outdoors without the uncomfortable heat gains associated with clear glass. The glazing is double-pane selective coating on clear glass: Tv=0.70, SHGC=0.37.)

Windows or Oil Wells?

Consider the following argument. An investment of $8M in a low-emissivity (low-E) coating system permits a manufacturer to produce 1.86 Mm^2 (20 Mft^2) of glass per year for 10 years and accumulate energy savings during the 20-year life of the window. The result is a savings of 36 M barrels of oil equivalent.

On the other hand, for an investment of $300M, a 10-well, 213-m (700 ft)-high oil platform off the coast of Santa Barbara can produce 10 K barrels per day for ten years. The result is a depletable supply of 36 M barrels of oil with consequences of oil spills, global warming, and environmental pollution.

(low-E) coating on the glass or on a film applied to the glass. There are also carefully engineered types of blue- and green-tinted glass that can perform as well in a double-pane unit as some glass with a low-E coating. Conventional blue- and green-tinted glass can offer some of the same spectral properties as these special absorbers because impurities in tinted glass absorb portions of the solar spectrum. Absorption is less efficient than reflection, however, because heat absorbed by tinted glass continues to radiate to the building's interior.

Spectrally selective glazings have been available since the 1980s and have been used extensively in private and Federal facilities. The technology is proven, reliable, and applicable in a wide variety of building types. Designers' lack of knowledge about spectrally selective glazings has been the principle barrier to their full market adoption.

Application Domain

Spectrally selective glazings can be used in windows, skylights, glass doors, and atria in all types of commercial and residential buildings. The majority of window manufacturers offer spectrally selective glazings as standard products, so these glazings can be easily obtained through local distributors and installed using conventional glazing practices. The raw glazing itself is produced by glazing manufacturers, listed in the Manufacturers Section, then sent to local fabricators and distributors across the United States for assembly into window units.

This technology is likely to be cost-effective for facilities that provide space conditioning (heating and cooling), use electric lighting, and are subject to solar radiation. Because the cost of electricity for cooling and lighting tends to be more than the cost of gas, oil, or coal for heating, buildings with large cooling and lighting requirements are most likely to benefit from spectrally selective glazing. Some selective glazings also reduce radiant and conductive heat gains and losses (even in the winter) and so are also beneficial in buildings with both summer cooling and winter heating requirements.

Energy-Saving Mechanism

The solar spectrum includes ultraviolet, visible, and infrared radiation. Spectrally selective glazings absorb or reflect heat-generating infrared solar radiation but transmit daylight or visible solar radiation (Figure 2). Because visible solar radiation also contains heat, selective glazings can be designed to reflect some of this radiation as well. This FTA defines spectrally selective glazings as those that sharply cut off or reduce solar transmission beyond the visible range, with a total solar transmission of no less than ~0.40 in the visible range. Of the various glazings shown in Figure 3, only the spectrally selective glazing demonstrates a sharp cutoff of transmission beyond the visible range.

Spectral selectivity is most effectively achieved by using microscopically thin, silver-based, multilayer, low-E coatings on glass or film. These coatings reflect rather than absorb incident solar radiation; less absorbed energy means less heat is transferred into the building. Selective coatings also tend to have lower emissivity and thus radiate less heat into or out of a space than conventional low-E coatings do. The coating is applied to the glass after manufacturing using a *sputtering* process; the resulting soft coating requires protection in an insulating glass unit (IG) or laminated[a] configuration. Coatings can also be deposited on a thin polymer film which can then be suspended

(a) Laminated glass does not inherently have spectrally selective properties. It relies on coated glass, tinted glass, or a coated film interlayer to achieve these properties. Laminated glass is a manufactured assembly of at least one sheet of glass bonded to at least one other sheet of glass or plastic glazing sheet material with an organic interlayer. The interlayer, usually a clear or tinted polyvinyl butyl (PVB) plastic, is specifically developed for bonding glass to glass or plastic. The thickness of the assembly typically is the same as standard monolithic glass sizes. When broken, glass fragments are intended to adhere to the interlayer. Laminated glass is now required to meet impact-resistant standards in Federal Courthouses.

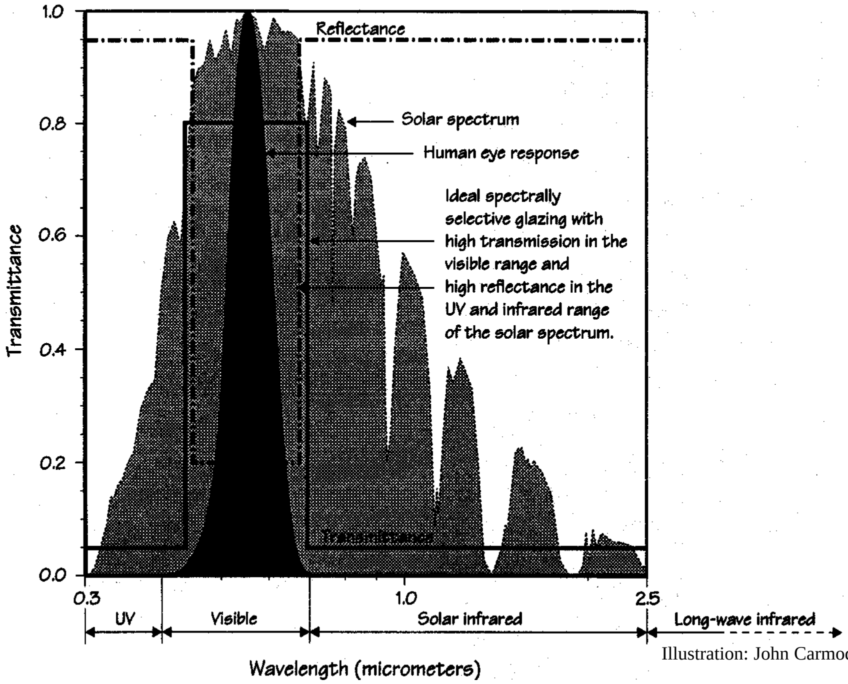


Illustration: John Carmody

Figure 2. Solar Spectral Properties of an Ideal Spectrally Selective Glazing (The response curve represents the eye's response to light.)

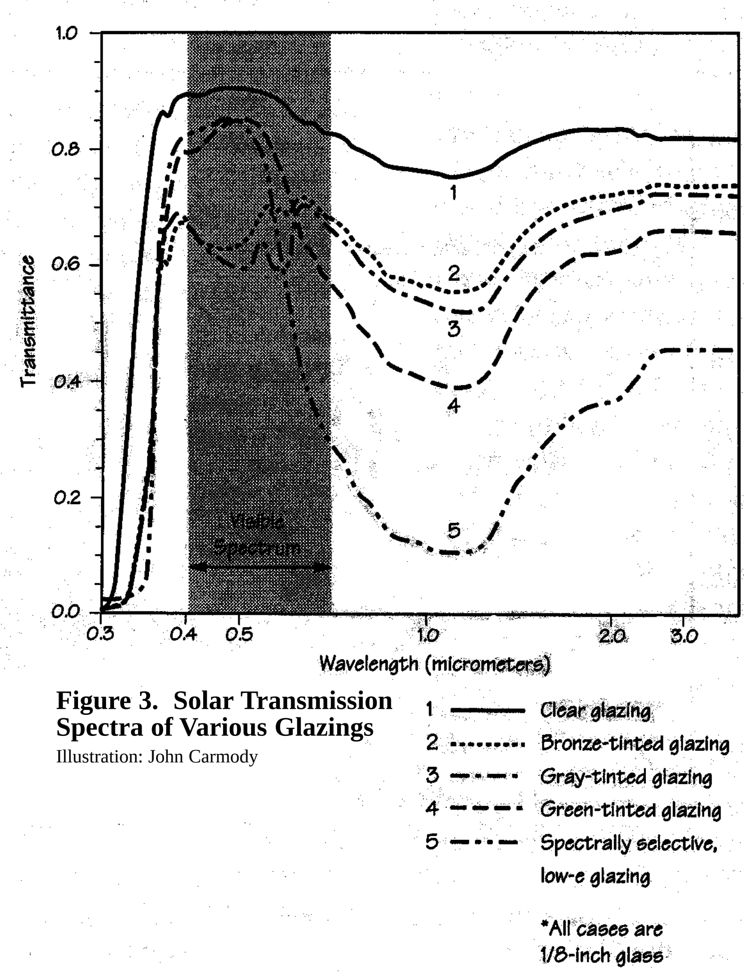


Figure 3. Solar Transmission Spectra of Various Glazings
Illustration: John Carmody

or laminated between two panes of glass or applied as a window film. The first spectrally selective coatings on glass were commercially available in the early 1980s with individual manufacturers holding specific U.S. patents for their own processes.

Conventional green- or blue-tinted glazings can have a spectral response similar to spectrally selective glazings. Chemicals in this glass absorb portions of the solar spectrum, which is less efficient than reflecting heat because some of the absorbed radiation will continue to reradiate to the interior. So a tint by itself can only achieve a modest level of reduction in solar heat transmission. Spectrally selective products are limited to the blue-green family; other colors (e.g., bronze, gray) are not currently considered selective although manufacturers continue to develop new products.

Blue-, green-, and aqua-tinted glass has been engineered during the past 10 to 15 years to increase spectral selectivity with a clearer appearance. These spectrally selective tints can provide increased solar control when combined with a selective low-E coating. For best performance, tinted glazings should be used in an insulating glass unit with the tinted pane on the exterior to minimize reradiation of absorbed heat to the interior.

Low-E *pyrolytic* (hard) coatings on glass, applied directly to a hot glass surface during manufacture, are not selective because they tend to transmit solar radiation evenly throughout the solar spectrum. They can be combined with selective tinted glass to achieve better performance.

SHGC and Tv

The most important performance variables for spectrally selective glazings are the **solar heat gain coefficient** (SHGC) and **visible transmittance** (Tv) of the glazing. The solar heat gain coefficient, a measure of total solar heat gain including both directly transmitted solar radiation and the inward flowing heat resulting from absorption by the glazing, has a direct effect on a building's cooling energy consumption, peak demand, and cooling system capacity.

Visible light transmittance is a measure of the percentage (0 to 100%) of visible light transmitted by the glazing. The higher the Tv, the closer interior daylight levels and view are to those provided by traditional clear glass, and the less tinted or mirrored effect is visible. Where manual or automatic lighting controls are used, transmission of daylight can substantially reduce electric lighting requirements and cooling loads associated with heat generated by the electric lighting system.

Two pieces of glass could have the same SHGC but appear very different—one glass might totally block all visible light (and appear black) while another might look completely transparent. Spectrally selective glazings have a high Tv and low SHGC. The ratio of these parameters, or the light-to-solar-gain ratio (LSG=Tv/SHGC), is typically between 1.25–2.0. Higher LSG products are under development. Often, because selective coatings also have low emissivity, the conductance or "U-factor" is also low, reducing conductive heat gains through the window.

At present, a wide range of spectrally selective products can meet any type of window application throughout the United States. Figure 4 shows the SHGC and Tv of commercially available, spectrally selective, dual-pane products for the nonresidential window market (see Appendix A for data on other product lines). Optimal products have low SHGC and high Tv, which corresponds to the lower right corner of the plot. However, any daylight also carries heat, so it is impossible to have a Tv greater than zero and a SHGC equal to zero. This results in a "forbidden zone" in the lower right corner of the graph, which represents performance that is physically impossible to achieve. The "color zone" defines a region in which it is impossible to create a coating without color. Manufacturers continue to develop improved selective coatings, tints, and films.

Energy Benefits

The use of spectrally selective glazing will generally result in the following energy performance improvements over conventional glazing:

- Cooling energy from solar gains will decrease because of spectrally selective glazing's lower solar heat gain coefficient.
- Lighting energy will decrease (if manual or automatic lighting controls are available) because of spectrally selective glazing's higher visible transmittance.
- Required heating energy may decrease if spectrally selective glazings with lower thermal conductance and emissivity are used.
- Summer peak demand from cooling and lighting will decrease because

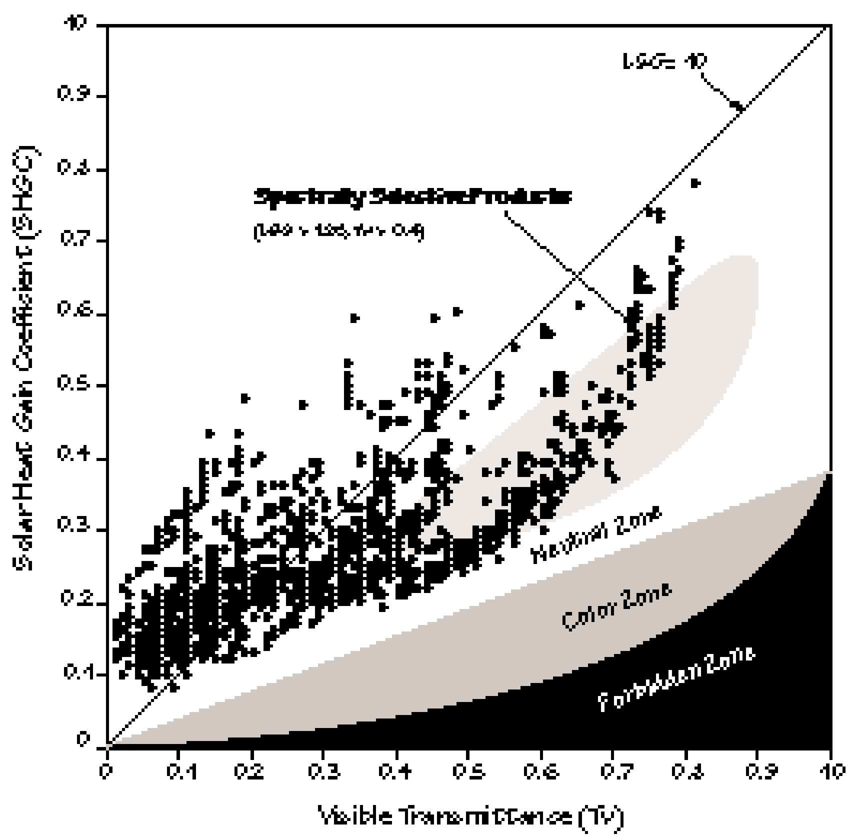


Figure 4. Center-of-Glass Properties of Commercially Available, Dual-pane, Spectrally Selective Glazings, Coatings, and Films for Commercial Applications

spectrally selective glazings will produce a reduction in solar heat gains, electric lighting requirements, and electric lighting heat gains.

- Because peak demand is used to size cooling equipment in commercial buildings, a downsizing of mechanical system capacity is possible when spectrally selective glazings are used, allowing a reduction in first cost and higher system part-load efficiency.

Other Benefits

Designers and owners often select glazing products for aesthetic or non-energy reasons. Spectrally selective glazings offer building occupants a number of direct aesthetic and comfort advantages:

- Because spectrally selective glazings reflect solar heat gains, the temperature of the interior glazing surface is often significantly cooler than that of the interior surface of absorptive tinted glazings, which absorb solar radiation that reradiates as heat to the interior. This is particularly true for monolithic (single-pane) glass with a heat-absorbing window film applied to the interior. Occupants sitting near this glass surface may be uncomfortable because of the difference between the hot window surface and the cooler interior (see Case Study: Retrofit of the Tucson Federal Building). Air conditioning can alleviate this problem to some degree (analogous to sitting in an air-conditioned room next to an oven). Building energy managers may be called in to "fix" the mechanical system in this situation even though the problem is in the control of radiant heat gains.
- Spectrally selective glazing is more transparent than tinted glazing, enabling occupants to have an unimpeded view and a sense of connection to the outdoors, as well as visual relief from tasks at hand. In contrast, low-transmission glazing can often alter the brightness and color of outdoor views, contributing to a lifeless interior space; occupants may feel cut off from time, weather, and the seasons.
- Spectrally selective glazings offer better night views than reflective and dark tinted glazings. Occupants can only see out of a reflective window at night if they turn out all interior lights; otherwise, the interior glass has a mirrored appearance. If light levels outdoors are low, reflective or heavily tinted glass will also reduce an occupant's ability to see what's going on outside.
- From the exterior, the appearance of spectrally selective glazing is clear, not mirrored or heavily tinted, even though it yields the same or better solar heat gain rejection capabilities as heavily tinted glass. Some zoning regulations in cities no longer permit the use of highly reflective glass (used extensively in the 1970s and early 1980s throughout the United States) because it imposes its solar load on adjacent buildings, surrounding plazas, vegetation, and pedestrians, and can be a source of reflected glare.
- Where building energy codes place restrictions on a building's energy use, tradeoffs between glass type and glazing area must often be made. With spectrally selective glazings, window area can be increased; e.g., for a building with clear, single-pane glass, the glazing area may be restricted to 15–20% of the exterior wall area, but with spectrally selective, insulating glass, a 50% glazing area may be allowed.
- For some glass products, low ultraviolet transmission can reduce fading of interior furnishings and fabrics (depending on the intensity and duration of solar radiation).
- One difficult issue raised by spectrally selective glazings is the likelihood of glare when visible transmittance is high. A typical office space receives daylight from only one side; the difference in brightness between the window and the darker interior can result in visual discomfort because of contrast glare. If glare is a critical issue year round, glazing with a lower Tv can be used. Other solutions include using light shelves, light-colored interior finishes, splayed window jambs, or brightening the back of the room with a skylight or other light sources. Direct sunlight glare is best avoided by window orientation, placement, sizing, and proper use of interior and exterior shading devices. For practical details, see the Illuminating Engineering Society's daylighting guide (RP-5-79) [(212) 248-5000 x112], or *Tips for Daylighting with Windows* at http://eetd.lbl.gov/btp/pub/designguide.

Variations

A window is typically composed of one or more panes separated by metal spacers, gas fill (air, argon, or krypton) if more than one pane, one or two structural seals, and a frame (Figure 5). Advanced window systems often achieve high performance simply through the optimal configuration (position and type) of these various components (Figure 6).

Each component can be designed for energy efficiency. Spectrally selective coated glass, tinted and laminated glass, suspended films, and window films are the choices for "panes." Table 1 presents a comprehensive list of spectrally selective coatings, uncoated glass, and laminated glass interlayers. The window frame can be "thermally broken" (i.e., there is no continuous metal contact between outdoor and indoor window surfaces) or made out of wood or vinyl to reduce conductive heat transfer and resulting condensation problems. The choice of gas fill (i.e., air versus argon or krypton) between the panes can improve the insulating value of the window unit by reducing conductive heat transfer. For retrofit applications (historic structures, replacement glass, or storm windows), the window can be composed of the same components described above.

Manufacturers of window products typically sell "product lines" in which the choice of components is predetermined. For some commercial applications, however, one may wish to specify each component to meet design requirements. For example, to meet impact resistance requirements with an energy-efficient insulating glass (IG) unit, the interior pane may consist of a laminated clear glass configuration or the exterior pane may consist of a laminated spectrally selective combination, i.e.,

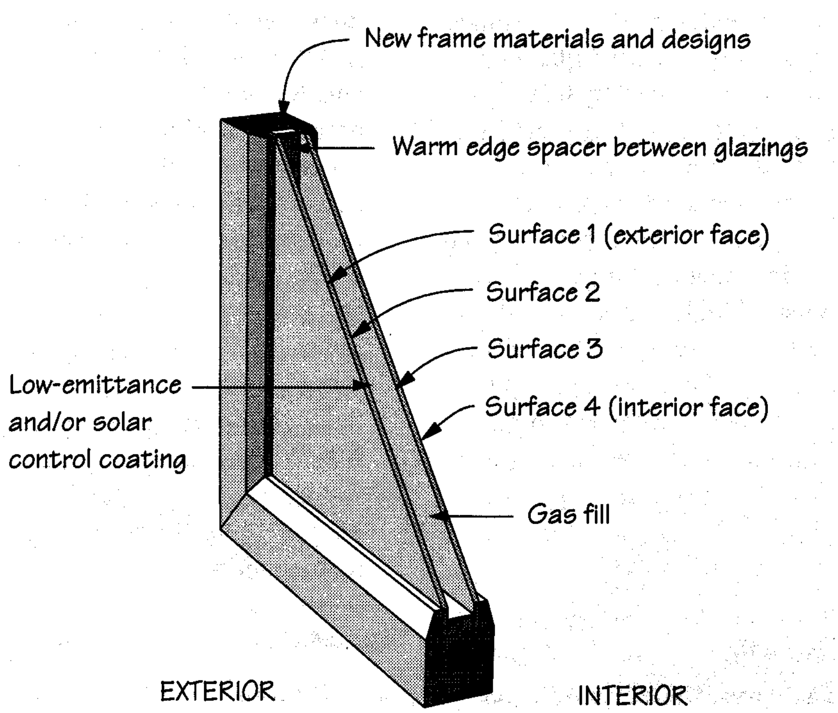


Illustration: John Carmody

Figure 5. Window Components in Section

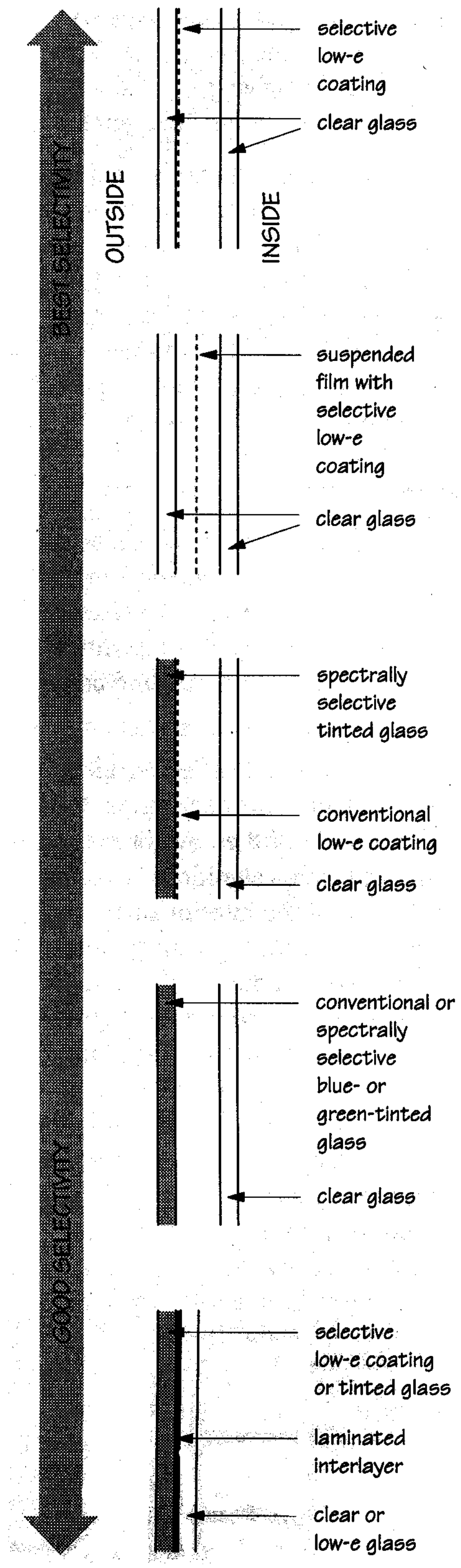


Figure 6. Spectrally Selective Window Assemblies

Table 1. Commercially Available, Spectrally Selective Products, by Manufacturer

Manufacturer	Product Type	Product
AFG Industries	Glass Coatings[3]	Green Blue-green Azurlite®[2] Evergreen®[2] Silver (ES140, ES152, ESB1, and ESN1)[4]
Cardinal IG	Coatings	LoE-178 LoE^2-171
Dupont Polymer Products	Laminate Interlayer	None. Interlayer can be used to laminate selective glass.[6]
Ford	Glass	Sunglas Green
Guardian	Glass Coatings	Green Performance Plus Performance Plus II
Interpane	Unknown[5]	
Libby-Owens-Ford	Glass	Blu-Green Evergreen®
Monsanto	Laminate Interlayer	Solarflex[6]
MSE Specialty Films	Unknown[5]	
PPG	Glass Coatings	Solex Solargreen Azurlite® Sungate 100 Sungate 1000
Southwall Technologies	Laminated Glass Window Films Suspended Heatmirror Films in an IG Unit	California Series XIR with: Azurlite®[2] Evergreen®[2] Green Solis Clear HM44, HM55, HM66, HM77, HM88, HMSC75 (Solar Control-75), HMTC88 (Twin-coated-88)
3M Corporation	Window Films	LE50AMARL
Viracon	Glass Coatings	Green Blue-Green Azurlite®[2] Evergreen®[2] Solarscreen 2000 Solarscreen VH Series: VE1-85, VE1-55, VE1-52, VE1-40

Notes:

1. We list spectrally selective products of known original equipment manufacturers. You can also check the Thomas Register of American Manufacturers or the Sweet's Catalog file. Spectrally selective products were determined by the following criteria: 1) exhibit sharp Tsol cut-off after 1.0 nm, 2) high Tsol (>0.40) in the visible range, 3) solar spectral properties determined either for coating on 6-mm clear glass, single 6-mm layer of tinted glass, film on #2 surface of 6-mm clear glass, or film suspended between two layers of 6-mm clear glass using spectral data provided by manufacturers and given in NFRC Spectral Data Library No. 5 (January 1998).
2. Azurlite is a registered trademark name and product of PPG. Evergreen is a registered trademark name and product of LOF.
3. Coatings can be used independently from the selective glass products in this table. For example, the AFG silver coating on clear glass will yield spectral selectivity.
4. The given product name refers to that noted in NFRC Spectral Data Library No. 5, provided by the manufacturer to NFRC. No analogous product with the same name was clearly listed in the manufacturer's catalog.
5. No spectral data available for this manufacturer so could not determine if selective products were offered.
6. Interlayer can be used to laminate two glass layers to form a single pane of laminated glass.

clear glass, safety film, then low-E, spectrally selective glass. The manufacturer can often assist the customer in determining the final window properties of unique assemblies using a simulation program called WINDOW 4.

In the residential sector, glazings and configuration choices are more limited than in the commercial sector. For new residential applications, IG units offer the best performance and can look comparable to conventional clear glass. Residential window manufacturers sometimes do not give Tv and SGHC data on product lines. However, a uniform national energy performance rating and labeling system developed by the National Fenestration Rating Council (NFRC) enables builders and consumers to directly compare commercial and residential fenestration products, as can now be done with labels developed for appliances (e.g., refrigerators, dryers). Look for the NFRC label when purchasing windows for residential applications.

Other Architectural Criteria

Spectrally selective glazing products can be configured or designed to meet particular architectural criteria. The glass can be tempered or heat-strengthened for safety and structural stability. Products can meet shatter, bullet, and shock resistance and hurricane criteria and provide electromagnetic interference (EMI) shielding of sensitive computer information.

Spectrally selective glass products can also be curved for bay windows or skylights. More complex shapes may be restricted to single-pane configurations, however. Ceramic frits, etching, silk screening, and other glass patterns can be used for architectural design. Between-pane shading systems (venetian blinds, roller shades) may also be combined with spectrally selective glazings for improved energy performance.

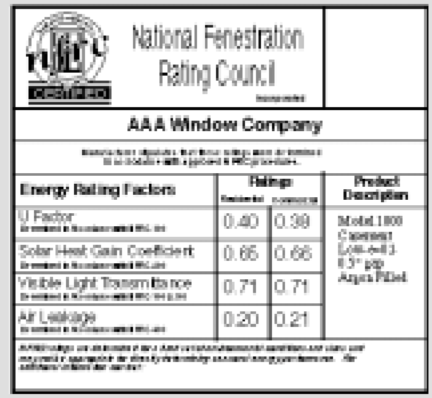
WINDOW 4

This publicly available PC program, developed by the Lawrence Berkeley National Laboratory, allows the user to predict the thermal properties (U-value, SHGC, Tv) of any window unit using a combination of commercially available components. The program also ensures that one product can be fairly and accurately compared to another. To obtain a free copy of this program, send a fax with name and address to WINDOW 4 at (510) 486-4089. Information via the internet is at http://windows.lbl.gov/software/window.

Installation

Selective glazings can easily be substituted for conventional ones because design, construction, and installation are the same.

Coated and tinted glazings are applicable to any size window up to ~3.3 by 5.2 m (10.8 x 17 ft)—subject to wind loads. With window films, applicability may be limited to a glazing area less than ~9.3 m^2 (100 ft^2); if the existing glass is highly absorptive (bronze tint) and/or an absorptive film is being applied, the increased thermal stress may cause the glass to break. Film manufacturers often offer warranties for breakage. Primary glazing manufacturers typically have no lead time on delivering the product to fabricators; window film manufacturers may have a four- to six-week lead time for a large order and shorter lead time for a smaller order.



National Fenestration Rating Council (NFRC)

The National Fenestration Rating Council (NFRC) was formed in December 1989 by the fenestration and building industries, government, utilities, and consumer groups to develop a voluntary, national energy rating system for windows, doors, skylights, and other fenestration products. Window, door, and skylight products bearing an NFRC label are considered "officially" certified. The NFRC does not set minimum performance standards; instead, NFRC ratings show product performance, so consumers can compare products and determine whether they meet state and local codes or other performance requirements.

In the past, only U-factor (representing total heat transfer resulting from the temperature difference between the interior and exterior of a window) was depicted on window labels. Solar heat gain coefficient (SHGC) and visible transmittance (Tv) data for more than 450 products are now available on labels and in the Certified Products Directory. Under the Federal Energy Policy Act of 1992, the NFRC will, during the next several years, include ratings of many other factors. Further information can be obtained from:

National Fenestration Rating Council, Inc.,
1300 Spring St., Suite 120
Silver Spring MD 20910
(301) 589-6372
or at their web site: http://www.nfrc.org

Table 2. Glazing Properties and Costs

Window Type	Description	Tv	SHGC	LSG (Tv/SHGC)	U-Factor (W/m^2-K)	U-Factor (Btu/h-ft^2-°F)	Cost (\$/ft^2-glass)
1	Single Clear	0.88	0.83	1.06	6.17	1.09	$2.50
2	Double Bronze	0.47	0.49	0.96	2.74	0.48	$5.50
3	Double Reflective	0.13	0.17	0.76	2.35	0.41	$7.00
4	Double Low-E	0.44	0.37	1.19	1.78	0.31	$6.50
5	Double Selective Tint	0.41	0.28	1.46	1.64	0.29	$8.00
6	Double Selective Clear	0.68	0.42	1.62	1.64	0.29	$7.15

Notes:

- Cost data have been defined for a single pane or insulating glass unit with a heat treated exterior pane and an annealed interior pane. The curtainwall or building's window framing system costs are not included.
- Double low-E is defined as an exterior pane of conventional low-E coating on conventional tinted glass and an interior pane of clear glass in a double-pane unit.
- Double selective tint is defined as an exterior pane of spectrally selective low-E coating on selective tinted glass and an interior pane of clear glass.
- Double selective clear is defined as an exterior pane of spectrally selective low-E coating on clear glass and an interior pane of clear glass.

15% to 60% of the exterior floor-to-floor wall area and modeled windows with an interior operable shade. Daylighting controls, used to automatically dim electric lights if sufficient daylight is available in a room, were also considered.

We computed two measures of performance: 1) cost-effectiveness measured in number of years to achieve a simple payback, and 2) peak demand reduction. The simple payback period was determined using energy data, glazing costs shown in Table 2, and a flat utility rate of \$0.064/kWh for electricity and \$0.36/therm for heating. Existing or baseline glazings were compared against spectrally selective glass types 5 and 6 listed above; results are summarized in Tables 3 and 4. Key energy and cost trends evident from this analysis are:

- If no daylighting controls are used, then the glazing with the lowest solar heat gain coefficient (SHGC) will have the lowest annual energy use and peak demand (disregarding non-energy benefits such as view and daylight). See Figure 7a.
- If daylighting controls, such as automatic photosensor or manual controls, are used, then the glazing with the lowest SHGC and the highest visible transmittance (Tv) will have the lowest annual energy use and peak demand (Figure 7b). Selective glazings provide this energy advantage.
- Selective glazings with high daylight transmission are cost-effective in commercial buildings with relatively small glazing areas throughout the United States. (Table 3a). Selective glazings with moderate daylight transmission (Tv≈0.40) are cost effective in buildings with large glazing areas throughout the United States (Table 3b).
- Selective glazings will provide greater reductions in cooling load on sunward facing facades of the building (south, east, and west) and on windows unshaded by trees, overhangs, fins, or other exterior building obstructions.
- Selective glazing is most cost-effective (payback less than 10 years) if used in cooling-load-dominated building types, in warmer climates, and with daylighting controls. In colder climates, like Madison, Wisconsin, these glazings are also cost-effective because spectral selectivity reduces cooling loads during the summer, and low emissivity and conductivity reduce heating loads during the winter.
- Selective glazings will pay back within 4 to 10 years for commercial buildings that currently have clear, single-pane or tinted, double-pane glass throughout most of the United States. Selective glazings will pay back within 4 to 10 years

Table 3a. Cost-Effectiveness (simple payback in years) of Double Selective Clear (Type No. 6) IG Unit

Climate →			Madison		Los Angeles		Miami		Phoenix	
Daylighting Controls? →			**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**
Glass Area*	**Baseline Glazing**	**Type**								
0.15	Single Clear	1	4	5	9	+10	6	10	4	6
	Double Bronze	2	7	4	+10	5	+10	4	8	4
	Double Low-E	4	+10	3	—	3	—	2	—	3
0.30	Single Clear	1	4	4	8	8	6	6	4	
	Double Bronze	2	5	4	+10	+10	+10	10	7	5
	Double Low-E	4	+10	7	—	+10	—	+10	—	+10
0.45	Single Clear	1	4	4	8	8	6	6	4	4
	Double Bronze	2	5	4	+10	+10	+10	+10	7	7
	Double Low-E	4	+10	10	—	—	—	—	—	—
0.60	Single Clear	1	4	4	8	8	6	6	4	4
	Double Bronze	2	5	5	+10	+10	+10	+10	8	7
	Double Low-E	4	+10	—	—	—	—	—	—	—

Table 3b. Cost-Effectiveness (simple payback in years) of Double Selective Tint (Type No. 5) IG Unit

Climate →			Madison		Los Angeles		Miami		Phoenix	
Daylighting Controls? →			**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**
Glass Area*	**Baseline Glazing**	**Type**								
0.15	Single Clear	1	6	+10	+10	—	8	+10	5	+10
	Double Bronze	2	+10	+10	+10	—	+10	+10	8	+10
	Double Low-E	4	+10	—	+10	—	+10	+10	+10	+10
	Double Selective Clear	6	+10	—	+10	—	7	—	6	—
0.30	Single Clear	1	5	5	8	10	6	7	5	5
	Double Bronze	2	7	7	+10	+10	9	10	6	7
	Double Low-E	4	+10	+10	+10	+10	+10	+10	9	+10
	Double Selective Clear	6	+10	—	5	+10	6	+10	4	9
0.45	Single Clear	1	5	5	8	9	6	6	5	5
	Double Bronze	2	7	7	+10	+10	9	9	6	6
	Double Low-E	4	+10	+10	+10	+10	+10	+10	9	9
	Double Selective Clear	6	+10	+10	5	6	5	5	4	5
0.60	Single Clear	1	5	5	8	8	7	6	5	5
	Double Bronze	2	7	7	+10	+10	9	8	6	6
	Double Low-E	4	+10	+10	+10	+10	+10	+10	9	9
	Double Selective Clear	6	+10	+10	5	5	5	5	4	4

Notes:

- * Glass Area is defined as the percentage of glass area to exterior floor-to-floor wall area.
- +10 Simple payback is greater than ten years.
- — Baseline glazing outperformed spectrally selective glass.
- • Glazings and cost for this analysis are the same as shown in Table 2.
- • If daylighting controls were used, then the electric lights at the perimeter zone were dimmed if there was sufficient daylight.

Table 4. Range of Peak Demand Reduction (W/ft^2-floor) with Double Selective Clear (Type No. 6) IG Unit

Climate →			Madison		Los Angeles		Miami		Phoenix	
Daylighting Controls? →			No	Yes	No	Yes	No	Yes	No	Yes
Glass Area*	Baseline Glazing	Type	W/ft^2	W/ft^2	W/ft^2	W/ft^2	W/ft^2	W/ft^2	W/ft^2	W/ft^2
0.15	Single Clear	1	0.56 to 0.88	0.51 to 0.84	0.71 to 1.01	0.64 to 0.98	0.53 to 0.96	0.47 to 0.84	0.86 to 1.14	0.75 to 1.11
	Double Bronze	2	0.07 0.15	0.12 0.16	0.09 0.20	0.12 0.21	0.05 0.20	0.12 0.13	0.17 0.25	0.11 0.27
	Double Low-E	4	0 -0.05	0.04 -0.03	-0.04 -0.07	-0.02 -0.03	-0.02 -0.02	0.02 0.02	-0.03 -0.05	-0.01 -0.03
0.30	Single Clear	1	1.40 1.87	1.44 1.89	1.46 1.94	1.47 2.01	1.31 1.84	1.31 1.86	1.79 2.33	1.73 2.31
	Double Bronze	2	0.27 0.40	0.31 0.42	0.28 0.37	0.30 0.39	0.29 0.34	0.31 0.37	0.43 0.59	0.41 0.54
	Double Low-E	4	-0.02 -0.11	-0.01 -0.10	-0.12 -0.15	-0.09 -0.13	-0.06 -0.15	-0.06 -0.13	-0.07 -0.07	-0.05 -0.08
0.45	Single Clear	1	2.02 2.65	2.03 2.66	2.21 3.05	2.26 3.10	2.05 2.77	2.08 2.71	2.6 3.41	2.61 3.44
	Double Bronze	2	0.44 0.59	0.45 0.58	0.40 0.53	0.41 0.56	0.40 0.43	0.39 0.39	0.65 0.86	0.63 0.86
	Double Low-E	4	-0.06 -0.15	-0.05 -0.16	-0.17 -0.23	-0.16 -0.24	-0.07 -0.24	-0.12 -0.28	-0.07 -0.11	-0.08 -0.12
0.60	Single Clear	1	2.56 3.39	2.56 3.38	2.95 3.79	3.00 3.19	2.72 3.51	2.70 3.50	3.33 4.29	3.36 4.34
	Double Bronze	2	0.58 0.79	0.57 0.78	0.52 0.66	0.54 0.72	0.58 0.69	0.55 0.67	0.84 1.07	0.87 1.08
	Double Low-E	4	-0.07 -0.21	-0.08 -0.24	-0.22 -0.43	-0.22 -0.38	-0.10 -0.42	-0.21 -0.38	-0.10 -0.20	-0.11 -0.22

Notes:

* Glass Area is defined as the percentage of glass area to exterior floor-to-floor wall area.

- Range defined by upper and lower number in Table. For example, for Madison with no daylighting controls, peak demand reductions achieved by the double selective clear glass compared to the single clear glass are 0.56 to 0.88 W/ft^2 of perimeter floor area. If a value is negative, the baseline glazing outperformed the selective glazing.
- Absolute peak values are given in Figure 7 and in Tables 1 and 2 of Appendix C.

for some commercial buildings in the southern United States if the baseline glazing is low-emissivity, double-pane windows.[b]

- In this analysis, first-cost savings associated with downsized mechanical systems (resulting from reductions in peak demand) were not incorporated in the cost savings equation; these savings may reduce the payback period.

Appendix C provides detailed data from the simulation work above for those who wish to draw analogies to their specific buildings. For specific applications in commercial buildings, an hour-by-hour building energy simulation program, such as DOE-2

(b) Note that there is great variability in "cost-effectiveness" depending on how one defines the baseline glazing. Choosing a low-E glass with slightly different characteristics can change these results substantially (especially with respect to the 10-year payback criterion), so these results should be regarded carefully.

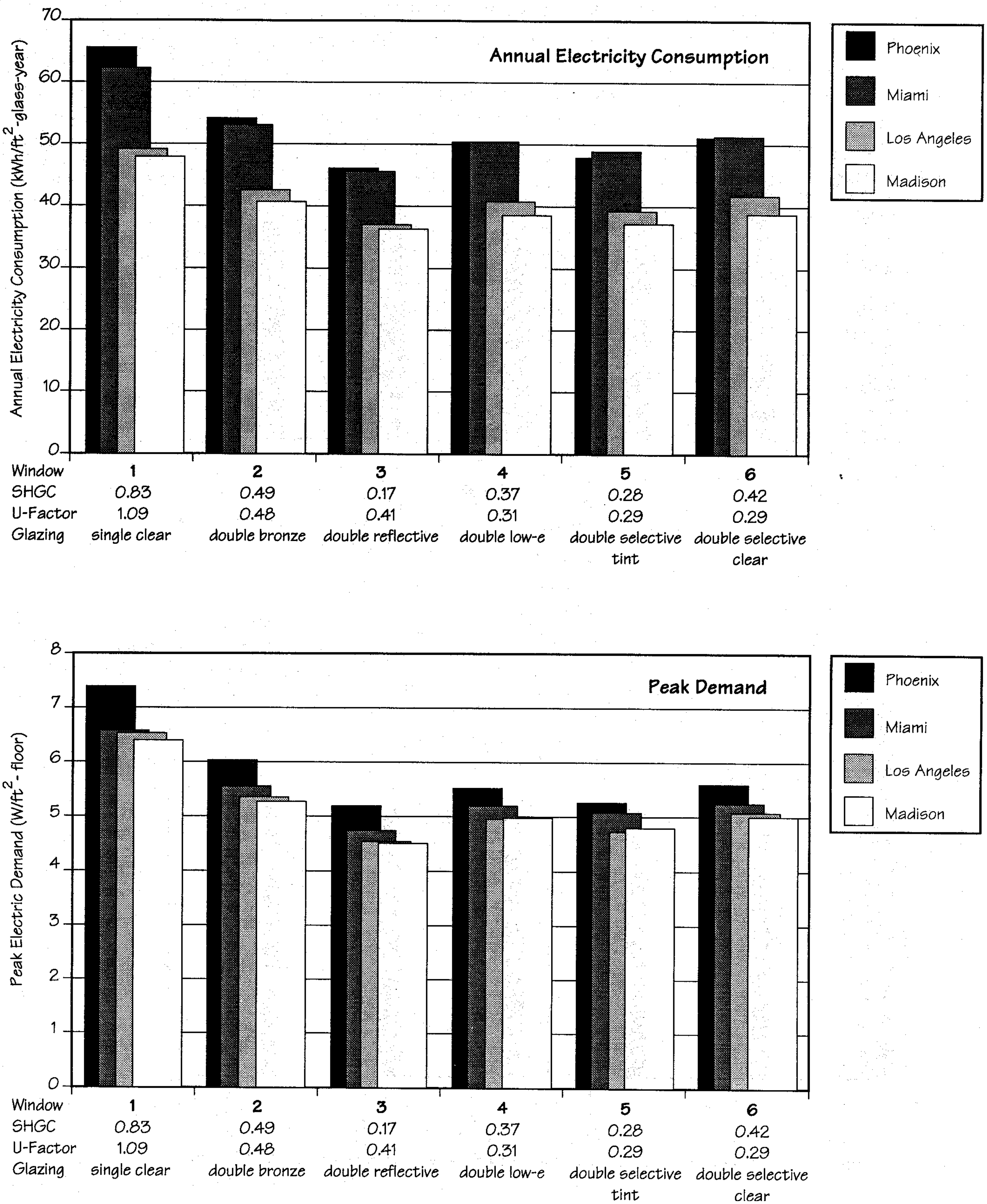
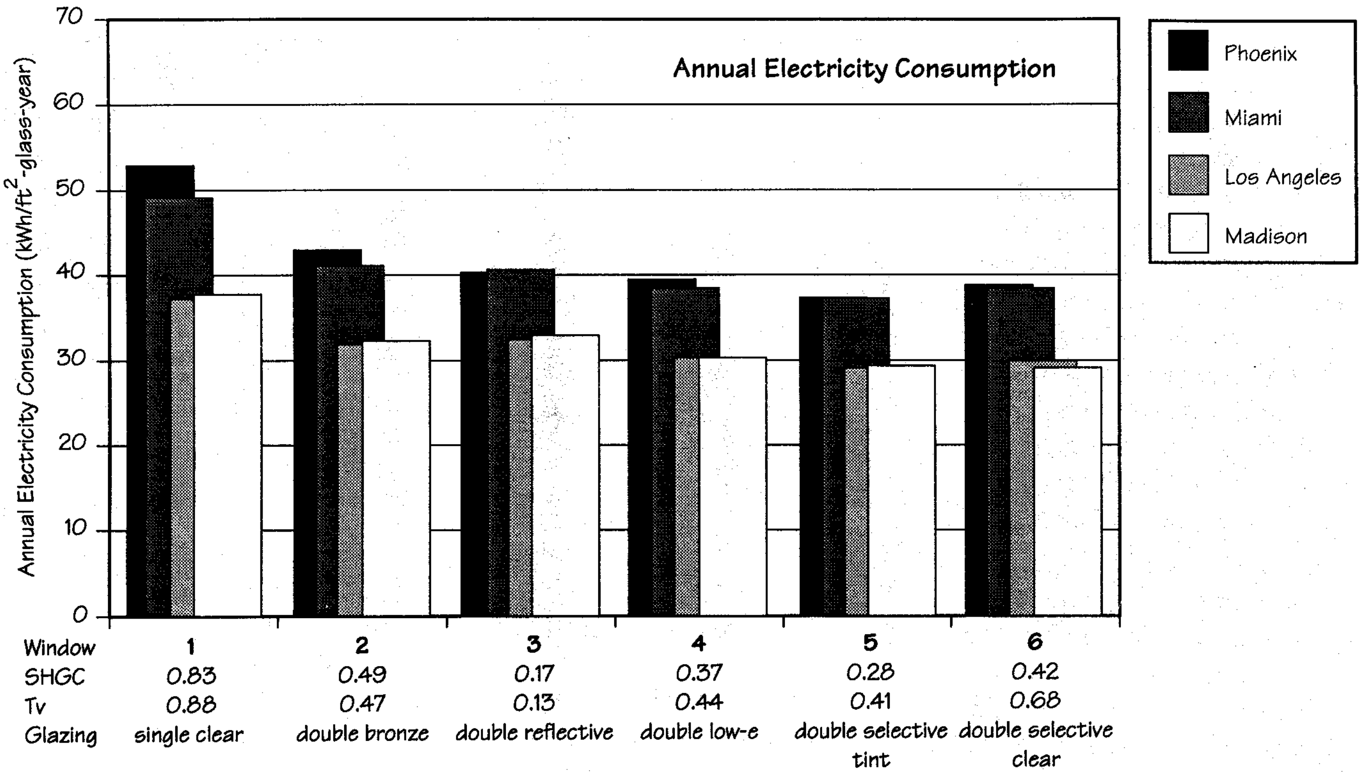


Figure 7a. Annual Electricity Consumption and Peak Demand for Six Different Glazing Types and *No Daylighting Controls* (Results are given for a glazing area that is 30% of the exterior wall area.)



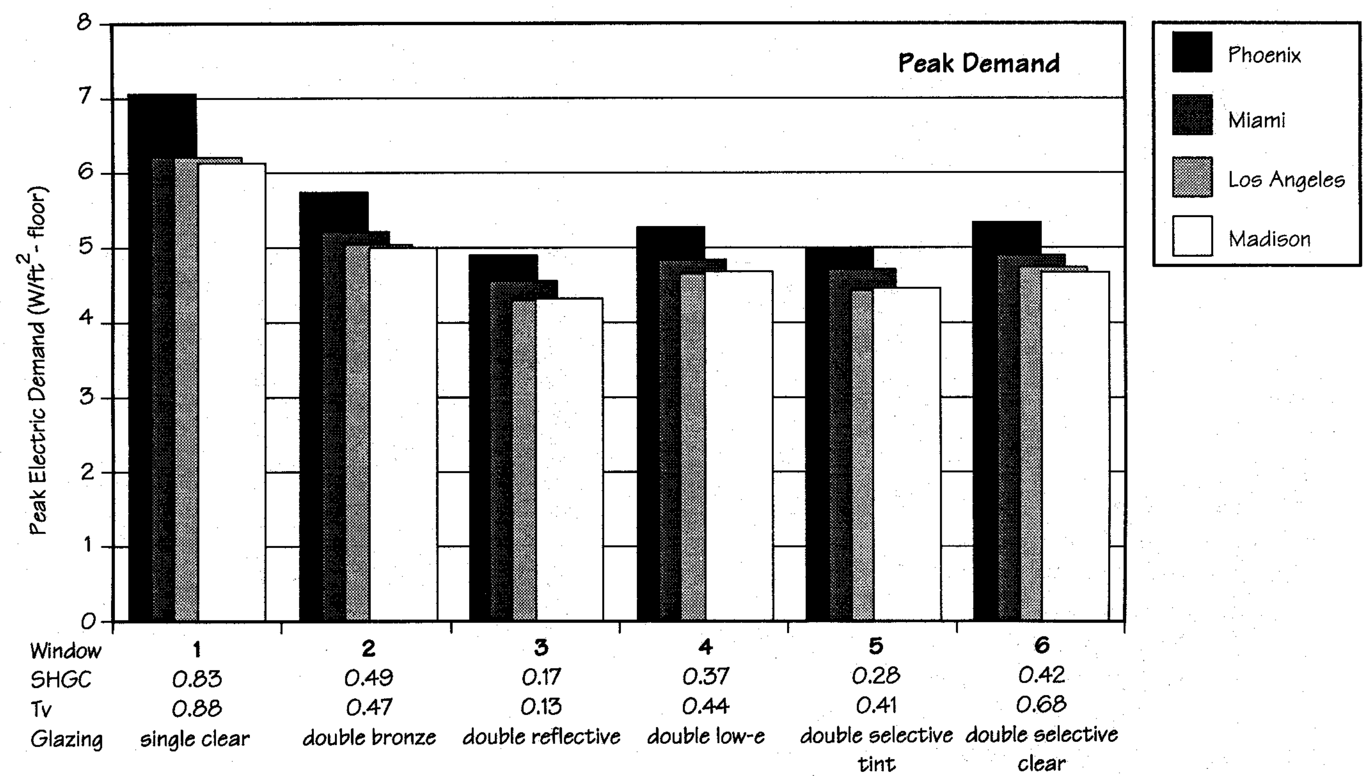


Figure 7b. Annual Electricity Consumption and Peak Demand for Six Different Glazing Types *with Daylighting Controls* (Results are given for a glazing area that is 30% of the exterior wall area.)

Phase-out of chlorofluorocarbon (CFC) refrigerants in the Federal sector will mean chiller replacements and retrofits during the next 10 years; paying attention to possibilities for reducing peak load by installing selective glazing at the same time chillers are replaced could increase energy and economic benefits.

(see "For Further Information"), which uses hourly weather data and can model the thermodynamics of advanced window systems, will provide more accurate estimates.

Laboratory Perspective

Laboratory testing, field testing, and theoretical analysis have shown that spectrally selective glazings are technically valid, reliable, and economically attractive in many applications (Klems et al. 1995; Lee et al. 1993; Gueymard and McCluney 1992). The primary barriers to full market penetration of this technology are 1) building design decision makers lack of knowledge about spectrally selective glazings and 2) the perception that these glazings are expensive. In addition, energy-efficiency and occupant comfort are often not weighted as highly as a building's exterior appearance in the design process for new construction. In retrofits, however, building managers may appreciate the benefits of high-performance windows because of complaints related to the existing windows: occupants who experience discomfort at the perimeter zones, high utility bills particularly during peak cooling periods, and/or high vacancy rates for spaces where the glazing causes discomfort. The incremental premium for spectrally selective glass may seem negligible in relation to these problems.

Budgets for building-wide window replacement are difficult to justify on the basis of energy payback alone. For windows older than 15-20 years, property managers can use repair and alteration funds to defray retrofit costs. For new windows with poor performance, property managers must consider alternatives such as interior shades, window films, or solar screens because the cost of full replacement is difficult to justify against other competing energy-efficiency technologies that involve replacing isolated equipment such as lamps or motors. To address this market barrier, educational programs such as this Federal Technology Alert can provide critical information to all decision makers in the building design process.

Application

Application Screening

Most commercial buildings can reduce cooling costs and increase occupant comfort by lowering solar heat gain, so selective glazing produces easy energy savings. A selective glazing can also mean only a subtle tint to windows when a highly reflective glass would otherwise be necessary to achieve the same performance, or clear glazing when a tint would otherwise be necessary. For cooling-dominated commercial buildings in mild to hot climates, property managers can identify a potential application by observing complaints from perimeter-zone occupants (too hot even during the winter despite a functional mechanical system), use of personal fans and space heaters in individual offices, or high utility bills that track hot, sunny weather. If the building is heavily shaded by exterior solar window screens, trees, buildings, or other obstructions, however, the benefits of spectral selectivity may not be fully achievable.

The transparency of selective low-E coatings is a major advantage for sunbelt residential applications where solar control is important and heavily tinted or mirrored glazings are undesirable.

Where to Apply

- The benefits from spectrally selective glazings are greater in buildings that are cooling dominated or both cooling and heating dominated (e.g., office and similar spaces, atria, etc.) and where utility rates are high.
- For retrofit applications, buildings with clear, reflective or dark-tinted windows will benefit from spectrally selective glazings. Buildings with clear, single-pane glass are prime candidates for spectrally selective glazing retrofits, either through addition of control films or replacement of glazing with laminated glass or IG units.
- Buildings undergoing renovation, including replacement of window glass and/or window frames, are good candidates for spectrally selective glazing. A building-specific energy analysis can determine the applicability of spectrally selective glazings.
- Buildings undergoing mechanical system renovation are also good candidates for spectrally selective glazing. Upgrade of the window system and mechanical system should be integrated because large peak load reductions derived from the window upgrade will reduce the required system capacity.

- Buildings where occupants complain about excessive heat during summer months may be good candidates for spectrally selective glazings.
- Situations where sensitive articles are stored may benefit from reduced temperature fluctuations provided by spectrally selective glazing's control of solar heat gains.

What to Avoid

Spectrally selective products may not be applicable in the following situations.

- Heating-load-dominated buildings with small or no cooling requirements.
- Unoccupied buildings that are not air conditioned, such as warehouses and storage facilities, or naturally ventilated buildings, such as workshops with open doors or windows.
- Buildings with exterior shading devices, such as blinds, overhangs, and shade trees. These buildings may not benefit from spectrally selective glazings. If low-transmission exterior shading devices are already in place, selective glazings will probably not be beneficial. However, if these exterior devices are poorly designed, obstruct view, or need to be replaced, selective glazings can provide comparable heat gain control and increase occupants' feelings of connection to the outdoors.
- Buildings with existing single-pane low-E windows. Applying spectrally selective films over the existing windows will eliminate the low-emissivity properties of the previous coating; selective films with low-E properties should be used in this situation.
- Buildings where there is glare from windows during daylight hours, especially on computer screens. In these buildings, glare may be increased if high-Tv spectrally selective glazings replace existing low-Tv glazings, such as darkly tinted windows. Although occupants may enjoy new clear views, architectural solutions may be needed to mitigate glare.
- Wet, humid, corrosive, or abrasive conditions with use of plastic retrofit films. These conditions may cause coating failure, edge degradation, or delamination of plastic retrofit window films after five years. Bubbling and edge degradation is less likely for typical interior environments because window film adhesives have significantly improved over the years. Poor film installation techniques (e.g., application over dirty glass) can degrade the view and overall appearance of the window system as well. Attention should be paid to the terms of the film manufacturer's warranty.

Equipment Integration

As noted above, use of spectrally selective glazing can substantially reduce building loads and peak demand. Because sizing of mechanical systems is typically based on peak load, there may be opportunities to downsize chiller capacity if selective glazings are introduced. Building operators may find that the decreased load resulting from addition of spectrally selective glazing may cause an existing HVAC system to run at a lower point of its part-load efficiency curve.

Maintenance Impact

Maintenance requirements for spectrally selective windows are essentially the same as for conventional windows. Installations using sealed IG units (double- or triple-pane) require no extra care because the spectrally selective coating is inside the IG unit and not exposed to abrasion from cleaning or weather. Window films may scratch if abraded and so should be cleaned with care. Additional maintenance costs are negligible for most applications.

Warranties

Window manufacturers typically guarantee selective glazings in the same manner as conventional glazings. For tinted glass, there is no special warranty needed against chemical degradation because the tint is an inherent part of the glass. For spectrally selective low-E and window film products, manufacturers often guarantee coatings against peeling, degradation, or defects for a period of 10 years.

Codes and Standards

Many states have adopted the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) 90.1 energy code standard, which acts as a guideline for commercial energy code legislation.

The easiest of three methods of compliance with this standard are the Prescriptive Criteria, which often force designers to choose smaller window area for lower heat loss. Alternate methods of compliance involve computer analysis, which is more complex but generally allows larger window area. Residential energy codes are structured in a similar manner.

With codes and standards, commercial buildings must often achieve solar gain by a darkened view or reflective appearance to windows. Spectrally selective glazings give architects more options for window design with fewer tradeoffs.

Costs

- Costs in this document are given per square foot of glazing area, not per square foot of floor area.
- For new commercial construction, the incremental materials cost for use of a selective coating versus a standard low-E coating is \$2.70 to 5.40/m^2 (\$0.25 to \$0.50/ft^2), which includes an average 30% markup added by local distributors.
- If selective tinted glazings are used, the incremental materials cost between clear glass and an excellent selective tinted glass can be \$17.75/m^2 (\$1.65/ft^2), which includes an average 30% markup added by local distributors.
- For comparison purposes, Table 2 gives materials costs for a variety of generic commercial IG units for a volume of approximately 2,787 m^2 (30,000 ft^2) including markup. For smaller volumes, the materials cost may increase by 10 to 15% or more. For larger volumes, price breaks may be given by some dealers.
- Glass manufacturers sell the raw glass or film product to fabricators who process the glass to produce laminates, window films, or full window products (IG units, wood windows with frames, etc.). These products are distributed to local representatives or general contractors. The materials cost of a final window unit will vary depending on quantity of units, unit sizes, and mix of sizes purchased by the customer, the perception of the local representative of the desirability of certain window attributes, and the customers' willingness to pay for these attributes. Therefore, the materials cost of commercial and residential windows varies locally.
- The incremental installation cost for selective products rather than nonselective products in new construction is zero. For retrofit situations, the incremental cost is zero if window replacement or improvements were already planned.
- For estimation purposes, the total cost for materials and installation is \$65 to 160/m^2 (\$6 to 15/ft^2) for glass in new and retrofit construction, and \$30 to 130/m^2 (\$3 to 12/ft^2) for window film in retrofit construction. Expect to pay \$15 to 30/m^2-glass (\$1.50 to 3.00/ft^2-glass) for removal of the film after ~10 to 15 years. Installation costs are subject to local labor charges, market pace, and the logistics of installation at each particular building site. For retrofit situations, difficult access to the windows from the interior, moving of furniture, removal of window coverings, removal of material on the windows (dirt or stickers for window film applications), or work during swing, graveyard, or weekend hours can increase costs.

Utility Incentives and Support

At present, there are no direct rebates or incentive programs that support market transformation for selective glazing; however, many *indirect* incentive programs promote its use. Many utilities give cash rebates for each kW of dem and reduced or deferred, engineering assistance or energy audits to help customers analyze design options, shared savings or 0% financing, customer services (workshops, billing services, etc.), or system commissioning assistance. These incentives are typically provided if certain criteria are met, e.g., if energy codes are exceeded or demand is reduced in major renovations or new construction. Often a utility requires that the demand reduction be measurable, verifiable, and permanent. Monitoring of demand reduction from windows will require supplementary simulations because window-related loads cannot be measured directly (unlike equipment plug loads).

Many rebates do not account for synergy among building systems. Selective glazing energy reductions are tied to the lighting control and mechanical systems, but equipment replacement rebates are usually made separately for these systems. Programs promoting envelope measures or rewarding performance options for load shedding, load management, or exceeding baseline code requirements should be investigated for the possibility that they may indirectly support spectrally selective glazings.

A customized approach is sometimes available where rebates are based on actual energy savings regardless of the technology employed. Utility representatives can give information on custom incentive programs.

A list of the latest utility incentives throughout the United States and Canada is given annually in *Energy User News*. Also, publications or surveys may be available from the Electric Power Research Institute (EPRI) at (800) 525-8555.

Technology Performance

For detailed discussions of field experiences with recent installations of spectrally selective glazing, see the case studies in the next section. Energy savings and maintenance issues are covered there as well. Interestingly, comments from users focus on aesthetics and comfort. Some anecdotal comments made by users of the technology include:

"The selection of the glass was extremely important for the building to meet stringent energy code requirements. Recent development of highly sophisticated glass and glazing systems permit high transparency with excellent solar shading performance. The energy consumption for HVAC, heating, and cooling and lighting is expected to be 1,058 kWh/m^2-yr (38,900 Btu/ft^2-yr)—only 65% of the suggested norm."

—*Architect and mechanical engineer for the Seattle Museum of Flight, which has 8,361 m^2 (90,000 ft^2) of glass on all four walls of an exhibit hall displaying full-size aircraft and more than $14M worth of aviation artifacts.*

"We wanted clear glass to make the hotel's lobbies open and natural, yet we needed the shading protection of dark glass. Too much heat from the sun would overtax the hotel's air-conditioning system.... The shading and insulating capabilities of selective glazings compared to any other glass available looked too good to be true. Because of lower air-conditioning demands, the extra cost compared to other options will be paid back within a year."

—*Project Manager, Marriott Hotel, Palm Desert, California.*

"The theater's dramatic, enclosed lobby can be enjoyed by patrons throughout the day and into the evening."

—*Architect of a movie theater in Universal City, California with 1,180 m^2 (12,700 ft^2) of barrel-vaulted skylights in the lobby.*

"An environment composed of pools, waterfalls and plants is like having a huge humidifier going all the time. We wanted to include the view from this location as a major design feature of the building. Considering the cold weather Colorado experiences, that view could be ruined much of the time by condensation on the windows. We were asked to design a system that would not allow any condensation on the windows. It would be expensive to use a typical heating and cooling system to accomplish this. Our solution to designing a cost-effective system that would meet all the design criteria was to use a type of glass that lets in light while controlling heat and condensation. According to our calculations, this building will save more than $4,000 annually compared with conventional double-paned windows, and no condensation will form on the windows even when the outside temperature is below –18˚C (0˚F)."

—*Mechanical engineer of a glass-walled recreation center in Westminster, Colorado, with 1,208 m^2 (13,000 ft^2) of glass walls and skylights.*

"The ability to achieve clear, natural lighting at acceptable levels was our greatest concern. Ordinary clear glass would permit too high an intensity of light into six new galleries—as high as 9,688 lux (900 fc) in May or June. Dark glass would reduce the light intensity, but would add unwanted color to the natural light."

—*Architect of Chicago Art Institute's 12,077 m^2 (130,000 ft^2) exhibit hall for 19th and 20th century American Paintings and European decorative arts.*

"High insulating value and the capability to reflect unwanted heat gain in a clear, colorless glass were considered valuable, both in terms of energy savings as well as aesthetics."

—*Representative of the development's owners of a seven-story office building and 145 condominiums for the National Wildlife Federation and Resources for the Future in Washington, D.C.'s Historic District.*

Case Studies

Case studies are presented for different types of spectrally selective products in new and retrofitted Federal facilities. Case studies using products that best fit our definition of spectral selectivity (see Energy-Savings Mechanism Section) are presented first, for new and retrofitted Federal facilities.

New U.S. Courthouse

Tucson, Arizona

Double-pane Clear Glass with a Spectrally Selective Coating

The new showcase Federal Building and U.S. Courthouse located in downtown Tucson, Arizona is now under construction and due to be completed by December 1999. The L-shaped building consists of two six-story towers connected by a curved atrium and walkway with a total gross floor area of 39,000 m^2 (419,000 ft^2) and an occupiable floor area of 24,000 m^2 (257,000 ft^2). On the south and west facades, an aluminum curtain wall and corrugated metal form a staggered exterior shading system in front of the windows; on the north and east, strip and punched windows with smaller area are used.

The windows for this building consist of insulating glass units that have an exterior pane of clear glass with a spectrally selective coating for excellent daylight transmission and solar heat gain rejection, and an interior pane of laminated clear glass to meet new 1997 courthouse security standards. The coating exhibits a sharp cut-off in transmission between the visible and infrared portion of the solar spectrum and thus is 30% more effective than standard low-E coatings at decreasing solar heat gains. The glass was selected by the architectural team for its clear, non-tinted appearance and for its ability to improve occupant comfort while reducing building energy consumption. Although this building uses an energy savings performance contract (ESPC) for other energy-efficiency measures, the glazing choice was part of the baseline building. A separate life-cycle analysis for the glazing was not done. The center-of-glass properties are: Tv=0.70, SHGC=0.37, U-factor=1.59 W/m^2-˚K (0.28 Btu/h-ft^2-˚F), LSG=1.89.

Contact: Mark Levi, Government Services Agency (GSA) Building Management Specialist, (415) 522–3374.

Case Studies Using Spectrally Selective Suspended Film

The following Federal facilities have employed a spectrally selective film suspended between two glass surfaces in an IG unit:

- Ordnance Damage Control Laboratory, Yorktown, Virginia, 1985.
- U.S. Coast Guard Facility Design and Construction, Norfolk, Virginia, 1985.
- Buckley Naval Reserve Training Center and Air National Guard Base, Aurora, Colorado, 1986.
- U.S. Federal Courthouse, Wichita, Kansas, 1987.
- U.S. Post Office, Johns Island, North Carolina, 1987.

New U.S. Courthouse

Sacramento, California

Selective Tinted Glass with Conventional Low-E Coating

The 69,000 m^2 (741,000 ft^2) new Sacramento Courthouse was completed in December 1997. It consists of a 16-story tower containing courtrooms, and a four-story entrance pavilion with a skylit rotunda. The masonry tower has a bowed glass curtain wall with floor-to-ceiling full-height windows and no exterior shading. The window system consists of a spectrally selective aqua-green-tinted glass with a conventional low-E coating on the exterior glass pane and an interior clear laminated glass pane. The center-of-glass properties are: Tv=0.35, SHGC=0.22, U-factor=1.87 W/m^2-˚K (0.33 Btu/h-ft^2-˚F), LSG=1.61.

Contact: Mark Levi, GSA Building Management Specialist, (415) 522–3374.

New U.S. Courthouse

Tampa, Florida

Conventional Tinted Glass with Conventional Low-E Coating

The Sam M. Gibbons U.S. Courthouse is a new building adjacent to the existing Timberlake Federal Complex in the central business district of Tampa, Florida; it was completed in September 1997. The 17-story rectangular tower contains 35,400 m^2 (382,000 ft^2) gross floor area.

A unique, well-integrated building envelope design addresses the admission of comfortable filtered daylight to displace lighting energy use while controlling direct sun and solar heat gains. The design does not rely solely on the glazing to mitigate solar heat gain; the west facade of the building uses exterior aluminum and concrete horizontal and vertical sunshades to control direct sun. Other facades have recessed the windows to control direct sun. Photoelectric sensors control the electric lighting response to daylight in the perimeter zones. Transom windows are used to daylight the 3.25-m-(10.5-ft) high perimeter tenant spaces.

The windows employ a conventional low-E coating on a conventional green-tinted exterior glass pane with a clear interior glass pane forming an insulating glass unit. With its exterior sunshades, the overall envelope performance is substantially better than one with unshaded glazing; the architect predicts net cooling load savings of 10.6 tons per floor compared to the load with unshaded, uninsulated, monolithic glazing. The center-of-glass properties are: Tv=0.43, SHGC=0.28, U-factor=1.93 W/m^2-˚K (0.34 Btu/hr-ft^2-˚F), LSG=1.54.

Contact: Brian Kimsey, GSA, for design information at (404) 331-5330 or Joe Marinaccio, GSA Project Manager at (404) 331-4238.

Retrofit of Federal Building

Tucson, Arizona—Detailed Case Study

Conventional Tinted Glass with Conventional Low-E Coating

The Tucson Federal Building is a 11,240 m^2 (121,000 ft^2) seven-story rectangular tower with a larger two-story base partially below grade. The building was completed in 1974 and is located in the central business district of Tucson, Arizona. The average yearly temperature is 20.2˚C (68.4˚F), with diurnal variations of 3.9 to 17.8˚C (39 to 64˚F) in the winter and 23.3 to 37.8˚C (74 to 100˚F) in the summer, and record temperatures of 47˚C (117˚F). There are 117 cooling degree days (base 18˚C, 65˚F) and 16 heating degree days. Solar gains will dominate the peak building load (as with the new Las Vegas Courthouse described below); average global incident solar radiation on a south-facing surface is 3,941 Wh/m^2 (1250 Btu/ft^2-day).

The precast concrete building envelope has large, fixed-frame, aluminum windows that are 1.8 m (6-ft) high and 3.0 m (10-ft) wide with two 1.52-m (5-ft) sections per bay. Each window is recessed from the facade by ~0.6 m (~2 ft), so there is partial horizontal and vertical shading of the window from direct sun. Interior, beige, 7.6-cm (3-in) opaque vertical blinds are installed at each window. No significant shading occurs from adjacent buildings or trees surrounding the structure one to two city blocks away.

Degrading exterior solar window screens were removed from the building for safety reasons in July 1995. These screens had covered 100% of the window surface and consisted of bronze aluminum horizontal slats 1.6-mm (0.0625-in) wide, spaced 1.6 mm (0.0625 in) apart. The tilt angle of the slats was designed to be changeable; however, the angle was left in a slightly downward position (ground view from the interior). The building manager noted that the screens were a maintenance problem (they had to be removed and replaced for window washing) and gave occupants a blurred view of the outdoors.

The glazing was single-pane, 6-mm (0.25-in) bronze tinted glass (Tv=0.21, SHGC=0.39, U-factor=6.2 W/m^2-˚K (1.1 Btu/h-ft^2-˚F), LSG=0.54). When the exterior window screens were removed, the property manager received numerous complaints about the window heat load from occupants in the building's perimeter zones—about a 10 to 15% increase in complaints, especially in winter when the sun angle was low. Tinted glass controls solar heat gains through absorption, so the interior surface of the glass tends to get quite hot, causing thermal discomfort to those nearby. The two-pipe fan coil unit under each window (controlled by a Johnson Controls Medisys system, hot or cold only, installed in 1994) supplied air conditioning but was inadequate to counter the increased load from the hot interior surface of the glass. About 10 windows broke per year from heat stress after the screens were removed. The cooling load (and utility operating cost) of the building also increased significantly as a result of removal of the screens.

The 23-year-old windows also showed signs of degradation and needed to be replaced. The property manager set design criteria for the new window system: 1) provide a good solar control solution that is inherent in the glass to minimize maintenance and operations costs (e.g., for window washing), 2) reduce thermal discomfort of the occupants, 3) reduce the cooling load and operating costs, 4) maintain the existing bronze color, if possible, but don't darken the view, and 5) use the existing aluminum window frames. Tucson Electric Power Administration was commissioned to do a preliminary audit and analysis of the building. The property manager reviewed trade magazines and manufacturer's catalogs and obtained samples of several glazing types. He experimented with different types of solar screens and glass types at full scale. He also consulted with the Technical Section of the Regional Government Services Agency (GSA) Building Services Branch to determine energy-efficiency options and means to fund the renovation. The Lawrence Berkeley National Laboratory's Windows and Daylighting Group was asked to review the final glazing performance specifications and to discuss options with the property manager. The performance specifications set minimum glass characteristics of: SHGC≤0.22, Tv≥0.32, U-factor=1.42–1.87 W/m^2-˚K (0.25–0.33 Btu/h-ft^2-˚F), and LSG=Tv/SHGC>1.44.

During the bidding process, one general contractor suggested a tinted green glass to meet the performance specifications. The property manager visited a nearby building where the glass was installed. His original preference for bronze glass to keep the building appearance the same shifted when he saw the bright interior views and the more natural color rendition of the exterior landscape through the tinted green glass; in contrast, the bronze glass gave a smoggy appearance to the view. The glass selected was an IG unit consisting of 6-mm conventional green-tinted exterior pane with a conventional low-E coating, an air gas fill, and a 6-mm clear interior pane. The center of glass properties are: Tv=0.43, SHGC=0.28, U-factor=1.93 W/m^2-˚K (0.34 Btu/hr-ft^2-˚F), LSG=1.54. The IG units were installed with a replacement glass stop, to accommodate the wider 2.5-cm (1-in) thickness, and caulked with silicone sealant. Johnson Controls, consultant project manager for Tucson Electric Power and GSA, had put out a request for proposals in early August 1996. The job was completed in April 1997 at a cost of \$161/m^2-glass (\$15/ft^2-glass) including materials, installation, overhead, profit, and bond. A life-cycle cost analysis was not required by the contract; however, an analysis was done using DOE-2 simulations and the Federal Building Life-Cycle Cost (BLCC) program issued by the National Institute for Standards and Technology (NIST). See Appendix D for a printout from this analysis. The installation was done with the building completely occupied, and with essentially no complaints from occupants. Some interior partitions attached to the window mullions had to be removed and replaced, but this was completed smoothly with no impact on the schedule.

Quantifying energy savings with actual metered data is difficult because cooling energy loads from window systems alone cannot be measured directly (in contrast, for example, to energy consumption of lighting equipment which can easily be measured with a watt transducer). One must be able to isolate changes in energy use patterns produced by the selective glazing from other changes to the building, e.g., increased occupancy, new equipment, or other upgrades to the building. To draw statistically significant conclusions, whole-building utility data must be collected for at least a six-month period, preferably during the summer, when only the window system has been changed. Because there were changes in the Tucson Federal Building's mechanical system, occupancy, and plug loads between the previous year and during the few months following the completion of the window retrofit, there are no "clean" monitoring data from which to draw significant conclusions.

Prior to installation of the spectrally selective glazing, the property manager had to resort to several strategies to try to avoid being charged for demand beyond the utility baseline. He used an off-the-grid emergency generator at times and had a plate-frame heat exchanger installed on the evaporative cooling tower, so he could avoid using the building's 200-ton York chiller during some periods. Tucson charges \$6.66/kW over 200 kW usage per month and \$0.066/kWh for electricity use. In June following the retrofit, the building manager began to notice changes that suggested improvements in building energy performance. He changed the mechanical system start time to one hour later than previous operation because demand had reduced substantially. He also reduced the lock on the chiller limit from 80% to 70%. In mid-July 1997 with outdoor temperatures of 37.8˚C (100˚F), he was able to run his chiller at 74%, down from 80% in 1996. In addition, he took side-by-side measurements of the new and old glazing interior surface temperature glass on a hot day. The bronze glass in full sun was 49˚C (120˚F) while the new glass was only 34.4˚C (94˚F), a 14.6˚C (26˚F) temperature difference. Many building occupants have remarked on the brighter view and more comfortable conditions since the new green-tinted glass was installed.

Contact: Cecilia Serrano, GSA Senior Property Manager, (520) 670-4738, Ron Sandlin, GSA Property Manager, (520) 670-4738, or Bruce Tanner, GSA Chief Engineer, (520) 670-4748.

Window Films, Oakland Federal Building

The Oakland Federal Building consists of two 18-story towers connected by a five-story glass rotunda, totaling 99.87 km^2 (1.075 Mft^2) gross floor area. The office building has been ~95% occupied since 1992 and is located in downtown Oakland, California. Annual electricity consumption is 11,125 MWh/year at an annual cost of $1,091,000 given the Pacific Gas and Electric Company (PG&E) time-of-use rate schedule. Annual natural gas consumption is 96,000 therms/year at an annual cost for heating and domestic hot water of $56,640.

The window system consists of 6-mm (0.25-in) single-pane conventional tinted green glass (Tv=0.75, SHGC=0.60, U-factor=5.44 W/m^2-˚K (0.96 Btu/hr-ft^2-˚F)) with custom aluminum frames. A typical window rough opening has a width of 4.57 to 7.62 m (15 to 25 ft) and a height of 2.74 m (9 ft), with divided lights ranging in width from 0.91 to 1.52 m (3 to 5 ft). The window glazing is recessed 0.15 to 0.41 m (0.5 to 1.33 ft) from the face of the building and has mullions that are 0.13 m (5 in.) deep on the interior and 2.5 cm (1 in.) deep on the exterior. Double-pane glazing was initially specified in the building but was taken out because of "value engineering," concern for keeping first costs low.

Steps to select and evaluate spectrally selective glazing options

The following procedure is a guide to determining the cost-effectiveness of selective glazings over conventional glazings. See the "Other Benefits" section of this report, and incorporate a cost for non-energy benefits (e.g., loss of productivity, tenant absenteeism) if possible. Software programs are listed in the section "For Further Information."

1) Choose selective glazing products based on the following simple center-of-glass criteria:*
   a) LSG=Tv/SHGC>1.25 or greater.
   b) Tv>0.40 for increased view and connection to the outdoors.
   c) Minimize SHGC for decreased solar heat gains and air-conditioning loads and for increased thermal comfort.
   d) U-factor≈1.42–1.87 W/m^2-˚K (0.25–0.33 Btu/h-ft^2-˚F).

   Consult manufacturer's product literature or the NFRC Certified Products Directory for these specifications. These guidelines are given for center of glass only, not whole window performance.
2) Consult with the manufacturer for exact window properties for a given building's window size, shape, frame construction, glass type, and gas fill. If the manufacturer does not provide this service, use WINDOW4.1 to determine exact window properties.
3) Build an input description of the building for DOE-2 or comparable program. Include WINDOW4 output data. Model exterior and interior shading conditions and daylighting strategies. Allow the mechanical system to be sized automatically by the program in order to determine HVAC downsizing opportunities. Run separate calculations for baseline and selective glazings where only the glazing type is changed (do not include with other energy-efficiency strategies).
4) Investigate cooling, lighting, and heating energy reductions for the perimeter zones only (do not include core zone). Break reductions down by window orientation. Do the same for peak demand reductions and relate to HVAC capacity reductions.
5) Determine simple payback for a quick check of cost-effectiveness. Multiply energy savings by an average flat utility rate or use built-in economics modules of DOE-2 to calculate energy savings for time-of-use rate structures.

   Divide annual energy cost saving by the glazing area. Divide the incremental cost of the spectrally selective glass (materials only) by the annual cost savings per glazing area to arrive at payback period. Include savings from downsizing the air-conditioning system or chiller, if applicable.
6) Run the Federal Building Life-Cycle Cost (BLCC) software program issued by the National Institute for Standards and Technology (NIST), to determine life-cycle cost payback.

For residential applications, use the RESFEN program, a WINDOWS-based PC program for calculating residential fenestration heating and cooling energy use and costs. Also consult the National Fenestration Rating Council (NFRC) for a list of all residential window products and their comparable thermal and solar properties.

*Properties are given for center of glass, not total window. These properties are typically given in manufacturer's catalogs. WINDOW4 computes these properties for the entire window system, which tends to be lower in performance than the center of glass.

Consideration of window films was undertaken in response to complaints from tenants that occupy the south tower and because of large energy and demand utility bills. Tenants complained that the space was too hot or too cold, especially for those occupying the south- and west-facing perimeter offices during the summer. The property manager noticed a large increase in energy use during the summer and deduced that the cause was increased cooling load because of heat gains through the single-pane glazing. Demand increased by 50% and electricity consumption increased 22% from the winter to the peak summer months. On a moderate 24˚C (75˚F) day, one 450-ton chiller was running at part load to serve the entire building. On a hot sunny day (32-39˚C, 90 to 100˚F), one 450-ton chiller and one 1,000-ton chiller were operating at maximum load. Yet Oakland's climate is fairly mild; ASHRAE design dry-bulb temperatures are 32.8˚C/91˚F (0.1%) and 25˚C/77˚F (2.0%).

The criteria for window film selection were (a) to minimize the reflectivity of the window film and its impact on the building appearance, and (b) to ensure the highest quality implementation for tenant satisfaction.

The building owner wanted to use GSA funds for the energy retrofit, which are provided through the Federal Buildings Fund. To qualify for these funds, an energy-efficiency retrofit must be cost-effective with a life-cycle cost payback of 10 years or less, determined by the BLCC program. See Appendix E for more information. Projects throughout the nation bid competitively for these funds; projects with shorter paybacks are typically implemented first.

Estimates of annual energy requirements must be available for BLCC analysis. Typically, a Federal building energy manager will rely on the window manufacturer to provide these data. Performance data (Tv, SHGC, etc.) for films applied to generic glazing types (e.g., clear, tinted, double-pane) can be obtained in manufacturer product literature. For properties of the film-glass assembly in a particular building, manufacturers can provide property managers with data using the LBNL WINDOW 4.1 program. Utility rebate/incentive programs sometimes offer comprehensive performance analysis services; however, at the time, the local utility, Pacific Gas and Electric (PG&E), offered prescriptive rebates for window films with specific performance properties; for east, south, and west facing windows, films with a minimum Tv of 0.50, a maximum SHGC of 0.61, and a ratio of Tv to SHGC greater than 1.15 were to be rebated at $4.84/m^2$ ($0.45/ft^2$) of installed window film.

The property manager researched various window film products, installed several in full-scale installations on various windows to evaluate the building's appearance, and obtained an energy analysis[c] performed by the manufacturer. The window manufacturer estimated total energy savings at $7/m^2$-glass-yr for the north facade and $20/m^2$-glass-yr for the south, with a simple payback of two years for the south, east, and west facades, and five years for the north facade. Exterior shading was not accounted for, and interior shading was considered negligible, so these payback estimates may be generous. The suggested window film, a combination of tinted gray film over a reflective film, had center-of-glass properties of Tv=0.13 and SHGC=0.25 installed on the existing glass. Material and labor costs were estimated at $37.67/m^2$-film ($3.50/ft^2$-film). Costs for removal 10 to 15 years later were estimated at $16 to 21.50/m^2$-film ($1.50 to 2.00/ft^2$-film) in today's cost terms, but these were not factored into the analysis.

The energy savings were based only on reduction in the building's cooling load and so were directly proportional to reduction in solar heat gain coefficient. However, the building also has stepped daylighting controls, so lighting energy use would be affected by reduced daylight transmission. The Tv of 0.13 proposed by the manufacturer was very low and would dampen exterior views, including the building's spectacular south and west views of the San Francisco Bay area.

The Lawrence Berkeley National Laboratory ran a preliminary DOE2.1E building energy simulation analysis for the Oakland Federal Building with a number of window film, shading, and lighting control options. The payback periods for the window films were found to be roughly comparable to those generated by the manufacturer's analysis, except for the north facade, which showed a payback of nine years. For a selective, low-E window film with high daylight transmission (Tv=0.58, SHGC=0.46, LSG=1.26), the payback period was increased to eight to 10 years for the east, west, and south facades and to 20 years for the north facade. If

(c) The Association of Industrial Metalizers Coaters and Laminators, Inc. (AIMCAL) FACTS program (call (602) 951-3997) is a simple PC program that calculates the cost and energy benefits of window films.

interior and exterior shading and electric lighting controls are considered, the simple payback becomes 11 to 20 years for all facade orientations. Interior, perforated, white, vertical, louver blinds are employed on all windows.

Several types of window films were considered. The slightly reflective, dark window film would change the exterior building appearance and impair views (reflective films obscure night views). Dark absorptive films with little reflectivity would increase occupants' thermal discomfort. The films with higher Tv would provide more daylight and a connection to the outdoors but had a long payback (eight to 10 years), which reduced the project's chances of qualifying for GSA funding because GSA funds for energy-efficiency projects are allocated to those with the shortest paybacks. Given these limitations, the property manager was unable to choose among the types of window film, so no film was installed.

This case study illustrates the consequences of "value engineering" or selecting exterior glazing systems simply to reduce first costs. A glazing system has a 20- to 30-year life and directly affects the comfort of employees (the highest paid employees often have window offices and thus suffer greatest discomfort). Glazing problems are very difficult to remedy once a building is built. For the added cost of the window film retrofit, the best spectrally selective insulating glass unit could have been installed from the start, avoiding loss in productivity and comfort and with no increase in operating costs. A reduction in original HVAC capacity could also have been factored in to justify increased cost of the selective glazing when the building was constructed.

Contact: Edgar Gray, GSA Property Manager, (510) 637-5000.

The Technology in Perspective

Conventional blue- or green-tinted glazings have been available commercially since the 1960s but have more recently been "tuned" to achieve higher selectivity. Sputtered, silver-based, multilayer, selective, low-E coatings were developed and commercialized in the early 1980s. A wide range of durable and reliable selective products exists for any type of window application in the United States.

The optical properties of these glazings should continue to improve during the next 5 to 10 years as material scientists push theoretical limits with new engineered coatings that are cheaper and easier to manufacture. If a good durable coating is developed that does not need the protected environment of an IG unit, then spectrally selective single-pane units could be more widely used. In addition, selective tinted glazings may eventually include colors other than the blue-green family. As conventional low-E coatings have transformed the window market of the 1980s, we anticipate that selective low-E coatings will do the same during the 1990s and beyond.

Manufacturers

AFG Industries

Mark Sullivan
AFG Industries
P.O. Box 929
Kingsport TN 37662
phone: 615/357-2450
fax: 615/357-8858

Cardinal IG

Mike Tourville
Cardinal IG
12301 Whitewater Dr.
Minnetonka MN 55426
phone: 612/932-6602
fax: 612/935-5538

Dupont Polymers

Ray Foss
Dupont Polymers
P.O. Box 1217
Parkersburg VA 26102
phone: 304/863-4355
fax: 304/863-2681

Ford Motor Company

Lowell Rager
Ford Motor Company
Glass Division
Fairlane Business Park
17333 Federal Drive, Suite 230
Allen Park MI 48101
phone: 313/845-5788
fax: 313/845-5986

Guardian Industries

Karl Straky
Guardian Industries
14600 Romine Road
Carleton MI 48117
phone: 313/654-4332
fax: 313/654-0935

Interpane

Donald Cheshek
Interpane Glass Company
950 East 133rd Drive
Thornton CO 80241-1141
phone: 303/452-9667, x323
fax: 303/452-1159

Libbey-Owens-Ford Co.

Paul Gore
Libbey-Owens-Ford Co.
811 Madison Ave., P.O. Box 799
Toledo OH 43697-0799
phone: 419/247-4833
fax: 419/247-4517

Monsanto

Claude Duquette
Monsanto
730 Worcester Street
Springfield MA 01151
phone: 413/730-2614
fax: 413/730-3394
MSE Specialty Films
Dave Swaggerty

MSE Specialty Films

4540 Viewridge Road
San Diego CA 92123
phone: 800/736-1836, 1272
fax: 619/576-8519

PPG Industries

Patrick Kenny
PPG Industries, Inc.
One PPG Place
Pittsburgh PA 15272
phone: 412/434-2616
fax: 412/434-3675

Southwall Technologies

Dave Jones
Southwall Technologies
1029 Corporation Way
Palo Alto CA 94303
phone: 415/962-9115 x123
fax: 415/967-0182

3M Construction Markets

James Mannix
3M Construction Markets
Bldg. 224-45-08
3M Center
St. Paul MN 55144
phone: 612/733-2222
fax: 612/736-0611

Viracon

Laura Dalland
Viracon
800 Park Drive
P.O. Box 990
Owatonna MN 55060
phone: 800/533-0482, x3189
fax: 507/455-4290

For Further Information

Organizations

American Architectural Manufacturing Association (AAMA)

1827 Walden Office Square, St. 120
Schaumburg IL 60173-4268
phone: 847/303-5664
fax: 847/303-5774

Association of Industrial Metalizers, Coaters, and Laminators, Inc.

211 N. Union Street, Suite 100
Alexandria VA 22314
phone: 602/951-3997

Energy Efficiency and Renewable Energy Clearinghouse (EREC)

800/DOE-EREC

Energy Efficiency and Renewable Energy Network (EREN)

(for Internet access to FEMP documents)
http://www.eren.doe.gov

Federal Energy Management Program (FEMP)

Help Line: 800/DOE-EREC

Florida Solar Energy Center (FSEC)

1679 Clearlake Road
Cocoa FL 32922-5703
phone: 407/638-1000
fax: 407/638-1010

Illuminating Engineering Society of North America

120 Wall Street
New York NY 10005-4001
phone: 212/248-5000
fax: 212/248-5017

Lawrence Berkeley National Laboratory (LBNL)

Building Technologies Program
1 Cyclotron Road, MS 90-3111
Berkeley CA 94720
phone: 510/486-6845
fax: 510/486-4089
http://windows.lbl.gov

National Fenestration Rating Council, Inc. (NFRC)

1300 Spring Street, Suite 120
Silver Spring MD 20910
phone: 301/589-6372
http://www.nfrc.org.

Primary Glass Manufacturers Council (PGMC)

3310 Harrison Street
Topeka KS 66611-2279
phone: 913-266-3666
fax: 913-266-0272

Sealed Insulating Glass Manufacturers Association (SIGMA)

401 N. Michigan Avenue
Chicago IL 60611
phone: 312/644-6610
fax:312/527-6783

Software

Window 4.1

This program calculates total window properties from individual component data (glass panes, gas fill, frames). To obtain a free copy of this program, send a fax with name and address to WINDOW4 at (510) 486-4089. In addition, there is access to information via the internet at http://eande.lbl.gov/BTP/therm.html.

Applied Film Laminator

This program calculates combined glass and film properties from spectral data of individual layers. To obtain a free copy of this program, send a fax with name and address to Applied Film Laminator at (510) 486-4089.

DOE-2 and RESFEN Energy Analysis Software.

These programs simulate building energy use, a useful way to compare energy-efficient alternatives, estimate energy costs, perform life-cycle cost analysis, determine code compliance, estimate peak power demands, disaggregate energy end uses, and—most commonly—compute loads for HVAC equipment sizing. A partial list of energy simulation software includes the following (not all model daylighting or show code compliance):

***DOE2.1E**

Lawrence Berkeley National Laboratory
(510) 486-5711

***RESFEN[4]**

National Fenestration Rating Council
(301) 589-NFRC

***ADM-DOE2**

ADM Associates
(916) 363-8383

***CEDDOEDC**

California Energy Commission
(916) 654-5106

***DOE24/Comply-24**

Gabel-Dodd Associates
(510) 428-0803

***DOE-Plus**

ITEM Systems
(206) 382-1440

***PRC-DOE2**

Partnership for Resource Conservation
(303) 499-8611

***Micro DOE2**

Acrosoft International
(303) 696-6888

***Visual DOE2.0 for Windows**

Eley & Associates
(415) 957-1977

BLAST

BLAST Support Office
(800) 842-5278

Trace 600

The Trane Company
(608) 787-3926

HAP

Carrier Corporation
(800) 253-1794
ASHRAE/IESNA Stnd.90.1 Compliance & ASHRAE Publications
(800) 527-4723

*For a list of software companies selling versions of DOE2, contact LBNL.

Literature

Manufacturer Technical Literature and Product Representatives are free sources of information and assistance. Product choices and suppliers can be identified in *Sweets Catalog* starting with section 08810. Many of the brochures in the section contain useful general information on glazing in addition to product-specific data. Most manufacturers will readily supply samples (typically 12" by 12" or smaller) and copies of their Sweets brochures. Some manufacturers will also perform energy calculations.

Books

There are only a few up-to-date materials available on glazing. The best source for timely information may be the architectural journals, which occasionally run glazing articles in their technical sections.

Residential Windows —A Guide to New Technologies and Energy Performance by John Carmody, Stephen Selkowitz, and Lisa Heschong (W.W. Norton, 1996) is a good concise book on window technologies, their implications for residential design, and their appropriate specification.

Building Technologies Program Publications: http://eande.lbl.gov/BTP/pub/papers.html.

“Tips for Daylighting with Windows” is a quick reference for designers using a set of easy steps and rules of thumb, emphasizing “how-to” practical details: http://eande.lbl.gov/BTP/pub/designguide.

A well-written, concise document, “Energy Management Program Window Film Training Guide,” explaining window film products is distributed by the Association of Industrial Metalizers Coaters and Laminators, Inc. (AIMCAL). In this document, non-energy benefits of window films are cited, such as improved shatter resistance, reduced fading of interior furnishings because of low ultraviolet light transmission, creation of desired privacy, creation of a uniform exterior building facade appearance, balancing of hot and cold spots in the building, increased tenant comfort, and reduced glare. Other information is also given, such as what films are composed of, what the definitions are for various solar properties, how long films will last, how windows with films should be cleaned, whether films kill house plants, whether window films can be used on low-E windows, and what may cause glass breakage.

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Appendixes

Appendix A: Properties of Spectrally Selective Glazings for Nonresidential and Residential Applications

Appendix B: Energy Performance Analysis

Appendix C: Energy, Peak Demand, and Cost Data from the Simulations

Appendix D: Federal Life-Cycle Cost Analysis

Appendix E: Federal Life-Cycle Costing Procedures and the BLCC Software

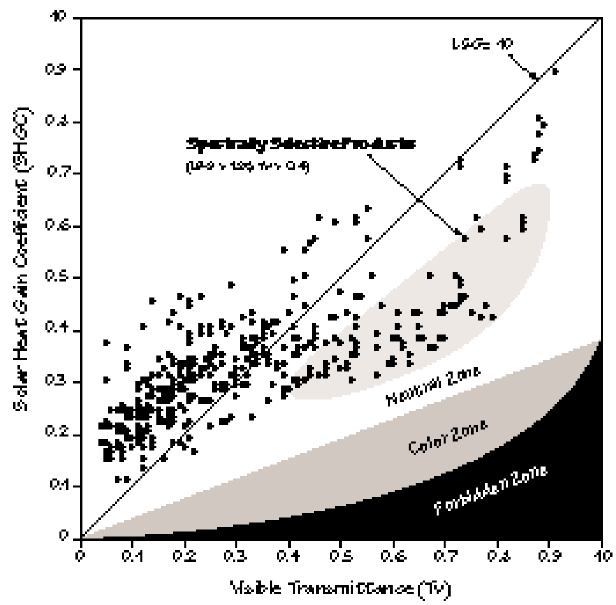
Appendix A

Properties of Spectrally Selective Glazings for Nonresidential and Residential Applications

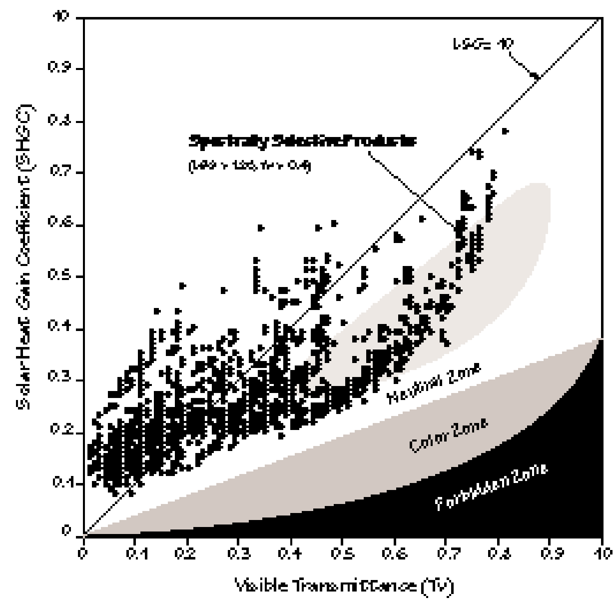
To give an idea of the number of spectrally selective products and options available for particular building applications, we show the center-of-glass visible transmittance (Tv) and solar heat gain coefficient (SHGC) properties for commercially available glazing products. Graphs are presented for nonresidential and residential markets for single-, double-, and triple-pane products. Data are from the NFRC Certified Products Directory (November 1996).

Non-Residential Applications

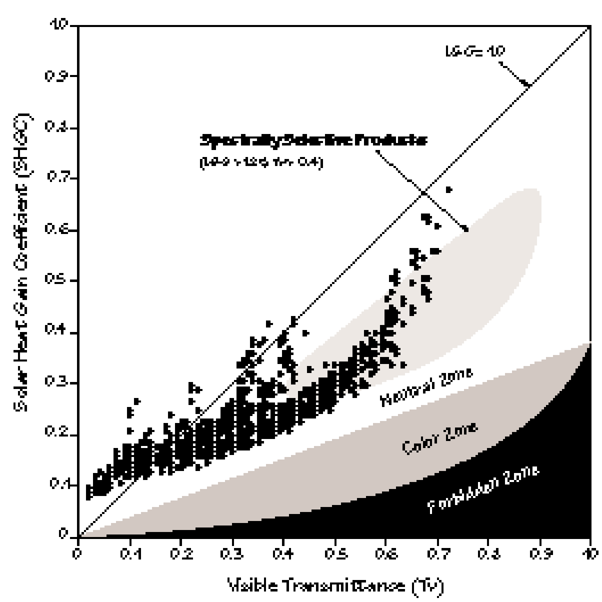
Single-Pane



Double-Pane



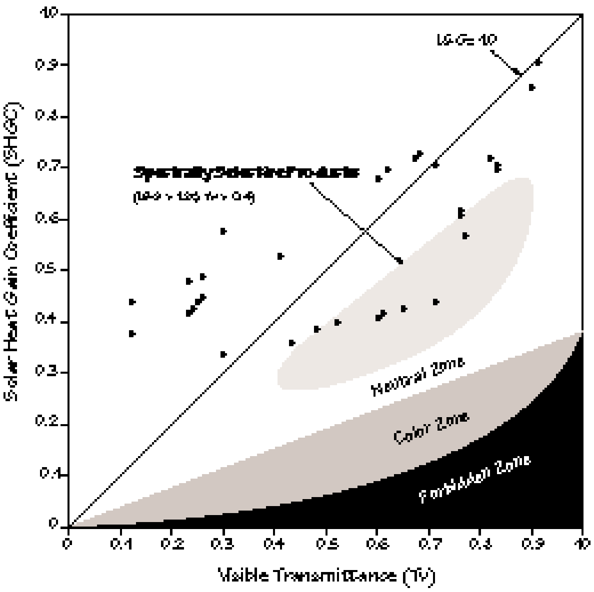
Triple-Pane



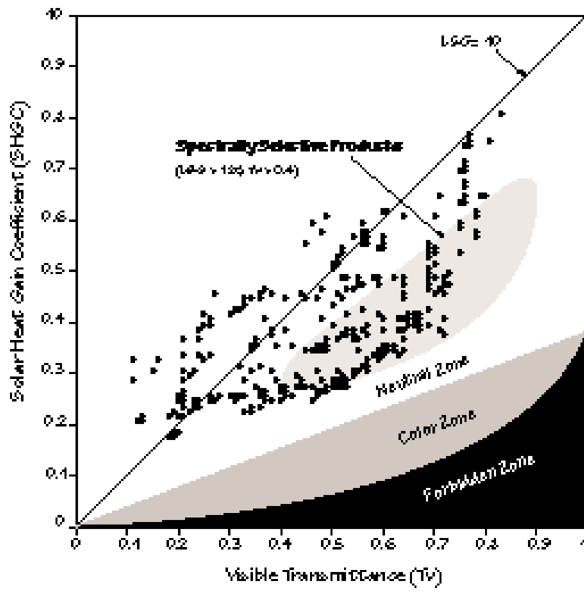
Properties of commercially available, spectrally selective glazings for nonresidential applications: single-pane, double-pane, and triple-pane products.

Residential Applications

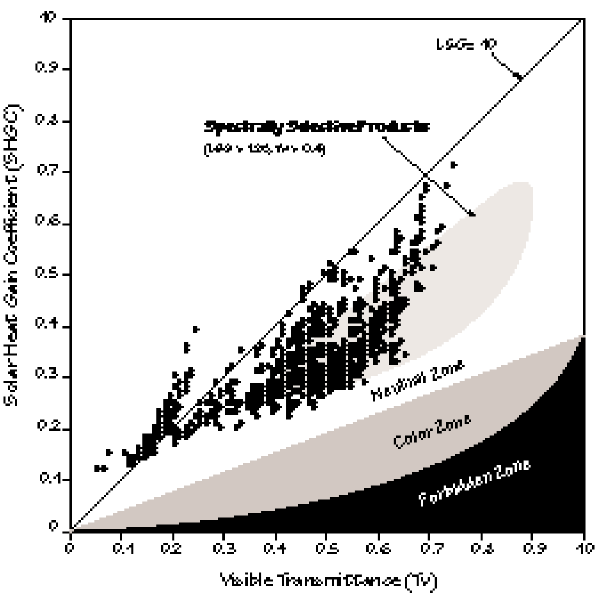
Single-Pane



Double-Pane



Triple-Pane



Properties of commercially available, spectrally selective glazings for residential applications: single-pane, double-pane, and triple-pane products.

Appendix B

Energy Performance Analysis

Energy performance of commercial glazing systems for this FTA was modeled and evaluated using the DOE-2.1E Building Energy Simulation Program. The DOE-2 program is the building industry standard, requiring as input a geometrical description of the building and a physical description of its construction, HVAC equipment, end-use load schedules, utility rates, and hourly weather data to determine building energy consumption. A five-zone prototypical office building module, consisting of ten 3.05-m-(10-ft)-wide by 4.57-m-(15-ft)-deep offices in each perimeter zone and a central 929-m^2 (10,000-ft^2) core zone was modeled in five climates. Perimeter zones were oriented to face the four cardinal directions. Continuous strip windows were modeled in the exterior wall of each perimeter zone. Glazing area was varied from 0% to 70% window-to-wall ratio (WWR) where the wall area was defined as the floor-to-floor exterior wall area, and the floor-to-floor height was 3.66 m (12 ft).

The performance of the glazing systems was determined assuming the use of an interior diffusing shade. The shade is modeled as "manually operated," drawn down completely by the occupant during daylight hours if direct sun or glare is present. The shade was triggered if the transmitted direct solar radiation exceeded 94.5 W/m^2 (30 $Btu/h{\cdot}ft^2$) or if the glare index computed using the Hopkinson Cornell-BRS formula exceeded 20. With the shade drawn, the Tv of the glazing was reduced by 35% and the SHGC by 25%. Although the components are "conventional," they are not yet in routine commercial use; the assumed operation is optimistic for a manually controlled shade.

The electric lighting system was designed to provide 538 lux (50 fc) of workplane illuminance at a lighting power density of 16.15 W/m^2 (1.5 W/ft^2) and incorporated, when noted, a continuous dimming control system. The lighting was dimmed to a minimum light output of 10% with a minimum power output of 33% if the daylight workplane illuminance level at the task location was equal to or greater than 538 lux (50 fc). Forty percent of the electric lighting system heat gains were vented to the return air plenum.

To isolate the energy effects relevant to glazing, interior surfaces were modeled as adiabatic (i.e., no heat transfer occurs). The effect of the thermal capacitance of the building was not studied. The building was modeled with lightweight construction. The exterior walls were modeled as no-mass quick walls with U-factor=0.52 $W/m^2{\cdot}K$ (0.091 $Btu/h{\cdot}ft^2{\cdot}°F$). The floors were modeled as adiabatic surfaces consisting of carpeting with a fibrous pad [U-factor=2.73 $W/m^2{\cdot}K$ (0.481 $Btu/h{\cdot}ft^2{\cdot}°F$)] over a 0.10-m-(0.33-ft-) thick, 5-kg/m^3 (80-lb/ft^3) concrete slab. The ceiling was modeled as an adiabatic surface consisting of 0.013-m (0.0417-ft) acoustical tile with the concrete floor slab above it. The interior partitions consisted of 0.016-m (0.0521-ft) gypsum board over stud walls.

To isolate zone loads from building system interactions, a separate single-zone constant-volume system was assigned to each zone. A constant cooling system coefficient of performance (COP = 3.0) converted the system loads to energy use. Hourly data therefore reflects a fixed COP for part-load performance and variations in exterior temperature and humidity conditions. Proportional thermostat cooling setpoints for weekdays were 22.2˚C (72˚F) between 7:00 and 19:00 and 32.2˚C (90˚F) between 19:00 and 7:00, and 32.2˚C for all hours of weekends and holidays. The design cooling temperature was set at 25.6˚C (78˚F).

For each climate, a simple payback was calculated based on electricity and gas energy savings at a cost of $0.064/kWh and $0.36/therm, respectively. The payback was based on the incremental glazing materials cost from the defined baseline glazing to the spectrally selective coating on clear glazing and the spectrally selective coating on selective tinted glazing. Peak demand reductions were also determined (W/ft^2 of floor area) compared to the spectrally selective coating on clear glazing. All window orientations were assumed to have the same glazing area.

Appendix C

Energy, Peak Demand, and Cost Data from the Simulations

In Tables 1 and 2 (on the following pages) we give annual electricity consumption, peak electrical demand, and annual heating consumption data for a prototypical commercial office building module, determined using the DOE-2 simulation program. These data can be used to determine roughly the viability of spectrally selective glazings for a particular building application. For commercial buildings, an hour-by-hour building energy simulation program—such as DOE-2 (see "For Further Information"), which uses hourly weather data and can model the thermodynamics of advanced window systems—will provide more accurate estimates for a specific building. We delineate the steps to select and evaluate spectrally selective glazing options in Appendix D.

Glazing area is varied from 15% to 60% of the exterior floor-to-floor wall area. We also present performance data with and without the use of daylighting controls, which automatically dim electric lights if sufficient daylight is available in the room. Data are given for the climates of Madison, WI; Los Angeles, CA; Miami, FL; and Phoenix, AZ.

Table 1. DOE-2 Energy Performance Data for No Daylighting Controls Case

Glass Area	Glazing	Type	Annual Electricity Consumption (kWh/ft^2-glass)				Peak demand (W/ft^2-floor)				Annual Heating Consumption (kWh/ft^2-glass)			
			Madison	LA	Miami	Phoenix	Madison	LA	Miami	Phoenix	Madison	LA	Miami	Phoenix
0.15	Single Clear	1	77.58	81.79	101.23	102.47	4.99	5.06	5.22	5.66	96.47	1.70	0.24	2.13
	Double Bronze	2	72.30	75.41	92.84	91.05	4.50	4.44	4.74	4.97	68.74	1.02	0.15	1.15
	Double Reflective	3	70.61	72.46	88.48	84.34	4.21	4.16	4.46	4.63	70.87	1.45	0.20	1.50
	Double Low-E	4	71.64	74.87	91.65	87.97	4.43	4.31	4.67	4.77	57.17	0.67	0.09	0.71
	Double Selective Clear	5	71.16	74.18	90.40	86.23	4.36	4.25	4.59	4.69	57.18	0.73	0.10	0.76
	Double Selective Tint	6	71.78	75.34	92.19	88.55	4.43	4.35	4.69	4.80	54.59	0.56	0.07	0.61
0.30	Single Clear	1	47.91	49.13	62.24	65.55	6.40	6.53	6.57	7.39	72.77	1.87	0.26	2.45
	Double Bronze	2	40.68	42.58	53.08	54.14	5.27	5.35	5.55	6.03	46.33	0.89	0.12	1.17
	Double Reflective	3	36.29	37.03	45.60	46.10	4.51	4.54	4.74	5.19	51.13	1.50	0.19	1.65
	Double Low-E	4	38.57	40.80	50.41	50.40	4.98	4.96	5.20	5.52	34.68	0.44	0.06	0.56
	Double Selective Clear	5	37.22	39.26	48.89	47.87	4.80	4.73	5.08	5.26	35.14	0.50	0.07	0.61
	Double Selective Tint	6	38.82	41.77	51.28	51.11	5.00	5.08	5.25	5.60	32.02	0.32	0.05	0.43
0.45	Single Clear	1	37.95	38.50	49.26	52.89	7.74	8.05	8.00	9.04	64.26	1.92	0.29	2.57
	Double Bronze	2	30.73	31.73	40.05	41.92	6.15	6.24	6.35	7.08	38.18	0.94	0.13	1.23
	Double Reflective	3	26.12	26.06	32.43	33.84	4.98	5.03	5.24	5.86	43.28	1.61	0.20	1.78
	Double Low-E	4	28.37	30.02	37.46	38.32	5.65	5.67	5.88	6.37	26.72	0.40	0.06	0.54
	Double Selective Clear	5	27.04	28.44	35.86	35.64	5.38	5.33	5.73	5.94	27.02	0.44	0.06	0.59
	Double Selective Tint	6	28.63	31.00	38.36	38.97	5.72	5.84	5.95	6.44	24.04	0.28	0.04	0.39
0.60	Single Clear	1	32.82	33.03	42.37	46.31	8.98	9.52	9.33	10.62	59.40	1.92	0.31	2.59
	Double Bronze	2	25.80	26.33	33.62	35.71	6.99	7.09	7.19	8.12	33.90	0.98	0.13	1.28
	Double Reflective	3	21.23	20.61	25.82	27.77	5.48	5.52	5.72	6.53	39.04	1.69	0.21	1.85
	Double Low-E	4	23.29	24.59	30.91	32.19	6.34	6.35	6.51	7.18	22.70	0.40	0.06	0.54
	Double Selective Clear	5	21.98	23.03	29.31	29.57	5.96	5.93	6.33	6.63	22.96	0.43	0.06	0.59
	Double Selective Tint	6	23.60	25.61	31.85	32.87	6.41	6.57	6.61	7.28	19.98	0.26	0.04	0.3

Table 2. DOE-2 Energy Performance Data for Daylighting Controls Case

Glass Area	Glazing	Type	Annual Electricity Consumption (kWh/ft^2-glass)				Peak demand (W/ft^2-floor)				Annual Heating Consumption (kWh/ft^2-glass)			
			Madison	LA	Miami	Phoenix	Madison	LA	Miami	Phoenix	Madison	LA	Miami	Phoenix
0.15	Single Clear	1	60.63	60.34	77.37	80.18	4.67	4.73	4.87	5.37	105.64	2.03	0.27	2.43
	Double Bronze	2	62.16	61.71	77.21	75.60	4.28	4.21	4.52	4.74	72.47	1.15	0.16	1.29
	Double Reflective	3	67.26	67.80	83.52	79.01	4.13	4.08	4.36	4.57	72.35	1.51	0.21	1.56
	Double Low-E	4	61.90	61.80	76.62	73.85	4.20	4.07	4.42	4.62	60.25	0.76	0.10	0.79
	Double Selective Clear	5	62.00	61.84	76.34	72.81	4.13	4.02	4.34	4.53	60.20	0.83	0.11	0.85
	Double Selective Tint	6	58.31	57.81	72.09	70.02	4.16	4.09	4.40	4.63	58.98	0.67	0.09	0.71
0.30	Single Clear	1	37.80	37.27	49.14	52.90	6.12	6.20	6.20	7.05	79.94	2.18	0.30	2.76
	Double Bronze	2	32.29	31.90	41.09	42.93	4.99	5.03	5.20	5.73	50.66	1.07	0.14	1.35
	Double Reflective	3	32.95	32.46	40.63	40.32	4.31	4.29	4.55	4.89	53.15	1.63	0.20	1.81
	Double Low-E	4	30.35	30.31	38.47	39.47	4.66	4.64	4.83	5.26	38.19	0.55	0.08	0.67
	Double Selective Clear	5	29.37	29.13	37.25	37.33	4.45	4.42	4.70	4.99	38.71	0.62	0.08	0.73
	Double Selective Tint	6	29.13	29.96	38.47	38.81	4.67	4.73	4.89	5.32	36.41	0.43	0.06	0.54
0.45	Single Clear	1	30.86	30.33	40.28	44.22	7.45	7.75	7.62	8.72	69.87	2.18	0.33	2.84
	Double Bronze	2	24.33	23.90	31.17	33.60	5.87	5.90	5.93	6.74	42.03	1.09	0.15	1.41
	Double Reflective	3	22.16	21.44	27.23	28.08	4.54	4.60	4.82	5.29	46.69	1.81	0.22	2.01
	Double Low-E	4	22.04	22.19	28.51	30.00	5.37	5.32	5.42	6.03	29.78	0.49	0.07	0.66
	Double Selective Clear	5	20.83	20.62	26.68	27.47	5.01	4.99	5.16	5.62	30.25	0.56	0.07	0.72
	Double Selective Tint	6	21.80	22.87	29.28	30.45	5.42	5.48	5.54	6.11	27.30	0.36	0.05	0.49
0.60	Single Clear	1	27.38	26.85	35.53	39.80	8.70	9.21	8.91	10.30	63.90	2.14	0.34	2.82
	Double Bronze	2	20.73	20.30	26.69	29.34	6.70	6.76	6.76	7.81	37.20	1.13	0.15	1.43
	Double Reflective	3	17.46	16.41	20.89	22.63	4.94	5.03	5.18	5.87	42.56	1.91	0.24	2.10
	Double Low-E	4	18.25	18.52	23.88	25.72	6.06	6.00	6.00	6.83	25.30	0.48	0.07	0.65
	Double Selective Clear	5	16.92	16.89	21.98	23.12	5.58	5.57	5.70	6.26	25.82	0.54	0.07	0.71
	Double Selective Tint	6	18.32	19.39	24.91	26.32	6.14	6.22	6.21	6.94	22.58	0.33	0.05	0.47

Appendix D

Federal Life-Cycle Cost Analysis for the Tucson Federal Building, Tucson, Arizona

A life-cycle cost analysis was conducted for the Tucson Federal Building using annual energy consumption data generated by the DOE-2 building energy simulation program. Analysis was done for each building orientation with a flat utility rate of $0.066/kWh and $0.36/therm (no demand charge). Materials and installation cost for the glazing per facade per floor was $15/ft^2-glass * 540 ft^2/facade = $8100.

Input File:

QBLCC filename = TUCFED.QI
Analysis type = Federal Analysis—Energy Conservation Projects
Project name = Tucson Federal Building
Base Date of Study = 1998
Service Date = 1998
Study Period = 25 years
Discount rate = 4.1%
Inflation rate = 0.00%
Cap replacements and residual values (if any) included as investment costs.
Residual values automatically calculated for capital components.
Residual values automatically calculated for capital replacements.

Common energy data	#1	#2	#3	#4
Energy type:	Electric	Nat.Gas		
Units:	(kWh)	(therm)		
Price per unit:	$0.066	$0.360		
Escalation type code:	2	2		

Data for DOE escalation rates:
DOE Escalation Rate File = ENCOST98
Rate Schedule Type = 2
State Abbreviation = AZ

DOE Price escalation rates for Electric

Year	Rate(%)	Year	Rate(%)	Year	Rate(%)	Year	Rate(%)	Year	Rate(%)
1998	-1.4486	2008	-0.3254	2018	-0.4098				
1999	-2.7501	2009	0.2176	2019	0.0588				
2000	-2.0965	2010	-1.5201	2020	0.0588				
2001	-1.3446	2011	-1.0474	2021	0.0000				
2002	-0.6057	2012	-0.5571	2022	0.0000				
2003	-1.4220	2013	-0.7283	2023	0.0000				
2004	-1.5971	2014	-1.2415						
2005	-1.5183	2015	-1.2571						
2006	-0.7974	2016	-0.5208						
2007	-1.1790	2017	-0.6399						

DOE Price escalation rates for Nat. Gas

Year	Rate(%)	Year	Rate(%)	Year	Rate(%)	Year	Rate(%)	Year	Rate(%)
1998	-0.8264	2008	-0.2146	2018	0.2237				
1999	-0.4167	2009	-0.4301	2019	0.8929				
2000	-0.4184	2010	-0.2160	2020	1.9912				
2001	-1.0504	2011	-0.8658	2021	1.9523				
2002	0.0000	2012	-0.6550	2022	1.7021				
2003	-1.0616	2013	-0.6593	2023	1.6736				
2004	-0.6438	2014	-0.6637						
2005	-0.2160	2015	-0.6681						
2006	0.2165	2016	0.4484						
2007	0.6479	2017	-0.2232						

Number of alternatives in file = 8
Number of groups in file = 4

ALT #	ALTERNATIVE NAME	GROUP CODE	LIFE (Y/M)	INITIAL COST($)	CAPITAL REPLACEMENTS FREQ*	CAPITAL REPLACEMENTS COST($)	ANNUAL OM&R COST($)	NON-ANNUAL OM&R FREQ*	NON-ANNUAL OM&R COST($)
1	north bronze	A	30/0	0	0/0	0	0	0/0	0
2	north select	A	30/0	8100	0/0	0	0	0/0	0
3	east bronze	B	30/0	0	0/0	0	0	0/0	0
4	east select	B	30/0	8100	0/0	0	0	0/0	0
5	south bronze	C	30/0	0	0/0	0	0	0/0	0
6	south select	C	30/0	8100	0/0	0	0	0/0	0
7	west bronze	D	30/0	0	0/0	0	0	0/0	0
8	west select	D	30/0	8100	0/0	0	0	0/0	0

*FREQ = Frequency of occurrence (in years/months)

ALT #	ALTERNATIVE NAME	GROUP CODE	ANNUAL ENERGY USE Electric (kWh) #1	ANNUAL ENERGY USE Nat.Gas (therm) #2	AN. ELEC. DEMAND CHARGE($)
1	north bronze	A	21096	1	0
2	north select	A	15828	1	0
3	east bronze	B	32609	0	0
4	east select	B	21813	0	0
5	south bronze	C	33022	0	0
6	south select	C	22119	0	0
7	west bronze	D	33804	0	0
8	west select	D	22226	0	0

Output File:

QuickBLCC (QBLCC 2.5-98) 03-21-1998/09:07:37

QBLCC filename = TUCFED.QI
Analysis type = Federal Analysis—Energy Conservation Projects
Project name = Tucson Federal Building
Base date of study = 1998
Service date = 1998
Study Period = 25 years
Discount rate = 4.1%
Annually recurring costs and energy costs discounted from end of year.
DOE energy price escalation rate file = ENCOST98
Number of alternatives in file = 8
Number of groups in file = 4

Note: Project alternatives displayed in increasing order of investment cost

Group code: A Alternative Name	----Present-Value Costs---- Investment Costs*	OM&R Costs	Energy Costs	Total Life-Cycle Costs
north bronze	$0	$0	$18782	$18782<—MIN LCC
north select	$7606	$0	$14090	$21696

Comparative measures are only calculated for the alternative with lowest LCC relative to alternative with the lowest present-value investment cost.

Can’t compute comparative economic measures for an alternative against itself.

Group code: B	------------------------Present-Value Costs------------------------			
Alternative Name	Investment Costs*	OM&R Costs	Energy Costs	Total Life-Cycle Costs
east bronze	$0	$0	$29025	$29025
east select	$7606	$0	$19415	$27021<—MIN LCC

Comparative measures are only calculated for the alternative with lowest LCC relative to alternative with the lowest present-value investment cost.

Comparative economic measures for east select relative to east bronze:
NET SAVINGS = $2004; SIR = 1.26; AIRR = 5.08%
Ratio of present-value energy savings to total savings = 1.00

Group code: C	------------------------Present-Value Costs------------------------			
Alternative Name	Investment Costs*	OM&R Costs	Energy Costs	Total Life-Cycle Costs
south bronze	$0	$0	$29390	$29390
south select	$7606	$0	$19686	$27292<—MIN LCC

Comparative measures are only calculated for the alternative with lowest LCC relative to alternative with the lowest present-value investment cost.

Comparative economic measures for south select relative to south bronze:
NET SAVINGS = $2098; SIR = 1.28; AIRR = 5.12%
Ratio of present-value energy savings to total savings = 1.00

Group code: D	------------------------Present-Value Costs------------------------			
Alternative Name	Investment Costs*	OM&R Costs	Energy Costs	Total Life-Cycle Costs
west bronze	$0	$0	$30088	$30088
west select	$7606	$0	$19782	$27388<—MIN LCC

Comparative measures are only calculated for the alternative with lowest LCC relative to alternative with the lowest present-value investment cost.

Comparative economic measures for west select relative to west bronze:
NET SAVINGS = $2700; SIR = 1.35; AIRR = 5.37%
Ratio of present-value energy savings to total savings = 1.00

* Investment costs include capital replacements and residual values (if any). Residual values for initial capital investment are calculated when life extends beyond end of study period. Residual values for capital replacements are calculated when life extends beyond end of study period.

Appendix E

Federal Life-Cycle Costing Procedures and the BLCC Software

Federal agencies are required to evaluate energy-related investments on the basis of minimum life-cycle costs (10 CFR Part 436). A life-cycle cost evaluation computes the total long-run costs of a number of potential actions, and selects the action that minimizes the long-run costs. When considering retrofits, sticking with the existing equipment is one potential action, often called the *baseline* condition. The life-cycle cost (LCC) of a potential investment is the present value of all of the costs associated with the investment over time.

The first step in calculating the LCC is the identification of the costs. *Installed Cost* includes cost of materials purchased and the labor required to install them (for example, the price of an energy-efficient lighting fixture, plus cost of labor to install it). *Energy Cost* includes annual expenditures on energy to operate equipment. (For example, a lighting fixture that draws 100 watts and operates 2,000 hours annually requires 200,000 watt-hours (200 kWh) annually. At an electricity price of $0.10 per kWh, this fixture has an annual energy cost of $20.) *Nonfuel Operations and Maintenance* includes annual expenditures on parts and activities required to operate equipment (for example, replacing burned out light bulbs). *Replacement Costs* include expenditures to replace equipment upon failure (for example, replacing an oil furnace when it is no longer usable).

Because LCC includes the cost of money, periodic and aperiodic maintenance (O&M) and equipment replacement costs, energy escalation rates, and salvage value, it is usually expressed as a present value, which is evaluated by

$$LCC = PV(IC) + PV(EC) + PV(OM) + PV(REP)$$

where PV(x) denotes "present value of cost stream x,"
IC is the installed cost,
EC is the annual energy cost,
OM is the annual nonenergy O&M cost, and
REP is the future replacement cost.

Net present value (NPV) is the difference between the LCCs of two investment alternatives, e.g., the LCC of an energy-saving or energy-cost-reducing alternative and the LCC of the existing, or baseline, equipment. If the alternative's LCC is less than the baseline's LCC, the alternative is said to have a positive NPV, i.e., it is cost-effective. NPV is thus given by

$$NPV = PV(EC_0) - PV(EC_1)) + PV(OM_0) - PV(OM_1)) + PV(REP_0) - PV(REP_1)) - PV(IC)$$

or

$$NPV = PV(ECS) + PV(OMS) + PV(REPS) - PV(IC)$$

where subscript 0 denotes the existing or baseline condition,
subscript 1 denotes the energy cost saving measure,
IC is the installation cost of the alternative (note that the IC of the baseline is assumed zero),
ECS is the annual energy cost savings,
OMS is the annual nonenergy O&M savings, and
REPS is the future replacement savings.

Levelized energy cost (LEC) is the break-even energy price (blended) at which a conservation, efficiency, renewable, or fuel-switching measure becomes cost-effective (NPV >= 0). Thus, a project's LEC is given by

$$PV(LEC*EUS) = PV(OMS) + PV(REPS) - PV(IC)$$

where EUS is the annual energy use savings (energy units/yr). Savings-to-investment ratio (SIR) is the total (PV) savings of a measure divided by its installation cost:

$$SIR = (PV(ECS) + PV(OMS) + PV(REPS))/PV(IC).$$

Some of the tedious effort of life-cycle cost calculations can be avoided by using the Building Life-Cycle Cost software, BLCC, developed by NIST. For copies of BLCC, call the FEMP Help Desk at (800) 363-3732.

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About the Federal Technology Alerts

The Energy Policy Act of 1992, and subsequent Executive Orders, mandate that energy consumption in the Federal sector be reduced by 30% from 1985 levels by the year 2005. To achieve this goal, the U.S. Department of Energy's Federal Energy Management Program (FEMP) is sponsoring a series of programs to reduce energy consumption at Federal installations nationwide. One of these programs, the New Technology Demonstration Program (NTDP), is tasked to accelerate the introduction of energy-efficient and renewable technologies into the Federal sector and to improve the rate of technology transfer.

As part of this effort FEMP is sponsoring a series of Federal Technology Alerts that provide summary information on candidate energy-saving technologies developed and manufactured in the United States. The technologies featured in the Technology Alerts have already entered the market and have some experience but are not in general use in the Federal sector. Based on their potential for energy, cost, and environmental benefits to the Federal sector, the technologies are considered to be leading candidates for immediate Federal application.

The goal of the Technology Alerts is to improve the rate of technology transfer of new energy-saving technologies within the Federal sector and to provide the right people in the field with accurate, up-to-date information on the new technologies so that they can make educated judgments on whether the technologies are suitable for their Federal sites.

Because the Technology Alerts are cost-effective and timely to produce (compared with awaiting the results of field demonstrations), they meet the short-term need of disseminating information to a target audience in a timeframe that allows the rapid deployment of the technologies—and ultimately the saving of energy in the Federal sector.

The information in the Technology Alerts typically includes a description of the candidate technology; the results of its screening tests; a description of its performance, applications and field experience to date; a list of potential suppliers; and important contact information. Attached appendixes provide supplemental information and example worksheets on the technology.

FEMP sponsors publication of the Federal Technology Alerts to facilitate information-sharing between manufacturers and government staff. While the technology featured promises significant Federal-sector savings, the Technology Alerts do not constitute FEMP's endorsement of a particular product, as FEMP has not independently verified performance data provided by manufacturers. Nor do the Federal Technology Alerts attempt to chart market activity vis-a-vis the technology featured. Readers should note the publication date on the back cover, and consider the Alert as an accurate picture of the technology and its performance at the time of publication. Product innovations and the entrance of new manufacturers or suppliers should be anticipated since the date of publication. FEMP encourages interested Federal energy and facility managers to contact the manufacturers and other Federal sites directly, and to use the worksheets in the Technology Alerts to aid in their purchasing decisions.

Federal Energy Management Program

The Federal Government is the largest energy consumer in the nation. Annually, in its 500,000 buildings and 8,000 locations worldwide, it uses nearly two quadrillion Btu (quads) of energy, costing over $8 billion. This represents 2.5% of all primary energy consumption in the United States. The Federal Energy Management Program was established in 1974 to provide direction, guidance, and assistance to Federal agencies in planning and implementing energy management programs that will improve the energy efficiency and fuel flexibility of the Federal infrastructure.

Over the years several Federal laws and Executive Orders have shaped FEMP's mission. These include the Energy Policy and Conservation Act of 1975; the National Energy Conservation and Policy Act of 1978; the Federal Energy Management Improvement Act of 1988; and, most recently, Executive Order 12759 in 1991, the National Energy Policy Act of 1992 (EPACT), and Executive Order 12902 in 1994.

FEMP is currently involved in a wide range of energy-assessment activities, including conducting New Technology Demonstrations, to hasten the penetration of energy-efficient technologies into the Federal marketplace.

FEMP
FEDERAL ENERGY MANAGEMENT PROGRAM

For More Information

FEMP Help Desk
(800) 363-3732
International callers please use (703) 287-8391
Web site: http://www.eren.doe.gov/femp/

General Contacts

Ted Collins
New Technology Demonstration Program
Program Manager
Federal Energy Management Program
U.S. Department of Energy
1000 Independence Avenue, SW, EE-92
Washington, DC 20585
(202) 586-8017
Fax: (202) 586-3000
theodore.collins@hq.doe.gov

Steven A. Parker
Pacific Northwest National Laboratory
P.O. Box 999, MSIN: K5-08
Richland, Washington 99352
(509) 375-6366
Fax: (509) 375-3614
steven.parker@pnl.gov

Technical Contact

Eleanor S. Lee
Lawrence Berkeley National Laboratory
1 Cyclotron Road, MSIN: 90-3111
Berkeley, California 94720
(510) 486-4997
Fax: (510) 486-4089
eslee@lbl.gov

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