



APPLICATION NOTE

An In-Depth Examination of an Energy Efficiency Technology

Energy-Efficient Window Glazing Systems for Commercial Facilities

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Summary

A commercial building's windows can play an important role in its cooling load. They should maximize daylighting, reducing lighting loads, and minimize summer heat gain. They should have high visible transmittance (the percentage of visible light that passes through) and a low shading coefficient (an indicator of heat gain due to solar radiation). This Application Note presents information on energy-efficient glazing alternatives for both new construction and retrofits.

For new construction, the primary alternatives for buildings that are concerned about cooling loads are tints, reflective coatings, and spectrally selective coatings. Tinted glazings lower the shading coefficient and give a bronze, gray, blue, or green tint. Reflective coatings are thin layers of metals or metallic oxides on the surface of the glass; they produce a better shading coefficient than tinted glazing, but light transmittance is very low. Spectrally selective glazings pass much of the visible daylight and block the infrared, for excellent shading and good visible transmittance. In the near future, there will be switchable glazings which change their properties in response to a signal.

For buildings that are concerned about heating loads, there are low-E glazings which minimize heat loss through the windows. They let the solar heat in and keep the warmth inside the room.

For retrofit, films can be applied to the interior surface of the window. Most films darken a window and give a mir-

ror-like look to the glass. However, at least one spectrally selective film is available.

How This Technology Saves Energy

Proper window design and selection can reduce a building's energy use throughout the year. Electric lighting requirements can be reduced by designing the windows in conjunction with **daylighting**¹ techniques. For buildings with significant cooling loads, special glazings can be selected to reject excessive summer **solar heat gain**. Shading with overhangs and side fins can also be an effective means for reducing solar heat gain through windows.

Where cooling loads are the major concern, as in most commercial buildings, the perfect window provides light but no heat. About 45 percent of the sun's energy is at visible wavelengths; the rest is invisible. To minimize cooling loads, it is desirable to transmit as much visible energy as desired for the application, while rejecting the rest of the solar radiation (Figure 1). Such a window has high **visible transmittance** (T_{vis}), the percentage of visible light that passes through, and a low **shading coefficient** (SC), an indicator of the heat gain due to solar radiation.

Alternatively, for buildings with significant heating loads, **low-E** glazings can be applied to double-pane glass to minimize heat loss through the window.

¹ Bold-Italic words are defined in the section titled Definition of Key Terms.

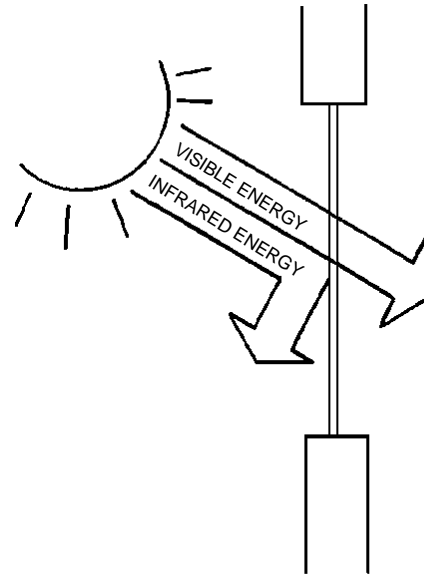


Figure 1: Characteristics of the Ideal Window in a Cooling Load Dominated Building (Reprinted with permission. Copyright 1992, "Architecture")

These glazings let the solar heat in to offset winter space heating and do not allow heat from within the room to radiate out (Figure 2).

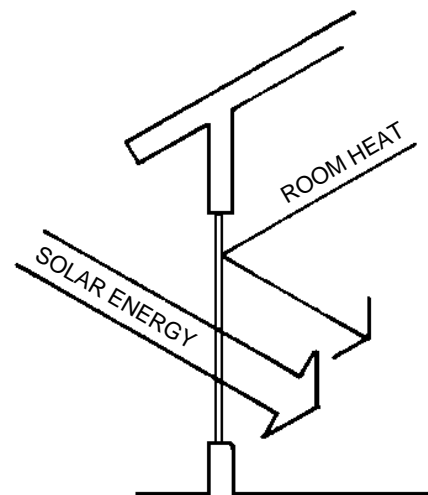


Figure 2: Characteristics of the Ideal Window in a Heating Load Dominated Building (Reprinted with permission. Copyright 1992, "Architecture")

A performance parameter that is gaining acceptance and beginning to appear in manufacturers' literature is the **luminous efficacy constant** (K_e). This is the ratio of the visible transmittance over the shading coefficient. Clear glass which lets in roughly equal amounts of visible light and solar near-infrared energy has a K_e close to 1.0. An ideal glazing for a cooling dominated commercial building, which would allow all visible light to pass through and block all the rest, would have a K_e of about 2.0, since about half of the solar radiation is in the visible spectrum. Several types of glazings achieve these characteristics to varying extents, including:

- **Tinted glazings**
- **Reflective glazings**
- **Spectrally selective glazings**
- Applied films
- Low-E glazings
- Switchable glazings

Figure 3 compares some of these types in terms of visible transmittance, shading coefficient, and luminous efficacy. The diagonal lines indicate K_e constants.

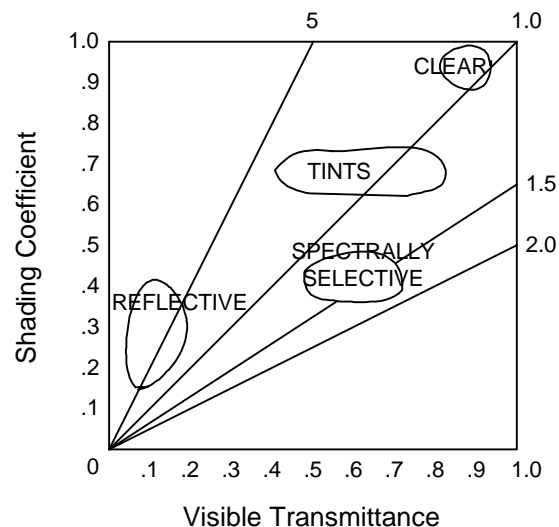


Figure 3: Luminous Efficacy (K_e) of Different Glazing Types
(Reprinted with permission. Copyright 1992, "Architecture". All rights reserved)

Tinted Glazings

Tinted glass, sometimes called absorbing glass, has energy-absorbing materials dispersed through it, lowering the shading coefficient and giving a tint—generally bronze, gray, blue, or green. Blue and green more naturally allow more visible light through than the bronze and gray.

A tint by itself achieves only a modest shading coefficient—typically 0.5 to 0.8—because some of the heat it absorbs eventually transfers into the space as radiant heat, as the window heats up. Shading coefficients vary by tint composition and glass thickness.

Reflective Glazings

Reflective glazing has better shading coefficients because it reflects rather than absorbs most of the infrared heat. The reflective coating is made of thin

Types of Window Glazings

Commercial building windows can be optimized for particular applications by using several different types of glazings. This section briefly describes them.

layers of metals or metallic oxides on the surface of the glass. Unfortunately, light transmittance is very low and the reduced cooling load due to barring infrared heat may be offset by the increased lighting requirements and indirect cooling load attributable to the lighting.

Reflective coatings should be applied on the outside surface of the glass or the outer pane of double-pane glass for best performance. This minimizes the amount of heat that is reradiated to the space by heated glass.

Spectrally Selective Glazings

Tinted and reflective glazings achieve a low shading coefficient at the price of making the window appear dark. Spectrally selective glazings bring in light without the heat. They are highly transmissive in the visible spectrum while blocking the infrared. They select to transmit or reflect specific wavelengths and the result is both an excellent shading coefficient and good visible transmittance.

Glazing is generally considered selective if it has relatively high visible transmittance and a relatively low shading coefficient. Luminous efficacy constants greater than 1.0 indicate that a glazing is selective.

Applied Films

Applied solar control films, also known as adhesive-backed films, are a common retrofit technology. They typically darken a window and give a mirror-like look to the glass, particularly the films that offer the highest degree of solar control. The advantages of films include

solar heat reduction, glare reduction, UV reduction, increased shatter resistance, and some improvement in insulation value.

Window films are multilayer assemblies of coatings and polyester films, as shown in Figure 4. These films are attached to the insides of existing windows by an adhesive backing. Current products are highly scratch-resistant, the adhesives are long lasting, optical clarity is excellent and the films gener-

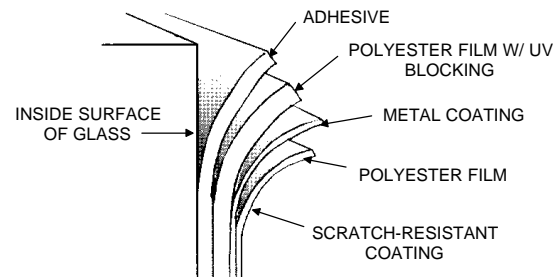


Figure 4: Multilayer Film Assembly

ally hold up 5-15 years.

Case Study: Application of a Spectrally Selective Window Film

At least one spectrally selective film is available which significantly reduces heat gain with minimal reduction in visible transmittance. Its K_e is about 1.4. A clothing store in Gilroy, California used it on 1,500 square feet of west-facing windows. They now spend less on air conditioning, the store is more comfortable, displays can remain in the windows longer due to reduced ultraviolet (UV) radiation, and there is still good visibility for customers to view displays from outside.

Low-Emissivity (Low-E) Glazings

Where heat loss is more of a concern, such as smaller buildings in cooler climates, low-E glazings may be economic. Glass is highly conductive, which means single-pane windows let heat pour out of a room. By trapping air between two panes of glass, the thermal resistance is doubled—a simple enough solution that the majority of windows in the U.S. are now manufactured with **insulating glass** (IG).

Low-E coatings further improve a window's thermal resistance. These ultra-thin, transparent, metallic coatings reflect heat back to its source. Applied to at least one of the inside glass surfaces in an IG unit or on a plastic layer suspended in the air gap, low-E coatings increase the window's ability to reflect long wave infrared radiation, reducing energy loss from a warm room.

Using gases such as argon and krypton between the glass surfaces can also improve thermal resistance. Low-E gas-filled windows are so effective that attention is now focused on the edge of the IG unit and the window frame as thermal weak points; improvements include thermal breaks in metal frames, greater use of wood and clad wood sash and frames, or the use of lower conductance frame materials like vinyl. On a winter day in a northern exposure **superwindows** actually achieve a net heat gain, contributing more useful solar heat gain than conductive losses.

Switchable Glazings

Switchable glazings, not yet mature products, change their properties, such as shading coefficient and visible

transmittance, in response to a signal. There are four categories, defined by the mechanisms that make them work.

- **Electrochromic:** Changes thermal and optical performance by the action of an electric field; changes back when the field is reversed. Runs on very low voltages (1-3V).
- **Liquid Crystal:** When current is applied, this material changes from translucent to relatively clear. Useful for privacy control but does not provide any energy savings. In addition, to maintain a clear state the voltage has to be continuously applied.
- **Thermochromic:** Change properties in response to changes in ambient temperature. As they get warmer they change from clear to diffusing, white and reflective.
- **Photochromic:** Darken in the presence of light, using the same technology used for years in sun glasses. At present they are still uneconomical for general applications. Suitable for glare control, but not as much for solar heat gain as they tend to reduce only the visible portion of the spectrum.

Applicability

The applicability of each type of glazing is a function of the particular application. Provided below are some guidelines on appropriate retrofit applications of films and a discussion of the particular glazing properties to consider for new construction.



Retrofitting Films

Most windows can be retrofitted with an applied film, but for some uses manufacturers do not recommend this, due to increased thermal stress. An example would be a dyed film on a partially shaded window: The dye absorbs solar energy and heats the glass, creating a large temperature difference between sunlit and shaded areas, possibly enough to break the glass. Other non-recommended uses include:

- Single panes larger than 100 sq. ft.
- Double panes larger than 40 sq. ft.
- Clear glass thicker than 3/8"
- Tinted glass thicker than 1/4"
- Laminated, reflective, wired, textured or patterned glass
- Triple-pane glass
- Visibly damaged glass
- Glass where sealant or glazing compound has hardened
- Glass in concrete, solid aluminum or solid steel framing

Selecting Glazings for New Construction

Energy properties of glazings are usually listed in product literature. Considering all of them leads to a good selection for maximum comfort and energy efficiency, while preserving view and other design intentions for the *fenestra-*

tion. Properties include:

- **Visible Transmittance (T_{vis}):** Glazing with high visible transmittance provides a good sense of connection with the exterior while admitting useful daylight which can offset the need for electric lighting and save significant energy. However, there can be a glare problem. Low transmittance glazing, while reducing glare, creates "gloomy" interiors and diminished view. Visual comfort can be achieved with high transmittance glazing through careful sizing and placement of windows, light colored interior surfaces, movable window coverings, and light diffusing deep sills and baffles.
- **Shading Coefficient (SC):** To minimize heat gain and air conditioning load, look for glazings with low shading coefficients.
- **U-Value:** U-values are important in colder climates, wherever 24-hour comfort is important, and where condensation must be avoided. The U-value (or R-value, the inverse of the U-value) is most important where heating costs are a concern, since the difference between indoor and outdoor temperatures is usually highest in winter. It is also critical for occupant comfort. In cold weather, anyone near a single-pane window with a high U-Value will feel chilled, regardless of room temperature, due to the body's heat loss by radiation to that cold glass surface. Additionally, room air chilled by contact with the cold glass falls along the window, creating a cold draft. Finally, cold surfaces have a higher likelihood for condensation than warm surfaces. The lower the U-Value, the lower the condensation possibilities.



- **Ultraviolet Transmittance:** Look for low ultraviolet transmittance when interior finishes or artwork need protection.

Field Observations to Assess Feasibility

This section discusses field observations to help determine the feasibility of energy-efficient window glazing in commercial buildings.

Related to Applicability

To determine whether a window film or new windows may produce energy savings, ask:

- **Are occupants complaining of overheating or glare?** Are they drawing shades or closing blinds and turning lights on to compensate for the loss in light?
- **Is an old window film worn, faded, or peeling off?**
- **Is a major renovation planned** that would allow installation of new windows?
- **Is the HVAC system undersized** and not meeting cooling demand?

If the answer is yes to any of these, an energy-efficient glazing may be appropriate.

Related to Energy Savings

For non-spectrally selective glazings, some trade-off is required between

reducing lighting requirements and cooling system energy requirements. The trade-off is a function of how strong the interaction is between the window, lighting, and HVAC systems and their efficiency. Typical characteristics for different glazings including combinations of tints and selective coatings, may be used in building simulation models which account for the system interactions and quantify energy savings.

Estimation of Energy Savings

Estimating energy savings from efficient glazings usually requires a computerized building simulation model, because the glazing will impact both HVAC and lighting loads, and the lighting loads also affect the HVAC loads. No hand calculation can fully account for these interactions.

Cost and Service Life

Factors That Influence Service Life and First Cost

Both first cost and service life of efficient glazings are affected by the quality of the material and the quality of the installation. Film manufacturers require professional installation in order to offer warranties. All quality films are warranted for 5-10 years.

Installed costs of window films range from \$1 to \$5 per square foot, depending on the film quality and the size and complexity of the installation. Figure 5



shows the relationship between installed cost and job size.

Typical Service Life

Five to ten years is a typical service life for window films. The CEE program assumes seven years. Typical for tinted and reflective glazings is 13 years.

Operation and Maintenance Requirements

All quality films include scratch-resistant coatings, virtually eliminating any need for extra precautions in cleaning. Windows with film are easy to clean without damage as long as a few guidelines are followed. Wash the window with a soft, clean cloth, soft paper towel or clean synthetic sponge. Use any normal glass cleaning solution that contains no abrasive materials. Dry the window with a soft cloth or squeegee.

Laws, Codes, and Regulations

Controversy in the 1980s led to regulations for window ratings published by glazing manufacturers. The **National Fenestration Rating Council** (NFRC), a coalition of industry and public sector groups, has developed standard procedures for calculating whole-window U-factor, solar heat gain coefficient, visible light transmittance, and air leakage. These data are available in the NFRC *Certified Products Directory* and on a sticker, such as that shown in Figure 6, on the window itself.

Local codes may restrict the type of glazing that can be applied. Depending

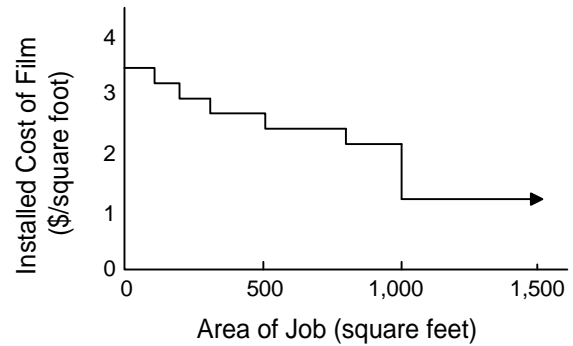


Figure 5: Retrofit Film Typical Installed Costs (Source: E-Source)

on the type of building, Title 24 may dictate a maximum shading coefficient and/or it may indicate a maximum U-Value for a project. ASHRAE Standard 90.1, a basis for many local energy codes, allows for increased glazing areas if selective glazings are used in combination with daylighting controls.

Zoning ordinances may limit the degree of exterior reflection or **visible reflectance**. For example, San Francisco has such a restriction.

Definitions of Key Terms

- **Daylighting:** Admitting only as much natural light as necessary and distributing it evenly and without glare. Light shelves, wide windowsills, special reflectors, louvers, walls, and blinds are commonly used to bounce light deep into the building.
- **Fenestration:** Any glazed opening in the building envelope. Components include: (1) glazing material, (2) framing, and (3) shading devices.


 National Fenestration Rating Council <small>Incorporated</small>			
AAA Window Company			
<small>Manufacturer stipulates that these ratings were determined in accordance with applicable NFRC procedures.</small>			
Energy Rating Factors	Ratings		Product Description
	Residential	Nonresidential	
U-Factor <small>Determined in Accordance with NFRC 100</small>	0.40	0.38	Model 1000 Casement Low-e = 0.2 0.5" gap Argon Filled
Solar Heat Gain Coefficient <small>Determined in Accordance with NFRC 200</small>	0.65	0.66	
Visible Light Transmittance <small>Determined in Accordance with NFRC 300 & 301</small>	0.71	0.71	
Air Leakage <small>Determined in Accordance with NFRC 400</small>	0.2	0.2	
<small>NFRC ratings are determined for a fixed set of environmental conditions and sizes and may not be appropriate for directly determining seasonal energy performance. For additional information contact:</small>			

Figure 6: NFRC Window Sticker
(Source: E-Source)

- Insulating Glass (IG):** An assembly of glazing materials that reduce heat transfer. Usually comprised of two or more panes of glass separated by air or other gas (such as argon or krypton).
- Low-E Glazing:** Has a special ultra-thin, invisible metallic coating which inhibits heat flow through the glass by reducing emissivity (the emittance of long-wave radiation (heat)). Usually applied to one of the protected surfaces of the glazing unit; for example, in one of the enclosed surfaces of an insulated glazing unit.
- Luminous Efficacy Constant (K_e):** A relatively new performance parameter which is gaining acceptance and beginning to appear in manufacturers' literature. It is the ratio of the visible transmittance over the shading coefficient.
- National Fenestration Rating Council (NFRC):** A national labeling and window rating council. Grew out of

the 1992 Energy Policy Act, to provide a standard method for comparing similar window related products from different manufacturers.

- Reflective Glazing:** Uses a metallic coating which reflects light striking it. Typically these glazings give a mirrored look and may have a colored effect, both on the reflective side and in the transmitted light. Shading coefficients tend to be low, as solar energy is neither transmitted nor absorbed by the glass.

- Shading Coefficient (SC):** Indicates heat gain due to solar radiation. A dimensionless number between 0 and 1 expresses total transfer of the sun's radiation as compared to a benchmark glazing (1/8" [3mm] clear glass) under identical conditions. The lower the number, the better. Widely used in air - conditioning calculations.

- Solar Heat Gain:** The incident solar radiation reduced by the glazing under a specific set of conditions. Part of the sun's energy is transmitted directly, part is bounced off by reflection, and part is absorbed; the absorbed energy warms the glazing which re-radiates this energy, both into the building and to the outdoors. Solar heat gain includes both the directly transmitted solar energy and the absorbed portion that is re-radiated inward.

- Spectrally Selective Glazing:** Such glazings reflect infrared with special coatings applied either directly on the glass or on a plastic film that is either suspended in an insulated glazing unit or applied directly on the glass.

- **Superwindow:** A window whose insulative value is high enough that over a winter day in a northern exposure it contributes a net heat gain to the building. To do so, R-6 to R-10 insulative values must be achieved with a shading coefficient greater than 0.5. In a sense these windows will outperform an insulated wall as they will be contributing more useful solar heat gain than conductive losses.

- **Tinted Glazing:** Has absorbing materials mixed into the glass and has a lower shading coefficient. The light that emerges appears to be of a particular color. The glass surface heats up and re-radiates part of the heat inward.

- **U-Value:** Measure of heat transfer through glazing due to temperature difference between inside and out.

- **Ultraviolet Transmittance:** Indicates the percentage of incident ultraviolet radiation that passes through the glazing. Ultraviolet radiation (UV) causes sunburn in people and plants, and contributes to fabric fading and artwork damage.

- **Visible Reflectance:** Indicates to what degree the glazing appears mirror-like, both inside and out; measures the percentage of light striking the glazing that is reflected. Most manufacturers provide both outside (exterior) and inside (interior mirror effect at night) reflectances. While all smooth clear glass is naturally somewhat reflecting, visible reflectance can be increased by glazing treatments such as metallic coatings. A higher visible reflectance represents a more mirror-like appearance, a darkened view and reduced

daylight transmittance.

- **Visible Transmittance (T_{vis}):** The percentage of visible light striking the glass that passes through to the interior. Manufacturers often list this as "daylight transmittance."

References to More Information

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3. E Source, Inc., "Commercial Space Cooling and Air Handling," Technology Atlas Series Volume II, 1995.
4. Loisos, G., "Windows and Glass," PG&E Energy Center.
5. PG&E Energy Center, "Applied Solar Films," Fact Sheet.
6. PG&E Energy Center, "Understanding Glazing Properties," Fact Sheet.
7. Schuman, J., "Cool Glazing," Progressive Architecture, April 1992.



Major Manufacturers

Glazings

Cardinal IG
12301 Whitewater Drive
Minnetonka, MN 55343
Tel (612) 935-1722
Fax (612) 935-5538

Libbey-Owens- Ford
2800 28th Street
Suite 133
Santa Monica, CA 90405
Tel (800) 522-9430
Fax (310) 450-6433

PPG Industries
1551 N. Tustin Ave
Suite 860
Santa Ana, CA 92705
Tel (714) 479-0890
Fax (714) 479-0287

Information on glazing rating procedures and the ratings for various products may be obtained from:

National Fenestration Rating
Council
1300 Spring Street, Suite 120
Silver Spring, MD 20910
Tel (301) 589-NFRC
Fax (301) 588-0854

A designer can also seek guidance with glazing studies at the PG&E Energy Center. The Center houses a wide array of design tools, resource information, technology exhibits, and technical expertise. The Center address and contact numbers are:

PG&E Energy Center
851 Howard Street
San Francisco, CA 94103
Tel (415) 973-7268
Fax (415) 896-1290

Window Films

Courtaulds Performance Films
16720 Maquardt Ave.
Cerritos, CA 90703
Tel (800) 447-8468
Fax (310) 926-4626

3M Construction Markets
1169 Chess Drive, Suite K
Foster City, CA 94404
Tel (415) 761-7611
Fax (415) 570-5892

Southwall Technologies
1029 Corporation Way
Palo Alto, CA 94303
Tel (415) 962-9111
Fax (415) 967-8713

