energydesignresources

design brief

GLAZING

With so many factors influencing glazing selections, whole-building lifecycle analysis is the best tool for determining the most cost-effective solution.

Summary

There are few decisions that designers make that have more impact on the appearance and utility of a building than the glazing selection. Glazing affects the look of a building from the inside as well as the outside, and it affects the comfort and productivity of the people who occupy the building. Furthermore, it has a large influence on the size and form of other building systems, including lighting and HVAC.

In recent years, the palette of glazing options available to designers has expanded greatly. Designers now have much more control over how much light glazing lets into a building and how much heat, cold, and noise it blocks out. They can alter the characteristics of glazing performance by varying tints, coatings, films, number of panes, and other glazing features. A whole-building lifecycle analysis using energy performance simulation software can help lead designers to the best solution among the many choices

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Good glazing selections can make buildings more attractive, more comfortable, more productive, and less expensive to own and operate.

Introduction

Few building systems affect the overall value of a building as much as glazing does. The building attributes that glazing can affect include:

- Exterior aesthetics,
- Indoor views,
- Occupant visual comfort,
- Occupant thermal comfort,
- Annual energy costs, and
- The size and form of HVAC systems.

In short, good glazing selections can make buildings more attractive, more comfortable, more productive, and less expensive to own and operate. Over the course of the last few decades glazing technology has improved significantly, greatly expanding designers' options to offer more value to their clients. For example, glazing is now better able to:

- Let in visible portions of the sun's energy while reflecting the nonvisible energy that can add unwanted heat to a building.
- Block out unwanted elements of the outdoor environment, including heat, cold, noise, and glare.

Yet, these new technologies seem underutilized in the marketplace. Why? For one thing, selecting from the options now available is complicated. The best glazing selection for any given application often depends on local climate, orientation, shading, and interior space usage. Secondly, these advanced glazing technologies cost more at first than the old standbys. To have a complete picture of their true lifetime cost, one must account for how they reduce both annual energy costs as well as the first costs of HVAC systems.

For example, when Apple Computers was designing a new research and development campus in Cupertino, California, the glazing was given a great deal of scrutiny (**Figure 1**). According to Ted Davalos, the project manager, "No one wanted reflective glass for aesthetic reasons; we just didn't like the mirror effect. But, of course, we needed to meet the state's energy efficiency requirements."

In the end, Apple selected Libbey Owens Ford's EverGreen glazing, which combines a light green tint with the capability to block out the sun's heat. The relatively high visible transmittance of the glazing affords the researchers in the building good visibility while providing plenty of natural light. "The tint color pleased everyone." said Davalos. "The first costs were a bit higher, but we saved enough in projected lifetime energy costs to raise the R-value of the roof from R-18 to over R-30."

Figure 1: Apple R&D Campus in Cupertino, California

Careful consideration of system interactions during the design process resulted in this attractive building that combines natural illumination and good overall energy performance.

Source: Pilkington LOF

Why Clear Glass Is Vanishing

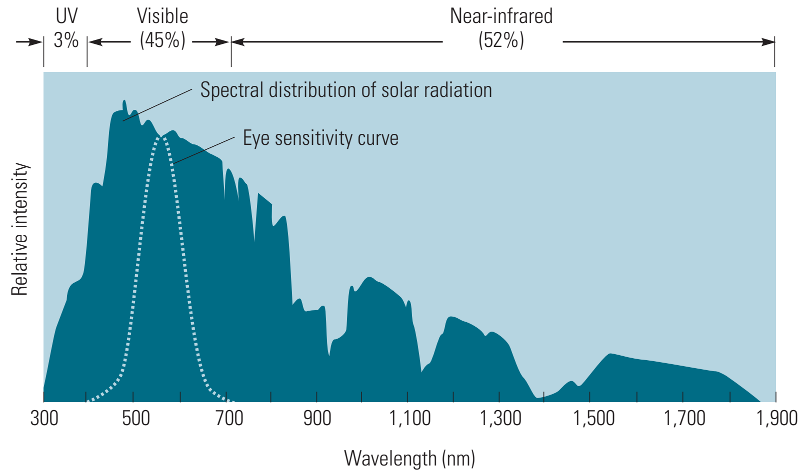
For many decades, single-pane, clear float glass dominated the commercial buildings market. Although clear glass still has many uses, it is being supplanted by other glazing technologies. Clear glass provides excellent views, but it also allows a substantial portion of radiation from the solar spectrum to pass through (**Figure 2**, next page). Although it is often desirable to get visible light into a commercial building, during the air-conditioning season nonvisible light adds unwanted heat that must be ultimately removed by the HVAC system at considerable cost.

For designers to effectively specify glazing, they need to have a good understanding of not only how a given glazing system transmits visible light, but also what portion of the sun's total spectrum provides heat to the interior (**Figure 3**, next page). These characteristics of glazing systems are typically expressed using the following technical terms:

- *Visual transmittance (Tv)* is a measure of the proportion of visible light that passes through a glazing system. Glazing

Figure 2: The solar spectrum

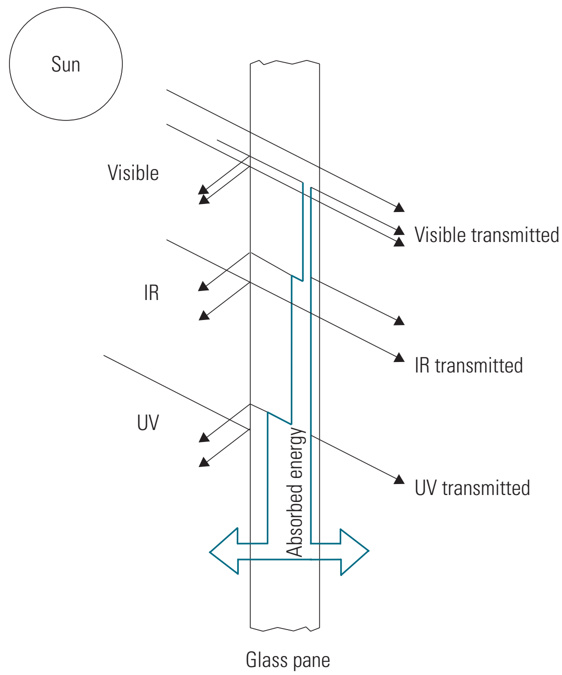
The human eye can see light between 380 and 720 nanometers in wavelength, less than half of the solar energy that strikes the earth. About 3 percent of the spectrum is in the ultraviolet region; the remaining nonvisible portion is in the near-infrared region.



Source: Kreith and Kreider

Figure 3: Heat and light reflectance and transmission

When the sun's rays strike a pane of glass, a portion is reflected, a portion is absorbed, and a portion is transmitted.



systems with high values of Tv (0.7 to 0.9) provide lots of natural light and good vision, but they can also be a source of unwanted glare if not properly controlled. Systems with lower values of Tv (less than 0.4) can be visually distorting and quite gloomy on cloudy days.

- *Solar heat gain coefficient (SHGC)* and shading coefficient (SC) are both measures of a glazing system's net solar gain. SHGC, which is the more modern index, is the sum of the solar radiation transmitted through the glazing and the portion of absorbed energy that ends up supplying heat inside. Glazing systems with high SHGCs (0.7 to 0.9) provide substantial solar gain, whereas those with low values (0.2 to 0.4) provide little solar gain. The SC expresses the net solar energy delivered by a given glazing system in relation to how much is transmitted through clear float glass 1/8 inch thick under the same circumstances.

- *The light-to-solar-gain (LSG) ratio* is simply Tv divided by SHGC. The LSG ratio is a useful index to compare how much light (and visibility) a glazing system provides in proportion to how much solar gain it produces. Systems with an LSG ratio greater than 1 provide more light than heat.

- *U-value* (also known as U-factor) expresses how much energy a glazing system transfers by conduction and convection. The lower the U-value, the more resistance a glazing system poses to heat transfer. Single-glazed units are worst-case; their U-values are typically higher than 1.0 Btu/hr–ft^2–°F, whereas double-glazed units with well-designed frames have U-values of less than 0.5 Btu/hr–ft^2–°F.

For example, clear architectural float glass of 1/8-inch thickness from Pittsburgh Plate Glass has a Tv of around 0.9. It transmits about 80 percent of the total solar radiation (visible plus invisible), reflects about 8 percent, and absorbs 12 percent. This absorbed energy is in turn transmitted to both the inside and

Systems with an LSG ratio greater than 1 provide more light than heat.

outside by conduction, convection, and radiation. The SHGC for this glass is 0.87, which means that it lets in a lot of heat. As a consequence, it was losing favor with designers even before Title 24, California's energy efficiency standard, officially discouraged its use.

Glazing Options

There are many more choices on the designer's palette than ever before, and the potential combinations are virtually endless.

There are many more choices on the designer's palette than ever before, and the potential combinations are virtually endless. Glazings may be clear, tinted, coated, or filmed—or some combination of these options. Windows may be single- or multiple-paned, and the multiple-paned units can be filled with air or inert gas. Thermal breaks that improve the performance of the windows at their edges are also available. The materials, the techniques used, and the degree to which various treatments are applied ultimately determine the key characteristics of each glazing unit. Note that throughout this brief, we will refer to "lites," meaning a single pane of glass in a glazing unit.

Tinted Glazing

Tinting is achieved by adding materials when glass is in the molten state. In general, colors are altered and transmittance is lowered, depending on which tinting agents are added and to what degree. Tinted glass can get quite hot because it absorbs a high percentage of the sunlight that strikes it. Old-style tinted glass tends to absorb across the spectrum, making it quite inefficient. For example, several large glass companies sell heavily tinted gray glass that has a Tv of only 0.08, an SHGC of 0.33, and an LSG ratio of only 0.24. Most of the solar energy absorbed by this particular glass is delivered to interior spaces by convection and radiation, and that can cause discomfort to people nearby.

Contemporary tinted glass performs much better. For example, both Libbey Owens Ford (LOF) and Pittsburgh Plate Glass (PPG) supply high-performance green- and blue-tinted glazings that have a Tv of 0.66, an SHGC of 0.52, and an LSG ratio of 1.3. This is a five-fold improvement over the old-style, heavily tinted gray glass.

Coated Glazing

By firing thin layers of metallic oxides or other materials onto clear or tinted glass, a wide range of optical and thermal effects can be achieved. One type of coated glazing, "reflective glass," acts like a partial mirror in both the visible and infrared regions of the spectrum. Typical clear reflective glass has a Tv of around 0.40 with an SHGC of 0.55. The best performance is obtained with the reflective coating on the outside surface, but building owners must then heed manufacturers' advice on using nonabrasive cleaning techniques. A reflective coating can be combined with an efficient tinted glass to limit visible transmittance even more—a design option that can help combat the effects of low-angle sunshine on east or west facades.

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Some coated glasses, known as "spectrally selective," "low-emissivity," and "low-e," have the ability to reflect much of the infrared portion of the solar spectrum while transmitting most of the visible. For example, a typical low-e lite has a Tv of 0.82 and an SHGC of 0.69, yielding an LSG ratio of 1.19, which means that it lets in much more light than heat. In cold climates, low-e glazings have the additional benefit of keeping warmth in the building during the winter. A typical pane of single glass might have a U-value of about 1.0 Btu/hr–ft^2–°F, whereas LOF's "Energy Advantage" low-e glass has a U-value of 0.63 Btu/hr–ft^2–°F.

Films

Thin films made of material that filter light of various wavelengths are used in two ways in new commercial buildings:

- To provide dead air spaces and specularly selective filtering when suspended between a pair of glass lites. This lowers the overall U-value of the glazing system while also delivering more favorable thermal and optical performance.
- To form laminated glass—a sandwich of two glass plates with a thin film of polyvinyl butyrate (PVB) in between.

Since it does not fall out of frames in large pieces when it is broken, laminated glass is sometimes specified in earthquake-prone zones.

Because the chief benefit of suspending film within glazing units is to provide additional insulation, this option is usually reserved for buildings in cool climates with large heating loads.

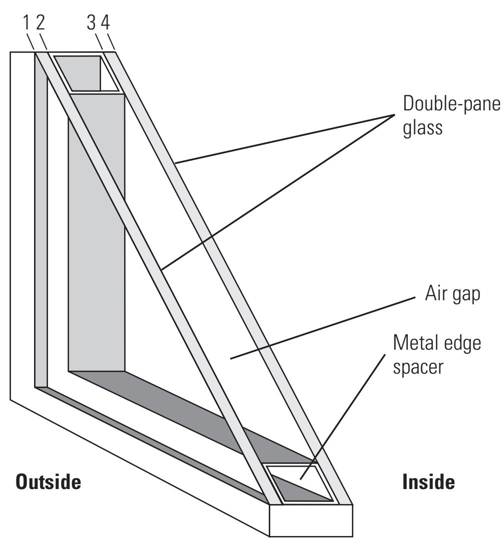
Laminated glass is widely used as safety glass in automobiles and doors, but it is also useful in commercial glazing applications. Clear laminated glass transmits quite well in the visible spectrum (with a Tv of 0.89), but it has a very sharp cutoff in the ultraviolet region; its transmittance is virtually zero between 250 and 380 nanometers. This quality helps to keep fine art, furniture, and carpets from suffering UV-caused fading. In addition, laminated glass can be formed from tinted or coated glass to achieve a variety of spectral and thermal effects. Since it does not fall out of frames in large pieces when it is broken, laminated glass is sometimes specified in earthquake-prone zones.

Multiple Panes

Multiple panes offer more insulation from conductive and convective heat transfer than single panes (**Figure 4**). Such insulation is not always wanted, however. For example, in warmer cli-

Figure 4: A double-pane glazing system

By incorporating two or more glazings into a single unit, designers can not only reduce conductive and convective heat transfer, but also take advantage of the benefits of several different types of glazing. Surfaces are numbered from 1 to 4, going from outside to inside.



mates, buildings with HVAC systems that are frequently in cooling mode when the outdoor temperature is lower than the indoor air temperature may gain little benefit from installing insulated glass. However, a similar building in a cooler climate where significant amounts of heating energy are required probably would benefit from insulated glass.

For buildings in which insulated glazing will be beneficial, the designer has creative opportunities to combine the virtues of several types of glass. For example, it is possible to use tinted glazing as the outside lite and put a clear lite on the inside. In Southern California climates, a low-e coating could be applied to the back of the outside lite (surface 2) to reflect the heat from absorbed solar radiation back outdoors. In colder climates, the low-e surface could be applied to the outside face of the indoor lite (surface 3), where it would help retain indoor heat. In both cases, the combination of dead air space and the clear inside lite of the insulated glass unit raises overall energy efficiency and improves comfort.

For buildings in which insulated glazing will be beneficial, the designer has creative opportunities to combine the virtues of several types of glass.

Applying delicate specularly selective coatings to surfaces 2 or 3 of an insulated glass unit makes it possible to protect fragile coatings from outside weather or inside cleaning processes that might otherwise damage them. In some cases, "soft coat" technology yields better optical or thermal performance than does "hard coat" technology.

It is possible to put three or more lites in an insulated glazing system, thereby creating more dead air spaces and lowering U-values. Although this can save energy in climates with long, cold winters, the added cost and complexity of this option is rarely cost-effective for most commercial buildings in California.

Inert Gas Filling

Many glazing manufacturers now offer the option of installing an inert gas such as argon or krypton between lites in place of air. This lowers U-values by 25 to 30 percent when the spacing between lites is quite small (around 1/4 inch). When the spacing between lites is a more common 1/2 inch, the improvement in U-value due to the addition of inert gas falls to 10 to 12 percent. As with other treatments whose main purpose is to make glazing more resistant to heat transfer, the additional cost associated with inert gas fills is usually only justified for buildings that require large amounts of heating energy.

Thermal Breaks

The thermal performance of insulated glazing units typically drops off abruptly at the edges of the glazing because both the spacer that holds the lites apart and the window frame itself are commonly made from highly conductive aluminum. As a result, the edges of the glazing conduct far more thermal energy than the center of the glass.

Proper glazing can significantly improve the benefits of daylighting.

The glazing industry is experimenting with non-conductive spacers, but currently, these new spacers are insufficiently reliable for widespread commercial application. Designers who seek to improve the thermal insulation of glazing, however, do have the option to specify thermally broken frames. These typically consist of polymer fillings or gaskets that break the connection between the inner and outer surfaces of the frame. Although thermal breaks are rarely used in buildings with dominant air conditioning loads, they are occasionally specified for these buildings as a means for controlling moisture and noise, in addition to extending the life of insulated glass units.

Daylighting Controls

Daylighting has gained in popularity as studies have shown that workers tend to be more productive in daylit spaces. Of course, it is also true that natural light is free for the taking. Proper glazing can significantly improve the benefits of daylighting. Although the size and location of windows is important, to get the most out of free natural light, designers should consider selecting a glazing with a high LSG ratio, which transmits daylight with less waste heat than electric light.

For electric lighting fixtures, the measure of efficiency is called luminous efficacy, typically quantified in lumens per watt (lm/W). An excellent lighting system with T8 fluorescent lamps may have a luminous efficacy of about 85 lm/W, whereas radiation from an excellent glazing system may have a luminous efficacy of 170 lm/W due to heat from solar gain.

To effectively displace electric light and to take advantage of Title 24 daylighting credits, several features must be incorporated into a building's design. They include:

- Strategically located lighting controls that adjust the levels of electric lighting in response to solar illumination, and
- Devices for controlling direct-beam sunlight that might cause glare in work spaces, preferably by reflecting light onto white ceilings.

Codes and Standards

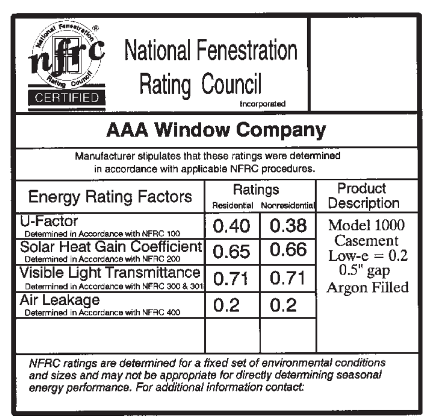
The National Fenestration Rating Council (NFRC) is a nonprofit corporation whose members represent the window industry, the research community, designers, and code officials. Using standard performance rating protocols agreed to by all parties, the NFRC labels thousands of glazing products for Tv, SHGC, and U-value (**Figure 5**).

Although the labeling system is voluntary, it has become quite widely accepted. The NFRC's three key rating components have formed the basis for the glazing standards included in Title 24, California's energy efficiency standards for buildings. Under the current version of the standard that has been in effect since the summer of 1999, all manufactured glazing products sold in California must carry a label showing the NFRC's U-value and SHGC ratings.

We encourage designers to use ratings from the NFRC label whenever computing gains and losses. For example, the U-value of the center of an insulated glazing unit is inevitably lower than

Figure 5: National Fenestration Rating Council label

All manufactured glazing products sold in California must have a National Fenestration Rating Council label that shows the U-value (listed as U-factor on the label) and the SHGC.


National Fenestration Rating Council Incorporated

CERTIFIED

AAA Window Company

Manufacturer stipulates that these ratings were determined in accordance with applicable NFRC procedures.

Energy Rating Factors	Ratings Residential	Ratings Nonresidential	Product Description
U-Factor Determined in Accordance with NFRC 100	0.40	0.38	Model 1000 Casement Low-e = 0.2 0.5" gap Argon Filled
Solar Heat Gain Coefficient Determined in Accordance with NFRC 200	0.65	0.66	
Visible Light Transmittance Determined in Accordance with NFRC 300 & 301	0.71	0.71	
Air Leakage Determined in Accordance with NFRC 400	0.2	0.2	

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:

Source: National Fenestration Rating Council the U-value of the unit as a whole because of additional conductive losses at the edges. The NFRC ratings reflect this difference—adjusting the U-value by 10 to 15 percent, depending mainly on window size—even though most product literature does not.

California's Title 24 standards also address envelope, mechanical, and lighting issues, reflecting the three primary professions—architecture, mechanical engineering, and electrical engineering—typically involved in the design and specification process. Glazing selections cross all three areas of expertise. Because they are part of the envelope, they influence lighting and electrical control design, and they have consequences for the size of the air-conditioning unit.

The Title 24 standards accommodate California's varied weather conditions by defining 16 climate zones. For two sets of zones, Title 24 specifies "not-to-exceed" prescriptive requirements for U-value and SHGC (**Table 1**). It is important to note that Title 24

Table 1: Title 24 prescriptive requirements for glazing

Although Title 24 defines 16 climate zones, its "not-to-exceed" requirements for U-value and relative SHGC are allocated among two sets of zones.

Performance Indices	Zones 1, 11–16[a]	Zones 2–10[b]
U-value (Btu/hr–ft^2–°F)	0.72	1.23
Relative SHGC, north-facing glazing	0.77	0.82
Relative SHGC, non-north-facing glazing	0.50	0.62

Notes:

a: Zones 1 and 11–16 include the counties of Alpine, Amador, Butte, Calavar, Calaveras, Colusa, Contra Costa, Del Norte, El Dorado, Fresno, Glenn, Humboldt, Imperial, Inyo, Kern, Kings, Lassen, Los Angeles, Madera, Mariposa, Mendocino, Merced, Modoc, Mono, Nevada, Placer, Plumas, Riverside, Sacramento, San Bernardino, San Diego, San Joaquin, Shasta, Sierra, Siskiyou, Solano, Sonoma, Stanislaus, Sutter, Tehama, Trinity, Tulare, Tuolumne, Yolo, and Yuba.

b: Zones 2–10 include the counties of Alameda, Lake, Los Angeles, Marin, Monterey, Napa, Orange, Riverside, San Benito, San Diego, San Francisco, San Luis, San Mateo, Santa Barbara, Santa Clara, Santa Cruz, and Ventura.

Some counties, for example Los Angeles and Riverside, include several climate zones.

Source: California Energy Commission

specifies values of relative SHGC, which are computed by multiplying a glazing system's SHGC by a factor that varies by the size of an exterior overhang relative to the glazed area. No credit is given for interior shading devices, only for exterior overhangs.

One consequence of these requirements is that virtually the only single-pane glazing that can be used in the cooler climate zones (zones 1 and 11–16) is one that features a low-e coating. In these zones, the U-value requirement is 0.72 Btu/hr–ft^2–°F, and only low-e single-glazed units qualify. Also, with SHGCs of about 0.70, single-glazed low-e units can handily match the relative SHGC requirement for north-facing windows. For other than north-facing windows, however, the only way for even low-e single-glazed units to pass the relative SHGC standard in these zones is to add an external overhang whose horizontal extent is between 27 and 35 percent of the height of the window in question.

It is impossible to provide one glazing specification that will be best for all California buildings.

Title 24 does allow designers to balance building components that are slightly out of compliance with those that are well within it. Designers may, at their option, avoid Title 24's prescriptive requirements altogether by taking advantage of the standard's performance methodology. To do so, designers model their buildings using software approved by the California Energy Commission, such as DOE-2 building energy performance simulation. These models, however, must demonstrate that the designs under consideration are as efficient—or more efficient—than they would have been if the prescriptive requirements had been followed. In practice, though, complying with the standards of the prescriptive approach is usually the most expedient way to meet Title 24 requirements.

Which Glazing Option Is Best?

Because climatic conditions vary so much across the state, and because important characteristics vary widely from one building to the next, it is impossible to provide one glazing specification that will be best for all California buildings. Instead, we recommend that designers do a whole-building lifecycle analysis for each project that takes into account:

- Lifetime building energy consumption, including lighting, heating, and air conditioning costs;
- Daylighting utilization; and
- The value of cooling equipment displaced by more advanced glazing systems.

In most cases, it is impossible to do this type of analysis intuitively or by hand calculations. Instead, we recommend using building energy performance simulation software, such as DOE-2 or eQUEST. To learn more about simulation programs, please see the "Building Simulation" design brief from Energy Design Resources.

To illustrate how to carry out the required analysis, we conducted some simulation studies using DOE-2. We assumed a well-built, 100,000-square-foot commercial building in Los Angeles with a glazing area that constitutes 24 percent of the surface area of the wall. We also assumed that daylighting controls would be used in the spaces within 15 feet of the outer walls. For this building, we compared clear single-pane glazing with five alternatives. The alternative glazing systems included double glazing, tinting, and spectrally selective coatings.

The results of our analysis are shown in **Table 2**. The most striking result appears to be that all of the glazing options, except the double-pane selective clear approach, saved more than their incremental cost over single-pane clear glazing by making it possible to install a smaller cooling system. Double-pane selective clear glazing turned out not to be a bad choice either. Taking into account energy savings and avoided cooling system costs, it pays for itself in about one year. The best choice, from a lifecycle costing perspective, is the double-pane selective tint glazing. According to our analysis, the cash-flow stream produced by this approach yields the greatest net benefits over its 20-year lifetime.

Table 2: Glazing options for an office building in Los Angeles

To illustrate how to compare glazing types using whole-building lifecycle analysis, we compared single-pane clear glass with five alternatives. The model is a 100,000-square-foot office building in which glazing comprises 24 percent of the total wall area. We used DOE-2 building energy performance simulation software to estimate annual energy savings. Based on lifetime net benefits, the double-glazed selective tint is the best choice.

	Glazing type					
	Single clear	Double bronze	Double selective clear	Double low-e	Single selective tint	Double selective tint
Visual transmittance (Tv)	0.88	0.47	0.68	0.44	0.66	0.41
Solar heat gain coefficient (SHGC)	0.83	0.49	0.42	0.37	0.51	0.28
LSG ratio (Tv/SHGC)	1.06	0.96	1.62	1.19	1.29	1.46
U-value (Btu/hr–ft^2–°F)	1.09	0.48	0.29	0.31	1.11	0.29
Annual energy savings ($/year)	N/A	7,179	8,825	9,730	7,347	11,842
Present value of lifetime energy savings ($)	N/A	71,332	87,687	96,679	73,001	117,664
Incremental glazing cost ($)	N/A	48,000	74,400	64,000	16,000	88,000
Avoided cooling system cost ($)	N/A	56,600	67,800	79,300	59,500	96,500
Simple payback period (years)	N/A	0	1	0	0	0
Net present value ($)	N/A	79,932	81,087	111,979	116,501	126,164

Assumptions:
- Daylighting controls assumed for the perimeter in conformance with Title 24
- Electric energy costs = $0.10/kWh
- Natural gas costs = $0.70/therm
- A/C system coefficient of performance = 2.0
- For present value calculation: discount rate = 10%, inflation = 2%, glazing lifetime = 20 years
- Incremental glazing cost represents cost of glass only. Labor and framing not included as these will vary little from the baseline
- Avoided cost of cooling equipment based on $1,200 per ton
- Net present value calculated by subtracting the incremental glazing cost from the sum of the present value of lifetime energy savings and avoided cooling system cost.

Note: N/A = not applicable

Source: Manufacturers' data, CTG Energetics, Lawrence Berkeley National Laboratory

Glazing Systems in the Future

We can look forward to further advances in spectrally selective glazing technologies, but even the best won't be ideal for all weather conditions. Ideally, glazing systems should be able to adapt to changing conditions in near real time.

Enter "smart" windows. "Electrochromic" windows are filters whose light-transmitting properties change substantially when a small DC voltage is sent across them. Two pieces of glass are plated with very thin coats of conductive material, and a metallic oxide is added to one of them. These plated pieces of glass are formed into a sandwich whose filling is a special polymer that acts like an electrolyte in a battery. With no voltage applied, the sandwich transmits light quite well, but when a voltage is applied, transmittance drops by a factor of five or more.

Electrochromic technology has already been incorporated into automobile glazing, particularly in rear-view mirrors whose reflectivity drops automatically when confronted with bright lights. Several organizations, however, are developing products specifically for building glazing.

For example, Lawrence Berkeley National Laboratory (LBNL) is currently carrying out a year-long test of large-area electrochromic windows at a federal office building in Oakland, California. The prototype windows are manufactured by Pilkington, currently the only company able to produce them. The office has a window wall whose lower lites may be controlled separately from the upper ones. Thus, an office worker may allow full daylight to come in at the top of the office, while controlling for glare during periods when direct sunlight falls on the lower windows. LBNL plans to quantify both the energy savings and comfort improvements that come from using various control strategies under different conditions of weather and user activities.

Another organization that is developing architectural products that use electrochromic technology is Tucson-based Schott-Donnelly LLC Smart Glass Solutions. The company is currently testing a product called "Ucolite" that is integrated into a 13-inch-diameter tubular skylight (**Figure 6**). Normally, the system's visual transmittance is around 65 percent, but when a voltage is applied, it gradually drops to 12 percent. The system's transmittance in the infrared, which is normally just 35 percent, drops to only 5 percent when a voltage is applied. Thus, in the heat of a bright day the overall solar gain is quite small, while soft light in the visible spectrum still supplies some illumination.

Figure 6: The Ucolite electrochromic system for a tubular skylight

When a electric voltage is applied to this skylight, it blocks nearly all the infrared energy that strikes it, yet it lets through some of the visible light.

Source: Schott-Donnelly LLC Smart Glass Solutions

When the voltage is turned off, the system returns to its original state. It takes about two minutes for the electrochromic effect to become fully effective and about three for the Ucolite to become completely clear again. "Presently, the Ucolite system's control has only two states," explains Stephan Hansen, Schott Donnelly's general manager, "but we have plans for a control that will allow us to have several intermediate states as well." The aim is to be able to adjust natural lighting levels to suit user needs under varying solar conditions.

For More Information

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)
1791 Tullie Circle NE
Atlanta, GA 30329
tel 404-636-8400 or 1-800-ASHRAE
fax 404-321-5478
web www.ashrae.org

ASHRAE's Handbook of Fundamentals is updated every four years. Chapter 29 on fenestration in the current Handbook (1997) contains detailed technical discussions of the theory and practice of many new glazing and window system technologies.

California Energy Commission
1516 Ninth Street
Sacramento, CA 95814-5512
Title 24 questions: 800-772-3300 (CA residents) or 916-654-5106
Requests for literature: 916-654-5200
web www.energy.ca.gov/title24/index.html

The California Energy Commission publishes the Title 24 Energy Efficiency Standard and related documents.

Efficient Windows Collaborative
Alliance to Save Energy
1200 18th Street NW, Suite 900
Washington, DC 20036
tel 202-857-0666
fax 202-331-9588
web www.efficientwindows.org

This Web site offers a variety of useful information on energy efficient glazings and window systems, including climate zone–specific recommendations such as "Selecting Windows in the California South Coast Region."

Florida Solar Energy Center
1679 Clearlake Road
Cocoa, FL 32922
tel 407-638-1000
fax 407-638-1439
web http://alpha.fsec.ucf.edu/-fen/

The Florida Solar Energy Center conducts fenestration and daylighting research focused on sunny regions that have mild winters. A variety of practical research findings by Dr. Ross McCluney and others is available at the Center's Web site, including "Solar Gain Tutorial" and "Fenestration Solar Gain Analysis."

Lawrence Berkeley National Laboratory

Windows and Daylighting Group
Building Technologies Program
Building 90-3111
Berkeley, CA 94720
tel 510-486-5064
fax 510-486-4089
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LBNL is the principal national laboratory for glazing, window, and daylighting research. The Web site features information ranging from technical papers on current research to educational material about energy efficient window and daylighting systems. The laboratory has also developed several public-sector software tools on the energy performance of a variety of window systems, such as REFSEN and WINDOWS. These programs may be downloaded from the Web site or ordered directly from the laboratory.

"Spectrally Selective Glazings," a Federal Technology Alert, DOE/EE-0173, was prepared by the LBNL windows group in 1998. It provides a helpful overview of new glazing technologies and simulation results of their use in commercial buildings in a variety of climate zones, including that of Los Angeles. "Tips for Daylighting," LBNL-39945, appeared in 1997. It is a very useful design guide for both beginners and experienced designers.

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Energy Design Resources is a program developed by Southern California Edison to provide information and design tools to architects, engineers, lighting designers, and building owners and developers. Our goal is to make it easier for designers to create energy-efficient new commercial buildings in Southern California. To learn more about Energy Design Resources, please see our Web site at www.energydesignresources.com.