energy-efficient glazing

XAVIER DE JAUREGUIBERRY

Built after the original footbridge was destroyed in a 1996 bombing, this glass- and steel-enclosed bridge connects two buildings in Manchester, U.K. The hyperboloid shape required careful detailing of the seals between the glazing panels, to make them resist high wind loads and pressure changes.

LEARNING OBJECTIVES

After reading this article, you should be able to:

+ DESCRIBE the basic process for producing float glass for use in architectural applications to enhance visible light transmittance, solar management, and thermal performance in high-performance buildings.
+ LIST several of the commonly used secondary glass treatment methods, such as heat treatment, lamination, coating, fritting, and tinting.
+ DISCUSS how glazing manages solar energy, based on the properties of transmittance, emissivity, reflectance, and absorption.
+ COMPARE various strategies for glass retrofits, including the use of building-integrated photovoltaics (BIPV).

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Virtually all building types need windows and glazing to provide occupants with exterior views, natural daylight, and relief from a feeling of confinement. In recent years, a wide range of developments have renewed focus on glass technology itself. New formulations are changing the performance of glass in terms of visible light transmittance (VLT), solar management, and thermal performance. These advances make possible ever more efficient enclosures with ever greater glazed area.

THE BASICS OF GLASS MANUFACTURING

Developing an appropriate energy strategy for a project's glazing requires an understanding of the selected glass products' technology and thermal-optical properties. These factors are tied directly to the manufacturing process.

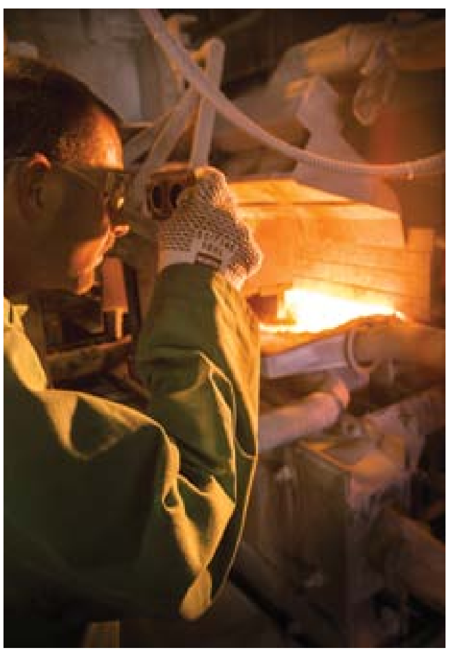
Smooth and nonporous, with generally high visible light transmittance and low thermal expansion qualities, flat glass has a proven record of use for windows and curtain walls. Component materials for building glazing tend to start with a variation on soda-lime-silica glass. The vast majority of glass used in architectural applications is produced using the so-called *"float glass" method*, which involves pouring the molten batch onto a bed of 99.9% pure molten tin, achieving a continuous ribbon with an optically flat surface. This process is widely used to produce large amounts of glazing of uniform thickness and especially flat surfaces, making it ideal for building applications.

A number of secondary glass treatment methods follow, most of which are essential to certain applications and to overall glazing energy performance:

- **Heat treatment.** In this process, the cooled float (called raw or annealed glass) is heated again and air-quenched to imbue the float with added strength. A high-pressure quench produces *tempered safety glass*, which is four times stronger than raw float and is made to shatter into tiny pieces when broken. A low-pressure quenching produces *heat-strengthened glass*. While heat-strengthened glass does not comply with federal safety glazing requirements, it is twice as strong as annealed glass, making it capable of resisting a wide range of wind and thermal stress loads. Heat-strengthened glass is commonly used in both the vision and spandrel panels of glazed curtain walls.
- **Lamination.** Manufacturers can create a single, strong safety glazing by sandwiching a polyvinyl butyral (PVB) interlayer (or other suitable material) between two lites and bonding them by applying heat and pressure. The interlayer often features a coating meant to affect the final product's light transmittance—for example, by blocking most ultraviolet rays. Laminated glazing is frequently used in applications where hurricane and blast resistance is essential. It also features a high level of acoustic insulation.
- **Coated glass.** As a strategy for achieving better thermal and optical performance, manufacturers may apply an ultra-thin metallic low-emissivity (low-e) coating to the surface of the glass. There are two common types of low-e coatings; pyrolytic low-e and sputter-coat low-e. *Pyrolytic low-e* is produced as part of the glass manufacturing process. In this process, a metallic oxide, such as tin, is applied to the glass while it is still in a semi-molten state, permanently bonding the coating to the glass and resulting in a very durable surface layer. This is why pyrolytic low-e is sometimes referred to as "hard-coat low-e."

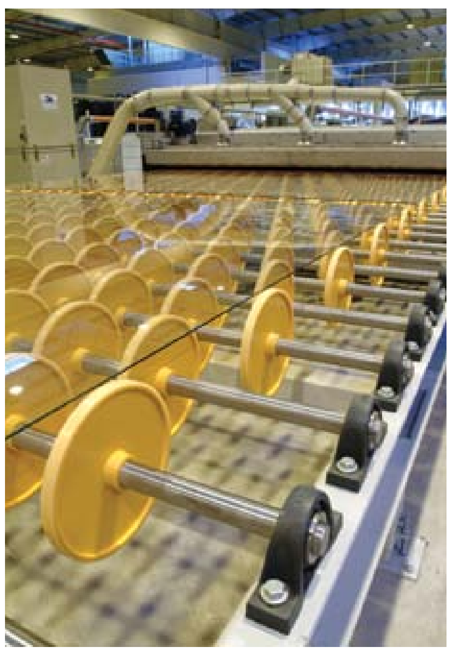
  Sputter-coat low-e is produced in a series of vacuum chambers, separate from the float glass manufacturing process. Sputter-coated low-e glasses include multilayered coatings composed of various metals, metal oxides, and metal nitrides that combine to achieve the desired performance and appearance. Historically, sputtered coatings were described as "soft-coat low-e." Although sputtering allows the use of high-performance materials such as silver, its chemical and mechanical durability is less than that of pyrolytic low-e. Advances in material science have significantly improved the durability of some sputtered coatings, but the glass industry continues to refer to sputter-coated low-e as "soft-coat."
- **Fritted glazing** is achieved by applying a diffuse pattern, or frit, to a (typically specular) glazing substrate. The frit composition is usually ceramic or glass batch, melted to or otherwise bonded to the glazing substrate at an intermediate point in the production of the glass. Frit can also be applied with a silk-screen to create bolder, more visible patterns for aesthetic purposes.
- **Tinted glass.** Additives in the batch can alter the glass color, an approach often used in architectural applications to alter solar energy transmission, as well as for aesthetics and added privacy. Because it typically absorbs more infrared radiation than other glass types, tinted glass is often called heat-absorbing glass, even when the glass appears quite neutral in appearance.
- **Insulating glass units.** IGUs are composed of two or more lites of glass connected by a perimeter spacer of steel, aluminum, or plastic and separated by a gap containing air or an inert gas (typically, argon) or even a vacuum. The space between the panes and the gas type can significantly improve the insulative value of the glazing unit.

All of these glazing technologies are in common usage. The best applications depend on how the glazing manages solar energy, based



COURTESY GUARDIAN INDUSTRIES CORP.

A technician checks the furnace in a glass production line, where silica sand and other select raw materials are heated—at temperatures up to 3000°F—to a liquid state and floated on a bath of molten tin to produce a ribbon of so-called "float glass."



Float glass being rolled along the process line. Glassmaking requires a profound knowledge of physics, chemistry, and related technologies to create a finished product with optimal visual light transmittance, clarity, and integrity for specialized treatments and fabrication.

on four properties: transmittance, emissivity, reflectance, and absorption. Transmittance, reflectance, and absorption are fairly common terms; however, emissivity is less commonly understood. The sum of percent reflectance out + absorbance out + transmittance = 100%. This is commonly referred to as the RAT equation.

Transmittance refers to the percentage of solar radiation that passes through the glass. Transmittance specifications will most often refer to a specific part of the spectrum of solar radiation; the most commonly referred-to ratio is *visible light transmittance,* or VLT. The higher the VLT, the more effective the glazing is for harvesting natural daylight and delivering views of the exterior.

Emissivity, or emittance, is the ability of the glass to radiate energy; it refers to the irradiation of absorbed energy that can be emitted toward both the exterior and interior of the building.

Most clear float glass emits about 84% of its potential energy to radiate, most of which will occur in the form of long-wave infrared, or heat; at room temperature, this would be described as an emittance ratio of 0.84. Low-emissivity coatings range in emittance from 0.14 to as low as 0.02.

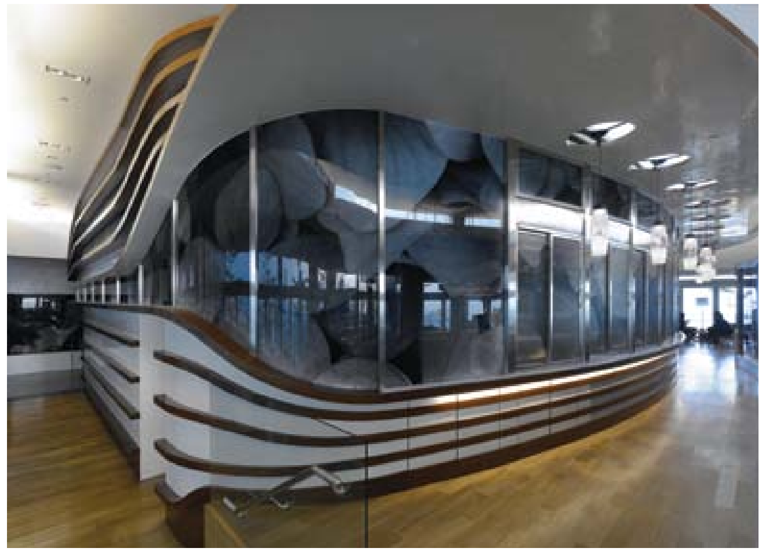
Reflectance ratios describe the amount of energy that bounces off the surface rather than passing into or through the glass. Surface quality, glazing type, the presence of coatings or films, and the angle of incidence of the solar energy all impact reflectivity.

It is important to note that reflectance occurs at each air-glass boundary. Most clear float glass has a reflectance of 4% (at a normal angle of incidence—about 30 degrees, according to ASHRAE), but this means that each lite will reflect 8% total since reflectance occurs at each surface. Angle of incidence is also crucial, since light striking the same surface at 80 degrees, for example, will have reflectance closer to 50%. This makes site selection and building orientation crucial for specifying glazing.

Absorption (or absorptance) refers to the fraction of energy that is not reflected, emitted, or transmitted, but which instead is absorbed by the glazing system. This figure is important, not least for its effect on air currents in the project interior as well as on the effective U-value of the glazing.

These properties undergird vital glazing specification details. *U-value,* for example, refers to the ability of glazing to resist heat transfer from the warmer side to the cooler side, and is expressed as a heat-transfer coefficient (Btu/hr x square feet x °F). Its inverse, *R-value,* expresses insulative value. *SHGC*, or solar heat gain coefficent, refers to the amount of solar energy transmitted through, or absorbed and emitted by, the glazing; it is always expressed as a number between 0 and 1. *VLT*, for visible light transmittance, is often called VT or Tvis in specification documents.

A new specification, *light-to-solar-gain ratio* (LSG), was defined by Ross McCluney, Principal Research Scientist at the Florida Solar Energy Center (www.fsec.ucf.edu), as the ratio of VT to SHGC. The higher this number is, the greater the spectral selectivity, a desirable characteristic of glazing systems for hot climates.



COURTESY JOSHUA ZINDER ARCHITECTURE + DESIGN

Sky on 57, a dining destination atop Singapore's Marina Bay Sands Hotel, incorporates unique glazing strategies for memorable aesthetics as well as energy management. The lamination within the central feature's IGUs displays a photographic floral image and protects stored wine from damage by solar radiation.

THE QUEST FOR ENERGY OPTIMIZATION

Demand for low-cost, energy-efficient solutions has led to some notable improvements and refinements in glazing technology. On the design side, a number of new approaches and new ways of thinking about enclosures have led to some important advances in building enclosure energy performance.

For example, Ajla Aksamija, PhD, LEED AP BD+C, CDT, Building Technology Researcher with design firm Perkins+Will (www.perkinswill.com), says that ceramic frit coatings can be used like low-e and reflective coatings to "reduce the transmission of solar heat gain," thereby reducing the load associated with cooling.

However, Agnes Koltay, Director of Dubai-based Koltay Façades (www.koltayfacades.com), says fritting may be efficient in reducing glare, but is not, in her view, an effective method for improving energy performance. "Fritted glass still absorbs solar heat and re-radiates it," she says, and suggests that coatings are more suitable to managing energy-related properties. Fiona Cousins, PE, Principal with Arup (www.arup.com), adds, "Triple glazing with low-e coatings is best for providing insulation, and can help to improve solar heat-gain coefficient. Fritted glass is best for providing diffused light."

"Architectural glass products have grown increasingly complex," says Mic Patterson, Vice President of Strategic Development for Enclos (www.enclos.com), a façade and curtain wall specialty contractor. "The use of annealed float glass unmodified by secondary processing is extremely rare. It is not a single secondary process that defines an architectural glass product, but multiple processes."

In fact, numerous factors must be considered in specifying glazing, says Urmilla Sowell, PE, Technical Director of the Glass Association of North America (www.glasswebsite.com). These include *building type, the function of the space, room geometry, glazing location*, and *glare control*. This list only covers energy-related metrics, she cautions, and does not even include interactions of components within a fenestration assembly, nor the interactions of the assembly with the enclosure.

Another consideration is the track record of the glazing products under consideration. Manufacturers have been responsive to concerns about product failure with improvements in both fabrication techniques and the products themselves. "The way IGUs are produced now is far superior to the way it was done 10 to 15 years ago," says Joshua Zinder, AIA, Founding Principal of Joshua Zinder Architecture + Design (www.joshuazinder.com). "I've spoken to several manufacturers and raised questions about products that exhibited seal failure," he says. "All of them answer that they've improved their sealant systems, as well as the coordination of the sealant type with the glazing type."

Dealing with climate factors. Building design and glass specifications hinge on project location, site characteristics, and climate. Not all interactions between climate and glazing strategy are intuitive, notes Sean O'Brien, PE, LEED AP, Associate Principal with Simpson, Gumpertz & Heger (www.sgh.com). "In heating climates you design to reduce heat loss; in cooling climates you design to reduce heat gain," he says. That sounds simple enough, but he cautions against one-size-fits-all approaches, even within specific climate zones. "Buildings in northern climates can still require tremendous cooling loads if the wrong glass is used. Siting and orientation also have a big impact on energy performance, so the designer should use an energy model to look at whole-building effects."

Most experts recommend low U-factor solutions like IGUs for northern climates, and solar control strategies such as low-e glass and laminates for warmer regions. In any case, the strategy must be tailored to the specifics of the project. In fact, IGUs and high-performance low-e glazing, in spite of their relatively high price points, are gaining in popularity in the U.S., thanks in great part to increasingly stringent energy and green building codes.

"Climate region drives glass choice through code," says Arup's Cousins. "In regions where heating is not an issue, single glazing is allowed by code and shading strategies are the most critical factor in minimizing energy use. Where the sun barely shines and temperatures are very low, triple glazing with minimal shading and interior glare control is the best solution. For most of the country, the balance is between the two extremes. Shading should be provided where overheating is a problem, insulation where cooling is needed."

COURTESY BISEM

Building integrated photovoltaic technology (BIPV) is rapidly improving. The BISEM net-zero manufacturing facility in Sacramento, Calif., is constructed from the company's unitized curtain wall assembly, which accepts both monocrystalline and polycrystalline PV panels.

Perkins+Will's Aksamija, author of the new book *Sustainable Facades: Design Methods for High-Performance Building Envelopes* (Wiley), points to the window-to-wall ratio, or WWR, as an important metric for façades. WWR refers to the proportion of glazed area over the total façade area. "In most cases, higher WWRs result in greater energy consumption. Minimizing WWR and proper building orientation are the two things every designer should take into consideration."

NEW ENERGY CODE CONSIDERATIONS

Glazing selection for commercial projects is especially beholden to state and local building codes, including energy and green codes. With energy standards becoming increasingly strict with each cyclical iteration, Building Teams have tight parameters set for them.

One of the most important new developments is the latest version of *ASHRAE 189.1,* which would modify the prescriptive window-wall ratio (WWR) recognized by various codes. Under the 2010 version of ASHRAE 189.1, buildings of less than 25,000 square feet have been limited to a 40% window-to-wall ratio; under the proposed version, the WWR in such buildings could be limited to no more than 30% glass, says Jonathan Hill, a senior staffer with Simpson Gumpertz & Heger's Building Technology Group in San Francisco. He adds that the new version of ASHRAE Standard 189.1 for High-Performance, Green Buildings, is already being adopted in California, and could be in effect there as early as next January.

Such a change to the WWR, he notes, does not take into account the improved performance of energy-efficient glazing. "While technology is helping glass become more energy-efficient," says Hill, "the building code seems to be lagging behind the technology." Critics of the proposed ASHRAE changes pointed out that they do not allow for adjustments to the prescriptive window-to-wall ratio to account for design innovation that achieves the aim of the code. As a result of comments from lighting designers, daylighting experts, architects, academics, and the glass industry, ASHRAE has put the WWR changes on hold, pending further analysis.

Another barrier to specification of commercial glazing is cost, especially where high functionality is not mandated, which is the case in the United States, laments Patterson. "Triple-glazing is the most accessible technology to improve U-factor, but adoption lags in the U.S. marketplace, largely due to lax building code requirements for energy consumption," he says.

Façade specialist Koltay says that "the price difference between glazing products needs to be viewed in the light of long-term life cycle costs and user comfort." Single-glazed, uncoated products are a thing of the past, she says: "At a minimum, coated double-glazed has become the standard assembly."

Building Teams must be aware of the complexities of glazed openings. "Care must be taken with the detailing of spacers, framing, frame connections, and interfaces with adjacent façade structures," says Koltay. "Both traditional punched windows and glazed curtain walls can perform well, but the latter relies less on site workmanship and hence generally results in better performance." Contractors and the trades are critical to success, she says; they must understand the importance of good workmanship in placing seals, providing continuity of insulation, and aligning gaskets.

In addition to ASHRAE 189.1, the 2012 iteration of the *International Energy Conservation Code* (IECC) sets out new rules for U-value and SHGC for each climate zone. In climate zone 1, the warmest zone, the maximum prescriptive SHGC for commercial windows changes from 0.30 to 0.25, while the maximum U-value is cut nearly in half, from 1.20 to 0.65. In climate zone 2, the SHGC drops from 0.30 to 0.25; maximum U-value goes from 0.65 to 0.40.

So even as energy performance in glazing products steadily improves, specifiers may see the new codes and standards as onerous. Mark Dubois, AIA, LEED AP, Partner at Ohlhausen Dubois Architects (www.boishaus.com), admits to concern over the 2012 IECC prescriptions. "The very high SHGC requires glass that is either reflective, tinted, or very expensive. All these options are problematic. We don't know how the profession and industry are going to find good solutions."

MAKING CHOICES IN COATING TRADEOFFS

Better coatings have emerged as a highly regarded solution to the problem of improving the thermal performance of glazed façade elements. The decision as to which coating to use, however, is not easy. "The interrelated nature of properties like U-factor and building interior glass surface temperature means that at times performance in one aspect may need to be reduced to achieve better performance in another," says GANA's Sowell.

Color and performance are not a simple choice, says Koltay, because not every color of coating can achieve a predetermined set of performance values. "For example, the better the SHGC, the darker the coating, meaning lower visible light transmission," she notes.

Yet an evolution in thinking has changed the role of coatings in the manufacture of glazing and the expected performance gains. In the past, the point of coating processes was to limit heat-flow emissivity, giving rise to low-emissivity coatings. "Yet subsequent advancements became multifunctional, providing additional benefits of solar control by blocking out selective infrared shortwave radiation," says Ming Leung, AIA, LEED AP BD+C, Senior Technical Coordinator with Perkins+Will.

Leung describes three "generations" of low-e coatings. The earliest tended to fall within an SHGC range of 0.28 to 0.54. "Two typical characteristics of these coatings were low reflectance and a direct relationship between SHGC and VLT reduction." This type of coating would darken the glass, as the application made the coating denser. Second-generation low-e glass was designed to retain VLT as SHGC dropped, although reflectance on both sides of the glazing went up. Both interior and exterior reflectance have undesirable effects, says Leung. The new, third-generation coatings retain VLT as

COURTESY TGP – TECHNICAL GLASS PRODUCTS

The Building Team of Richard Meier & Partners (architect), Englekirk & Sabol Consulting Structural Engineers (SE), Enclos Corp. (glazier), and Hensel Phelps Construction (GC) specified a 1,200-sf channel glass system for the U.S. Courthouse in San Diego, completed in 2012.

SHGC drops, without an increase in reflectance. "Because of these improved attributes, this latest generation of low-e coatings is our current preference," says Leung.

In determining which surface should be coated, "The location of the coating can vary by area, and does have an effect on overall performance," says SGH's Hill. "Obviously, exterior coatings pose concerns about durability." Coating types vary in terms of durability and scratch resistance, and it is important that the coating be properly adhered, and integrated with the IGU seal to prevent degradation of the seal, delamination of the coating, and air leakage into the IGU.

The No. 2 surface—that is, the inside surface of the exterior lite—is one of the more common surfaces to be coated. According to Sowell, "There are also new fourth-surface low-e coatings that can be used on the exposed interior of the building when combined with a traditional low-e unit, to provide additional energy efficiency."

Other factors have to be taken into consideration in dealing with coatings. For example, glass coated with the softer type of sputter coat must always be protected from impacts and abrasion during installation and occupancy; a coating placed on the outermost and innermost surfaces must be chemically and mechanically durable, which historically dictated the use of pyrolitic, or hard-coat, low-e. Yet sputter coat has its advantages, including better thermal performance, a wide range of performance and aesthetic options, and good color uniformity. Pyrolitic coatings tend to exhibit better chemical and mechanical durability but are limited in variety and often need to be used with heat-absorbing glass to achieve a reasonable level of energy management.

In the construction phase, "Certain types of coated glass can be stored longer than others, which may impact lead times," warns Koltay. Also, certain coatings cannot be bent. "That means no curved glass," says Koltay.

A recent development here is the *post-temperable sputter coat,* which allows for downstream fabrication, like bending or lamination, after the coating is applied. With performance as good as traditional sputtered coatings, this technology provides designers with greater design flexibility. Other coatings are designed to affect reflectance rather than emissivity. Reflective coatings are used to manage high levels of anticipated heat gain that tints and low-e coatings are less able to tackle. They're also recommended for glare control and aesthetic uniformity. Reflective coatings are typically metallic in appearance, so Building Teams must be careful to avoid unpleasant mirroring effects on both the interior and exterior. Reflective coatings act like a mirror on whichever side faces the stronger light, so a mirror effect on the exterior by day can turn into an awkward mirror effect inside at night—possibly to the detriment of occupant privacy.

TECHNICAL CONSIDERATIONS FOR GLASS RETROFITS

Arguably the most publicized energy retrofit of recent memory, that of the Empire State Building in New York City, was part of a truly gigantic modernization to prep the grand ol' gal for better market position. Its 6,514 double-hung windows were out of date and underperforming. The classic question facing the Building Team: Restore or replace?

To preserve the building's truly iconic aesthetic, the team ultimately elected to keep the old glazing, but devised an equally original strategy. The double-glazed units were disassembled and rebuilt: the steel spacers were replaced with warm-edge spacers, and the lites were thoroughly cleaned. The reassembled units also suspended a specialized low-e coated film between the two lites and a nonconducting gas fill, effectively transforming the double-glazed units into triple-glazed IGUs without significantly increasing the thickness of each unit. R-values for the assemblies increased from R-2 to between R-5 and R-8.

This was certainly an expensive strategy (although mitigated somewhat by tax incentives) and therefore unlikely to be a model for most modernization projects. But this does indicate that there is more than one way to skin a building. "Most retrofit projects typically involve replacing or upgrading single-pane clear windows in older buildings," says Sowell. "Replacement with insulating glass provides a huge benefit resulting from energy savings. There are also new systems to add low-e glazing units or panels to existing single glazing to create a double- or triple-glazed low-e system without full rip-out and replacement."

Avoiding rip-out can help control a retrofit budget, but the new systems Sowell mentions still carry heavy installation and materials costs that the stakeholder must weigh against expected performance and return on investment. The least expensive option, and one that does demonstrate energy-effective results, is to apply reflective and low-e films to existing windows. Window films are certainly a viable retrofit strategy for most residential modernizations where the fenestration assembly is thermally tight and up to date. For commercial (and large multifamily) typologies, however, it may not work well.

"Most retrofit clients can't afford expensive replacement strategies, and therefore prefer to look at low-e coated window films," says Zinder. "We've done this a lot, but it is not necessarily the best solution." Zinder says that if the film is applied to glazing in the south-facing wall, the added exposure to solar energy causes some shrinkage of the film over time, creating a line of transparency perhaps 1/32 to 1/16 of an inch in width. "The window will continue to perform well energy-wise, but the client may be unhappy about the aesthetics." He recommends using this strategy only on north- or west-facing walls.

Koltay argues that post-installed films can't compete in either performance or durability with coatings applied during glass processing. Patterson is equally unenthusiastic about films: "They are not a robust, long-term solution to building façade performance, especially with respect to curtain walls. These systems are typically not renovated but replaced."

Current approaches to new construction may be continuing a cycle that requires replacement retrofits as façade systems age, Patterson warns. "We are building façades with no consideration of their future adaptability to emerging technology," he says. "Too many of the old buildings will require the complete replacement of the facade system." Likewise, some experts express concern that curtain walls built in the 1960s and 1970s cannot support the weight of a double-glazed system. This eliminates retrofit as an option, leaving demolition as the only alternative.

In general, replacement of glazing seems to be the preferred method for retrofits, budget allowing. But there's another possibility: *overcladding.* "Reskinning projects may also be carried outside the existing skin, which minimizes impact on the occupants and can improve the economics," says Cousins. Hill concurs: "Overcladding is becoming much more common. These projects tend to be more expensive but provide quite the performance upgrade."

ENERGY-MANAGEMENT GLAZING

Fortunately, new glazing technology is rapidly unfolding. Currently available technologies are seeing performance gains, and cutting-edge products and systems continue to gain a foothold in the mainstream. Examples of such technologies include:

State-of-the-art IGUs. In addition to construction improvements like warm-edge spacers, IGUs are beginning to benefit from alternatives to gas fills. Aerogel insulation, made of synthetic solids that consist almost entirely of air, exhibits extremely low thermal conductivity. Some aerogels can be integrated with polycarbonate sheets to form a translucent cladding material, while others, such as silica aerogels in granular form, can fill the spaces between the glass lites of insulating units, says Perkins+Will's Aksamija.

Aksamija also mentions *vacuum-insulated glazing* (VIG) units. "These units use a vacuum between lites of glass to raise the assembly's thermal resistance," she says. With no gas or fill, conduction

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Solar energy impact will vary depending on the orientation of each façade of a building. In Tacoma, Wash., the Center for Urban Waters, designed by Perkins+Will, uses automated exterior blinds in the west façade and fritted glass in the south façade.

and convection are virtually eliminated, which also allows the space between the lites (and total glazing thickness) to be greatly reduced, enhancing design flexibility. Patterson notes that vacuum glazing holds the most promise for producing vision glass with a U-factor good enough to justify continuing to build highly glazed facades. He cautions, however, that “a viable solution for widespread application seems to remain beyond the horizon.”

Electrochromic glass. Often called smart glass, electrochromic glazing alters its transmittance characteristics when an electrical current is applied, through the use of a specialized lamination that essentially integrates shading into the glazing unit. For instance, one type of smart glass appears frosted until the current is applied, at which point it becomes nearly transparent.

This technology has been in the works for some time, but cost has been a drag on broad market acceptance. There have been problems with the sealants, which are part of the system that carries the electrical current, says Zinder, who has worked with the products on several occasions. “A broken seal means a lost electrical connection in the lamination field, which means a loss of the electrochromic functionality in one or more adjacent panels,” he warns, but manufacturers are working to address this problem. “Electrochromic glazing appears to be on the verge of widespread adoption,” says Patterson. “The industry has recently invested in the manufacturing infrastructure necessary to produce materials with the right combination of aesthetic and performance attributes at a tolerable price point. These dynamic glazing materials still leave the problem of thermal performance.” Nevertheless, more use of smart glass is likely due to its flexible VLT, which can be integral to daylighting strategies that reduce illumination loads.

Building-integrated photovoltaics. In recent years, BIPV systems have shown signs of living up to their promise. With improvements in thin-film PV products to performance levels needed for use in vision glazing, they are getting closer to those of solid solar cells, used in spandrels and shading devices.

Façade orientation and *inclination angle* are both crucial to the successful integration of PV technology, and the improvement of thin films means that more of a project’s façade area can be integrated for solar harvesting without sacrificing transparency or translucence. Of course, BIPV is an energy-producing technology, not an energy-managing one: Passive solar, which works by managing the temperature of internal thermal mass, according to Cousins, is more closely associated with energy-managing techniques.

One cutting-edge technology is the *integrated concentrating solar façade,* or ICSF, currently in development by the Center for Architecture Science and Ecology (http://www.case.rpi.edu), a collaboration between Rensselaer Polytechnic Institute and Skidmore, Owings & Merrill. This is a dynamic façade system composed of moving gem-like solar collectors that can harvest daylight and fulfill a number of other energy requirements—heating, cooling, hot water, and electricity production.

Phase-change materials. PCMs are solid at room temperature but liquefy at higher temperatures, absorbing and storing heat in the process, says Aksamija. They are currently commercially available integrated into IGUs. Composed of either waxes or salts, PCMs can absorb high exterior temperatures by day and emit the heat to the interior at night.

Aluminosilicate glass, which is used to cover the displays of personal digital devices, is extremely thin and highly impact resistant. This glass type is essentially unheard of in building applications, because manufacturing large spans of the glass is prohibitively expensive. However, manufacturers are investing in improving the process because thin, impact-resistant glass could be an enormous boon to architectural glazing.

ETFE. Ethylene tetrafluoroethylene is a fluorine-based plastic originally conceived for its anti-corrosive properties, but which also demonstrates benefits for glazing applications, namely low weight, recyclability, and, in double- and triple-ply configurations with a gas fill, excellent thermal properties. But pumps are required to maintain constant air pressure relative to varying wind loads, and (worst-case scenario) when it burns the material releases hydrofluoric acid, which is highly toxic and corrosive.

EXCITING NEW GLAZING TO COME

New glazing technologies are emerging all the time; existing ones are constantly improving. SGH’s O’Brien mentions *triple-glazed mirror glass,* with an impressive R-20 rating. So be on the lookout for exciting new architectural uses for these emerging products.

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