The Benefits of Dynamic Glazing

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BUILDING DESIGN
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Introduction

2013 marks the 10^{th} anniversary of commercial installations for the world's leading electrochromic glass product. While a decade may appear to be a long time, it is a relatively short horizon for the construction industry. Awareness for electrochromic (EC) glass has been building during this time, yet there is still opportunity for growth. This paper defines and explains EC technology and discusses its many benefits, with the goal of helping architects, building owners and contractors understand its value for their projects.

During the past decade, SAGE has gained a wealth of knowledge about daylighting from those who design — and occupy — buildings. More than ever, the goals of using EC glass in commercial and institutional buildings are improving the built environment and reducing humans' impact on the natural environment.

Figure 1. EC glass installed in the Morgan Library expansion at Colorado State University shown in its fully clear and fully tinted states.

Electrochromic glazing has been shown to save energy, reduce CO_2 emissions and contribute to occupant comfort and productivity in buildings. The energy and sustainability benefits are well established in industry literature and field studies. Architects are increasingly adopting electrochromic, or "dynamic," glazing as an efficient all-in-one means of providing solar control in commercial and institutional buildings.

The use of EC glazing is expected to increase dramatically in the near future. Industry reports suggest that the market could grow to more than $700 million by 2020.[1] Market growth is being driven by an increasing awareness of the technology, a growing emphasis on sustainable solutions in the construction industry, and reduced pricing as additional capacity comes on line.

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1 Nanomarkets, LC, "Transparent Electronics Markets - 2012" Nano 436, Dec. 2011, p.73.

1. Electrochromics 101

Electrochromic (EC) glazing consists of float glass coated with a series of metal oxide layers. The coated glass is then fabricated into an industry-standard insulating glass unit (IGU). The IGU can be tinted or cleared through the application of low-voltage DC power, and it can be switched manually or integrated into an automated building management system (BMS). The EC IGUs on the market today fit into most standard framing systems.

When integrated with the BMS and dimmable lighting controls in commercial and institutional buildings, EC glazing can provide substantial energy savings and improved indoor environmental quality. Importantly, EC glazing also makes possible greater window-to-wall ratios while decreasing overall energy use.

There are a growing number of suppliers and products in the category of dynamic glazing, and the product offerings within it vary widely in terms of performance and suitability for building types and uses. SAGE Electrochromics, Inc, based in Faribault, Minn., is the market leader with hundreds of installations, over 250 patents, and more than 10 years of commercial sales in the U.S. and worldwide (sageglass.com).

2. EC Glass: Definition, Standards and Benefits

Also known as "smart glass" and "switchable glass," electrochromics are a subset of chromogenic technologies employing electrically switchable glass that varies light transmission when voltage is applied. Related technologies include suspended-particle devices (SPDs) and liquid crystal devices (LCDs).

EC glass tints by a darkening of its coated surface, which has multiple layers, according to Lawrence Berkeley National Laboratory (LBNL) (Fig. 2). Lithium ions and associated electrons transfer from the counter electrode layer to the electrochromic electrode layer when voltage is applied; reversing the voltage polarity causes the ions and electrons to return to their original layer, and the glass clears.

A low-voltage DC power supply is typical for most applications. It takes less than 5 volts (5V) to effect the switch.

Typical benefits: Used as part of an integrated or whole-building design strategy, EC glass can be used to:

- reduce electrical lighting needs by increasing transmission of natural daylighting;
- reduce associated heating, ventilation and air-conditioning (HVAC) loads by decreasing solar heat gain;

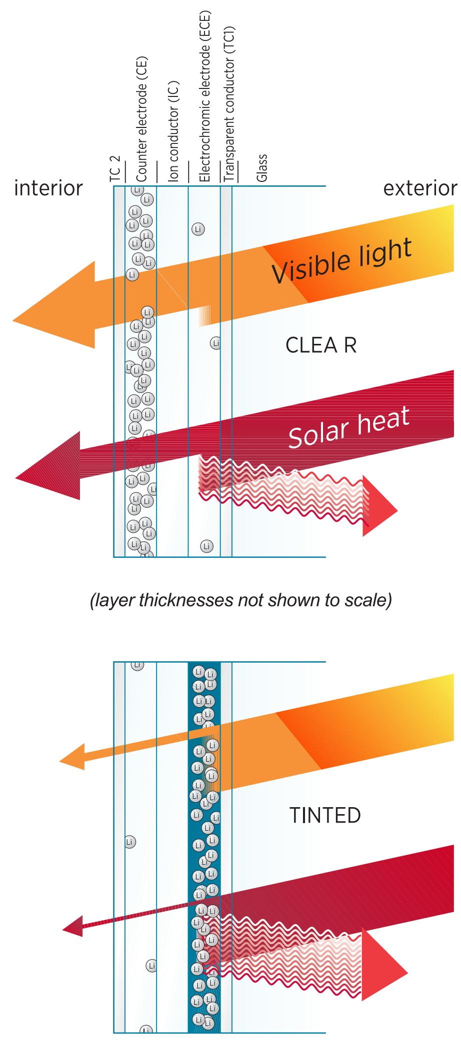

Figure 2. The electrochromic coatings are sputter-coated onto float glass. When the user tints the glass, it means they apply a low-voltage DC charge to it, which causes the nano-particles within one layer of the coatings to migrate to another layer. The total thickness of the layers is approximately 1/50th the thickness of a human hair.

- eliminate the need for blinds, curtains, exterior shades or other solar-control assemblies;
- increase the use of daylighting and outdoor views within a building by allowing greater window-to-wall ratio; and
- protect building materials, finishes and contents by reducing fading and degradation due to harmful solar irradiation.

Typical Projects and Applications: EC glass has been used for architectural applications for 10 years. According to LBNL, EC glass is "considered to be the most suitable chromogenic technology for energy control in buildings."[2] With intensive R&D, enhancements are underway throughout the industry.

Above: The employee cafeteria in the Siemens wind turbine nacelle manufacturing plant in Hutchinson, Kansas.
Below: Port of Entry, Torrington, Wyoming. Both sets of photos show the glass in its fully tinted state (<2% VLT) and in its clear state (62% VLT).

Hundreds of U.S. building projects have employed EC glass. Prominent recent examples include university buildings and K-12 schools in almost all climate zones, including states as diverse as Colorado, Kansas, Minnesota, and California. Commercial offices, worship facilities and government buildings have also used EC glass for a variety of reasons, but a consistent theme is a desire for more natural light and a stronger connection to the outdoors, while still maintaining an energy-efficient building.

3. EC Glass Performance

While dynamic glazing may be new technology relative to traditional windows or low-E glass, its durability and performance have been tested extensively by the U.S. Department of Energy (DOE) and numerous industry participants, as well as national and international codes and standards organizations. In addition, the EC product has undergone extensive testing in the field in numerous climate zones to evaluate its functionality and durability. SAGE installed its first commercial project in 2003 at Desert Regional Medical Center in Palm Springs, Calif., and the glass is still operable today.

Several converging trends have helped increase market acceptance of EC glass in recent years:

1. A number of energy codes and green-building standards have been enacted, such as the International Energy Conservation Code (IECC) and the International Green Construction Code (IgCC), which attempt to reduce the use of static glass. Some codes even recommend envelope designs with a reduced window-to-wall ratio.

2 http://windows.lbl.gov/materials/chromogenics/

2. The use of EC glass can benefit projects where designers are seeking LEED® certification for their buildings.

3. There is an increasing awareness of research such as the seminal Heschong-Mahone Group studies in the late 1990s that underscore the benefits of increased daylighting on building efficiency and occupant productivity and health.[3,4,5,6]

As architects and building designers have gained experience with EC glass, a truer picture of the product has come into focus.

EC Glass vs. Privacy Glass: These two products have opposing objectives, yet there is still confusion in the marketplace. Both EC glass and privacy glass are activated by electricity but that is where the similarity ends. Privacy glass is intended to completely block the view through the glass. This product is usually laminated with a sheet of polymer liquid crystals. When turned off, the crystals in the film are randomly oriented and diffuse light in all directions which makes the glass look opaque; when switched on, the crystals align, allowing a view through the glass. This technology is primarily used for interior partitions or walls where visual separation without drapes or blinds is desired, such as patient areas of hospitals and conference rooms in office buildings.

The purpose of EC glass, on the other hand, is to control the sun while still providing a view to the outdoors for building occupants. Even in its darkest state, less than 2% visible light transmission (VLT), the glass is transparent. EC contributes to energy savings and blocks the ultra-violet spectrum. Liquid crystal and suspended particle devices can only block UV light on a limited basis.

Low Electrical Needs: The electricity required to switch the tinting level of EC glazing is minimal and does not significantly impact the energy-efficiency benefits of EC glass. As noted earlier, as little as 5V is required for the glass to change state. To switch from clear to fully tinted, a 2,000-square-foot façade of EC glass uses about as much energy as turning on a single, 60-Watt incandescent light bulb.

Integrated Design Methods: The use of EC glass has also opened doors for applying several techniques for integrated design. According to an article in the *Whole Building Design Guide* by architect Don Prowler, FAIA, and Stephanie Vierra, the concept of "whole building design" requires an integrated design approach as well as an integrated team process to consider "project objectives, and building materials, systems, and assemblies from many different perspectives."[7] The authors assert that by analyzing the building's interdependencies and then implementing whole-building design strategies, "a much more efficient and cost-effective building can be produced."

Using these techniques, building teams have developed dynamic building envelopes to effectively control light and heat fluctuations due to seasonal and daily weather variations. Solar control can be achieved using mechanical means or electronically tintable EC glass, or both, by allowing variable VLT and solar heat gain to optimize interior comfort and minimize energy required for cooling and lighting. According to the DOE, the goal of achieving a zero energy building by 2030 isn't possible without the use of dynamic glazing.[8]

3 Heschong Mahone Group (2001). "Re-Analysis Report: Daylighting and Schools, Additional Analysis," for California Energy Commission, Public Interest Energy Research report.

4 http://www.h-m-g.com/projects/daylighting/publicity%20daylighting.htm

5 Fisk, William J,"Potential Nationwide Improvements in Productivity and Health from Better Environments," 1998 ACEEE Summer Study on Energy Efficiency in Buildings

6 Nicklas and Bailey "Analysis of the Performance of Students in Daylit Schools," Innovative Design, Raleigh, NC, http://www.innovativedesign.net.

7 http://www.wbdg.org/wbdg_approach.php

8 Lee, E.S., Yazdanian, M., Selkowitz, S.E., 2004. "The Energy-Savings Potential of Electrochromic Windows in the US Commercial Buildings Sector." LBNL Report No. 54966.

Window-to-Wall Ratios: The most significant design benefit of EC glass is the ability to increase window-to-wall ratios (WWRs) without energy penalty to the building.[9] In general, windows have higher solar heat gain coefficients and higher conductive heat losses than opaque walls, which has increased the focus on reducing prescriptive WWRs in energy codes such as IECC and ASHRAE 90.1.

In fact, static glass studies have shown that optimum energy efficiency for EC glass is delivered in combination with dimmable lighting controls. The results of these studies show that lighting controls alone can save 7% to 25% in overall energy usage.[10]

The use of EC glass further improves these savings by allowing the modulation of VLT across a large range, from greater than 60% to less than 2%. Dynamic, electronically tintable windows can be controlled independently of each other, further increasing energy savings by grouping or zoning glazed areas for even more effective control of VLT.

4. Tapping into the Benefits of EC Glass: Energy, Sustainability and User Base

Through scores of case studies of recent building projects, numerous industry analyses, and computer simulations, EC glass has demonstrated its value in enabling varied architectural expression while also improving the energy performance in dynamic façades and whole-building approaches. EC glass is also a valuable ally in meeting new, stricter energy codes and green-building goals such as those in LEED or the DOE's zero-energy building program.

Four facets of electronically tintable glass contribute to the rationale for expanding its use:

(a) Energy Efficiency. The DOE has identified several façade technologies to achieve very low-energy-consumption building designs, including low-U-factor glazing, which reduces conductive losses, and mechanical solar control systems integrated with dimmable lighting controls. A third technology is dynamic solar control.

Conventional operable solar control products, such as mechanical louvers and blinds, have been compared against EC glass, which also provides variable solar control automatically or by user input. In both cases, the SHGC and VLT can be changed to respond to occupancy needs and environmental changes.

In terms of operating cost and life-cycle cost, LBNL has evaluated electrochromic windows and concluded that they can eliminate up to 60% of daily lighting energy needs.[11] Further, a DOE analysis shows that commercial buildings using EC windows can reduce energy costs by up to 28% as compared to those with static, spectrally selective, low-E windows. The DOE studies[12] have also shown that EC glass can contribute:

- 10% to 20% reductions in operating costs
- 15-24% peak demand reduction
- 25% decrease in HVAC system size

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9 "Study of the impact on building energy of EC glazing and increasing window-to-wall ratio," R. Mistrick, Penn State University, to be published.

10 "A Pilot Study to Investigate Building Energy With and Without Daylighting Control as a Function of Window-to-Wall Ratio," by S. Treado and R. Mistrick. The study was commissioned by AGC, Guardian Industries, Lutron Electronics, Pilkington, PPG, SAGE Electrochromics and Wattstopper.

11 IEA Task 31/45, Daylighting/Lighting Seminar on Research and Practice, Pacific Energy Center, San Francisco, April 21, 2005, Eleanor Lee, Lawrence Berkeley National Laboratory.

12 LBNL in http://best2.thebestconference.org/pdfs/034_WB9-1.pdf.

There are other benefits to consider that impact operating and life-cycle costs that did not figure in these studies. For example, dynamic solar control using EC glass does not require moving parts nor the associated maintenance.

Moreover, recent studies and reports from field applications show that there are potentially more energy savings from using EC glass than with static solar-control solutions, for a few key reasons:

- The ability to modulate the solar heat gain coefficient (SHGC) also provides the designer with a controllable heat and light valve for their building;
- The amount of light and heat coming into the space can be tuned depending on the exterior environmental conditions and the needs of the occupants.[13] By dynamically controlling the light and heat flow, significantly more energy savings can be captured than when using a static solution, and—importantly—enhanced occupant comfort with maintained exterior views can be realized. In fact, the use of EC glass provides an architect with the ability to design with more glass without energy penalty.

Studies show that EC glass can save about 20% of building energy use, deployed properly and in conjunction with dimmable lighting. Greater savings are also possible: A study by green-building consultant Paladino and Co.[14] compared the energy performance of windows incorporating dynamic EC glazings with conventional and high-performance static glazings. Using computer energy simulations based on the ASHRAE 90.1-2007 national energy code, the study concluded that energy savings of 45% are achievable as compared to static, single-pane fenestration, without the use of daylight controls (Table 1).

Table I.

Minimum Annual Energy Savings for SAGE Dynamic Glazings Compared to Static Commercial Glazing Types

	Static Single Pane (no daylighting controls)	ASHRAE 90.1-2007	Commercial Triple
SageGlass Double	45%	20%	NA
SageGlass Triple	53%	34%	14%

Eight story office building, 160,000 total sq. ft., 60% window-to-wall ratio

(b) Embodied Energy and Life-Cycle Analysis. In terms of embodied energy of building products, life-cycle studies have shown that electrochromic IGUs have an embodied energy similar to that of non-dynamic IGUs. This suggests significant embodied energy savings over façades using mechanical systems such as louvers and blinds. This is because low-E glass would be used in most commercial projects anyway, so the use of EC glazing is not incremental – it is a different version of the glass. But its use means that mechanical solar control (shades, canopies, light shelves, blinds and the like) are not necessary.

Still, savings of both costs and energy in the building operations phase greatly exceed the initial embodied energy costs. In addition to the energy savings demonstrated, there is an ongoing energy penalty for using mechanical louvers or blinds, which must be operated, maintained , cleaned, and periodically replaced.

CO_2 Emissions: EC glass has been shown to be an effective means for reducing carbon emissions, which contribute to climate change. First, the carbon emissions associated with the embodied energy to produce mechanical solar control products, as indicated above, can be completely eliminated.

Second, and more to the point, EC glazing can reduce total annual energy use in buildings. This results in less primary energy and associated CO_2 emissions produced by power plants.

13 Helen Sanders, "Electronically Tintable Glass: Façade Design Without Compromises," *Intelligent Glass Solutions,* April 2011

14 Paladino & Co., "Performance Assessment of SageGlass Electrochromic Coatings and Control Scenarios," June 2010.

Third is peak CO_2 emissions reduction, according to Paladino & Co., because utility companies run their most efficient power plants to meet base-load demand and slowly bring on less efficient, more CO_2-emitting plants as demand increases. EC glazings "reduce the load on a building during peak utility times," says the report, so "their use exponentially reduces power plant emissions." EC glass is shown to reduce peak-load carbon emissions by as much as 35% in new construction and 50% in renovation projects.

(c) Sustainability. EC glass has been shown to be an effective component of green building, with varied contributions to green standards, codes and certifications. The increases in daylight and exterior views made possible with EC glass are beneficial to indoor environmental quality (IEQ) measures as well as IEQ credits in LEED and other green standards. It is also possible to reduce light pollution using EC glass. In its tinted states the glazing transmits less than 2% of visible light[15] so at night this capability can reduce light trespass.

Other benefits include reduced energy use, as detailed above, and techniques to improve occupant comfort by reducing glare and controlling solar heat gain. In winter, for example, the glazing can be kept in its high transmission state when maximum solar light and heat are desired, and the low-E EC coating helps keep the heat inside the building. In general, projects may qualify for the following LEED credits in part or fully due to the use of EC glazing:

- Energy And Atmosphere, Credit 1: Optimize Energy Performance
- Energy And Atmosphere, Prerequisite 2: Minimum Energy Performance
- Sustainable Sites, Credit 8: Light Pollution Reduction
- Indoor Environmental Quality, Credit 7.1: Thermal Comfort – Design
- Indoor Environmental Quality, Credit 8: Daylight And Views – Daylight
- Indoor Environmental Quality, Credit 6.2: Controllability Of Systems – Thermal Comfort

As suggested by these green building benefits, there are potential improvements to building occupant health and performance associated with the use of EC glass.

(d) Health and Productivity Improvements. As described by the Heschong-Mahone Group studies, people perform better and are more satisfied with their jobs when they have a view to the outdoors and exposure to natural daylight. Because of this, there is a variety of health, safety and welfare (HSW) benefits that can be attributed to the use of EC glass because it eliminates the need for shades and blinds, which block the view. In a 2012 survey conducted by SAGE and Hanley Wood,[16] virtually all architects surveyed agreed that people perform their jobs or activities better in buildings when exposed to natural light. Similarly, about 98% also agreed that building occupants perform better when they have a view of the outdoors.

The impact on morale, healing, productivity and health is an important goal for building design teams. Yet the Hanley Wood/SAGE survey also notes that about 93% of architects consider solar control "a significant challenge when designing glass into buildings." EC glass is another tool architects can use in dealing with these challenges.

15 SageGlass.com/wp-content/uploads/2011/08/MKT-008-LEED-2-pager-print-version.pdf
16 http://sageglass.com/architects/

5. Case Histories

With VLT levels as low as 2%, EC glass can block glare while also maintaining views to the outside - mechanical alternatives block or obstruct the view. The building designer and operators can also modulate or tune heat gain and daylight VLT levels as needed without moving or mechanical parts, which can break or wear out, or that require electrical power or human intervention to operate.

Based on the weather and other environmental factors – and based on the needs of building occupants – the building team can set the parameters for fenestration performance. A number of case histories demonstrate these benefits.

Eliminating HVAC Systems: EC glass was used in a two-story atrium in the Chabot College Student Services Center in Hayward, Calif. This building design, by tBP/Architecture along with engineer Thornton Thomasetti, allowed for a fully naturally ventilated interior to meet LEED certification criteria.

The Student Services Center at Chabot Community College shown with EC glass in its tinted state (left) and clear state.

The space includes a curtain wall that faces south and west in a cooling-dominated climate zone. The project team studied the use of EC glass to control glare and heat gain. Interior temperature and comfort would be served by radiant heating and cooling in the concrete slab, combined with roof and ceiling air scoops for natural ventilation. The automatic controls scheme activates the EC glass in three zones and is integrated with the BMS.

According to Phil Newsom, the architect from tBP/Architecture, the use of EC glass made possible the combined ventilation and radiant heating/cooling technique because it controls the amount of sunlight entering the space. “As a result it has become an architectural enabler that has allowed us to create an HVAC-free space,” Newsom said.

Managing Solar Heat Gain: The Kimmel Center for the Performing Arts in downtown Philadelphia was designed with a spectacular vaulted glass roof. However, the interior space often experienced unbearably hot temperatures due to the greenhouse effect created by the glass roof. The Kimmel Center’s Hamilton Garden Terrace, situated immediately beneath the roof, was unusable from May through October due to the excessive heat and glare. When EC glass was installed in the ceiling above the terrace (and below the vaulted roof) in 2012, the facility gained the ability to control heat and glare and now books events in the space year-round.

Kimmel Center for the Performing Arts in Philadelphia. The skylight with EC glazing makes it possible to use the space year round. Photo on the right shows the terrace roof where SageGlass is installed beneath the massive vaulted roof.

Protecting furnishings: Protecting building contents against fading is a matter of economics and aesthetics, but for historic buildings and museums it can also be part of preserving a legacy. When the Athenaeum in St. Johnsbury, Vt., had to replace the glass in the building's original skylight, it had to do so while also preserving "the unique and authentic atmosphere that people experience when they visit," said John Mesick, the lead architect involved in the renovation. The art gallery, constructed in 1873, is one of the oldest, unaltered museums in the U.S. In addition to the other requirements for the renovated skylight, high energy performance was also desired.

In terms of fading protection, clear glass would reduce solar energy that causes fading by up to 30% based on the International Commission on Illumination's standard (Tdw-ISO), or by 45% if measured using the Krochmann Damage Function (Tdw-K). That compares to 52% Tdw-ISO and 77% Tdw-K for typical low-E glazing. EC glass in the tinted state, on the other hand, would block 97% and 98%, respectively, of the solar energy that causes UV fading, using those same measures. More important, said Mesick, "Using traditional glass with mechanical shades or other sun controls would have severely compromised the aesthetic appeal of the gallery."

Looking up at the skylight inside the St. Johnsbury Athenaeum. The skylight, glazed with EC glass, protects one of America's most beloved paintings from fading. Bottom photo shows the skylight, replicated to match the Victorian style of the museum, being set onto the roof.

Correcting Solar Control and Glare Issues: A recent retrofit in a multi-purpose residence hall at Ball State University in Muncie, Ind., used SageGlass electrochromic IGUs to correct glare and hot spots caused by the large skylight in the space Architect Ryan Benson of Schmidt Associates, Inc., evaluated conventional solar control options of – such as shades, exterior fins or louvers – relative to switchable glass.

The client participated in the evaluation, concluding, "We looked at installing mechanized shades and blinds, but that option was not attractive and would have created on-going maintenance issues," said Gary Canaday, manager of campus construction for the school's Facilities Planning & Management department. "EC glass controls the sunlight and heat that enters and leaves the building, reducing our energy use while enhancing and increasing students' use of the space," he said.

The architect, Ryan Benson, called EC glass "the best option, because it enabled us to maximize natural light and a view to the outdoors, while creating a space that's thermally and visually comfortable for the students inside."

Ball State University recently retrofitted an old skylight with EC glass, which has created a much more comfortable space for students.

6. Conclusion: Moving Forward with EC Glass

As shown in this paper, dynamic glass has multiple architectural benefits. In addition to reducing energy consumption and promoting more sustainable building design, electrochromic glass enables occupants to experience a view and connection to the outdoors – the very reasons buildings have windows in the first place.

Traditional “static” windows have accounted for about 30% percent of a building’s heating and cooling energy usage on a historical basis.[17] EC glass such as the patented SageGlass product has been shown in government studies to reduce energy loads for buildings by up to 20% and lighting costs by 60% percent, while providing building occupants with the maximum amount of natural daylight.

As shown through recent studies and two decades of field experience, EC glass technology is an established and effective tool for energy-efficient, high-performance building design. In particular, EC glass allows dynamic control of enclosure light and heat flow, resulting in significantly more energy savings than comparable static solutions. EC glass also has numerous salutary benefits for building occupants and can also protect building contents. At the same time, EC glass can enhance occupant comfort and also maintain outdoor views .

Momentum for the use of established EC glazing technology, such as the materials and IGUs marketed by SageGlass, is considerable, with hundreds of actual installations. EC glass allows architects and building teams to design and build new or renovated structures with more glass yet without an energy penalty.

Products like SageGlass will be increasingly used in the commercial and institutional building markets, and we anticipate increasing demand for the category of dynamic glass going forward.

17 Saint-Gobain N.A., www.saint-gobain-northamerica.com/media/newsItem.asp?ID=90