Developing The Next Three Generations of Zero-Energy Windows

Brandon Tinianov, Ph.D., P.E., LEED AP[1]

It is without question that building façade and envelope design is an extremely complicated science. Thousands of materials come together to create a dynamic interface between a constantly changing outdoor environment and stable indoor conditions.

Advanced glazing has great importance due to its profound impact on total building energy performance. In some cases, the glazing may have the single greatest impact of any single building component. In fact, research indicates that high performance glazing is critical in “fulfilling the vision of zero energy buildings”.[1] Analytical tools and policy have matured in the last several years providing additional impetus for its adoption. Additionally, advanced glazing is in the midst of a technological revolution which heightens its potential energy savings and accelerates the payback period (and financial rationale) both in new construction and in energy retrofits of existing buildings. For these reasons, a brief overview of state-of-the-art glazing is in order.

A new market For glazing

One of the key influencers to the expanded discussion of advanced glazing systems is the restructuring and refocus of the current and future construction market. Traditionally, code mandated building energy requirements have been modest and most insulated glass systems could meet these basic performance demands. However, there is a growing market demand for green or high performance buildings that mandate energy efficiency beyond code minimums. In many cases, the total building consumption must be reduced by 15 to 40 percent. Advanced glazing is a key enabler to these targets.

A second, important market influence is the shift from new construction to retrofit construction activity. New buildings represent only 2.5 percent of the U.S. building market, while retrofitting provides an enormous market opportunity for owners and green builders and, recently, energy service provider companies (ESCOs).

Currently, energy focused and green building comprises 5 to 9 percent of the retrofit and renovation market activity by value. This equates to a $2 to 4 billion marketplace for major projects. By 2014, researchers estimate that the share is projected to increase by 20 to 30 percent, creating a $10 to 15 billion market for major retrofit projects in only five years.[2] Boosted in part by the American Recovery and Reinvestment Act (ARRA), which will provide significant funding for renovations to federal buildings, the total potential market for major green renovations in the commercial building sector could grow to as much as $400 billion, according to another study.[3]

[1]Brandon Tinianov, Ph.D., P.E., LEED AP, is the Chief Technology Officer at Serious Materials.

"Three generations" of advanced glazing
In my opinion advanced glazing in the mid-term future will take the form of "three generations" of technology. These generations, in order of market availability, are:

Generation 1 – low u-factor glazing (u 1. ≤ 0.20);
Generation 2 – dynamic glazing; and 2.
Generation 3 – building integrated photovoltaic glazing. 3.

Other interesting technologies, façade elements and glass features may take shape along the way, but these three advances will be the landmarks along the path of fenestration improvements and the establishment of zero energy buildings.

Generation 1: high thermal performance glazing
Fenestration systems with low u-factors reduce the heat flux (both into and out of) the building. Improving on common dual pane systems, low-e with a typical full frame performance of a u-factor of 0.50 to 0.254 will achieve u from-factors of 0.20 to ≥ 0.10. There are multiple, well established methods to achieve these benchmarks, with the greatest success found in three or more separated coated panes (with internal panes of either glass or suspended coated films) having the greatest commercial success.

At the time of publication such a window, which employs two external glass panes and three internally suspended coated films, is currently listed as the National Fenestration Research Council's (NFRC) highest performing assembly, with a full-frame u-factor of 0.09.5 An example is shown in **Figures 1 and 2**.

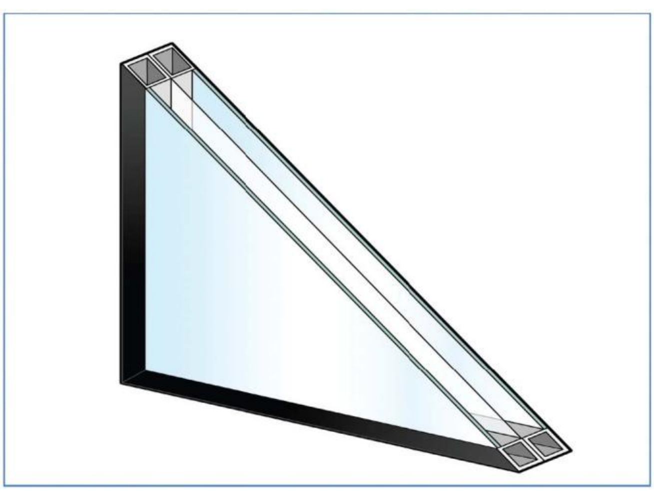

Figure 1. Cutaway of triple- pane insulated glass unit. Image courtesy Serious Materials.

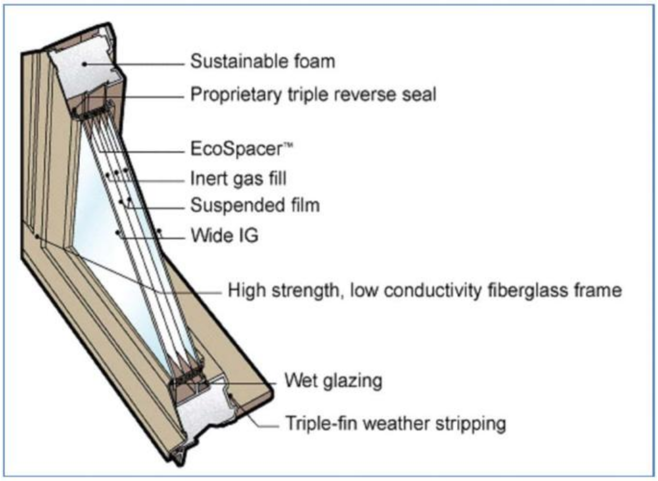

Figure 2. Cutaway of a quad pane window including the frame. Image courtesy Serious Materials.

One advantage of this system is its well understood benefits (demonstrable via energy models) and its design and performance flexibility. Multiple layers and a broad library of low-e coatings allows for systems that can be tuned for low or high solar gain, tint and value in all of the forms and styles that architects are comfortable using. Other technologies to improve glazing thermal performance currently in research or undergoing initial market adoption include vacuum glass panes and evacuated insulated glass. These units may soon be widely available. As with many emerging technologies, the shortcomings of these new methods are that they are costly, difficult to fabricate across a range of typical dimensions, and are unproven over a typical 20 year service life.6

This first generation of advanced glazing is finding traction in the national building market right now. This is not because the technology required is new (suspended coated films have been available and in service for over 30 years), but because their unit pricing is now attractive to architects and building engineers. A u-factor 0.15 Generation 1 system may have a comparable cost to many “performance” dual pane systems and may have a very short (2 to 5 years) premium payback period when compared to a commodity glass system with a u-factor of approximately 0.5. Such Generation 1 glazing should enjoy rapid adoption because 2× performance is possible at little or no incremental cost (see **Figure 3**).

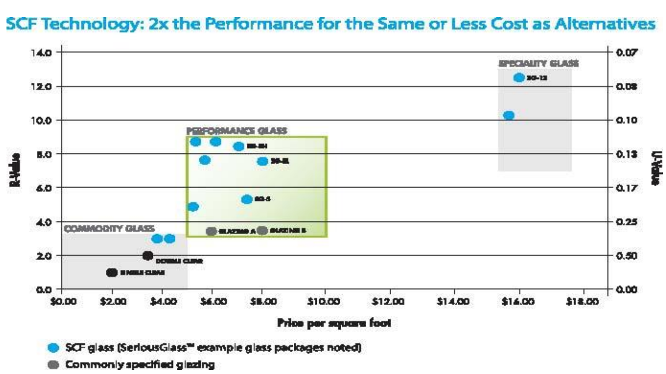

Figure 3. Chart depicting the high relative performance of triple pane glass systems. Courtesy of Serious Materials.

Generation 2: dynamic glazing

In the context of this article, dynamic glazings are those that can modulate their transmission properties to improve energy efficiency while allowing daylight to offset electric lighting re-quirements and encourage a connection to the outdoor environment. A secondary role of some user-controlled systems is that they can act as light shades or privacy glass as needed.

Dynamic glazing can admit solar heat when it is needed to offset heating energy needs, reject solar gain to reduce cooling loads, possibly reduce a building's peak electricity demand, and offset much of a building's lighting needs during daylight hours. To do so, the solar heat gain coefficient (SGHC) of the window may vary from approximately 0.50 to 0.05. The trigger for this performance switching can be controlled either actively (user) or passively (environment).

The energy saving benefits of dynamic glazings are highly case specific and vary with building type and climate, but can be profound at a national scale. A 2004 study of optimized applications of dynamic glazings was done by Lawrence Berkeley National Labs. It concluded that "perimeter zone primary energy use is reduced by 10 to 20 percent in east, south and west zones in most climates if the commercial building has a large window-to-wall ratio" when compared to insulating static glazing, and that peak demand in these example buildings was reduced by 20 to 30 percent. The study also found that at 40 percent market adoption, dynamic windows with daylighting controls could save approximately 9×10^{13} Btu in the year 2030.7

Dynamic windows can be based on a number of possible technologies, including electrochromic layers, reflective metal hydride coatings, suspended particle devices, or thermo-chromic liquid crystals. Previous researchers have classified ideal dynamic glazing into three types whose transmittance switched over different spectral ranges: the entire solar spectrum, the visible spectrum only, or the solar infrared spectrum only. Additionally, each of these activations can take place either by absorption or reflection.

At this time, several companies are offering versions of passive, active, absorptive and reflective systems. RavenBrick is a new manufacturer that is developing both electro-reflective and thermo-chromatic technology. Another manufacturer, Switch Materials, has a hybrid approach. In their designs, a photo/electrochromic hybrid dye automatically darkens when exposed to high intensity light and can be reset to a clear state by the application of low voltage electricity.

Of these possible variations, by far, the most common are active electrochromics blocking full spectrum light via absorption.8 The advantages of this current technology approach is that unwanted solar gain can be controlled by either building environmental controls or users, and that they can be readily incorporated into traditional glazing systems (including Generation 1 technology)..

However, there are several disadvantages to current EC technology. By far the greatest is the cost. Existing EC products can cost $60 to 100 per sq.ft., far exceeding the energy savings. Second, the approach is full spectrum absorption so that artificial lights must be used when the glass is active.

Dynamic glass will see widespread adoption when it is demonstrable that the incremental cost of the technology can be recovered as energy savings within a 10 to 15 year period. Given the current trend in energy costs and climate policy, it is reasonable to expect that dynamic glazing technology with an incremental cost of $5 to 10 per sq.ft. would enjoy broad market adoption. Last, it is important to note that for full energy savings, dynamic glazings must be paired with low u-factor systems. Without such a combination, the solar gain passing into and heating the building is immediately lost through the poorly insulating glass.

Generation 3: building integrated photovoltaic glazing

The last generation of energy efficient fenestration is one that generates its own renewable energy, effectively reducing the total building consumption. Generation 3 fenestration products are commonly known as building integrated photovoltaics (BIPV). For the purposes of this discussion, I will consider fenestration BIPV as that which incorporates photovoltaics into the viewable area.

Third generation BIPV will come in two main forms: partially opaque/light transmitting; and transparent. As implemented today, light transmitting BIPV consists of solar cells made from thick crystalline silicon either as single or poly-crystalline wafers (**Figure 4**). These deliver about 10 to 12 Watts per ft^2 of PV array (under full sun). Such technology is best suited for areas with no light transmission requirements (e.g. spandrels) or shading areas such as overhangs and sunshades.

Figure 4. Image of a commercially available “light thru” BIPV product. Courtesy SunTech Corp.

Transparent BIPV systems are thin-film products that typically incorporate very thin layers of PV active material placed on a glass superstrate or a metal substrate using vacuum-deposition manufacturing techniques similar to those employed in the coating of architectural glass (**Figure 5**).

Figure 5. Image of a commercially available “see thru” BIPV product. Courtesy SunTech Corp.

Presently, commercial thin-film materials deliver about 4 to 5 watts per ft^2 of PV array area (under full sun). Thin-film technologies hold out the promise of lower costs due to much lower requirements for active materials and energy in their production when compared to thick-crystal products. Although the thin film technology is designated as transparent, its actual light transmittance is typically between 1 to 10 percent. Such systems are not currently suitable for high transparency applications, but are well suited for atriums and glass canopies. There are several current manufacturers of both types of BIPV, including Schott (under the name ASI Glass), SunTech and Rainbow Solar.

In order to be more than a technology showpiece, BIPV incremental costs need to come down to the point where they can demonstrate a financial payback period comparable to other non-building integrated PV.

Conclusion

Now is an exciting time for advanced building glazing, as building energy has caught the attention of both technology companies and energy policy advisors. Along the path of future glazing technologies are three generational milestones: low u-factor, dynamic properties and energy generation. Developing these next three generations of zero-energy windows will provide products for both existing buildings undergoing window replacements and products which are expected to be important contributors to a zero-energy building future.

References

1. Arasteh, D., Selkowitz, S., et al., Zero Energy Windows, Proceedings of the 2006 ACEEE Summer Study on Energy Efficiency in Buildings, August 13-18, 2006, Pacific Grove, CA, LBNL-60049.

2. SmartMarket Report: Green Building Retrofit & Renovation, McGraw Hill Construction, 2009.

3. Energy Efficiency Retrofits for Commercial and Public Buildings, Pike Research, 2009.

4. In all cases u-factor is given in English units of BTU/h·ft2·˚F and represents full frame values.

5. As manufactured by Serious Materials, www.seriousmaterials.com.

6. Vacuum glass panes are being produced under the name Spacia 6.(www.nsg-spacia.co.jp) and vacuum IGUs created via a metal-to-glass diffusion bonding process are under development by EverSealed Windows Inc., (www.eversealedwindows.com).

7. Lee, E., Yazdanian, M., Selkowitz, S., The Energy-Savings Potential of Electrochromic Windows in the US Commercial Buildings Sector, Completed April 30, 2004. LBNL-54966.

8. At the time of publication, SAGE Electrochromics is the leading manufacturer of commercially available EC glazing (www.sage-ec.com).