Reprint of Manuscript from the 51st Annual Technical Conference Proceedings of the Society of Vacuum Coaters

2008 Study of Architecture Professionals on the Subject of Smart Glass, Daylighting and Clean Technology

G.M. Sottile, Research Frontiers Incorporated, Woodbury, NY

This work is reproduced here with permission from the Society of Vacuum Coaters. This work was presented at the 51st Annual Technical Conference, Society of Vacuum Coaters, April 19–24, 2008 in Chicago, IL.

The Proceedings of this conference will be published fall 2008 and can be ordered from the SVC by sending an E-mail to svcinfo@svc.org or by completion of the SVC publications order form on the SVC Web Site at http://www.svc.org/P/Publications.html.

2008 Study of Architecture Professionals on the Subject of Smart Glass, Daylighting and Clean Technology

G.M. Sottile, Research Frontiers Incorporated, Woodbury, NY

ABSTRACT

Many opportunities now exist to use advanced materials, products and processes that protect scarce resources and enhance people's quality of life. Interest in such clean technologies is especially strong in the architectural community. The United States Department of Energy reports that buildings now account for nearly forty percent of all energy consumed in the country, the highest level to date. To reduce buildings' environmental impact, architects and others increasingly rely on daylighting strategies that leverage the design and location of windows, skylights and other glazings to reduce energy consumption, improve human comfort, and marshal a resource available to virtually everyone – natural light.

One of the most robust new categories of daylighting technologies is smart glass. Smart glass is a growing category of building materials that visibly change their light-control properties in response to a stimulus. They offer unprecedented daylighting benefits including the dynamic control of light, glare and heat passing through windows and glazings. This paper summarizes a market research study of architectural professionals on the subject of smart glass as a clean technology because of its daylighting potential.

INTRODUCTION

The modern movement of sustainable architectural design continues to evolve. With roots in the ecology initiatives of the late 1960s, pressing environmental concerns and growing energy costs have transformed the movement into one of the most pervasive forces in architectural design today. The pressure toward sustainability is strong from many perspectives. A growing number of developers, architects and homeowners are motivated altruistically toward sustainable design. In their opinion, sustainable building practices support the long-term welfare of society and health of the planet. Many federal, state and local initiatives complement these motivations through the introduction of regulations and the promotion of incentives designed to reduce energy consumption and encourage greater use of renewable resources. Likewise, technology developers and their respective investors continue to devote substantial amounts of time and capital toward research and the commercialization of innovative solutions that profitably address the growing desire to "go green."

SUSTAINABILITY AND CLEAN TECHNOLOGY

Historically, a holistic view of sustainability has existed. In 1987, the Brundtland Commission, formerly the World Commission on Environment and Development convened by the United Nations, claimed "Development is sustainable when it meets the needs of the present without compromising the ability of future generations to meet theirs" [1]. Within this viewpoint, sustainable initiatives are evident along multiple dimensions and with growing frequency. From the design of energy efficient buildings and automobiles to the more localized commitments for open space preservation, sustainability is an emerging point of commonality among governments, organizations and individuals worldwide.

Sustainable architectural design, often referred to as "green building," involves practices that increase the efficiency of buildings, support the health and well being of building occupants, and minimize the impact that buildings have on the environment. It is in these areas that the drive toward sustainability is especially pronounced and with apparent justification. For example, according to the U.S. Green Building Council, buildings in the United States account for 39% of energy use, 71% of electricity consumption, 40% of non-industrial waste and 38% of carbon dioxide emissions [2].

The concept of clean technology is a recent manifestation of the movement toward sustainable design. Inclusive of a range of products and processes across many industries, clean technology integrates the ideals of sustainability with profit-making objectives. The Cleantech Network describes clean technology as "new technology and related business models offering competitive returns for investors and customers while providing solutions to global challenges" [3]. Investments in the development of clean technologies have accelerated recently, with spending in 2007 projected to increase 14% from the prior year and surpass $55 billion globally [4]. Similarly, venture capital investments in clean technology are growing strongly. Such investment in North America totaled $2.9 billion in 2006, a 78% increased from the prior year. Further, during 2006, energy-related investments represented 74% of total venture capital investments made in clean technology [5]. The infusion of equity investments into clean technology is occurring at a time of growing societal and government demands for proactive action with regard to

51st Annual Technical Conference Proceedings, Chicago, IL, April 19–24, 2008 ISSN 0737-5921

sustainability. As these forces converge, it is likely the costs for sustainable products and processes will decrease, thus availing such innovations to a larger number of end-users. This appears to the case with photovoltaic (PV) technology, a renewable energy innovation that has existed for several decades but has not experienced a sizeable upturn in production until fairly recently. Since 2002, production of photovoltaics has doubled every two years, making it the fastest-growing energy source in the world [6]. Looking ahead, some expect that PV technology will achieve grid parity – the point at which the lifetime costs of acquisition and usage are equivalent to electricity costs from conventional sources such as a utility – within two years [7].

Interest in sustainable living has existed for millennia. Many cultures through history have survived and thrived because of responsible stewardship of their natural resources. Today, an inflection point in the evolution of sustainable architectural design appears to have been reached. With buildings accounting for substantial amounts of resource consumption and environmental impact, heightened interest within the design community and a growing set of innovative solutions offered by industry are making sustainability an achievable objective.

DAYLIGHTING

There are few conditions in the history of humankind as pervasive as the need for natural light and the desire to control it. Daylighting involves the purposeful introduction of natural light, also known as daylight, into the interior of a building. Varying perspectives on daylighting exist within this broad context. In a study of mostly North American and Australian design professionals, an architectural definition of daylighting that involves "the interplay of natural light and building form to provide a visually stimulating, healthful, and productive interior environment" was deemed the most relevant. However, daylighting definitions pertaining to other orientations such as lighting energy savings and building energy consumption also were considered relevant to some [8].

The strategic application of daylighting primarily involves shading from the sun, protection from glare and the redirection of natural light [9]. Studies examining the effect of daylighting strategies signal both economic and human benefit. Properly designed daylighting systems in retail, educational and workplace settings have been associated with dramatic increases in individual well being and productivity [10]. This is consistent with pioneering research on windows and their effect on building occupants. Collins (1975), for example, reported that a building's windows were typically mutli-functional. In addition to offering a view to the outside, windows offered occupants aesthetic advantages, enhanced psychological states and other positive benefits [11].

The sun provides bountiful energy. Harvesting this energy through daylighting strategies offers the opportunity to reduce the use of interior electric lighting, lower heating and cooling costs, increase occupant well being and health, and minimize environmental impact. Driven by a combination of energy efficiency goals and human well being desires, demand for daylighting solutions is growing. Some of these solutions are passive in nature and involve decisions as fundamental as the siting of a building or the size and placement of conventional windows. Others are of a more active nature, integrating daylighting products and processes with computerized building controls systems. Effective use of both active and passive solutions will help to advance the sustainability of buildings.

SMART GLASS

Smart glass is a category of materials whose light-control properties change in response to a stimulus [12]. Also known as chromogenics, switchable glass and dynamic glazings, a growing number of smart glass products exist ranging from aerospace windows to automotive sunroofs and mirrors. In the architectural application, smart glass can be integrated into windows, doors, skylights, partitions, light tubes and other products. Control systems, as basic as a simple switch or more advanced using ambient light or temperature sensors, allow building operators and occupants to adjust the light-transmission properties of smart glass, a major advancement over conventional windows that typically must be supplemented with view-blocking and space-consuming blinds or shades to control light transmission. Sleek, easy to maintain and requiring very low amounts of energy to operate, smart glass also permits dynamic light-control while preserving the view to the outside, a desired property but one that is typically not available from conventional shading systems. Most importantly to many, smart glass can reduce energy demands for interior lighting and heating, ventilation and air conditioning systems. The outlook for smart glass is especially strong, with the Freedonia Group projecting that the dollar value of smart glass demand in the United States will reach $1.34 billion in 2015, a 250% increase from 2005 [13].

Two broad segments of smart glass exist. Passive smart glass has no electrical interface, reacting instead to other stimuli such as ultraviolet light. Photochromic eyewear is an example of passive smart glass. The larger of the two segments, and that which is experiencing the greatest interest from many industries, is active smart glass. The light transmission properties of active smart glass change in response to changes in an electrical stimulus. Included among the set of active smart glass are three unique types of active smart glass technology, each with its own distinct chemistry and performance characteristics. In architectural settings, liquid crystal (LC) smart glass is primarily used for interior applications such as partitions where privacy is occasionally needed. Tunable in milliseconds and offered with two states – transparent and translucent – LC smart glass diffuses incoming light and offers essentially complete privacy, but it provides only nominal shading benefit. Suspended particle device (SPD) smart glass is a shading system that can block 99.4% or more of incoming visible light, a level that is approximately 20 to 40 times darker than typical window tints. Clear state levels are almost as light-transmissive as an ordinary window, and SPD smart glass is tunable within seconds to any point between dark and clear. Thus, users can achieve privacy in the dark state, peak light transmission and visibility of the outside in the clear state, and varying degrees of shading and view preservation in intermediate states. Electrochromic (EC) smart glass is similar to SPD smart glass in that it offers light transmission states from dark to clear. Of all the active smart glass technologies, EC smart glass is the slowest to switch, with architectural EC smart glass often taking many minutes to change its light-control properties. The switching speed of EC smart glass also is disproportionately slower as panel size increases. As such, architectural EC smart glass is typically offered with two states, shaded and clear.

Active smart glass offers architectural designers a very powerful tool in their quiver of energy efficient daylighting strategies. Perhaps most fundamentally, smart glass transforms conventional windows into devices with unprecedented light-control properties. Traditionally, architectural windows were integrated with standard blinds, shades or curtains to provide light-control for those times when shading or privacy was desired. In such events, one of windows' primary utilities – occupant views to the outside – was diminished by these view-blocking treatments. Except in its most heavily tinted states, smart glass offers dynamic shading, glare reduction and solar control without loss of view.

Smart glass also can be combined with non-dynamic glazings to offer a blended approach to daylighting strategy. For example, multiple windows with different performance features could serve a single interior space. In a modestly sized office, for example, glazings near the ceiling could be integrated with exterior reflective light shelves that would supply natural light deep into the room. Below this glazing would be a larger smart glass panel that preserves one's view while adjusting to changes in exterior light conditions or control system parameters, thus protecting against solar radiation and excessive glare while also supporting natural light needs for one's more immediate work area.

Finally, because of its electrical interface, active smart glass also offers a great leap forward in terms of integration with intelligent building systems. While many daylighting strategies strive for ongoing penetration of natural light, some of these strategies are hindered by the fact that penetration of natural light into a building's interior occurs even when areas such as discrete office space or others rooms are unoccupied. By using photocells or other types of advanced control systems, daylight can be introduced reliably into these interior spaces only when rooms are occupied, thus providing desired occupant benefits while also more efficiently managing heat gain and its attendant demands on a building's cooling systems.

SURVEY OF ARCHITECTURE PROFESSIONALS

Introduction and Methodology

This is the first market research study to examine the attitudes of architecture professionals on the subject of smart glass, daylighting and clean technology. Because of its empirical nature, it offers the building industry and related constituents a series of benchmarked metrics against which future results can be compared.

The population for this study is United States LEED® Accredited Professionals who cite "architecture" as their practice area. LEED is an acronym for Leadership in Energy and Environmental Design, a program of the U.S. Green Building Council (USGBC). The USGBC, which administers this program that results in the rating of buildings along a number of measures, accredits professionals who are involved in various facets of the design and operation of buildings. To many industry participants, LEED is the primary accreditation and rating system in architecture today, and it is widely acknowledged for its success in advancing sustainability.

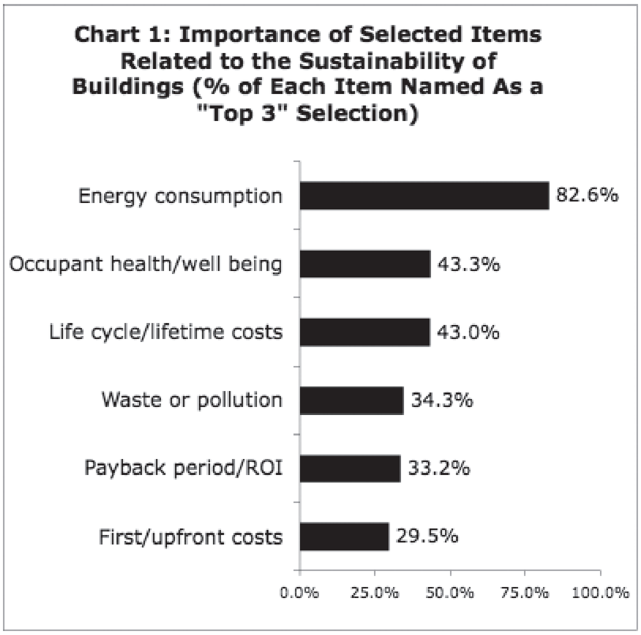
In January 2008, an email communication was sent to 10,407 of these professionals. The email requested participation in the study and provided a link to an online survey. Receipt of a summary of the study's results was offered as an incentive to participate. Through mid-February, a total of 1,510 usable surveys were submitted, resulting in a 14.5% response rate and a margin of error (α=0.05) of +/- 2.5%. To address non-response bias, responses were weighted by the region of the country to which respondents belong in a manner that reflected the distribution observed for the population of professionals.

Respondent Profile

Of the architecture professionals surveyed, 80.9% claim they have been LEED Accredited Professionals for two years or less. Approximately ninety one percent are employed by an architectural, design or engineering firm, and 50.7% are licensed architects. In terms of the focus of their work, 94.6% and 54.3% claim they are involved with commercial and residential projects, respectively. Of those surveyed, 84.1% say they have been involved with sustainable design projects in the past year and fully 32.2% claim to have evaluated, recommended or specified solar power such as photovoltaics in the past 12 months.

Attitudes Regarding Sustainable Design

Respondents were asked to identify the three most important items to consider when evaluating the sustainability of buildings being designed or in use. The item overwhelmingly selected most often was energy consumption, mentioned by 82.6% as one of their three items. Chart 1 summarizes citation levels for the six most important items, many of which are of an economic nature.

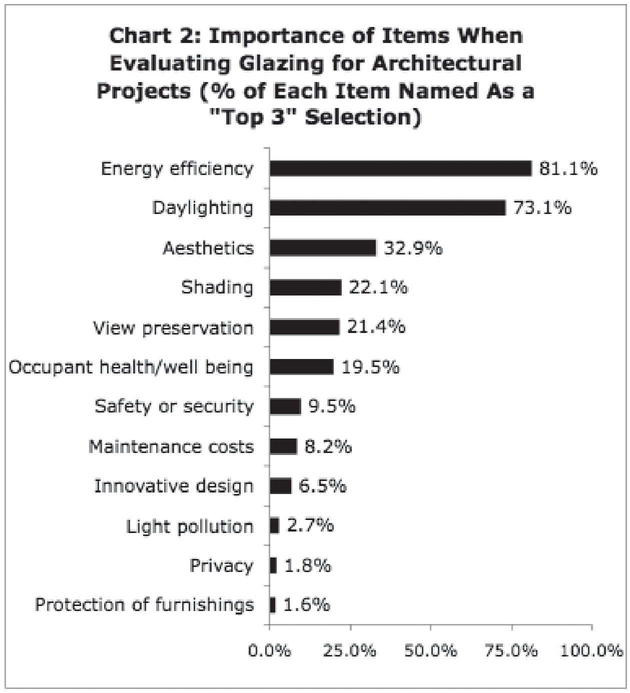


Forward-looking attitudes regarding sustainable design are very strong. When asked to comment on the expected change in the next five years in the proportion of United States architectural design work that involves sustainable design, 73.6% expect this proportion to increase greatly.

Respondents were asked again to consider expected trends related to sustainable architectural design over the next five years. Not surprisingly, 99.3% agreed with the statement that "demand for sustainable buildings will increase" over that time period. Levels of agreement were high as well with regard to expectations that: 1.) use of passive solar energy strategies (e.g. those using conventional windows or skylights) will increase (94.3%), 2.) the prevalence of buildings codes or standards mandating sustainable building will increase (93.3%), 3.) returns on investment in sustainable design will increase (93.0%), 4.) demand for solar control building products will increase (92.5%), and 5.) use of active solar energy strategies (e.g. photovoltaics) will increase (88.6%).

Architectural Glazing and Daylighting

Approximately three-quarters of those surveyed claim that they have evaluated, recommended or specified architectural glazing materials in the past year. When asked to identify the three most important items pertaining to glazing for architectural projects, energy efficiency (cited by 81.1% of the sample) and daylighting (cited by 73.1%) are clear leaders. As Chart 2 exhibits, while aesthetics ranks third overall, it falls considerably short of energy efficiency and daylighting, suggesting that for these professionals, the desire for visually appealing architectural glazings may often be superceded by the need to lower energy consumption.



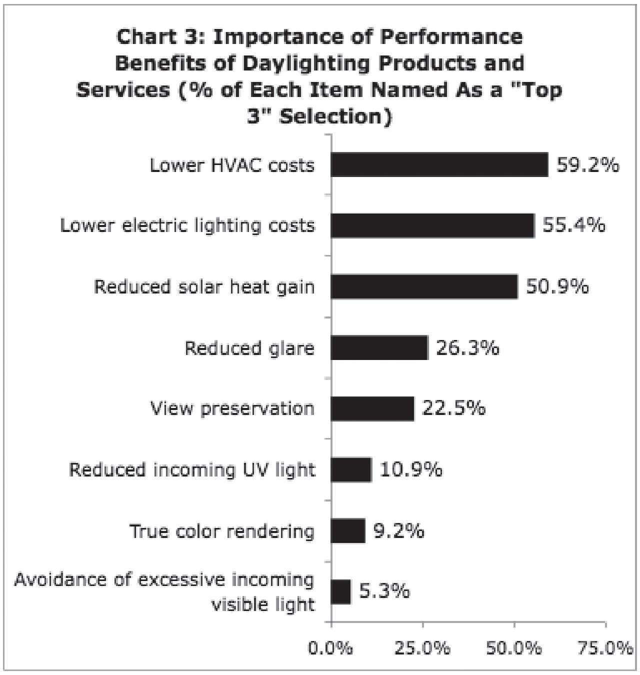
With regard to daylighting, respondents were asked to rank the importance of four general items that pertain to daylighting in architectural projects. Consistent with the results discussed earlier regarding the importance of items in sustainable buildings, respondents name energy savings and occupant health and well being as the two most important items. These are followed by aesthetics and organizational productivity.

The professionals surveyed were also asked to identify the three most important performance benefits of daylighting products and systems. The results, summarized in Chart 3, signal a strong bias toward the desire for positive economic impact from daylighting.

Smart Glass

Attitudes toward smart glass are very positive and suggest the potential for accelerating market adoption. Among the architecture professionals surveyed in this study, 75.6% said they were aware of smart glass prior to the study. Interest in smart glass appears to be growing, with 10.4% and 2.4% of those surveyed claiming to have evaluated, recommended or specified smart glass for a commercial or residential project, respectively. This is an increase from similar metrics observed for a 2007 study of LEED Accredited Professionals. In that study, 6.6% and 2.0% of the professionals surveyed said they or their firm had evaluated, recommended or specified smart glass for commercial and residential projects, respectively

[12]. Looking ahead, when asked about their likelihood to recommend or specify smart glass for a project, 87.6% said they would be highly likely or somewhat likely to do so if the price for smart glass is reasonable and it meets performance specifications.



Respondents were presented with twelve performance attributes of smart glass and asked to identify the three most important to clients who would have an interest to integrate smart glass into an architectural daylighting system. Energy efficient operation of the smart glass panel was the leading attribute (cited by 28.6%), followed by solar heat gain control that varies with the tint level of the smart glass (26.5%), elimination of the need for window treatments and coverings (24.3%), ability to change the light transmission of the glazing quickly (18.7%) and integration with building intelligence systems (16.7%).

These perceptions appear to drive what are reasonably strong beliefs about the potential returns on investment when daylighting systems integrate smart glass. Under the assumption that the incremental costs for smart glass are reasonable, 39.8% of those surveyed expect returns on investment from smart glass will be better than those from other sustainable products and systems of which they are aware. Fully 73.1% expect that ROI levels will be better or about the same when compared to these other products and systems.

CONCLUSIONS

The twenty-first century has ushered in a period of pressing threats to the environment, rising energy costs, and a firming resolve that sustainable architectural design can yield dramatic gains in long-term resource preservation and overall quality of life. Supporting all of this is the growing portfolio of clean technology products and processes that not only advance sustainable ideals but do so profitably.

A convergence is taking place, where societal and economic forces are meeting powerful technologies that offer unprecedented performance features and open new opportunities for innovative solutions. Smart glass is among these technologies. It is in the earliest stages of its life cycle, but the underlying daylighting benefits that it can deliver – control over light, glare and heat passing through glazings – are substantial and address a wide range of sustainability objectives. While awareness levels of smart glass are reasonably high among those surveyed, specification rates compared to conventional glazings remain modest. This is not an atypical state for a new category of technologies, and it is likely that as production volumes increase, costs for smart glass will decline and adoption rates will rise. A new, exciting and incredibly challenging era has arrived, and it's one where smart glass will offer architecture professionals and their clients innovative and effective approaches to sustainability.

REFERENCES

1. United Nations World Commission on Environment and Development, *Our Common Future*, Oxford University Press, New York, 1987.
2. U.S. GBC Research Committee, *A National Green Building Research Agenda*, U.S. Green Building Council, November 2007 (Revised February 2008).
3. Cleantech Network, LLC, *Cleantech Defined*, Retrieved from http://cleantechnetwrk.com on December 6, 2007.
4. J. Thaler, "Global Cleantech Spending Set for 14% Growth in 2007; Asia Ahead of U.S.," *Business Wire*, May 31, 2007.
5. A. Sweeney, "2006 North American Cleantech Venture Investment Totals $2.9 Billion," *Business Wire*, January 11, 2007.
6. J.G. Dorn, "Solar Cell Production Jumps 50 Percent in 2007," *Earth Policy Institute*, Retrieved from www.earth-policy.org on February 27, 2008.
7. A.E. Braun, "Photovoltaics Ready for Next Big Market," *Semiconductor International*, February 20, 2008.
8. C.F. Reinhart, J. Mardaljevic and Z. Rogers, "Dynamic Daylight Performance Metrics for Sustainable Building Design," *Leukos*, 3 (1), 7-31, 2006.

9. International Energy Agency, Energy Conservation in Buildings and Community Systems Programme, *Daylight in Buildings: A Source Book on Daylighting Systems and Components*, Report of IEA SHC Task 21 / ECBCS Annex, July 29, 2000.

10. J. Loveland, "Daylight By Design: Studies From the Betterbricks Daylighting Lab in Seattle Illustrate How Daylight Can Be Integrated Into Site And Building Design," *Lighting Design + Application*, October 2003.

11. B.L. Collins, *Windows and People: A Literature Review. Psychological Reaction to Environments With and Without Windows*, National Bureau of Standards, Washington D.C.

12. G.M. Sottile, "2007 Study of United States LEED Accredited Professionals on the Subject of Smart Glass," *50th Annual Technical Conference Proceedings of the Society of Vacuum Coaters*, pp. 32-35, 2007.

13. The Freedonia Group, "Advanced Flat Glass to 2010," 2006.