

2004 Survey of United States Architects on the Subject of Switchable Glazings

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ABSTRACT

The twenty-first century has ushered in an era marked by the growing integration of technology and other scientific advances into commercial buildings and residential homes. Of particular interest to many architects, developers and builders are "switchable" glazings, a new category of technologically advanced glass and plastic building materials that can be used to control light, glare and heat entering an office or a home. Interest in switchable glazing technology is influenced by a variety of factors, including a growing movement to offer sustainable, energy-efficient building solutions, and the emerging desire by users to maintain greater control over their working and living environments.

This paper examines the movement toward sustainable development and the end-user needs that are driving it. Further, it presents the results of a proprietary survey research study of United States architects on the subject of switchable glazings. This study includes an examination of the attributes most desired by architects regarding smart window technology, and provides additional insight into the potential application of this smart material to the building community.

INTRODUCTION

Switchable glazings, more commonly referred to as "smart" glass or plastic depending on the substrate with which they are integrated, are an emerging category of products that use electrical voltage or current to manage light passing through glass or plastic. Switchable glazings have applicability for a growing number of product applications including windows, interior partitions, skylights, automotive mirrors and sunvisors, eyewear, appliances, instruments, flat panel displays, advertising signage and more. Various types of switchable glazings exist, including electrochromic (EC), liquid crystal (LC), and suspended particle device (SPD). Each type has its own distinctive physical properties and performance characteristics, and these differentiating features, coupled with the timing of their respective introductions, influences the current landscape of product diffusion in the marketplace.

The business literature readily acknowledges that product categories move through a series of major stages known as the product life cycle (PLC). These stages begin with the introduction stage, advance to the growth and maturity stages, and conclude with a period of decline [1]. A variety of data signal that switchable glazings are in the introductory stage of their PLC, a stage characterized by low levels of product knowledge and sales volumes that are growing but below longer-term expectations [2]. Recent evidence indicates that although market awareness of switchables is moderately strong, knowledge of the product category is limited. For example, a 2000 study of United States window manufacturers reported that 71.7% of executives and managers involved in new product development or product planning were aware of switchable glass. However, knowledge of specific characteristics of switchable glass was limited, with only a portion of all respondents able to cite even the most basic properties of products in the category. [3].

Further, industry sales for switchable glazings are modest relative to their promising medium-term forecast. A 2002 study by the Freedonia Group (Cleveland, OH) reports that demand for smart glass in the United States is projected to grow at a compound annual rate of approximately 20.0% through 2006 to \$445 million [4]. This rate of industry growth is nearly five times the 4.3% compound annual growth rate of total flat glass sales by U.S. producers from 1997 through 2002 [5]. Advanced flat glass, of which smart glass is a segment that also includes reflective glass, security glass and other niche glass products, is expected to account for 22% of the total amount of fabricated glass in the United States by 2006 [6].

To the extent that these rates of growth are duplicated in other regions of the world, a high probability exists that switchable glazings will be among the leading new classes of technology products in coming years.

DRIVING FORCES

Robust forecasted growth rates in the switchable glazings market are influenced by a set of factors that are expected to propel demand in the near-term. These factors, known

as driving forces, are "the major underlying causes of changing industry and competitive conditions" [7]. Several driving forces are influencing the rising levels of demand for switchables in the architectural market. These forces are consistent with the heightened level of attention devoted to sustainable building designs that attempt to minimize environmental impact, manage costs, and maximize user well-being and productivity. These driving forces are briefly outlined below.

Large-Scale Introduction of Smart Glass

The Freedonia Group (2002) claims that demand for switchable glazings is driven by the large-scale introduction of these products for residential homes and commercial buildings, further noting that windows using smart glass "offer unprecedented control, aesthetics, and energy efficiency" [6]. Market demand of a product category can fall short of its maximum potential when several conditions exist, including end-users' lack of product awareness and producer-imposed limits on product availability and service. Large-scale introduction of switchable glazings likely will be associated with increased aggregate marketing and promotional investments that should raise both awareness and interest at the end-user and business levels. Likewise, accelerating sales volumes should support incremental investments in the distribution infrastructure, further expanding the availability of switchables.

Steadily Rising Demand for Windows and Doors

Worldwide demand for windows and doors is expected to climb by 5.7% annually to \$147 billion by 2007 [8]. Increased income levels and growth in average home size will support consumer demand for these products that are ideally suited for switchable glazings. These forecasts are consistent with the expected growth rates in U.S. home improvement spending over the next several years. The Home Improvement Research Institute forecasts U.S. home improvement spending in 2007 of \$254 billion. This amount is based on a 4.6% annualized growth rate in spending from 2003 through 2007 [9].

Interest in Quality-of-life Enabling Technologies

Recent global trends in technology demand highlight consumer interest in products that improve productivity or offer greater flexibility and control [10]. For many people, such technologies are central to supporting one's quality of life. An example of this driving force is the rapid diffusion of personal computers in the U.S. By 2001, personal computers were in 56 million households, equivalent to a 52.3% penetration rate of all households in the country, and more than three times the 1990 incidence rate [11]. Another example is the high level of consumer interest in personal digital assistants (PDAs). Worldwide sales of

PDAs totaled nearly 15 million units in 2003, and are forecast to grow at an annual rate of 18.3% through 2007 [12]. A trend toward technologically advanced smart homes also is observed in residential housing. ABI Research reports that the home automation controls market, estimated to be \$1.5 billion in 2003, will grow at an annual rate of 20.4% through 2008 to \$3.8 billion [13]. In addition, smart homes of the new millennium will have independent networks controlling various systems including communications, entertainment, lighting, heating, and security [14]. A recent study found consumers highly attracted to the convenience that smart homes offer, with the greatest level of consumer appeal in the area of climate and lighting monitoring and control [15]. This trend toward home automation is especially supportive of the growth of switchable glazings, which easily can be integrated into these systems to support the energy savings, security, and aesthetic objectives of homeowners and commercial developers.

Positive Impact of Daylighting

In addition to reduced energy costs associated with the introduction of effective daylighting into building environments, a growing body of evidence indicates the use of daylighting provides significant benefits in terms of added productivity and comfort for a building's occupants. According to the Green Mountain Institute, the leading factors that improve worker productivity are (most important listed first): 1.) the quality of lighting, 2.) high levels of daylighting, 3.) increased individual control over the workplace environment, 4.) improved acoustics, and 5.) improved indoor air quality [16]. Several studies indicate that occupant productivity can be increased 15-20% with proper daylighting [17]. Such gains in productivity can increase an organization's profit. A comparative study of the impact of daylighting on sales at a large retail store chain found that the use of skylights to introduce daylighting increased sales by 40% [18].

Movement Toward Increased Energy Efficiency

Consumers and businesses alike are under growing pressure to stabilize or reduce costs associated with energy consumption. Recent trends in US energy consumption indicate the nation's energy use is growing at a modest but somewhat unabated pace. From 1990 through 2002, residential energy consumption grew at an annual rate of 1.8%, while consumption in the commercial sector grew at an annualized rate of 2.3% [19]. Worldwide energy consumption is expected to grow at much faster rates than that which has been observed recently in the U.S. The United States Energy Information Administration forecasts worldwide consumption of commercial energy will increase 58% by 2028 [20].

Despite the steady growth in aggregate energy consumption, evidence suggests efforts toward improved energy efficiency are gaining ground. The International Energy Agency (IEA) reports that the economies of its member countries have reduced their energy consumption per unit of gross domestic product by 45% since 1973 [21]. Other data correlate with this trend. U.S. shipments of photovoltaic cells and modules have increased at an annual rate of 124.9% from 1993 through 2002 [22]. Similar trends are beginning to emerge in the automotive market as well. For example, the number of alternative-fueled vehicles in use in the U.S. has doubled between 1992 and 2002 to 518,919 [23]. Likewise, hybrid vehicle sales in the U.S. are forecasted to reach 350,000 units in 2008, more than an eight-fold increase over the estimated 2003 sales level of 40,000 units [24].

The preceding summary highlights driving forces shaping demand for switchable glazings. The next section of the paper presents the findings of an exploratory study of United States architects on the subject of switchable glazings.

EXPLORATORY SURVEY OF US ARCHITECTS

Introduction and Methodology

The range of applications for switchable glazings is extensive. However, it is likely the greatest levels of demand will be in two areas: 1.) switchable architectural products like windows, doors, skylights and interior partitions, and 2.) switchable automotive products like sunroofs, sunvisors, mirrors and side- and rear-view windows. In the architectural market, professional architects play a central role in the design of a substantial portion of residential and commercial projects. Aggregate revenues of U.S. architectural firms are estimated to have exceeded \$19.9 billion in 2001, an all-time high [25]. Despite architects' extensive scope of involvement and the positive expectations of switchable glazings for architectural applications, no market research studies have been published to date about the attitudes of architects regarding switchable glazings.

Such a condition provides an opportunity for a first-of-its-kind exploratory research study of US architects on the subject of switchable glazings. Exploratory research is especially useful when little or no data regarding the attitudes and behaviors of the study population exist. Practically, the flexible nature of exploratory research helps the researcher avoid preconceptions and allows for the capturing of unexpected but valuable insights that typically yield a depth of understanding not achievable through a traditional quantitative study [26, 27]. This particular study provides the foundation for more extensive

quantitative research of architects on the topic of switchable glazings in the future.

The exploratory research methodology used in this marketing research study involved in-depth telephone interviewing of randomly chosen US architects drawn from a master contact list of architectural firms. The in-depth interviewing approach is used because it can accommodate the wide range of geographic locations of those interviewed and also offers some degree of interviewer control [28]. Discussions with 16 architects included closed-ended and open-ended questions, with the former providing directional insights into attitudes and behavior and the latter offering exploration into areas deemed important by the architect or the researcher. Interviews lasted up to 15 minutes or more in length, and all data collection was conducted during January and early February 2004.

Study participants are represented from all regions of the country. Median firm size is 16.5 employees, with a range within the sample of 3 to 350 employees. Median annual revenue for these firms is \$1.9 million, with ranges from \$1.0 million to \$46.2 million. The strong majority of firms in the sample serve only U.S. clients, while a limited number have both a domestic and international client base. The majority of architects provide services for both residential and commercial projects.

Usage of Glass in General

In general, the U.S. architects interviewed currently are using the same or more glass in their projects when compared to five years ago. However, architects whose primary business focus is residential projects are more likely to be using more glass in their projects now than those whose primary focus is commercial projects. According to those interviewed, growing demand for glass in residential projects is influenced by several factors, including: 1.) consumer desire for larger volumes of glass in homes, and 2.) improvements in glazing materials that are allowing for the introduction of more glass into projects. Several residential architects noted the growing influence of building code requirements mandating impact-resistant glazings. These codes are described as especially prominent in areas along the eastern coast of the U.S. Architects whose projects are influenced by such codes express an interest in glazing products that dually address code mandates while also meeting consumer preferences for daylighting.

One-third of architects whose focus is commercial projects claim they are using more glass now than five years ago. Many within this group cite heat gain concerns, material costs, load-bearing considerations, and the growing

influence of energy code requirements as factors that can restrict the use of glass in their projects. This comment from an architect whose firm serves both residential and commercial customers throughout the nation highlights some of the challenges posed by integrating glass into building designs: "The challenges we face are driven by the diverse climates in which we work. Each area is different environmentally, and building codes also vary. Getting the appropriate level of external shading in various types of climates is a challenge that often requires trade-offs."

Awareness, Knowledge and Usage

Nearly three-fourths of the architects interviewed are aware of switchable glazings. However, relative to this moderately high level of awareness, architects' knowledge of the product category is limited. Overall, architects know of the light variability and electrical interface properties of switchable glazings, but few are able to provide additional perspective on other properties or distinguishing features of different types of switchable glazings.

Only one architect in the sample works for a firm that has ever specified a switchable glazing project. When probed as to the reasons why architects have not specified switchable glazings, two primary inhibiting factors are cited: 1.) lack of knowledge regarding the product category, and 2.) a perception that the material costs associated with switchable glazings are prohibitively high.

A subset of architects primarily serving the commercial market also express some concern about the limited installation history of switchable glazings, with several noting the need for assurances of product reliability, particularly for projects with long expected useful lives. Despite these concerns, the architects studied are very positive overall about the availability of switchable glazings as additional light-control product alternatives. Several noted greater aesthetic or functional flexibility as resultant potential benefits to them and their clients. Switchable glazings are particularly valued in situations where innovative designs are desired, when shading needs exist that cannot be addressed using traditional shading devices or window treatments, and when clients seek low-maintenance glazing solutions.

Satisfaction with Current Products and Systems

Study participants were asked to assess their current level of satisfaction with products and systems (excluding switchable glazings) currently available to manage exterior and interior light. Attitudes differ somewhat based on the focus of the firm. Organizations that primarily focus on residential projects are generally highly satisfied with the current offering of blinds, shades and curtains available to

them. Architects whose primary focus is commercial applications are less satisfied but still maintain a positive bias. The opinions of this latter group are primarily influenced by costs and by building and energy code issues that can impede the full extent to which they integrate light into their designs.

Interest in Switchable Glazings

Even with this positive orientation toward more traditional shading products and window treatments, the architects interviewed are amenable to consider substitute or complementary products to manage light, clearly expressing a keen interest to consider switchable glazings for their projects over the next three years (assuming reasonable costs for materials). Residential architects are optimistic about integrating switchables into their designs, while those focusing on commercial projects are also positive but tend to be somewhat more reserved in their willingness to specify these products. In a number of these cases, the architects noted that some of their clients were federal, state or municipal agencies that tend to be cost-conscious and would likely be disinterested in higher-priced alternative products at the present time. However, several of these also noted a countervailing trend of government projects to install "super windows" that are energy efficient, ensure privacy, and also offer protection from bombs or incoming projectiles.

Importance of Various Attributes

A variety of product-related attributes were presented to architects who were then asked to comment on the importance of these attributes to clients of theirs who might at some point be interested in switchable glazings. Attributes expected to be of greatest importance include: 1.) the ability to control light without blocking one's view, 2.) product warranties, and 3.) protection against heat gain. Some notable differences are observed in the comments of the architects interviewed. Compared to architects whose primary focus is commercial work, architects whose primary focus is residential design place greater importance on the ability to instantly change light transmission from dark to clear or clear to dark.

Other differences exist. For example, architects focusing on the residential market place a high level of importance on the noise attenuation and energy saving properties of switchable glazings. Conversely, architects focusing on the commercial market place greater relative importance on the ability of switchable glazings to block almost all light and thus eliminate the need for window coverings like curtains, blinds and shades.

Expected Market Penetration of Switchable Glazings

The architects interviewed were asked to hypothetically assess the penetration rate of switchable glazings within the next 5 years assuming reasonable costs of materials. The median expected percentage of all interior and exterior windows, doors and skylights installed or retrofitted with switchable glazings in the US by 2009 is 13.5%, with opinions consistent when segmented based on the focus of the firm.

Architects were asked to comment on the greatest need for switchable glazings at the present time. The most commonly cited applications include: 1.) exterior window applications in residences and office buildings, 2.) interior partitions for conference room and office dividers, 3.) skylights, and 4.) retail storefronts to manage heat gain and occupant comfort. Architects also cited numerous other potential applications of switchable glazings, including glass atriums and ceiling glass, curved glass, curtainwalls, displays, glass elevators and retail showrooms. Several commented that switchable glazings have unique characteristics that make them ideal for windows and skylights that are either difficult to shade or challenging to clean.

Finally, when asked to summarize their attitudes toward switchable glazings, one architect offered this comment: "We're generally pleased with the traditional shading devices available to us. Not many architects are aware of switchable glazings. Sure, blinds and other shading devices also add cost, but they also provide the opportunity for decorative treatments. However, the ability to adjust light entering a room is a very nice feature. People like having more freedom to integrate different options into their designs, so a variable tint would be more appealing than simply clear and opaque options." Another architect whose primary focus is commercial applications offered this statement: "Being able to have a choice of visible light transmission ranges is a good benefit. I see this having a lot of application in green building design. We're in a northern climate, so our clients generally are dealing with low light levels. We want the warmth of the sun but glare can be very difficult. Glare in the summer on a western exposure can be very uncomfortable. With a variable tint, you could tie the window to a calendar that would manage light and glare depending on the time of year."

SUSPENDED PARTICLE DEVICE TECHNOLOGY

While it is likely that each of the most widely known switchables glazings has enjoyed some measure of commercial success, no switchable glazing technology has experienced as much market momentum over the past several years as suspended particle device (SPD) technology, developed and licensed by New York-based

Research Frontiers Incorporated (www.smartglass.com). The company's licensees include many of the world's leading glass, chemical and solar control film companies.

SPD technology is a film-based switchable technology. Its basic operating principle is straightforward. The SPD film contains microscopic particles that are randomly dispersed and absorb light in their off state. As small but increasing amounts of electrical voltage are applied, the film's particles become aligned and allow light to pass through. SPD film is adjustable over a wide range of light transmission levels, thus yielding an infinite number of light transmission levels from clear to dark. The film can be integrated into virtually any product where control of light is needed. SPD products, which operate off of AC voltage or battery power, consume very little power (0.05 watts/sf maximum) and can be operated manually or automatically using standard sensing or control devices.

SPD technology has numerous characteristics that positively differentiate it from other switchable glazings. It is the only switchable technology that offers the ability to control light transmission instantly *or* slowly (depending on the desired application) and to offer a range of light transmission ranges as opposed to simply clear and opaque states. SPD film also varies light transmission uniformly over an entire surface area regardless of size, and as such, is particularly appropriate in design applications that involve surfaces of differently sized panels. In its "dark" state, SPD film can block more than 99.5% of incoming light. In addition, SPD film can be applied to curved surfaces, operates over a wide temperature range of -40C to +120C (-40F to +248F), and can be used with either glass or plastic substrates. SPD film is highly durable as well, and has been tested successfully at millions of on/off switching cycles. Products incorporating SPD film block up to 99% of ultraviolet (UV) light. Because they are film-based, SPD products also have strong noise attenuation and impact resistance properties. Further, these products can be produced with various configurations of substrates, coatings and static films to optimally meet the needs of a particular project.

While commercial availability of SPD products is less than two years old, they already have been installed in a wide range of applications worldwide. In the architectural market, installations include exterior windows, skylights and conference room windows and partitions. Installations in the automotive application include the use of SPD technology on the panoramic glass roof of DaimlerChrysler's new Setra S 415 HD luxury bus. In addition, DaimlerChrysler's new Jeep Rescue was outfitted with an SPD-Smart sunroof and exhibited at the 2004 Detroit and Chicago Auto Shows. SPD-Smart windows

also have been installed in jets, helicopters, watercraft and appliances. In 2002, readers of Popular Science magazine voted SPD technology as their favorite technology out of the year's 100 leading innovations. Also in 2002, the Society of Automotive Engineers named SPD-Smart aircraft cabin windows as one of the year's top technologies.

CONCLUSION

Demand for switchable glazings is expected to be highest in the architectural and automotive application segments. Recent increases in glass usage in both of these areas point to concomitant needs to manage light, glare and heat. While aggregate category revenues are relatively small, several factors indicate that growth over the coming years in the focus of this study – architectural switchable glazings - will be significant. A number of driving forces are propelling this advancement. These forces include: 1.) the large scale introduction of smart glass, 2.) steadily rising demand for windows and doors, 3.) consumer interest quality-of-life enabling technologies, 4.) the positive impact of daylighting, and 5.) a movement toward increased energy efficiency.

An exploratory study of US architects on the subject of switchable glazings revealed moderately strong levels of awareness of this category of products but limited knowledge. A variety of factors will influence the degree to which architects specify switchable glazings in future projects. Product attributes will certainly play a major role, with those of greatest importance including: 1.) the ability to control light without blocking one's view, 2.) product warranties, and 3.) protection against solar heat gain. Current usage of switchable glazings is modest and growing, and interest is strong. Assuming reasonable costs, the architects studied expect that 13.5% of all new exterior and interior windows, doors, and skylights will contain switchable glazings by 2009. Opportunities presently exist for switchable glazing products that can accommodate innovative architectural designs, offer significant functional benefits for projects that are difficult to shade or that require low maintenance, and that contribute significantly to the safety and security demands of the new millennium.

Switchable glazings are in the introductory stage of their product life cycle. The benefits and value they bring to end-users are significant, and their future is extremely bright. In the near-term, the greatest opportunity to accelerate market demand for switchable glazings may exist in simply bringing their benefits to the attention of a larger and wider sphere of consumers and businesses. Thus, while the market's driving forces clearly are leading the way for switchable glazings, market development

initiatives by businesses associated with switchables can further propel their evolution as one of the world's most pervasive technological advances.

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