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ESTABLISHING THE VALUE OF ADVANCED GLAZINGS

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ABSTRACT

Numerous glazing technologies are under development worldwide to improve the performance of building facades. High-performance glazings can provide substantial energy and related environmental benefits, but often at greatly increased first cost when compared to conventional design solutions. To increase market viability, we discuss strategies to reduce the actual and owner-perceived costs associated with developing and producing advanced window systems, specifically switchable electrochromic glazings, and we also suggest marketing strategies designed to appeal to early adopter and mainstream purchasers. These strategies may be applicable to a broad range of advanced glazing materials.

INTRODUCTION

Numerous glazing technologies are under development worldwide to improve the performance of building facades. High-performance glazings can provide substantial energy and related environmental benefits, but often at greatly increased first cost when compared to conventional glazing design solutions. Since first costs are high, the market potentials are uncertain, thus reducing R&D and production investments and further slowing the drive toward market introduction. The performance goals of these systems varies, but typically include reductions in energy use and peak demand for heating, cooling and lighting. In a world of 'value engineering,' it is often difficult to justify these new technologies since their direct payback through annual energy savings is longer than desired.

Electrochromic coatings[1] are emerging as one of the most interesting of the new generation of advanced glazing materials. Although these glazings are not yet commercially available, substantial research has been done to estimate their energy-saving potentials for commercial building applications (Sullivan et al. 1997). Comprehensive life-cycle cost benefits and environmental quality improvements have been explored less extensively. Projections for commercial office building applications of this switchable glazing with daylighting controls show simple paybacks of ten years or more in the U.S. To improve market viability of this and other innovative advanced glazings, new approaches must be taken to reduce conventional cost barriers.

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[1] "Smart" electrochromic glazings now under development offer the best long-term potential for dynamic control. The technology consists of a multilayered, thin-film device that changes from a clear to an increasingly dark, colored state when low-voltage current is applied. By employing electrochromic glazings in a curtainwall or window system, we can dynamically alter daylight levels and visual privacy in the space and control thermal energy flows in the entire building envelope. Good progress is being made in R&D labs, but readily specifiable products are not yet available from glass companies.

Borrowing from historical efforts to establish value with energy-efficiency products, we discuss strategies to reduce the actual and owner-perceived costs associated with developing and producing advanced window systems, specifically switchable electrochromic glazings, and we also suggest marketing strategies designed to appeal to early adopter and mainstream purchasers. Many of the strategies are derived from related efforts to promote energy-efficient technologies. We give examples of how these strategies were applied. We also broaden our discussion to include other less quantifiable, non-economic strategies, such as improving comfort (and occupant productivity) or addressing global environmental issues (e.g., carbon emissions) so that these advanced technologies can be properly valued by utility, environmentalist, and building-owner stakeholders. These strategies may be applicable to a broad range of advanced glazing materials.

MANUFACTURER COSTS

Over the life of a product line, the manufacturer incurs 1) start-up development costs to engineer, test, and validate that a new technology works and is durable under real-world conditions, 2) initial and continued manufacturing costs, including capital costs to build tooling, manufacturing equipment, and production facilities, and when product sales begin, the costs to produce the product, and 3) sales, technical support, and marketing costs, to advertise the benefits of the product, to service the customer, and deliver the product with associated warranties, technical support, and customization for a particular application. ‘Window products’ for commercial buildings include individual windows, skylights and doors, curtainwall facades, atria skylights and windows, and storefront windows. Applications include new construction, complete retrofit of an existing building, or replacement glass.

To launch an advanced glazing product, historically, only large manufacturers have had the internal capital to finance the initial start-up costs. Privately-owned, smaller companies use a variety of creative financial agreements to secure sufficient funds to start a new business venture, in addition to conventional options such as bank loans. For example, joint venture agreements between a glass company and a window manufacturer enable the initial costs to be shared. Manufacturers might also line up a large volume purchase, then use this assured income stream to secure a loan. The desired profit margins can be reduced for an initial period, to gain marketshare in a potentially lucrative market. All decisions to add new product lines are based on an assessment of market potential, competitive positioning, the return-on-investment, risk to shareholders if publicly-owned, and an assessment of potential reward.

To obtain a good return-on-investment, from an elementary point of view, manufacturers can reduce their out-of-pocket initial investment, capture a sufficient volume of sales within a given time period, or sell the product initially at a higher, non-competitive price to recoup the start-up investment more quickly. As demand increases and the market becomes established, the manufacturer can decrease production costs by spreading fixed costs over a larger volume. The manufacturer can also improve production facilities and processes; e.g., adding automation which reduces product manufacturing costs. Based on these business practices, we suggest strategies that are designed to reduce start-up costs or limit the price premiums that are added to the original equipment manufacturer’s (OEM) cost:

1. Cost-share development costs with other stakeholders.

Government, state, and other agencies advocating energy-efficiency have programs in place to cost-share development costs with industry. For example, the U.S. Department of Energy's (DOE) Small Business Innovative Research program solicits requests for proposals from industry for energy-efficient technological solutions that are applicable to specific building sectors. DOE funded development of low-E coatings in the late 1970s and early 1980s, and spectrally-selective coatings from the late 1980s to present, providing material science engineering, coating deposition process improvements, product testing in the laboratory and field, performance simulations, development of design and analytical tools, testing and rating procedures, and promotional efforts with demonstrations and educational workshops (Geller and McGaraghan 1998). The DOE Electrochromic Initiative is a new multi-phase government-initiated, cost-shared program with industrial partners designed to accelerate the development and introduction of an electrochromic window product. Material science, durability, and energy performance support has been provided by two national laboratories. State programs such as the California Institute for Energy Efficiency and the New York State Energy Research and Development Authority solve industry-wide problems or support the development of new technologies to encourage job growth and reduce energy requirements within the state. All these programs serve to broaden and leverage the resources of a single manufacturer.

2. License new expertise to reduce time to market.

Licensing or partnering with other manufactures or research organizations can shorten the time to market and reduce development costs. For example, developers of electrochromic coatings are typically companies with expertise centered on glass, plastic, and coatings. Controls, sensors, electronic hardware and software design required for this dynamic facade fall outside their normal realm of expertise. Rather than develop this needed expertise 'in-house', an electrochromics manufacturer might license technologies from existing manufacturers of commercially-available automated window shade products—up/down shades, motorized venetian blinds or louvers—which have been used in Europe and, to a limited extent, in the U.S. over the past three decades. Many of the electrochromic systems engineering problems may have been partly or fully solved by companies making these related products, thus speeding progress toward the marketplace.

3. Associate with other emerging markets.

Associating with other related emerging markets can reduce start-up design costs and time to market, and allow manufacturers to take advantage of an existing informed customer base. A successful example of this is the Energy-Efficient Refrigerator Procurement program in Sweden, where the refrigerator-freezer market was transformed in part by taking advantage of the participant's impending need to replace existing units and concerns regarding the phase-out of CFCs (Eto et al. 1996). With electrochromics, there is a related emerging market trend that is further along in its development and use in buildings: energy-management control systems (EMCS).[2] Issues relevant to electrochromics are being solved at a whole-building level: engineering (wiring, communications protocol, sensors, etc.), integration within buildings, commissioning, and design of supporting infrastructure. The electrochromic window could be

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2 These systems allow the building operator to control, optimize, monitor, and diagnose the operation of the mechanical system and, in more advanced systems, the lighting, emergency, and security systems throughout the building.

designed and marketed as a plug-and-play module within a whole-building environmental control system. In-the-field installation, tuning, monitoring and verification costs could be reduced. Having been exposed to the concept of an 'intelligent' building, consumers may be more receptive to new intelligent, high-technology window systems. The market has essentially been created and primed by another building technology.

4. Limit the cost of production.

Another strategy used in many industries is to introduce a new product with limited options and features. This minimizes the manufacturer's initial engineering, production, liability, and inventory costs, and offers consumers the least-cost, basic item that addresses the most pertinent applications. Tailored products can be made available, but at a much higher premium. For example, electrochromics can be offered initially in modular sizes within a fixed, non-operable window unit. This simplifies both the coating production aspect as well as installation, since the problem of bringing power to a movable window unit is deferred.

5. Limit the cost of sales.

Window manufacturers and distributors add a price premium for energy-efficient windows. These premiums cover the hard and soft costs incurred with inventory, shipping, distribution, and handling special products, but also may reflect what the market will bear, i.e., the perceived value of a new and improved product. The experience with low-E windows provides an illustration of this issue. Generally, if the market volume is large, price premiums can be on the order of $10-30/m^2-glazing[3] (for a product whose OEM cost is less than $10/m^2), while for areas where market penetration is low and low-E is a custom product, the premium can be as high as $100/m^2 (Eto et al. 1996).

To reduce cost premiums, manufacturers can reduce the number of middle-men in the supply chain, or sell in volume. Once a product has become established, glazing manufacturers can negotiate terms with window manufacturers to sell advanced glazing products in volume at a lower profit, to cut national and foreign competition and capture a larger percentage of the market.

6. Limit the cost of use.

Costs incurred by the customer include 1) material costs to purchase the technology, 2) search costs to determine applicability of the new technology to a specific building, 3) costs to cover changes in infrastructure, and 4) potential 'liability' or inconvenience costs. Design decisions made by manufacturers are instrumental in facilitating the successful use of the technology by all users downstream of the manufactured product. Manufacturers must design the technology for all end-users. For example, to minimize in-the-field installation costs, an electrochromic-curtainwall assembly may be detailed such that electrical connections are integrated with the curtainwall framing system. This 'life-cycle' philosophy should be extended to anticipating maintenance issues as well. This is discussed in more detail in the Customer Costs section below.

7. Counter price-pressures by adding value.

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[3] All costs are given per square meter of glazing area.

Consumers are willing to pay more for added benefit. If the manufacturer provides convincing, unbiased evidence that the new product provides superior performance, especially non-energy benefits such as improved comfort, consumers may be willing to pay more for added benefit within certain limits. This is discussed in more detail in the Customer Costs section below.

8. Use procurement programs to cover start-up costs.

To stimulate commercialization of new energy-efficient technologies, stakeholders will aggregate the purchasing power of individual, small or even large customers to create volume purchases, thus creating a sustained demand for products, which in turn drives down the market introductory price of a new technology. By guaranteeing a market, this strategy reduces the manufacturers' risk of not recouping the cost of their investment. This tactic has also been used to pull energy-efficient technology into the marketplace from an unmotivated industry group. The U.S. Super-Efficient Refrigerator Program 'challenged' industry to produce a more efficient refrigerator by guaranteeing volume through aggregate purchases and rebates (Eto et al. 1996). Sustained purchasing patterns by consumers occur if the new product addresses a real-world need at an affordable price.

The price of window products is partly governed by volume, so such strategies are likely to be of benefit. However, the requirements for windows are individualized and diverse, varying widely between buildings and clientele. It may be difficult to find a sufficient number of customers with the same window requirements to create an aggregate purchase; however, variants of this strategy may be worth considering.

CUSTOMER COSTS

There are essentially two 'classes' of purchasing behavior (Moore 1991): 1) the enthusiastic leaders or early adopters who require technical proof that the product works and is durable, but are willing to incur some risk to establish themselves as leaders in the field; and 2) the followers, or the entrenched mainstream customers, who pragmatically require much more convincing data to overcome the IBM-coined term, 'FUD' factor—fear, uncertainty, and doubt—that comes with unfamiliar territory. The manufacturer and other stakeholders can appeal to customers by considering the mentality of the purchaser, then designing and marketing the product appropriately.

The electrochromic window requires a fundamental shift in behavior within all sectors of the building infrastructure. Similar to the electric car, high-definition TV, and microwave oven, electrochromics require the purchaser, installer, and end-user to modify their thinking about how windows work in commercial buildings. While early adopters may be interested in the latest innovation and willing to 'try out' a new technology, the rest of the market may not adopt the technology as readily due to a number of other factors in addition to high first cost: 1) it's too difficult to figure out how to start using it (search cost), 2) even if it works perfectly, it's not sufficiently superior or equal in functionality to existing technologies to warrant the trouble of switching over, and 3) the required technical competence of the end-user is too high to sustain use of the technology throughout the entire building sector.

Early Adopters

The buildings industry is particularly risk-averse and recalcitrant to change (compare this to the electronics industry). Early adopters, however, have the insight, temperament, and charisma to match an emerging technology with a strategic opportunity. Some architects, building owners, and environmental stakeholders fall into this category. This class of individuals is typically willing to go the distance to make something new work: enduring product glitches, working with the manufacturer and other involved parties to work out rough details, and negotiating new processes or mechanisms to get the job done. They're also amenable to publicly promoting the product, if it meets their expectations. Strategies can include:

1. Identify strategic opportunities.

Products that meet a specific, well-defined need for a preferably large constituency will often be more quickly adopted into the market, despite high initial costs. For example, the initial Apple Computer's user-friendly interface set the standard for desktop computers. There have been numerous suggested uses for electrochromics. To date, they have been used successfully by the automotive industry for side and rear view mirrors to control nighttime glare from headlights. For commercial buildings, the image of a dynamic, adaptable, and intelligent facade is compelling to many architects. Equally compelling to utilities is a controllable, demand-limiting envelope technology that can reliably reduce peak-loads during critical summer daytime hours. The marketing team must therefore determine the powerful application, or market niche, that distinguishes the technology from any other technology in the field, and provides value and appeal to both visionary and mainstream customers.

2. Public relations incentives.

Commercial developers and corporations welcome public relation opportunities that improve their image as a visionary and environmentally-sensitive organization. Various federal, state, and utility-sponsored programs have been designed to recognize and reward early adopters. The EPA Green Lights and DOE-EPA Energy Star Windows programs promote building owners or organizations that go beyond standard practice in the interest of the environment. Building owners, themselves, will even initiate their own efforts to join the distinguished ranks of the visionary green environmentalists by conducting well-publicized showcase demonstrations. For example, Wal-Mart attracted substantial positive press for their showcase 'eco-store', citing increases in retail sales in the daylit portion of their store.

Mainstream Purchasers

Mainstream purchasers are pragmatists, conservatives, and skeptics that are interested in making incremental predictable progress rather than quantum leaps forward (Moore 1991). Risk has a negative connotation. They are willing to pay a modest price for top quality. A typical end-user (building owner, architect, contractor) is above all interested in knowing that the product is cost-effective, works properly, has little associated risk, and can be integrated smoothly into existing operations. Expectations for window products are also greater than for most other building systems: modular and self-contained, requiring minimal design and construction custom tailoring, life of 25 years minimum with no degradation in performance, ten year warranty, and minimal maintenance (other than washing). In this sense, the design criteria for windows are analogous to a wall component, despite their diverse functionality (view, privacy, color rendition, ventilation, egress, climate control, etc.).

From marketing studies, researchers have found that some building owners are willing to pay an additional 10-15% or more for advanced glazings, if there are clear benefits over standard products with no added risk. If the added cost exceeds 15%, owners feel that an energy-efficiency product must meet more rigid criteria; e.g., for public government buildings, the simple payback must be within three to 15 years; for private developments, three- to five-year paybacks are required. At a 10-15% premium, the maximum end-user cost is \$88 to \$92/m^2, if the baseline glazing is a spectrally selective low-E double-pane unit priced at \$80/m^2 with a volume purchase.

Given the assumptions and results of earlier building energy simulations in a hot climate (Sullivan et al. 1997), a large-area, west-facing electrochromic window would yield a simple payback of six years, based on recovery of annual operating costs alone, if its price lay within this 10-15% premium range. To meet a ten-year payback, the system must cost no more than \$100/m^2 for this non-conservative application. Electrochromic developers are estimating that with volume sales, the end-user cost of the insulating glass unit *alone* will be \$100/m^2. If the supporting control system and increased design, construction, commissioning, maintenance, and operating costs are added, this figure increases to \$120-150/m^2. Clearly, a gap exists between building owner cost expectations and what the manufacturer can provide.

Working within the confines of these simple payback or even life-cycle cost analysis procedures, we broaden this analysis to suggest strategies that make these equations work for the pragmatic customer:

1. Identify market niche applications.

The best probable venue into the buildings market is to identify strategic market niche applications where the performance of advanced glazings excel. At present, building energy simulations indicate that the most promising electrochromic applications (i.e., greatest energy savings) will be for west-facing, unshaded, large-area commercial windows in hot climates and where electricity rates are high (e.g., Hawaii).

Scrutinizing modeling assumptions can also reveal new ways to improve the energy-efficiency potential of these glazings. To date, the electrochromic controls have been simulated to meet the design workplane illuminance level with daylight. Similar to the electric lighting industry, other control algorithms can add incremental energy improvements: occupancy-based control (‘close’ window, shut lights off), scheduling, peak load strategies, etc.

Definition of the base case condition is often a point of contention, which can grossly affect the payback calculation. What is ‘typically’ used in real-world buildings and how is it used? Real-world human behavior is not well characterized, yet can have a substantial impact on the viability of energy-efficiency technologies. For example, a lighting controls study revealed that lighting energy savings on the south side of the building, contrary to intuition, were less than the north because occupants tended to draw the south-facing window shades to control glare and direct sun (Rubinstein et al. 1990). Electrochromics may yield shorter paybacks than predicted, when compared to actual shade use on the south side of the building.

Another venue is to identify applications where only cumbersome expensive solutions have solved the problem to date. For example, historical (and increasingly modern) art museums use daylight to illuminate art, which in turn requires careful control of the interior illuminance levels and the spectral content of the daylight to meet conservation criteria. Many modern art museums, for example, employ various types of automated louver systems to control skylight illuminance levels. A non-mechanized electrochromic system may improve control and reliability, and reduce costs.

2. Life-cycle cost-effectiveness.

Reductions in life-cycle building, operating, maintenance, and administrative costs should been folded into the cost-benefit equation, not just reductions in annual operating costs. For example, the HVAC chiller capacity reductions resulting from the reduced peak solar and lighting load can result in first cost savings of $10-30/m², depending on window size, lighting load, and climate (Warner et al. 1992). Advanced glazings reduce HVAC requirements and liability. HVAC-related litigation claims related to improperly commissioned systems cost insurance companies and owners on average (for a settlement) 1% of construction costs (Brady and Dasher 1998). Higher resale or appraised value and expanded borrowing privileges could be allocated to a building with a net operating budget that is lower than other contending properties.

Packaging more costly energy-efficiency strategies with less costly, more economical strategies can often help design teams meet the payback criteria, particularly for federal projects. The Cool Sense Chiller retrofit program helps building managers offset the cost of CFC phase-out by reducing envelope and lighting loads, which in turn reduces chiller capacity requirements (Gartland and Sartor 1998). In the case study of the New York Life building in Kansas City, Missouri, advanced windows, daylighting controls, and replacement of the mechanical system yielded a simple payback of 5-7 years. **–**

3. Buy-down the incremental cost.

There are numerous federal, state, and utility programs that essentially reduce the out-of-pocket cost to the consumer for energy-efficient products (although many are being phased out or revamped). In the past, utilities have offered rebates and incentives for the use of numerous energy-efficient technologies, including low-E and spectrally selective glazing. Some utilities are still willing to 'purchase' these 'negawatts' with up front rebates that help offset the building owner's first cost. Conceptually, the glazing system is perceived as an energy source (relative to a conventional alternative) and the utility makes an investment in this 'energy system' as if it were a new power plant. These payments can range from $5-$50/m². As the electric utility industry is restructured state by state, distributed generation options and real-time pricing will provide additional incentives to manage electric demand carefully. As with all these programs that provide initial support to create a market (and then are withdrawn), the continued success of an advanced glazing product depends on a lasting reduction in price or demonstration of market value to achieve significant market penetration.

4. Provide supporting data.

Pragmatic decisionmakers rely on useful, hard data that show that the new innovation measures up to performance, quality, and reliability expectations. However, there is often very little data that document product performance with new technologies. Recognizing that data are required and that the source of this data should come from unbiased parties, numerous 'consumer reports' programs exist to evaluate product performance and reduce customer search costs. As mentioned earlier, federal, state, and other R&D supporting programs work with test laboratories, market transformation programs, and showcase demonstrations to build a defensible record of performance for energy-efficient products. The National Fenestration Rating Council (NFRC) certification procedures and international protocols (i.e., International Energy Agency (IEA) Task 18 and 21) help to create tools and metrics so that products can be compared. The judicious use of field demonstrations have also been used to substantiate manufacturer's claims in a credible manner. Showcase demonstration programs, such as the Federal Energy Management Program's New Technology Demonstration Program (FEMP NTDP), seek to demonstrate, evaluate, and document state-of-the-art commercially-available technologies, showing that a product can be delivered predictably to a particular market sector at a reasonable price.

5. Reduce risk and uncertainty costs.

As indicated earlier, product design can substantially affect end-user costs. The manufacturer must bear in mind the mentality of the end-user and design the product accordingly. Initial products must be modularized and ready-to-use. This can significantly reduce design, installation, and commissioning costs to the consumer. With dynamically-controlled electrochromic systems, self-commissioning and self-tuning algorithms can reduce operation and maintenance costs considerably. In the 1980s, daylighting controls were notoriously unreliable. The history of that technology may influence the success of electrochromics. To reduce risk and uncertainty costs, manufacturers must take a proactive life-cycle philosophy to the design of their products, examining cross-system effects to ensure product reliability.

6. Build infrastructure.

Other intervention techniques include directed market transformation activities within a specific region to mutually solve search and information cost problems faced by the multiple stakeholders. Tactics have included regional construction/ builder training, code official training, demonstrations, technical assistance, and financial incentives to reduce the high transaction costs of working with a new product.

7. Provide amenity.

Ultimately, the decision to choose an advanced glazing product does not depend on simulation or statistical field data. There are too many simplifications made with simulations and too many detailed field assumptions that can alter the 'true' outcome of an argument. Typically, the mainstream consumer will make a decision based on these data and a melange of word-of-mouth, aesthetics, perceptions of added value, and other non-rational arguments.

Added value and amenity can often weigh in equally to energy-efficiency arguments. With the low-E glass product, arguments of reduced condensation and improved thermal comfort essentially created the impetus for this market—even though early purchasers found that the non-thermally-broken aluminum frame, standard at the time, contributed equally to problems of condensation. Advanced dynamic window systems are purported to yield substantial 'soft' benefits that are difficult to quantify using standard building modeling techniques: improved visual and thermal comfort, greater environmental control, and increased flexibility to respond to various criteria (occupant, weather, real-time pricing signals). While there are little hard data that show a direct relationship between energy-efficient daylighting designs and productivity, there is anecdotal evidence that clear views, connection to the outdoors, and a glare-free and thermally comfortable environment all contribute to a more satisfied worker—who is likely to be more productive than an unhappy, uncomfortable worker. Productivity is the ultimate price in commercial buildings, exceeding utility costs by a factor of 100 or more.

CONCLUSIONS

Advanced glazings are projected to have significant energy-savings potential within buildings, but their increased first cost slows their drive toward market introduction and penetration. With electrochromic glazings as the focus technology, we suggested several possible near-term strategies that could reduce costs to the manufacturer and customer, which in turn may facilitate the successful deployment of a broad range of advanced glazings. This initial endeavor to identify ways to reduce the higher costs of advanced glazings will require a more detailed study to determine the viability of these strategies. Contextual changes such as introduction of carbon emission taxes or a significant increase in energy costs will alter the effectiveness and applicability of these strategies.

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