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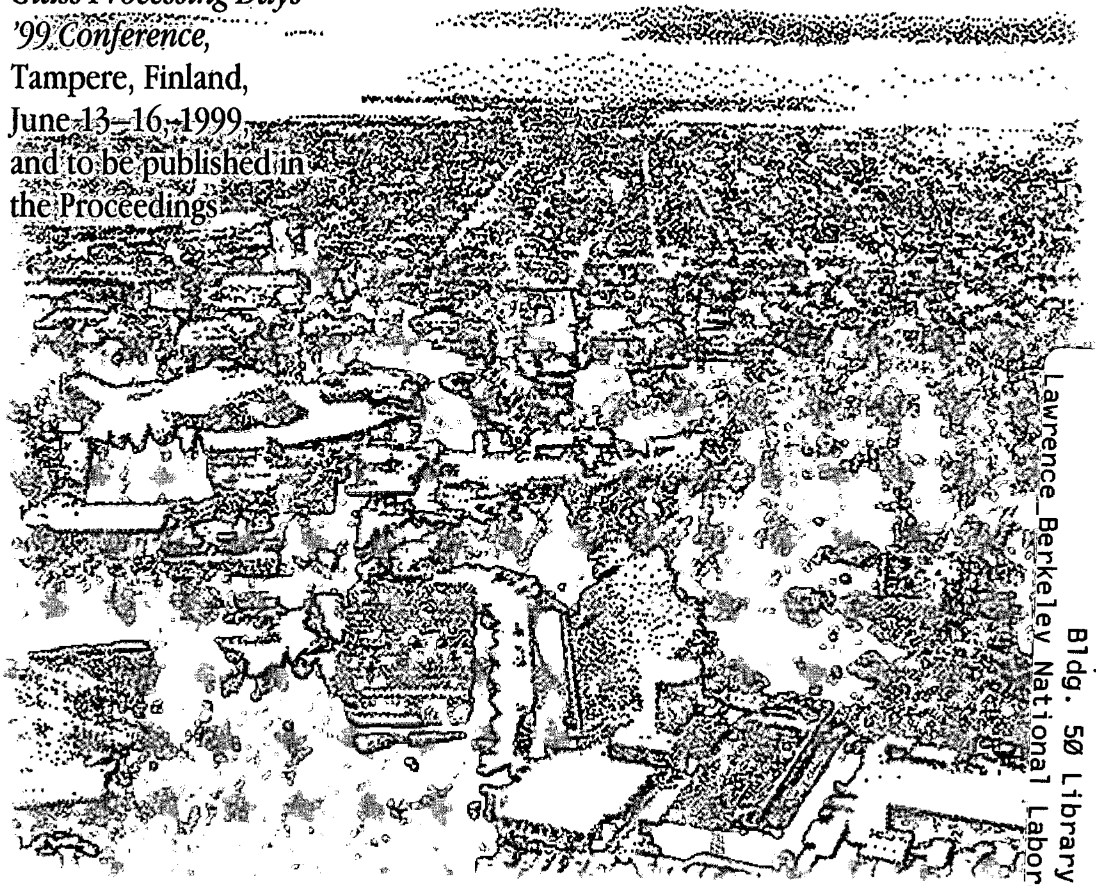

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High Performance Glazing Systems: Architectural Opportunities for the 21st Century

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Abstract

Glazing systems will fulfill important new roles in buildings in the 21st century. This paper provides an overview of three different functional impacts for advanced glazing systems. New technology and better integration with daylighting and climate control systems allow advanced glazings in building facades to 1) improve the comfort and performance of building occupants, 2) add value and reduce energy operating costs for building owners, and 3) assist in national and global efforts to reduce greenhouse gas emissions that contribute to global warming.

Introduction

Although change in the building industry characteristically occurs at a very slow pace, the last 25 years of the 20th century have seen significant advances in the nature of glazing systems for buildings. Windows have always been an essential element in building design but it is innovation in glass properties and performance attributes that have made it possible for the architectural window to fulfill its role without adverse impact on occupants and owners. The window has always been an essential element of the building façade, providing a distinguishing appearance from the outside of the building, and helping to define the nature of space indoors, by providing natural light with its attendant variable quantity and quality over time and weather. From the owner's perspective, better windows keep the natural elements at bay, keep unwelcome visitors out, and help to reduce annual energy costs. From the occupants' perspective, daylight in the building enhances the quality of most indoor spaces, and the view and connection with the outdoors provides essential amenity for the 20th century office or factory worker.

Even with hindsight, it is often difficult to accurately assess the key determinants of the important advances over the last 25 years that have resulted in today's glazing and fenestration systems. It is logically therefore even more difficult to extrapolate into the future to suggest how emerging trends and themes will ultimately influence buildings of the 21st century. Notwithstanding this difficulty, we attempt to identify and explore what we believe are several of the key issues facing the glazing and fenestration industry, to meet overall building needs in the years ahead.

Three brief explanations may assist the reader. First, the words "high performance glazings," "fenestration systems" and "building facades" at times appear to be used interchangeably, although they have distinct meanings in the glass and buildings business. This is one of the messages of the paper, that it will be increasingly difficult to consider glazing alone as the critical technology. Rather the manner in which glazing is incorporated into a complete fenestration system and then the building façade, and in fact the manner in which the building façade is integrated into the entire building, will be increasingly important, as noted below. Second, in its role as a transparent façade system, glazing systems must perform a wide range of "functions," which in turn challenges a wide range of performance criteria. In this paper there is a clear focus on the subset of those architectural criteria related to comfort, view, daylight and energy use. Additional critical performance issues such as structural, acoustics, and blast protection are not extensively addressed here, although in any given building application they may be critically important performance factors. Finally, the paper takes a North American perspective based on experience and observations in the North American marketplace, which ideally will generate some useful discussion to the extent that technology and design practice vary around the world.

Eight Factors Driving Glazing and Façade Design for the Next 20 Years

We describe below eight factors that will influence or drive the design and selection of glazed facades in buildings in the first few decades of the 21st century. These may be roughly categorized as technology issues, human needs, building issues, and global issues.

#1: Technology Improvements Will Continue to Enhance Glazing Performance.

The significant energy-related performance challenges for glazings are to 1) control heat loss, 2) admit daylight with minimal solar heat gain, 3) dynamically control solar heat gain and glare, and 4) redirect incident daylight for more effective use in buildings. The first two have been largely solved in the last 25 years, and the third is well on its way to becoming a viable product, leaving the fourth as a serious technical challenge. (We ignore a variety of other challenges for glazing, e.g., acoustics, blast resistance, etc.)

The single more important innovation in glazing technology over the last 25 years has been the development and widespread use of large area, low cost, multilayer thin film coatings. Coatings have provided the critical technologies in each of the first three categories. These coatings have dramatically improved the range of performance capabilities for architectural glazings as well as for many other glass and glazing applications. Good quality multilayer coatings had been in widespread use in precision optics for years but their small size, low yield and high price kept the technology out of the realm of architectural application. In the 1970s the development and further enhancement of large area magnetron sputtering and later improvements in on-line pyrolytic deposition have both revolutionized the glazing business. Significant advances in quality control, production speed, and reproducibility of thin films coatings have dropped the cost of sophisticated multilayer coatings from $500/sq.m to under $5/sq.m. The primary objective of the initial coating development effort was the transparent, low-emissivity coating for glass and plastic. First introduced in the U.S. in the early 1980s to reduce winter heat loss, these technologies have now captured about 1/3 of the glazing market. These coatings are available from virtually every glass supplier and their performance is well understood. Improvements continue, such as reducing color and haze, lowering emissivity to the .03 range, improving handling properties and durability, developing temperable coatings, etc. Low-E coatings can be incorporated into an insulating glass unit with gas fills and low-conductance spacers to reduce the conductance of the unit below .6W/sq.m-K. At this level, in winter the window will outperform an insulating wall, even when oriented to the north in a cold U.S. climate. (See #2 below.)

Due to the importance of cooling loads in the U.S., most new buildings are now built with central cooling systems. To meet an increase in energy use for cooling, the initial clear, high transmittance low-E coating has been replaced by many manufacturers in the U.S. by a modified version with a double silver layer that reflects much of the sun's energy in the near-infrared portion of the spectrum. This spectrally selective glazing causes little change in daylight transmittance but reduces solar heat gain by 50-70% compared to conventional low-E coatings and by an even greater factor compared to conventional tinted glasses with equivalent light transmittance. Whereas the ratio of visible transmittance to solar heat gain ranges from .6 to 1.0 for most conventional glazings, spectrally selective glazings have a ratio of 1.1 to 1.8 or up to three times the "efficacy" of more conventional glazings.

Although these spectrally selective coatings are highly optimized to maximize the daylight/cooling load ratio, they can not respond to changing sun and sky conditions. The next big advances in coated glazings will be "smart glazings" that respond dynamically to changing occupant and building needs. After 15 years of laboratory development these coatings are now beginning to be scaled up in prototype form for use in buildings. These smart glazings can be divided into two major categories, 1) "passively activated," such as thermochromic (heat sensitive) or photochromic (light sensitive), and 2) "actively controlled," such as electrochromic, which can be switched as needed with a small applied voltage. Each of these should ultimately find a market niche but the actively controllable electrochromic is likely to be the preferred choice, assuming the remaining durability and cost issues can be favorably resolved.

Directional light control remains the primary optical challenge of glazings. Reflective and refractive optical elements, holographic glazings, diffractive microstructures, micromachines, etc. all represent potentially viable technical approaches to creating planar glazings that can redirect sunlight into spaces. Another class of daylighting elements, including light pipes and light shelves, can serve similar purposes at a scale larger than planar windows. There have not yet been significant advances in this area, leaving the field ripe for new technical breakthroughs.

#2. *Glazings will become "Energy Suppliers" as well as "Energy Managers"*

The traditional role of the glazing has been as a "climate moderator," an element of the façade that mediates between the changing outdoor conditions and the relatively constant desired indoor conditions, filtering and modifying energy flows. Using the technology described above, the next few years should see continued advances in efforts to use the façade to directly become an energy and service provider to the building, a source of heat, light, and "onsite electric power."

A quick analysis of the magnitudes of energy flows at a façade suggests that there is more than adequate energy available at a building site to power most buildings. For example, the luminous flux contained in a square meter cross-section of sunlight is enough to adequately light 200 square meters of interior building space. The fundamental challenge is distributing and controlling those flows that are not readily stored, e.g., daylight, and storing and managing the release the heat and power. One option to facilitate "storage" of daylight is conversion and storage: sunlight → via PV → electricity → storage → electric lighting. However such a pathway is very costly and while it may provide the option for lighting at night it is not likely to be cost competitive with direct use of daylight in the building whenever possible.

Passive solar heating is a well-understood design strategy and there is little reason why most buildings should require significant winter heating in low to mid latitudes. Glazings are key element to reduce envelope heat loss and potentially to collect and help redistribute solar energy to other parts of the building. For any given perimeter space, particularly in homes, the challenge for glazings is to minimize conductance and maximize solar gain. There are several useful techniques to produce glazing systems with conductances in the range of .6W/sq.m-K. These include: 1) three-layer windows with two low-E coatings, argon or krypton gas fills, and low-conductance edge spacers; 2) vacuum windows with two glass layers, a narrow spacing, and a low-E coating; 3) aerogel windows filled with a slab of highly insulating aerogel (a microporous material with excellent insulating properties); and 4) various transparent insulating materials, e.g., transparent honeycombs. Multilayer windows are commercially available today using well-proven technology. Continued improvements in both vacuum and aerogel window technology could make them a strong competitor in the next 10+ years. Annual energy simulations show that the best performance in a cold climate is obtained when the highest possible solar heat gain factor is maintained while the conductance is reduced. Even the solar energy available on the north façade is more than sufficient to counter small daytime losses and turn the window into a net energy provider. Calculations followed by field measurements over 10 years ago in cold northern climates in the U.S. demonstrated that multilayer, low-E, gas-filled units will outperform the best insulated wall even on the north wall of homes. The additional glazings and coatings will reduce the total solar gain of the window. A successful vacuum window or aerogel window could provide equivalent conductance values with somewhat higher solar gain values, thus providing even greater benefit. Such windows will also provide warm interior surfaces and thus excellent thermal comfort, with minimal risk of condensation.

Windows can be part of an active solar heat collection or rejection system. Air flow windows or extract air windows typically allow interior air to flow over a between-panes venetian blind or similar absorber, after which the air can be exhausted in summer to reduce cooling or recirculated within the building in winter to utilize the solar heat that is collected. These systems are commercially available but are more costly and require a degree of systems engineering that makes them difficult to utilize in the U.S. Some of the newer double envelope buildings being erected in Europe employ similar systems. Glazings can also be designed to deliver thermal energy at their surface from electric sources. Low-E coatings are electrically conductive coatings and these glazings can be wired to a power source to deliver a range of heat uniformly over the surface of the glazing. This technology is used today to provide comfort conditions adjacent to large glass areas in cold climates, to reduce condensation risk, and to melt snow from horizontally glazed surfaces.

An emerging role for the window is to become a producer of electricity by incorporating photovoltaic (PV) cells or coatings. A first step has been the use of small modules (approximately 300 sq.cm.) to provide local power to a motorized shade or blind. PV units have been built and tested both as part of the glazed or opaque building façade as well as used as shading elements above windows. An entire glazed unit can be coated with a semitransparent amorphous silicon coating and other thin film technology, and thus admit light and provide a partially obscured view, as well as producing electricity. System efficiencies range from 5% to 20% and will produce up to 200 W/sq.m under peak conditions. In designs without storage, the output goes into the power grid on an instantaneous basis. In a remote power or standalone situation and storage capabilities will be provided. Building integrated PV systems are useful contributors to the building load but they are typically far from being "cost-effective" in any traditional sense of the term. Furthermore unless the building is designed from the start to be highly energy efficient it makes little sense to employ expensive power producing technology to satisfy loads that can be more cheaply reduced with alternative designs and equipment selections.

#3. Facades will be optimized for Daylighting and Natural Ventilation, which emerge as central design themes for the next generation of buildings.

If one compares how glazing is now being utilized in leading building designs compared to standard practice in the recent past, several new trends are apparent. These include: 1) increased use of innovative daylighting solutions, 2) increased use of natural ventilation strategies, 3) specification of large glazed areas such as atria and exhibit halls, and 4) renewed interest in fabric covered spaces.

Daylighting is once again being rediscovered as an important design strategy for many building types. It provides a long list of potential benefits but is not without problems. Glare and overheating are commonly associated with many new attempts to create daylighted spaces, particularly by firms without prior experience in this field. Any space with glazing can be claimed to be daylighted. However, the light and heat gain must be carefully controlled if the solution is to be successful to occupants (performance and comfort) and owners (cost). Some design solutions seem to suggest that if some glass is good then more must be better. In typical U.S. climates, most of the achievable daylighting savings are captured using high transmittance glazings with window areas of about 35% of the wall and with skylight areas of less than 5% roof coverage. Additional area can be used, assuming that glazing type and shading strategies are selected carefully. Roof lighting solutions are the most straightforward since interior distribution is relatively uniform. Side-lighted spaces represent problems of light distribution as the perimeter of the room can easily be over 10 times brighter than the interior, thereby creating contrast and glare problems. This is particularly important when computer-based visual tasks are present in spaces. One solution is to add systems such as light shelves and light pipes that "push" light deeper into the space and balance contrast ratios. Another approach is to separate the facade into a lower low-transmission "view" window and a higher transmission daylighting glazing higher on the facade that is less likely to create glare problems. Dynamic systems such as blinds and smart coatings discussed elsewhere are also viable solutions. Successful daylighting solutions require a combination of good design skills and an understanding of lighting as well as specifying the right technology. Integration with electric lighting controls is essential if energy savings are to be achieved.

Natural ventilation is increasingly popular in European buildings both as an occasional "free cooling" strategy to reduce cooling system energy use as well as a replacement for traditional cooling systems. The facade system often acts as an inlet or outlet as a part of a larger building wide airflow system. In buildings that are being designed without mechanical cooling, it is essential to design a high performance facade that minimizes direct cooling loads from the glass since natural ventilation alone is typically unable to provide adequate comfort in such a situation. Most of these designs are unique solutions requiring extensive simulation using advanced tools and sometimes employing scale model testing. There appear to be some successful solutions but the overall performance of these systems is still under investigation.

There is increased interest in creating architectural spaces of grand scale that are highly glazed, e.g., atria, lobbies, exhibit halls where some characteristic dimensions may be in excess of 100 meters. When conventional glazing is used, very elaborate shading and sun control solutions are needed.. Alternatively there is renewed interest in large area fabric structures that provide only modest insulating levels but with light transmittance of 3-10%. This can be a very efficient and low cost approach to create large span, naturally lighted spaces. The use of very large glazed facades presents structural and security concerns beyond the scope of this discussion which must be addressed for each design solution.

#4. Glazings will be viewed as dynamic building elements rather than static components, and will function as an element in integrated building systems.

The traditional view of window performance is a static perspective on a single building component. Conventional engineering design took a worst-case perspective that tended to analyze performance under peak heating or peak cooling conditions. The design challenge was then to provide adequate heating and cooling capability under those peak conditions. Only limited attention was paid to the manner in which glazing performance was dependent on other building systems.

Design today takes a more enlightened perspective. Not only is there tremendous variability in the external climate and associated thermal and daylighting conditions, but occupant needs vary significantly in interior spaces. This variation arises from several sources: the intrinsic variability of occupant preferences and associated differences in clothing and metabolic levels, the variability in the nature of visual tasks present in a given space, and the effects of changing office tasks and changing company business needs. A different type of dynamic control is needed when the desired building impact should be relatively constant but the external climate driver is highly variable. This is the situation with daylight where external levels can vary by a factor of 10 in a matter of seconds as the sun moves behind a cloud, but where interior levels should be maintained at relatively constant levels.

Given this high degree of internal and external dynamic change it is only logical that glazing systems should have the ability to respond to such change. The most rapidly changing conditions are those related to solar gain and daylight, and it is in the area of dynamic control of solar optical properties that much of the current interest is focused. Automated blinds and shades have never achieved the acceptance in the U.S. that has been achieved in Europe and it is likely now that the emerging technology of smart glazings will ultimately fill this important technology niche. The initial interest is dynamic control of intensity of transmitted heat and light, which will reduce glare and moderate cooling loads. A second objective would be dynamic optical control of light distribution within a space to moderate interior changes as the daylight provided by sun and sky varies widely. The challenge is to provide this degree of control without moving parts, or other costly or complex technology.

This more dynamic view on glazing performance lends itself to a perspective of glazing and facade systems as an integrated part of overall building performance. Buildings must be designed and operated as an integrated whole, rather than a loosely coupled collection of parts. This suggests that glass and fenestration system manufacturers should consider partnering with structural system suppliers to create thermal storage systems, with HVAC systems suppliers to create systems that can effectively utilize natural ventilation strategies, and with lighting systems suppliers and furniture suppliers to provide daylighting solutions. Building control systems that manage the overall building operations (traditionally lighting and HVAC) should now also manage an active facade system that helps to modulate cooling loads and lighting energy needs. As the electricity market is restructured there is likely to be a premium placed on the ability to dynamically manage load throughout the day, a need that is well met by a dynamic facade system if properly linked to building automation systems.

#5. As buildings become more complex, better computer tools will be developed for both design and operations.

Computers are changing every aspect of our lives and there is no reason to believe they will not have a significant impact on architectural design generally and the design of glazed facades specifically.

Improved design tools and CAD environments will allow designers to rapidly explore complex design options and to communicate these options more effectively to clients, and later to fabricators and contractors. Where once there was pressure to standardize designs to reduce the tedium of producing endless variants of architectural details, these tasks can now be relegated to computers, freeing the designer to spend time more creatively. Once design options have been generated, the emerging ability to analyze and compare the designs with a variety of new engineering tools will allow designers to optimize design, to better anticipate building performance issues and to specify the proper glazing products to meet user needs. The ability to reliably estimate the impact of a change in glazing type and daylighting strategy on the size of the chiller system in a building is a new capability that is still not widely accepted and used to advantage. A new generation of computers tools that facilitate whole building energy analysis will allow designers to better meet occupant needs by exploring the impact of options early in the design process when changes can be made with minimal cost and effort. Specialized tools, which today are used largely by consultants, will become available to designers on their desktop. Challenging design problems that are ignored or avoided today will become readily solvable as new and more powerful tools become more accessible. Computational fluid dynamics (CFD) tools will estimate the effects of natural ventilation and daylighting tools will provide a quantitative and qualitative assessment of the impact of glazing selection on interior daylight levels and glare, under any climate conditions.

The advent of this new generation of tools will be a mixed blessing. Each tool will have a series of direct costs, e.g., purchase, and indirect costs, e.g., training, associated with it. Designers may find themselves inundated by the challenge of converting megabytes of data outputs from one set of tools into inputs for the next tools, each with its own interface and data format. The International Alliance for Interoperability (IAI), a world-wide alliance of 600 companies, is working to create a standard building specification that would allow all building software to share a common building data model. The promise of software interoperability is very powerful—how quickly the marketplace will capture that promise remains to be seen.

Collaboration is the essence of design and the internet promises to ultimately provide a powerful vehicle for true collaboration among design team members from all disciplines. realtime video conferencing, shared whiteboards, online product and project databases, etc. will initially be treated with caution, then viewed as a convenience, and will ultimately change the nature of the design process itself in ways that we cannot yet fully comprehend. These information technologies will further accelerate the trend to global partnerships, and may well allow smaller firms and consultants to compete as virtual teams against much larger traditional firms in the global marketplace.

The design and construction phase of a building lasts a few years but the occupancy and operations phase lasts for decades. New computer-based information systems will be used to commission buildings, to ensure that their day-to-day operation meets occupant requirements and over time meets evolving performance needs, and to help diagnose and even correct failures when they occur. Buildings have rarely had on-site skilled staff to operate them properly due to cost concerns. By installing extra sensors and controls in buildings, and linking them over the internet, the buildings of tomorrow can be continuously monitored and controlled by a trained staff from a remote location. The end result will be buildings that provide more effective living and working environments for people and place fewer burdens on the environment.

#6. Changing business perspectives: satisfied workers demand better work environments with properly designed glazed facades.

Business managers increasingly recognize that their most important asset is not the buildings they occupy but the people that occupy them. For most businesses, employees are also their most costly asset. Building design parameters that influence worker satisfaction and productivity are thus very important economic considerations. Consider some typical annual costs for a U.S. office building: worker salaries at $1800/sq.m-yr are 6 times the cost of rent at $300/sq.m-yr or 60 times the cost of utilities at $30/sq.m-yr.

Furthermore the cost of recruiting and training new workers to replace those who leave is very high. There is growing evidence that workers value offices that provide daylight and/or view or visual connections with the outdoors and that these spaces have measurable consequences on satisfaction and performance. In Germany this connection to windows is translated into design requirements that ultimately influence building form and shape. It seems reasonable to assume that these trends will continue and that there will be increased incentive to provide better workplace environments for workers and that a significant element of these solutions will be provision of thoughtfully designed glazed facades.

Although we often argue that better buildings can be built at little or no increased cost due to system integration tradeoffs and savings, there are almost always higher first costs to achieve savings that are well above standard practice. Even though more attention will be paid to these "human" operating costs, due to the way that buildings are typically financed in the U.S. many owners will continue to face a challenge of finding adequate capital to support these new energy efficient designs. Only a few owners to date are willing to look at the numbers above and conclude that their capital budgets should be increased to accommodate these needs. (There are, of course, many costs in buildings that are not "cost justified"—they are selected for aesthetic, image, or other reasons.) It remains a challenge to justify investments above the norm to provide designs that promise better interior work environments.

Some costs involve well-defined extra hardware but other costs are "soft" costs that come from an attempt to reduce risk and uncertainty. A contractor bidding for the first time on installation of a high performance facade will add costs to cover the inevitable mistakes and delays that come with first use of a new technology. Strategies that reduce these real and perceived risks can result in measurable reductions in first cost.

#7. Utility restructuring will impact the way buildings are designed, built, and operated.

For decades the utility industry in the U.S. was a fully regulated industry. The industry is now undergoing a fundamental restructuring and deregulation which is changing many of the existing relationships between building owners and energy suppliers, and ultimately may influence product suppliers as well. In the past, the building owner's only option was to purchase power from the regulated local utility. Now power can be purchased from a wide variety of sources, and there are many new players in the marketplace, each of whom is now eager to sell building owners a much broader set of services. These might include cleaning, maintenance, other utilities such as communications, and could include complete responsibility for the operation of the building infrastructure, including heating, cooling and lighting. Such companies might also get involved in the design phase, offering to develop and finance a portion of the building that is then leased back to the owners via a long term lease. This could be beneficial to owners who are unable to otherwise find the capital to invest in energy efficiency improvements. One might imagine the "utility-service" company of the near future investing in an innovative façade system linked to the building HVAC system, and then leasing the complete system back to the owners over a 15-year period, and providing the maintenance needed to keep the system in good operating condition.

Economists have traditionally forecast rising utility costs and used these forecasts to justify added investment in efficiency options. One by-product of these regulatory changes is that the cost of electricity is likely to decrease for the foreseeable future in most parts of the U.S., further reducing the direct economic incentives for investing in energy efficiency.

#8. Global environmental concerns will play a larger role in public and private sector pressures on building decisions.

There is a growing realization that industrialization and the associated development patterns of the last 100 years have created an increasingly dangerous and unsustainable impact on the natural ecosystems upon which we depend for many services, e.g., clean air and water, natural resources. The direct and indirect effects of energy extraction, conversion, and use are one of the single largest impacts on the environment. After a decade of debate there is a growing scientific consensus that human activities are responsible for much of the observed global warming effect and that it would be desirable to reduce the carbon emissions that drive this cycle. There is much less consensus on the steps that ought to be taken, by whom, and at what real or imagined cost. Since buildings use 65% of all U.S. electricity use, energy efficiency strategies are a cost-effective approach to slow or reverse carbon emissions. This has generated new interest in efforts to create a new generation of highly resource-efficient buildings. Examples of activities in this area include:

1) Increased interest in sustainable design strategies, virtually all of which involve the use of highly energy efficient facade systems and daylighting. While many "efficient" buildings today would target a performance that is 25% less than code requirements, there are a few examples in the U.S. of highly efficient buildings that achieve 70% savings. Any such building will almost certainly employ high performance glazings and daylighting strategies.

2) Materials assessment: New attention is being paid to life cycle assessment of materials and products, including embodied energy in the materials, toxic emissions associated with production processes, use of scarce, non-renewable natural resources, and the ability to recycle and reuse materials at the end of the useful life. This "cradle-to-grave" accounting presents new challenges and opportunities to manufacturers with both existing and new products. Early analysis suggests that well designed glazings and facade systems emerge from such analysis looking like reasonable options.

3) National programs to reduce energy use and emissions: these can be lumped into several different categories:

    a) Economic solutions: Raising the price of a resource will ultimately reduce its use in the marketplace. Energy prices in the U.S. are lower now in real terms than they were at the time of the oil embargo in the 1970s and are lower by factors of 2 or 3 compared to typical prices in Europe. Prices could be raised by imposing a carbon tax that might raise the price of energy overall and provide a differential between cleaner and dirtier sources. Although such approaches are actively under consideration and development in Europe, there is little political will to implement such approaches in the U.S. at this time.

b) Market transformation programs: because of hidden costs and subsidies, and low energy prices, most markets for building technologies do not provide adequate incentives for investment in energy efficient solutions. In the past, governments and utilities tried to create change in the marketplace by various economic subsidies for new energy efficient products, e.g., $10/sq.m for more efficient windows. Experience with these programs suggests that the short-term change they create in the marketplace does not persist after the subsidy is removed. Newer programs are designed to support activities that will result in lasting changes, by permanently transforming market behavior. For example, new glazing technology may be expensive because the market volume is low and manufacturers cannot justify investment in expensive, automated production equipment. A market transformation program might assemble a number of buyers who agree to guarantee a purchase of a minimum quantity of product meeting a required performance at a given price, thus providing the volume that justifies the manufacturer's investment in new facilities. Market transformation programs include a variety of innovative programs i.e., c) and d) below.

c) Voluntary market-based mechanisms, such as product or building rating and labeling programs, can be effective in reducing energy use. These programs are based on the belief that better-informed decisionmakers will make wiser decisions about energy use. The National Fenestration Rating Council (NFRC) has developed a set of window rating procedures and labeling systems now in use by most major manufacturers in the U.S. This provides a level playing field within which the properties of various window systems can be readily compared. This allows other voluntary market promotion programs such as the Energy Star Windows program to easily identify those windows meeting certain performance requirements.

d) Mandatory programs (such as minimum efficiency standards for appliances or buildings), if properly implemented in partnership with industry, have been shown to provide benefits for consumers and manufacturers, as well as for the public interest in terms of reduced energy use and emissions. While mandatory building standards can sometimes prevent poor design, they can rarely guarantee good design. But they also set a performance floor that becomes a benchmark for other voluntary programs.

Conclusions

Glazings and fenestration have always been a prominent element of architectural form and expression. Significant changes have already occurred in glazing and facade design over the last 25 years, laying the groundwork for additional technical breakthroughs in the coming years. New technology options will improve energy efficiency by managing and filtering the flow of heat and light, and ultimately turning the building façade into a local power plant. New trends in building design and operation, the changing utility marketplace, and new global environmental concerns are likely to continue to create interest and opportunities for further advances in glazing systems. Advanced glazings will be dynamic elements in facades that are fully integrated into building operations, providing daylighting and natural ventilation, and operated in a manner not only to reduce energy costs but to enhance occupant comfort and performance, and thus maximizing overall value to the building owner. These glazing and façade systems will become essential elements of virtually all "green buildings," the best of which will reduce energy use by 70% compared to buildings today. Better computer tools will allow designers to fine tune complex façade designs and to "experience" the appearance and lighting environment associated with facades on these "virtual" buildings, thus reducing design time and cost, and lowering the likelihood of costly mistakes or dissatisfied clients. Owners and developers will continue to search for clever financing approaches to pay for these improved systems. As new, highly innovative systems are tried on leading-edge buildings, the experimental systems of the last decade will be refined and become the mainstream solutions in the years ahead.

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Further information resources

A complete list of over 200 LBNL papers on the subject of glazings and fenestration can be found on our web site: http://windows.lbl.gov or can be obtained by contacting Pat Ross at (510) 486-6845 or via E-mail: PLRoss@lbl.gov. These contacts also provide information on a series of computer tools for the design of high performance window systems and for energy efficient buildings.

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