Market Transformation Opportunities For Emerging Dynamic Façade and Dimmable Lighting Control Systems

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ABSTRACT

Automated shading and daylighting control systems have been commercially available for decades. The new challenge is to provide a fully functional and integrated façade and lighting system that operates appropriately for all environmental conditions and meets a range of occupant subjective desires and objective performance requirements. These rigorous performance goals must be achieved with solutions that are cost effective and can operate over long periods with minimal maintenance. It will take time and effort to change the marketplace for these technologies and practices, particularly in building a series of documented success stories, and driving costs and risks to much lower levels at which their use becomes the norm. In recent years, the architectural trend toward highly-transparent all-glass buildings presents a unique challenge and opportunity to advance the market for emerging, smart, dynamic window and dimmable daylighting control technologies.

We believe it is possible to accelerate product market transformation by developing projects where technical advances and the interests of motivated manufacturers and innovative owners converge. In this paper we present a case study example that explains a building owner's decision-making process to use dynamic window and dimmable daylighting controls. The case study project undertaken by a major building owner in partnership with a buildings R&D group was designed explicitly to use field test data in conjunction with the market influence of a major landmark building project in New York City to stimulate change in manufacturers' product offerings. Preliminary observations on the performance of these systems are made. A cost model that was developed with the building owner is explained.

Introduction

There is a significant and growing interest in the use of highly-glazed façades in commercial buildings (Oesterle et al. 2001, Compagno 1999). Large portions of the façade or even the entire façade are glazed with relatively high transmittance glazing systems, and typically outfitted with some form of sun control as well. With origins in Europe, the trend is expanding to other regions including the United States. The stated rationale for use of these design approaches varies but often includes a connection to occupant benefits as well as sustainable design associated with daylighting and energy savings. These developments can be explained in part as the confluence of several technical and design trends. Technological advances such as low-E glass and spectrally selective glazings have made it possible to increase glazing areas while reducing unwanted heat loss and heat gain, and with no reduction in comfort. Innovations in sealants and structural use of glass have made a wider range of architectural solutions feasible and cost effective. At the same time there has been an increased interest in the use of daylighting both as an energy saving strategy as part of broader green building designs and because it is thought to provide other occupant amenities and benefits. Occupants are increasingly expressing an interest in more transparent facades as a means to visually connect with the outdoors at a time when there is emerging evidence that the attributes of daylight and view enhance performance as well as amenity and satisfaction.

Despite these trends the all-glass, highly-transparent façade still poses numerous practical challenges for the typical building owner. The building skin must serve a crucial function in its role to help maintain proper interior working environments under the extremes of external environmental conditions. Exterior temperature conditions vary slowly over a wide range. Solar and daylight levels can fluctuate rapidly over an even wider range. The technical problem of controlling thermal heat loss and gain is largely solved with highly insulating glazing technologies on the market today. The challenge of controlling solar gain and managing daylight, view and glare is at a much earlier stage. In most cases, a static control solution, e.g. fixed shading, will not suffice. Some degree of active, rapid response to changing outdoor conditions and to changing interior task requirements is needed. This can be provided with technology within the glass or glazing assembly itself, or the functionality can be added to the façade either on the interior or exterior of the glazing. In all cases, sensors, actuators, and control logic must be applied for proper functionality. Traditional manually-operated shading systems such as blinds or shades can be motorized and then controlled by occupant action or by sensors and building controls. Emerging smart glass technology can dynamically change optical properties, and can be activated manually or by automated control systems. In all of these cases, electric lighting should be controlled to meet occupant needs, while maximizing energy efficiency and minimizing electric demand. As with the fenestration controls, lighting control requires sensors (photocells or the human eye), actuation (switching or dimming) and a control logic that determines what action should be taken under each set of conditions. Some variation on the combination of all of these elements comprises the typical equipment and systems found in most commercial buildings today.

The new challenge is to provide a fully functional and integrated façade and lighting system that operates appropriately for all environmental conditions and meets a range of occupant subjective desires and objective performance requirements. And finally these rigorous performance goals must be achieved with solutions that are cost effective and can operate over long periods with minimal maintenance.

The building systems that would achieve these performance results do not exist today, at least as readily specifiable and cost-effective options. The challenge to develop such solutions presents the context for ongoing developments in this field. While daylighting strategies can be successfully implemented today in buildings with skylights and with some success in buildings with modest fenestration, highly-transparent buildings present a unique challenge and opportunity to advance the market for emerging, smart, dynamic window and dimmable daylighting control technologies. Without such systems, the original architectural design intent will be at risk for glare and overheating, and be subject to the ad hoc manual control of interior shades and light switches, with results that are likely to be less than satisfying. With the integration of these two technologies, the cost-effectiveness of the resultant package is made more compelling. This may also lead to a renewed interest to design the floor plate and interior of highly-glazed buildings to optimize daylight utilization throughout a greater percentage of the building's floor area.

There is a growing list of energy efficiency and demand management technologies and design strategies that are sufficiently routine, cost effective and low risk that they make it into most “to do” checklists, rating systems, utility programs and building codes. Daylighting, particularly using sidelighting with dimming ballasts, is not yet typically on these lists. It will take time and effort to change the marketplace for these technologies and practices, particularly in building a series of documented success stories, and driving costs and risks to much lower levels at which their use becomes the norm. Some of this will happen at a slow pace based on business-as-usual practice. But we believe it is possible to accelerate this process by developing projects where technical advances and the interests of motivated manufacturers and innovative owners converge. Some of the most powerful market forces for such convergence are carefully planned demonstration projects that not only produce objective and credible performance data but also demonstrate owner commitment to technology investments that signal manufacturers to alter their product offerings. In this paper we present a case study example that explains a building owner’s decision-making process to use dynamic window and dimmable daylighting controls with an all-glass facade. The case study project undertaken by a major building owner in partnership with a buildings R&D group was designed explicitly to use field test data in conjunction with the market influence of a major landmark building project in New York City to stimulate change in manufacturers’ product offerings. We follow with a short discussion of additional market-based activities that could be used to achieve widespread use of these systems in commercial buildings in the years ahead.

Insights into the Building Owner Process

We review the above trends for a specific building design case study to explain how a leading building owner in the US came to understand the concepts of daylighting and active shade management as a result of the architectural design trend toward all-glass, highly-transparent facades.

The New York Times, a major private sector corporation and an internationally known news company, decided to build a new headquarters building in Manhattan. A design competition was held where world-renown architects presented a variety of proposed design solutions to the building owner. The owners selected a design that codified their philosophy of presenting the image of the company to the world and in creating a high quality work environment for employees. The exterior of the building was proposed as a transparent floor-to-ceiling, all-glass façade that encouraged openness and communication with the external world. For a corporation whose daily business was gathering and disseminating news, facile communication between departments was encouraged by a number of the design features selected.

The building owner accepted the concept of “transparency” that was communicated by the architect in several ways: clear water-white low-iron glass, communicating stairs between floors, skylights, gardens, transparent lobbies that gave pedestrians at street level a view to the interior garden. “Daylighting” was not a term used explicitly by either party. The building owner did not establish explicit parameters for daylighting in their initial design charrette program. But they did have a requirement for demonstrating competence with ecologically sustainable design that was used not only in the selection of the lead architect but for other members of the design team as well (e.g., engineer, interiors, lighting). As the initial design evolved, the architect focused on many aspects of the façade design but left the details of how the design would affect the interior daylight quality and quantity to the interior design team and lighting consultants. The owner challenged the interiors design team to address how daylight in the space would affect occupant comfort and potential energy savings without compromising the architectural statements of transparency. The concept of the highly glazed, high transmittance façade with fixed external shading evolved to describe the corporate vision of transparency, openness and access. The occupant realities of comfort, light levels and energy efficiency would be addressed by additional solutions such as interior operable shading and dimmable lighting.

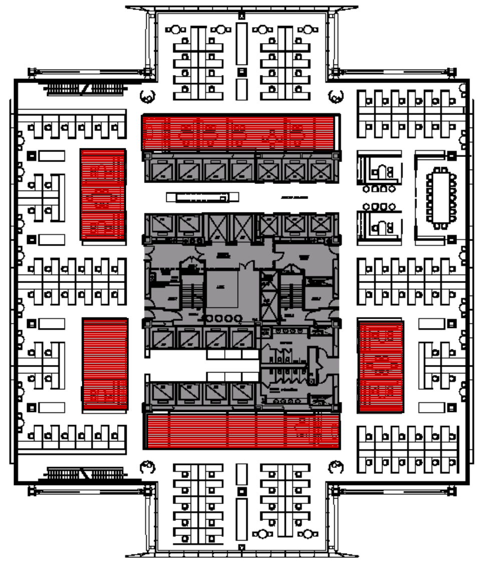
This dawning realization and exploration of issues was a slow process. Many building owners rely on word of mouth or meetings with design consultants to flush out the relevant issues. In this case, the building owner was interested in environmental technologies so in the course of their discussions with their design team and consultants daylighting control systems was mentioned as a technology option in addition to a whole array of other systems: underfloor air distribution systems, cogeneration systems, photovoltaics, wind generation, etc. This was their first introduction to the term: “daylighting”. Daylighting controls, manual switching, automated switching, and DALI-enabled lighting control were options initially investigated by the lighting design consultant. Conventional lighting and energy simulation tools were used to determine the cost-benefit of daylighting controls. The initial cost estimate for the daylighting system and the resultant estimated payback led to the conclusion that this design approach was not economical and the idea of automatically harvesting daylight by dimming the electric lighting as an energy efficiency strategy was tabled. Later, daylighting control systems once again became an option to consider because more sophisticated daylighting simulations and meetings with other potential vendors provided new information.

In parallel, the building owner worked with the interior designer to preserve the architect’s concept of transparency and the owner’s own internal goal of providing a built environment that would “enhance” the way their employees work. “Enhance” was described in terms of an environment that is friendly, that makes occupants feel better and do better at their tasks. This approach was not explicitly to increase “productivity” (increase throughput of widgets at a faster rate), but rather to enable occupants to focus, thrive, interact, and feel enlivened and connected to their work within a stimulating environment.

Transparency and access to an exterior view for virtually all employees was preserved by an open plan furniture layout. Occupant access to view is deemed to be so important in Europe that in some countries (e.g., Germany), it has become a mandatory code requirement. Low 1.22-m (4-ft) high partitions were used to foster the concept of an open transparent organization and to let the daylight penetrate deeper into the space. Since the architect employed a cruciform floor plan (Figure 1), with distances from interior offices to façade of less than 7.62 m (25 ft), view would be available in three directions from most locations within the perimeter zone. Conference rooms and glazed private offices were placed 23 ft (7 m) from the window wall. The ceiling height at the window wall was set at 3.15 m (10.3 ft) then stepped down to 2.92 m (9.58 ft) high after a setback of 1.07 m (3.5 ft) from the window. With a window-to-exterior-wall ratio of 0.76 and a glazing transmittance of Tv=0.75, daylight was anticipated to be abundant throughout the entire perimeter zone even with the exterior fixed shading system.

The overall solar heat gain would be a concern in any highly glazed façade. In this design, it is controlled with spectrally selective glazing (the glass solar heat gain coefficient is 0.39 and the U-factor is 1.53 W/m^2-°K (0.27 Btu/h-ft^2-°F)) and with an array of exterior fixed ceramic rods designed to block and diffuse sunlight. Even with these systems it was readily apparent to the owner that the transparency of the façade would generate potential glare and visibility problems. The building owner started to consider the use of automated roller shades as a means of managing window glare and maximizing the openness of the architect’s design.

Figure 1. Exterior View of an All-Glass Façade and Shading System (Left) and Cruciform Floor Plan (Right)



However it was felt that if shade management were left to the occupants sitting closest to the window wall, the shades would most likely be down most of the time since employees are often too busy to manage the shades. The potential "random" operation of each shading system became a critical concern to the building owner both in terms of appearance and management of the daylight. Too much shade use at the wrong time would compromise view and potential energy savings as well. If daylight was not managed automatically, then conventional manually operated interior shades might degrade many of the key design features that made the architectural design so compelling in the first place.

The concern revolved primarily around glare and enhancement of daylight. Thermal discomfort due to direct sun on occupants was initially thought to be a minor issue because 50% of the façade is shaded by 4.12 cm (1.625 inch) diameter off-white horizontal exterior ceramic rods spaced at variable center-to-center distances and placed 0.46 m (1.5 ft) off the face of the glazed façade. These rods shade the upper and lower portions of the main glazed facade on each floor. A vision portion of the window wall from 0.76-2.13 m (2.5-7 ft) above the floor is left open for view for a standing or seated occupant. Solar heat gains and thermal discomfort were to be countered with an underfloor air distribution system. With further analysis, thermal discomfort resulting from direct sun transmitted through the vision portion of the window wall became yet another reason to consider automated shade management.

The building owner had sufficient foresight to begin addressing these critical lighting quality and façade issues early enough in the design process while there was still sufficient time to explore potential design options and implement them in the final building. One major challenge was finding design and technology solutions that addressed the thermal and luminous issues as an integrated, cost-effective and reliable package. A search on the web led the owner to daylighting experts at the Lawrence Berkeley National Laboratory (LBNL), who had worked with a variety of integrated daylighting and shading systems over the last ten years. LBNL provided the building design team with two new directions. First, dimming ballasts had been dismissed as viable options based on current manufacturer quotes of $60-120/ballast. LBNL staff had been exploring market trends and costs and had concluded that it should be feasible to profitably manufacture and sell dimming ballasts at prices that were much lower (e.g., $20-30/ballast). Direct contacts with key manufacturers confirmed these possibilities. The LBNL team also proposed that dimming ballasts be considered for use throughout the building, simplifying replacement logistics and allowing tuning of light levels and peak electric demand control at all locations. There still remained significant uncertainly on how all the hardware would be integrated and controlled, as well as commissioned and operated, and how that operation would influence the quality of light in the space.

Second, to address issues of glare, lighting quality and hardware integration, LBNL advised the owner to consider altering their plans for a conventional furniture mockup (typically built full-scale indoors in a warehouse) and building an outdoor mockup instead. This would allow the owner to address some of the commissioning and integration issues, to see the impact of automated shade and dimmable fluorescent lighting management on lighting quality under real sun and sky conditions, and to assess the benefits of these technologies to harvest daylight. Allowing manufacturers to test their products in a mockup prior to bidding the job was envisioned as reducing uncertainty and risk and thus an additional key strategy in lowering costs. In addition, the owner considered the added advantage of being able to get feedback from future occupants of the newly designed spaces well in advance of construction, thus providing input into some critical interiors design issues. Weighing all the costs and benefits, the owner decided to construct a 401 m^2 (4318 ft^2) mockup of approximately one quarter of a typical floor.

Technology Options: Integrating Control OF Window Shading and Lighting

Manual operation of windows or shades might work in homes and some small buildings. But in a larger building with many occupants and an operating design strategy that might involve predictive algorithms, thermal storage and/or integration of façade and lighting systems, ad hoc control by occupants must be replaced by more consistent and reliable automated controls to capture the full benefits of the technology investment. Window management and dimmable electric lighting controls are making slow but continuous progress toward this vision of adaptability and innovation. Commercially-available window shading systems (motorized roller shades, Venetian blinds, and louvers) and lighting controls now include some or all of the following features:

- Stand-alone central computer with proprietary communications within the shade or lighting network and a gateway connection to the building management system.
- Automated shade control of the depth of direct sun penetration, solar radiation, window glare, and/or daylight illuminance. For exterior shading systems, there are automated limits on operation if there is ice, snow, or high winds. Closed-loop shading systems have the ability to compensate for urban surroundings and complex exterior shades. Open-loop systems can do the same if a geometrical model of the surroundings is input and correlated to each shade zone.
- Time delays that affect the rate of shade response to changes in exterior weather.
- Automated dimmable lighting control in response to available daylight. Systems typically top-up daylight to maintain a minimum desired light level at the work plane.

- Manual override via remote control or wall-mounted switch or wall-mounted touch-screen. Manual switch can control individual or groups of lights and shades. Web-based user interfaces on some lighting control systems.
- Schedules for occupancy or day- or night-time operating conditions. Schedules for when occupant override of shading is permitted (user comfort mode versus energy-savings mode). Heating and cooling mode of HVAC or indoor temperature factored into shade controls.
- Fault detection and automated diagnostics that help to troubleshoot hardware failure, enable software-based commissioning of zones, and provide real-time plots showing control history.
- DALI-compliant dimmable fluorescent ballasts that enable reconfiguration of dimming zones in software. Graphical user interfaces that allow facility managers to map the physical location of ballasts to a reflected ceiling plan.

The range of products is both a useful indicator of availability and a problem itself as it is challenging to create a robust, viable integrated system from this ad hoc kit of parts. As a starter, a comprehensive list of such products accompanied by a breakdown of features is needed for designers and building owners to identify even those products that are currently available on the market. An explicit integration plan is also needed along with tools that enable reliable commissioning and performance assessments so as to ensure effective system operation over the life of the installation.

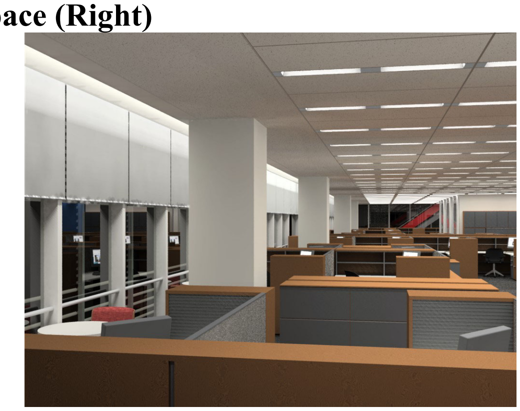
Performance Assessment at the New York Times Mockup

As the building owner researches technology options, the usual questions surface that concern the purchase of any new product: how will it work for my application, are the vendor claims valid, what risks are incurred, and will the performance benefits be sustained over the life of the installation? Most designers and owners do not have ready access to answers to these questions, thus slowing innovation. The New York Times mockup test program was designed to accomplish several objectives: 1) enable vendors to not only prove the various features of their systems but also fine tune their systems to meet the evolving requirements of the building owner, and 2) understand the benefits and limitations of each manufacturer's approach to shade management and daylighting controls. A 401 m^2 (4318 ft^2) mockup was constructed near the final building site and the southwest corner of the building was reproduced at full scale and fully furnished. The mockup was divided into two areas where two different roller shade manufacturers and two different manufacturers of dimmable lighting systems installed commercially-available systems in each area with different types of sensors and control strategies. The objective of the test was not to perform a side-by-side comparison of the two "competing" systems but rather to understand how vendor decisions regarding control infrastructure and design might impact actual field operation. The end goal of the monitoring phase was not the selection of one or another of the manufacturer's products in the mockup but rather the development of a detailed performance specification that would be open for bid by any vendor.

Lighting energy use, workplane illuminance and distribution, various parameters related to visual comfort, control operations, exterior solar conditions, and other environmental parameters were monitored continuously (1x/min, 24/7) in each area by either LBNL instrumentation or by the manufacturers' control systems. Area A of the mockup had only a western exposure while Area B of the mockup had both a western and southern exposure so the two data sets are not directly comparable. Monitored data were collected from December 21 to June 21 to capture the full range of solar conditions. During this time, the manufacturers were permitted to tune their systems to obtain optimal performance and improve their designs. The building owner, upon seeing the effect of their initial control specifications, tweaked some control settings to obtain a system that better met their needs. In some cases, manufacturers altered their systems in response to interim performance data from LBNL indicating that the owner's specifications were not being met. A subjective study to determine occupant satisfaction with the resultant lighting environment and acceptance of the automated technologies was conducted. Detailed luminance maps were taken at various locations within the mockup to better understand the visual environment over selected days.

To supplement this monitored data, a series of RADIANCE simulations of the space were prepared to explore design issues related to the shade systems and lighting controls (Figure 2). Simulations can enable the building owner to explore and visualize the impact of numerous design options on glare, visual display terminal (VDT) visibility, illuminance and luminance distribution. Detailed optical properties of all interior furnishings, curtainwall finishes including the ceramic rods, and the VDT were measured. Future work may include use of RADIANCE to select shade cloth density for other façade orientations, to help define the depth and size of lighting zones per orientation and floor level (this is a high-rise building), and to fine tune control setpoints given the shading impacts of the built-up urban surroundings.

Figure 2. Photograph of Mockup (Left) and Radiance Nighttime Rendering of the Same Space (Right)



At the time of writing this paper, analysis of the data was not completed, therefore the following observations are expected to change with our final analysis. The window and automated shade system provided sufficient daylight throughout the 13.4 m (44 ft) deep perimeter zone, enabling significant dimming of the electric lighting throughout most of the zone. With conventional window design with either high partitions or private offices immediately adjacent to the window wall, a 3.0-4.6 m (10-15 ft) daylit perimeter zone is typical. For this building design with its all-glass façade and minimal interior obstructions, daily lighting energy savings were 35% at 3.0 m (10 ft) from the west-facing window and 10% at 9.14 m (30 ft) from the window during the December to March period. These savings are given for daylight hours (sun up) and are compared to a zone with no daylighting controls. The shading systems were controlled to provide a bright interior environment and control direct sun. Lighting energy savings were greater across the zone daylit bilaterally from both the south and west facades: 50-70% on average at 3.0 m (10 ft) from the west or south window and 40-45% at 4.6-7.6 m (15-25 ft) from the window for the winter period.

The control system design used to dim the electric lighting system and its commissioning upon installation can significantly affect lighting energy savings. In Area A of the mockup, a closed-loop proportional control system was used to dim multiple lighting zones in response to input from a single shielded photosensor mounted in the ceiling plane. The performance of this system met the control requirements well throughout the monitoring period: for more than 90% of the day, the total workplane illuminance was maintained in all lighting zones to within –10% of the design setpoint. In Area B of the mockup, an integral reset control system was used to dim single lighting control zones in response to input from a single shielded photosensor mounted in the ceiling plane. Initially, the performance of this system was quite poor due to control hysteresis between the narrow lighting zones. Data from LBNL convinced the manufacturer that adjustments were required to improve performance. By rezoning the area, the manufacturer was able to increase the percentage of the day that the workplane illuminance was maintained in all lighting zones to within –10% of the design setpoint from ~50% of the day to 80-90% of the day. Interestingly, the building owner was very satisfied with the lighting operations in Area B despite its initial poor performance. The lights were turned off throughout the day and the building owner thought there was sufficient daylight to conduct normal office tasks.

Controlling the window shades to manage glare reduced interior daylight levels and the lighting energy savings. Each of the manufacturers used different sensing and control approaches in the mockup resulting in some noticeable performance differences. The roller shade systems under consideration had an openness factor of 3% with an associated visible transmittance of about 6%. The shades were woven with two colors: the white surface faced out and the gray surface faced inward. In initial meetings, we discussed alternative interior shade design options with the building owner so that daylight would not be compromised in order to control glare. Some of these included dividing the window wall so that the upper portion of the window wall could be shaded separately from the vision portion of the window wall. Variable-density shade fabrics were suggested. Bottom-up shades were also suggested. In an effort to contain costs and meet the design aesthetic of the architect, the building owner set aside these suggestions for future review.

The low sun angles of the southwestern exposure caused the worst-case situation for glare. The building owner was able to immediately assess the glare from the low winter direct sun early on and discuss options with the manufacturers, the architect, and interior design team. Monitored data revealed that glare from either the solar disk or from the shade backlit by direct sun would be a significant problem for some viewpoints within the space. Glare from the bright sky would also be a significant problem for some viewpoints (however, most of the primary tasks are conducted with one facing away from the window). To control this glare, adjustments to the operation of the shades and potentially the shade fabric were required. Changes to the interior design may also be in order.

The building owner clearly preferred the brighter daylit space compared to the darker, less daylighted spaces that most currently work in. They found the quality of daylight to be palpably different in the morning versus the afternoon and were delighted with the subtle shifts in color, intensity, sparkle, and mood throughout the day. The rise and fall of the automated shades tuned the occupant's awareness to the varying outdoor solar conditions. In Area A, the manufacturer had initially controlled the shade stringently for glare but the building owner requested that daylight levels and view be increased so the setpoints were relaxed. In Area B, the manufacturer was asked to permit deep sunlight penetration in the circulation zone in order to increase interior brightness and one's connection to the outdoors. In both areas, after the interim LBNL assessment of glare and several face-to-face discussions, the manufacturers made adjustments to their control systems in an effort to reduce glare. A human factors test was conducted after these adjustments were made (data has yet to be analyzed). In the final building, the systems will be tuned to the specific requirements of the occupants and work groups, window orientation, and degree of obstruction and/or daylight reflection from the urban surroundings. Throughout the building, a wall-mounted manual switch will enable occupants to override the automated shade control system.

The various features of each of the manufacturer's products were not rigorously tested. For example, in Area B, the shade and lighting systems were two separate proprietary products. Although the manufacturers said that their products could talk via a gated network connection, this systems integration feature was not implemented for this test. In Area A, a single manufacturer provided both the shade and lighting system as a single package. In this case, the diagnostic and fault detection features of this integrated product were demonstrated to the building owner. In Area B, prototypical DALI-compliant ballasts were used. The manufacturer demonstrated their advantages by rezoning the lighting system to an arbitrary layout specified by the building owner, conducting a blink test to prove that the fixtures were rezoned, and then returning the system to its original layout in a matter of minutes. LBNL requested various complicated scheduling sequences for the lighting systems (nighttime tests were needed to characterize the lighting system) and the manufacturers were able to deliver reliable, automated control. Several other glitches were found over the course of the monitoring period but most were resolved satisfactorily.

Moving from "One-of-a-Kind" to "Mainstream" Solutions

There are powerful market forces that are pushing some owners and design teams to architectural solutions utilizing highly glazed, transparent facades. We have followed these trends and note that there are clear potential benefits to such approaches but at the same time real risks and costs associated with them as well. The interest in potential benefits from these design solutions can be summarized with the following generalized statements:

- More building owners desire daylight. Many find the architectural concepts and buildings that employ highly transparent facades a refreshing turnabout from the opaque, dark tinted or reflective buildings of the 1970s and 1980s.
- More building owners are aware of the potential health and productivity benefits of daylight. Even without rigorous proof of these benefits the interest remains.
- With the increased use of low-reflectance, higher brightness flat-screen LCD monitors, architects can now turn away from the practice of hiding people in dark rooms so that they can view their older CRT screens and can now use design solutions that involve increasing the daylight and luminance levels within buildings.
- The shift toward highly glazed facades can be coupled with interior designs that complement the desire of building owners to provide view and daylight to more employees. With open-plan, low-height partition furniture layouts, the daylit zone can be

extended from a conventional 3.0-4.6 m (10-15 ft) depth to a 6.1 m (20 ft) or even 9.1 m (30 ft) depth from the window wall.

At the same time the potential risks associated with highly glazed facades are understood by many design teams and owners as well. These include:

- Inadequate tools to reliably predict thermal and optical performance of components and systems, and to assess environmental quality.
- Increased cooling loads and cooling energy use for the larger, highly transparent glazings, with the potential for thermal discomfort.
- Increased visual discomfort from sun penetration and from brightness levels that exceed good practice for those using computer systems in daylighted offices.
- High cost of purchasing lighting controls utilizing dimming ballasts and difficulty in commissioning the system after installation.
- High cost of automated shading systems and difficulty in commissioning the system after installation.
- Cost and technical difficulty of reliably integrating dimmable lighting and shading controls with each other and with building automation systems to ensure effective operation over time.
- Uncertainty in occupant behavior with use of automated, distributed controls in open landscaped office space and potential for clash between different needs and preferences.

To capture the potential benefits and minimize the risks there is a growing recognition that at least in work spaces (as distinct from circulation, lobbies, etc.), large glazed spaces require much better sun control and glare control, and that these solutions must be delivered by dynamic systems whose properties change in response to exterior climate and interior needs. A major challenge for manufacturers is thus how to provide the needed increased functionality at lower cost and risk to owners. Using detailed experience from the mockup, LBNL and the New York Times team have evolved a model for how the markets for integrated daylighting controls and automated shading systems might be transformed to provide improved functionality at lower cost. Dimming ballasts and automated shading systems are key technologies whose cost and performance are critical to the building solution; however, there are several fundamental limitations: 1) they are too costly and 2) they can not be readily and cheaply commissioned after construction.

The business model for transforming the markets for dimming ballasts and dynamic shading is based on creating a much larger market for these systems, and shifting the market perspective from the current "low volume, high cost" to a "high volume, low cost" paradigm. This requires purchasing power and ideally large volume purchases by a small number of owners to minimize transaction costs. The initial target buildings are thus large owner-occupied buildings where the owners have a long-term stake in the future operations and occupant satisfaction in the building. In the case of dimming ballasts, we have studied component and manufacturing costs and concluded that it is possible to meet target sales prices of $20-25/ballast, figures which have been quoted privately by several vendors to the Times. The overall cost to the owner is not only the ballast cost alone but includes installation of the dimming ballast into the fixture, and connections to building power and control wiring. The team is looking at procurement and assembly options that maximize the value added for each cost increment. The ability of smart controls to facilitate commissioning and reduce those costs is part of the assessment as well.

The overall strategy utilizes the mockup to gain practical experience as to assembly, installation and controls integration and commissioning, and to translate this experience into a competitive performance-based procurement specification that will be widely offered to all vendors, thus stimulating a competitive price response. Not only is the order for this building a large one but it is intended to lead directly to other orders as well. The New York Times team has actively collaborated with owners and design teams from other major projects in the New York area by inviting them to visit the mockup and join the effort to promote the vision of low cost dimmable lighting and dynamic shading. The message to potential ballast and shading suppliers will be that there are large potential orders for technologies that meet the cost and performance goals established by the team in the mockup facility.

We note that these are issues of greater concern to "owner-operators" rather then developers who are building for the speculative market in which unknown future tenants will occupy the building. The technology and performance issues are similar but the investment decisions and design process issues can be quite different. In the near term we expect these technical and market developments to be driven by the leading edge of the owner-operator market, although results will be ultimately useful in all buildings. In some circumstances these technology packages are expected to be useful in major renovations and some retrofits, further expanding the market impacts. Once the bid-data from the Times procurement are evaluated late in 2004 we expect to refine the approach and work with other public and private partners to promote the vision of cost effective, low risk integrated daylighting solutions.

The automated shade systems have both similarities and differences compared to the dimmable ballasts. The overall market transformation model is similar, using experience in the mockup to resolve and specify lower cost approaches to integration and commissioning. One strategy to reduce automated blind costs is to reduce the number of motors to a minimum in driving the largest practical number of roller shades. This has implications in terms of the size of window area that can be individually controlled and the approach might be different in open office spaces as compared to single or double occupancy spaces. The number and type of sensors used to control the shades, their ability to integrate with the dimmable lighting system, and the commissioning requirements will all have impacts on overall costs. The owner cost analysis also includes some assessment of maintenance and operating costs and the costs involved in future hardware changes based on possible space use changes.

Conclusions

Dynamic façade and dimmable lighting systems have been commercially available for decades without achieving significant market share or energy savings in the US. The most significant barrier for daylighting controls has been cost and reliable performance. With automated shading and lighting systems, most building owners are not convinced that the benefits outweigh the high first costs and the trouble of maintaining these systems over the life of the building. With the architectural trend in Europe and now the U.S. toward more highly-transparent buildings, the economics and technical arguments have become more positively biased in favor of more widespread use of these emerging technologies.

One might argue that the "safe" façade solution is to limit glazing area and transmittance but this then restricts the degree to which view and daylight will be available to building occupants, particularly beyond a narrow 4.57 m (15 ft) perimeter zone. Our assessment is that the trends we are seeing today for highly glazed facades are likely to continue, so a more proactive approach for the “energy efficiency” community is to determine how this design trend can be leveraged to produce better buildings that are also more energy efficient.

Use of dynamic window and daylighting control technologies enable building owners to preserve the design intent (e.g. daylight, view) of a highly glazed building for a greater percentage of the year while reducing energy use and controlling demand. Smarter, more flexible and easily commissionable window and daylighting systems are being developed and are entering the market. The control algorithms, control architecture, and supporting diagnostic tools are also increasing in sophistication. Building owners can look forward to more reliable, reconfigurable systems in the future. Initial measured results from field tests in a mockup of a portion of a major new building that will utilize the integrated, automated shading and daylighting systems are discussed in this paper, illustrating the technical validity of these new performance approaches and benefits.

While building owners are coming to the conclusion that such technologies are desirable, they are finding that there are few supporting market transformation programs that can assist them with specifying and adopting such technologies. One major building owner has directly attacked this problem by building a 401 m^2 (4318 ft^2) mockup and field measurement facility that is documenting the performance of these systems and partnering with manufacturers to improve performance and reduce costs. The field test data will result in a procurement specification and competitive bids for dynamic daylighting and shading systems for a large new corporate headquarters building and may be the first major step in changing traditional cost and performance expectations for these technologies. The architectural trend toward more transparency in building facades is likely to remain with us and perhaps to accelerate, thus adding more urgency to provide cost effective solutions that help manage energy, demand and comfort. Utilities and other energy-efficiency public agencies should leverage these initial results to help move these emerging technologies from one-of-a-kind to mainstream energy-efficiency solutions.

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