Integrating Automated Shading and Smart Glazings with Daylight Controls

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1. INTRODUCTION

Most commercial buildings utilize windows and other glazed envelope components for a variety of reasons. Glass is a key element in the architectural expression of the building and typically provides occupants with a visual connection with the outdoors and daylight to enhance the quality of the indoor environment. But the building skin must serve a crucial function in its role to help maintain proper interior working environments under extremes of external environmental conditions. Exterior temperature conditions vary slowly over a wide range and solar and daylight fluxes can vary very rapidly over a very wide range. The technical problem of controlling 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, fixed control solution 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 a “control logic” must be applied for proper functionality. Traditional manually operated mechanical 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 operate over long periods with minimal maintenance.

This paper explores two classes of emerging solutions for the challenge outlined above. In each case the challenge is how to provide a wide range of performance and comfort with a highly glazed façade. In one case we explore several options based on motorized blinds and roller shade systems and in the other we explore the use of electrochromic glazings. Each study involves both engineering measurements and some exploration of human factors issues. Initial results are presented and the field studies continue with both systems to better understand performance options.

2. Dynamic, Integrated Façade Systems

2.1 Overview of Automated Building Systems

Manual operation of windows or shades might work in home and some small buildings. But in a larger building with many occupants and a 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 reliable automated controls. Such controls will accept inputs from a wide range of building sensors (wired and wireless) as well as anticipatory signals for predicted evening wind and temperature, day ahead utility price signals and next day expected building occupancy. New low cost sensors and controls with communications based on internet protocols have been developed and tested at our lab for motorized blinds and electrochromic windows. Motors, actuators or dynamic coatings must activate reliably in response to control system outputs. Building automation systems will track and display key system performance metrics over time, providing comparison to archived performance data, and employ fault detection and automated diagnostics to correct faults when they are discovered. Finally the best systems would provide building occupant feedback via the web to building operators. In advancing toward this vision we have focused a series of studies over the last decade on the challenge of developing responsive facades that are fully integrated with automated dimmable lighting systems.

2.2 Motorized Blind Systems

Venetian blind systems are well-established technologies for controlling solar gain and glare. Because both the optical properties of the slats and their tilt can be controlled there is a wide range of optical control available. However manually operated blinds are rarely controlled in an optimal manner and when rooms are empty but the heating and cooling systems are operating they may not be operated at all. Motorizing the blinds and adding appropriate sensors and controls is thus an approach that should permit better control of both energy use and comfort, assuming that the proper control strategies can be successfully developed, implemented and maintained. These systems are not commonly available in the U.S., nor are systems that further link to automated lighting controls. Beginning with “off the shelf” components we developed and tested these systems in two identical side by side test rooms in a southeast facing office building in Oakland, CA. (Figure 1) Not only were cooling and lighting energy savings achieved, and peak electrical benefits measured but the resultant automated systems were acceptable to occupants, in a limited occupancy study. Despite the success of the demonstration, the lack of a cost effective system delivered by a single vendor or groups of vendors continues to limit use of such systems.

Figure 1: Smart controls on the automated blind systems (left photo) keep direct sun out of the space, reducing glare and cooling loads. The same hardware system with different control strategies (right photo) admits sunlight to offset heating loads but creates excessive glare.

2.3 Motorized Shade Systems

Roller shade systems are available with fabrics encompassing a wide range of solar optical properties. Although mechanically simpler, the shade systems have more limited optical control than blinds in terms of position, although it is also possible to layer blinds or use variable fabrics. A new field test program is now underway using an automated shade system in conjunction with a high transmittance, all glass façade for the New York Times headquarters building under design for a site in New York City. The 52-story building will utilize fixed exterior shading and fritted glass in some locations but will require shades for sun control and glare control and for thermal and visual comfort as well as energy management. In these tests a 450 square meter testbed was constructed near the site and the southwest corner of the building was reproduced at full scale and fully furnished. Two different shade manufacturers are testing products and two different dimmable lighting systems are also installed, together with different sensors and control strategies. (Figure 2) In addition to energy use, computer screen visibility is being studied to determine the best shade properties and operating strategy. (Figure 2) Testing will be undertaken through mid-2004 to capture the full range of sun conditions.

Figure 2: Interior photos of newly constructed testbed for New York Times building. At left, view toward the west façade, with two different shade systems partially deployed. At right, an instrumentation cluster at a workstation, including illuminance and luminance mapping sensors, and a webcam.

A series of RADIANCE simulations of the space were prepared to explore design and operating issues related to the shade systems and lighting controls. (Figure 3) Detailed optical properties of all interior furnishings were measured. RADIANCE images will allow extension of measured results to other orientations and to account for other site conditions such as adjacent buildings.

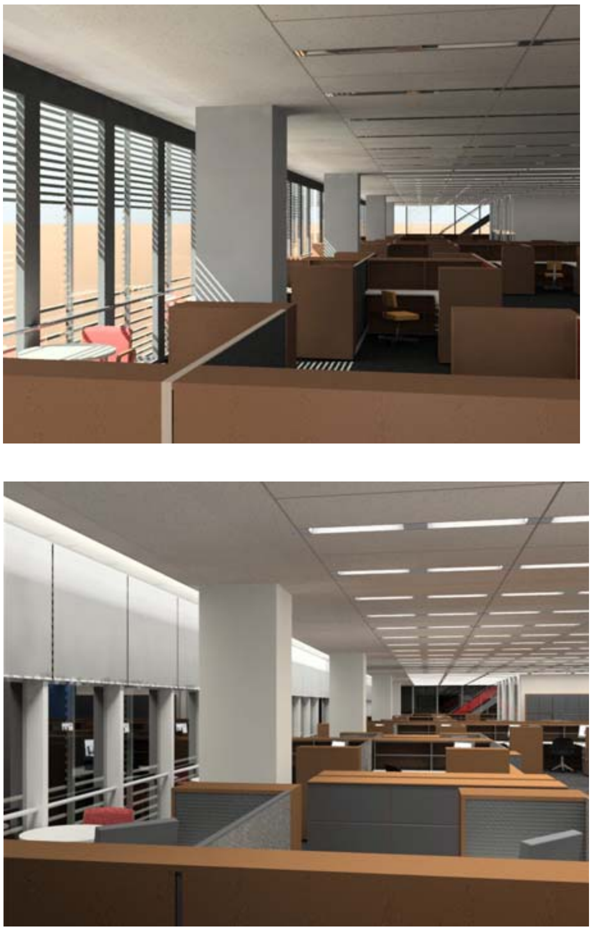

Figure 3: Initial RADIANCE simulations of the west façade of the New York Times building. Left: Without interior automated shading, the exterior ceramic rod shading system is insufficient to control glare on work surfaces. Right: A night view of a more refined image with actual furniture layout, electric lights on, with shades partially deployed.

2.3 Electrochromic "Smart Windows"

Researchers have been developing switchable "smart glazings" for over a decade and the laboratory accomplishments are now beginning to become available for field-testing in larger prototype form. These glazings require low voltage wiring linked to control systems. The actual performance in buildings will be a combination of the intrinsic properties of the materials as well as the operating strategy in the building. These operating strategies must be developed not only for energy and load control but to meet occupant needs in terms of the interior work environment. Field studies in test rooms and mockups are an important adjunct to the extensive computer modeling studies that have already been completed to quantify potential savings.

Following the successful test of the venetian blind systems in the Oakland test building described above in section 2.1, the window systems in the two test rooms were retrofitted with a first generation electrochromic switchable window. The optical system changed from a clear state with a transmittance of 51% to a dark state with a transmission of 11%. The dimmable lighting controls were modified to integrate with the electrochromic switching controls and a variety of control strategies were explored- e.g. minimize lighting, minimize cooling, control glare on computer screen. The system performed well although full switching could take in excess of 15 minutes and the coatings had a noticeable blue tint in the switched mode. When glazings were tested in the “minimize glare” mode the room could become so dark that electric lights were partially on, as shown below. Additional tests were undertaken with the upper row of small windows in a clearer state to admit daylight while the lower windows were darkened for glare control. These results suggest that overall architectural design of the façade is an important element in addition to the control strategies and the properties of the glazing itself.

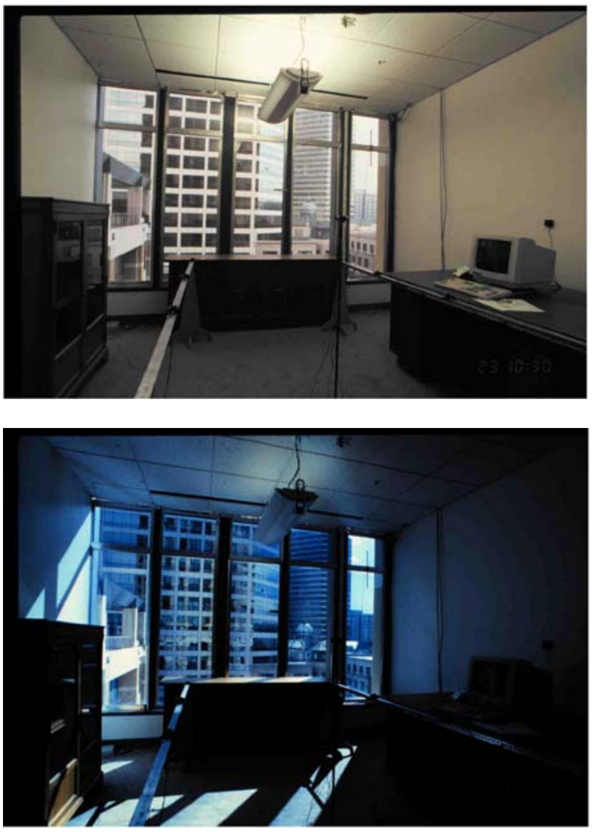

Figure 4: Electrochromic test rooms in Oakland, CA. The room at left is in a clear transmission state on an overcast morning; at right the sun has emerged and the window switches to its darkest state to control glare at the computer workstation.

Field tests in the Oakland building were limited to the orientation of the building and required that the electrochromic glazings be inserted inboard of the existing building glazing which could not be removed.

In 2002 we constructed a new test facility at LBNL with three side-by-side test rooms with unobstructed south views. The entire façade can be replaced. The lighting power and the heating and cooling in each room is individually monitored and the rooms have a full array of illuminance and luminance sensors for monitoring. The rooms have now been fitted with new electrochromic samples over the complete façade as shown in Figure 5. Since the prototypes were of limited size the façade requires 15 glazing panels.

Figure 5: Three sequential views of one test room in the LBNL façade test facility, showing the darkening sequence. The visible transmittance of these prototypes can be switched from 60% to 4% in several minutes.

Engineering tests in the facility are now underway exploring the energy savings achieved with different control strategies. We have also conducted a series of human factors studies to determine desired operating and control parameters of the glazing and lighting systems and to better understand the human factors issues associated with smart control strategies. We plan to explore adaptive controls that will allow the "intelligent systems" to learn the preferences of users thereby improving the acceptability of these dynamic systems.

3.0 Summary

Growing interests in daylighting and sustainable design have led architects in the direction of using highly glazed building facades. In order for these designs to meet their performance objectives they will need to have a degree of consistent active management of solar and daylight transmittance through the building envelope that has rarely been achieved in buildings. Fortunately the technology elements to provide active control of fenestration transmittance and associated control of electric lighting in building interiors are now becoming more available. However it will take better and cheaper hardware, additional exploration of systems integration solutions, new sensors and controls, improved commissioning, a better understanding of occupant needs and preferences, and better real time, adaptive controls to fully realize the potentials of these emerging technologies. The continuing studies described here are intended to play a role in providing these solutions.

4.0 References

We list references below to results of the studies cited above. Results of work in progress at the New York Times mockup and the Façade test facility at LBNL will be published in the next year.

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2.6 Acknowledgements

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