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Perspectives on Advanced Facades with Dynamic Glazings and Integrated Lighting Controls

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ABSTRACT

There is growing interest in North America on the subject of highly glazed building facades. The concept of a smart, interactive façade is not new – the ability of specific facade systems to work reliably and effectively is a far greater challenge. We have been exploring various dynamic façade systems with integrated lighting and HVAC over the last 10 years. These include automated blind systems as well as emerging electrochromic glazings, both with automated dimmable lighting and smart controls. More recently we have extended this work to include internet-based control of lights, blinds and glazings using low cost chips embedded in fixtures, motors, and glazing controls. As each window and lighting element becomes a node on the internet they can be controlled via the existing building energy management system either from an occupants desktop computer, an on-site facility manager or even from a remote location. Recent experience in California with disruptions in electric supply and costly peak power suggest value for such capabilities. This paper briefly summaries the state of recent work in this field, describing a new facility with three side-by-side test rooms in Berkeley to test new electrochromic window prototypes, and identifies key performance, systems integration and cost issues now being studied. The authors bring a cross section of both North American and European experience to address the many technology, design and business issues involved.

1. Introduction and Background

As we begin the 21st century, "advanced building facades" are attracting the attention of many in the building industry. We use this term broadly to refer to building skins that are highly transparent but provide the required strategies and mechanisms to provide comfortable interior work environments without excessive energy use or adverse environmental impact. The interest in North America is growing rapidly, but in general has followed a trend that seems to have had its origin or at least re-birth in Europe. Carefully designed and well executed highly glazed building facades are intended to provide plentiful daylight indoors, visual connection with the outdoors, solar energy to offset heating needs and fresh air for ventilation purposes, all in a package that makes an appropriate architectural statement and meets the aesthetic needs of the owner and design team, and at "affordable" cost. The creation of highly glazed spaces in buildings is not novel. A history of architectural interest in such spaces and the evolving technologies to produce them would stretch back 150 years to the Crystal Palace and is beyond the scope of this paper but suggests that designers and owners have struggled with the problem for some time. The difficulty in meeting these performance goals in specialized spaces within buildings such as atria and exhibit halls suggests that creating entire buildings in a glass envelope is an even more difficult task. However there are an evolving set of technologies and design strategies that make this undertaking more readily achievable now than in the past, and new technologies now under development should further facilitate these future solutions. In the current generation of design solutions, buildings with “double envelope” facades have attracted the most attention and controversy as well. There are now numerous new buildings that employ such facades and their variants. The actual performance of these systems is unclear, and the profession suffers from a lack of objective, quantifiable data on the field performance of both the design solutions and the technology. Simple observation and word-of-mouth suggests that some solutions are working well but that others do not. Distinguishing between these, and understanding the underlying causal reasons for performance differences, is the challenge.

This paper outlines some of the technical challenges that must be solved to make transparent facades an energy-efficient, environmentally sound market reality in North America and reviews recent work at Lawrence Berkeley National Laboratory (LBNL) that is intended to contribute to this international effort. The U.S. Department of Energy’s (DOE) long-term goal is a new generation of “Zero Energy Buildings”, buildings that use no net annual non-renewable energy. This requires minimizing all existing energy end uses for heating, cooling and lighting, and then providing the remaining energy needs with photovoltaics or other renewables. The current generation of building facades must be vastly improved to meet these challenges. Better tools, design strategies and façade technologies are intended to emerge from our research in support of these DOE goals.

2. Context and Challenge

Building performance is fundamentally characterized by change, short term and long term, anticipated and unexpected. Many aspects of building design are driven by an assessment of projected worst-case conditions and provision of a solution for those conditions. But buildings operate under a very wide range of conditions, both internally and externally. Internal environmental needs vary widely with occupant and tasks. A young office worker with good eyesight reviewing laser printed documents has different visual needs than an older worker with glasses at a computer terminal beside a window. The preferred thermal environment varies among workers over a range of humidity, temperature and airflow. But some of the largest and often uncontrolled changes have as their origin the external world – temperature, sunlight, wind, and moisture. A façade system must respond dynamically over a very wide range of these conditions in a manner that meets numerous occupant and owner needs. The building envelope and its support systems must control interior daylight and sunlight and associated temperatures over a relatively narrow indoor range while the exterior variation is enormous, spanning from darkness to direct sun; and controlling temperatures that range from –40C to +50C. There is no static façade solution that can be optimized to provide good results at all times. One classic architectural response has been a well-insulated façade with minimal fenestration in which the glazing properties are a small contributor to total impacts. But this is no longer the case with the new generation of highly glazed building facades.

The only workable solution in such a situation is the use of “dynamic” façade systems whose properties can be actively controlled to achieve the desired operating properties in response to changing indoor and outdoor conditions. Furthermore since the façade systems will be more complex than existing static products, and since many new buildings also have more stringent requirements for security the facades introduce a new level of required integration with the rest of the building. In the best of the new solutions the facades play multiple roles throughout much of the occupied building in providing natural ventilation, daylight and thermal tempering. But this requires a degree of integration, beginning early in the design process, that is the exception, not the norm today. It also suggests levels of technology integration that are not routinely practiced in buildings, although they are consistently achieved in other manufacturing endeavours such as the automotive and aircraft industries. Finally it suggests the need for integration across the stages of the building life cycle, so that design intent is properly implemented during commissioning, and so building operators can effectively manage the commissioned systems over time as building use profiles change. To add to the difficulty these solutions will likely cost more than traditional solutions, at least for first cost, and in the risk averse, cost-conscious building industry this always presents a challenge.

“Advanced facades” today are characterized by three key features: systems integration, dynamic operation, and changing life-cycle performance issues. To better understand how facades can meet these challenges our work has raised a number of issues that are now being addressed by researchers and industry throughout the world. These are outlined below, with a brief description of our current work in each of these areas.

3. Challenges and Opportunities for Dynamic Façade Systems

a. Advanced facades require greater first cost investment in hardware and façade technology, some of which may be offset elsewhere in the building

In the majority of cases the additional technology needed to provide new levels of dynamic control will add to the first cost compared to a base case building. In some cases portions of this increased first cost will be offset by other design changes, e.g. smart glazings could allow smaller chillers or elimination of conventional blinds or shades. Modelling studies suggest these values could lie in the range of \$3-\$15/m^2 but field data are sparse. These offsets involve more than engineering calculations. Rightsizing a chiller system or eliminating it entirely requires risk assessment on the part of the engineer that the operation of the building by the owner for years to come will follow original design intent. The U.S. General Services Administration is now building an office building in San Francisco without mechanical cooling on many of its floors, using cross ventilation at night from automated, operable windows. This was only possible with substantial additional design and analysis, and from a motivated and knowledgeable client. **[1]** There are also operating cost savings, e.g. energy savings, as well that will partially or fully amortize the added first cost over longer time periods. Future credits for demand response and time-variable pricing of electricity as well as carbon emissions could all add to the owners’ annual benefits from buildings with advanced facades.

b. Advanced facades will require enhanced automation and better sensors and controls for optimal operations

In a small building with a few occupants the opening of a window or lowering of a shade might be done by the occupant based on a sense of the needs of the space. In a larger building with many occupants and a 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 with communications based on internet protocols have been developed and tested at our lab for motorized blinds and electrochromic windows. **[2]** Motors, actuators or dynamic coatings must activate reliably in response to control system outputs. **[3,9]** Building automation systems will provide enhanced software that tracks key system performance metrics over time, comparison to archived past performance data, fault detection and automated diagnostics to correct faults when they are discovered. Some of these services may be delivered remotely over the internet. Since the skills to operate such systems are not cheap a new paradigm of providing expert operators with control over many buildings at a central location makes sense if the two-way communications and controls provides the data and feedback necessary**.** Our work also extends to involving building occupants directly into providing feedback via the web to building operators.

c. Design of advanced facades will require better simulation and design tools, better ways of organizing the design team around the goals and better tools for commissioning and building operations

Traditional design of simple façade systems is based on minimal use of simulation tools primarily for peak load estimates. Dynamic systems that are responsive and properly sized for all expected operating conditions must be studied under these diverse conditions. The ability to create and model a “virtual building” and explore its operational modes with different glass façade controls is a major objective of new long term research work. Increasingly the facades are being linked to building ventilation systems, both natural and mechanical, to provide some or all of the fresh air and thermal comfort. This requires a new degree of tool integration so that thermal interactions of facades are properly considered in whole building energy modelling. **[9]**

Better tools for modelling all aspects of complex, dynamic facades are now being developed and should be available over the next few years. In the U.S. the WINDOW/THERM/Optics suite of tools is being extended to model more optically complex glazings. **[4]** Radiance already does a good job of modelling light in complex spaces but new improvements are underway as part of IEA task 31 so that Radiance can better model more complex glazing materials. **[5]** The primary building energy simulation tool in the US is DOE-2, developed over 20 years ago. This is now being replaced by a new and more powerful whole building simulation tool, EnergyPlus, with numerous new features such as thermal comfort, moisture adsorption, etc. A companion tool, SPARK, also allows complex HVAC systems and control algorithms to be modeled. **[6]** EnergyPlus is now linked to COMIS for multizone air movement and links to CFD tools are also being explored. The long-term goal is a suite of tools that shares the same building data model and facilitates exploration of virtually any design, from schematics to design development, and even through commissioning and operations of the systems. The underlying building data model from the International Alliance for Interoperability is well developed but must be extended further to meet specific façade modelling needs**. [7]**

d. Technological Innovation will improve performance and reduce costs

Although glass and operable shading systems have been part of buildings for many years continued innovation drives progress towards meeting new performance goals more effectively and more economically. Innovations over the last 20 years have reduced the overall U value of best-available glazing from about 3 W/m^2-C to about 1W/m^2-C with future potential to fall to .6. Highly spectrally-selective glazings transmit nearly all visible but reflect most of the near-infrared radiation in sunlight that contributes to excessive cooling loads. Motorized shades, blinds and louvers use improved motors, controllers, sensors, and wired and wireless networks. There is a renewed push toward smart glazings, with coatings that dynamically change from clear to absorbing or reflective to reduce solar gain and control glare, a crucial function in an office environment. Delivering dynamic, responsive control of solar gain and glare, but permitting daylight use, is still the holy grail of façade technology. The emerging generation of electrochromic glazings has the best chance of providing these capabilities in the years ahead. R&D is focused now not only on development of better, cheaper coatings with improved durability and greater dynamic range but also on the systems integration issues that will allow maximum energy and non-energy benefits to be achieved**. [8. 9]** A new three-room field test facility has just been opened at LBNL to evaluate these systems solutions and directly measure engineering performance data as well as occupant response to the systems. The research is aimed at creating heightened interest in "plug and play" technologies so that smart glass, dimmable lighting and other systems elements work seamlessly as a system without conflicts.

e. Field testing of design concepts and technologies plays a crucial role in understanding and validating system performance

In an ideal world with perfect modelling tools one could move with confidence from tool predictions to construction of the building and then occupancy. In the real world it is useful to explore issues, options and solutions in a testbed or mock-up whenever feasible prior to completing construction documents or pouring concrete for a real building. Mock-ups and test rooms can be expensive but provide levels of performance detail that are currently unattainable any other way. For system integration studies they are essential tools for studying and understanding complex systems where the performance of some parts depends on the performance of all other parts and systems. Testbed studies can accommodate human factors experiments in the spaces as well as engineering optimization studies, and they provide invaluable data that should be immediately useful to other owners, designers and manufacturers of façade systems. Over the past 5 years LBNL has examined automated blinds and electrochromics in test rooms in buildings in California with an emphasis on the integration of solar control, glare control and daylight dimming. **[8,9]** New studies will continue this work at the LBNL test facility, and near New York City in an outdoor mock-up of a major new office building with an all glass façade, exterior fixed shading and interior automated blinds and dimmable lighting.

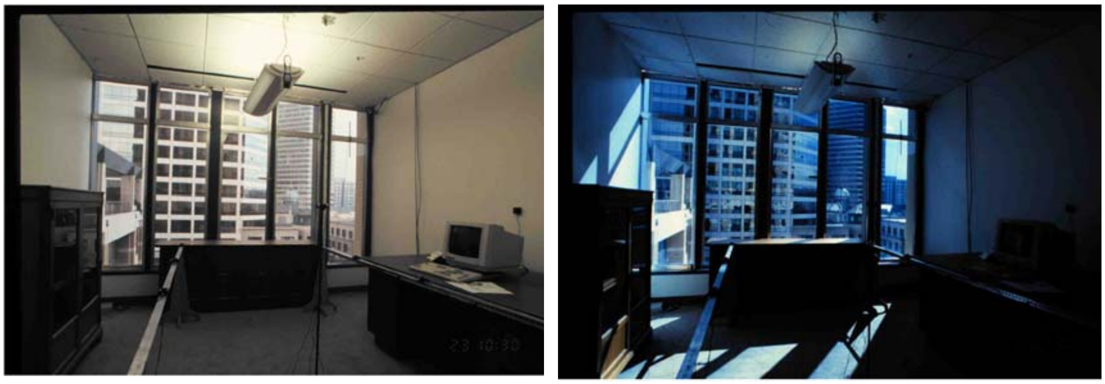

Figure 2. Interior view of test room on partly cloudy day at Oakland Federal Building. The electrochromic windows are in the clear state under diffuse light conditions (left). When sun enters the window, they switch to their fully colored state (right)

f. The performance of buildings and their infrastructure systems will be more intimately linked to the electric grid.

Several years ago California experienced electricity shortages and more recently the northeast part of the country experience a massive power outage. California is beginning to provide economic incentives for customers to adopt smarter building control strategies that are responsive to real time price signals from the electric grid. With proposed critical peak pricing programs in California, for 15 to 30 hours per year, with day-ahead notice, electric prices will rise ten-fold, with offsetting reductions during non- peak periods. Buildings with smart, responsive controls that can minimize electric use but maximize productivity and comfort can benefit from these new rates. [9] The challenge for facades is to make the critical engineering tradeoffs between cooling and lighting use, while accommodating thermal comfort, glare and satisfaction of users. Responsive systems that are put in place for such price-responsive rates structures would also function well during emergencies caused by natural or man-made disasters or disruptions.

g. Human factors issues will influence design solutions

In the process of optimizing building design there is sometimes a tendency to forget that (most) buildings exist to house the activities of people and must therefore accommodate their needs as well as their wants and perhaps even their whims. These vary somewhat because human physiology varies but there are also preferences and desires that may be harder to understand and design for. Extreme conditions, e.g. high levels of glare or high mean radiant temperatures, can clearly have a quantifiable impact on some people. Some aspects of occupant satisfaction and preferences can be effectively assessed but others remain elusive. The single largest annual economic impact in buildings is the salary of occupants. Ultimately the impact of the façade on overall productivity is probably quantifiable under some conditions but not within the useful limits at the current time.

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