DAYLIGHTING THE NEW YORK TIMES HEADQUARTERS BUILDING

FINAL REPORT 06-05
JUNE 2005

NEW YORK STATE
ENERGY RESEARCH AND
DEVELOPMENT AUTHORITY

NYSERDA

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New York State Energy Research
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17 Columbia Circle
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toll free: 1 (866) NYSERDA
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fax: (518) 862-1091

info@nyserda.org
www.nyserda.org

Daylighting the New York Times Headquarters Building

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DAYLIGHTING THE NEW YORK TIMES HEADQUARTERS BUILDING
Final Report

Prepared for

THE NEW YORK STATE ENERGY RESEARCH AND DEVELOPMENT AUTHORITY
Albany, NY

Marsha Walton, Project Manager

Prepared by

LAWRENCE BERKELEY NATIONAL LABORATORY
Berkeley, CA

Eleanor S. Lee, Stephen Selkowitz, Robert Clear, Mehlika Inanici, Vorapat Inkarojrit, Judy Lai

In collaboration with

THE NEW YORK TIMES COMPANY
New York, NY

Glenn D. Hughes, Director of Construction

ANYHERE SOFTWARE
Berkeley, CA

Greg Ward, President

INSTITUTE OF ENERGY AND SUSTAINABLE DEVELOPMENT
DE MONTFORT UNIVERSITY, THE GATEWAY, LEICESTER, UK

John Mardaljevic, Senior Research Fellow

Project Co-Sponsors

U.S. DEPARTMENT OF ENERGY
Washington D.C.

Marc LaFrance, Program Manager

CALIFORNIA ENERGY COMMISSION
PUBLIC INTEREST ENERGY RESEARCH PROGRAM
Sacramento, CA

Chris Scruton and Martha Brook, Contract Managers

7827
LBNL-57602

June 30, 2005

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ABSTRACT

The technical energy-savings potential for smart integrated window-daylighting systems is excellent and can yield significant reductions in US commercial building energy use if adopted by a significant percentage of the market. However, conventional automated shades and daylighting controls have been commercially available for over two decades with less than 1-2% market penetration in the US. As with all innovations, the problem with accelerating market adoption is one of decreasing risk. 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? In their effort to create an environment that "enhances the way we work" in their new 139 km^2 (1.5 Mft^2) headquarters building in downtown Manhattan, The New York Times employed a unique approach to create a competitive marketplace for daylighting systems. A monitored field test formed the strategic cornerstone for accelerating an industry response to the building owners' challenge to a sleepy market (i.e., US automated shading and daylighting control products have had few major technical advances over the past 10 years). Energy, control system, and environmental quality performance of commercially-available automated roller shade and daylighting control systems were evaluated. Procurement specifications were produced. Bids were received that met The Times cost-effective criteria. The Times will proceed with the use of these systems in their final building. Competitively-priced new products have been developed as a result of this research and are now available on the market.

Key words:
Daylighting, automated window shades, automated daylighting controls, energy-efficiency, visual comfort.

ACKNOWLEDGMENTS

This work was supported by the New York State Energy Research and Development Authority, with additional cost shared support from the California Energy Commission through its Public Interest Energy Research Program, and by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, State and Community Programs, Office of Building Research and Standards of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

We are indebted to Glenn Hughes, Director of Construction/ Real Estate, David Thurm, Chief Information Officer, and Hussain Ali-Khan, Vice President, Real Estate Development at The New York Times for their generous support and dedication to this collaborative effort. We are also indebted to our industry partners whose patience, hard work, and collaborative spirit proved their dedication to this project's objective of transforming the market. Industry partners included Stuart Berjansky from Advance Transformer Company, Dragan Veskovic, Pekka Hakkarainen, and Jim Moan from Lutron Electronics, Inc., Joel Berman, Jan Berman, Steve Hebeisen, and Alex Greenspan from MechoShade Systems, Inc, and Hans-Joachim Langels, Gary Marciniak, Dan Jablon, J. Marcelo Banderas, and Chris Lesnik from Siemens Building Technologies, Inc. The architectural-engineering team included Robin Klehr Avia, Ed Wood, Rocco Giannetti, Tom Lanzelotti, EJ Lee, Tiana Robinson, Robert Fuller, Patricia Aponte, and Susana Su from Gensler, Bernard Plattner from Renzo Piano Building Workshop, Bruce Fowle and Dan Kaplan from Fox and Fowle Architects, Susan Brady and Attila Uysal from SBLD Studio, Inc., Fred Holdorf, Lenny Zimmermann, David Cooper, Eric Mitchell, Cheryl Massie, and Joselito Espina from Flack + Kurtz, Peter Mead from Turner Construction, John Forster from Gardiner & Theobald, and John Hassett from Constantin Walsh-Lowe, LLC. Finally, we would like to thank our LBNL colleagues: Dennis DiBartolomeo, Daniel Fuller, Chad Howdy Goudey, Steve Johnson, Sila Kiliccote, Christian Kohler, Steve Marsh, Robin Mitchell, Francis Rubinstein, Duo Wang, and Mehry Yazdanian.

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The technical energy-savings potential for smart integrated window-daylighting systems is promising and can yield significant reductions in New York commercial building energy use and electrical demand if adopted by a significant percentage of the market. However, although conventional automated shades and daylighting controls have been commercially available for over two decades, they have achieved less than 1-2% market penetration in the US. As with all innovations, the problem with accelerating market adoption of new technologies and systems is one of decreasing cost and risk. As the building owner researches technology and system options, the usual questions surface that concern the purchase of any new product or system: how will it work for my application, are the vendor claims valid, what risks are incurred, how do I integrate all the system elements, and will the performance benefits be sustained over the life of the installation?

In their effort to create an environment that "enhances the way we work" in their new 139,000 m^2 (1.5 Mft^2) headquarters building in downtown Manhattan, The New York Times employed a unique approach to create a competitive marketplace for daylighting systems and to understand and reduce the risks associated with innovative technologies. A monitored field test in a 401 m^2 (4318 ft^2) daylighting mockup formed the strategic cornerstone for accelerating an industry response to the building owners' challenge to a sleepy market. Energy, control system, and environmental quality performance of several commercially-available automated roller shade and daylighting control systems were evaluated in the daylighting mockup from solstice to solstice for six months. Procurement specifications were then produced as a result of the lessons learned by The Times at the daylighting mockup. Competitive bids were received that met The Times' cost-effective criteria. The Times is proceeding with the use of these systems in their building, now under construction. New competitively priced systems with improved performance capabilities have been developed as a result of this research and are now available on the market.

This report provides a detailed third-party assessment of the performance of these systems under real sun and sky conditions over a nine-month test period. Supplementary Radiance visualization simulations were used to explore alternate design options. An occupant survey was also administered at the daylighting mockup to 53 office workers to evaluate their subjective appraisal of the quality of the interior environment. These data were presented at interim stages to the building owner and were used to provide feedback to the industry partners who were demonstrating their systems in the daylighting mockup. The system design and functionality evolved to address problems that arose in the field or to add new features that would enhance user acceptance or the quality of the interior environment. After the completion of the six-month study, the vendors were encouraged to continue testing and developing their systems for an

additional three months prior to selection of the final manufacturers via a competitive performance specification.

Two types of daylighting control systems were installed: one in the north zone of the daylighting mockup (Area A) which was daylit primarily by west facing windows and one in the south zone (Area B) which was daylit by both west-facing and south-facing windows. Both systems provided continuous dimming of T8 lamps (T5 lamps were later specified) over a 35-100% power range. The lights were switched off if there was sufficient daylight to meet the design setpoint of 510 lux. Due to the unique façade design with partial exterior shading, transparent floor-to-ceiling clear glass (visible transmittance was 0.75), and low-height interior furnishings, average daily lighting energy savings in Area A were 30% at 3.35 m (11 ft) from the window and 5-10% at 4.57-9.14 m (15-25 ft) from the window compared to a non-daylit reference case. In Area B, these savings were 50-60% and 25-40% for the same distances, respectively, given a bilateral daylit condition. HVAC energy use was not monitored or simulated – the focus of the monitoring was on lighting energy use savings due to the complexities of accurately monitoring thermal loads given an innovative underfloor-air distribution system.[1] Both lighting systems, after some period of commissioning, performed reliably: work plane illuminance levels were maintained above 90% of the maximum fluorescent illuminance level for 100% and 98% of the day on average in Areas A and B, respectively. The DALI-EIB protocol control system in Area B exhibited faulty behavior (erratic on, off, or loss of proper zone assignment throughout the test period) that remains unexplained.

Two types of automated roller shades were installed. Both systems met their respective design intent expectations. In Area A, the shade control system was designed to balance window glare, daylight, and view requirements and was able to deliver a tunable system that satisfied the building owner's desire for daylight, a bright interior, and view while addressing window glare. The dc motorized operations were quiet, smooth and provided accurate lower edge alignment over the nine-month test period in Area A. In Area B, the shade control system was designed to block direct sun penetration to a specified depth from the window wall and accomplished this goal well throughout the duration of the test. In the latter three-month test period, Area B's manufacturer began development of new control algorithms to control window brightness and results of this development work are included in this report. The ac-motorized operations exhibited more mechanical problems initially due to improper installation of the system at the ceiling header – these were explained and fixed in short order. Neither system exhibited undesirable control hysteresis. Both systems will require further work to better address visual comfort requirements.

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[1] Despite the floor-to-ceiling windows, the effective solar heat gain coefficient (SHGC) of the façade system was competitive with smaller sized windows. The center-of-glass SHGC of the spectrally-selective low-e insulating glass units was 0.39. With the exterior shading provided by the ceramic tubes and the reliable control of direct sun by the interior shades, the effective SHGC of the façade was significantly less than 0.39.

The visual environment was evaluated in detail in terms of lighting quantity and quality. For the main viewing direction toward the east (facing away from the window) in Area A, occupants will be visually comfortable performing computer-based visual display terminal (VDT) tasks for the majority of the day throughout the year, particularly if the shades are controlled for glare. The new commercially available low-reflectance, high-brightness liquid crystal display (LCD) flat-screen monitors were used in this evaluation. The average west window luminance was consistently maintained below 2000 cd/m^2 by the automated shade control for the majority of the day (maximum of 54 min in a day when this limit was exceeded). With the shade operating, average daily total (daylight + electric light) illuminance levels were within ~800-1200 lux at a distance of 3.35 m (11 ft) from the window wall. Unobstructed outdoor view (i.e., shade retracted above vision level) was available for at least 65% of the day. With Area B's control strategy of limiting direct sun penetration to 0.91 m (3 ft) from the window wall, the performance in Area B on the west façade was nearly comparable to that in Area A. Luminance ratios were maintained to acceptable levels for the majority of the day throughout the year for the east viewing direction and for tasks involving the VDT. The average west window wall luminance was maintained below 2000 cd/m^2 for the majority of the period (maximum of 71 min in a day when this limit was exceeded). View was available for at least 75% of the day.

In the south zone within Area B with the strategy of limiting direct sun penetration, the shading system did not provide consistently acceptable comfort conditions. This was due primarily to the lack of shade closure when the south window wall luminance levels were high even when there was no direct sun. Occupants performing VDT tasks with the south window in the field of view will experience glare because the luminance ratio limit of 1:10 between the VDT and south window was exceeded for a significant percentage of the day (>40% of the day throughout the monitored period). South window luminance levels exceeded 2000 cd/m^2 for the majority of the day (>200 minutes per day). Direct sun and glare control is clearly needed on the south façade to achieve comfortable conditions. In both Areas A and B, the direct orb of the sun will cause visual discomfort and disability glare when directly viewed by the occupant even when the 3%-open fabric roller shade is down.

The findings derived from the monitored data were supported by the subjective appraisals conducted on 53 subjects. With automated control, glare from windows reached the "uncomfortable" level when luminances in the space became high. Monitored data showed that the occupants manually overrode the control system to lower the shade a significant fraction (30%) of the time. This was much more likely to occur at relatively low exterior light levels than at high exterior light levels. It was also far more likely to occur when people spent a significant fraction of their time in meetings in the open plan area. There was a distinct trend for increased glare from electric lights for work stations farthest from the west window. There was a noticeable increase in difficulty in reading computer screens adjacent to the window, and, consistent with the trend in glare from electric lighting, farthest from the window. The problem nearest the window is presumably due to glare from the windows themselves, while the problem in readability farthest from the windows is presumably due to glare from the electric lighting. A higher density shade and modifications to the control algorithm were recommended.

A second phase of work was conducted in order to provide timely engineering data to the selected manufacturers. Radiance visualization simulations were conducted on typical floors of the Headquarters building in its urban context and data resulting from these simulations were used to assist with specifying fabric type, photosensor locations, and shading and lighting control zones on the shop drawings that were issued in the Spring of 2005. Shadow studies provided detailed information on how the complex urban obstructions surrounding the 52-story tower and podium would shade the various facades of the new building at different floor levels. This information was used to define shade and lighting control zones. Illuminance data were provided to give the lighting controls manufacturer an idea of how the distribution of daylight across typical floors of the headquarters tower changed over the course of typical solstice and equinox days. Photosensor and desk illuminance data were also provided to help the manufacturer characterize the correlations between the ceiling-mounted photosensor response and work plane illuminance thus optimizing sensor placement and zoning. Time-lapse images were produced to help the building owner and manufacturers understand the visual comfort and quality of the space from various viewpoints. Annualized Radiance simulations were also conducted to quantify window luminance and illuminance frequencies resulting from various control algorithms. This information was used by the manufacturer and building owner to assist in making their fabric selection for various facades and floors of the new building.

Over 600 architects, engineers and building owners toured the mockup and were able to experience the integrated daylighting solution. Broader outreach to the New York A/E community was made via a comprehensive project website, presentations at Lightfair and press articles. The performance specifications were published to assist other New York owners in following the pathway set by the Times. Even in this early phase of the work the project has stimulated new interest in these daylighting solutions and their potential for energy savings and demand reductions in New York buildings. An additional phase of work is planned that will develop commissioning procedures for automated shade and daylighting control systems in the newly constructed building.

Section 1
INTRODUCTION

Energy use in commercial buildings continues to grow despite progress with improved building technologies, voluntary efficiency programs and more stringent building codes. Electricity use and electric demand are critical national and state issues, and can be particularly important in specific areas such as New York City where the ability to provide new power generating capacity to meet growing demand is limited. Energy efficiency and demand reduction strategies that reduce end use requirements are both important elements in New York State's efforts to maintain reliability of the electric grid and reduce customer bills for electricity. Within commercial buildings, electric lighting and cooling represent two of the largest electric end uses. Strategies that reduce these end uses will thus provide benefits to building owners and to State efforts to provide reliable supplies. Daylighting strategies that manage solar gain and glare while providing adequate interior daylight to dim or turn off electric lighting are thus key approaches to reducing lighting and cooling loads. These strategies must be carefully integrated so that both cooling and lighting are minimized. Furthermore they must be designed and implemented in a manner that is affordable to the owners and provides reliable long term benefits in order for owners to make the required initial investments. Daylighting strategies in the form of dynamic envelope and lighting systems can provide the needed savings but these systems are rarely specified and used today for a number of reasons. Research studies in the recent past have established the technical capabilities of these systems but many practical obstacles remain slowing widespread adoption and routine use of these approaches.

The Lawrence Berkeley National Laboratory (LBNL) has been advocating dynamic envelope and lighting systems over the past decade. In a four-year project supported by the California Institute for Energy Efficiency, automated Venetian blinds and daylighting controls were integrated together to form an integrated dynamic system. This system was an off-the-shelf precursor to the switchable electrochromic windows under laboratory development at the time and allowed us to play with proof-of-concept prototypes, test its performance under real sun and sky conditions, and evaluate its energy savings potential as well occupant acceptance and satisfaction with the technology and resultant environment [Lee et al. 1998]. Recently, LBNL progressed to similar field tests using large-area electrochromic windows with daylighting controls to prove similar concepts and performance [Lee et al. 2006]. These smart window and lighting systems may advance us toward the goal of net zero energy buildings through real time management of solar heat gains and daylight. The systems also enable building owners to achieve flexible real-time load management of two of the largest end uses in commercial buildings, air-conditioning and lighting, which will prove to be useful for demand response programs designed to improve grid reliability. Comfort and amenity can also be improved. Similar activities have been conducted or are underway in research institutions across the world using either macroscopic devices such as louvers and shades (including double-envelope systems) or microscopic coatings on glass (i.e., electrochromic, gasochromic, thermochromic glazings) [Compagno 1999, Lee et al. 2002].

These studies show that the technical energy-efficiency potential for smart integrated window-daylighting systems is promising and can yield significant reductions in US commercial building energy use if adopted by a significant percentage of the market. However, conventional automated shades and daylighting controls have been commercially available for over two decades with less than 1-2% market penetration in the US. So we must ask ourselves what is the market-achievable energy savings for these technologies? Daylighting technologies face significant first-cost and non-economic barriers, unlike prior drop-in replacement technologies such as the successful low-E windows and electronic ballasts of the 1980s, which now enjoy 40-50% market share. Energy costs represent approximately 1% of the total commercial building annual operating expense and these costs are typically passed through to the tenant. Building owners invest in measures that yield the highest rates of return. With a payback of 10+ years given the initial cost of these emerging technologies (with mature and lower cost products, payback time decreases), these technologies are unlikely to be adopted based on savings on energy costs alone. The added value, non-energy benefits can be used by early adopters/ building owners to justify such investments. We would argue that these added-value benefits are now becoming more relevant in a competitive real estate market due to the movement toward and market recognition of sustainable building design. Not only are reductions in energy use, peak demand, and reduced HVAC capacity relevant, improved environmental quality, comfort, and health are increasingly capturing the attention of building owners and facility managers.

In today's market, daylighting appears to be enjoying a comeback. After the 1980's architectural trends towards using "dark" tinted or reflective glazing to control solar heat gains and the availability of competitively priced, clearer, more transparent spectrally selective low-E windows, architects are now enjoying the freedom of being able to specify large-area clear windows without the penalties of solar heat gains. The design aesthetic of the EU landmark status double-envelope buildings constructed in the 1990s has migrated to the US. These façade designs are more open and communicative to the urban environment and are purported to counter some of the maladies of the 1980s and 1990s – sick building syndrome, seasonal affective disorder, etc. – by providing plentiful daylight, view connection to the outdoors, and natural ventilation. Technological advances in computer monitors also enable the interior daylight levels to be raised without reduction in task visibility. Digital control systems are more robust enabling more reliable real-time optimization of environmental controls.

As with all innovations, the problem with accelerating market adoption is of decreasing risk. Most building owners and A/E teams are risk averse and don't want to be the first to adopt a new technology. 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 the adoption rate of innovative technologies. In the case of daylighting controls, the technology has been on the market but due to historical failures and high cost, lighting designers avoid suggesting such systems to their clients. With commercially-available automated shading systems, the same can be said: the few anecdotal case studies available in the US have indicated that there was occupant dissatisfaction and rejection of the system. In general, there is considerable uncertainty over the performance of innovative systems. Inadequate simulation tools lead to incorrect conclusions on the overall benefits of such systems. The design team must determine if such systems increase cooling, visual discomfort, occupant dissatisfaction, or have other unknown impacts. High first costs and commissioning costs are major deterrents.

Monitored field tests on emerging technologies help to provide such information to end users thus reducing risk. Other mechanisms can be used jointly with field tests to reduce cost. In support and in parallel with the US Department of Energy's (DOE) activity toward developing innovative technologies, other US public agencies that advocate energy efficiency also promote technological innovation in building science for the purposes of reducing global climate change, achieving independence from foreign oil sources, improving grid reliability, and postponing the expansion of conventional generation capabilities. The "loading order" for California, New York, and the Pacific Northwest is energy efficiency as the first priority, renewable energy, then conventional generation as a means to meet the growing demand for energy use in the years to come [Peevy 2004]. Many of the "emerging" technologies programs supported by these public agencies are not focused on developing the basic innovative technology like DOE, rather bridging the gap between innovation and commercialization. The main objective of these programs is to transform the market for emerging technologies so that energy-efficient products become the norm. Interventions used to get technologies to market include R&D support (using a venture capitalist model for funding innovators), putting a competitive market in place, documenting and demonstrating that the technology works and generates energy savings in real world applications, providing field demonstration support so that third party performance data are made available, and providing technology subsidies, consumer education, technology training, technological assistance, etc. in support of deployment. Among these programs, the New York State Energy and Research and Development Authority (NYSERDA) promotes technological innovation through their R&D product development program which selects project teams using competitive solicitations with a 50% cost-share requirement to share the risk of innovation. The types of technologies they promote are ones that do not require being pushed into the marketplace, rather those that are being demanded in the marketplace. Their most successful value propositions have been those that provide energy savings as well as other benefits [Douglas 2004].

Having seen LBNL's research on dynamic shading and lighting systems, The New York Times approached LBNL for advice. Their new corporate headquarters was designed to promote "transparency" to the public (being a news organization that provided factual information to its customers) via floor-to-ceiling clear glass windows shaded by a unique exterior shading system. Enhancing the way employees work was the key objective, with sustainable building design as a second objective. The Times learned on their own devices that some sustainable designs would help them achieve their primary goal since they believed that such designs foster employee (occupant) creativity, productivity, health through the environment of the space and its connectivity to the outdoors.

Sustainable building design was a key objective. To control window glare and promote daylight harvesting, automated roller shades and daylighting controls were under consideration. The slow rate of market adoption has been due primarily to cost barriers but other issues such as system reliability have also impeded their use. The New York Times was willing to consider these technologies but needed third party data to understand the risks associated with the use of such technologies.

The partnership that was subsequently created between the building owner, LBNL, and industry met the requirements of the NYSERDA R&D product development program. The integrated technologies held significant potential for energy-efficiency while adding other amenities of value to commercial building owners. Additional cost-share was provided by DOE and by the California Energy Commission Public Interest Energy Research program. The overall strategy the building owner employed was a good one. To achieve a competitive marketplace, the building owner built a full-scale daylighting mockup and invited two sets of vendors to install their shading and daylighting equipment. This field test formed a key strategic cornerstone for accelerating an industry response to the building owners' challenge to a sleepy market (i.e., US automated shading and daylighting control products have had few major technical advances over the past 10 years). At LightFair 2004, the major US lighting convention, The New York Times issued a challenge to industry in the form of a "big, hairy, audacious goal (BHAG)" (made popular by the Harvard Business Journal [Collins et al. 1994]): 1) there should be no premium for a dimmable system in a commercial office building, 2) lighting control systems need to self-commission, and 3) whoever can do this will own the market. At the same time, the building owner publicized the project garnering interest from many architectural and engineering publications and gave tours of the daylighitng mockup to interested parties, including major building owners and developers in the Manhattan area. At the end of the field test, the building owner incorporated what they learned about each system and created a procurement specification. This procurement specification was let out to eligible manufacturers for competitive bidding. The winning vendors were then invited in a further partnership with the building owner and LBNL to develop, test, and prove the capabilities of their systems in the daylighting mockup prior to installation in the final headquarters building.

This report documents this major R&D effort to accelerate market deployment of automated shading and daylighting control technologies (future activities will be added as an addendum to this report):

Early Design

- **Section 2:** For the purpose of project documentation, the building owner's early rationale and requirements for these technologies are stated prior to working with the actual technologies in the daylighting mockup.
- **Section 3:** Several alternative shade designs and control strategies were explored using the Radiance visualization tool to determine if interior daylight illuminance could be increased over the base case design.

Field Test at the Daylighting Mockup

- **Sections 4-6:** These sections present lighting energy use, control system performance, and visual comfort data that resulted from field monitoring at a full-scale daylighting mockup under real sun and sky conditions over a nine-month period. A whole buildings approach to energy-efficiency is needed to address the dynamic interactions between the building and the environment, among the building's various energy systems, and between the building and the occupant. The discussion focuses on how the dynamic systems were tuned to achieve a good balance between the competing requirements.
- **Section 7:** This section presents the results from a subjective survey conducted on 53 subjects who spent approximately four hours in the daylighting mockup performing their normal work activities in the provided workstations.

Bid and Procurement

- **Section 8:** This section provides the final procurement specifications that were used for bid and award of the largest procurement of automated roller shades and daylighting controls in U.S. history.
- **Section 9:** Pre-shop drawing engineering studies were conducted using the Radiance visualization tool. Data and images were provided to help the lighting controls manufacturer specify zoning and photosensor placement for the daylighting control system. Annualized data were provided to the roller shade manufacturer and building owner to assist them with their decision on the proper types of roller shade fabrics to be used on the various orientations and floors of the final headquarters building.

Outreach Activities

- **Section 10:** Provides information on the types of market transfer activities that occurred to accelerate market adoption of cost-effective daylighting systems.

Section 2
BUILDING OWNER REQUIREMENTS

2.1. INTRODUCTION

This document establishes the owner's early performance requirements for dimmable lighting and automated shading systems and is meant to give other building owners, design teams, and industry a perspective on how a particular commercial building owner investigated technology options and then crafted first drafts of their performance and commissioning specifications.

The requirements were developed through discussions between The Times, their design team, and with the Lawrence Berkeley National Laboratory (LBNL). These requirements include functional performance as well as cost, lifetime, maintenance, and other requirements. This document was written in 2003 before The Times had direct experience gained from working with the technologies. Two years after working with these systems in an outdoor daylighting mockup, many of these questions were resolved or became irrelevant concerns to The Times. However, these initial requirements provide a valuable insight on how an inquiring building owner like The Times can initially have numerous questions about an unknown technology. The final requirements are given in the procurement specifications in Section 8.

2.2. BACKGROUND: BUILDING DESIGN DESCRIPTION

The New York Times Building (Figure 2-1) will run from 40th Street to 41st Street on the east side of Eighth Avenue. The 51-story building will have an unusually large footprint of approximately 7432 m^2 (80,000 ft^2), extending 122 m (400 ft) back from the Avenue. The building is approximately 139 km^2 (1.5 Mft^2), of which The New York Times will occupy approximately 74,322 m^2 (800,000 ft^2) as its new headquarters.

Figure 2-1. Rendering of tower from 8th Avenue looking east. © The New York Times.

The building is composed of two elements: a four story "podium" that extends the full 122 m (400 ft) back from the avenue and a 51-story tower with 2322 m^2 (25,000 ft^2) floor plates that rises from the podium along Eighth Avenue. The large podium floors are ideally suited for the operating style of The New York Times newsroom. On the ground floor there is 2322 m^2 (25,000 ft^2) of retail space and The Times Center, a complex consisting of a 378 seat auditorium distinctively designed with wood walls, floors and ceiling, an ancillary space to support companion events and a retail store for Times' related material.

The building is being designed by Renzo Piano, an internationally distinguished, Pritzker prize winning architect in association with Fox & Fowle, a leading high rise architectural firm based in New York City. As such, this building will be a signature presence in the New York City skyline. In concert with Renzo Piano's design, the interiors are being designed by Gensler, a leading interior design firm. By combining these talents, there will be a unity of design between the interior and exterior of the building.

There are a number of distinctive features in the building. First, there is the formative idea of *transparency*. This structure will stand in marked contrast to the mirrored facades that line the avenues. In place of these lifeless exteriors, The New York Times Building is designed to be transparent, animated by the ever-changing activities within the building. The lobby is designed to be open and inviting, with layers of transparency (Figure 2-2). From Eighth Avenue, one can see through the split elevator core, to a glass enclosed, open-air garden rich with birch trees and moss and then into The Times Center auditorium. This same level of transparency will be evident from 41st and 40th where a vista is available from street to street.

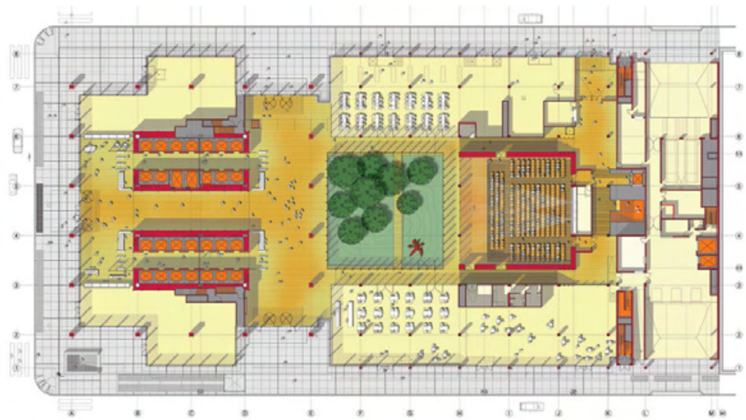
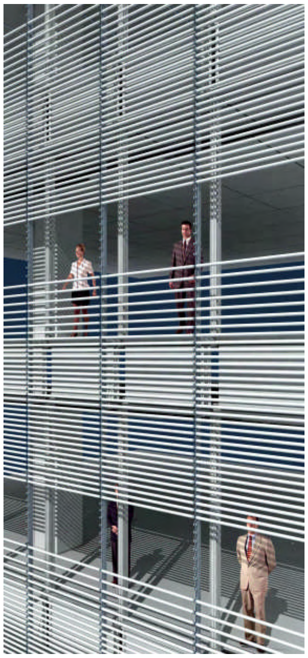


Figure 2-2. Rendering of the first floor of the podium. © The New York Times.

The curtain wall of the building is unique with a double wall (Figure 2-3). The inner wall is floor to ceiling low-iron glass. This high level of light and transparency is made possible by a second, exterior wall: a “lattice work” of ceramic rods that are designed to reflect approximately 50% of the sun's energy. The rods are 1.52 m (5 ft) long and 4.13 cm (1-5/8 inch) in diameter. They are tightly spaced at the spandrel and open as they rise to eye level. The rods allow the inhabitants of the building to have unusually clear views and lots of light. For those enjoying the building from the outside, there is a higher level of animation provided by the clear glass. Moreover, the rods will further animate the building by reflecting the colors of the city. The rods continue past the roofline making the building appear to “dematerialize”. Furthering the design concept that the building should be solidly anchored in the ground with a strong expression of the structure of the steel and should end with the lightness of the dematerializing rods, the building is capped with a mast that rises 91.4 m (300 ft) above the roof.



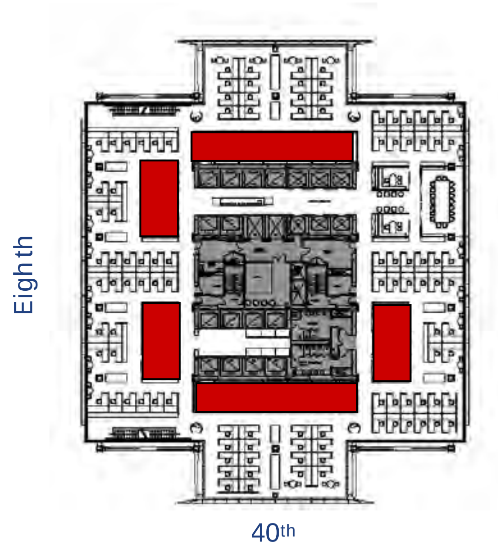


Figure 2-3. Rendering of the curtainwall design (left) and typical floor plan of the 51-storey tower with full-height offices near the core in red (right). © The New York Times.

The activation of the building – for inhabitants and passersby – is further enhanced by the placement of convenience stairs interconnecting all of The Times' floors at the north and south corners along Eighth Avenue (Figure 2-4). It is critical for The Times operation that they enhance communications among employees, and these stairs act as a physical manifestation of this core principle. For passersby, they will see people moving through the building: transparency and animation.

Figure 2-4. Rendering of the convenience stairs. © The New York Times.

The Times is committed to creating a special space for its employee. The cruciform shape of the building not only brings more light into the space, but also gives employees near-panoramic views. For most floors, the open plan is by the windows, with the offices placed against the core. There are higher than customary ceilings with a generous floor-to-ceiling height of 2.92 m (9 ft- 7 in). The height rises to 3.15 m (10 ft- 4 in) in the cove by the windows. Floor-to-ceiling glass is made possible by ceramic rods (exterior shading). The core concept is transparency, animated by activities within the building, open and inviting. Work conditions have guided the design: transparency, flexibility, ease of movement from floor to floor, while privileging the sense of community and guaranteeing the necessary privacy. Put simply, there should be no place where an employee does not see natural light and a view.

2.3. INTERIOR LIGHTING QUALITY ISSUES

From the start of the interior design, The Times insisted on a thorough investigation of daylight harvesting. This was motivated by the belief that natural light would enhance the way The Times works. Also The Times realized that many employees today demand different levels of light than the standard 50 footcandles design being turned out by the lighting design community today. Thus a daylighting study was included in the scope of work for the lighting consultant. The Times also investigated other sources of information on daylighting in buildings using web searches and talking to vendors and experts in the field of daylighting. The design of the interior locates open-plan, low height workstations at the perimeter of the floor plate and enclosed offices in the interior, encircling the center core. This respects and fully coordinates with the idea of *transparency*. This allows natural light to permeate the space by virtue of no walls to block the light. The challenge, indeed the promise of daylighting is to optimize the amount of natural light and to provide a tunable work place to meet employee needs. At the same time, daylighting offers an efficient light source which may aide in the synchronization of the individual’s Circadian rhythm to the local light/dark cycle.

The Times recognized that the highly-transparent curtainwall system could pose problems with glare and thermal comfort. The architect specified low-iron “water white” glass. This high-transmittance glazing (center-of-glass visible transmittance, Tv, is 0.75) combined with the large window area could be a significant source of glare despite the provision of the exterior shading. The Times decided to investigate the use of automated shading to control glare and direct sun in the open plan perimeter zones of their new building. It would also unify the appearance of the façade if all shades for a particular orientation or wing of the building were positioned at the same height.

The initial daylighting study by the lighting designer identified some interesting and difficult issues. In order to tune the work place a dimmable lighting system would be required. Initial inquiries into dimmable ballasts indicated that capital costs would be significantly increased. When coupled with daylight controls, which had little demonstrated operating experience in large commercial buildings and high commissioning costs, the economic viability of a daylight controls scheme was a key issue. Using present cost structures in the lighting industry and present energy costs it was difficult to imagine a reasonable return on investment. However it was clear that not enough information about daylight harvesting was available to prepare real projections of energy savings and it was unclear why dimming came at such a premium in the marketplace.

Once the general decision to investigate automated shading and dimmable lighting was made, the Times put forth the following overall goals for the performance of these technological systems. "To attain a *great working environment* across the wide range of tasks associated with publishing a daily newspaper and managing a large media company. The work environment should be bright, connected to the outdoors through view and daylight, visually comfortable for all tasks including flat-screen visual display terminal (VDT)-based tasks, and thermally comfortable during the winter and summer. Energy-efficiency is an important related goal."

2.4. TASK REQUIREMENTS

The new building will house two principle activities of The Times:

1) Floors 2-7 will house the newsrooms of The Times, where Floors 2-4 overlook the ground-floor garden (in the podium). The work schedule is 18-20 hours per day. Activity starts at 10:00 AM, with maximum activity from 4:00 to 10:00 PM, and ends at approximately 2:00 AM.
2) Floors 8-28 will house other aspects of NYT. The work schedule is normal working hours from 8:00 AM to 6:00 PM. The occupancy in these areas is approximately 50-60% occupancy rate due to off-site meetings. The remaining floors will be leased by The Times development partner to tenants who will probably work normal working hours from 8:00 AM to 6:00 PM.

The majority of The Times departments will conduct conventional office tasks: paper-based reading and writing, phone use, computer use, and face-to-face meetings. There is significant computer use in the building. In the new building, all of the computers will be flat liquid crystal display (non-cathode ray tube (CRT)) screens.

Paper-based reading and writing tasks will be conducted on typical matte paper, not glossy paper such as that of magazines. A small percentage of people will work on The New York Times Magazine, which involves glossy paper. The majority of people work with a normal level of detailed work (sufficiently sized typeface (greater than 10 point) on high-contrast backgrounds). There is minimal work that involves fine detail on low-contrast backgrounds.

There is a wide range of tasks and lighting conditions in the existing building. In the one department, there is exclusive visual display terminal (VDT) use where people take orders for advertisement over the phone – there is no mixed use of VDT and paper-based tasks. In another department, the lights are turned off all day and the punched windows provide very little daylight, particularly because they are shaded by opposing buildings. Illuminance levels may be on the order of 108-215 lux (10-20 fc) in these areas (with occupants that are both young and old). In the newsroom, the window shades are typically drawn, because the occupants are too busy to manage the shades. There are no brightly lit spaces (greater than 538-753 lux or 50-70 fc) in the existing building so there is no precedent set for departments that would prefer more brightly lit work environments.

The current lighting design provides a uniform ambient lighting level of 484-538 lux (45-50 fc) on the horizontal work surface 0.76 m (2.5 ft) above the finished floor. Task lighting will be part of the furniture package. There is presently one type of swing-arm downlight fixture that can be selected by the user. This task light increases the light level to a 1076 lux (100 fc) maximum at the work surface. The visual clutter of floor and pendant fixtures did not meet the Times' design aesthetic.

The Times wished to create a specification where flexible control packages would be developed by the shade and lighting controls manufacturers. These packages would enable illuminance setpoints to be tailored by department or blocks of floors (e.g., 50, 40, 30 fc). They would also accommodate special tasks, zone orientations, and exterior obstructions.

2.5. GENERAL TECHNOLOGY REQUIREMENTS

As with all building owners, The Times defined pragmatic goals for the technologies installed in their building. Specific requirements for the shading and dimmable lighting are given later.

- The proposed solution must be cost-effective. The determination for "cost-effective" includes the capital cost of the product, design and installation costs, commissioning costs, product warranties, expected lifetime of the product, maintenance costs, etc. These costs could be offset by energy savings and other non-energy benefits such as increased worker productivity, if any, due to improved environmental quality (lack of glare and thermal discomfort). (The Times had their own internal methods of determining cost-effectiveness, which are not disclosed publicly in this report.)
- The shading and lighting system must be easily reconfigured when physical changes to the work spaces are made. The system must have the flexibility to accommodate changes in control objectives over the life of the installation.

- System integration between the building management control system, lighting control system, and shading control system is highly desirable. Systems using the same networking and communications protocol are highly desirable. Systems that are capable of working synergistically to achieve optimal building performance are highly desirable.
- The control systems must be designed so that adjustments or maintenance to the system can be done routinely by the facility manager without undue cost and inconvenience or over-reliance on the vendor. Diagnostic information must be easily available to the facility manager including information on hardware failures, commissioning constants, setpoints, control status, etc. Monitored data logging capabilities are highly desirable.
- The system must be reliable over the course of its installed lifetime. The system must achieve its stated control objectives at all times. Commissioning of zones should be accomplished conveniently and routinely using methods that are transparent to the facility manager. For example, commissioning of the lighting system using hand-held wireless devices to map components to their appropriate IP address or tune their sensitivity (gain/ offset values) are highly desirable. Systems that are self-commissioning are highly desirable.

2.6. AUTOMATED SHADING REQUIREMENTS

The following is a list of typical reasons why building owners install interior shades on vertical windows:

- Block direct sun to prevent direct source glare (view of sun disk).
- Control luminance of window and surrounding surfaces to prevent visual discomfort and to ensure VDT visibility.
- Block reflections of sunlight off neighboring buildings to prevent visual discomfort and to ensure VDT visibility.
- Control thermal discomfort due to radiant asymmetry from direct sun on an occupant.
- Control thermal discomfort due to radiant asymmetry due to cold and hot window surface temperature.
- Provide privacy.

Several drawbacks of interior shades are:

- Blocks view.
- Reduces interior brightness.
- Changes architectural aesthetic of the building from open and transparent to closed and non-communicative.

For The Times, glare was the single most important reason for installing automated interior shades. "The lighting environment can be variable over the course of the day. When there is direct sun, the shades can be down and interior lighting level will vary upward from 50 fc. How much depends upon the shade density. When there is no direct sun, the shades will be up and the interior lighting levels may be significantly greater than 50 fc. That's ok. We're not trying to tune the shades all day so as to provide for the same level of light all day long. It's desirable to have variation in light levels over the course of the day since it connects one to the outdoors. There must however be no glare."

However, the Times also did not want a dim lighting environment in a newly constructed building designed to be transparent. The final solution should provide a bright interior environment and maintain connection to the outdoors.

Privacy was not an issue for The Times. The open plan office with low 1.22 m (4 ft) high partitions was designed to promote interaction between occupants and to allow for more natural light in the space. Privacy from the outside was a non-issue – the building design promotes transparency and views to the inside.

The Times acknowledges that not all occupants will be satisfied with the automated system. Some of this dissatisfaction may be reduced by educating the employees as to when and why the shades are operating and when it is acceptable for the employees to override the shade system. The Times will review how the occupant interface is designed and ask the vendors how the user interface has been used in prior installations.

2.6.1. Shade design and material

The Times decided to use an automated roller shade. While there are many examples of installed automated exterior louver systems in Europe and some automated interior louver products, the design aesthetics and practical problems of louvers or Venetian blinds made them unacceptable to the architect and owner.

The Times decided to specify fabric roller shades due to the partial view it affords to the outdoors. The full-scale testbed mock-up was used to determine shade openness. The shade fabric weave must be of sufficient density to block direct sun so that 1) direct source glare from the sun disk does not occur, 2) luminance of the window is sufficiently controlled, and 3) luminance of surrounding surfaces are within acceptable levels. A single fabric type will be used over the full height of the window. Roller shades can be made of different fabrics to improve daylighting. The Times briefly considered this option but discarded it due to the increased cost and added complexity of the system.

The interior and exterior sides of the shades can differ. For example, the shade can be white on the outside and dark gray on the interior. Manufacturers suggested that this minimizes glare and allows a better view out. A white surface on the exterior will reflect solar heat gains. A white surface on the interior can increase interior lighting levels and room brightness.

Different types of shade can be used on the various window orientations. For example, a 5%-open shade can be used on the south, east, and west, while a 7%- to 10%-open shade can be used on the north.

2.6.2. Motorized shade

The Times decided to use a motorized shade on all orientations of the building if the results indicate that the product is cost-effective. Alternatively, The Times will use a non-motorized window shade.

A quiet shade is preferred, but cost is a major factor. Acoustical insulation should be specified in the design when installing the shade motorized unit in the ceiling plenum. A noise level of less than 10 db when operated is desirable.

A smooth, non-jerky motion when the shades are actuated up or down is desirable. The speed of shade movement can be slow or fast. (The speed was be judged at the mockup to determine if it would cause a visual distraction to the occupant.) The shade should take less than 30-60 s to travel from the full height of the window wall in either the upwards or downwards direction.

The Times preferred that all shades along a single façade be positioned to the same height across that façade (46 m, 150 ft width). Where specific conditions will enable more natural light to be enjoyed, then a façade may have shades at different heights in discrete areas. The shade heights should be set to align with physical features of the curtainwall design. The bottom edge of all the shades should be aligned so that there is an unnoticeable difference in height across the 46 m (150 ft) width (e.g., less than a 0.64 cm or 0.25 inch variation in height between shades).

The Times preferred to have individually-motorized shades per window width (the façade is divided into 1.5 m (5 ft) wide glazed sections) if the cost for the motors and associated power and control wiring installation was not prohibitive. Alternatively, shades can be grouped up to the limit specified by the manufacturer. At present, the width is set to a 4.6 m (15 ft) wide group of three 1.5 m (5 ft) wide shades per motor.

2.6.3. Shade operations

The following describes the desired operational characteristics of the shading system defined initially by the Times for the perimeter windows adjacent to the open plan workstations. Operational characteristics for the shades near the interior open staircase are similar since the shading can affect occupant comfort in the open plan areas.

If the vendor offers a product that controls direct sun, then the shade should be positioned so that direct sun penetrates no more than 0.9 m (3 ft) from the window wall during all times of the year. This direct sunlight penetration criterion may vary from 0.9 m (3 ft) in areas where work stations are immediately adjacent to the perimeter and up to 3.05 m (10 ft) in circulation areas adjacent to the interior communicating stairs. The sunlight penetration distance is defined as the horizontal distance measured normal to the exterior face of the glass to the interior at floor level on all orientations of the building. Direct sun is defined as when the sun disk is not obscured by clouds. It is also defined by a distinct contrast between the shadow and light areas on an indoor horizontal plane.

If the vendor offers a product that controls glare, the shade should be lowered when direct source glare from the window exceeds 850 cd/m^2 or when the contrast between task and background exceeds 3:1 or 1:3.

When direct sun or glare occurs, the shade should be activated with minimal delay (less than 1 min). The shade should be activated without significant hysteresis (annoying up and down movements as the sun comes in and out of the clouds under partly-cloudy conditions). For example, when the shade is lowered, the shade must maintain this position for a minimum of 20 min. If the threshold to raise the shade has been met during this time, then the shade can be retracted to its fully-raised position after this delay has been satisfied. The delay to retract the shade should be longer than the delay to extend the shade since it is assumed that the occupant can tolerate less daylight for a longer period than they can tolerate direct sun or glare.

The shade should be fully raised after sunset in order to maximize views and connection with the outdoors. The shade controls should not include occupancy of the floor or zone as a variable. Automatic shade controls should be independent of occupancy.

Users should be able to control individual shades manually using a switch located in the perimeter zone. The switch should allow occupants to set the height of the shade to several (5 minimum) pre-set heights. If manually-activated, the automatic system shall override the manual setting after a specified delay.

If there is shading on some fraction of the window wall due to exterior urban obstructions (e.g., opposing buildings) and not on other portions of the window wall, then the shades should be operated to the same height across the entire window wall based on the unshaded portion of the window wall. This will cause the remainder of the workplace to be dark even though some areas are in direct sun. In this case, the occupant will have the option to override the shade position.

The shade control system should be designed to account for the presence of the exterior ceramic tube shading system. When there are periods when the exterior shading device blocks direct sun, the interior shades should not be lowered unnecessarily to “block” direct sun.

The facility manager should be able to override the automatic control system from a centralized position in the building. This can be in response to occupant complaints or other factors. For example, the facility manager should be able to close the shades in anticipation of a hot day or to respond to time-of-use or other demand-responsive utility rate schedules. During the day, the shade should be retracted in the event of an emergency (e.g., fire), if power is available. A communications plan for informing employees about the shades will be developed.

The facility manager should be able to set different shade control configurations in different zones. The control modes should be able to accommodate different schedules, response rates, setpoints, etc. on different orientations and floors.

2.7. DAYLIGHTING CONTROL REQUIREMENTS

The functional specification for the daylighting control system is comparatively simpler than the shading system. The Times is considering the use of T8 or T5 fluorescent lamps for the ambient lighting in the open plan area of the perimeter zones. Occupancy sensors and lighting controls will be included in The Times specification but are not discussed in this report.

The dimming range of the dimmable ballasts is tied to cost. A dimming range of 1-100% is desirable but may be too expensive. The cost for a dimming range of 10-100% appears to be close to that of 20-100% range. The Times will determine the dimming range based on the results of the mockup field study and cost estimates from the vendors.

There is concern that occupants will complain that the fixtures are not working properly with dimmable lighting. A communications plan for informing employees about the lighting will be developed.

The Times is considering the use of dimmable ballasts across the entire floor to avoid installation errors in the field and to enable tuning to the work requirements of each work group, i.e. the lighting control system must be capable of being defined with different setpoints on different floors or even on specific areas within a floor.

Ceiling-mounted photosensors for daylighting control must be integrated at a special location (face plate) in the lighting fixture for aesthetic purposes. It is desirable for the sensors to self-commission and as a backup the facility manager should be able to independently recommission the daylighting control system using a system or device that does not require his staff to climb up on a ladder or furniture to physically adjust the sensor to control response to available daylight. The facility manager should be able to redefine the configuration of lighting zones at a main system console without rewiring.

Automated dimming in response to available daylight will occur in the open plan office zone. Manual dimming and switching will occur using a wall-mounted dimming switch located in the private offices, situated 7.16 m (23.5 ft) from the window wall. Private offices located adjacent to the window wall will also have a wall-mounted dimming switch. Automated dimming in response to available daylight will also occur in the aisles around the central core.

Manual override of the lighting system will not be provided to individual employees. The lighting design in the space does not lend itself to a one-to-one correspondence between occupant and light fixture(s). Task lights will be provided to offer some measure of individual control at each work place. A communications plan will relay instructions to the employee on how to report complaints about the lighting system.

The Times is interested in digital control of dimmable ballasts for the primary advantage of reconfigurability when there are changes in occupancy over the life of the installation. Also for maintenance since the “intelligence” at the ballast provides ballast and lamp condition analyses reported back to the lighting control system main console. This is an ancillary goal that is achieved if all other points are met.

Section 3

PRE-DESIGN ASSESSMENTSOF SHADING AND LIGHTING OPTIONS USING RADIANCE

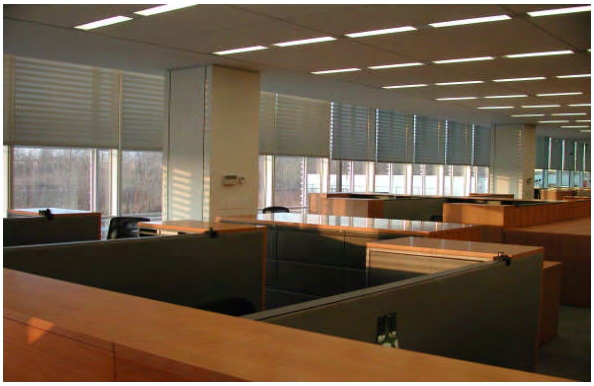
3.1. INTRODUCTION

A series of daylighting simulations were conducted using the Lawrence Berkeley National Laboratory (LBNL) Radiance ray-tracing software. These simulations of the mockup, in conjunction with the field test at the daylighting mockup (see Sections 4-6), were intended to help the building owner visualize and understand the daylighting implications of automated shade design and control system alternatives that were under consideration. There were a number of givens when LBNL entered the discussion (see Section 2). The Times specified that direct sun was to be controlled to within a specified distance from the window wall to avoid occupant thermal and visual discomfort. Window glare was to be controlled. The fabric weave and color were to be determined based on a complex mix of aesthetics and practical concerns.

After a series of discussions, The Times and LBNL identified issues of immediate concern that Radiance simulations were then directed to address: 1) control of the roller shade for glare could cause significant reductions in interior daylight illuminance levels – were there design alternatives that The Times could consider that would enable one to preserve bright interior daylight levels and energy savings while preventing discomfort glare from the large-area window walls, and 2) would these design alternatives degrade daylighting control system reliability. To investigate these issues, a detailed Radiance input description of The Times outdoor daylighting mockup in Queens, New York was constructed. Floor plan views showing work plane illuminance and surface luminance levels were generated for equinox and solstice clear sky and overcast sky conditions. Additional interior views were generated to understand potential sources of visual discomfort or answer questions that developed during the course of the field study. Selected views were generated for The Times and lighting designer to discuss electric lighting design issues. The primary result of the Radiance simulations was a constructive dialog between the building owner, the A/E team, industry, and LBNL using the Radiance images as a means of visualizing and communicating perceptual issues related to the interior environment, which then shaped the detailed decisions made on aspects of the automated shading system.

3.2. METHOD

The Radiance visualization program takes a three-dimensional geometrical description of a space and a physical description of its surfaces, such as bi-directional transmission and reflectance data, color, and texture, then performs Monte Carlo ray-tracing calculations to generate pixel by pixel luminance data from a specific view within the simulated space [Ward 1990]. A diffuse calculation is made by tracing rays that sample the sky hemisphere. Rays are used to trace some number of diffuse reflections from a surface to others illuminating it. The diffuse reflection for each pixel is not computed separately, but all computed values are cached. A weighted average of the cached values is used to compute pixels whose value is not known. Radiance is well suited for computation of the distribution of direct and reflected light distribution in a space. The resultant image is a photorealistic depiction of the space from various views.



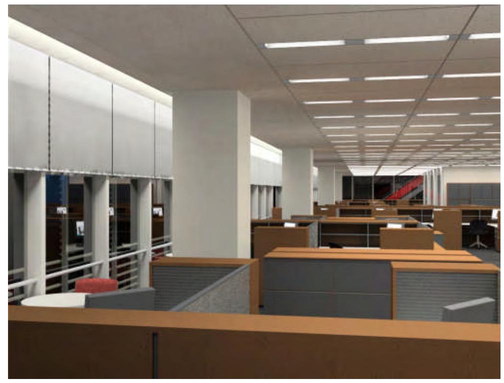


Figure 3-1. Photograph of actual daylighting mockup (left) and Radiance nighttime rendering of the same space (right).

The southwest corner of a typical floor in the 51-storey tower was selected to be constructed as a full-scale mockup and this fully-furnished mockup was modeled using Radiance. The mockup was a 401 m^2 (4318 ft^2) single-story building located in the parking lot of The Times printing facility in Flushing, New York (latitude 40.77° and longitude 73.90°). The mockup orientation to true north was the same as that of the final building in Manhattan, New York. The “south” windows faced 28.65° west of true south and the “west” windows faced 118.65° west of true south. Significant time was invested in the Radiance input model to ensure better than typical accuracy. The geometry of the building was derived from drawings produced by the project architect and interior designer. The finishes were either measured using actual samples of the materials to be used in the final building (e.g., the ceramic exterior rods, curtainwall, carpet, etc.) with a handheld photogoniometer or were matched to similar materials provided by the interior designer. The surface reflectance of exterior paving was determined using a Munsell color chart. Exterior obstructions from nearby trees and buildings were not significant and were therefore not modeled (the altitude angle of all obstructions was less than 10°).

Samples of the shade fabric were characterized using data provided by the manufacturer. The modeled roller shade fabric was made of a PVC-coated polyester and vinyl fabric that used flat white threads in one direction and flat black threads in the opposing direction (Mechoshade ThermoVeil type 6020). The color of the shade was predominately white on one face and gray on the other face. The gray side was faced toward the interior. The manufacturer provided measured data: the visible transmittance at normal incidence was 0.02 and the openness factor (percentage of open space to fabric) was 3%. Transmittance and reflectance properties of the glazing were provided by the manufacturer. The optics of the lighting system was determined using candlepower distribution light output data from the lighting designer and manufacturer. The chairs were not accurately modeled but the remainder of the furniture was modeled according to design documents.

A flat-panel computer visual display terminal (VDT) under consideration for use in the final building was measured and characterized as well. The VDT had an average luminance of 250 cd/m^2 as reported by the manufacturer. The specular reflectance of the VDT was 0.02. The diffuse reflectance of the VDT was 0.01. An image of both text and graphic were rendered so that VDT visibility could be assessed. The luminance of the black and white characters was 2 cd/m^2 and ~180 cd/m^2, respectively.

The simulation model was tuned iteratively over a period of three to four months while the interior design was being modified and updated. Ambiguities in the drawings were resolved by meeting with the A/E team and by visiting the partially-completed mockup. Tests were conducted to evaluate trade-offs between computation time and accuracy. Falsecolor contour images of the space were produced to quantify illuminance and luminance distributions. Each rendering took 6-12 hr to compute. Rendering computations were conducted from December 2003 through January 2004. These images were then post-processed to ensure that the scale of all images were comparable. Analysis was conducted on a comparative basis. The absolute values given in the images are less meaningful because of the considerable uncertainty in the actual sky luminance distributions, the surrounding exterior environment, and inaccuracies in modeling the complexities of the shade fabric, ceramic tube array, and the interior surfaces. Illuminance and luminance levels are expected to be accurate to within a factor of two.

To address the issue of how to maintain bright interior daylight levels while controlling direct sun and glare, several shade design alternatives were proposed:

1) Divide the window into upper and lower apertures and provide independently-operated roller shades for each aperture. Control the upper aperature for daylight (and direct sun penetration at low sun angles). Control the lower aperture for glare. With independent control, the occupant nearest the window wall can be comfortable without compromising interior brightness, daylight, and view for the remainder of the occupants in the open plan office area. With the upper aperture shaded by the exterior ceramic tubes for significant times of the day and year, direct sun can be controlled without compromising on daylight. With the high ceiling near the window wall, daylight may also penetrate deeper. This option was tabled due to the added cost of the motorized roller shade system and aesthetics.

2) Create a shade that has a denser weave fabric in the lower portion and a looser weave fabric in the upper portion of the roller shade so that daylight can be admitted at the top and glare can be controlled within the lower vision portion of the window wall. This option was also tabled due to added cost and the undesirable aesthetics of a horizontal seam where the two fabrics are joined.
3) Control the shade so that it only goes down to the bottom of the vision portion of the window wall (0.91 m or 3 ft above the floor, preset 3) instead of extending it all the way down to the floor (preset 4). Figure 3-2 shows the preset heights allowed by The Times. Allow direct sun to penetrate greater than the specified depth from the window as along as the sun does not adversely affect thermal or visual comfort. The unobstructed lower aperture (still shaded by the lower ceramic tube array) may increase interior brightness, permit partial view, and increase interior daylight levels so as to offset electric lighting requirements. This option was of interest to The Times because it had no adverse cost impacts (in fact, it could potentially save them the cost of the additional fabric length and increase lighting energy use savings) and was aesthetically acceptable. This is referred to in the analysis as **Condition 1**.

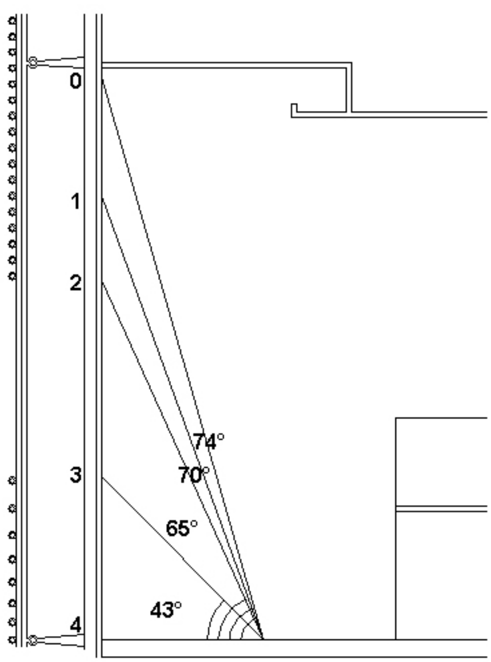


Figure 3-2. Preset shade heights, where preset 0 is full up and preset 4 is full down. Vertical cut-off angles are shown for each preset height for a 3-ft depth of sunlight penetration.

As the monitoring at the daylighting mockup progressed, it became apparent that two additional factors of shade control would conspire to reduce interior brightness levels:

1) Irrespective of direct sun control, The Times desired that window glare be controlled. In the morning and afternoon hours on the west façade at the mockup, for example, the brightness of the sky seen

through the vision portion of the window wall can be a significant source of glare. To reduce glare, the shade should be dropped to cover the vision portion of the window wall (preset 3) instead of in the full up position (preset 0). This is referred to in the analysis as **Condition 2**.

2) In the afternoon at the mockup, the shade control system in Area A was found to control the window shade between preset heights 3 and 4 in an effort to reduce window glare irrespective of direct sun penetration. This too will reduce interior daylight levels. This is referred to in the analysis as **Condition 3**.

As a result of these three conditions, the following shade configurations were rendered using Radiance:

- Roller shades fully up on both the south and west facades (preset 0).
- Roller shades fully down on the south and west façades (preset 4).
- On the west façade, roller shades are drawn down to the bottom of the vision portion of the window wall (preset 3). Roller shades fully down on the south façade. This corresponds to Condition 1 above.

For all three configurations, the shades on the south façade adjacent to the staircase were modeled in Radiance on the north side of the stair as was desired by the architect at the time of these renderings. Later, The Times decided to place the shade directly adjacent to the south façade. On the other sections of the south façade, the shade was modeled directly adjacent to the south façade. In Radiance, direct sun was permitted to penetrate 0.91 m (3 ft) from the west window wall and 3.65 m (12 ft) from the south window wall. The control algorithm itself was not modeled in Radiance. Instead, the images were post-processed to determine which preset height would apply for the given hour and solar conditions.

The above shade configurations were modeled for all daytime hours and two sky conditions:

- March/September 21 (equinox): 9:00-18:00 ST under CIE clear sky conditions
- June 21 (summer solstice): 7:00-19:00 ST under CIE clear sky conditions
- December 21 (winter solstice): 8:00-16:00 ST under CIE clear sky conditions
- One CIE overcast condition was modeled.

The following views were generated for each test and day/sky condition:

- View 1: photorealistic floor plan view – this image gives photorealistic depiction of daylight patterns within the mockup space (Figure 3-3a). The top edge of the floor plan view is project east, the right edge is south, and the bottom edge is west.
- View 2: daylight illuminance falsecolor plan – this image has the same view as View 1 but shows the illuminance levels (lux) of each surface seen in the image (e.g., desk, floor, etc.) (Figure 3-3b). The scale on all images is limited to 950 lux – values exceeded this limit. The maximum illuminance is shown as a single value within the image.

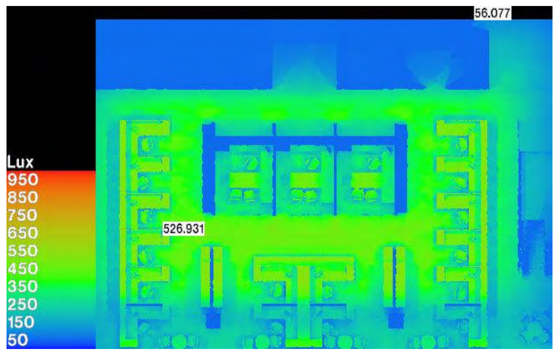
- View 3: daylight luminance falsecolor plan – this has the same view as View 1 but shows the luminance levels (cd/m^2) of each surface seen in the image (e.g., desk, floor, etc.). The scale is limited to 950 cd/m^2 – values exceeded this limit. The maximum luminance is shown as a single value within the image.

This analysis focused on the daylight conditions in the workstations adjacent to the west window wall. For these daytime renderings, the electric lighting was off. The workstations are referred to in the analysis by number starting with workstation 1 at the west window wall progressing east to workstation 6 near the east corridor. Area A is the north side of the mockup. Area B is the south side of the mockup. The dividing line between the two areas runs east-west and divides the center private office in half.

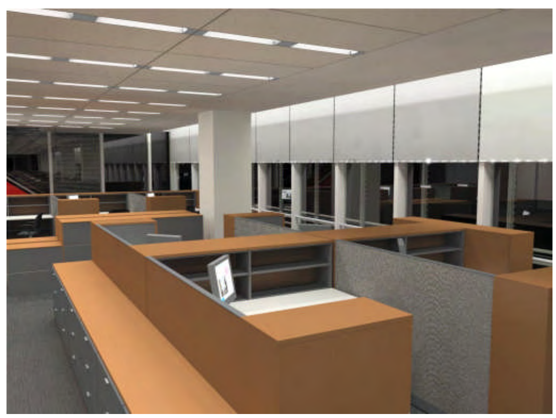
Nighttime views were generated with the shades fully up on both the west and south facades. These were relayed to the lighting designer to review and discuss with The Times. A second set of images were generated with the roller shade partially down to better understand the impact of the cove lighting system as an architectural lighting feature. Nighttime illuminance distribution images were also provided to the lighting designer. Example images are given in Figure 3-3.

a) Photorealistic plan view, electric lights only

b) Falsecolor illuminance map, electric lights only



c) Radiance-generated interior view at night looking at southwest corner of mockup



d) Radiance-generated interior view at night looking at southeast corner of mockup

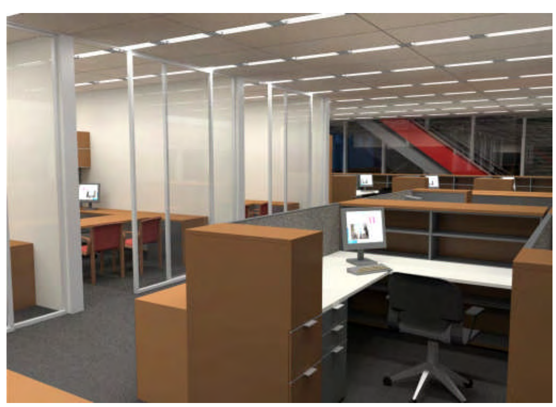


Figure 3-3. Example Radiance renderings at night.

3.3. RESULTS

3.3.1. Impact on interior daylight illuminance under Condition 1

Condition 1: will allowance of direct sun through the lower tube array (preset 3 versus preset 4) help to increase daylight work plane illuminance levels?

Over the course of a typical clear sunny day, the roller shades on the west façade will exhibit a predictable pattern of operation if controlled only for direct sun. In the morning hours when the sun is out of the plane of the window, the shades will be fully retracted (preset 0). When the sun comes into the plane of the window, direct sun gradually starts to penetrate into the interior at greater depths. The shade is lowered gradually to presets 1 and 2. As the sun drops lower toward the horizon, the shade must lower over the vision portion of the window wall (preset 3), then the lower portion of the window wall (preset 4) to control direct sun to within 0.91 m (3 ft) from the window.

For solar profile angles less than 43° (which is the vertical cut-off angle of preset 3), direct sun will penetrate greater than 0.91 m (3 ft) with no interior shades (Figures 3-4a and 3-4b). If the shade is at preset 3 and covering the vision portion of the window wall, direct sun is incident on the lower leg and feet of occupants seated near the window wall or for a short period on the lower half of the occupant (less than 89 cm or 35 inches above the floor) when the sun is close to setting (altitude angles of 0-10°). Direct sun is not incident on the work plane or on the vertical surfaces such as the VDT facing the west window wall (assuming that the viewing portion of the VDT is at minimum 15.2 cm (6 in) above the surface of the desk).

a)

b)

c)

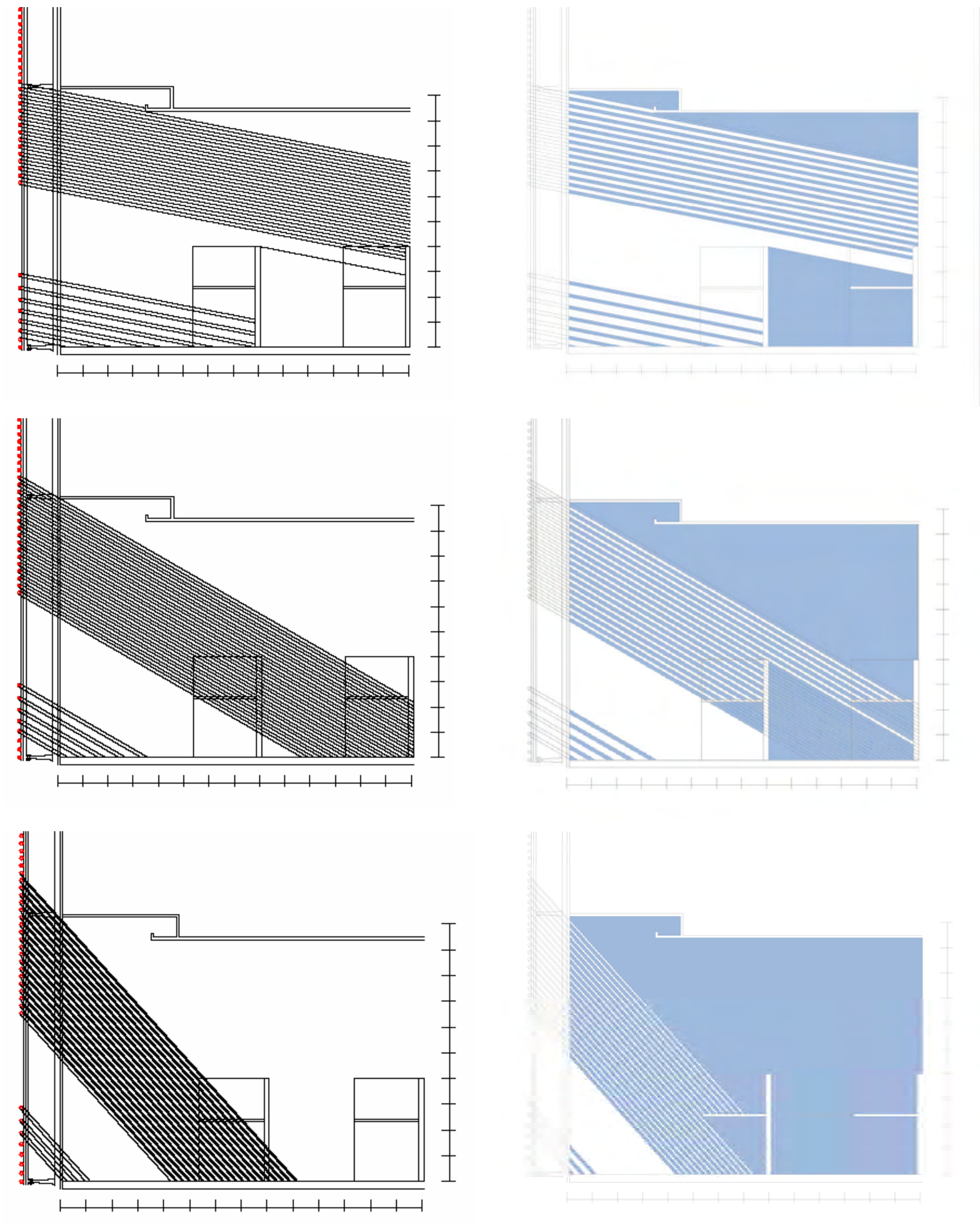


Figure 3-4. Example of direct sun penetration for solar profile angles of 11° (top), 30° (middle), and 48° (bottom) with shades up.

If the shade is kept at preset 3 and direct sun is permitted to penetrate greater than 0.91 m (3 ft) (i.e., Condition 3), then there were several times, of the times modeled, that can be used to evaluate the potential increase in daylighting: March 21: 16:00, 17:00 and June 21: 15:00, 16:00, 17:00, and 18:00. Daylight illuminance renderings for selected times are shown in Figure 3-5.

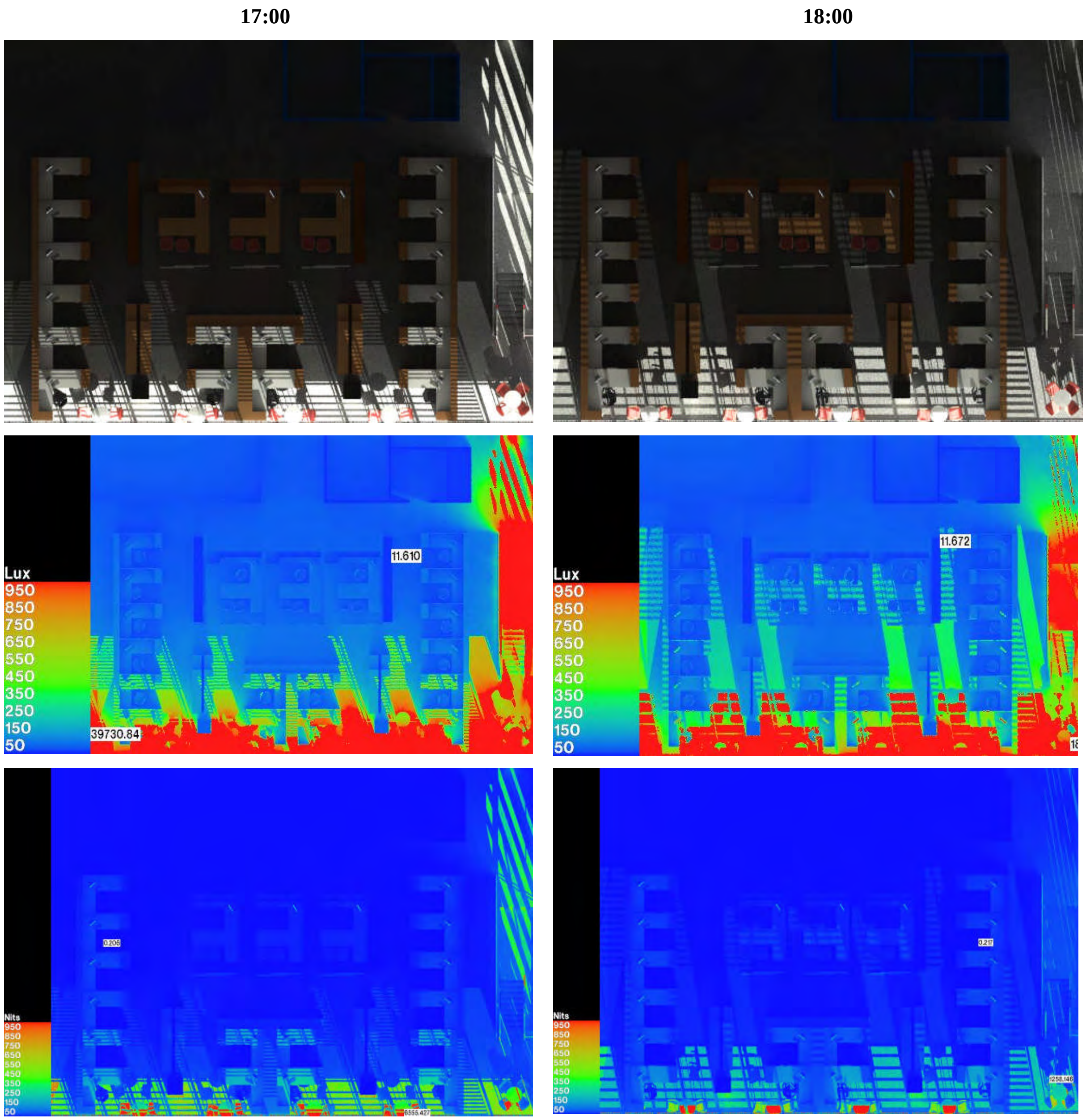


Figure 3-5. Example floor plan views for June 21 at 17:00 (left) and 18:00 (right), CIE clear sky conditions. Shade down fully on south and shade at preset 3 on west façade.

Median work plane illuminance levels were calculated using pixel values of 1600 random points on each of the L-shaped workstations. The absolute and percentage difference in illuminance levels between using preset 4 versus 3 on the west façade were then computed for the times noted above (Table 3-1). The south shade was set at preset 4 for both cases.

Daylight work plane illuminance levels were increased significantly in the first three workstations closest to the west window wall during mid-afternoon hours (15:00-16:00 on June 21) under CIE clear sky conditions. Interior illuminance levels were increased by 30-60 lux or 6-11% of the total desired 538 lux in many of the first three workstations and less than 30 lux in the remaining workstations.

Table 3-1.
Difference in median daylight work plane illuminance between preset 3 and 4 on the west façade
Preset 3 allows direct sun to penetrate greater than 0.91 m (3 ft) from the west window
(south shades at preset 4)

				Difference (lux)						Percentage difference (%)					
Day	Hour	Workstation		1	2	3	4	5	6	1	2	3	4	5	6
3-21	16:00	A	north	22	26	16	10	3	1	19%	52%	41%	22%	8%	2%
		A	center	16	16					16%	32%				
		B	center	14	14					9%	28%				
		B	south	20	18	8	4	0	0	15%	32%	20%	9%	0%	0%
3-21	17:00	A	north	8	12	9	3	2	0	5%	22%	21%	6%	4%	0%
		A	center	6	10					7%	20%				
		B	center	1	7					0%	14%				
		B	south	13	7	2	1	0	0	11%	12%	3%	1%	0%	0%
6-21	15:00	A	north	61	53	35	19	10	5	74%	103%	87%	45%	23%	13%
		A	center	38	35					48%	69%				
		B	center	37	33					36%	63%				
		B	south	50	38	22	12	7	4	48%	64%	52%	30%	17%	11%
6-21	16:00	A	north	47	41	24	14	8	4	38%	77%	59%	34%	18%	11%
		A	center	24	26					20%	48%				
		B	center	33	24					20%	43%				
		B	south	34	28	17	10	5	3	20%	45%	41%	24%	14%	9%
6-21	17:00	A	north	49	28	18	10	5	3	11%	41%	44%	24%	12%	7%
		A	center	21	20					14%	35%				
		B	center	9	17					4%	23%				
		B	south	19	16	12	7	4	3	10%	22%	29%	17%	9%	8%
6-21	18:00	A	north	22	16	11	5	3	1	16%	27%	24%	10%	7%	4%
		A	center	6	10					5%	17%				
		B	center	7	9					3%	15%				
		B	south	8	11	8	4	2	3	4%	16%	18%	9%	6%	7%

Additional renderings were made from the occupant's viewpoint within the interior space. Several observations can be made from these images:

1) Semi-directional sunlight is admitted through the shade fabric (Figure 3-6). These patterns cause distinct luminance contrasts between areas that are in absolute shadow and areas that are partially

protected by the shade fabric. These contrasts may be cause for annoyance and visual discomfort. For example, with one's back to the window wall, one casts a diffuse shadow over one's work surface.

2) Stripes of direct sun are admitted through the 2.54-cm (1-inch) gap between the 1.52-m (5-ft) wide shade bands (Figure 3-7).

Irrespective of the height to which the shades are controlled, there may be problems with task visibility and visual comfort under direct sun conditions. A denser weave fabric that virtually eliminates direct sun will be required to control the shadow patterns through the fabric, which in turn will reduce interior daylight levels.

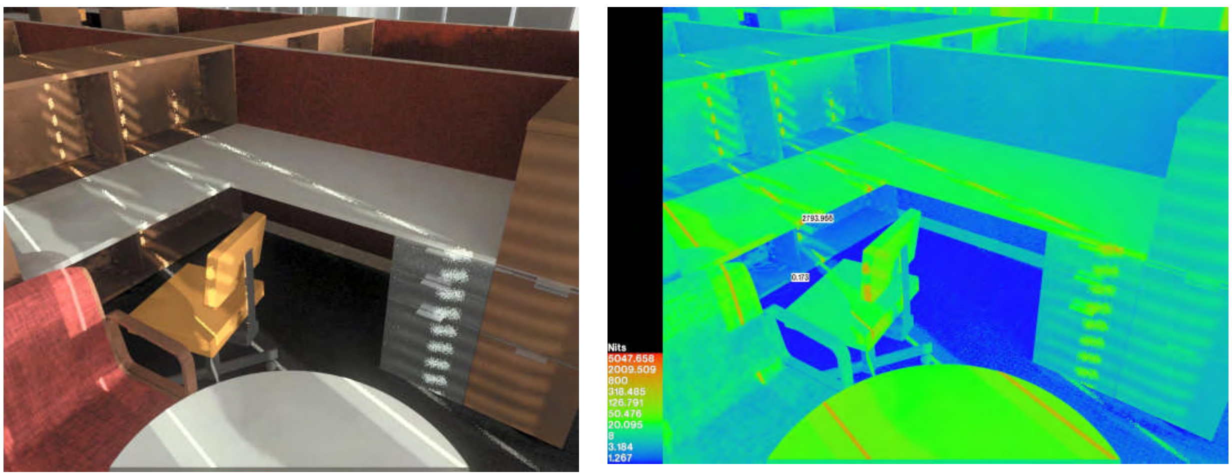


Figure 3-6. Radiance images showing ceramic tube shadow patterns cast through the shade fabric on December 21 at 15:00, CIE clear sky.

Figure 3-7. Photographs at the actual mockup showing shadow patterns cast by direct sun transmitted through the shade fabric. Direct sun also was admitted through the 2.5 cm (1-in) gaps between shade bands.

3.3.2. Impact on interior daylight illuminance under Condition 2

Controlling window glare will cause the shades to be deployed irrespective of the direct sun criteria. To reduce glare, the shade should be down to cover the vision portion of the window wall (preset 3) instead of fully up (preset 0) (Figure 3-8). Interior daylight levels will be significantly reduced to control window glare.

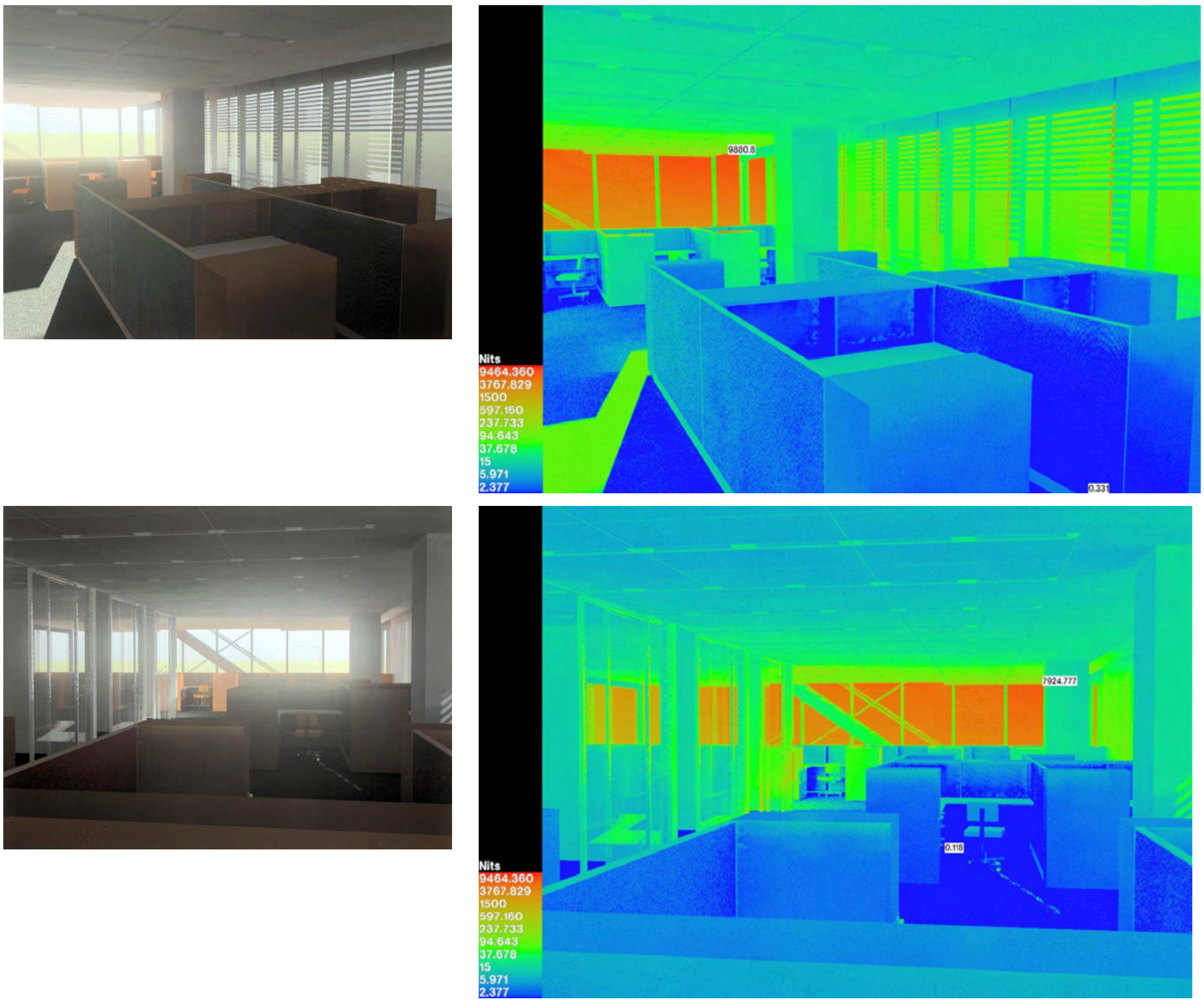


Figure 3-8. Radiance image showing two viewpoints of window glare caused by the south window wall on December 21 at 15:00 with the south shades up and the west shades down. The left-hand image shows what the human eye will see given scattering in the eye. The right-hand image shows the corresponding window luminance values at standing height with no direct sun in the field of view (sky luminance only). Glare will be less if the electric lighting is on.

In the early afternoon hours, the direct sun was controlled to within 0.91 m (3 ft) from the window by the ceramic tubes alone. Median work plane illuminance levels were calculated for these hours with the west and south shades either at preset 0 (no direct sun control) or the west shades at preset 3 (shades providing glare control) and the south shades at preset 4. These values are given below in Table 3-2. Only values in Area A are given, since the south shade position of preset 4 confounds the analysis. Interior daylight illuminance levels will be significantly reduced at the three workstations closest to the west window wall, up to seven times lower, if the shades on the west façade are used to control window glare using preset 3 versus preset 0 (full up) in the early afternoon hours. Work plane illuminance levels at the more interior workstations are also significantly reduced but at these depths, daylight illuminance levels are fairly low in any event.

Table 3-2.
Difference in median daylight work plane illuminance between preset 0 and 3 on the west façade

				Daylight illuminance for preset 0 (lux)						Difference (lux)			Percentage increase (%)		
Day	Hour	Workstation		1	2	3	4	5	6	1	2	3	1	2	3
3-21	13:00	A	north	713	265	109	76	56	46	624	185	43	701%	234%	65%
		A	center	640	240					562	168		717%	231%	
3-21	14:00	A	north	613	193	79	60	48	42	536	132	28	701%	214%	55%
		A	center	509	171					443	114		673%	200%	
6-21	12:00	A	north	624	220	81	61	49	42	524	148	27	526%	206%	52%
		A	center	570	197					483	132		551%	204%	
6-21*	13:00	A	north	533	177	77	59	48	42	466	119	26	692%	207%	51%
		A	center	482	165					422	110		694%	199%	
6-21	14:00	A	north	821	262	97	66	50	43	715	181	37	676%	223%	63%
		A	center	705	230					617	158		705%	223%	
12-21	13:00	A	north	383	141	70	56	45	41	325	85	20	553%	153%	39%
		A	center	337	129					284	76		528%	144%	
12-21	14:00	A	north	395	134	64	53	43	39	338	83	20	596%	166%	44%
		A	center	323	120					272	71		530%	147%	

* Values are lower than previous hours because sunlight is parallel to ceramic tubes and tubes are in shadow.
Differences for workstations 4-6 were insignificant: less than 15 lux or 3% of 538 lux.

3.3.3. Impact on interior daylight illuminance under Condition 3

To reduce window glare, the shade may be set to preset 4 (fully down) instead of preset 3. For example, Area A controlled the average overall window luminance by covering the window area below the vision portion of the window wall in the afternoon. Lowering the shade to the floor may produce very little if any change in glare (particularly workstations 2-6) compared to lowering the shade to the bottom of the vision portion of the window wall, but could significantly reduce daylight levels for some solar conditions. The occupant's field of view in the first workstation may not be significantly influenced by this glare source since it is in one's peripheral view. For all other workstation locations, the 1.2-m (4-ft) high partitions cut off one's view to this lower portion of the window wall.

Median work plane illuminance levels were calculated for the early afternoon hours when the direct sun was controlled to 0.91 m (3 ft) from the window by the ceramic tubes and the west shade at preset 3. For the glare mode, a second set of illuminance levels were calculated with the west shade at preset 4. The south shades were fully down in both conditions. These values are given in Table 3-3. Under diffuse sky conditions, interior daylight illluminance levels were reduced in the first two workstations closest to the west window wall under some CIE clear sky conditions. Interior illuminance levels were decreased by 30-44 lux (5.6-8.2% of the 538 lux desired illuminance) in the first two workstations and less than 30 lux in all remaining workstations during the mid-afternoon hours during the equinox and summer solstice (3/21 15:00, 6/21 14:00).

Table 3-3.
Difference in median daylight work plane illuminance between preset 3 and 4 on the west façade
Diffuse sky conditions
(south shades at preset 4)

				Daylight illuminance with preset 3 (lux)						Difference (lux)				Percentage decrease (%)			
Day	Hour	Workstation		1	2	3	4	5	6	1	2	3	4	1	2	3	4
3-21	13:00	A	north	89	79	66	61	50	42	28	33	26	18	45%	72%	66%	43%
		A	center	78	72					17	24			27%	49%		
		B	center	93	65					18	19			24%	41%		
		B	south	97	75	58	49	43	40	20	22	16	9	27%	42%	39%	23%
3-21	14:00	A	north	77	62	51	50	43	38	19	18	13	8	33%	42%	34%	21%
		A	center	66	57					10	12			18%	27%		
		B	center	82	56					13	13			18%	29%		
		B	south	83	63	48	42	39	38	15	14	7	3	22%	28%	17%	9%
3-21	15:00	A	north	114	85	64	56	47	40	41	38	25	14	57%	80%	62%	33%
		A	center	97	73					30	25			44%	53%		
		B	center	120	70					28	23			30%	47%		
		B	south	120	83	56	47	41	39	29	29	15	7	33%	54%	35%	17%
3-21	18:00	A	north	83	52	42	43	40	37	12	7	4	1	17%	17%	9%	3%
		A	center	77	51					6	4			8%	9%		
		B	center	108	51					15	6			16%	12%		
		B	south	98	54	42	39	38	37	11	4	2	0	12%	8%	6%	0%
6-21	12:00	A	north	100	72	53	50	45	41	35	25	14	8	55%	52%	34%	19%
		A	center	88	65					20	15			30%	30%		
		B	center	99	63					17	15			20%	31%		
		B	south	111	77	57	49	44	42	27	21	14	7	32%	37%	32%	16%
6-21	13:00	A	north	67	58	51	51	46	41	13	15	12	9	24%	35%	32%	22%
		A	center	61	55					6	10			11%	22%		
		B	center	73	52					9	9			14%	22%		
		B	south	74	60	51	48	44	43	10	11	9	6	16%	22%	22%	14%
6-21	14:00	A	north	106	81	60	54	46	41	44	35	21	12	72%	76%	54%	28%
		A	center	88	71					24	24			39%	50%		
		B	center	104	68					27	21			34%	45%		
		B	south	110	79	58	50	44	43	33	25	16	8	43%	46%	38%	18%
6-21	19:00	A	north	91	56	44	45	42	39	9	8	4	2	11%	17%	10%	4%
		A	center	90	53					5	4			6%	9%		
		B	center	116	51					6	2			5%	4%		
		B	south	115	57	45	42	41	42	4	3	2	1	4%	5%	6%	1%
12-21	13:00	A	north	59	56	51	49	42	38	10	14	12	7	21%	34%	32%	17%
		A	center	54	53					5	9			10%	21%		
		B	center	62	49					5	7			8%	16%		
		B	south	64	55	47	46	40	39	7	8	6	4	13%	17%	15%	9%
12-21	14:00	A	north	57	50	45	45	40	36	7	9	6	3	13%	21%	15%	8%
		A	center	51	49					4	6			7%	13%		
		B	center	63	46					5	4			9%	10%		
		B	south	63	52	45	44	41	40	4	3	3	2	7%	6%	7%	4%
12-21	15:00	A	north	67	53	47	45	39	36	12	11	8	3	22%	26%	19%	8%
		A	center	59	51					9	8			18%	19%		
		B	center	73	49					7	7			10%	15%		
		B	south	77	58	46	43	41	42	9	8	4	2	13%	16%	10%	4%
12-21	16:00	A	north	66	49	43	42	39	36	6	6	4	2	9%	14%	9%	4%
		A	center	57	48					4	3			7%	8%		
		B	center	73	45					5	3			7%	6%		
		B	south	67	52	41	39	38	44	5	4	1	1	7%	8%	2%	1%

Although positioning the shade to preset 3 increases interior daylight levels at the first two workstations, there are several considerations that may impact visual comfort in the first workstation. Specular reflections of direct sun off the lower ceramic tube array may be cause for annoyance and visual discomfort. The luminance contrast between the unshaded and shaded portions of the window wall, even in one's peripheral view, may also cause discomfort if one is using the side work surface to conduct tasks (the primary work surface places one's view to the east with one's back to the window wall).

Limited Radiance renderings were made to understand if this concern was warranted. Figure 3-9 shows the luminance of the west window wall on March 21 and June 21 at 16:00 when the solar profile angle was 33° and 40°, respectively. On June 21 at 16:00, reflected daylight off the ceramic tubes produced luminance levels ~1500 cd/m^2 in the lower section below the vision portion of the window wall with the shade at preset 3. This level of brightness may warrant cause for some concern, particularly since the furniture design was changed after these simulations were made. In these simulations, the height of the cabinet adjacent to the window was 1.2 m (4 ft). This shielded an occupant's view of the lower window. In the final workstation design, this cabinet was eliminated in favor of extending the desk surface to the window wall. This exposes the occupant to more direct views of the lower section of the window wall. Direct sun will also strike the desk area that is within 0.91 m (3 ft) from the window wall unless the shades are set down to the lower preset 4 and the criteria for direct sun penetration is changed.

	March 21 16:00	June 21 16:00
Preset 3		
Preset 4		

Figure 3-9. Radiance image showing a side view of the window wall with ceramic tubes and shade in the field of view. These images show a photorealistic depiction of the daylit environment on March 21 and June 21 at 16:00 with the west shade at either preset 3 or preset 4.

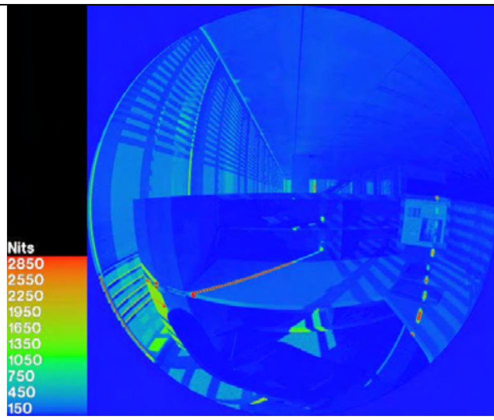
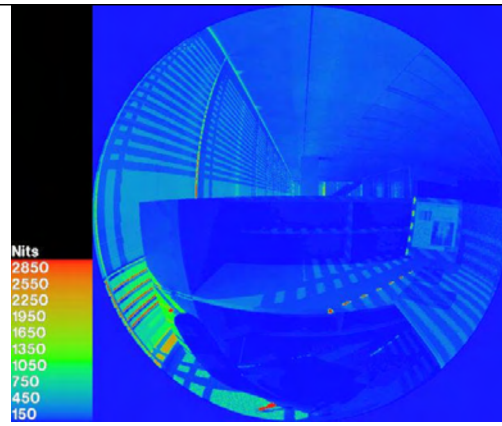
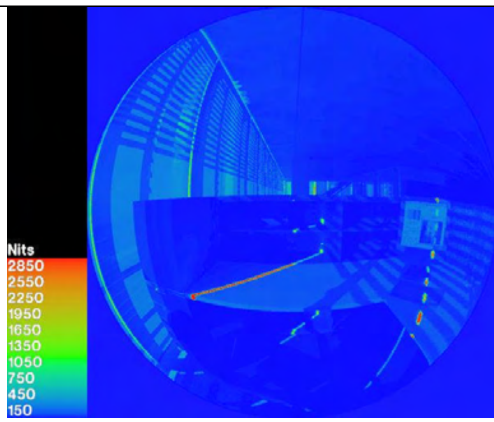
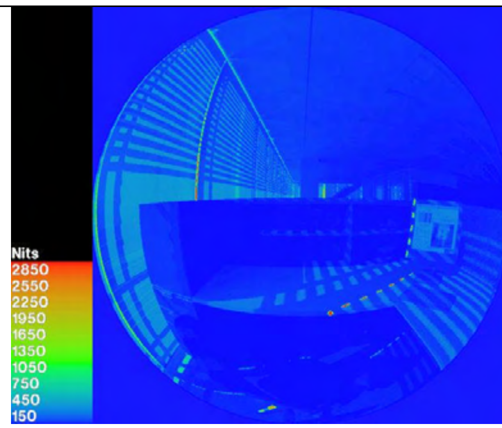
	March 21 16:00	June 21 16:00
Preset 3		
Preset 4		

Figure 3-10. Radiance image showing a side view of the window wall with ceramic tubes and shade in the field of view. These images show the luminance levels (nits=cd/m^2) for the same set of conditions as Figure 3-9: March 21 and June 21 at 16:00 with the west shade at either preset 3 or preset 4.

3.3.4. Impact of Condition 1 on daylight control reliability

Daylighting control systems often rely on uniform lighting conditions to achieve reliable maintainance of the design setpoint illuminance level. For example, a proportional control system, such as that demonstrated in Area A of the mockup, relies on a fairly predictable relationship between the ceiling-mounted photosensor signal and work surface illuminance levels to achieve reliable control. For Condition 1 where deeper penetration of direct sun may be allowed, the non-uniformity of the daylight may influence the ceiling-mounted photosensor readings and cause over-dimming of the lights. Work plane illuminance levels may be less than the desired setpoint.

As noted above, the depth of direct sun penetratration exceeded 0.91 m (3 ft) from the west window in the late afternoon from the vernal to autumnal equinox or thereabouts with Condition 1. When this occurred, the direct sun was not incident on the work plane horizontal surfaces; it was incident on the dark grey carpet (r=0.07) and parts of the vertical partitions due to the low-angle sun (see Figure 3-5 above) and therefore may have small influence on the ceiling-mounted photosensor signal. These direct sun patterns influenced primarily the first two workstations with significantly less effect in workstations 3-6. The degree of influence varied depending on the orientation of the workstation partitions to the south and west windows. Diffuse daylight through the shade fabric caused patterns of light and dark but these occurred irrespective of whether the shade was dropped to preset 3 or 4. The influence of Condition 1 may be minor on daylighting control reliability.

3.4. CONCLUSIONS

Radiance simulations were used to determine the impacts of three alternate shade control strategies on interior daylight illuminance levels. None of these strategies increased interior daylight illuminance levels on clear sunny solstice or equinox days without incurring other penalties such as thermal or visual discomfort. Using a single density top-down, automated roller shade, increased glare control will significantly reduce daylight levels.

If direct sun is allowed to penetrate deeper into the space without being incident on the work surface (Condition 1: preset height 3 instead of 4), interior daylight levels can be increased by 30-60 lux (5-11% of the total desired 538 lux) in the first three workstations closest to the west window wall during mid-afternoon hours under CIE clear sky conditions during the summer solstice. This strategy may increase visual interest in the space but may adversely affect thermal comfort since the low-angle direct sun will be incident on the lower half of the occupant's body in the first workstation closest to the window.

In the early afternoon hours when direct sun is controlled to within 0.91 m (3 ft) from the window wall by the ceramic tubes on the west façade, the shades will be fully raised if no glare control is implemented. With glare control (Condition 2) and the 3%-open fabric shades lowered to preset 3 (covering the upper vision portion of the window wall), daylight illuminance will be significantly reduced by up to a factor of 7. Illuminance levels were reduced by 20-624 lux in the first two workstations closest to the west window wall under CIE clear sky conditions during equinox and solstice conditions. Similar reductions are anticipated if glare control is implemented during the morning hours.

Controlling the shade in the lower portion of the window wall (Condition 3: preset 3 versus 4) may have some effect on controlling glare in the first workstation. For hours when the ceramic tubes and west shade is already at preset 3 to restrict direct sun to within 0.91 m (3 ft) from the window, daylight illuminance levels will be decreased by 30-44 lux (6-8% of the 538 lux desired illuminance) in the first two workstations if the shade is further dropped to preset 4 to control glare.

Irrespective of the shade control design, the patterns of sunlight and shadow that occur on work surfaces when the shade is down and backlit by direct sun will cause minor visual discomfort and annoyance. These patterns are evident primarily in the first workstation closest to the window but also on the top edges of the workstations farther from the window. Increased fabric density may be required to prevent this from occurring. A more detailed study on fabric choice as related to glare-daylight trade-offs was conducted in a second phase of Radiance modeling (Section 9).

SECTION 4
FIELD STUDY OF DAYLIGHTING CONTROL SYSTEMS

4.1. INTRODUCTION

The main objective of this monitored field study was to provide timely information to the building owner about commercially available daylighting control systems. This information was used to make an informed business decision on whether to purchase such systems. It was also used to determine which desirable features and functions of daylighting control systems should be specified in the procurement specifications prior to the bid phase, irrespective of whether the manufacturers currently offered these features in existing product lines. This section provides details on the overall field study experimental setup, methods of analysis, then provides an analysis of the two daylighting control systems' performance over a nine-month monitored period.

The building owner's main motivation for procuring dimmable ballasts and a daylighting control system was:

- Productivity. The Times believes that the dimmable lighting system with daylighting controls integrated into the overall lighting control system will enhance the way they work: people do not like fluorescent lighting (due to its color temperature, frequency, blinking) and prefer more natural daylight.
- Sustainability. Sustainability translates into daylight harvesting or the use of a "natural" resource – the sun – to offset the need to expend fossil fuels. Daylighting would enable the building owner to reduce lighting and cooling energy use, deploy a demand response to variable energy pricing signals, and reduce operating costs.
- Amenity. The building owner believes that having the ability to tune the electric lighting levels to different setpoints throughout their building would better address departments' preferences and therefore increase occupants' satisfaction with their lighting environment. To clarify, this amenity was not defined at the level of personal control of individual light fixtures, rather entire lighting zones in this open plan office were to be tuned to a desired lighting level.
- Flexibility. The building owner was particularly interested in individually-addressable ballasts since churn costs for rezoning the lights could be reduced over the lifetime of the installation.

The building owner's main concerns with procuring dimmable ballasts and daylighting control system included:

- Energy savings. Are there significant energy savings for the owner with dimmable lighting systems in both daylighting and non-daylighting zones?

- Uncertain reliability. Does the system dim properly? Will the lighting system provide adequate light to the task at all times? Will there be annoying hysteresis, noise, or other operational features that will impact occupant acceptance of the technology?
- Increased complexity and cost. Implementing such systems will increase design and installation costs. The electrical trade unions may bid up the cost of installing unfamiliar systems. The A/E team was unfamiliar with the type of information required to design and specify such systems. How should the zones be defined and where should the photosensors be located? How many photosensors are required to ensure that the system would perform well? What were the cost trade-offs with adding photosensors to improve reliability versus minimizing photosensors to decrease cost?
- Appearance of the space. What message does it send to those viewing the space with the overhead lights dimmed to different levels? Will the space look gloomy or bright? Will the lights blink if the lights are turned off and on?
- Features of vendor products. Which variables and what adjustments can be made by the facility manager (e.g., target setpoints at the workplane, zoning, etc.)? What are the implications of these adjustments? What does the interface to the control system look like? Does it provide one with an easily understood graphical depiction of the zones, allow the facility manager to easily reconfigure the zones, provide useful diagnostic information if there are occupant complaints, etc. What level of expertise is needed to maintain the system? How dependent will the building owner be on the vendor to maintain the systems? How can these systems be tied to the main building management control system?

This field study answered most of the above questions using the following methods:

- Sustainability. Lighting energy use was monitored in the daylighting mockup. In the sections below, the installed lighting control systems, monitoring instrumentation, definition of monitored zones, lighting control configuration, method of analysis, and experimental results are described in detail. The analysis addressed the following questions: 1) what were the lighting energy savings in the various zones at different depths from the window wall and when did they occur? And 2) changes in the shade control algorithm produced changes in daylight availability and lighting energy savings. Were these changes in energy use significant?
- Amenity. The feature of tunable lighting levels was not confirmed directly in this analysis. This capability was demonstrated by the vendors informally.
- Flexibility. The ease of rezoning individually-addressable ballasts was tested anecdotally in this study. This is discussed in the experimental results.
- Reliability. Control reliability was monitored in the daylighting mockup. The instrumentation, method of analysis, and experimental results are described in detail in the sections below. The analysis addresses the following questions: Does the daylighting control system dim in proportion to available daylight? Does it meet the minimum design setpoint at all times throughout the day

and if it does not, to what degree does it fail? What dimming profiles and rate of response can be expected over the course of the day and throughout the year? The daylighting control system should operate properly under all sun and sky conditions despite permutations of the lighting configuration and shade control algorithm. What were the causes for poor performance?

- Increased complexity and cost. There was considerable experience gained by the A/E team, building owner, and contractor when implementing these systems in the mockup. Cost trade-offs between various zoning and photosensor options were discussed in private with the vendors and were not detailed in this study.
- Appearance of the space. Anecdotal observations by the building owner are given in the discussion. Interior illuminance data for the entire monitored period are presented as an indicator of interior brightness. Visual comfort data, detailed time-lapse photographs and high-dynamic range luminance maps of the space over time, and results from a human factors study conducted to obtain a subjective appraisal of the daylighting mockup are given in separate sections of this report.
- Features of vendor products. The various features of the products used in the mockup are not detailed in this study. The building owner worked with the vendors to understand what the current capabilities of the installed systems were and requested that many of the features be improved. Readers are urged to go directly to the vendors for the most up-to-date information on product features. Some features are anecdotally reviewed in the results discussion of this report.

4.2. EXPERIMENTAL METHOD

4.2.1. Overall experimental design

As an extension to the Introduction in Section 1, we elaborate on how the field test experiment was designed. Two sets of vendors were invited by the building owner to install their shading and lighting equipment in a daylighting mockup, which represented the south-west corner of the 51-storey tower of The New York Times Building. One set of vendors placed their technologies in the northern section of the mockup predominantly sidelit by the west-facing windows. The other set of vendors placed their technologies in the southern half of the mockup daylit by both south and west-facing windows. Therefore, the two vendor data sets were not directly comparable.

The relationship at the mockup was that of a team formed by the public funding agencies, the building owner and their A/E team, LBNL, and the manufacturers all of whom shared the risk that is associated with innovative technologies. The public sector energy efficiency agencies cost-shared with the building owner to evaluate the technologies for public benefit. The owner team provided significant cost-share by constructing the daylighting mockup, maintaining its operations over the monitored period, working with all partners to justify their investment, resolve technical uncertainties, and conduct their own qualitative assessment. LBNL played the role as a facilitator and owner agent, helping to communicate technical requirements to the vendors and provide objective third-party feedback on product performance to the building owner. The manufacturers worked hard to meet the expectations of the building owner, providing time and equipment at their cost, working through product performance expectations with the building owner, and developing new features and amenities as they received feedback from both LBNL and the building owner.

The test protocol at the mockup was therefore one that evolved. No direct comparisons between the two sets of vendors were intended. A six-month, solstice-to-solstice study was planned from December 21, 2003 to June 21, 2004 to coincide with the development and release of procurement specifications for bid in early August 2004. Monitored results were discussed with the building owner and each vendor at the end of March and June 2004. All vendors were encouraged to use the mockup as their own test facility after June 21, 2004 to continue to test and develop their systems as needed. Because the furniture systems remained in place until the end of September and there was little significant incremental cost to continue monitoring, LBNL extended the analysis to broaden the dataset. There was no active diagnostics performed by LBNL to support the activities of the manufacturers after June 21, 2004. Since each vendor's product evolved, data collected over the nine-month study were subdivided based on each design iteration. There was no single summation of data for the entire nine-month period.

This study demonstrates the feasibility of achieving energy-efficiency goals, However, direct extrapolation of the monitored data to other building projects is not advised. First, the façade design was unique: shading provided by horizontal ceramic tubes affected the results considerably. The interior design was also rather unique: the open plan office design used 1.22-m (4-ft) high partitions throughout. This case study provides useful objective data and demonstrates the need for A/E firms to create building specific designs that can accomplish energy-efficiency and a pleasing, comfortable, and healthful environment.

4.2.2. Facility description

4.2.2.1. Building description

A new 51-storey high-rise building is under construction in downtown Manhattan between 7th and 8th Avenue and West 40th and West 41st Street of New York City. To evaluate daylighting, a 401 m^2 (4318 ft2) one-storey, full-scale, fully-furnished, outdoor mockup was built in the parking lot of the building owner's printing press site in nearby Flushing, New York (the city borough of Queens). The mockup reproduced the southwest corner of a typical floor in the 51-storey tower of The New York Times Building (Figure 4-1). The mockup was located at latitude 40.77° and longitude 73.90° and its orientation matched the orientation of the Manhattan site. The "south" windows faced 28.65° west of true south and the "west" windows faced 118.65° west of true south.

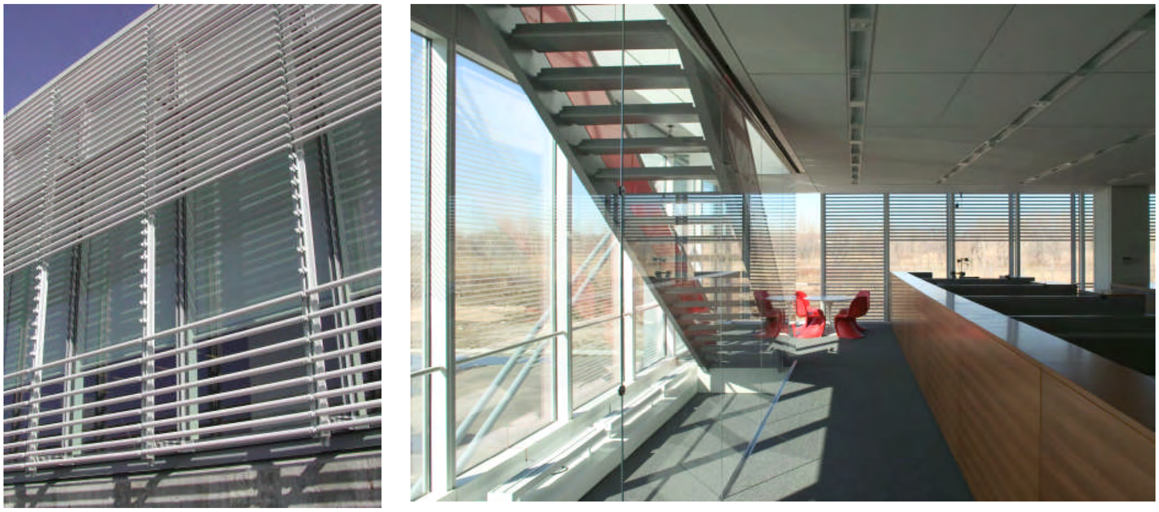


Figure 4-1. Exterior view of the west façade of The New York Times headquarters mockup (left) and interior view of Area B (right) on February 23, 2004 with south windows on the lefthand side of the photograph.

Figure 4-2. View of exterior obstructions with the printing plant to the southeast (left) and trees to the south to northwest (center, right).

The view immediately out the south-facing windows was of a parking lot with a black asphalt surface. Cars and snow caused the ground surface reflectance to vary from 0.05-0.10 (black asphalt) to ~0.8-0.9 (snow). The interior finished floor height was 1.78 m (5.83 ft) above the ground. The printing plant to the southeast and trees to the west constituted the horizon obstructions (Figure 4-2). The altitude of these obstructions was no greater than 10° in any direction.

The interior daylit space was 13.34 m (43.75 ft) deep along the east-west axis from the west window wall to the face of the core wall and 23.62 m (77.5 ft) wide along the north-south axis from the south window wall to the face of the mirror wall. A mirror was placed along the entire length of the north wall so that the daylighting conditions would be nearly representative of a continuous open plan environment. The mirror caused specular reflections of direct sunlight for some sun angles that would not normally occur in the actual building. These effects were judged to have little impact on the overall results from this field study particularly since direct sun was blocked automatically by the shades. Private offices with clear glazed fronts (facing west) were placed 7 m (23 ft) 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

Several types of open plan office furniture were installed in the mockup but all were of similar dimensions (1.83-m wide by 2.44-m deep by 1.22-m high; 6x8x4 ft) and nearly the same surface reflectances. Desk surfaces were white composite material (r=0.84), low 1.22-m (4-ft) high partition walls were gray fabric (r=0.226), and the carpet was gray (r=0.071). The interior lobby corridor wall was initially a gray fabric (r=~0.70) but was painted with a saturated red (r=0.176) and blue color (r=0.20) after January 19, 2004. The ceiling was composed of hung white gypsum acoustical tiles (r=0.87). The surfaces of the filebars between the work surfaces and at the columns of the mockup were changed from a cherry wood (r=~0.20) to a white laminate (r=~0.8) on 4/29/04 then to a light gray laminate (r=~0.25) in late May 2004.

A flat panel liquid crystal display (LCD) computer video display terminal (VDT) was used on some desks (Hewlett-Packard L1730). This display had a 2% diffuse reflectance and a 1% specular reflectance with a roughness value of 0.07 (measurements taken with a Minolta spectrophotometer CM-2002, ±2%). The maximum luminance was 250 cd/ m^2. Displayed image during monitoring was black 12 pt Helvetica text on a white background that covered the entire display area of the VDT. The text was shifted up and down slightly every 2 s but the overall average luminance was thought to remain constant (within the measurement accuracy of our instruments).

The space was conditioned using an underfloor air distribution (UFAD) system. Conditioned air was supplied at floor level through 15.24 cm (6 in) diameter floor diffusers and a 10.16 cm (4 in) continuous grille register at the window wall. Return air was brought back through registers at the east corridor and through the ceiling plenum. The temperature in the ceiling plenum was roughly the same as the air temperature of the upper stratified air layer in the main interior space. It would have been interesting to evaluate the thermal conditions with the automated shade, recessed lighting system, and UFAD system, but the mockup's UFAD system did not entirely replicate the system to be installed in the actual building. Furthermore, more detailed tests of thermal distribution were already in the works in a separate laboratory study.

4.2.2.2. Façade description

The curtainwall façade was of a rather unique design: an all-glass façade shaded by exterior ceramic tubes. On the west façade, the window wall was composed of a continuous band of 1.52-m (5 ft) wide, 3.15-m (10.3 ft) high, floor-to-ceiling double pane windows separated by narrow vertical mullions. The 2.54-cm (1 in) deep window consisted of two layers of 6 mm (0.25 in) low-iron clear water-white glass where the outboard layer was treated with a neutral spectrally selective low-e coating (Viracon VE13-2M). The window-to-exterior-wall ratio was 0.76 and the center-of-glass window transmittance was T_v=0.75. The center-of-glass solar heat gain coefficient was 0.39 and the U-factor was 1.53 W/m^2-°K (0.27 Btu/h-ft^2-°F). The interior surface reflectance of the glass was Rb=0.12. The windows were set in a 20.3 cm (8 in) deep thermally-broken custom aluminum frame. The window framing was white with a surface reflectance of ~0.7.

Figure 4-3. Exterior view of the west façade.

Approximately 50% of the west façade was shaded by 4.12 cm (1.625 in) diameter off-white horizontal exterior ceramic tubes spaced at variable center-to-center distances and placed 0.46 m (1.5 ft) off the face of the glazed façade (Figure 4-3). The tubes shaded the upper and lower portions of the glazed facade. A vision portion of the window wall from 0.76-2.13 m (2.5-7.0 ft) above the floor was left open for view for a standing or seated occupant. For the upper ceramic tube array, the tubes were spaced 8.9 cm (3.5 in) on center. For the lower tube array, the spacing decreased from 15.4 cm (6.06 in) at the top to 9.68 cm (3.81 in) at the bottom of the lower tube array.

On the south façade, the same window type was used on some sections of the façade while on other sections a 50% horizontal stripe frit pattern was applied (Viracon VE13-2M with V175 frit on surface #2). The frit consisted of horizontal clear and etched glass stripes (50% open) that formed a diagonal pattern matching the stringer course of the stairway located immediately adjacent to the window wall (Figure 4-4). Most of the south façade was not shaded by ceramic tubes; a small section was shaded the entire height with ceramic tubes near the southwest corner. Structural columns and cross-bracing also provided partial exterior shading of the south façade near the southwest corner.

Figure 4-4. Exterior view of the south façade.

In the actual building, the open communicating stair is continuous over many floors of The New York Times's portion of the 51-storey tower. At the mockup, a clear glazed skylight (T_v=0.76) was constructed above the stair to approximate the daylight contributions from the upper floors. The skylight did not have any interior or exterior shading. The stair itself had open treads and a 96.5-cm (38 in) high opaque handrail. Floor-to-ceiling 1.27-cm (0.5 in) thick clear glass walls formed the north side of the stairwell.

4.2.2.3. Shading and lighting system descriptions

The mockup was divided into two nearly equal areas where two different automated roller shade manufacturers and two different manufacturers of dimmable lighting systems installed systems in each area. Area A was designated as the north area of the mockup. Area B was designated as the south area of the mockup. There was no physical wall dividing the two areas. Since Area B was south of Area A, the control sensors and the monitoring equipment in Area A were placed so as to be minimally influenced by the daylighting conditions in Area B.

The automated roller shade systems are described in detail in Section 5. In both areas, a 3%-open woven fabric roller shade was installed with the white side facing out and gray side facing in. The shades were controlled to five preset heights and activated so that all shades on a single orientation were operated to the same height. In Area A, the automated shade control system was designed explicitly to balance window glare, daylight, and view requirements. In Area B, the automated shade control system was designed to lower the shade to block direct sun at a designated distance from the window wall and if no sun was present, to raise the shade to its fully retracted position. Shades on the south and west facades in Area B operated differently.

4.2.2.4. Lighting system in Area A

The fixtures in the open plan area were custom made recessed fluorescent downlights (either Zumtobel Staff Lighting or Mark Architectural Lighting) with two 0.61-m (2-ft) long, 2.54-cm (1 in) diameter 17-W T8 fluorescent lamps (Philips TL835/ ALTO 3500K, CRI=86) placed end to end (essentially a single-lamp fixture) in a steel housing nominally 12.7-15.2 cm wide by 15.24 cm deep by 1.52 m long (5 or 6 in by 6 in by 5 ft), with a matte white enamel finish metal vertical fin reflector, lightly frosted extruded acrylic diffuser, and integral electronic dimming ballast. Two 38.7 cm^2 (6 in2) return air diffuser slots were located at each end of the fixture to allow heat to pass to the ceiling plenum. Two types of dimming electronic ballasts were used. For some lighting zones in Area A, both types of ballasts were used within the same zone.

A single 277 V, 4-wire, 0-10 V dimming ballast (Lutron ECO-T817-277-2, http://www.lutron.com/ballast/specs/eco-120-277.pdf) controlled the light output of the two lamps. Its light output dimming range was 10-100%. Its power dimming range was ~35-100% for this lamp type and configuration. A second 277 V, 4-wire, 0-10 V dimming ballast (Advance Transformer Mark VII VZT-2S32-SC, http://www.advancetransformer.com) also controlled the light output of the two lamps. Its light output dimming range was 5-100%. Its power dimming range was also ~35-100%.

All recessed fixtures in the open office area including the corridor were designated as daylight-controlled fixtures. These fixtures were grouped into six zones that ran parallel to the west window wall (Figure 4-5). All lighting zones were controlled using a single ceiling-mounted shielded photosensor (Lutron MW-PS-CPN2342). The photosensor had a 180° field of view looking toward the window (no significant view toward the back of the room) and a vertical angle (angle from a vector normal to the floor) of ~60° so that its view was broad (cosine spatial response) toward the window wall. This same photosensor was used to control the shades. This sensor was located in zone L3 (third row of fixtures from the north mirror wall and first row of fixtures (3.35 m, 11 ft) from the west window wall) so that it was not significantly influenced by the lighting conditions in Area B. The supervisory embedded control system (Lutron Grafik7000 lighting processor) used input from the photosensor to control each lighting zone. The lighting control system was essentially an open-loop system, but in the first zone closest to the window wall, the photosensor was influenced by the electric lights. The control algorithm was proportional control.

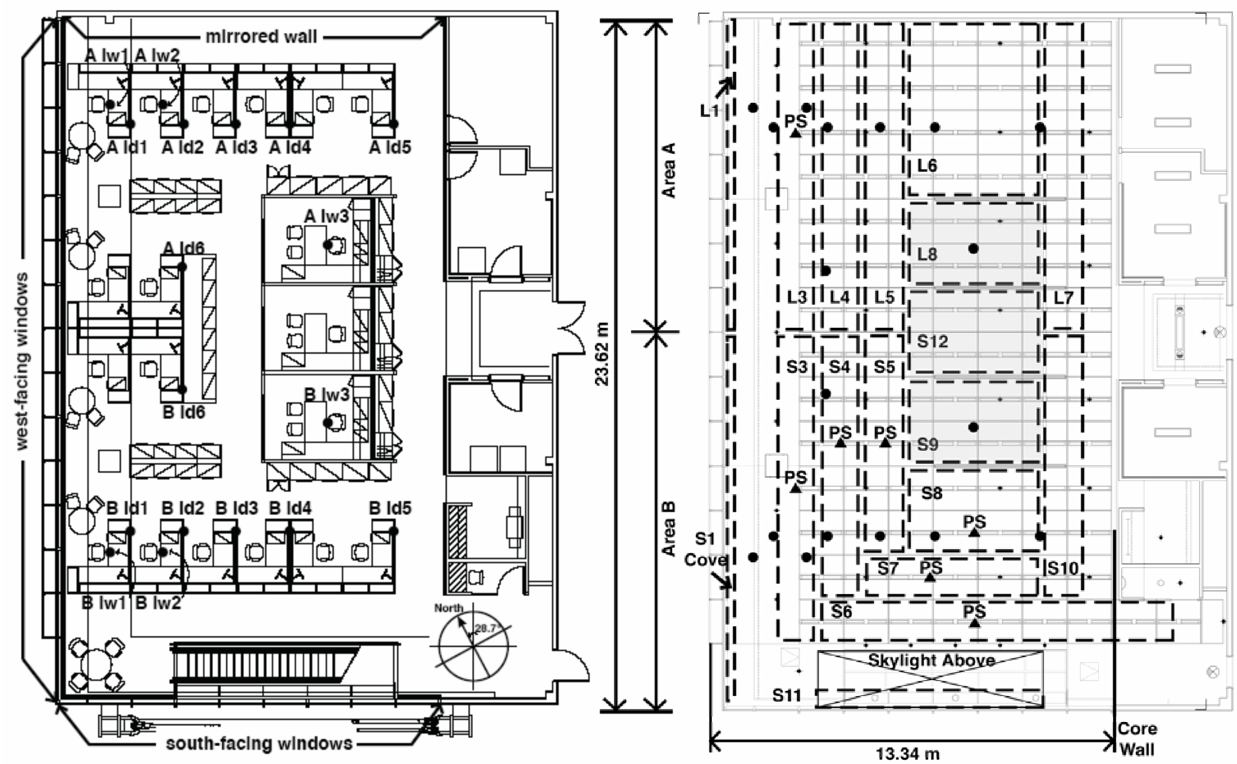


Figure 4-5. a) Floor plan showing the location of the interior illuminance sensors (left) and b) reflected ceiling plan (right) showing the lighting zones and location of photosensors (PS – triangle symbols). Note that there was not a one-to-one correspondence between illuminance sensors and the lighting zones above – illuminance sensor locations are shown on the reflected ceiling plan for reference. Photosensor in S4 was used to control grouped zone S4/S5 and photosensor in S7 was used to control zone S7/S8. North is approximately at the top of the diagram. In the text and on some graphs in Sections 5 and 6, A Iw1 and A Id1 are referred to as A Iwpi1 and A Idist1, as are all remaining illuminance sensors in the above diagram.

The same types of fixtures and ballasts were used in the north private office (Office 106) except that the lighting was manually controlled using a wall mounted keypad connected to the Grafik 7000 system via a digital link. Cove uplighting was installed parallel to the west window wall to provide architectural lighting at night. The cove lighting was scheduled to turn on to full power 20 min after sunset and turn off 15 min before sunrise.

The daylighting control system was designed to dim all lighting zones in the open plan office area in response to daylight so as to maintain the design work plane illuminance level of 484-540 lux from sun up to sun down. However, the average work plane illuminance at 100% power was on average ~400 lux for most work surfaces. Hence, the design setpoint was met only when there was sufficient daylight. During some test periods over the monitored period, the lights were shut off if there was sufficient daylight (0% light output, 0 W). The dimming response occurred over 60 s with a variable turn-off delay once the low end dimming range was reached. During other test periods, the lights were only dimmed down to minimum power. The system was commissioned once in mid-December 2003 during the day with Area B lighting on.

Adjustments were made to the photosensor gain via a control panel setting in the Grafik 7000 system located in the electrical closet. Further tuning of the daylighting system occurred after this initial commissioning.

4.2.2.5. Lighting system in Area B

Similar fixtures and the same lamps used in Area A were used in Area B. All fixtures (Zumtobel Staff Lighting) in Area B were 12.7 cm (5 in) wide. The ballast and lighting control system differed. A prototype 277 V, 4-wire, DALI dimming ballast (Advance Transformer ROVR IDA-2S17 DALI T8 ballasts) was used to control the light output of the two lamps. Its light output dimming range was 3-100%. Its power dimming range was ~35-100% for this lamp type and configuration. The ballast used the same main board as Advance's Mark VII 0-10 V ballast and Advance's DALI interface module; the combination of these two components to control a 17-W T8 lamp had not been previously attempted. The manufacturer stated that there were no unresolved design issues with this prototype ballast. The ballasts were compliant with an evolving DALI ballast protocol being developed by the NEMA DALI working group.

All recessed fixtures in the open office area with the exception of those located in the east corridor were designated as daylight-controlled fixtures. These fixtures were grouped into zones that ran parallel to the west or south window wall (Figure 4-5). A dedicated interior shielded closed-loop integral reset ceiling-mounted photosensor (Siemens Brightness Controller GE 254/ 5WG1-254-4AB-1, http://www.ad.siemens.de/et/gamma/html_76/support/techdoku.htm) served each zone and communicated via an EIB communications network to the EIB DALI Siemens Lighting Panel (*instabus* EIB). The photosensor was pointed downward and had a 360° field of view with an unspecified cut-off angle. Control output from the EIB DALI Lighting Panel was via a 5-conductor cable to the DALI ballasts (62 per group). Individual ballasts were addressable and could be reassigned to a new zone using software within minutes. Independent monitoring of the lighting control system was conducted using the Siemens Apogee Modular Building Controller (MBC-24 Panel, No. 545-141).

The same type of fixtures and ballasts was used in the middle and south private offices (Offices 107 and 108) except that the lighting was controlled using a wallbox manual dimmer (linear slider). Cove uplighting was installed parallel to the west window wall to provide architectural lighting at night. At the request of the building owner, the cove lighting was scheduled to dim up linearly from off to full power over a 30-min period starting 30 min before sunset and dim down from full power to off over a 30-min period starting 30 min before sunrise. Three spot lights (MR16) were mounted above the stair and were on at all times for safety.

The daylighting control system was designed to dim all lighting zones in the open plan office area in response to daylight so as to maintain the design work plane illuminance level of 484-540 lux from sun up to sun down. Like Area A, the average work plane illuminance at 100% power was on average ~400 lux for most work surfaces. The lights were shut "off" if there was sufficient daylight (0% light output, 4% of full power consumption). The daylighting control system was commissioned once in mid-December 2003 during the day with Area A lighting on. Adjustments were made in software to the photosensor gain via the EIB DALI Lighting Panel located in the electrical closet. On 2/28/04, the system was rezoned and recommissioned. The same type of photosensor was used to control the new zones. In the new configuration, zones S4 and S5 were grouped and the photosensor in zone S4 was used to control both zones. Zones S7 and S8 were grouped and the photosensor in zone S7 was used to control both zones.

4.2.3. Monitored data

The mockup was instrumented with LBNL sensors to monitor outdoor solar conditions, lighting energy use, shade positions, and interior lighting levels throughout the day. Time-lapse photographs were also taken at regular intervals during the day. Data were logged using the LabView National Instruments data acquisition software using a standard PC. Additional data were monitored on separate PCs by each of the three participating manufacturers.

A networking system was implemented to enable secure, real-time access to the LBNL PCs and to archive LBNL and the manufacturers' data on a nightly basis. Computerized scripts performed nightly clock synchronization and remote data transfer to a server located at LBNL via an optical/ wireless telecommunications link from the mockup to The New York Times network. The clocks on all the computers were synchronized to within a few seconds so that data collected on the multiple PCs could be compared. Data from the vendors were segregated and encrypted for security purposes.

Power was supplied to the mockup via a diesel generator. This generator was serviced regularly every two weeks, which resulted in momentary power outages. An uninterruptible power supply provided emergency backup power to essential equipment including the LBNL computers.

Field conditions were logged regularly by the Times and vendors. Each maintained their own written log of events that occurred throughout the monitored period including changes to the control system setpoints, glitches, equipment replacements, visits, etc.

Data were recorded every 1 min over a full 24-h day from December 21, 2003 to September 21, 2004. All data were sampled and recorded within a few milliseconds of the time stamp. All data are given in Standard Time unless otherwise noted. Data were post-processed at LBNL using automated scripts to first verify that the test conditions at the site were correctly implemented then compute various performance metrics. Written logs maintained by the manufacturers, the Times, and LBNL were used to corroborate any errors found in the data (e.g., erroneous data caused by power outages or visitors to the mockup, etc.).

4.2.3.1. LBNL instrumentation

Global and diffuse horizontal exterior illuminance were monitored on the roof of the mockup. The sensors were located above any immediate roof obstructions. Global vertical illuminance were also sampled on the south and west facades. These sensors were located so that there was no localized shading from the immediate surroundings (e.g., ceramic tubes or structural cross-bracing). All exterior illuminance levels were monitored using a photopic- and cosine-corrected silicone diode photometric sensor (LI-COR LI-210SA, ±1.5% to 150 klux). All data were sampled and recorded every 1 min. The diffuse exterior illuminance data were not corrected for the effect of the shadowband.

Interior horizontal illuminances (denoted as “Iw” or “Iwpi” in the figures or text) were monitored with LI-COR photometric sensors on either the desk surface (73.6-76.2 cm or 29-30 in above finished floor) or, since the building owner wished to have some of the workstations usable, on the top edge of the workstation partitions (denoted as “Id” or “Idist”, 1.22 m or 48 in above finished floor). The LI-COR photometric sensors have the spectral sensitivity of the human eye. Sensors progressing back from the west window wall were located in either the north-most region of Area A or the south-most region of Area B to avoid influence from the adjacent area; several sensors were located near the center of the mockup so that lateral illuminance distribution could also be evaluated (Figure 4-5). Workplane illuminance was also monitored in the private offices. All data were sampled and recorded once per minute with a reported precision of ±1-2 % for illuminance levels greater than 12 lux.

Average surface luminances were monitored using shielded and unshielded photometric illuminance sensors. Unshielded sensors measure illuminances, but these are equivalent to π times the weighted average luminance of the hemisphere facing the sensor. For shielded sensors, data were converted from illuminance to luminance using a constant, not equal to π, that accounted for the solid angle viewed by the sensor. The shield geometry was designed to cut off the view of the sensor so that it viewed a specific area of a surface. The average luminance of the west- and south-facing windows, vertical partitions with a LCD flat-screen video display terminal (VDT) within view, vertical partitions with bookcases within view, and the horizontal desk surface were monitored. The shield itself was fabricated out of black Delrin plastic. The luminance sensors were mounted on a vertical pole at specific distances from each surface or on the top edge of the workstation partition. All data were sampled and recorded once per minute with a reported precision of ±1-2 % for illuminance levels on the sensor itself of greater than 12 lux. The luminance levels corresponding to this 12 lux lower limit depend upon the shield geometry and range from 30 to 80 cd/m^2.

Window luminance measurements were made over an area defined by 1.2 m (4 ft) above the floor to ceiling height and ~3.66 m (12 ft) width across the west or south façade. These measurements included the luminance of the upper area of the ceramic tubes and the vision portion of the window wall. Separate measurements were made in Areas A and B. The west window luminance was measured from within the private offices. Since the single-pane clear glass doors to the private offices were always closed, the window luminance within the private office would be diminished by the glass transmittance. Therefore, for the west window luminance outside the private offices, the monitored values were divided by 0.9, the assumed glass door visible transmittance.

The accuracy of the illuminance sensors was validated by checking their readings against those of a hand-held Minolta T-1 illuminance meter. The accuracy of the luminance sensors was validated by averaging the luminances of a grid of points over the field of view of the luminance sensor. The luminances of the grid points were measured with a Minolta LS-110 1/3° spot luminance meter.

With all illuminance and luminance sensors, the downstream hardware (cable length, amplifier, and data acquisition system) was designed to minimize electronic noise so that low sensor signals could be read with accuracy. A novel solution using a fiber-optic communications network between PCs was also implemented to minimize electronic noise.

Lighting energy use was monitored for each lighting zone using a watt transducer (Ohio Semitronics GW5, ±0.2% of reading). Lighting energy data were sampled every 6 s then averaged and recorded every 1 min.

The height of each roller shade group was monitored using a shade height transducer (Micro-Epsilon WDS-5000-Z200-CA-P, ±0.1% of full scale output) located below the finished floor of the mockup. A shade height transducer measures distance using a draw wire attached to the bottom hem of the shade. The wire extends and retracts (similar to a fishing reel) using a drum and spring motor as the shade is raised or lowered vertically. The shade height was defined as the distance between the finished floor and the lowest edge of the roller shade. For a fixed shade height of 315 cm (124 in), the measured value varied by 0.48-1.45 cm (0.19-0.57 in) or 0.15-0.46% over a 30-min period due to electronic noise. All data were sampled and recorded every 1 min.

The sky condition was monitored using a charged coupled device (CCD) camera with a wide-angle lens looking vertically through the clear glass skylight above the staircase. Direct sun can swamp the image exposure so the camera was coupled with a shadowband. Images were taken every 10 min from 4:00-20:00. Interior photographs were also taken in each Area's first workstation (from west window) looking at the VDT monitor or at the bookcases and from the ceiling looking east at the workstations using a low-resolution CCD camera. Images were taken every 10 min from 4:00-20:00 for diagnostic purposes.

Digital luminance maps were taken for the spring equinox condition. For a given viewpoint, five exposures were taken of the scene in less than 1 min using a digital camera with an equidistant projection fisheye lens (Nikon Coolpix 990 camera and FC-E8 lens). These exposures were then processed using the Photolux image processing software [Coutelier and Dumortier 2003, ENTPE 2001] to convert the image into a luminance map. The accuracy of this procedure had been determined prior to these measurements by photometering a scene both with the camera to get luminance maps, and with a Minolta LS-110 luminance meter to get the luminances of marked areas in the scene. The calibration range was from 70 to 8000 cd/m^2, and the standard deviation of the fit of the luminance map values to the Minolta values was ± 9%.

Spot illuminance measurements were taken at the mockup during the vernal equinox site visit using a hand-held illuminance meter (Extech model 401036, ±3% of reading, http://www.extech.com/instrument/categories/light/light.html).

4.2.3.2. Data provided by the manufacturers

All manufacturers logged sensor and control data on the same computers used to control their shade and/or lighting systems in the mockup. These data were used by the manufacturer to troubleshoot operations and evaluate performance independently from LBNL. Data were recorded every 1 min over the 24-h day. Data used by LBNL for this analysis ware described as follows.

Occupancy in Areas A and B was monitored by the two lighting control manufacturers. In Area A, four ultrasonic ceiling-mounted occupancy sensors (Lutron MOS-CM2W-15-WH) were located throughout Area A with very broad views of the space. In Area B, ceiling-mounted motion detectors (Siemens 5WG1 258-2AB11) were located in six locations with also broad views of the space. Some sensors were falsely triggered by shade movement so the space was deemed occupied only if the same status was registered on multiple sensors.

Interior dry-bulb air temperature was monitored in Area B at a height of 1.52 m (5 ft) above the finished floor using a wall mounted platinum RTD temperature sensor (Siemens 536-752, precision of ±0.39°F). The sensor was shielded from direct solar radiation.

Several lighting zones were not monitored by LBNL. These zones included the cove lighting in Areas A and B, the stair lighting (3 MR16 pointing down on staircase) and the center private office (Office 107). The cove and private office lighting zones were to be off during the daytime. The stair lighting was to be on at all times. The on-off status of these lighting zones was determined by using the manufacturers' data.

The control status of each shade group was monitored by the manufacturers. When automatic operations were overridden by the manual wall switch or by the main control computer, this status was reflected in the logged data as a flagged event or a change in control mode. The manual control status was logged properly in Area A after February 10, 2004 and in Area B after March 2, 2004. Prior to these dates, the written log provided the dates when the shades were manually overridden.

4.2.4. Methods of data analysis

4.2.4.1. Overall approach

Data analysis consisted of evaluating the shade and lighting control systems' performance, daily lighting energy use savings, and visual comfort and quality (view) in each Area of the mockup. The data were filtered prior to analysis to eliminate erroneous data. If there were errors, data were eliminated for the entire day since most errors occurred over the majority of the day. The mockup served a role as both a daylighting laboratory and a furniture mockup for The New York Time's employees to view and comment on their new workspace. Tours were also given to interested outside parties. During or in preparation for these activities, sensors were blocked, disconnected, or moved, furniture was misplaced, VDTs were moved, private office lights were turned on, and the automated shading systems were overridden. A combination of written logs, occupancy data, control status data, and webcam images were used to filter the data for these events. Other errors occurred. Some of these events invalidated some of the data, depending on the performance parameter being computed. For example, occupancy invalidated the data used to evaluate the daylighting control system performance and visual comfort because the illuminance sensors could have been shadowed by visitors or covered inadvertently by a coat. Lighting energy use was not affected by occupants since daylight control systems are expected to function properly with or without the presence of occupants. Data filters are discussed below for each performance parameter.

Although the initial intention of this field test was to maintain the same shading and lighting control configuration over the entire monitored period in order to obtain statistically significant results that would reflect annual performance, adjustments of the control system were later permitted to improve overall system performance. When significant changes to the shading or lighting control system occurred, summarizing the data (e.g., averaging) is of limited statistical significance because the solar angles, weather conditions, and length of the test period differed between the datasets. Test period 1 may have included two weeks worth of data with the shades and lighting operated one way in January while test period 2 may have included three months worth of data from February to April with the shades and lighting operated another way, for example. Both the difference in daylight availability and sun path relative to the window confounds the results. An average of the lighting energy savings for each of these periods would not inform the reader whether control algorithm 1 performed better than control algorithm 2. Analyzing the data to correlate the performance values to deterministic factors and thus explain or extrapolate the measured performance to annual performance was beyond the scope of this work. When possible, some data were related to deterministic factors such as daylight availability or solar position, but for the most part this analysis simply discusses the incremental changes in performance as the systems were tuned.

There were some direct comparisons made between the automated shade performance in Area A versus B. For all other performance metrics, these Areas were not compared because of the difference in space and window geometry. This analysis was not focused on a side-by-side comparison to determine who provided the "best" product. This analysis focused on understanding within a specific Area of the mockup what the performance would be and how it could be improved.

4.2.4.2. Tested configurations

The monitored field test was designed to measure the energy and comfort impacts of automated shading and daylighting controls in the area influenced by those technologies. The manufacturers were therefore requested to configure their respective areas when the sun was up as follows:

- Designated recessed fixtures in the open plan office zone to be daylight controlled.
- Cove lighting near the west-facing windows turned off.
- Stair lighting near the south-facing windows turned on (to meet building owner's safety requirements). Illuminance contributions to the daylit zones were insignificant and did not affect the monitored lighting energy savings or control system performance.
- Private office lighting off. Illuminance contributions to the daylit zones were significant. To isolate lighting energy savings to the windows alone, the private office lights were turned off.
- Shades in automatic mode.

For the majority of the monitored period, these conditions were adhered to by the manufacturers. Several complications did occur. Tours of the mockup were given by the building owner and on occasion, the private office lights (any of the three offices) were left on for an arbitrary length of time. Momentary power outages occurred every two weeks when the power generator was being maintained. These outages caused the lighting system in Area B to reset its control configuration and not return immediately to the automatic mode (e.g., cove lighting would be turned on or other zones that should have been on were off for an arbitrary length of time). For some of these conditions, the data was analyzed as alternate configurations; for others, the data were deleted. Analysis methods for these arbitrary conditions are discussed for each performance parameter in the following sections below.

Manufacturers were encouraged to tune their products in response to feedback from the building owner and LBNL. In both Areas, the shade control system settings were tuned several times throughout the monitored period to either respond to new building owner requirements or to improve performance. In Area B, the lighting control system was rezoned in order to improve performance. These test configurations or control algorithm adjustments are given in Tables 4-1 and 4-2.

Table 4-1.
Tested configurations in Area A

Automated Roller Shade

From mm/dd/yy	(DOY)	To	(DOY)	Config. No.	Shade algorithm
12/21/03	-11	01/20/04	20	1	Improperly adjusted: ignore data
01/21/04	21	02/09/04	40	2	Daylight mode 1: more daylight, less glare control
02/10/04	41	04/13/04	104	3	Daylight mode 2: more daylight than config. 2
04/14/04	105	04/22/04	113	4	Glare mode 1: more glare control, less daylight
04/23/04	114	09/21/04	265	5	Glare mode 2: more glare control than config. 4

Daylight-controlled Lighting System

From	(DOY)	To	(DOY)	No.	Ballast errors	Lights off?
12/21/03	-11	02/05/04	36	1	L4 out +	yes*
02/06/04	37	02/23/04	54	2	All ok	yes
02/24/04	55	04/14/04	105	3	All ok	no**
04/15/04	106	06/20/04	172	2	All ok	yes
06/21/04	173	08/06/04	219	4	L6 out ++	yes
08/07/04	220	09/21/04	265	2	All ok	yes

DOY: day of year; mm/dd/yy: month/day/year
+ 1 fixture in zone L4 was non-operational; no effect on data.
++ 1 fixture in zone L6 was non-operational; lighting energy data adjusted, illuminance data eliminated.
* The fluorescent lights were dimmed between full to minimum power and turned off if sufficient daylight.
** The fluorescent lights were dimmed between full and minimum power in response to available dayl

Table 4-2.
Tested configurations in Area B

Automated Roller Shade

From mm/dd/yy	(DOY)	To	(DOY)	Config. No.	Sun Penetration depth (m) West	Sun Penetration depth (m) South	Glare control West
12/21/04	-11	01/11/04	11	1	0.91	0.91	no
01/12/04	12	03/01/04	61	2	0.91	3.05	no
03/02/04	62	04/15/04	106	3	0.91	3.05	no
04/16/04	107	08/04/04	217	4	0.91	1.83	no
08/05/04	218	09/21/04	265	5	0.91	1.83	yes

Daylight-controlled Lighting System

From	(DOY)	To	(DOY)	No.	Ballast errors	Zoning
12/21/03	-11	02/06/04	37	1	S6 off, S7 error+	All separate zones
02/07/04	38	02/26/04	57	2	All ok	All separate zones
02/27/04	58	03/10/04	70	3	All ok	S4/S5 and S7/S8 grouped
03/11/04	71	05/25/04	146	4	S3 error	S4/S5 and S7/S8 grouped
05/26/04	147	07/25/04	207	5	S3 off	S4/S5 and S7/S8 grouped
07/26/04	208	08/02/04	215	6	S3 off, S6 error+	S4/S5 and S7/S8 grouped
08/03/04	216	08/06/04	219	5	S3 off	S4/S5 and S7/S8 grouped
08/07/04	220	09/03/04	247	4	S3 error	S4/S5 and S7/S8 grouped
09/04/04	248	09/21/04	265	6	S3 and S6 error+	S4/S5 and S7/S8 grouped

DOY: day of year; mm/dd/yy: month/day/year
If there was sufficient daylight, the fluorescent lights were turned off.
+: error: unknown effect on data; off: lighting energy adjusted, S3 illuminance deleted, S6 illuminance unaffected.

The building owner made several changes to the mockup space that affected the surface reflectances of the room interior:

- The east core wall was changed from gray fabric to a bright red in Area A and bright blue in Area B on 1/19/04. Surface reflectance data are given above in Section 4.2.2.1.
- The surfaces of the furniture in Area A were changed slightly. The surfaces of the filebars between the work surfaces and at the columns of the mockup were changed from a cherry wood to a white laminate on 4/29/04, then to a light gray laminate in late May 2004.

4.2.4.3. Daylighting control system performance

The daylighting control system performance was evaluated by determining the percentage of day (sun up) when the total horizontal illuminance (from daylight and the fluorescent lighting) was less than 1) 90% of the maximum fluorescent illuminance level achieved at each sensor (or –10% "sag" in the illuminance), or 2) the minimum design setpoint of 484 lux for visual tasks at sensors Iw1 and Iw2. The desired 484-538 lux setpoint range was not achieved on all desk surfaces even when the fluorescent lighting was at full power with no daylight. This was due to improper manufacturing of the fixtures, the lighting design, and late changes to the lighting design by the owner. Therefore, the daylighting control system was evaluated using the maximum fluorescent lighting level. The maximum fluorescent illuminance levels were defined when all the open plan daylight-controlled lighting zones in a single Area were set to full power at night for at least 30 min (nighttime tests were regularly scheduled every month throughout the monitored period). All other lights were turned off: the cove lighting in the open plan area, the private office lighting zones, and the other Area's lighting system. Maximum levels were adjusted if ballast failures occurred and there were nighttime data available to establish the new maximum levels. These maximum fluorescent illuminance levels should be met by the daylighting control system at all times during the day.

The manufacturers stated that they commissioned their system to provide a total illuminance (daylight plus fluorescent light) of 484-538 lux at the work plane surfaces throughout the mockup. So the second evaluation method above was applied to the work plane sensors closest to the window wall (Iw1 and Iw2). The remaining sensors located at partition height could not be evaluated using the same criteria because it is not possible to derive work plane illuminance from the partition-high illuminance data.

The illuminance data were filtered prior to analysis as follows:

- If the average daytime interior dry-bulb temperature was not within 18.3-23.9°C (65-75°F), then data were deleted. This filter provided some assurance that the electric lighting system was operating at approximately the same level of efficiency throughout the test period.
- If the space was occupied, then data were deleted. Visitors may have blocked the horizontal illuminance sensors.
- If sensors were disconnected or misplaced or furniture was misplaced, then data were deleted.

- If the lighting system was not in automatic mode due to a power outage, vendor or building owner override, or other event, then data were deleted. The manufacturer had remote access to the control system to make updates or implement changes so logs and data were checked to determine control status.
- If the automated shade was not operating properly (either due to mechanical problems or manual override), the daylighting control system should still work. Data were not deleted if this occurred.
- If the cove lighting was on, data were eliminated.
- If some fluorescent lighting zones were on or when they should have been off or on, then data were corrected or flagged as described below.

4.2.4.4. Lighting energy use savings

Daily lighting energy use savings were determined for each daylight-controlled zone where:

- the base case was defined by the installed fluorescent lighting system without daylighting controls operating at 100% power over the entire day, and
- the test case was defined by the same installed fluorescent lighting system with daylighting controls being dimmed in proportion to available daylight over the entire day.

The savings were computed using several different schedules (hourly, weekday, or holiday lighting load schedules were not applied to the computation):

- Sun up to sun down. For reference, the sun is up 4:40-19:20 ST during the summer solstice and 7:20-16:40 ST during the winter solstice. Note that the base case (no dimming) daily lighting energy use consumption varies due to seasonal variation in daylight hours. This metric is useful for understanding the maximum energy savings potential.
- Lighting energy use during the 12-h period from 6:00-18:00 (DST).
- Lighting energy use during the 10-h period from 8:00-18:00 (DST).

Daily total perimeter zone lighting energy savings were computed by summing the lighting zone energy use of all daylight-controlled zones (L3-L7 or S3-S8) in each Area using the three above schedules. This quantity is given in kWh per unit floor area, where the perimeter zone floor area was defined by the area from the west window to the east wall of the corridor (including the private office floor area). The energy use of the cove, stair, and private office lighting was not included in these computations. The data were filtered in the analysis to adjust for ballast failures and unintended light sources (private office, cove, or corridor lighting) being erroneously controlled as described below.

Lighting energy use data were filtered prior to analysis as follows:

- If the average daytime interior dry-bulb temperature was not within 18.3-23.9°C (65-75°F), then data were deleted. This filter provided some assurance that the electric lighting system was operating at approximately the same level of efficiency throughout the test period.
- If the lighting system was not in automatic mode due to a power outage, vendor or building owner override, or other event, then data were deleted.
- If the shading system was not working properly or was in manual mode, data were deleted. The shade operations affect daylight availability so lighting energy savings are dependent on the automatic shade system.
- Data were not deleted if the space was occupied or if the interior illuminance sensors were not working. The daylighting controls should work irrespective of occupancy or the independent sensors.
- In the instances when ballasts failed, the power levels of both the base and test cases were corrected using monthly nighttime data.
- If some fluorescent lighting zones were on or off when they should have been off or on, then data were flagged as sub-cases to the main analysis as described in the next two sections below.

4.2.4.5. Ballast errors

There were three types of lighting control errors that occurred at the mockup:

1. A ballast failed and the two lamps within the fixture failed to operate (no light output). However, the non-functioning ballast did not affect the control of its zone nor the adjacent zones.
2. A ballast failed and the non-operational fixture (no light output) did affect the control of its zone and the adjacent zones.
3. The operation of a ballast was intermittent or different from the operation of the other ballasts in the same zone. Its operations did affect the control of its zone and the adjacent zones.

In Area A, since ballast control was via 0-10 V (1-way communication only), there were no diagnostic features that notified the user of lamp or ballast outages. Visual checks of the lighting were performed during periodic site visits, but since the lights were dimmed, ballast failures often went undetected unless it was an overcast day and the adjacent lights were near or at full light output. Therefore, the exact dates when ballast failures occurred were determined by looking at nighttime power consumption levels and comparing these levels to previous days. The manufacturers typically controlled their lights to maintain the 484-538 lux setpoint during the night. Drops in this maximum level over a sustained period of days typically indicated a true ballast failure. These failures were confirmed by observations at the mockup. The date when ballast replacements were made was confirmed by the written log and by reviewing nighttime power consumption levels.

In Area B, the DALI ballasts have the capability to report when lamps or ballasts have failed. However, this output feature was either not programmed properly at the beginning of the test or was not functioning reliably. Therefore, the dates of when the lamps or ballasts failed were determined using the same method as in Area A. Erratic DALI ballast operations that occurred in Area B were much more difficult to detect. The same nighttime tests were used. Reliance was also placed on the written logs indicating unusual operations at the mockup.

Corrections to data given ballast error type 1 in zones L4, L6, and S6a.

Total daily lighting energy use varied when ballasts failed. In order to maintain the same energy baseline from which to refer to *percentage* of daily lighting energy savings, a power correction was made to the data. To illustrate the purpose of this correction, take an extreme example where 50% of the installed equipment failed for some part of the monitored period. Comparing the percentage of daily lighting energy savings on only half of the operational equipment to the percentage savings when all the equipment is operational would be misleading since the baseline power consumption was not the same.

To make the corrections, an assumption was made that the same dimming level would have occurred if the ballast was operating properly. For Area A, this assumption was correct since the failed ballast in L4 (southern-most fixture) and L6 (west most row, second fixture from the north wall) did not influence any zone seen by the photosensor. For Area B's zone S6 eastern-most fixture (S6a), this assumption was also correct, since the failed ballast did not influence any zone seen by the photosensors. (At the startup of the test, several ballasts were not working and no spares were available. The non-operational fixtures L4 and S6a were located in places that had the least influence on the monitored results.)

The corrections were made as follows:

$$P'(t) = [P(t)/Pmax(t)] * Pmax.installed \qquad (1)$$

where,
P'(t) is the power consumption of the dimmed zone at time t if there were no ballast failures
P(t) is the monitored power consumption in the dimmed zone at time t
Pmax(t) is the maximum power consumption if the zone is set to 100% (with ballast failures)
Pmax.installed is the maximum power consumption in the non-dimmed zone if there were no ballast failures

Maximum fluorescent illuminance levels for these alternate zone configurations were established using nighttime tests. For the case of failed ballasts L4 and S6a, nighttime data were available. For the case of failed ballast L6, no nighttime data were available so data from the affected sensor, Id4, were flagged.

Corrections to data given ballast error type 2 in zone S3

In the case of the type 2 error, the ballast was known to be off (completely non-operational). The baseline could not be corrected because the errant ballast affected daylighting control of its own lighting zone and the immediately surrounding lighting zones. Savings were therefore computed relative to a new baseline maximum power consumption level: the total load minus the power consumption of the non-operational ballast. This type of error occurred in zone S3 (west-most row, fourth fixture from the south window) where the fixture was the one that held the zone's photosensor centered between the two non-operational lamps. Maximum fluorescent illuminance levels for this alternate zone S3 configuration were established using nighttime tests.

Corrections to data given ballast error type 3 in zones S3, S6b, and S7

There were several ballasts in Area B with intermittent operations that were difficult to detect. These occurrences were frequent enough to cause the entire dataset to be severely reduced. However, since only one ballast was affected per zone and no more than two ballasts were affected in Area B at any one time, these data were retained in the analysis. The intermittent ballasts were in zones S3, S6b, and S7 where the fixtures affected were the ones that held the zone's photosensor centered between the two non-operational lamps. The start and end dates for these operations were established using the nighttime power comparisons described above for ballast error type 1. Since this test was not always conclusive for ballasts in zones S3 and S6b, the data were flagged. Observations in the field indicated that the fixtures were either on at what appeared to be full power compared to the rest of the fixtures in the same lighting control zone, dimmed, or off. The ballast in zone S7 was fixed before the lighting control system was properly commissioned so lighting energy data and control performance for this zone and period (12/21/03 to 2/6/04) can be ignored.

For ballast errors of type 3, neither the power level nor the maximum fluorescent lighting illuminance level could be adjusted. Note that the operations of the intermittent ballasts did affect its own and the adjacent lighting zones. The lighting energy use savings should be regarded as a completely different case from the other test cases.

The intermittent ballast caused the maximum illuminance level at the sensors to vary arbitrarily (unknown dimming level at an unknown time). For the case of the intermittent ballast S3, the maximum fluorescent illuminance was used assuming all ballasts were operating properly. Reducing the maximum illuminanace levels of S3 to that established for error type 2 above would have yielded a less conservative assessment of the daylighting control system performance. For the case of zone S6b, the nearest sensor was ~6 m (19.7 ft) away so its intermittent operation had an insignificant impact on sensors. The maximum fluorescent illuminance was established assuming all ballasts were operating properly.

4.2.4.6. Unintended light sources

The lighting configurations in Areas A and B deviated from that defined by LBNL in three ways:

- Any one of the three private office lights were on for greater than 60 min during the day and at an arbitrary dimming level.
- The cove lights in Areas A and B were on (independently) for greater than 60 min during the day and at an arbitrary dimming level.
- Zone S10 was off for greater than 30 min during the day when it was supposed to be on at 100% power.

The private office lights were sometimes on inadvertently. In Area A, the control photosensor was beyond the influence of the private office lighting so the daylighting controls were not affected by this unintended light source. Even so, the maximum fluorescent lighting level at the nearest sensor Id7 was increased by no more than 12 lux and all other sensors were increased by no more than 7 lux when the lights in the private office 106 closest to the Area A open plan sensors were on at full power. The maximum fluorescent lighting levels were not adjusted for the daylighting control system evaluation because the influence was small and because there was no reliable method of correcting the data due to ballast failures in Area B’s offices 107 and 108 and erratic switching and dimming levels in all three offices. In Area B, the private office lights affected daylighting control of the adjacent lighting zones S4 and S5, and possibly others as well. Since this represents a realistic case that will occur in the actual building, lighting energy use data were flagged if any one of the three private office lights were on for greater than 60 min during the day and at an arbitrary dimming level. These data show the additional savings that can be attained by harvesting other sources of light. As an indication of magnitude, the illuminance level at 76.2 cm (30 in) above the floor in the middle of the corridor in front of the private offices was increased by 80-130 lux when the lights in all three offices were turned on to 100% power. Similar to Area A, the maximum fluorescent lighting levels at the work plane and partition sensors were not adjusted for the daylighting control system evaluation.

If the cove lighting was on for greater than 60 min during the day at some arbitrary level during the day in either Area, the lighting energy savings data were flagged. This was done primarily to broaden Area B’s dataset. The daylighting control system performance data were deleted if the cove lighting was on. Cove power levels were not monitored so we were unable to accurately assess daylight control system performance. Unfortunately, this was a fairly critical period for evaluation because the daylighting control system is typically in its transitional dimming range (not fully on or off) due to diminishing daylight levels. This is expected to skew the daylighting control system evaluation at primarily the first workstation from the west windows. When at full power, the cove lights contributed 53 lux (Iw1) and 12 lux (Iw2) in Area A and 76 lux (Iw1) and 10 lux (Iw2) in Area B.

If the corridor lighting zone S10 was off for greater than 30 min during the day when it was supposed to be on at 100% power, the lighting energy savings data for Area B were flagged, primarily to broaden Area B's dataset. Lighting energy savings would have been greater had S10 been on as designed. Data for sensor Id5 were eliminated from the daylighting control system analysis. With respect to lighting energy savings, the photosensors controlling zone S6 and S7/S8 may have been affected by S10 since they were 3.05-4.57 m (10-15 ft) from the center of the S10 fixtures. The position and view of the closed-loop photosensors were designed to see the light within their specific zone.

4.3. EXPERIMENTAL RESULTS

Since both the lighting and shading control configuration changed several times over the monitored period, the control configuration number (see Tables 4-1 and 4-2) was plotted on the second y-axis for reference. Data for similar solar conditions before and after a change in shade and lighting controls are presented in time-of-day plots.

4.3.1. Daylighting control system performance

4.3.1.1. Area A

Dimming profiles showing lighting power and total illuminance (daylight + fluorescent lighting) versus time of day are given for clear sky conditions in Figure 4-6 (4/24/04) to illustrate the operation of the open-loop proportional control system in Area A. For this west-facing window, daylight contributions were from the sky during the morning hours when the shades were fully retracted, then from brighter diffused sunlight as the sun moved into the plane of the window and the shades were gradually lowered to control glare and direct sun in the afternoon. The fluorescent lights dimmed down gradually to minimum power (~35% of full power) then were turned off when there was sufficient daylight (e.g., zone L3 at 11:15). All sensors maintained illuminance levels above maximum nighttime levels (Imax) during daytime hours (for each sensor, the Imax value can be seen at 5:00 in Figure 4-6).

One might argue that for this day at least, greater lighting energy savings could have been attained since Imax or the 484 lux setpoint (at the work plane sensors) were exceeded significantly at all sensor locations throughout the majority of the day. Sensors Iw2 and Id2 were on the border between zones L3 and L4. Sensor Iw2, which was shadowed by the 1.2 m-high partitions, measured total illuminance levels that were greater than 520 lux for the majority of the day. Illuminance levels at sensor Id2 (unobstructed by vertical partitions) were greater than 600 lux for the majority of the day (Imax=505 lux). Lighting zone L3 could have been dimmed more given the setpoint level of 484 lux. Other days may have been less conservative.

The daylighting control system was responsive to changes in daylight levels. Nearly instantaneous changes in the fluorescent lighting occurred when the shade was adjusted. For example, in Figure 4-6 at 14:30, zone L3 was switched between 0% and 60% power in less than 2 min. The building owner did not notice or complain about the rate of these adjustments.

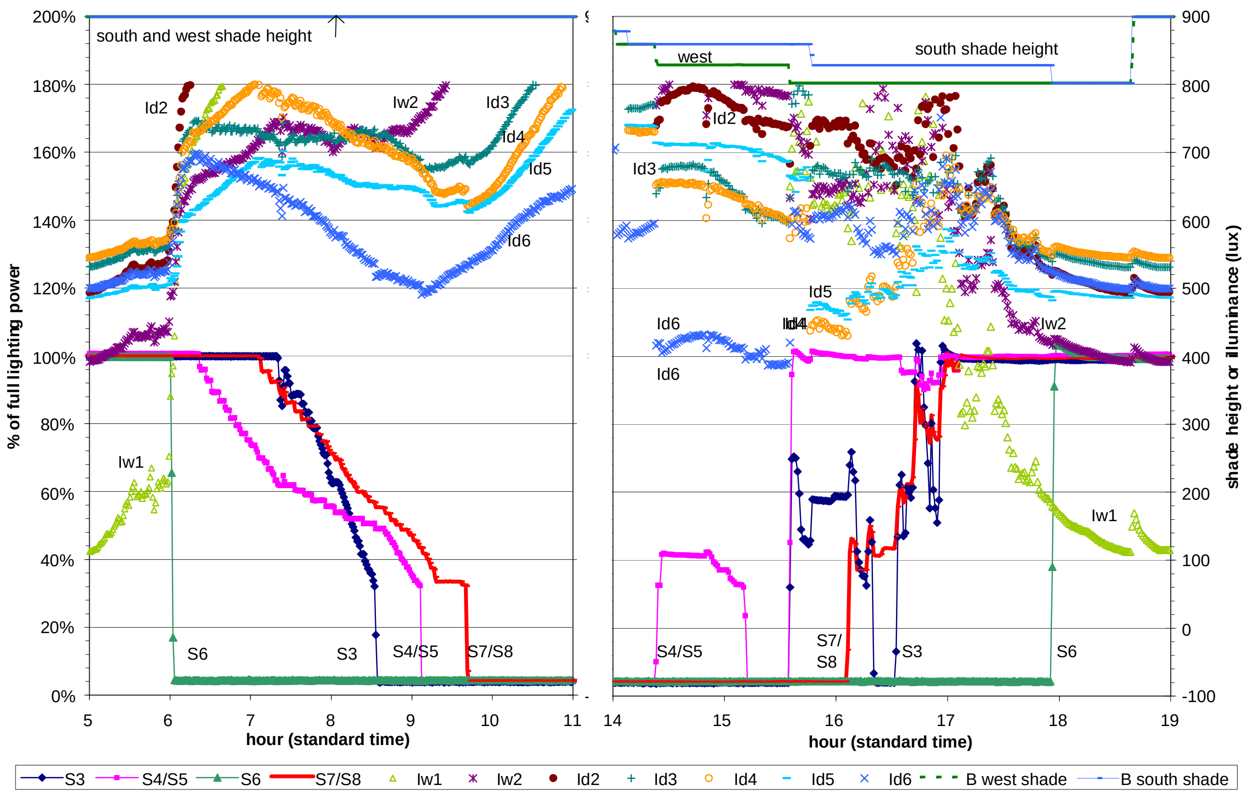


Figure 4-6. Area A (west-facing window): Dimming profiles for zones L3-L6 and total illuminance on a clear sunny day, April 24, 2004. The dimming profiles are shown as a percentage of full power (left y-axis). Total illuminance levels are given on the right y-axis (values are truncated above 800 lux), where maximum values (lux) were: Iw1=111, Iw2=391, Id2=505, Id3=556, Id4=563, Id5=502, Id6=482 lux. The right y-axis also shows the position of the shades (900=up, 800=down). Zone L7 (not shown) was dimmed down to 97% minimum. The work plane illuminance setpoint was 484 lux. Automated shade in glare control mode. Sunrise: 5:06, sunset: 18:54.

Initially, the daylighting control system was not commissioned properly so the performance criteria were met for as little as 38% of the day at some sensor locations. The system was tuned following two one-day site visits (one to troubleshoot operations, the second to re-commission the system) between late December and late January. Good control system performance was achieved over the remaining monitored period. The control system maintained total illuminance levels above 90% of Imax for greater than 98% on all days at all sensor locations and on average 99.9±0.5% of the day at all sensor locations from 1/21/04 to 9/21/04. The 484 lux work plane setpoint level was maintained at sensors Iw1 and Iw2 for 75% and 78% of the day, respectively, on average. This lesser performance was likely due to the limited capacity of the fluorescent lighting system, where the setpoint was not met just after sunrise and just before sunset as illustrated in Figure 4-6.

4.3.1.2. Area B

The dimming profiles for Area B differed from those of Area A because daylight was admitted from both the south- and west-facing windows and the zones were laid out differently from Area A. The illuminance profiles also differed because unlike the sensors in Area A, which progressed back from the west window wall, the sensors in Area B progressed back from the west window but also ran parallel to the south window wall with an intervening staircase and skylight affecting sensors Id3-Id5.

Dimming profiles are shown for 4/24/04 under clear sky conditions in Figure 4-7 to illustrate the operation of this closed-loop integral reset system. Plentiful daylight came from both the south and west windows enabling all dimming zones to be turned off from 9:45-14:10. Under clear sky conditions in the morning, south and west shades were fully retracted. Direct sun was controlled to 1.82 m from the south window and later in the day, to 0.91 m from the west window wall. Sensor Id4 was positioned just south of the photosensor (located in zone S7) controlling grouped zone S7/S8. Its total illuminance was greater than Imax (=556 lux) throughout the morning. Under slightly cloudy conditions in the afternoon, however, its illuminance was less than 90% of Imax (556*0.90=500 lux) for ~30 min or 5% of the day. Illuminance levels were maintained above 90% of Imax throughout the day for all other sensors. For sensors Id2 and Id3, which correspond roughly to grouped zone S4/S5, illuminances were maintained well above Imax (=496 and 534 lux, respectively) in the morning and afternoon. Sensor Id6 data are also shown in Figure 4-7 for reference, but this sensor was influenced by Area A's shade and lighting operations and so was not used to evaluate operations.

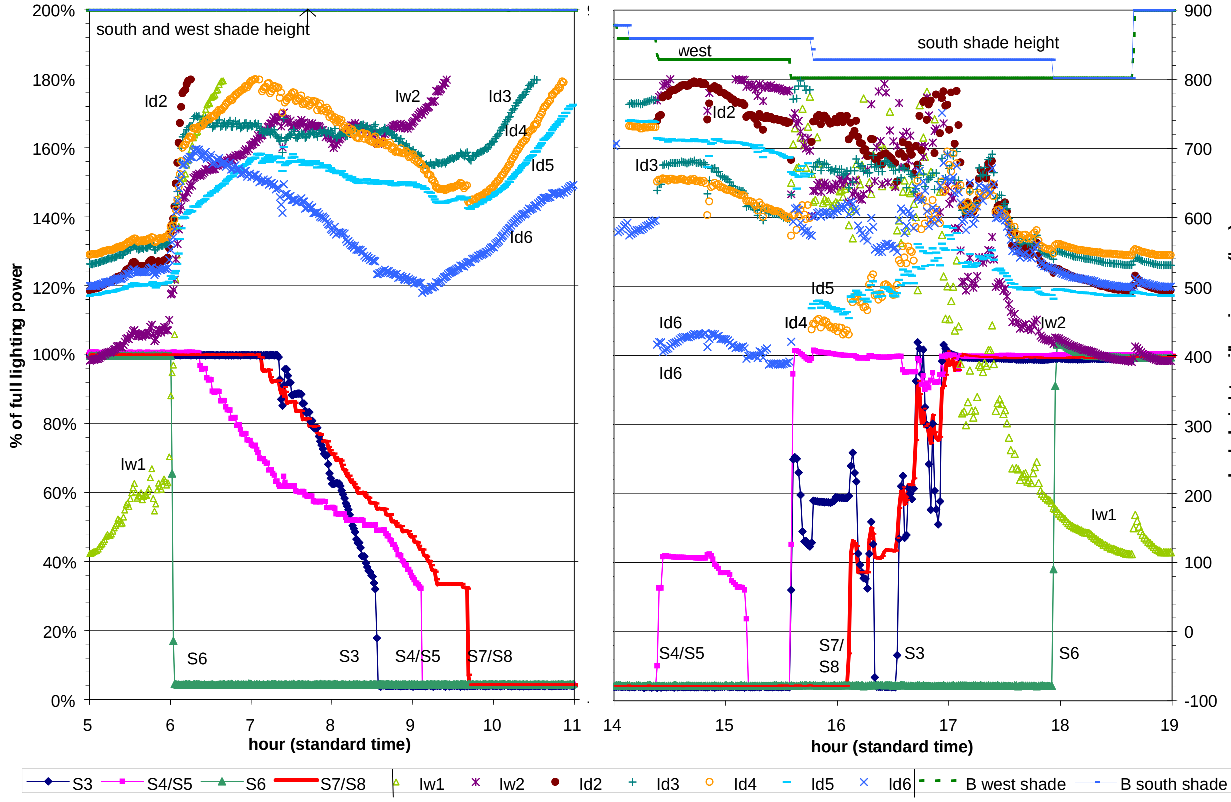


Figure 4-7. Area B (south and west-facing windows): Dimming profiles for zones S3-S8 and total illuminance on April 24, 2004. The dimming profiles are shown as a percentage of full power (left y-axis). Total illuminance levels are given on the right y-axis (values are truncated above 800 lux), where maximum values (lux) were: Iw1=115, Iw2=392, Id2=496, Id3=534, Id4=556, Id5=492, Id6=471 lux. The right y-axis also shows the position of the shades (900=up, 800=down). Work plane illuminance setpoint was 484 lux. Sunrise: 5:06, sunset:18:54. Hours 11-14 are not shown because lighting was turned off in all zones.

After some adjustments to the lighting control zones, photosensors, and commissioning parameters, the control system maintained the total illuminance levels above 90% of the maximum fluorescent illuminance level for greater than ~60% of the day at most sensor locations and on average 97.9±6.1% of the day at all sensor locations over the monitored period from 2/27/04 to 9/21/04 (Figure 4-8). There were 16 days out of the total 72 useable days that met these criteria for less than 90% of the day. When this occurred, illuminance levels at numerous sensors were inadequate, possibly due to erratic ballast behavior such as that in zone S3 or S6, poor commissioning, or inadequacy of the photosensor control system. These outlier datapoints occurred initially at sensors Id3, Id4, and Id5 (until ~6/28/04 or DOY=180), then later included the sensors near the west window.

The control system maintained the work plane illuminance setpoint of 484 lux for 77% and 80% of the day on average at sensors Iw1 and Iw2, respectively. Like Area A, the setpoint level was typically not met just after sunrise and just before sunset because of the limited capacity of the fluorescent lighting system.

Figure 4-8. Area B: Percentage of day when the illuminance at each sensor was greater than 90% of the maximum fluorescent illuminance level. S3 flag: likely to reduce Id1 illuminance very slightly; S6 flag: not likely to affect data; S10 flag: Id5 data deleted.

4.3.2 Lighting energy use savings

4.3.2.1. Area A

Daily lighting energy use savings (sun up schedule) for each lighting control zone are shown for all shading and lighting configurations in Figure 4-9. Lighting energy savings were inversely proportional to the distance from the window wall: savings were greater closer to the daylight source. This window source was largely diffuse since direct sun was always controlled to within 0.91 m from the window wall by the roller shade. As expected, savings were also linearly proportional to daylight availability. Sunnier conditions yielded greater lighting energy savings. Total daily lighting energy use savings for Area A to a depth of 7 m (zones L3-L5) are also shown for the sun-up schedule in Figure 4-9. These average area savings were computed to a zone depth of 7 m so as to enable comparisons between this sidelit space and the 7-m deep bilateral sidelit Area B space. Daily area lighting energy savings from the 6:00-18:00 DST and 8:00-18:00 DST schedule correlated linearly to the sun-up schedule by a factor of 1.08 (r^2=0.89) and 1.15 (r^2=0.91), respectively.

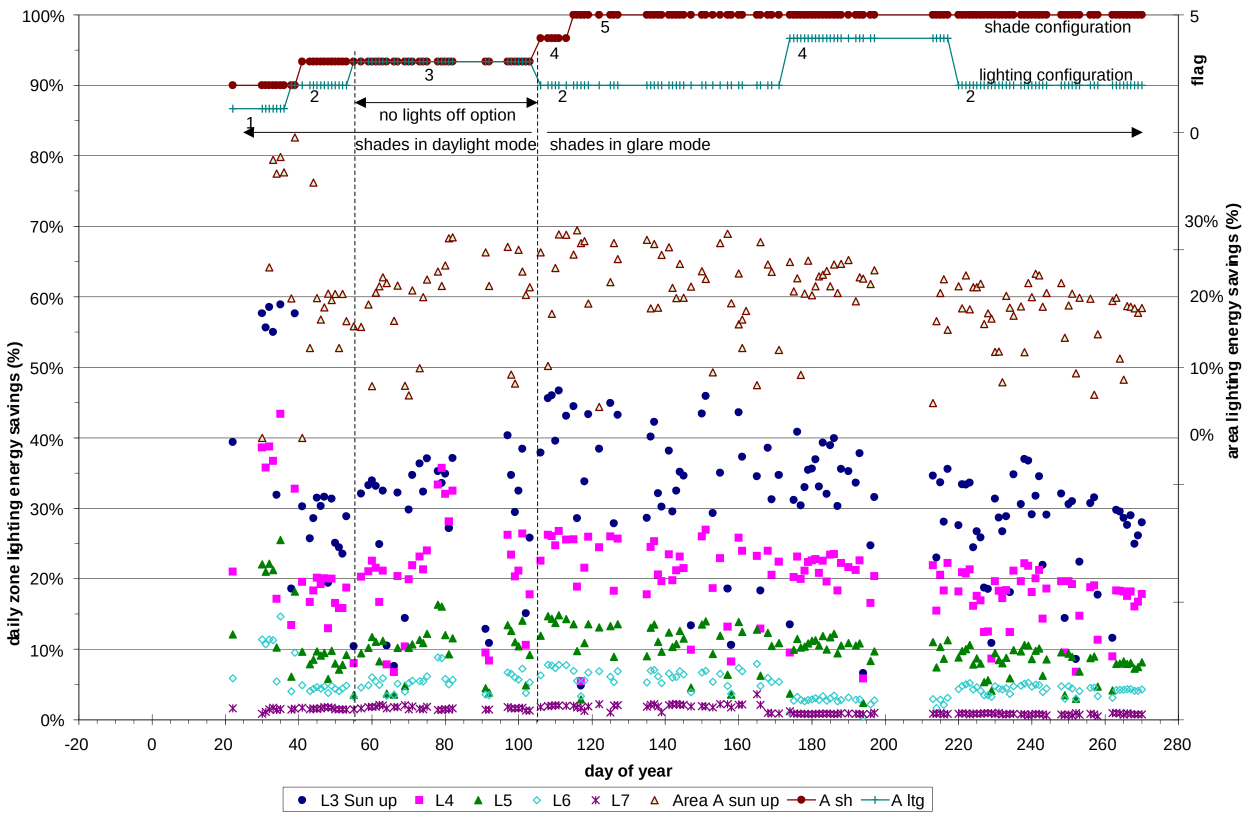


Figure 4-9. Area A (west-facing window): Percentage daily lighting energy savings for each lighting zone (L3-L7) and for Area A to a depth of 7 m from the window compared to the reference case with no daylighting controls (16.1 W/m^2 (1.495 W/ft^2)). Savings were computed for the sun-up schedule. On second y-axis ("flag"), shade ("A sh") and lighting ("A ltg") configuration numbers are noted (see Table 4-1).

Monitored data in April (DOY=96-112) gave some indication of the differences in lighting energy use one could expect if the shade control algorithm was changed from a daylight to glare control mode. No clean comparisons could be made between the two control modes because the electric lighting control algorithm differed before and after the changes in the shade control algorithms. To make this comparison, the lighting energy use for the glare/ lights-off mode was first corrected to the no-lights-off mode using the minimum dimming power level (35% of full power). Then, specific days were selected where solar conditions were comparable. If the sun path was nominally the same (within an 16-day period) and the range in average daily horizontal exterior illuminance was kept to within 10% (52±2 klux), then the change in shade control mode produced less than a 1% difference in lighting energy use in all zones. Greater differences may occur at different times of the year and with more stringent glare control setpoint levels.

Turning the lights off (0% power), instead of dimming them to minimum power level (35% power) when there was sufficient daylight, increased daily lighting energy use savings from 37-39% to 44-47% in zone

L3 but had no effect in zones L4-L7 because the daylight levels were never great enough to allow the lights to be turned off (glare control mode, 4/17/04-4/24/04). From 4/14/04 to 9/21/04 (glare control mode), the lights-off option saved at most 9% and on average 1% in additional daily lighting energy savings in zone L3 located 3.35 m from the window. In zone L4 located 4.88 m from the window, this option saved at most 1% and on average 0% per day in lighting energy use.

4.3.2.2. Area B

Daily lighting energy use savings (sun up schedule) for each lighting control zone are shown in Figure 4-10. Lighting energy savings were greater than Area A because of the bilateral sidelit south and west-facing condition and because the lights were turned off when there was sufficient daylight. Data after DOY=58 (2/27/04) are valid. Data prior to this day are not valid because the daylighting system was not providing sufficient illuminance on the work plane. For the days with faulty S3 and S6 ballast operations and zone S10 corridor lighting off for greater than 30 min/day, lighting energy savings may be greater than that depicted on the graph. For days when the private office lights were on erroneously, lighting energy savings in S4/S5 may be slightly less than that depicted on the graph.

Lighting energy savings in zones S3-S5 were inversely proportional to the distance from the west window wall: savings were greater closer to the daylight source. There was less of a difference in lighting energy savings between zones S3 and S4/S5 in Area B than for the same zones in Area A, due perhaps to the contributions of daylight from the south windows in Area B and because Area B grouped the control of zones S4 and S5.

The savings in the S6 south zone were significantly greater than that in the S3 west zone even the distance from the window wall was nominally the same. Daylight availability was greater on this south-facing façade because direct sun was in the plane of the window for a greater percentage of the day than the west-facing façade. Direct sun was also allowed to penetrate deeper from the south window than from the west. Lighting energy savings in zones S6-S8 were inversely proportional to the distance from the south window wall. Lighting energy savings were also proportional to daylight availability: sunnier conditions yielded greater energy savings with zone S6 attaining 67% daily lighting energy savings on the most overcast day.

Total lighting energy use savings for Area B to a zone depth of 7 m (all zones) for the three schedule types are shown in Figure 4-11. There was no evident correlation between the three schedules. With a bi-laterally daylit space, daily lighting energy savings ranged from 40% to 80% (sun up schedule) between 2/27/04 to 9/21/04. Turning the lights off when there was sufficient daylight instead of simply dimming to minimum power (35% of full power) yielded up to 25% greater daily lighting energy savings in all west and south zones. The lights-off option saved significant lighting energy use even in the zones further from the window.

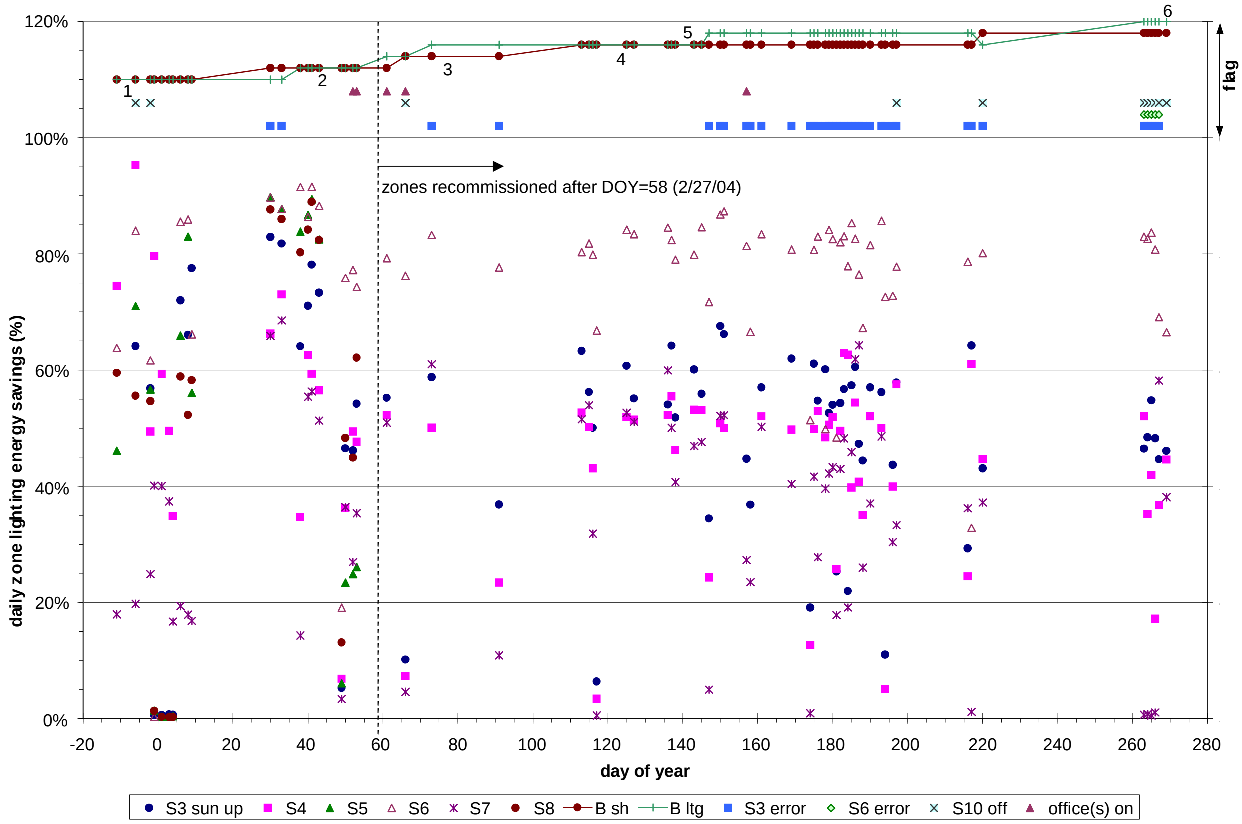


Figure 4-10. Area B (south and west-facing windows): Percentage daily lighting energy savings for each zone (S3-S8) compared to reference case with no daylighting controls. Savings were computed for the sun-up schedule. On the second y-axis, shade ("B sh") and lighting ("B ltg") test configurations are given (see Table 4-2). S3 and S6 error: effect unknown but likely to be small; S10 off: savings in S6 and S7/S8 slightly greater if S10 on; office on: S4/S5 savings may be slightly less if offices were off.

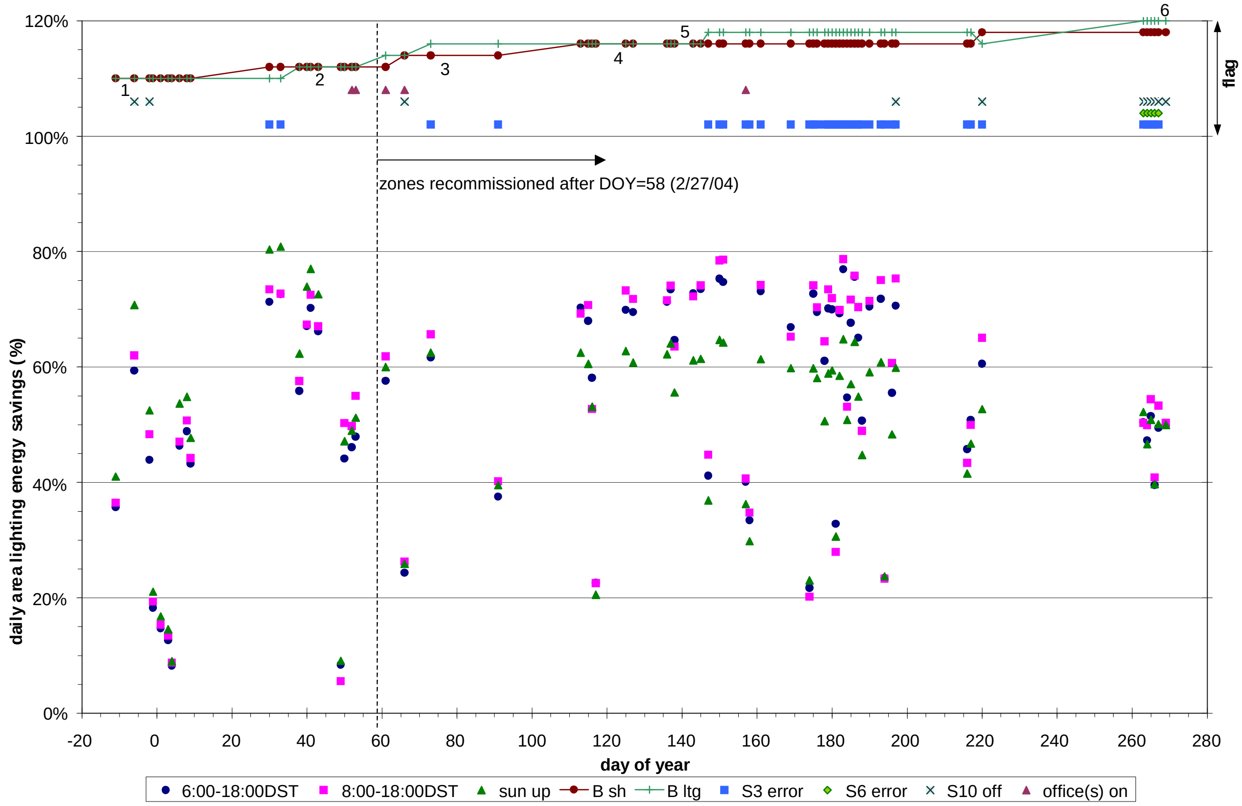


Figure 4-11. Area B (south and west-facing windows): Percentage daily lighting energy savings for Area B (zone depth from south and west windows of 7 m) compared to reference case with no daylighting controls (15.48 W/m^2 (1.44 W/ft^2)). Savings were computed for the three different lighting schedules.

4.4. DISCUSSION

4.4.1. On the bad reputation of daylighting control system reliability

LBNL has consistently promoted the superior performance of closed-loop proportional (P) control algorithms over integral-reset (IR) control algorithms for reliable daylight control [Rubinstein et al. 1997]. Area A used an open-loop proportional algorithm and controlled all of the open-plan dimmable lighting zones reliably for 99.9±0.5% of the day on average over the monitored period. Area B used an integral reset algorithm and did indeed appear to have a great deal of trouble from the outset to meet the control performance requirement. Without prompting from LBNL, the manufacturer may never have realized that the lighting control system was over-dimming for the majority of the day. When notified, the manufacturer made adjustments to the lighting control system by first broadening the lighting control zones (the narrow zones were initially a constraint in the lighting design) then re-commissioned the system. The manufacturer admitted to not having checked their control system after the initial commissioning phase when there was no furniture in the mockup. Two one-day visits to the mockup (one to run diagnostics, the second to commission the system) produced reliable performance after 2/27/04. While the control performance in Area B was still less reliable than Area A for the remainder of the test, the IR control system in Area B was able to meet the design illuminance setpoint for 97.9±6.1% of the day on average over the monitored period.

There are several reasons why these field data refute prior findings (i.e., 97.9% reliability in Area B is most likely acceptable): 1) the IR photosensor had a restricted field of view, 2) the IR photosensor was commissioned during the day with the shades adjusted to block direct sun, and 3) the automated shading system reduced variations in the spatial distribution of daylight. On the first two items, Rubinstein et al. [Rubinstein et al. 1989] found that P control outperformed IR control because the ratio of work plane illuminance (lux) to photosensor input signal (V) differed significantly between sidelit (daylight) and toplit (fluorescent lighting) conditions given an unshielded photosensor. The IR photosensor was typically commissioned at night and would therefore tended to undershoot the setpoint during the day. With a restricted field of view and daytime commissioning of the IR photosensor in Area B, the lux/V ratio better approximated the ratios that occurred during the day, hence the more reliable performance.

On item 3, use of the automated fabric roller shades resulted in a significantly more uniform daylit environment than that with manually-operated shades. Direct sun skews the lux/V relationship, causing lights to overdim. Area A performed better than Area B because direct sun was always controlled in Area A to 0.91 m from the window. In Area B, the depth of direct sun penetration was allowed to vary over the test period from 0.91 m to 3 m from the window. Most of the south-facing windows were not shaded by ceramic tubes, so sunlight was also admitted through the roller shade fabric.

Generally, the relationship between fluorescent work plane illuminance and photosensor response is well characterized and degrades slightly due to lamp aging and dirt over time, while the relationship between daylight workplane illuminance and photosensor response can be extremely variable and is often the root cause of poor daylighting control performance [Mistrick et al. 2000, Choi and Mistrick 1999]. Open-loop and closed-loop proportional control photosensors aggregate the two relationships into a single constant lux/V proportional gain setting (and nighttime offset level) that is commissioned once at the job site. If the setting is not conservative, over-dimming will occur. While this field study was not focused on analyzing and characterizing the reasons behind poor performance, we attempted to characterize how much the lux/V ratio varied with daily and seasonal variations in the distribution of daylight. Systems (which are a combination of photosensor spatial and spectral response and location) with less variation in this ratio would tend to be more reliable. This involved correlating lighting power use to fluorescent task illuminance for each of the 17 zones and each of the 16 sensor locations, then computing the minute-to-minute ratio of daylight work plane illuminance to photosensor signal, using the actual lighting power use of the 17 zones during the day. This detailed matrix calculation was done for one of the early test periods, but the manufacturers failed to follow the nighttime fluorescent lighting protocols consistently throughout the entire test period and hardware failures and intermittent errors complicated the analysis. Despite our desire to explain why one system performed better than the other, there were simply inadequate data and resources to determine the source of differences in performance.

The manufacturer in Area A may simply have commissioned the system more conservatively than the manufacturer in Area B and sacrificed potential lighting energy savings to achieve good reliability. If one compares the total illuminance (fluorescent plus daylight) and dimming curves in Area A versus B, one might quickly come to the conclusion that Area A was insensitive to available daylight compared to Area B because the dimming curves were very gradual throughout the morning, while in Area B, the dimming curves were very abrupt. Part of this behavior is due to the behavior of the two control algorithms that convert the photosensor signal into a ballast control signal: integral reset algorithms exhibit a sharp step function response due to its infinite gain while proportional algorithms exhibit a more gradual response. Another factor is that there was greater daylight availability in Area B due to the bilateral window design so dimming levels should be greater than that in Area A. This confounds the analysis and does not allow us to determine whether one system was commissioned more conservatively than the other.

The overall reliability of both systems was quite good, indicating that existing commercial systems are capable of achieving reliable performance and delivering significant energy savings given sufficient attention to commissioning. The challenge is how to achieve such performance routinely and cost-effectively. To be critical, one might say that the best engineering expertise was brought to bear on this project in an effort to prove to the owner of a landmark status building (with monitored data that would be publicly disseminated) that a product was worth purchasing. Such reliable performance may not be expected in normal applications because either the technical expertise would not be of such high caliber or the amount of time dedicated to commissioning each zone cannot be as long given cost constraints. Each vendor made a total of three visits (up to one day each) to calibrate their systems in order to deliver reliable performance.

Several tactics will be used by the building owner to prevent poor performance in the actual building: 1) the manufacturer will be held responsible for commissioning all daylighting zones in the actual building prior to occupancy, and 2) the performance specifications mandate that reliable performance (work plane illuminance levels must be maintained above -10% of setpoint for greater than 90% of the day) in all zones of the actual building be proven by the manufacturer before final payment is made. The selected manufacturer was asked to test their lighting zone layout, photosensor designs and locations, and commissioning procedures in the mockup after the competitive bid process. By mid-2005, the selected manufacturer had demonstrated to the owner that their DALI-based open-loop proportional control system could meet the performance specification in the mockup (LBNL monitored this second phase of testing). Basic instrumentation and protocols for commissioning and evaluating the system in the final building have been prototyped and discussed. These procedures continue to be refined prior to execution in the final building in mid- to late-2006.

One might argue that such tactics can only be used by building owners who have the leverage to demand this of a manufacturer (due to the high visibility of the project or the large volume of the purchase). However, if the design team stipulates tactics 1 and 2 in the procurement specifications, has the manufacturer include these costs in their bid, then follows through with the requirements, daylighting control systems may enjoy a larger market share in the future.

<u>**4.4.2. Pros and cons of the lighting control systems**</u>

Comparing open-loop versus closed-loop systems, the open-loop (proportional) control system in Area A had several advantages over the closed-loop system in Area B. One photosensor was used to control multiple zones thereby reducing costs. The open-loop lighting control zones can be fairly small and narrow without causing hunting or oscillations between adjacent zones. This enables one to achieve greater lighting energy savings over closed-loop systems (with photosensors that have a broad field of view) that require large zones to achieve reliability. This is pertinent to DALI-controlled systems where one can now define a zone down to a single fixture, as is being done in the final Times building. On the other hand, to commission the system, the open-loop system relies on a predictable daylight distribution as a function of distance from the window wall to set the lux/V constants in the control system. This predictable distribution is being supplied by the automated shade. One will encounter less reliable control if manual override of the shade allows direct sun to enter the space because the open-loop sensor cannot "see" the impact of direct sun on the lighting zones behind it.

Closed-loop systems, like that in Area B, do have the advantage of being able to harvest light from any source – the private office lights, corridor lights, or daylight. In Area B, dimming was affected by the private office lighting operations. The building owner noticed this effect and noted it in their log. When the private lights were turned on, the lighting in zone S4/S5 dimmed. Such systems require a one-to-one mapping between photosensor and zone, however, which increases costs.

Although the cost of a static versus dimmable electronic ballast is at this time significantly less, this particular building owner would never consider a daylight-controlled on-off switching system for several reasons: 1) the owner saw value in being able to tune setpoint levels for each department, circulation zones, etc. (dimmable ballasts will be installed throughout the building), 2) sudden changes in light output or on-off hunting are known to be distracting and annoying, 3) rezoning in software is cheaper than altering hardware, and 4) dimmable ballasts enable the owner to shed significant loads during periods when utility rates are high (e.g., dim or shut lights off depending on time-of-use rate schedule or curtailment signal from a demand-response program). To reduce capital outlay, on-off static ballasts could be installed in the zone closest to the window (e.g., zones L3, S3, and S6) with dimmable ballasts installed in the remaining floor area, but the labor cost of troubleshooting improperly installed ballasts can be a major deterrent, particularly given electrical labor rates.

Historically, daylighting control systems have been dismissed as viable options based on manufacturer quotes of $60-120 US/ballast, particularly since static electronic ballasts cost ~$15/ballast. High-low static ballasts that provide stepped switching (0, 50%, 100% of full power) add a premium over on-off static ballasts. LBNL explored market trends and costs and concluded that it should be feasible to profitably manufacture and sell dimming ballasts at prices that are much lower (e.g., $20-30/ballast). The owner received final bids between $30-75 per dimmable electronic ballast, with manufacturers expressing willingness to continue to reduce costs down to commodity levels. The owner reduced design, installation, and commissioning costs in numerous ways; for example, by pre-wiring fixtures prior to shipping to the job site and providing hands-on wiring demonstrations to installers prior to bidding to minimize markups due to an unfamiliar technology. The system was cost-justified by reducing first and operating costs through setpoint tuning, daylight dimming, occupancy, and demand response lighting control strategies in conjunction with the automated shade. Additional energy savings due to reduced solar and lighting heat gains were not quantified in this study but will add to the total operational cost savings. Given control of peak cooling conditions (solar and lighting heat gains constitute up to 30-40% of the total peak cooling load in typical commercial buildings), first costs can also be reduced by downsizing the chiller plant and distribution system.

4.4.3. Qualifying the lighting energy savings

Daily lighting energy savings were shown to be significant at depths of up to 7 m from the window wall, the cause of which can be attributed to the façade and interior design and the use of automated shades. Without active shade management, lighting energy savings are expected to be significantly less due to non-optimal control by the occupants. In an attempt to simplify one's view of the analysis, a lumped average of all test conditions was computed, despite the fact that this is statistically incorrect since test conditions were non-comparable across the dataset (Figure 4-12 and Table 4-3). In Area B, savings were the same at depths of ~4.57-7.62 m from the window because the inner lighting control zones S7/S8 were grouped (Figure 4-12). In Table 4-3, average savings for each area are given to the same depth (7 m) so as to make an equitable comparison between a west-facing sidelit and south- and west-facing bilateral sidelit condition.

Lighting energy savings were accomplished while generally meeting visual comfort criteria, particularly in Area A, which controlled the shades for daylight and glare. Lighting energy savings are expected to decrease when glare control is implemented in Area B – the degree of reduction is dependent on the final fabric choice and how stringently window luminance is controlled at the expense of daylight admission. With respect to site context, the lower floors of the 52-story tower in downtown Manhattan will receive significantly less daylight due to urban obstructions, while the upper floors will receive significantly more. We attempted to calibrate Radiance simulations to field monitored data so as to extend the results to the Manhattan site, but were unable to calibrate standard sky models to match field data.

Direct extrapolation of the monitored data to other building projects is not advised. First, the façade design was unique: exterior shading provided by the ceramic tubes reduced interior daylight levels considerably. The interior design was also rather unique: the open plan office design used 1.22-m high partitions throughout increasing daylight levels at greater depths from the window. This case study provides useful objective data and demonstrates the need for A/E firms to create building-specific designs that can accomplish energy-efficiency and a pleasing and comfortable environment.

Table 4-3.
Average lighting energy savings and average lighting power density savings for a sidelit (A) and bilateral-sidelit (B) 7-m deep zone

Schedule	Area A			Area B			Area A		Area B	
	avg		stdev	avg		stdev	W/m^2	W/ft^2	W/m^2	W/ft^2
sun up	20%	±	6%	52%	±	12%	3.17	0.29	8.00	0.74
6:00-18:00 DST	22%	±	7%	58%	±	16%	3.52	0.33	8.96	0.83
8:00-18:00 DST	23%	±	7%	59%	±	17%	3.75	0.35	9.16	0.85

Average: Area A to a depth of 7 m from west window, zones L3-L5, 2/10/04-9/21/04; Area B to a depth of 7 m from west or south window, zones S3-S8, 2/27/04-9/21/04.
DST: Daylight savings time; avg: average; stdev: standard deviation.
Lighting power density at full power: Area A: 16.1 W/m^2 (1.495 W/ft^2); Area B: 15.48 W/m^2 (1.44 W/ft^2).

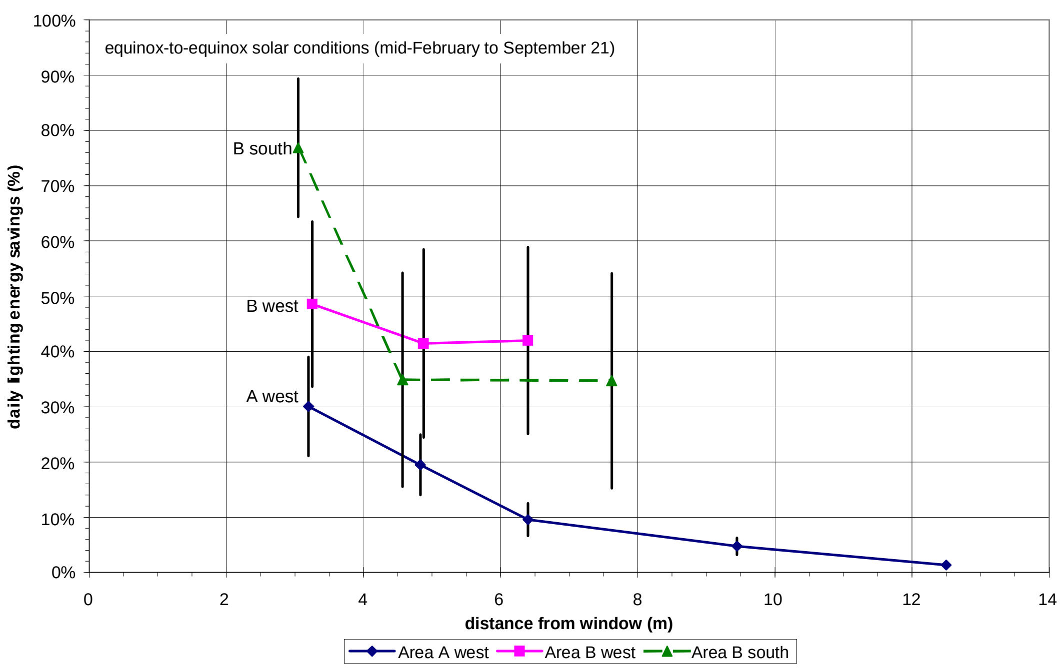


Figure 4-12. Average and standard deviation of daily lighting energy use savings versus distance from the west window wall in Area A or west or south window wall to the center of the lighting zone in Area B. For Area B, zones S3 and S4/S5 data are given in relation to the west window wall and zones S6 and S7/S8 data are given in relation to the south window wall.

4.4.4. On the performance of the DALI ballasts and control system

DALI ballasts were controlled by an EIB supervisory control system in Area B and this combination seemed to have caused a fair number of problems. Aside from ballast failures, which occurred at a greater rate in Area B than in Area A (four ballasts were replaced in Area B, two ballasts were replaced in Area A), the assignment and control of individual DALI ballasts were not reliable. Errors cannot be explained entirely by the improper control system reset after brief (20-30 s) bi-weekly power failures that occurred when the power generator was undergoing maintenance. The lighting control system manufacturer in Area B conducted some tests toward the end of the monitored period and provided some possible explanations. Some DALI ballasts either stopped being automatically controlled and were on at all times, some ballast(s) became part of two different zones and would respond to whichever zone gave the last command, and some ballast(s) remained dimmed at all times. At the EIB/DALI gateway level, the manufacturer found that all ballasts in a zone could be commanded to on or off but the individual faulty ballasts could not be commanded. The control manufacturer's interpretation is that the address at the ballast-level was somehow being corrupted or lost. The ballast manufacturer stated that the mockup DALI ballasts used the same circuit board as their conventional 0-10 V ballast and their DALI interface module. While both components have been used separately on other applications with no faults, the combination of these two components to control a 17-W T8 lamp had not been previously attempted. The manufacturer stated that there were no unresolved design issues with this prototype ballast. The ballasts were compliant with an evolving DALI ballast protocol being developed by the National Electrical Manufacturers Association (NEMA) DALI working group. Faulty ballasts were returned to the ballast manufacturer to determine the cause of failure. Separately, LBNL conducted limited bench-scale tests on non-faulty DALI ballasts from the mockup by creating various groups (with different control software) then simulating power failures. No problems occurred with the addresses nor were there any changes in the zoning. The exact cause of these problems remains unknown.

4.5. CONCLUSIONS

A nine-month monitored field study of the performance of automated roller shades and daylighting controls was conducted in a 401 m^2 unoccupied, furnished daylighting mockup. The mockup mimicked the southwest corner of a new 110 km^2 commercial building in New York, New York, where The New York Times will be the major tenant. This paper focuses on evaluating the performance of two daylighting control systems installed in separate areas of an open plan office with 1.2-m high workstation partitions.

The overall reliability of both systems was quite good, indicating that existing commercial systems are capable of achieving reliable performance and delivering significant energy savings given sufficient attention to commissioning. The open-loop proportional control system in Area A performed very reliably, meeting the design illuminance level 99.9±0.5% of the day on average after it was commissioned properly. The closed-loop integral reset control system in Area B performed less reliably due possibly to the more complex bi-lateral daylit environment. The design illuminance level was met 97.9±6.1% of the day on average after the control system was commissioned properly. The well-controlled daylight from the automated shade contributed to both area's level of reliability. Each manufacturer invested three one-day site visits to achieve this level of performance. The bid package and performance specifications were designed to ensure similar control performance in the final building.

Lighting energy savings were significant over equinox-to-equinox solar conditions in both areas of the mockup compared to a non-daylit reference case. For the sidelit Area A, average daily lighting energy savings between mid-February to September 21st were 30% and 5-10% at 3.35 m and 6.10-9.14 m from the west-facing window (29° north of west), respectively. For the bilateral daylit Area B, daily lighting energy savings were 50-60% at 3.35 m from the window and 25-40% at 4.57-7.62 m from the west- or south-facing (29° west of south) windows. Average savings for the 7-m deep dimming zone were 20-23% for the sidelit Area A and 52-59% for the bilateral sidelit Area B, depending on the lighting schedule. Unlike Area A, Area B turned lights off when there was sufficient daylight, increasing savings. Newer DALI ballasts with a wider power dimming range (~20-100% versus the ~35-100% power range of ballasts used in this field study) will yield even greater savings. Exerting glare control will decrease savings – the degree will depend on how stringently the automated roller shade controls glare to the detriment of daylight admission.

The 0-10 V ballasts had two ballast failures over the nine-month monitored period but in all other respects exhibited faultless operations. The DALI ballasts and/or supervisory control system exhibited faulty operations throughout the test period, the cause of which is unknown. This was a prototype system. Operational errors are expected to be resolved as DALI ballast products reach full maturity.

The building owner received very competitive bids ($30-75 US/ballast) and was able to justify use of the daylighting control system based on operational cost savings and increased amenity. Industry indicated willingness to continue to reduce costs down to commodity levels.

Section 5
FIELD STUDY OF AUTOMATED ROLLER SHADE SYSTEMS

5.1. INTRODUCTION

Similar to the objectives stated in Section 4, the main objective of this monitored field study was to provide timely information to the building owner about commercially available automated roller shade systems. This information was used to make an informed business decision on whether to purchase such systems and to determine which desirable features and functions of these systems should be specified in the procurement specifications prior to the bid phase, irrespective of whether the manufacturers currently offered the features in existing product lines.

In this section, analysis focuses on how well the motorized roller shade system functioned mechanically, whether the automated control system met its stated objectives, and how the shading system operated under various sky conditions over the course of the day and throughout the year. Note that the shades were controlled to minimize visual discomfort and this aspect was not evaluated in this section. Evaluation of the resultant environmental quality as related to visual discomfort, view, and interior brightness is given in Section 6.

The building owner's main motivations for procuring an automated roller shade system were:

- Amenity. The building owner recognized that without automation manually-operated interior shades would not be raised on a regular basis by those few individuals seated next to the window wall. This would result in a loss of view to the remaining occupants in the open plan office and diminish overall interior daylight and brightness levels. The fundamental architectural design concept revolved around a transparent building that was open and communicative to the exterior allowing the public to see in and enabling views out as well as permitting ample daylight to enter on three sides of each building wing. Manually-operated interior shades could defeat this design objective.
- Sustainability. The building owner believed that with the more reliable operation of the roller shades that one obtains with automation, lighting and cooling energy and demand savings could be maximized. With reliable peak load reductions, HVAC capacity reductions could also be realized but the HVAC/ underfloor-air distribution system design was too far advanced to take advantage of this opportunity.
- Façade appearance. With automated shades controlled to the same height, the building owner liked the idea that their clear-glazed, transparent façade would have a uniform exterior appearance compared to the adhoc appearance of a facade with manually-operated shades.

- Health. The building owner wished to achieve a mix of natural and electric lighting to provide a healthful environment for their occupants. While this would be achieved with conventional manually-operated shading and daylighting control systems, automated systems have the potential to optimize or maximize these benefits more reliably.

The building owner's main concerns with procuring an automated roller shade system were:

- Performance. What type of fabric and level of control will be required to maintain a comfortable and energy-efficient interior environment for the occupants? Will there be view and adequate daylight once direct sun and window glare are controlled?
- Design intent preserved. Can the architectural design intent of a transparent building be preserved? Or will the automated shades be down throughout the day for the majority of the year on most facades?
- Reliability. Do products deliver reliable and acceptable performance under real sun and sky conditions? Can these systems adequately balance a complex and competing set of interior requirements: e.g., control direct sun, control glare, maintain exterior view, maintain interior brightness?

The field study answered most of the above questions in the following manner:

- Performance. Interior illuminance, lighting energy savings, view, glare, visual comfort were monitored in the mockup. In Sections 4-6, the installed shading systems, monitoring instrumentation, definition of zones, control configuration, method of analysis, and experimental results are described in detail. The analysis addresses the following questions:
    - Section 5: How did the shading system operate over the course of the day and throughout the year under clear sky, partly cloudy, and overcast sky conditions? What was its rate of response to variable conditions? How did its operation change with changes in the control algorithm? Analysis is given for two types of roller shade systems with differing control algorithms.
    - Section 6: How comfortable was the visual environment for reading, writing, and computer-based tasks involving flat-screen LCD visual display terminals over the course of the day and throughout the year? Was the interior environment bright yet glare free? Was view obstructed for the majority of the day in order to control window glare? Did changes to the shade control algorithm result in improved visual comfort?
- Implementation, increased complexity and cost, and vendor features were discussed anecdotally in the discussion. This analysis provides no direct link to the health effect of such systems. However, the subjective appraisal in Section 7 provides detailed information on the level of comfort occupants experienced in the daylighting mockup.

5.2. EXPERIMENTAL METHOD

Details concerning the overall experimental method, facility setup, monitoring instrumentation, and tested configurations are given in Section 4.2. Details related to the shading system technology and method of shading system analysis are given in this sub-section.

5.2.1. Shading system description in Area A

On the west façade in Area A, four sets of motorized roller shades were installed 1.27 cm (0.5 in) inboard from the face of the window frame and 15.24 cm (6 in) from the interior face of the double pane window glazing. Each roller shade consisted of one to two 1.52-m (5-ft) wide shade "bands" which were coupled at the header and controlled using one motor. All shades were 3.12-m (10.25-ft) high. See Figure 5-1 for the shade band groupings. The vertical gap between the shade bands was approximately 2.5 cm (1 in) and was directly aligned with the vertical window framing member. The lower edge of the roller shade was 1.27-2.5 cm (0.5-1.0 in) horizontally (between the glass and the diffuser) and 5.1-7.6 cm (2-3 in) minimum vertically from the linear floor diffuser running parallel to the window. For the purposes of this study, a group of shade bands controlled by one motor will be simply referred to as a single "shade".

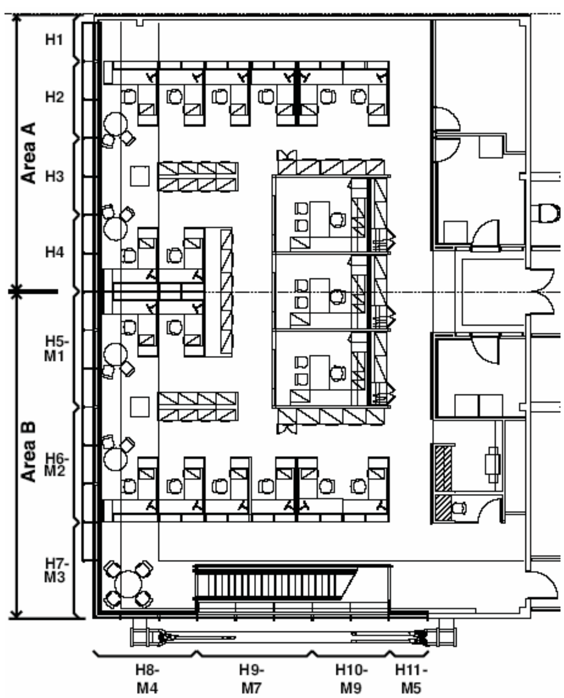


Figure 5-1. Floor plan view showing shade band groupings (north is approximately at the top of the diagram).

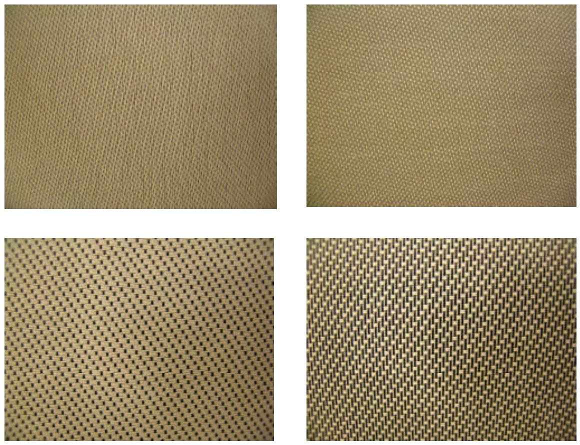


Figure 5-2. Photograph of the white (left) and gray (right) sides of the roller shade fabric with Hexcel XL2 (for Area A) shown in top row and MechoShade 6020 (for Area B) shown on lower row.

The roller shade fabric (Figure 5-2) was made up of PVC-coated polyester and vinyl yarns woven into a shade cloth with flat white yarns in one direction and flat black yarns in the opposing direction (Hexcel type XL2 S065 Blanc Ris). The color of the shade was predominately white on one face and gray on the other face. The gray side was faced toward the interior. The transmittance properties are given in Table 5-1. The openness factor (percentage of open space to opaque fabric) was 3%.

Table 5-1.
Transmittance properties of Area A and B roller shade fabrics

	Area A	Area B
Product No.	XL2	6020R
Exterior color	White	White
Interior color	Gray	Black
Tsol	0.07	0.08
Tv	0.06	0.06
Refl		0.56
Ref2		0.37
O-F	0.03	0.03

Despite the tightness of the weave, the shade fabric does not act simply as a diffusing surface. The fabric allows some direct transmission of sunlight (no change in direction) through the interstitial space between the threads for sun angles that are near normal to the fabric and it also diffuses incident light. View out is also permitted depending on the relative brightness of the interior and exterior and the color and openness of the fabric. For oblique solar angles, the fabric appears to provide complete diffusion of the incident light and blocks view out. The fabric's bi-directional optical properties were not measured or characterized for this phase of the monitored study.

The shade motor was a 24 V dc-operated tubular motor mounted directly within the roller of the shade (Lutron QED). The four shade motors were powered via a single dc power supply located in the electrical closet. Power to each motor was supplied using a twisted-pair low-voltage wire (typical installations would use 2 #16 for power). Control of the motors was accomplished using RS485 routed from each motor, through a wall-mounted keypad (for manual shade control) then to the main supervisory control system. Each motor was individually addressable. All shades were activated simultaneously when controlled automatically.

In the automated mode, all shades were grouped into one single control zone. All shades were always controlled to the same five preset heights designated by the building owner: full up, full down, two positions that aligned with the top and bottom of the vision portion of the window wall, and a position that was mid-height within the upper ceramic tube array. In the manual mode, a single shade could be set either to the preset heights or to any continuous height between full up or down.

The automated shade control algorithm was designed explicitly to balance window glare, daylight, and view requirements. For the sake of simplicity, the algorithms will be referred to as a “daylight” or “glare” mode depending on the relative weight that was placed on the control thresholds to achieve either more or less daylight and view or more or less control of window glare. The algorithms used to achieve shade control were proprietary although the vendor did venture to say that two operating modes were defined by the periods when the sun was and was not in the plane of the window. The setpoints for these two modes differed and were adjusted in response to building owner feedback. Limiting the depth of direct sun was not explicitly addressed by the vendor. The building owner felt that this requirement was explicitly stated to the vendor so this analysis includes evaluation of direct sun control. A single shielded ceiling-mounted sensor (Lutron MW-PS-CPN2342) was mounted 3.35 m (11 ft) from the window wall centered on the shade (H2). The sensor is described in the Section 4.2.2.4 “Lighting system in Area A”. The supervisory embedded control system (Lutron Grafik7000 shade control processor) used input from the photosensor to control each shade. A keypad was mounted on a column in the open plan portion of Area A so that the automatic shade operations could be manually overridden. This keypad connected to the Grafik 7000 system via a digital link.

5.2.2. Shading system description in Area B

In Area B, three sets of motorized roller shades were installed on the west façade and four sets of shades were installed on the south façade. Each roller shade consisted of one to three 1.52-m (5-ft) wide shade “bands” which were coupled at the header and controlled using one motor. See Figure 5-1 above for the shade band groupings. In all other respects, the placement of the shades was identical to that described for Area A above.

The roller shade fabric was made up of PVC-coated polyester yarns woven into a shade cloth with flat white yarns in one direction and flat black yarns in the opposing direction (Mechoshade ThermoVeil type 6020) (Figure 5-2). Further details on the fabric can be found above in the description for Area A.

The shade motor was a 120-V ac-operated electric tubular motor mounted directly within the roller of the shade (Somfy 504 and 510). Control of the motors was accomplished using an Echeolon Neuron TM based communication and control network which operated over a 78 kbps free-topology, two-twisted pair backbone. Each motor was individually addressable. Motors were wired to a 2-motor controller bus interface unit (IMCS2-BI) then connected digitally to a manually-operated keypad or the main supervisory control system (MechoShade AAC-PC). The shades were activated so that there was a slight time delay (~0.5 s) before the next shade was deployed. Motors were sound rated for no greater than 47 db per manufacturer's specification. Two types of motors were used to illustrate speed of shade movement to the building owner: motor speed was 14 rpm or 56 s to fully extend on the west; motor speed was 38 rpm or 23 s to fully extend on the south.

In the automated mode, all shades assigned to a particular control zone were always controlled to the same height. All shades on the west were assigned to one control zone. All shades on the south zone were assigned to a second control zone. The five preset heights were the same used in Area A. In the manual mode, a shade could be set either to the preset heights or to any continuous height between full up or down.

The shade control algorithm was designed to control the depth of direct sun penetration from the face of the shade at floor level. On the west window wall, direct sun was controlled 0.91 m (3 ft) from the shade at floor level. On the south window wall, direct sun was controlled to 0.91 m, 1.83 m, or 3.05 m (3, 6 or 10 ft) from the shade at floor level. The control system was later modified to control window glare and direct sun (to 0.91 m, to 3 ft) on the west facade. The sensors and method used to control window glare are proprietary. See Section 4.2.4.2 for tested configurations. Three pyranometers were mounted on the roof to measure total global horizontal irradiation. Three sensors were used for redundancy in case one should read erroneously due to failure or an external event (e.g., bird sitting on the sensor). The cables from these pyranometers were run through a weatherproof enclosure to the control system located in the building interior. The supervisory PC-based control system used input from the pyranometers to determine if the sky conditions were clear and then controlled the window shades. A keypad was mounted on a column in the open plan portion of Area B so that the automatic shade operations could be manually overridden. After a shade had been manually overridden, the shade was designed to return to automated mode when the next automated shade movement was required, as requested by the building owner.

5.2.3. Methods of data analysis

As described above, the automated shade control algorithms differed in the two areas. In Area A, the shades were designed to balance window glare, daylight and view requirements. The building owner had also requested that direct sun be controlled to a specified depth from the window wall. Direct sun can cause thermal discomfort if it is incident on an occupant. Direct sun can also cause visual discomfort or annoyance because it causes high brightness contrasts to occur across a work task. In Area B, the shades were designed initially to block direct sun to a specified depth from the window wall. Later, the shade control system was modified to also control window glare.

Evaluation of the automated shade system was conducted in two parts. First, we evaluated whether the shades operated as intended using methods described in this section. Second, we evaluated the resultant comfort and quality of the interior visual environment in Section 6. These two parts constitute the complete evaluation.

5.2.3.1. Mechanical operations

Shade operations were evaluated using the shade height transducer data. Data were discarded prior to analysis:

- if the height transducers had been physically disconnected while work was being performed on the shade or shade hardware or when there was a momentary power outage when the mockup's power generator was being serviced.
- if the shades were manually overridden or if the manufacturer's log indicated that the control system was not in the automatic mode.

Mechanical or other types of glitches occurred occasionally that caused some shades within a group to differ in height (the reasons for these glitches are discussed in the Results). A data filter was created to determine if and when all shades along a single façade were not synchronized in height. If the shades were not aligned for a significant period, the day's data were deleted. To detect when the shades were not operating as designed, the maximum difference in height between all shades within a shade group was computed for each minute over the entire day. The number of minutes, n, when this height difference was greater than 5 cm (2 in) was summed for each day. The average height difference, Hn, was also computed for each day for the subset of data when the height difference was greater than 5 cm (2 in). Data were then discarded as follows:

- In Area A, if the average height difference, Hn, was greater than 12.7 cm (5 in) for more than 5 min in a day, then we assumed that the shades were not operating properly for that day.
- In Area B on either the west or south façade, if the average height difference, Hn, was greater than 30.5 cm (12 in) for more than 30 min in the day, then we assumed that the shades were not operating properly for that day.

These differing criteria were used to increase the number of days available for the daylighting controls and visual comfort analysis in Area B.

To evaluate shade operations, we computed the percentage of the day (sun up) when the shade was set at the various preset heights. Shade height data were binned according to the installed preset heights with a ±15 cm (6 in) range. If the shade height was not within any of these preset ranges (primarily because the shade was moving when data was sampled), the data was placed in a "not at preset" bin.

Repeated reversals in shade height were investigated by hand. Plots of each shade's movement over the course of the nine-month monitored period were reviewed. When shade glitches were detected, the data were reviewed with the manufacturer to determine the cause of the glitch. A computation was also made to detect shade hysteresis/ oscillations (i.e., annoying up and down movement of the shade within a short period of time). For a given minute in a day, if there were more than three reversals in shade direction within the past 5 min period (e.g., up, down, up, down = 3 reversals), then there was shade hysteresis (this criteria was acceptable to the building owner). To filter out electronic noise in the height transducer measurement, the shade was assumed to not have moved if the difference in shade height between five consecutive minutes was less than 0.32 cm (0.125 in). The number of minutes when shade hysteresis occurred was summed for each day.

5.2.3.2. Direct sun control

Checks were conducted using time of day plots to determine whether the shades in either area controlled direct sun to a specified depth from the window wall.

First, the vertical cut-off angles were computed for each installed shade height and for the exterior ceramic tube array on the west façade (Figure 5-3 and Table 5-2). Each preset shade height resulted in a unique vertical cutoff angle. To compute these blocking angles, the installed shade height was used. The installed shade heights were determined for each of the preset positions by averaging the monitored height of a fixed shade over a one-hour period. These average heights did not vary beyond the precision of the shade transducers over the nine-month monitored period. If the manufacturers' had accounted for the ceramic tube array in their shade control algorithms, the interior shades would not be deployed until the solar profile angle was less than 65°. For solar profile angles equal to or greater than 65°, the upper ceramic tube array blocked direct sun completely. Direct sun would still pass through the lower vision window but it would penetrate less than 0.91 m (3 ft) from the window wall. However, neither Area A nor Area B's control system explicitly addressed the exterior tubes – the building owner assumed this would be addressed but the vendors stated that this requirement was not requested.)

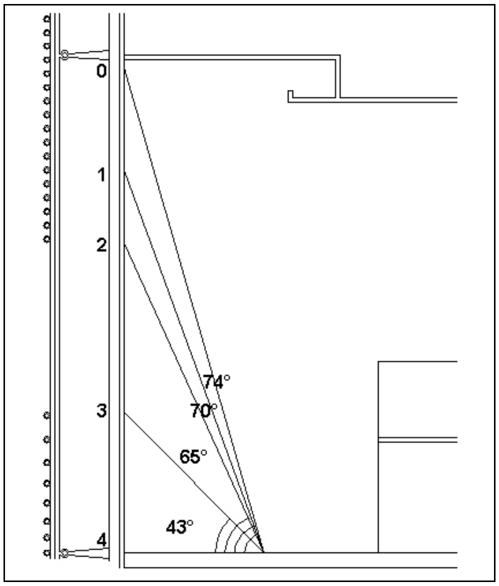


Figure 5-3. Vertical cut-off angles provided by the ceramic tubes and the interior roller shade at each of the preset heights.

Table 5-2.
Vertical cut-off angles for the west and south facades based on installed shade heights

Preset height		Vision & tube heights from drawings (inches)	Area A Installed shade heights west (inches)	Area B Installed shade heights west (inches)	Area B Installed shade heights south (inches)	Shade transducer accuracy (0.45% error) (inches)
0	fully up	125.50	122.70	124.34	124.33	0.56
1	midway UT	102.09	92.80	98.04	97.24	0.44
2	top of vision	78.69	72.80	73.87	73.54	0.33
3	bottom of vision	35.63	34.70	35.73	34.86	0.16
4	fully down	0.00	2.04	2.34	2.17	0.01

Preset height		A west cut-off angle (deg) for 36 inches direct sun*	B west cut-off angle (deg) for 36 inches direct sun*	B south cut-off angle (deg) for 36 inches direct sun*	B south cut-off angle (deg) for 72 inches direct sun*	B south cut-off angle (deg) for 120 inches direct sun*
0	fully up	73.6	73.9	73.9	59.9	46.0
1	midway UT	68.8	69.8	69.7	53.5	39.0
2	top of vision	63.7	64.0	63.9	45.6	31.5
3	bottom of vision	44.0	44.8	44.1	25.8	16.2
4	fully down	3.3	3.7	3.5	1.7	1.0

UT Upper tube array
* Allowable depth of direct sun penetration measured from the interior face of the façade

Second, for each time and day of the monitored period, the solar profile angle was computed for the west and south windows. This profile angle was then used to evaluate if the shade was controlled to the proper height to block direct sun 0.91 m (3 ft) from the window as follows:

- If the sun was not in the plane of the window or if the solar profile angle was between 74-90°, the shades should be fully up.
- For solar profile angles between 70-74°, the shade should be at preset 1.
- For solar profile angles between 65-70°, the shade should be at preset 2.
- For solar profile angles between 45-65°, the shade should be at preset 3 (covering the vision portion of the window wall).
- For solar profile angle between 0-45°, direct sun could pass under the interior shade at preset 3 and through the lower ceramic tube array. The shade should be at preset 4 to block direct sun.

Similar logic was applied to the south façade for the 0.91, 1.83, and 3.05 m (3, 6, 10 ft) depths without the ceramic tubes. Partial shading provided by the fritted glass, exterior columns, and exterior cross-bracing were ignored.

To determine if the control systems successfully blocked direct sun also required one to know definitively that direct sun was actually present. It is very difficult to determine systematically using inexpensive instrumentation whether the orb of the sun was obscured by clouds. Time-of-day plots were produced for clear sunny days. Clear, sunny days were identified by a clean bell-shaped curve of the exterior horizontal global illuminance then cross checked using the time-lapse fisheye images of sky conditions over the course of the day. Diffuse exterior illuminance data were also used to supplement the assessment. Time-of-day plots were then produced for these clear sunny days. The theoretical shade height required to block direct sun 0.91 m (3 ft) from the window shade at floor level was computed and graphed to analyze the differences between actual and theoretical shade operations. This theoretical shade height took into account the shading effect of the exterior ceramic tubes. Time-of-day plots were also produced for partly cloudy days. Photographs of the interior taken every 10 min were used to analyze direct sun control.

A computation was also made in each area to determine how frequently and by how much the specified direct sun limit was exceeded. When the depth of direct sun penetration exceeded 0.91 m (3 ft), the minimum, maximum, and average distance of direct sun penetration were computed for the west facade. The percentage of day when the prescribed depth of 0.91 m (3 ft) was exceeded was also computed. Direct sun was determined to be present when the ratio of global-to-diffuse exterior horizontal illuminance exceeded 2.0 (distinct edged shadows). Near sunset when the global exterior illuminance was less than ~15,000 lux, this ratio became too noisy, so this period was not included in the computation. If shades were not aligned to within 5.1 cm (2 in), sun penetration was not computed. The shading effect of the exterior ceramic tubes was accounted for (blocked solar profile angles greater than 65°). The depth of direct sun penetration from the face of the shade was computed at floor level using the average height of the four shades and the solar profile angle. The depth of direct sun penetration at desk level from the west edge of the desk was also computed. The desk was 73.7 cm (29 in) above the floor. The workstation started 35.6 cm (14 in) in from interior face of the window glass or 20.1 cm (7.9 in) in from the face of the shade.

5.3. EXPERIMENTAL RESULTS

Since both the lighting and shading control configuration changed several times over the monitored period, the control configuration number (see Tables 4-1 and 4-2) was plotted on the second y-axis for reference. Data for similar solar conditions before and after a change in shade and lighting controls are presented in time-of-day plots.

Time-of-day plots showing exterior solar conditions, shade operations, and interior environmental conditions were created to visualize and analyze the data (Figure 5-4). Shade height (in inches above the floor) was plotted for each shade ("A H1" through "A H4" for Area A's west façade; "B H5.M1w" through "B H10.M9s" for Area B's west and south facades). The theoretical shade height was also plotted (dashed line), showing what the shade height ought to be to control direct sun to a specific distance from the window if it were sunny ("Height if sun").

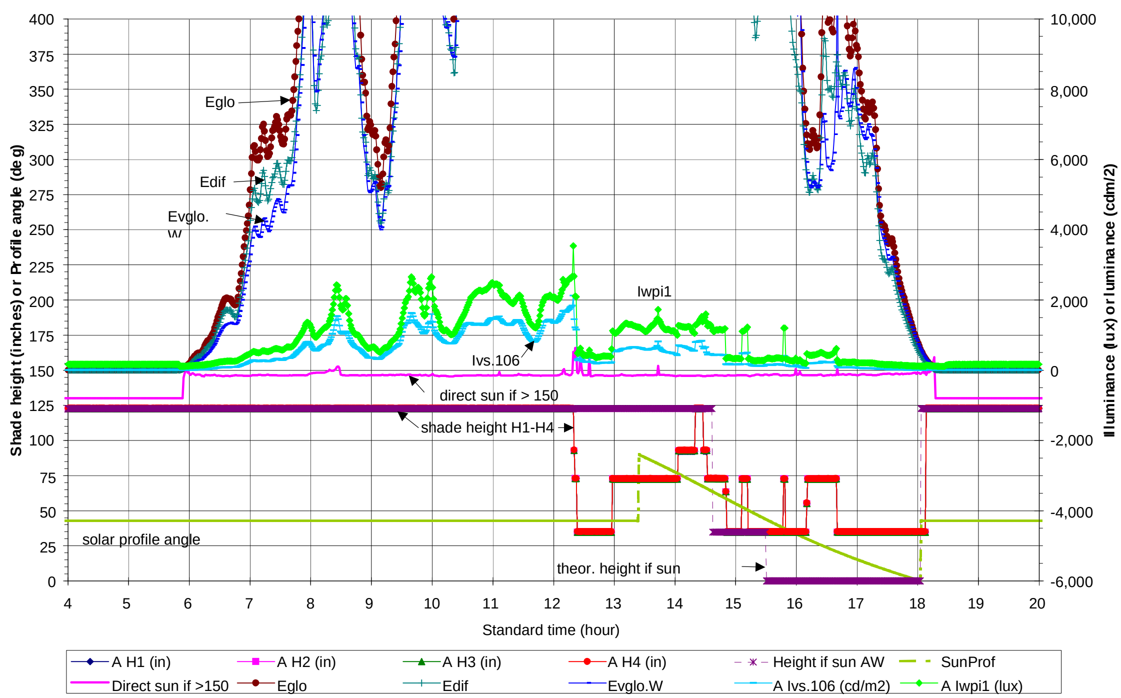


Figure 5-4. Example of shade plot.

Environmental conditions plotted included solar profile angle ("SunProf"), the ratio of global to diffuse exterior horizontal illuminance ("Direct sun if > 150" – see below), exterior global ("Eglo"), diffuse

("Edif"), and vertical illuminance for the west or south facade ("Evglo.W" or "Evglo.S"), and the average window luminance of the west or south window ("A Ivs.106 (cd/m2)" or "B Ivs.108 (cd/m2)"). Interior illuminance data included total (daylight + electric light) workplane illuminance in the first workstation closest to the west window wall ("A Iwpi1 (lux)" or "B Iwpi1 (lux)") or the total partition-high illuminance (1.2 m or 4 ft above floor) at the fifth workstation from the west windows in Area B ("B Idist5"). The ratio of global-to-diffuse exterior horizontal illuminance was converted: 130+ratio*20/1.5. A ratio of 1.5 would be plotted as 150. A ratio of 2 would be plotted as 156.7. On clear days, the ratio would be typically much greater than 2.

<u>5.3.1. Area A</u>

5.3.1.1. Motor operations

The shading system in Area A operated with no mechanical problems and no hysteresis throughout the nine-month life of its installation. Hysteresis was defined where the shade reversed position three times within a 5 min period. The building owner did not note any mechanical problems with the shade.

Checks on shade alignment were used to locate problems with control or motor operations. During the monitored period, the shades were within 3 cm (1.2 in) of the installed preset heights for 99-100% of the day over the entire monitored period. The building owner did not note any alignment problems with the shade.

5.3.1.2. Direct sun versus glare control

This section compares the differences in operations between direct sun and glare control and remarks on how Area A's system achieved control of the window luminance. On clear days generally, the shades were lowered along this northwest-facing facade more often in the summer than any other season due to the increased hours when the sun was in the northwest quadrant of the sky and the greater levels of incident sunlight during this period. Figures 5-5 to 5-8 shows the shade control patterns for glare control (mode 4) under clear sky conditions. Between the spring equinox (~4/28/4) to the summer solstice (~6/12/04), there was a steady progression towards earlier shade deployment (lowering) when the sun came into the plane of the window in the early afternoon and later deployment (raising of the shade) at sunset as the days became longer. The trend then reversed from the summer solstice to the fall equinox (~9/19/04).

It is interesting to note that there are small differences in shade operations between the glare versus direct sun control modes under clear sky conditions (note that this glare mode was tuned for "moderate" glare control by the manufacturer in keeping with the desires of the building owner). Figures 5-5 to 5-8 show the differences in operation with time-of-day plots. The theoretical direct sun control mode was computed using methods described above.

From 4/28/04 to 6/12/04 on clear days, the glare control mode deployed the shades ~2 h earlier than the block direct sun mode, extending the shades in the upper portion of the window wall with the ceramic tubes. This in effect blocked the sky one can see through the ceramic tubes but provided no change in window luminance in the vision portion of the window wall (noting this effect led the building owner to define the average luminance of the vision portion of the window wall as the controlling criteria for glare in the procurement specifications, instead of the vision and upper portion of the window wall). The average whole window luminance, however, was reduced. The shades were then moved to cover the vision portion of the window wall at the same time between the two control modes. After this, the glare control mode moved the shades 10-45 min earlier than the direct sun mode to cover the lower 0.91-m (3-ft) high portion of the window wall with ceramic tubes. This produced very little to no reduction in the brightness of the window wall seen by the sensor and occupants not seated adjacent to the window wall since this window area is below the field of view and is blocked by the 1.2-m (4-ft) high partitions. The average luminance of the window wall, however, was reduced for occupants seated next to the window but this effect was not monitored. Finally, the shades were retracted at the end of the day at the same time in both control modes (low direct sun in the plane of the window). By 8/22/04 and 9/19/04, there was an insignificant difference in time and pattern of operation between the glare and block direct sun modes.

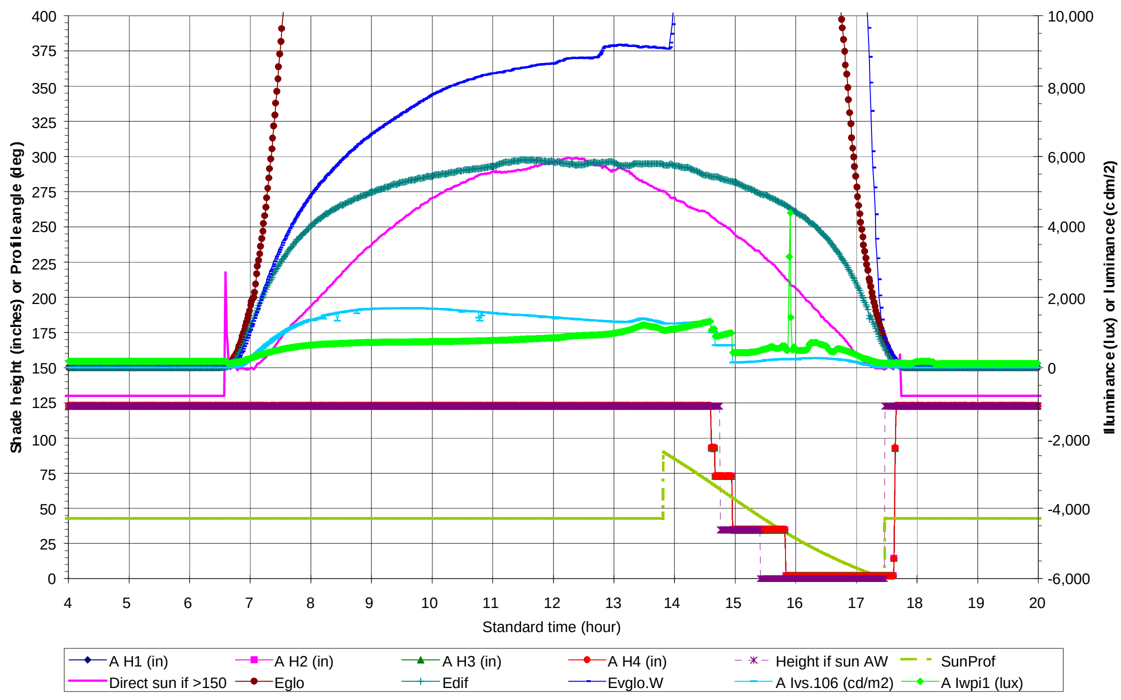


Figure 5-5. Area A. Shade operations on 2/16/04, clear sky conditions. See introduction to Section 5.3 for explanation of plot.

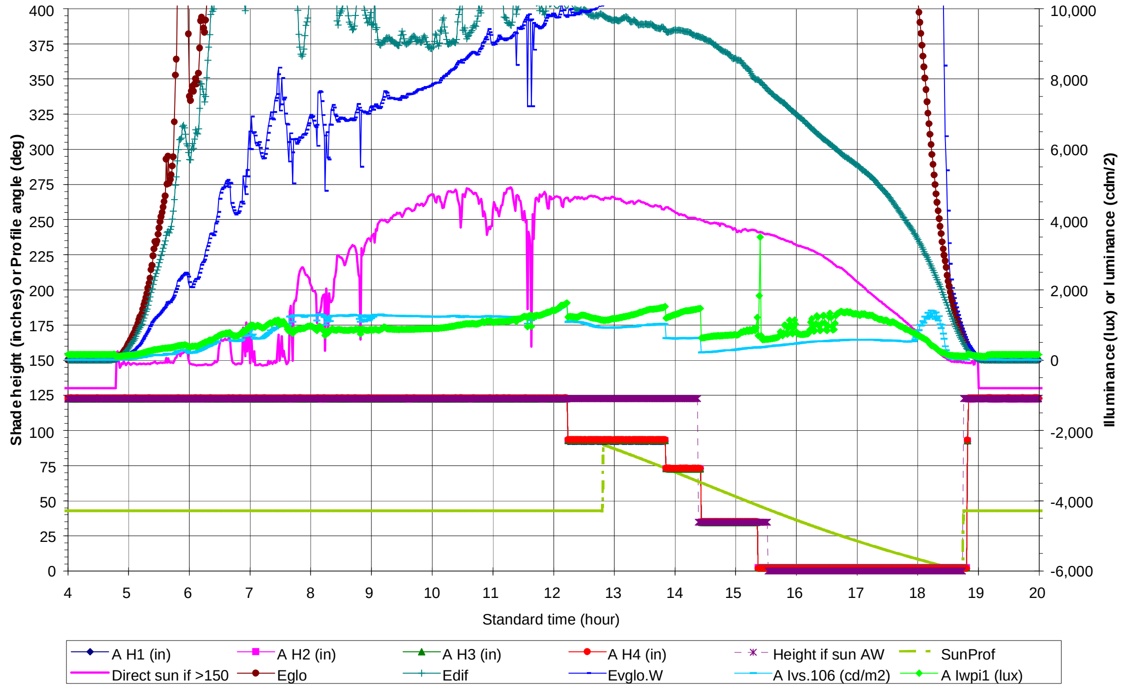


Figure 5-6. Area A. Shade operations on 4/28/04, clear sky conditions. See introduction to Section 5.3 for explanation of plot.

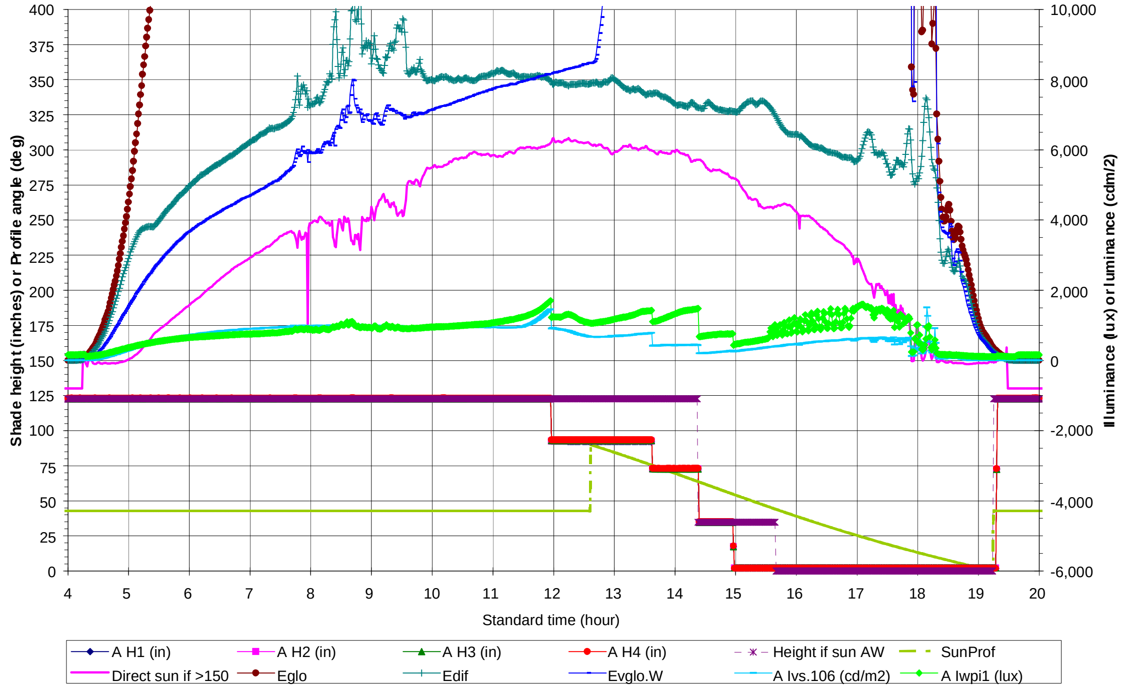


Figure 5-7. Area A. Shade operations on 5/29/04, clear sky conditions. See introduction to Section 5.3 for explanation of plot.

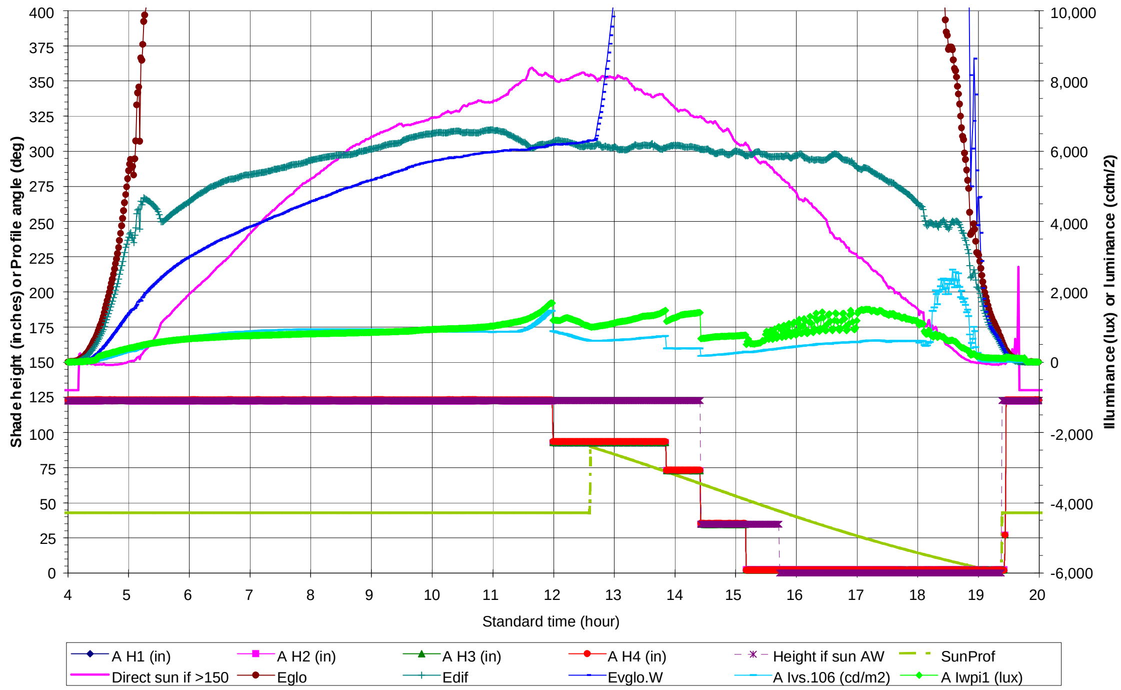


Figure 5-8. Area A. Shade operations on 6/12/04, clear sky conditions. See introduction to Section 5.3 for explanation of plot.

Note that if intermediate shade heights were permitted within the vision portion of the window wall, there could be more time during the day when seated occupants could see a partial view through the lower part of the vision window. Greater window glare control may also occur. An additional preset height in this region was later included in the procurement specifications. Also, if the period is short when the solar profile angle is less than 43°, then the interior shade could be controlled to remain at preset 3 to increase daylight to the interior. This low angle sunlight strikes seated occupants and can cause thermal discomfort (to the lower body) but if the duration is short, the increased daylight and interior brightness may be worth considering, particularly during the winter season. This option was considered in the Radiance simulations (see Section 3).

Over the course of the monitored period, the control of the shade during partly cloudy days differed very little from clear sky operations except that it was retracted and extended as the sky condition changed. Examples of shade control are given in Figures 5-9 to 5-12. That is, the shade was typically extended only after the noon hour, it extended first in the upper portion of the window wall (preset heights 1 and 2), then extended downwards to lower presets if needed. Shade control was typically triggered when the average window luminance was between 1500-2200 cd/m^2. There were occasions in the morning when the window luminance reached 1800 cd/m^2 and the shades were not extended. When the shades were extended, the shade was always moved to the next consecutive preset height with 1-2 min minimum before moving to the next preset height. The shade was controlled prior to noon on a few days over the nine-month monitored period (Figure 5-9 5/17/04).

On cloudy days, the sky luminance is often greater than the clear sky luminance (e.g., white cloud within the occupant's field of view) and can cause significant glare if the shades are not extended to cover in particular the vision portion of the window wall where there is no protection from the ceramic tubes. Digital luminance maps were taken during the vernal equinox under cloudy conditions and the luminance of the unobscured portions of the window wall were between 2000-4000 cd/ m^2 (or greater). The shades in Area A should be extended over the vision portion of the window to control sky glare, even in the morning hours. There can be several explanations why this did not occur over the nine-month period: 1) the building owner asked the manufacturer to tune the control system to control window glare yet admit daylight, which led to less conservative glare control or 2) the ceiling-mounted photosensor viewed the average window and interior horizontal surface luminances and therefore was unable to detect sky luminance. Sky luminance is best measured using a shielded vertical sensor that has a view that mimics that of the occupant's view toward the horizon (when conducting computer-based VDT tasks).

Fulfilling the goal of glare control (e.g., maintain window luminance below 2000 cd/m^2) will cause the shades to cover the vision portion of the window wall for greater periods throughout the day on both sunny and partly cloudy to overcast days. The acceptable balance between interior daylight levels, brightness, and view versus glare and direct sun control will need to be worked out with the occupants in the open plan office zones.

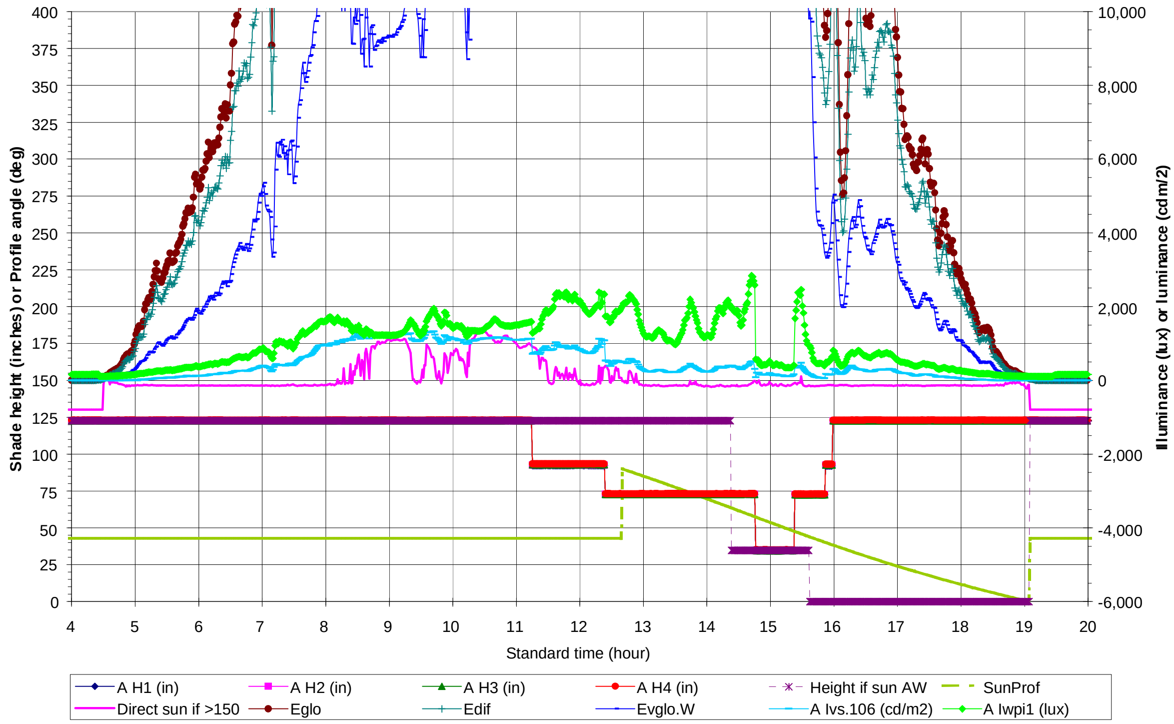


Figure 5-9. Area A. Shade operations on 5/17/04, partly cloudy conditions.

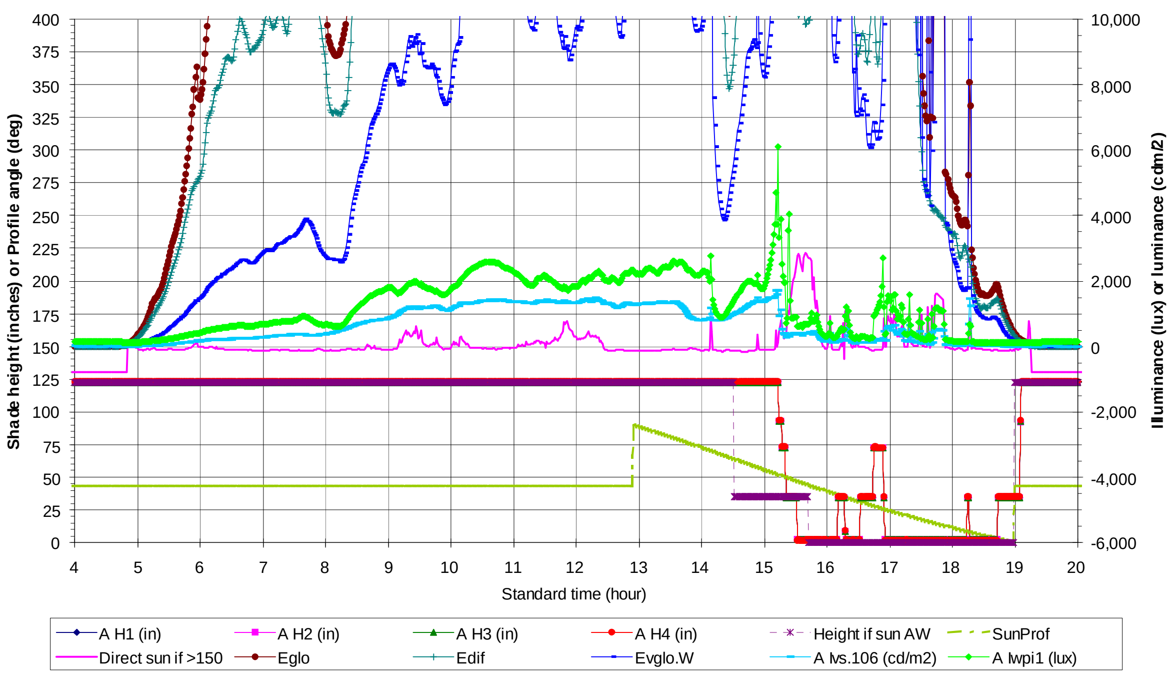


Figure 5-10. Area A. Shade operations on 8/7/04, partly cloudy conditions.

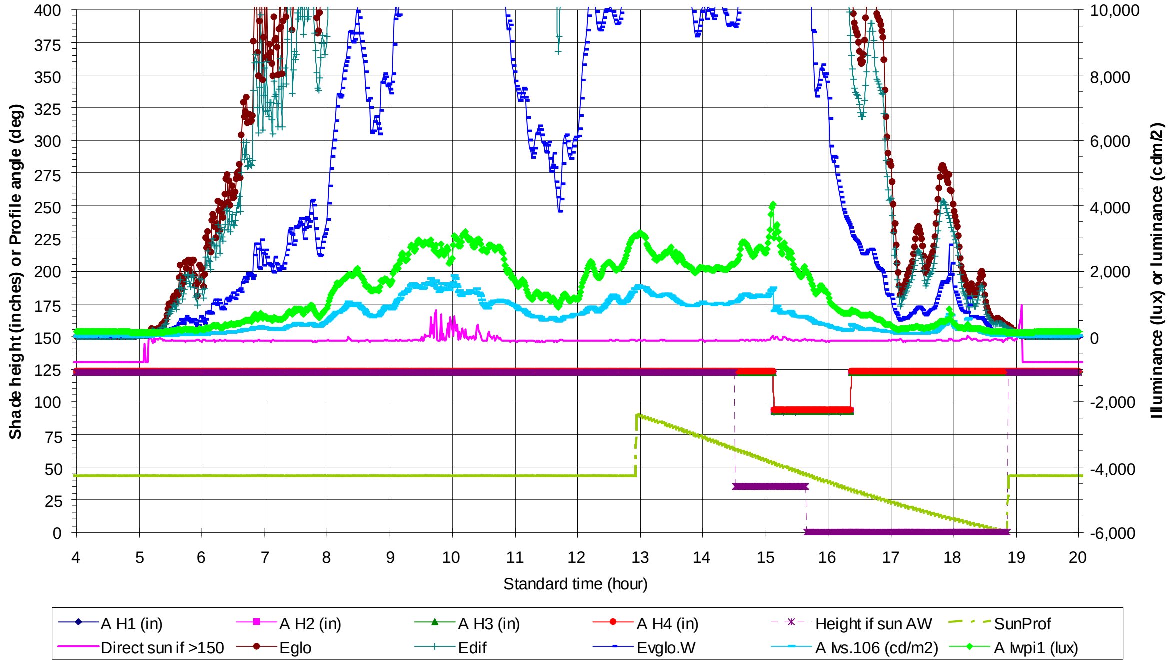


Figure 5-11. Area A. Shade operations on 8/13/04, partly cloudy conditions.

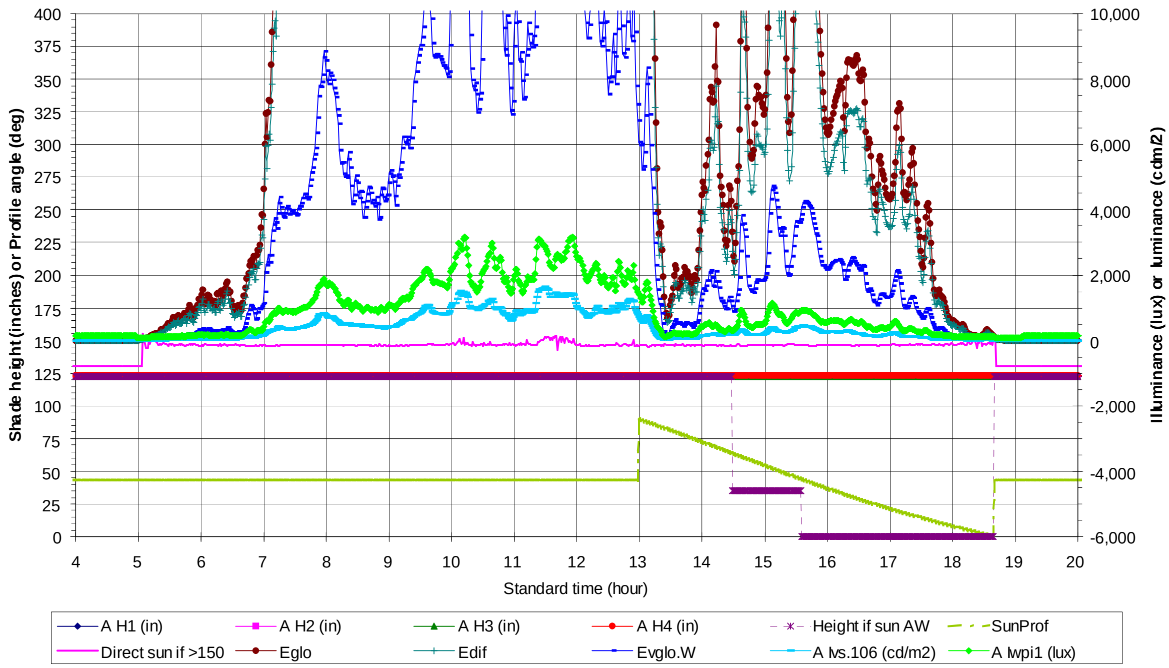


Figure 5-12. Area A. Shade operations on 8/21/04, partly cloudy conditions.

5.3.1.3. Depth of direct sun penetration

The shading system did not successfully limit direct sun penetration to 0.91 m (3 ft) from the window throughout the monitored period. The vendor did not explicitly address this requirement as explained in the Method section above. Direct sun penetrated 1.07-2.51 m (3.5-8.24 ft) for 23 min on average per day on 100 days out of the total 280 monitored days (Figure 5-13). The building owner noted that direct sun exceeded the requested 0.91 m (3 ft) depth during periodic site visits. At desk level, direct sun penetrated typically 0.30-1.22 m (1-4 ft) and at worst 1.22-3.05 m (4-10 ft). A worst case example is shown for 2/8/04 in Figure 5-14 when direct sun penetrated up to on average 1.83 m (6 ft) from the window wall at floor level for 93 min in the day. Figure 5-15 shows direct sun on the floor and desk surfaces. In both Areas, direct sun also came through the 2.5 cm (1 in) gaps between shade bands whenever the sun was in the plane of the window. Sunlight also passed through the open holes in the fabric, casting a diffuse shadow pattern on work surfaces.

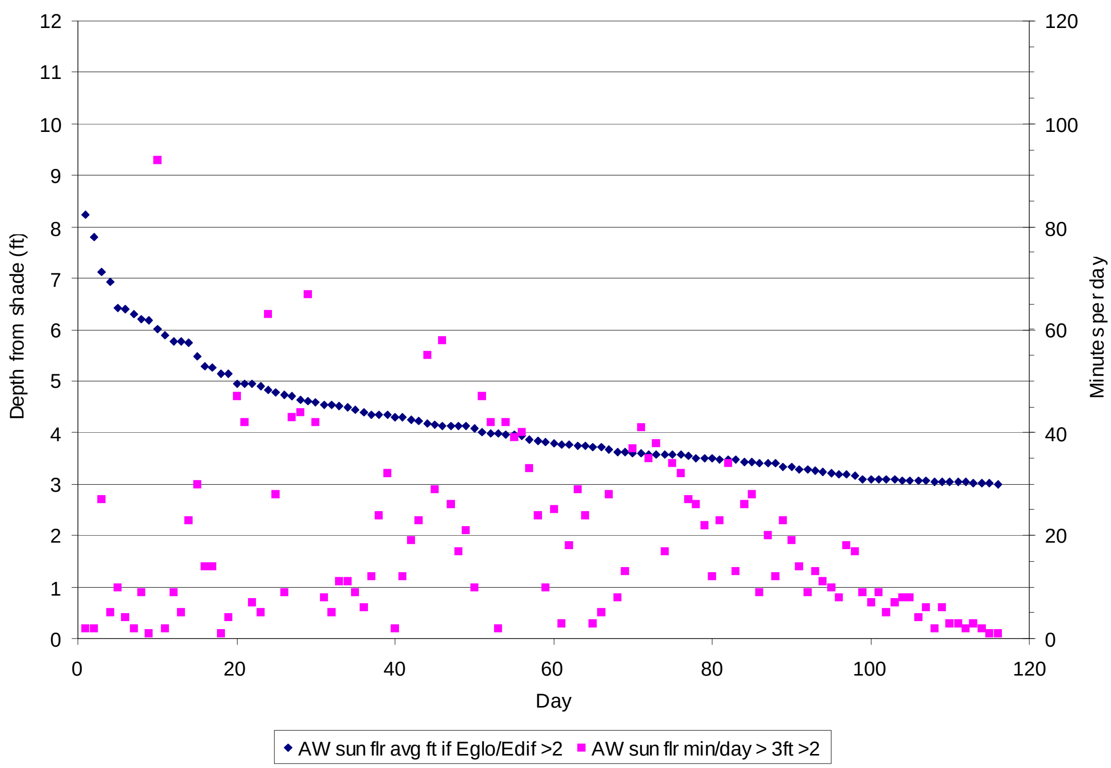


Figure 5-13. Day versus average daily depth of direct sun penetration at floor level and number of minutes per day that direct sun penetrated deeper than 0.91 m (3 ft) from the face of the shade at floor level in Area A.

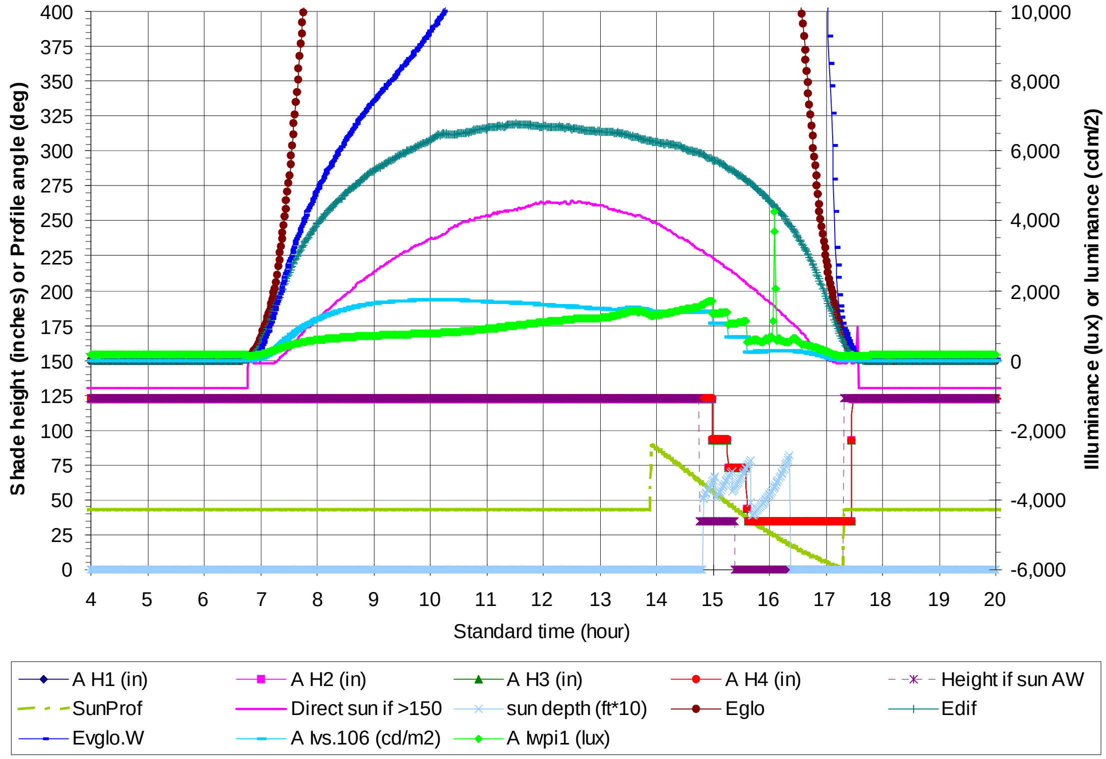


Figure 5-14. Area A. Shade operations on 2/8/04 when direct sun occurs.

Figure 5-15. Area A. Photographs of direct sun on work surfaces on 2/8/04 at 16:20.

5.3.1.4. Difference in preset heights between glare and direct sun control mode all year

Figure 5-16 shows the percentage of day that the shades were at each preset height. These percentages are given for the actual shade control that occurred each day and for a theoretical shade control mode if it was sunny and the shades were controlled to block direct sun 0.91 m (3 ft) from the window shade. The difference between the two values indicate how closely actual control mimicked shades controlled for direct sun. There are several reasons why actual shade control deviated from the theoretical mode: 1) it was not sunny and shades were fully retracted because there was no glare, 2) it was not sunny and shades were extended to control glare rather than fully retracted, and 3) it was sunny and shades were at a lower preset than the theoretical direct sun control mode to control glare.

When the shades were in control modes 1 and 2 for “daylight”, Figure 5-16 shows that there was close agreement for the open shade preset and theoretical modes for many days (DOY=40-105). The shades were more open in the daylight control mode. When the control mode was shifted to “glare” (modes 3 and 4), the shades were less open over the course of the day (DOY=105-230). This summary data agrees with the time-of-day assessments made on individual days in the analysis above.

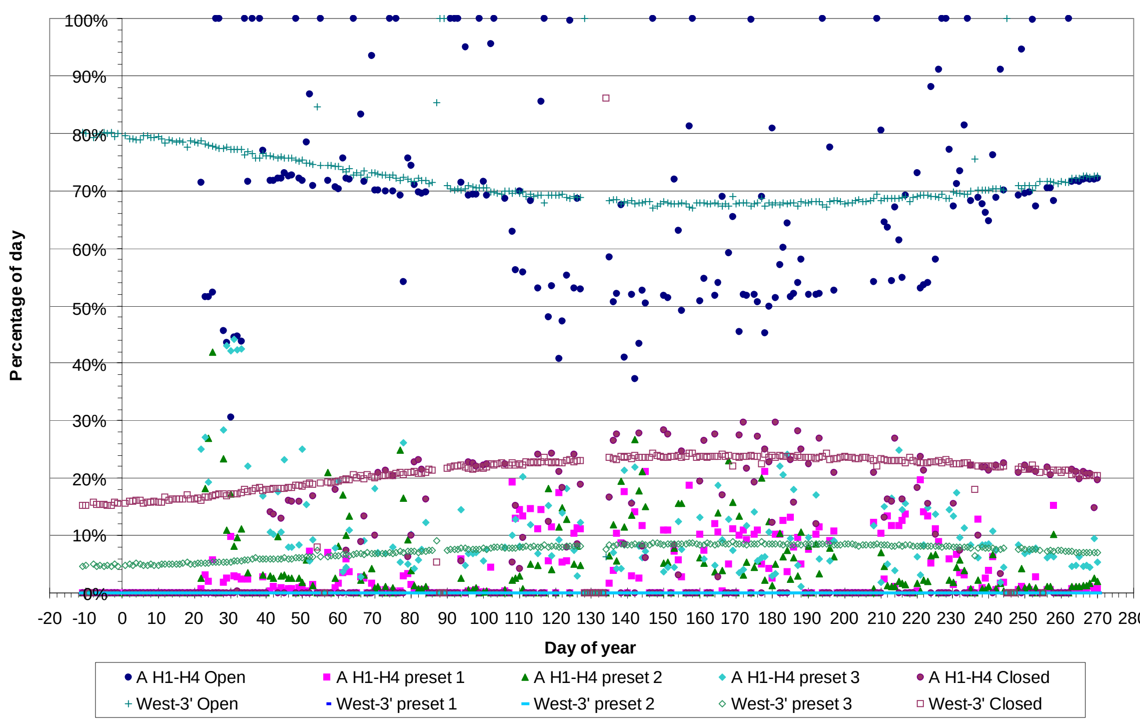


Figure 5-16. Area A. Percentage of day that the shades were at each preset height over the nine-month monitored period. Closed symbols show the actual shade use. Open symbols show the theoretical shade control mode if it was sunny and shades were controlled to block direct sun.

5.3.1.5. Response rate under stable and unstable skies

The shade control system demonstrated quick responsiveness to variable sky conditions. Shade control operations are shown for several partly cloudy days in Figures 5-17 to 5-18 (3/18/04 daylight control mode 2 and 5/28/04 glare control mode 4). The sky conditions in both of these examples are highly variable. On 3/18/04 with control configuration 2, the shade was retracted and extended in response to the changing sky conditions. The shade was extended from preset 0 to preset 3 to reduce window luminance at 12:25 then retracted to preset 2 at 12:58. At 14:05, the shade was gradually retracted then extended again at 14:30. Three shade reversals occurred within 2-8 min between 14:20 and 15:50. This example shows the day with the most shade movement in the nine-month monitored period. A similar level of movement for a partly cloudy day 5/28/04 is given in Figure 5-18 which can be compared to clear sky conditions on 5/29/04 in Figure 5-7. The procurement specifications addressed this issue by requiring retraction to occur one preset at a time with a 5-min delay between each move. For extension (or lowering) of the shade, instant response was specified in order to avoid visual and thermal discomfort caused by direct sun or window glare. For retraction, a slower response time was specified.

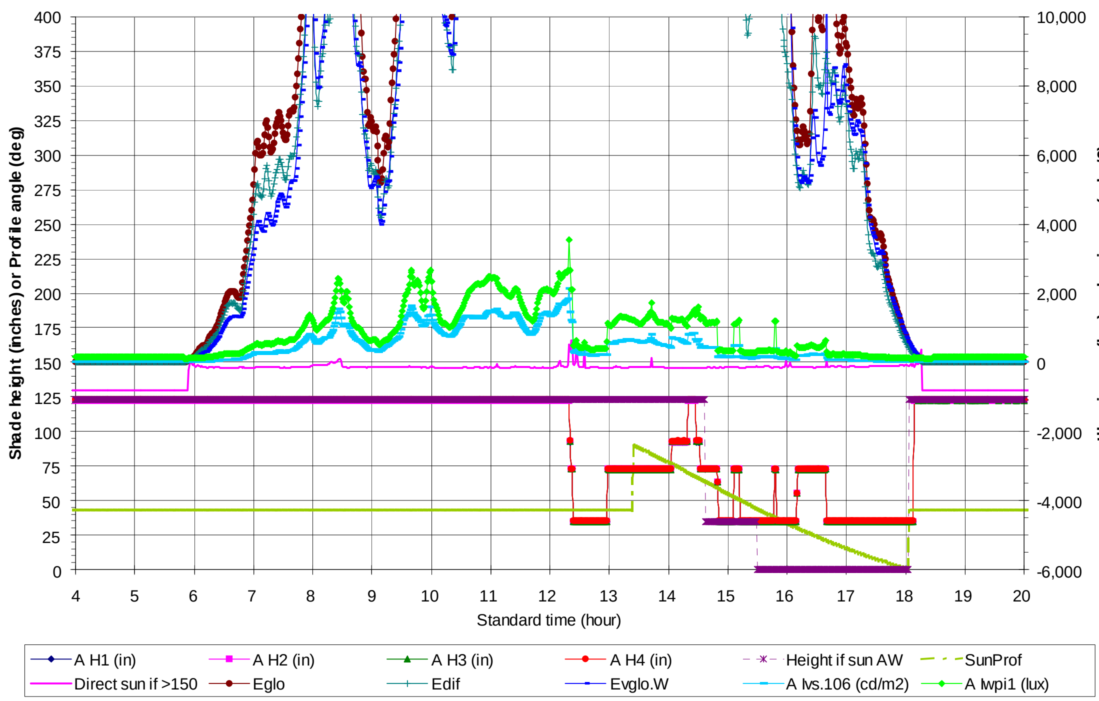


Figure 5-17. Area A. Shade operations on 3/18/04 with daylight control.

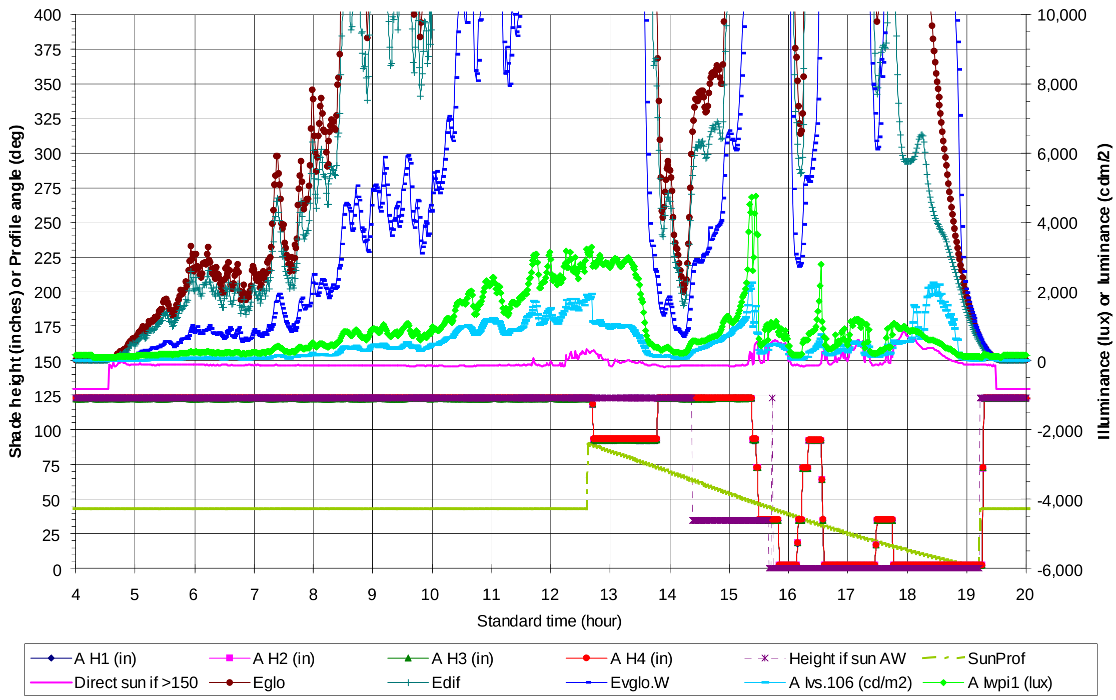


Figure 5-18. Area A. Shade operations on 5/28/04 with glare control.

5.3.2. Area B

The shading system in Area B exhibited some mechanical problems that were caused by improper installation of the shades where field conditions differed from the construction documents. Other complications arose when new software customizations for The Times caused inadvertent problems with the existing software and then required debugging in the field. The manufacturer's product was designed to impose random delays on motors within the same control group to prevent power surges when large shade zones might be actuated as a group. However, upon startup of the monitoring phase, individual shades within a group were moved within a delay of 1-60 min or more of each other. This problem was resolved for the most part by March 2004 when the building owner requested that all delays be eliminated so that all shades in the same group would be moved simultaneously for a clean, orderly appearance. Timing delays were limited to a few milliseconds in the final procurement specification. These various problems (summarized in Table 5-3) complicated the analysis. Therefore, the criteria for evaluating whether the shades were operating "properly" throughout the day were relaxed in order to capture a broader dataset, particularly for the daylighting controls and visual comfort assessments reported in other sections of this report.

Table 5-3.
Summary of mechanical problems with the shade motors

Motor	Dates	Problem
H5, H6	4/1 - 4/13/04	Stuck in full up position with unknown cause
H5, H6	4/17 - 4/21/04	Stuck in full down position with unknown cause
H9	2/24 - 3/2/04	H9 had motor disconnect plug pinning fabric at corner of the pocket. Fixed 3/2.
H9, H10	3/11 - 3/22/04	Motors not tracking with the rest of the shades. Manual overrides not returning consistently to automatic mode. Fixed 3/25/04.
H9	3/23/2004	Fixed mounting bracket condition.

Figures 4-35 (1/15/04) and 4-36 (3/11/04) show the nature of how individual shades were not operating to the same height as the rest of the shades across a facade. On 1/15/04, timing delays occurred between the individual shades. On 3/11/04, shade H9 did not move with the other three shades from preset 3 to preset 4 between 16:55 and 17:50 on the south facade. This type of error occurred intermittently from 3/11/04 to 3/22/04 and was fixed on 3/25/04. The error was attributed to custom software changes (the change logged when manual overrides of the shades occurred), which caused the shade to not return consistently from the manual override mode back to the automatic mode.

Shade hysteresis did not occur throughout the nine-month life of this installation. Hysteresis was defined where the shade reversed position three times within a 5-min period.

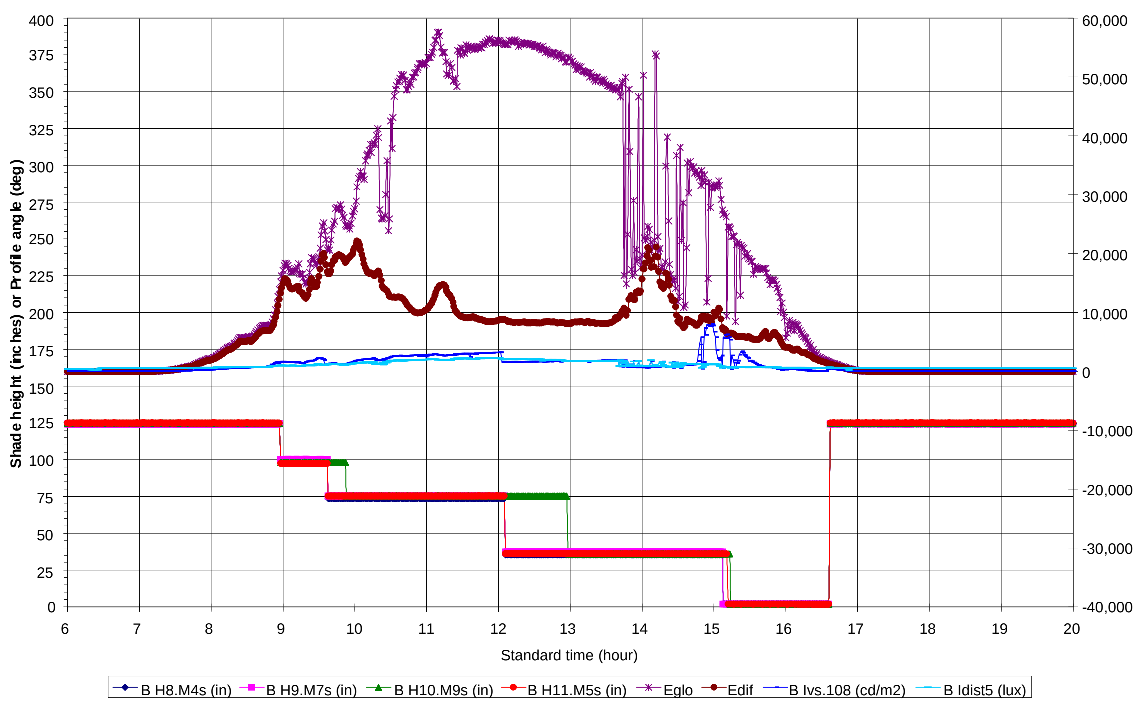


Figure 5-19. Area B. Shade operations on 1/15/04 south façade – 10 ft direct sun depth.

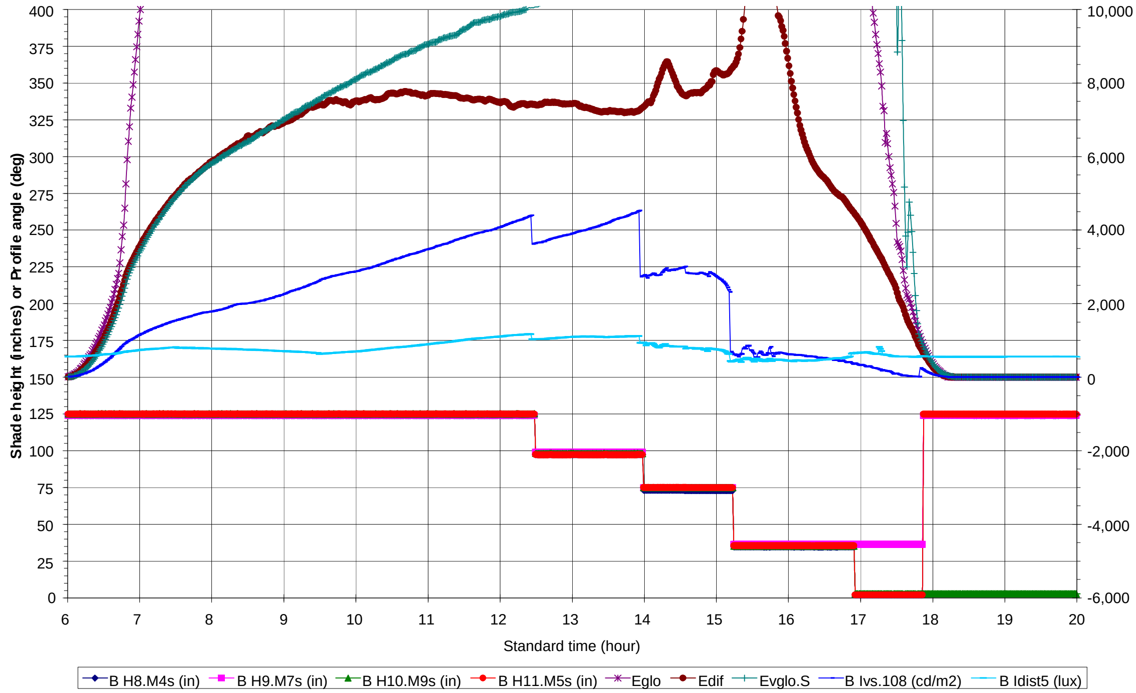


Figure 5-20. Area B. Shade operations on 3/11/04 south façade – example of non-tracking H9 motor.

5.3.2.1. Direct sun control

Shade operations for the west facades are illustrated in Figures 5-21 to 5-28 for sunny, clear sky conditions throughout the monitored period. On the west façade, the shades were deployed in the mid- to early-afternoon and closed fully when the sun was low on the horizon and directly in the plane of the window. Differences between the actual and theoretical direct sun control modes occurred in the early afternoon: the actual shade was deployed earlier because the manufacturer did not account for the shading effect of the ceramic tubes while the theoretical mode did. (Later, the procurement specification required that the control system take this effect into account.) Shade operations on a partly cloudy day 5/28/04 are given in Figure 5-29 and can be compared to Figure 5-26 (5/29/04).

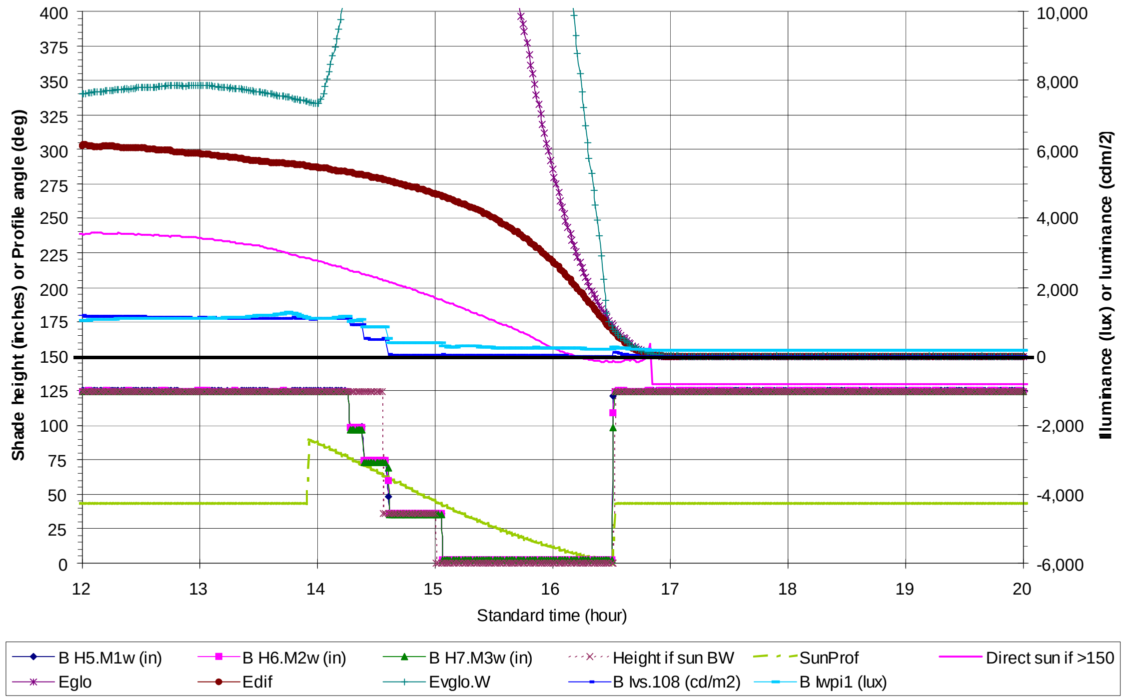


Figure 5-21. Area B. Shade operations on 12/27/03 west façade, clear sky conditions.

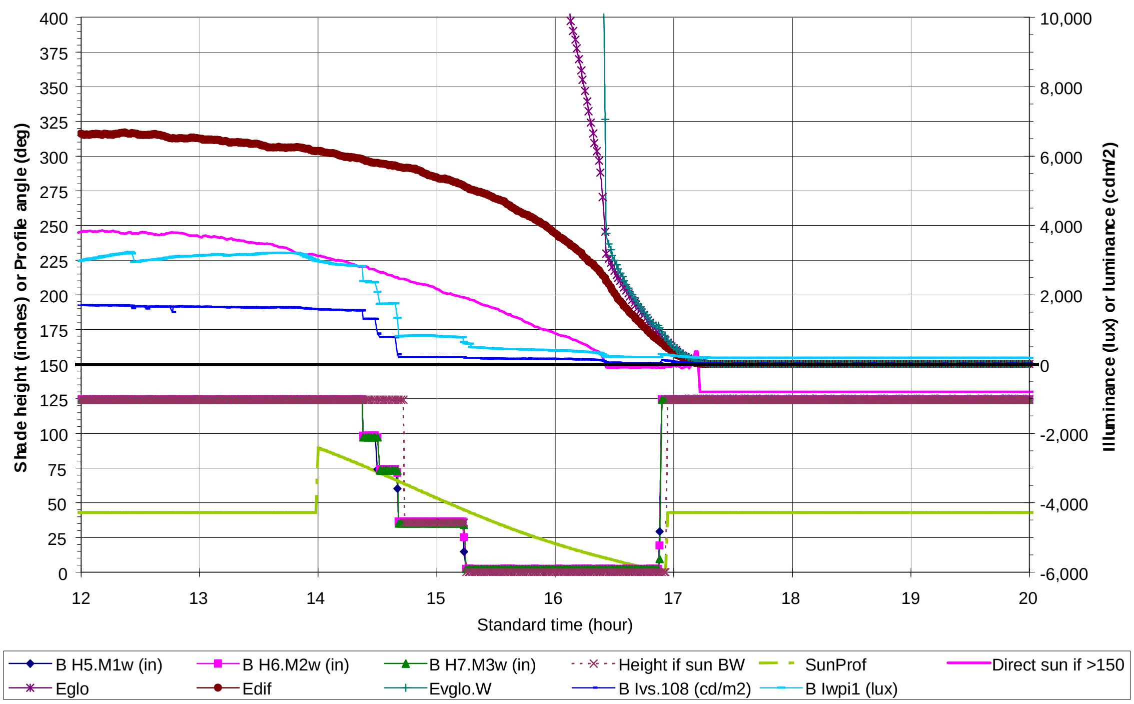


Figure 5-22. Area B. Shade operations on 1/21/04 west façade, clear sky conditions.

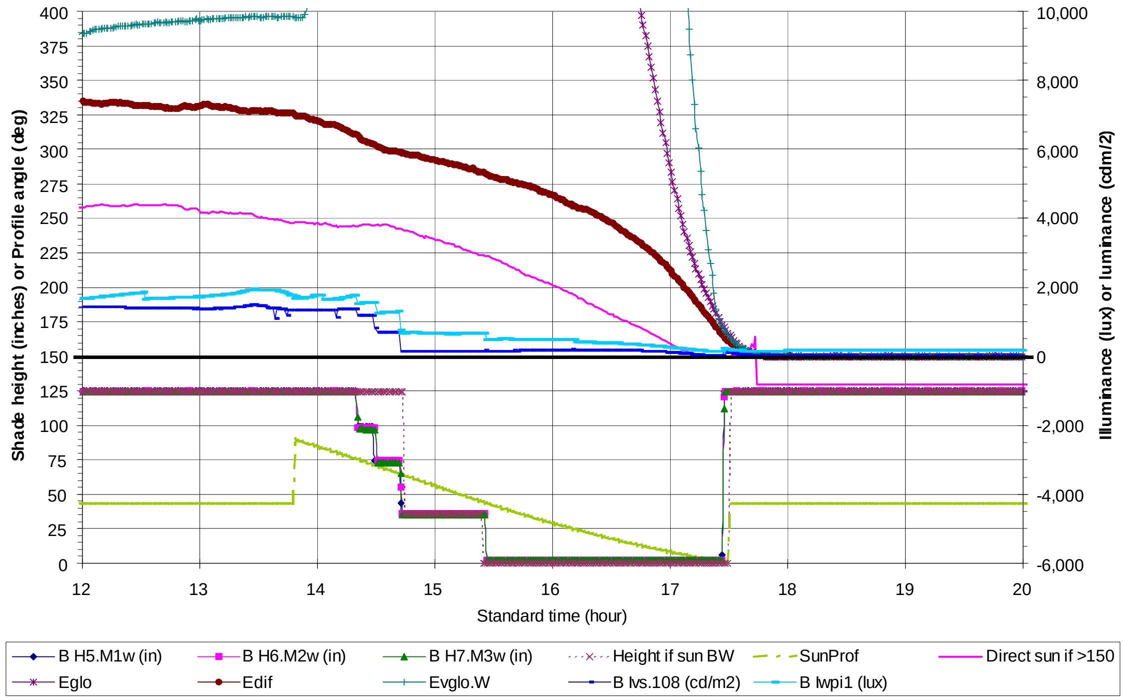


Figure 5-23. Area B. Shade operations on 2/18/04 west façade, clear sky conditions.

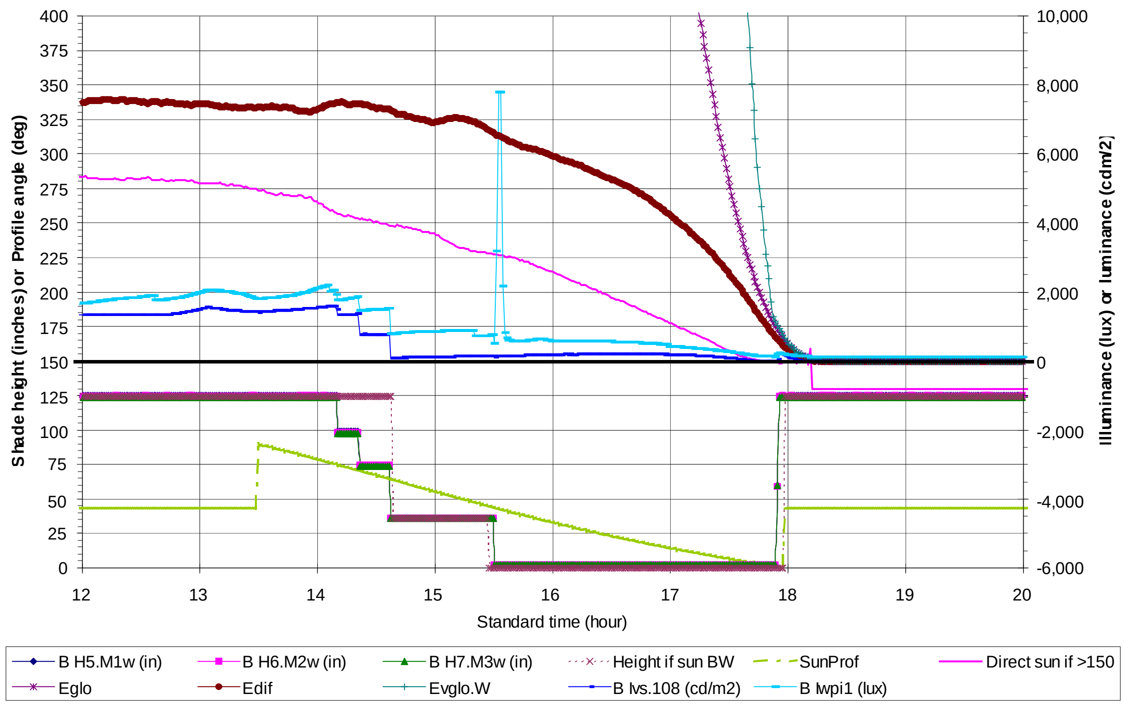


Figure 5-24. Area B. Shade operations on 3/13/04 west façade, clear sky conditions.

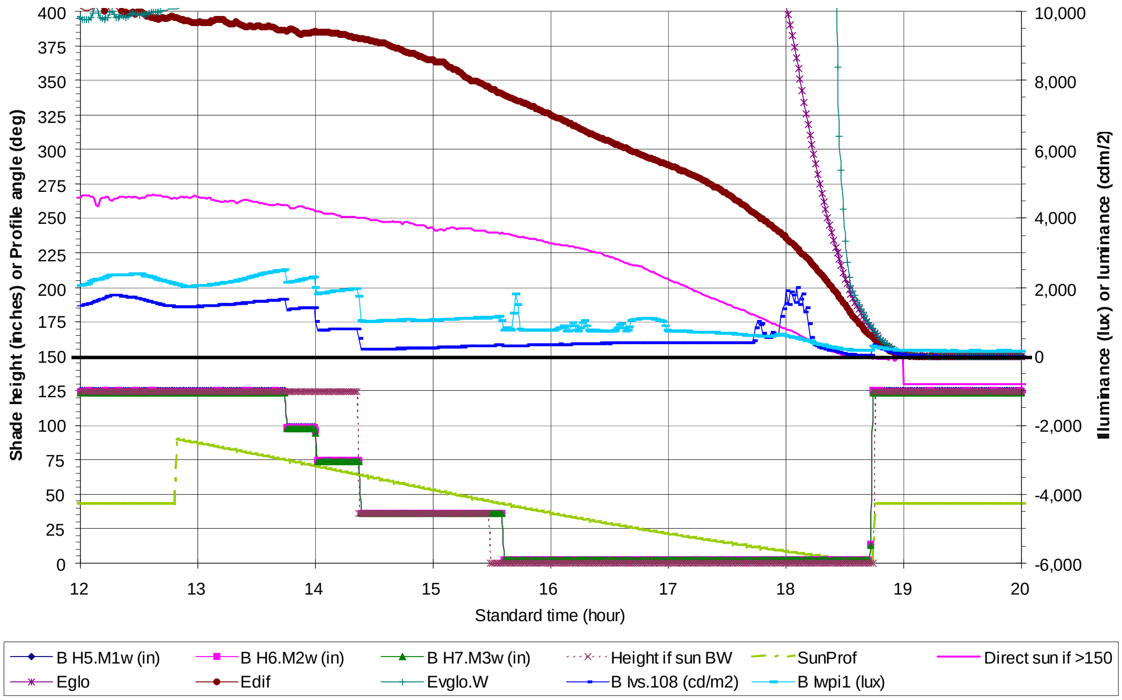


Figure 5-25. Area B. Shade operations on 4/28/04 west façade, clear sky conditions.

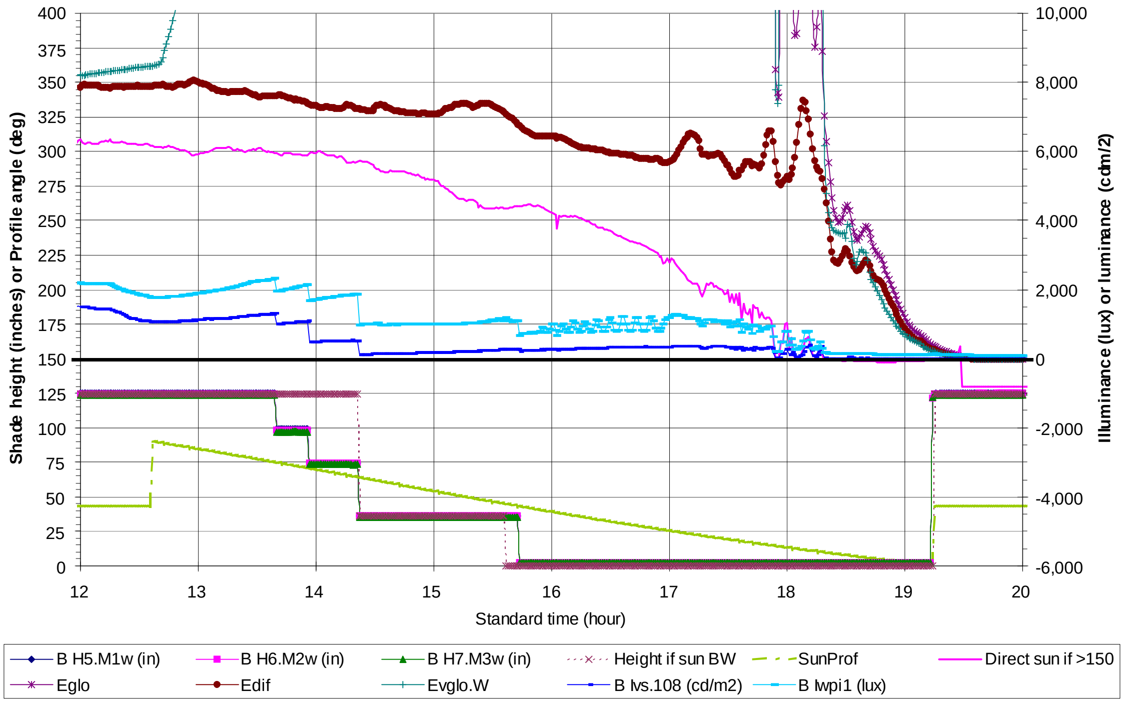


Figure 5-26. Area B. Shade operations on 5/29/04 west façade, clear sky conditions.

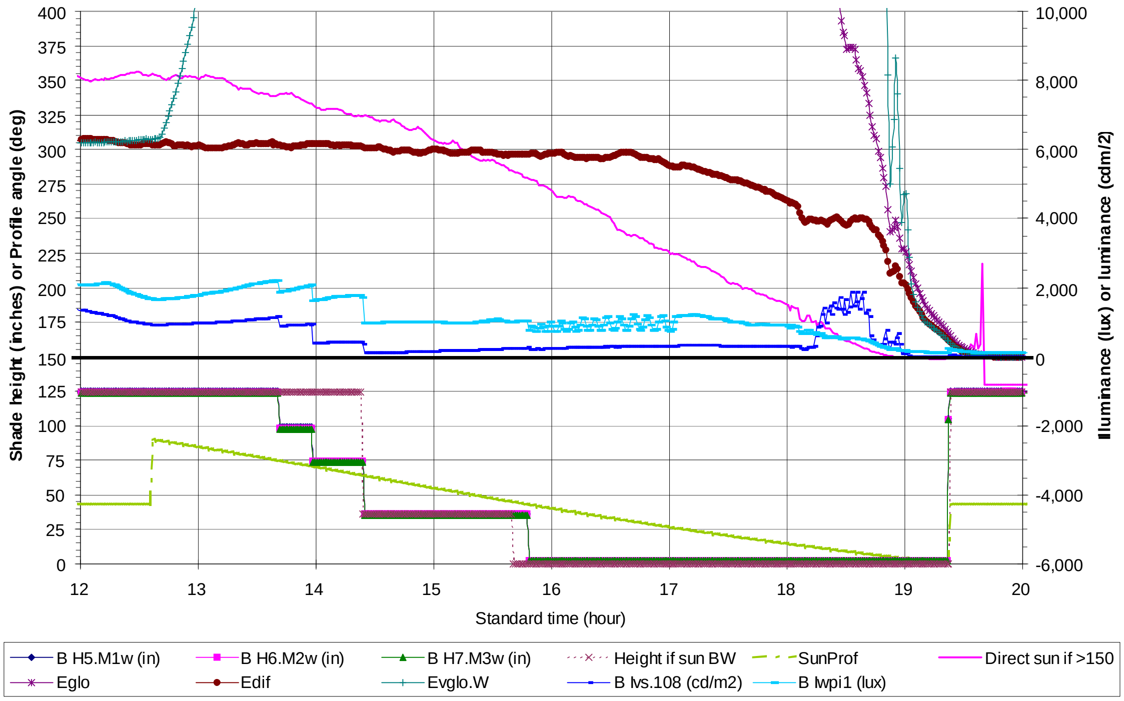


Figure 5-27. Area B. Shade operations on 6/12/04 west façade, clear sky conditions.

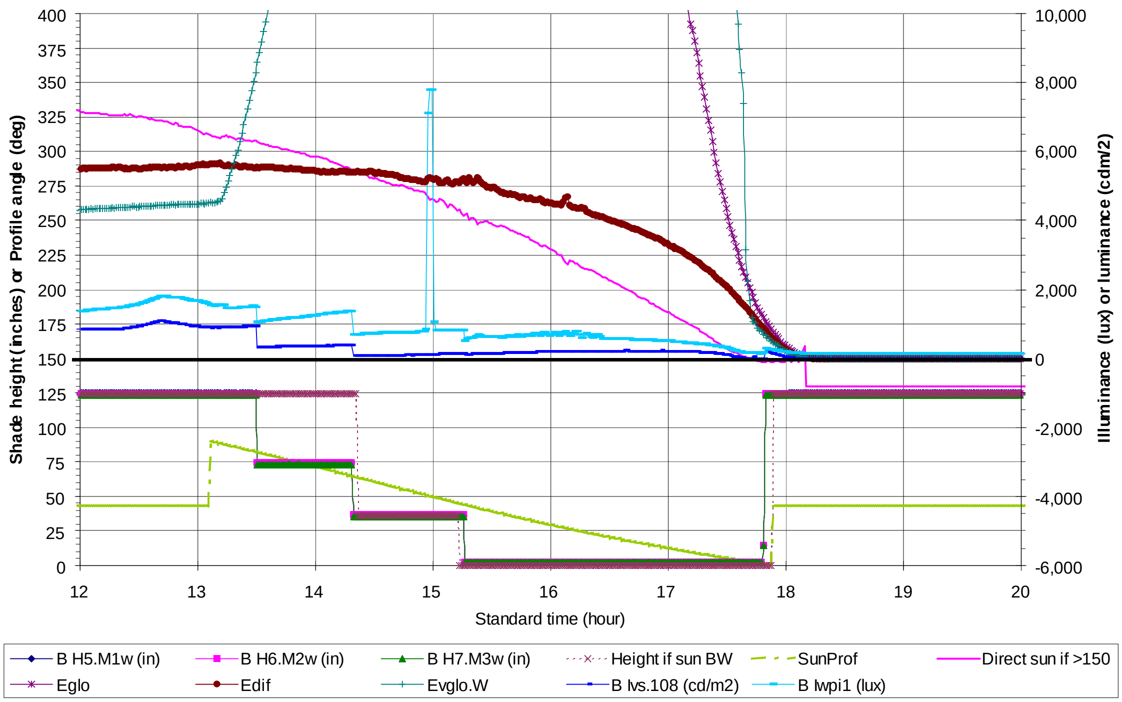


Figure 5-28. Area B. Shade operations on 9/19/04 west façade, clear sky conditions.

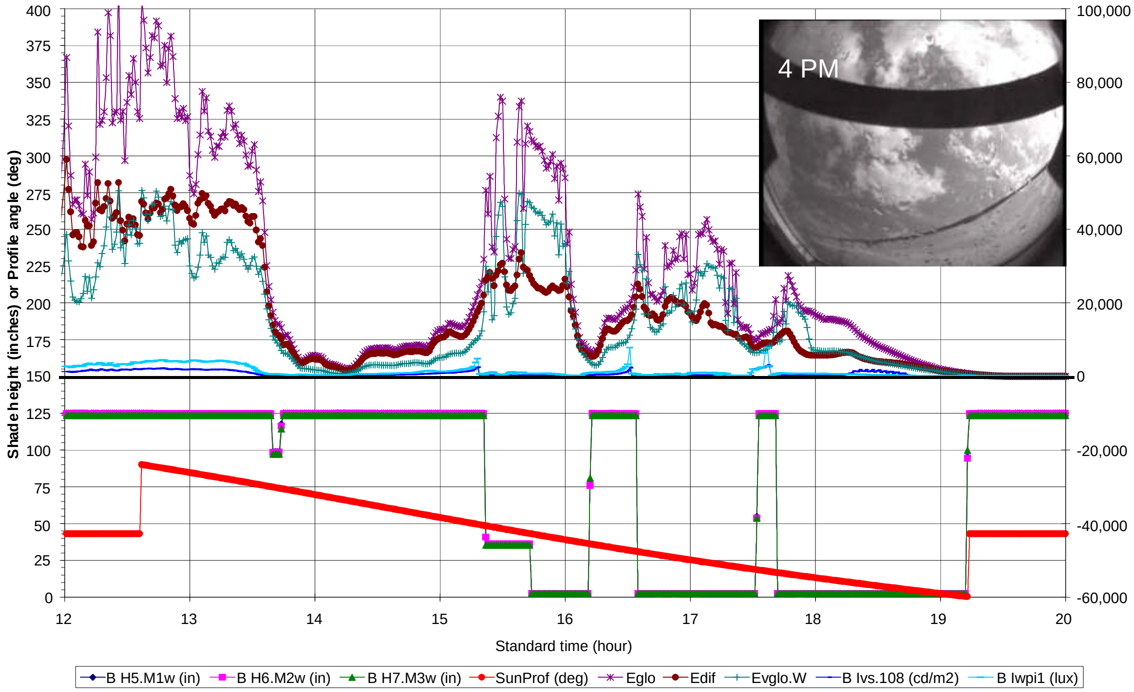


Figure 5-29. Area B. Shade operations on 5/28/04 west façade, partly cloudy conditions.

On the south façade, the shades were fully down throughout the day if it was a clear sunny day during the winter because of the low sun angle and because the depth of allowable sun penetration was set initially at 0.91 m (3 ft) from the window wall (Figure 5-30 1/11/04). When the building owner observed that the shades were down all day, the allowable depth of sun penetration was raised to 3.04 m (10 ft) from the window wall on 1/12/04 to increase view and brighten the interior in the circulation zone near the stair (particularly during dreary winter days), then later reduced to 1.83 m (6 ft) on 4/16/04 to control window glare. The control pattern after the change to 3.04 m (10 ft) was made is shown in Figure 5-31 for 1/20/04. The control pattern after the change was made to 1.83 m (6 ft) is shown in Figure 5-32 for 4/28/04. Note that more view and daylight were permitted with these changes. By the summer solstice when the sun was higher in the sky (Figure 5-33 6/12/04) with a 1.83 m (6 ft) allowable depth, the shades were modulated only in the upper portion of the window wall. The computed shade heights for the three setpoint depths are shown on the graphs. The pattern was not symmetrical over the noon hour because the south window faces 28.65° west of true south.

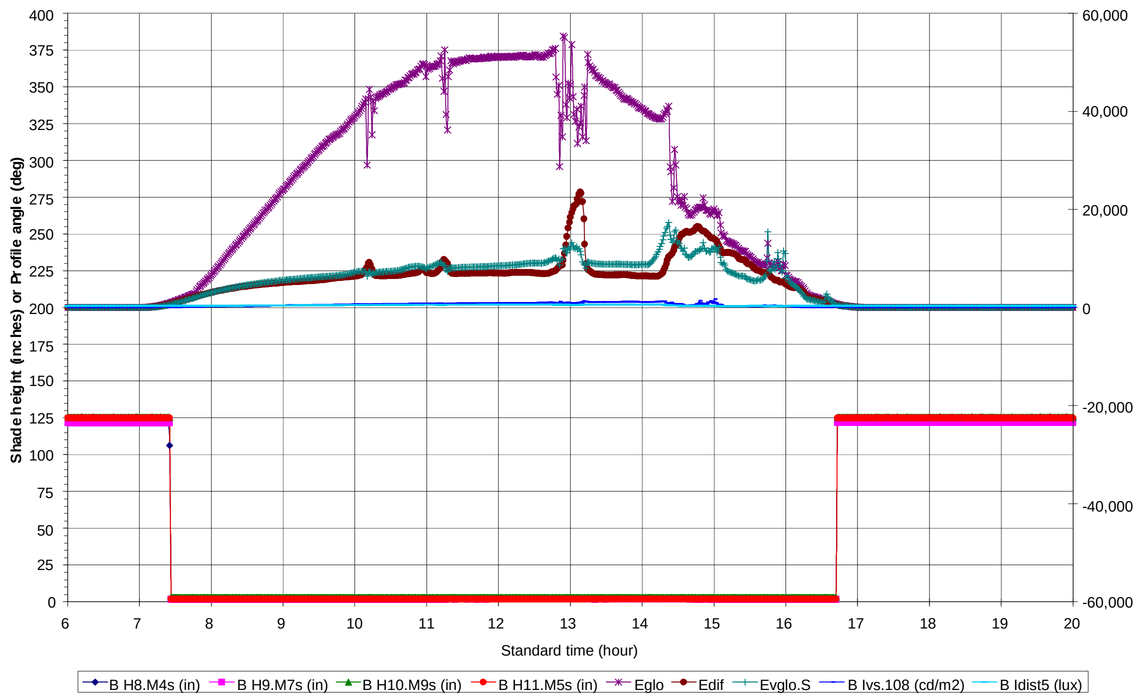


Figure 5-30. Area B. Shade operations on 1/11/04 south façade, clear sky conditions – 3 ft depth.

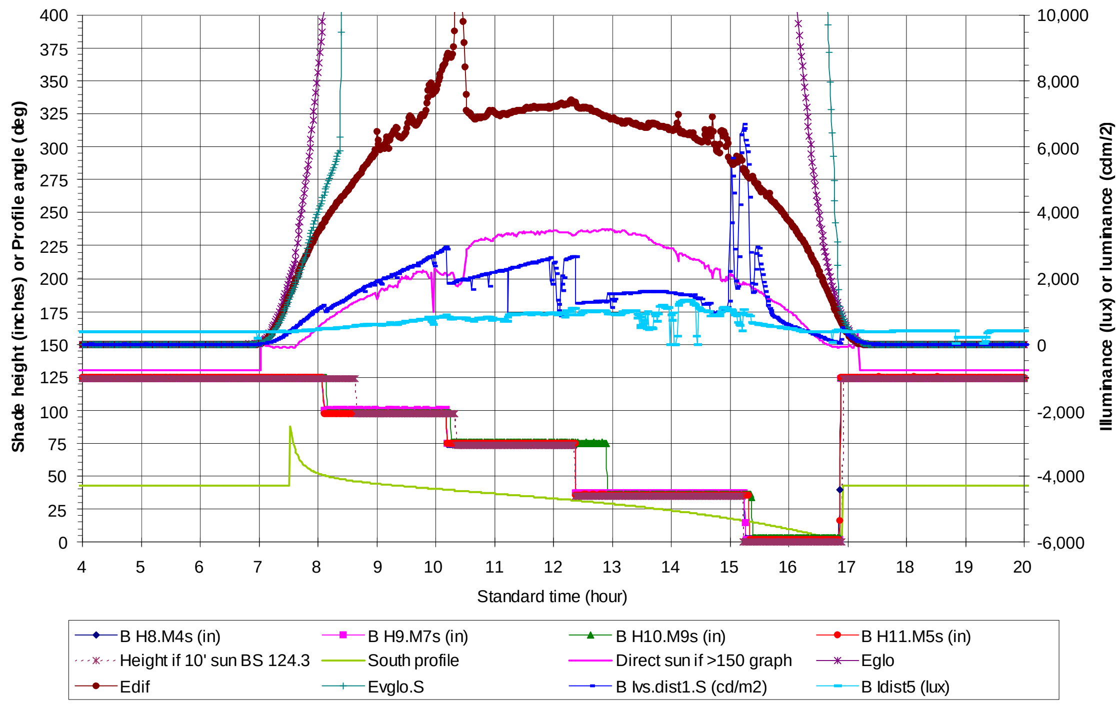


Figure 5-31. Area B. Shade operations on 1/20/04 south façade, clear sky conditions – 10 ft depth.

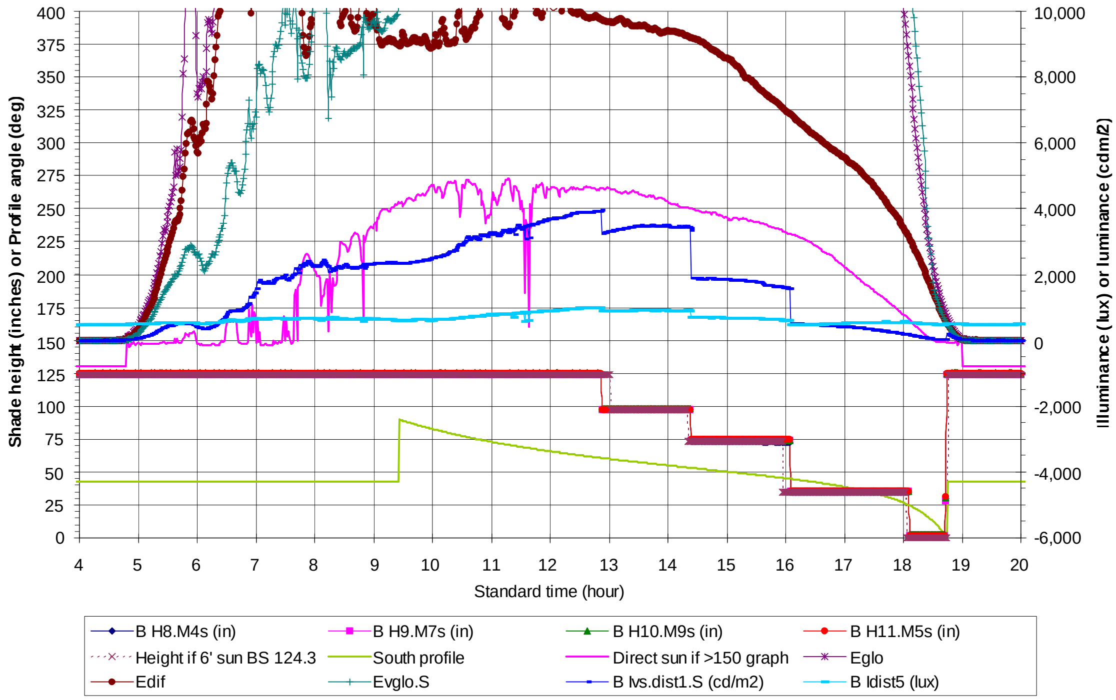


Figure 5-32. Area B. Shade operations on 4/28/04 south façade, clear sky conditions – 6 ft depth.

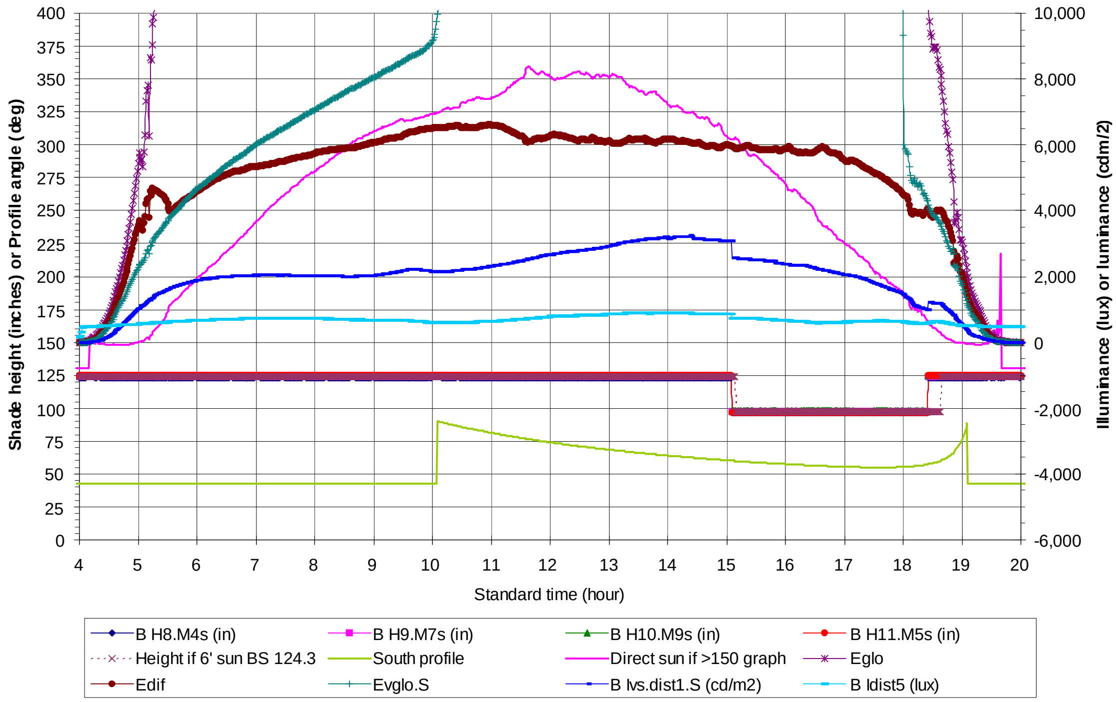


Figure 5-33. Area B. Shade operations on 6/12/04 south façade, clear sky conditions – 6 ft depth.

The shade patterns shown in Figure 5-30 for the south façade with a 0.91 m (3 ft) allowable depth are indicative of what will occur in the open plan office zones in the south wing of the final headquarters building. An example of shade operations under winter partly cloudy conditions (1/3/04) is given in Figure 5-34 (0.91 or 3 ft allowable depth). The shades cycled between fully up and fully down over the course of the day. After observing this behavior and at the recommendation of the manufacturer, the building owner requested that the control system be modified so as to limit the movement to the next preset height (no skips in the preset heights allowed) with a check on control at each stage of retraction. Extension or lowering of the shade was to occur instantly across multiple preset positions as necessary.

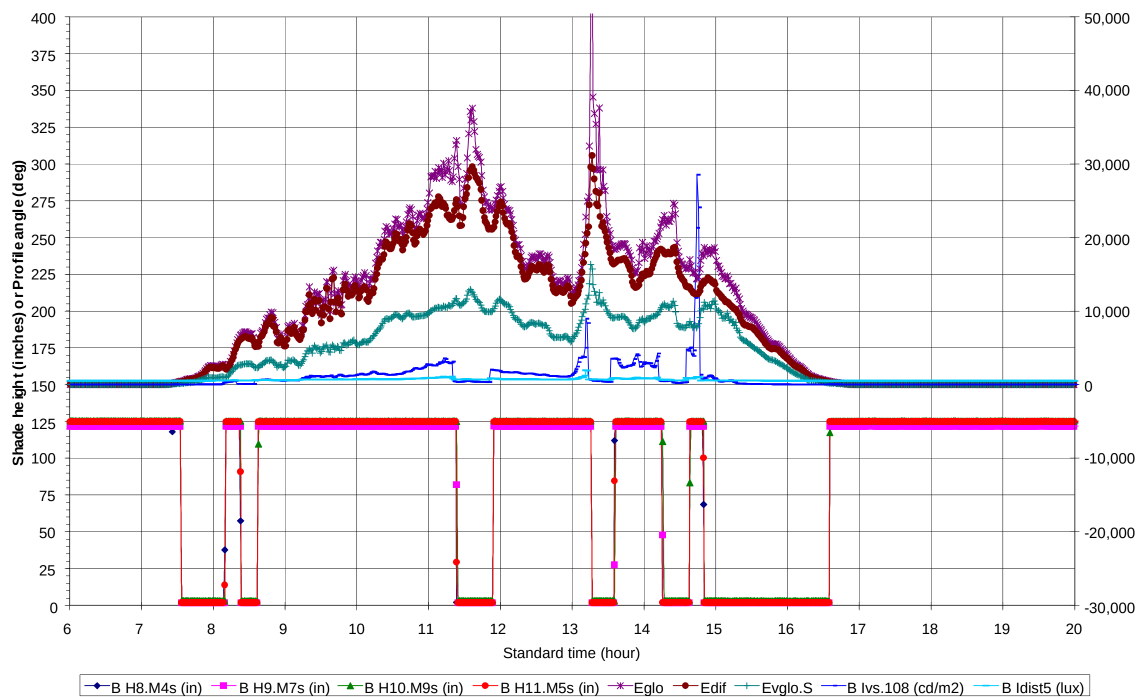


Figure 5-34. Area B. Shade operations on 1/3/04 south façade, partly cloudy conditions – 3 ft depth. Shade pattern will be the same for the SW tower.

In March 2004, the building owner observed that direct sun patches occurred greater than 3.04 m (10 ft) from the south window wall, for example on 3/22/04 at 11:30. The manufacturer located the source of this problem. The windows from the upper "floor" above the staircase (a skylight was used to model this in the mockup) did not have an automated shade as would occur in the actual building. Checks on the Radiance simulation model confirmed that direct sun would occur from the skylight during this period of the year. The sunlight occurred on the floor just south of the workstations and was not within view of the daylight control photosensors in Area B.

Direct sun penetrated greater than 0.91 m (3 ft) on the west window wall infrequently and with minor consequence. Over the monitored period (280 days), there were 25 days when direct sun penetrated greater than 0.91 m (3 ft) from the window shade. Figure 5-35 shows for each of the non-compliant days, the average daily depth of penetration, which ranged from 0.91-4.4 m (3.0-14.5 ft), and the number of minutes per day that this occurred. Direct sun penetrated up to 4.4 m (14.5 ft) on average from the window wall but for no more than 12 min in a day. The ability of the fabric to block glare from the sun orb is discussed in the Results section on visual comfort.

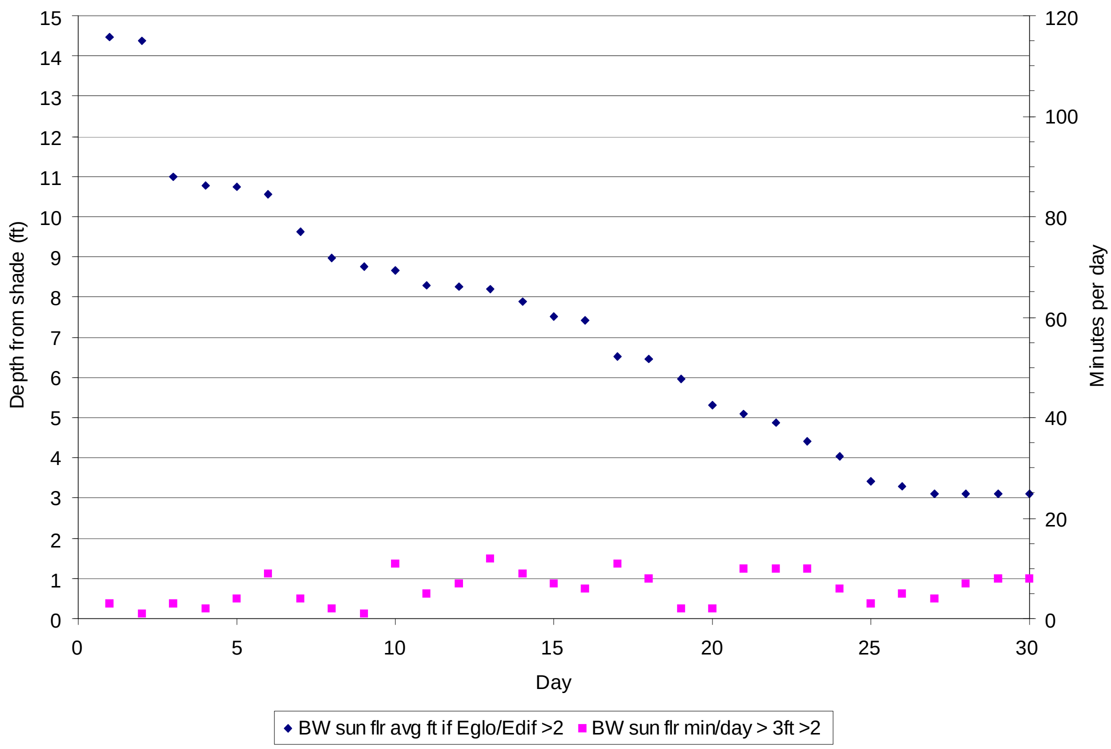


Figure 5-35. Day versus average daily depth of direct sun penetration at floor level and number of minutes per day that direct sun penetrated deeper than 0.91 m (3 ft) from the face of the shade at floor level in Area B. Diamonds: depth of sun penetration (ft). Squares: number of minutes.

The shade control system demonstrated moderate to good responsiveness to sky conditions. Only after a cloudy sky condition was stable for a lengthy period, were the shades retracted. This indicated conservative commissioning of the control system where shade movement was dampened in order to avoid unnecessary shade movement and to protect against intermittent direct sun. An example of good responsiveness is given in Figure 5-36 where the shades on the west façade were controlled to prevent direct sun penetration 0.91 m (3 ft) from the window wall on a clear sunny day 1/21/04. The shades were moved immediately to the proper preset height to meet the direct sun control criteria. On an overcast day 1/17/04 in this same week (Figure 5-37), the shades were opened and closed after 14:30 in response to variable cloud conditions but during stable overcast sky conditions from 15:35 to 16:50 (sunset), the shades remained down even though direct sun was not present. This control setting was later adjusted in February 2004 to be more responsive to outdoor conditions.

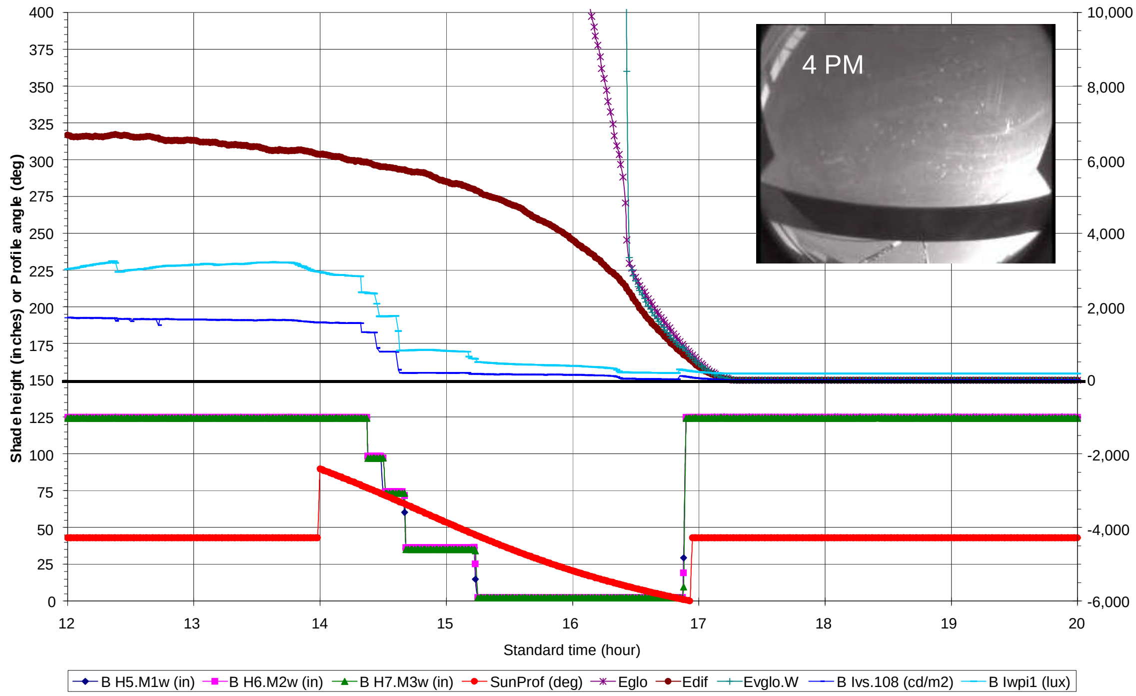


Figure 5-36. Area B. Shade operations on 1/21/04 west façade, clear sky conditions – 3 ft depth.

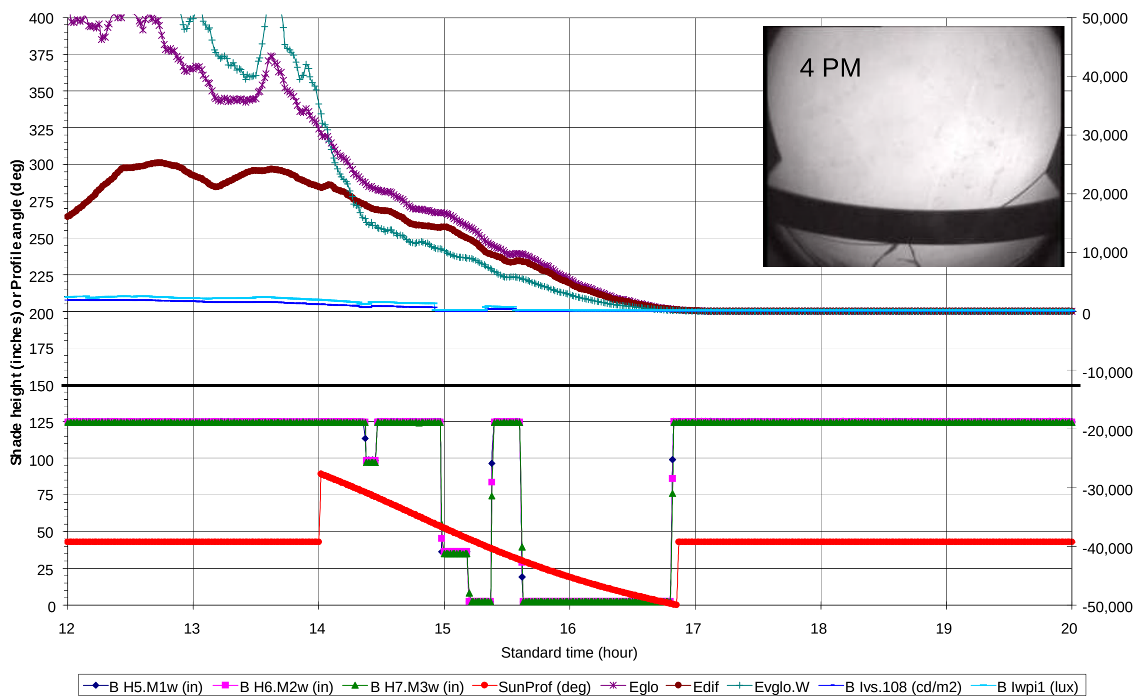


Figure 5-37. Area B. Shade operations on 1/17/04 west façade, partly cloudy conditions – 3 ft depth.

The manufacturer has control settings that allow the building owner to increase the responsiveness of the control system to changes in sky conditions. This setting must be tuned carefully to avoid hysteresis which could annoy occupants under unstable sky conditions. Generally, the manufacturer erred on the conservative side to meet the broad requirements in an open plan office and to insure comfort.

5.3.2.2. Difference in preset heights between glare and direct sun control mode all year

Figures 5-38 and 5-39 shows the percentage of day that the shades were at each preset height for each day of the year. These percentages are given for the actual shade control that occurred each day and for a theoretical shade control mode if it was sunny and the shades were controlled to block direct sun 0.91 m (3 ft) from the window shade. The difference between the two values indicate how closely actual control mimicked shades controlled for direct sun. There are several reasons why actual shade control deviated from the theoretical mode: 1) it was not sunny, 2) it was sunny but shades were not retracted because of delays imposed to avoid annoying the occupants, or 3) it was sunny and shades were at a lower preset than the theoretical direct sun control mode to control glare (after 8/5/04).

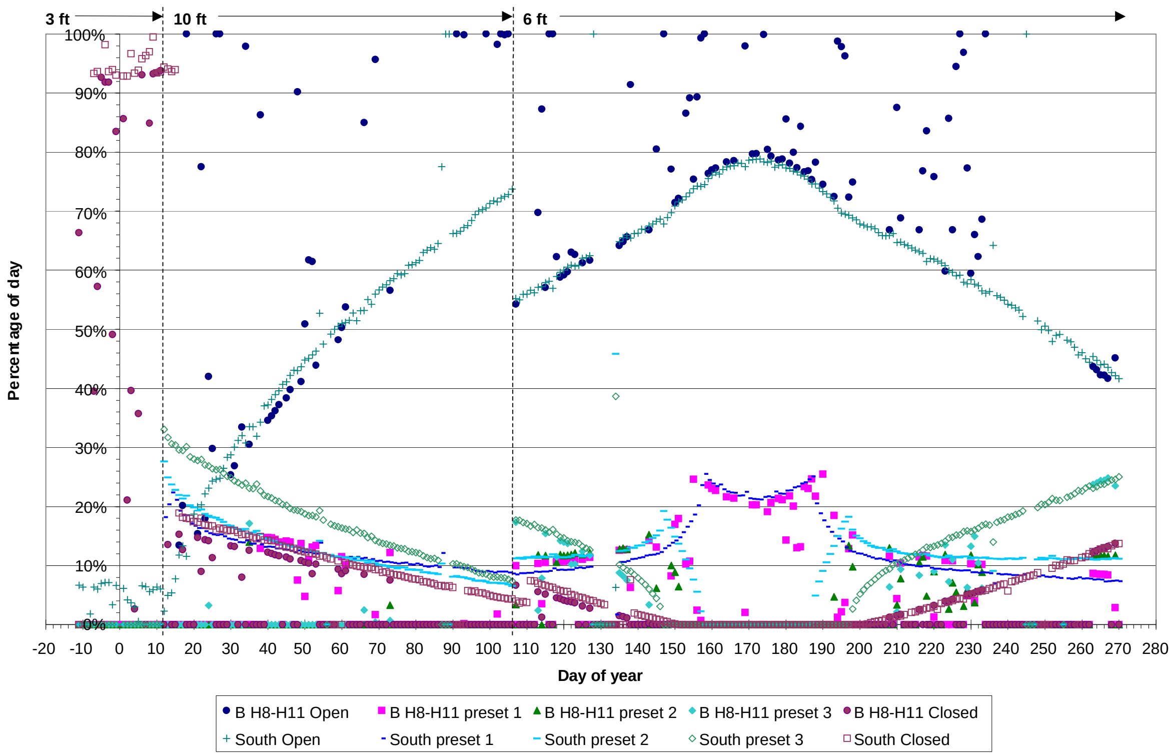


Figure 5-38. Area B. Percentage of day that the shades were at each preset height over the nine-month monitored period. West façade.

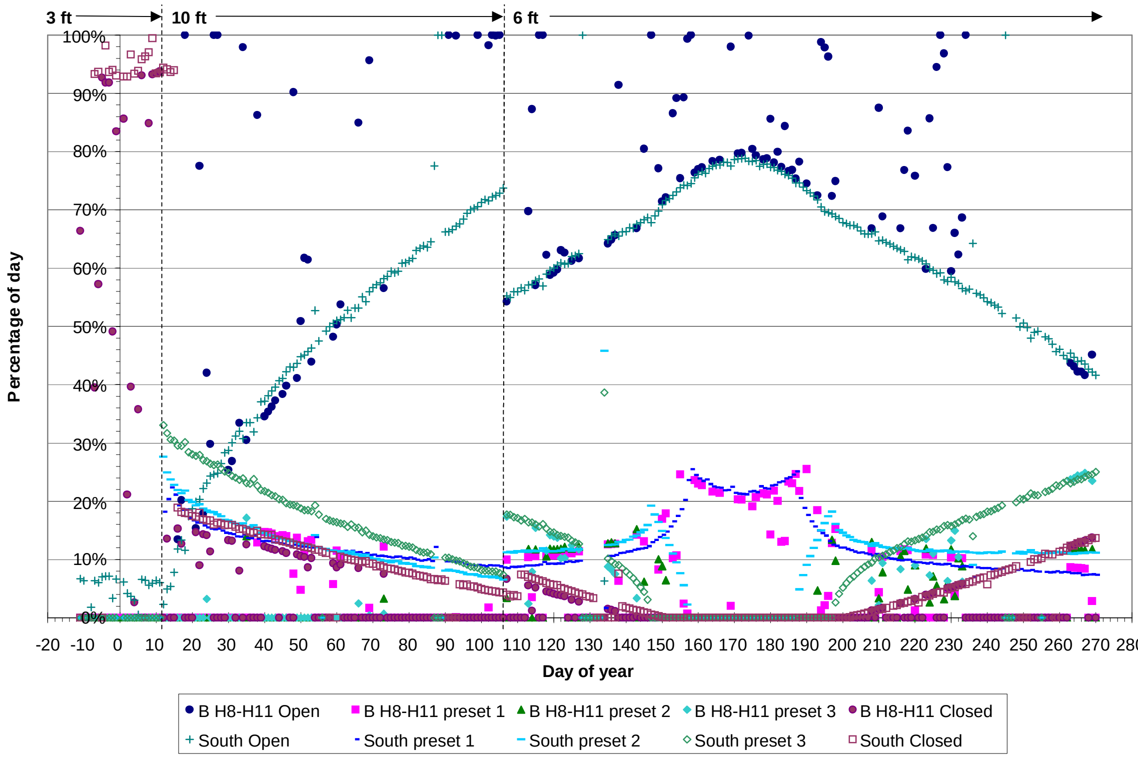


Figure 5-39. Area B. Percentage of day that the shades were at each preset height over the nine-month monitored period. South façade.

On the west façade, when the shades were in the control mode to block direct sun, Figure 5-38 shows that there was close agreement for the actual and theoretical modes for the majority of the days. The shades were less open than the computed mode because the ceramic tubes were not accounted for in actual operations: note how the actual percentage of day was 4-6% less than the theoretical mode for the fully retracted shade position. Since the theoretical mode assumed sunny conditions, one could conclude that a) the monitored period was a fairly sunny period, or b) the threshold for determining whether conditions were sunny was set conservatively (assumed direct sun when there was not). Note that the threshold can be tuned to a lesser or greater degree of conservatism. When the control mode was shifted to the glare mode, the shades were less open over the course of the day (DOY=218-265). This summary data agrees with the time-of-day assessments made on individual days in the analysis above.

On the south façade, the setpoint for the depth of direct sun control were 0.91, 1.8, and 3.0 m (3, 6, and 10 ft). Figure 5-39 again shows close agreement between the actual and computed modes for the majority of the days. Since there are no ceramic tubes on the south, the percentage of day values between the theoretical and actual modes agreed quite well.

5.3.2.3. Glare control

After the core six-month monitoring period, the manufacturer took it upon themselves to modify their control system so as to include window glare and direct sun control. A prototype system was tested in August 2004. Figures 5-40 to 5-44 show how the window shade was operated with this new control mode. Several observations can be made:

1) The shades were extended immediately to the proper position but when retracted, the shades were moved by stepping to the next upward preset height, held at this position for 1-2 min, then further retracted if necessary. This staged retraction was requested by the building owner in the procurement specifications and can be noted in the graphs; e.g., 8/11/04 10:25-10:55.
2) When in the glare control mode (before computed direct sun control mode could go into effect at ~14:30), the control system would sometimes retract, determine that the situation exceeded the glare threshold, then extend the shade back down again. See Figure 5-40 for 8/7/04 at 11:20 and 12:45. When these checks occurred, the average whole window luminance varied from ~500 cd/m^2 to ~1000 cd/m^2 then back down to ~500 cd/m^2. The manufacturer stated that this method of operation was used to gather data to develop their system and that such behavior will not occur in the final implementation.

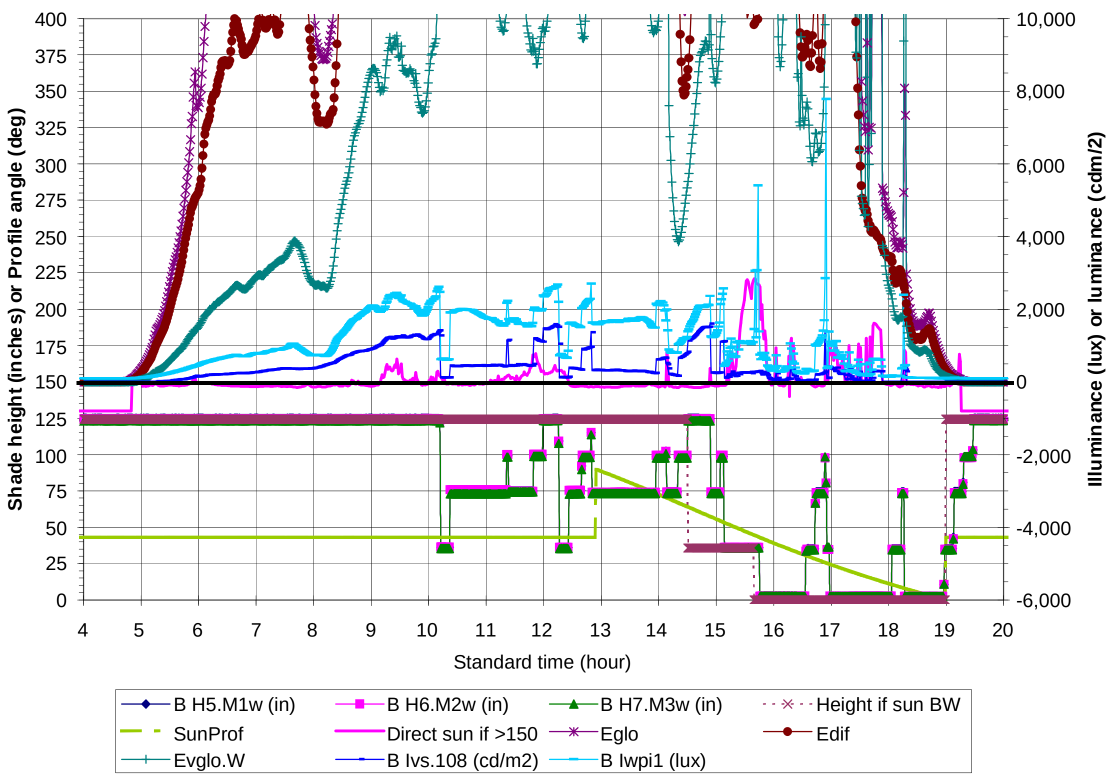


Figure 5-40. Area B. Shade operations on 8/7/04 west façade, glare mode – 3 ft depth.

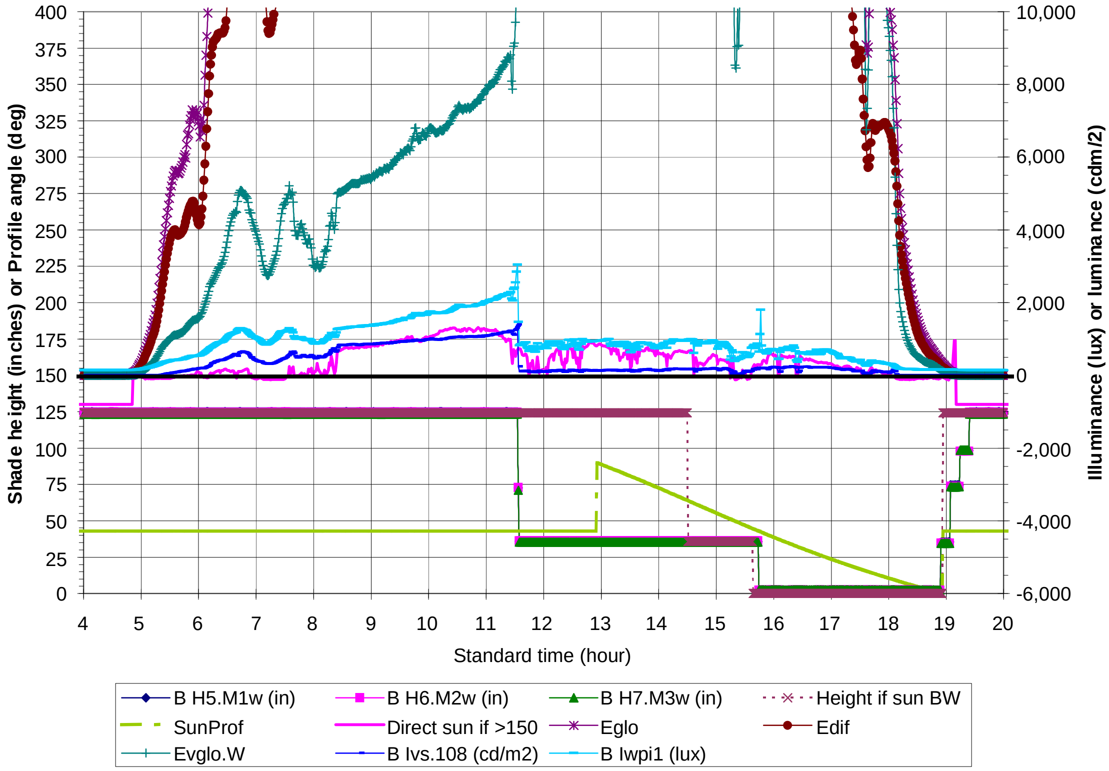


Figure 5-41. Area B. Shade operations on 8/10/04 west façade, glare mode – 3 ft depth.

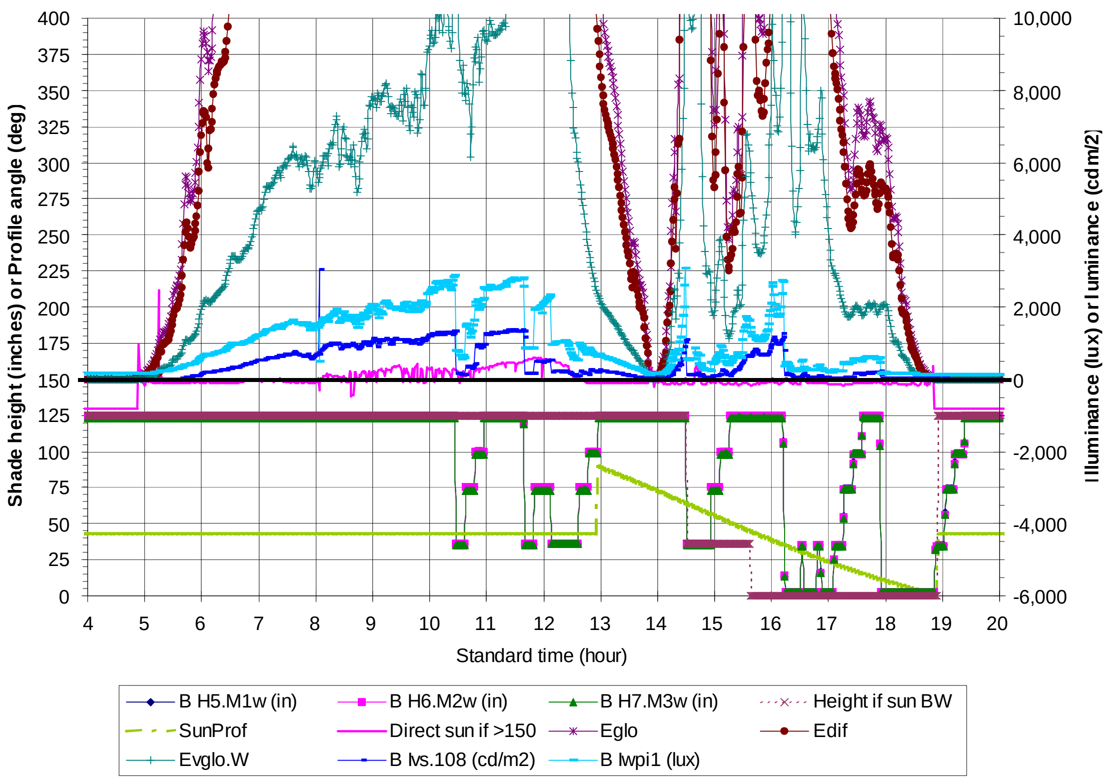


Figure 5-42. Area B. Shade operations on 8/11/04 west façade, glare mode – 3 ft depth.

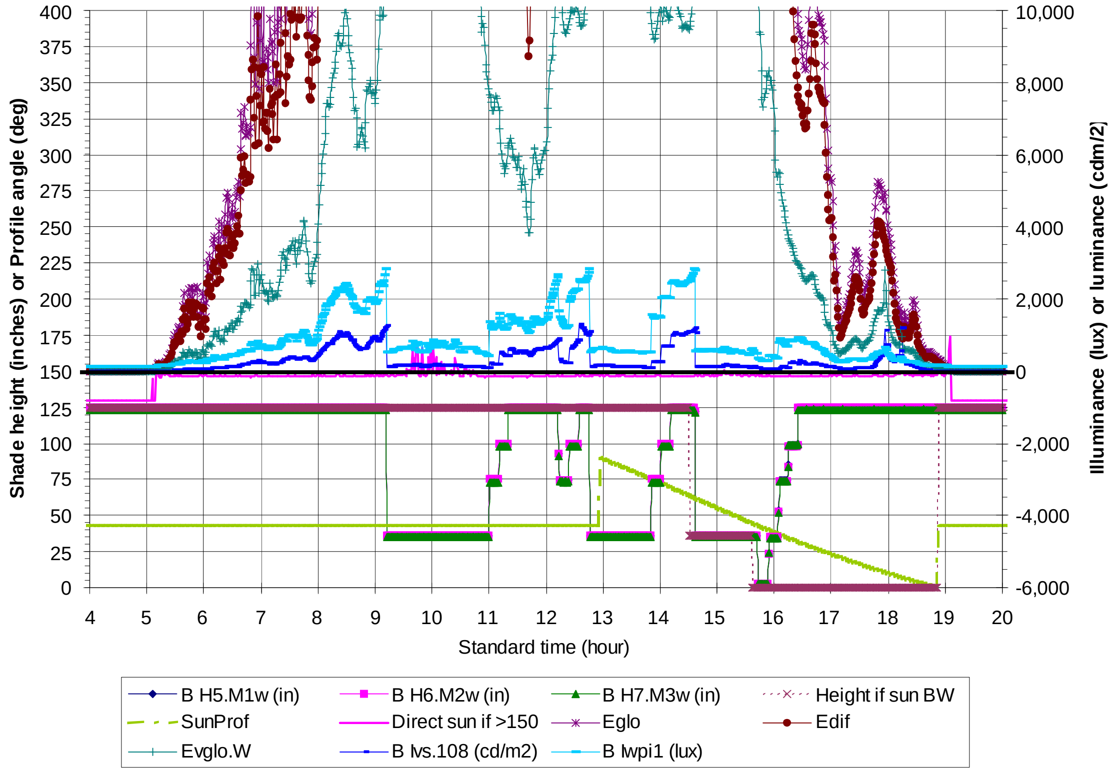


Figure 5-43. Area B. Shade operations on 8/13/04 west façade, glare mode – 3 ft depth.

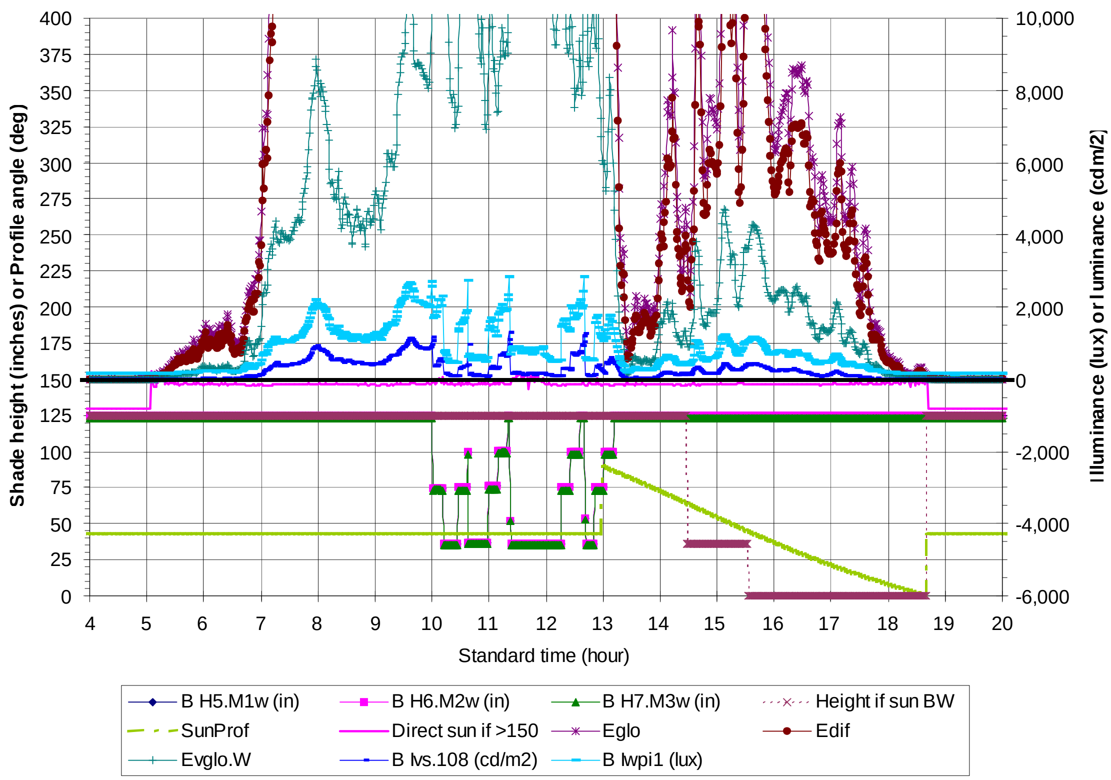


Figure 5-44. Area B. Shade operations on 8/21/04 west façade, glare mode – 3 ft depth.

In Area B, the shades were lowered when the average whole window luminance was between 1000-2000 cd/m^2. For example, on 8/7/04, the window luminance was allowed to rise to 1300 cd/m^2 at 10:10 before the shades were lowered, then later at 12:15, a window luminance of 1500 cd/m^2 caused the shades to be lowered. On 8/5/04, a luminance of 2000 cd/m^2 failed to lower the shades at 12:20. The shade control system did maintain an average whole window luminance that was lower than 2000 cd/m^2 throughout the monitored period. When the shade was extended, the window luminance was often very low – between 200-500 cd/m^2 – and interior illuminance levels 3.35 m (11 ft) from the window wall were often less than 1000 lux.

Area B's control system was designed to modulate the shades in the vision portion of the window wall where window glare is most likely to be perceived by the occupants. Because the LBNL instrumentation did not measure luminance in the vision portion of the window wall, further assessment is needed. No definitive conclusions can be drawn on the accuracy of sensor to predict window luminance or the control system. However, these examples provide interesting insights into how the shade may be controlled to meet the procurement specifications.

Note that such glare control was not implemented on the south façade where the shades were controlled for direct sun only. The average whole window luminance exceeded 2000 cd/m^2 for an average of 65 min per day during the winter when low sun angles occurred and direct sun was controlled to 0.91 m (3 ft) from the window shade (12/21/03-1/11/04). When direct sun was controlled to 3.05 m (10 ft), the luminance exceeded 2000 cd/m^2 for an average of 205 min per day for the period from 1/12/04 to 4/15/04. Finally, when direct sun was controlled to 1.8 m (6 ft), the luminance exceeded 2000 cd/m^2 for an average of 426 min per day for the brighter summer period from 4/16/04 to 9/21/04. Here, the average whole window luminance reflected more accurately what the occupant would see out the vision portion of the window since there were no ceramic tubes covering portions of the window wall.

5.4. DISCUSSION OF EXPERIMENTAL RESULTS

5.4.1. On shade controls

In both Areas, the control systems accomplished what they were designed to do. Area A demonstrated its ability to tune between more window glare control or more daylight. Area B demonstrated its ability to control the depth of direct sun penetration and made good progress on a prototype system designed to control window glare in the vision portion of the window wall. The motorized operations were quiet, smooth, and provided accurate alignment in Area A. There were more problems with the motorized operations in Area B primarily at the southwest corner where the blocking (attachment point at the ceiling) was inadequate but these were explainable and fixed in short order. Neither system exhibited hysteresis. Both systems could be tuned to be as responsive to exterior sky conditions as desired by the building owner.

Both systems had sufficient control parameters that could be tuned to the wishes of the facility manager; e.g., degree of glare control, depth of direct sun penetration, rate of response, and preset heights.

The control method to achieve visual comfort requires further study. Area A's solution was typically to modulate the whole window luminance by covering the upper portion of the window wall (with ceramic tubes) in the early part of the afternoon for this northwest-facing façade on cloudy and sunny days. The window luminance in the vision portion of the window wall, even in the morning hours, can well exceed the desired maximum level of 2000 cd/m^2. Area A's control system did not extend the roller shade during the morning hours due to its two-mode morning-afternoon method of operation. Area B's prototype system did extend the window shade over the upper and vision portions of the window wall in the morning and afternoon hours during the partly cloudy period monitored in August. A more accurate luminance measurement of the vision portion of the window wall is needed for LBNL to make a proper assessment. Trade-offs between controlling window glare versus increasing interior brightness are discussed in the Results for visual comfort.

The shade operations in both Areas mimicked the theoretical shade operations for direct sun control. In Area A with glare control, one might expect more shade closure to control glare than the direct sun control control mode under clear sky conditions, but the differences in control were subtle. In Area B, there was also close agreement between the actual and theoretical shade control over the monitored period, indicating a conservative trend to protect against direct sun under partly cloudy to cloudy conditions. A less conservative assessment would raise interior daylight levels. Tuning the setpoints could eliminate these criticisms but raise other concerns: less responsiveness raises occupant dissatisfaction with the interior environment, more responsiveness raises occupant dissatisfaction with shade movement if the movement is distracting or noisy.

The final procurement specifications that was let out for bid included several additional control requirements that were not addressed in either system explicitly: 1) the shades should be retracted if there is direct sun in the plane of the window but urban obstructions shadow the façade, and 2) if there is reflected glare from opposing buildings (e.g., a reflective façade), the shades should be extended. Both of these requirements pose serious challenges to the manufacturers.

5.4.2. On implementing automated shading in commercial buildings

A few anecdotal notes on the implementation of the shading systems are warranted. Installing such systems appeared to be relatively trouble-free. A recessed pocket was provided in the gypsum board ceiling to place the motor. The networking and low voltage wiring for Area A and 120V wiring for Area B was run through the ceiling plenum. The dc-power transformer for Area A served up to 10 motors: all shades could be moved simultaneously, i.e., no sequential movement was required (although a smaller power supply could make the system cheaper).

Area A's sensors were installed in the ceiling. One sensor was used for a 10.6-m (35-ft) wide shade zone. Area B's three exterior sensors (serving the entire installation) require careful planning for this 51-story building. Obstructions above the roof – a 91.4-m (300-ft) high mast at the center of the tower and the ceramic tubes on each façade – will shadow the sensors and replacing or maintaining the sensors will pose a safety risk, particularly during high-wind or winter conditions. The manufacturer states that these sensors are in general very reliable and that the three sensors provide adequate redundancy, therefore minimizing maintenance requirements. Area B's interior sensors are still under development.

After installation, few details were provided by the manufacturers on how they commissioned their systems. For the ac-powered motors, the preset heights were established by timing each motor and will require periodic trimming every 2-3 years over the life of the installation. Mapping the physical IP address of each motor to building location is done prior to installation: each shade motor is assigned to a specific position on a set of architectural drawings, labeled in the factory, then checked after installation. The user interface to the PC supervisory control system was impressive for Area B. This system has been commercially available for over 20 years. There were numerous screens and graphics that displayed the setpoints for each control zone. Plots showed how the shades were or will be controlled. Detailed data logs were available that documented when a shade group was moved and what values were used to determine how it should move (e.g., control mode, profile angle, etc.). There appeared to be no automated diagnostics. Some of the shade motor problems went undetected for more than several days (this again could be due to the unique field test requirements). Area A had a minimal user interface to its supervisory control system as this was a prototype system developed specifically for this building owner. One would expect that for non-mechanical problems, a fair degree of technical expertise would be required to troubleshoot either control system.

Initially, LBNL observed that the motor noise in both Areas was indiscernible over the rather loud background noise of the diesel generator when the shades were first installed. In March, a second visitor from LBNL noticed that the shade operations were rather noisy in Area B (observations were made over the course of a week with no other occupants present in the mockup). The building owner was pleased with the quietness of both types of shade motors throughout the monitored period and did not find the shade movement distracting. Forced conditioned air coming through the floor registers parallel to the window did not cause the window shades to sway unduly when the shades were fully extended. Further observations are reported in the human factors study.

There was a great deal of discussion on the tradeoffs between the number of shade bands assigned to a single motor and cost. With ac-motor driven shades, multiple shades can be coupled to a single motor and controlled as one group with up to 18.3-30.5 m (60-100 ft) widths. With dc-motor driven shades, Area A could couple a more limited number of shade bands, up to a 9.1 m (30 ft) width. The building owner expects that individual occupants will want to override the shade. Wider shades would deter this activity since the overrides would affect a greater number of occupants. The lower cost of less motors must be weighed against the cost of employee dissatisfaction. The building owner settled on a 9.1 m (30 ft) wide group of shades to be controlled by one motor.

A few comments can be made on the design of the manual override system. There was a great deal of discussion on just how to return to the automated mode after an occupant had manually overridden the shades. Several options were considered:

- Return to the normal automatic mode after a specified period of time (20-30 min).
- Return to normal automatic mode after the interior or exterior conditions had changed substantially from when the shades were manually overridden.
- Return to a modified automatic mode where the automatic setpoints are adjusted gradually as it “learns” user preferences.

The first option is easily understood by occupants but may not result in occupant satisfaction, particularly if occupants simply have to get up again to override the shade after the delay period has timed out.

Modified versions of the second and third options were implemented in Area A. The resultant shade operations were intriguing to the owner. The owner spent a good deal of time speculating on why the shade did or did not move to a particular height (while referencing Area B’s shades for comparison) and whether the shade was in automatic or still in manual mode. Since the shade was controlled in a closed-loop mode, the owner could also not understand how the interior sensor could detect that a reduction in exterior illuminance or glare conditions would warrant opening the shades. Still, collaborative discussions between the owner and vendor occurred, resulting in many concepts initiated by the vendor being incorporated into the final specifications.

In the procurement specifications, the building owner specified a recovery system that ideally was responsive to the complex daylighting environment in an urban context and user preferences. The system would also resolve and mitigate conflicts between multiple users in the open plan office. Further work is required to understand how to design such a system.

5.5. CONCLUSIONS

The shade control system performance was evaluated using monitored data over a 9-month period. Reliability of motor operations, oscillations in shade movement, and shade alignment were evaluated. Reliability of the control system was evaluated; specifically the ability to control the depth of direct sun penetration from the window wall. Reliability to control window glare is discussed in Section 6.

The patterns of shade movement were characterized and discussed in terms of how shade movement was minimized to avoid occupant annoyance yet made responsive enough to fulfill the control objectives. Time-of-day plots were used to illustrate shade operations over the course of clear and partly cloudy days so that end users could understand how a roller shade might be controlled for direct sun and glare. Suggestions were made to improve performance, some of which were included in the final procurement specifications.

In terms of reliability and performance, both systems accomplished what they were designed to do. Area A demonstrated its ability to tune between more window glare control or more daylight. Area B demonstrated its ability to control the depth of direct sun penetration and made good progress on a prototype system designed to control window glare in the vision portion of the window wall. Operation of the dc motor was accurate and reliable in Area A. Operation of the ac motor in Area B was more problematic but due to external issues. Neither system exhibited hysteresis. Both systems had sufficient control parameters that could be tuned by the facility manager. The shades could also be manually overridden by the occupants. Some modifications to shade operations were made to improve acceptability such as staged retraction of the shades to avoid distracting shade movement. The time-of-day plots illustrate what could happen if such details such as time delays, staged retraction, and other specifications are not carefully specified; e.g., full up then full down shade operations that would annoy the occupants.

Prior to this study, there were no commercially-available automated roller shade systems that addressed sun, daylight, and glare control simultaneously. Most automated shading systems simply addressed direct sun control (lower shade to block direct sun at a specified distance from the façade) without due consideration of exterior near (complex shading devices) and far (opposing buildings, trees, etc.) obstructions. At the conclusion of this study, two manufacturers demonstrated new solutions that could be tuned to meet these criteria. When the shade system was bid out, the building owner received acceptable bids from various manufacturers and decided to proceed with installing automated roller shades in the new building. The selected manufacturer has since developed a more mature control solution for balancing the tradeoffs between the various criteria. Other control features have been incorporated: e.g., raising the shade when the façade is shadowed by exterior obstructions and lowering the shade when there is reflected glare off opposing buildings or other sources. User interface features continue to be developed.

Section 6

FIELD STUDY OF INDOOR ENVIRONMENTAL QUALITY IN THE DAYLIGHTING MOCKUP

6.1. INTRODUCTION

One of the primary reasons for the building owner's interest in automated roller shades was amenity. Without automation, manually-operated interior shades would not be raised on a regular basis by the few individuals seated next to the window. With automation, there would be potentially a greater number of hours when view would be available out one of the three facades in each building wing. Interior daylight and brightness levels may be greater, particularly during overcast sky conditions.

This section addresses the indoor environmental quality in the daylighting mockup resulting from use of automated roller shades. The dimmable fluorescent lighting also played a significant role in the lighting quality of the space but dimming patterns were not related to a measured quality value. Instead, the analysis focused on evaluating how comfortable the visual environment was for reading, writing, and computer-based tasks involving flat-screen LCD visual display terminals, how often was unobstructed view to the outdoors permitted, and gauging interior brightness levels.

Monitored data were collected over a nine-month period. Comparisons in performance are given as the glare-daylight thresholds for the control system were tuned based on feedback from LBNL and the building owner.

6.2. EXPERIMENTAL METHOD

Details concerning the overall experimental method, facility setup, monitoring instrumentation, and tested configurations are given in Section 4.2. Details related to the methods used to evaluate indoor environmental quality are given in this sub-section.

Several performance metrics were computed to evaluate visual comfort, interior brightness levels, and view as explained in detail below. For this, the illuminance and luminance data were used only if the lighting and shading systems were operating correctly and the space was not occupied. Shade height data were used if the shades and the transducers were operating properly. All data were evaluated for the period between sunrise and sunset.

6.2.1. Visual comfort and performance

Visual comfort was evaluated using conventional metrics: luminance ratios, window luminance, and the daylight glare index. Under controlled conditions these metrics have all been shown to be correlated to visual performance or subjective appraisals of comfort. However, the conditions under which they have been studied are fairly limited. Many of the factors underlying visual performance are known, and practitioners can have a moderate degree of confidence in predictions made about it. The underlying factors for visual comfort are much less well understood. The metrics listed above represent the best current knowledge, but there is significant uncertainty as to their underlying physical relationship to comfort, and therefore debate about the meaningfulness of applying these measures to complex real-life situations. They are likely to be fairly imprecise measures of the actual potential for a space to produce comfort or discomfort. Research under the International Energy Agency Task 31 and other research activities are working towards improving such metrics, but no agreed upon improvements are available at this time.

The values of all of the metrics listed depend upon the visual task and its orientation in the space. The most critical visual task being performed in the open plan offices at The Times involves using flat-screen LCD screens. There are specific comfort and visibility guidelines for VDT use, but they were based on the luminances and reflectances for CRT screens, and need to be modified for LCD screens. With the use of any of the types of VDT screens, one's view is typically near horizontal where the average height of a seated occupant is 1.2 m (4 ft). With the partition height at 1.2 m (4 ft), one's view includes the VDT, the back partition wall, and the remote surfaces behind the partition wall. Depending on the location of one's workstation, the remote surfaces can include direct or side views of the window. A secondary task is that of paper on the desk. Adjacent surroundings are the desk surface itself, while remote surroundings would be the partitions and floor.

6.2.2. Luminance ratios

Luminance ratios are recommended (by organizations such as Illuminating Engineering Society of North America [IESNA 2000], International Commision on Illumination [CIE 1986], and Chartered Institute of Building Service Engineers [CIBSE 1994]) to keep the luminance values in balance between the task and other elements within the field of view. The purpose of limiting the ratios is to limit glare and to reduce the impact of transient adaptation of the eye as it goes from one area to another. The recommended ratios by IESNA [IESNA 2000] are given as:

Between task and adjacent surroundings:	3:1 or 1:3
Between task and remote (nonadjacent) surfaces:	10:1 or 1:10

Earlier versions of the IESNA handbook (1947) have a restriction on the luminance ratios anywhere in the normal field of view of 40:1, and current ISO 9241 specifications suggests that remote ratios be limited to no more than 100:1. It is important to note that these recommendations are based on consensus among committee members, and are meant to be general guidelines, not unbreakable rules. These ratios apply to large areas only. The IESNA does not explicitly describe the size of the areas considered in the luminance ratio recommendations, but their descriptions are consistent with areas on the order of one steradian. In small areas of perhaps 0.1 steradians or less, ratios that are much larger than these provide sparkle, interest and detail, and it is actually recommended to have higher luminance ratios in small areas for adding visual interest to the scene [IESNA 2000].

Luminance ratios at the mockup were evaluated with detailed luminance maps taken by a calibrated digital camera and by the average luminance estimates from the shielded and global sensors. A set of shielded and unshielded sensors was mounted in the workstation nearest the west wall on both the farthest south and farthest north sides of the mockup (Figures 6-1 to 6-5). Global illuminance sensors were mounted vertically (Evert) facing east, and to the side (north at the north side of the building, south at the south side). Shielded sensors located just below the global sensors view the back or side partitions of the workstation (Lpartition). Shielded sensors looking down view the desk (Ldesk). There are shielded sensors in the private offices that view the west windows, and there is a separate shielded sensor viewing the south windows (Lwindow). The average luminance of the VDT in a dark environment was measured with a spot luminance meter at 190 cd/m^2. The overall luminance of the VDT is the sum of reflected light and the luminance of the display. An estimate of the reflected luminance component was made using data from the shielded illuminance sensor facing the VDT but further analysis has shown that it consistently underestimated the reflected values. Fortunately, the error in the reflected component estimate has a fairly minor effect on luminance ratio calculations, because the corrected reflected component of VDT luminance was small relative to the self-luminance of the VDT even at the highest room illuminances.

Figure 6-1. Photographs of unshielded and shielded luminance sensors

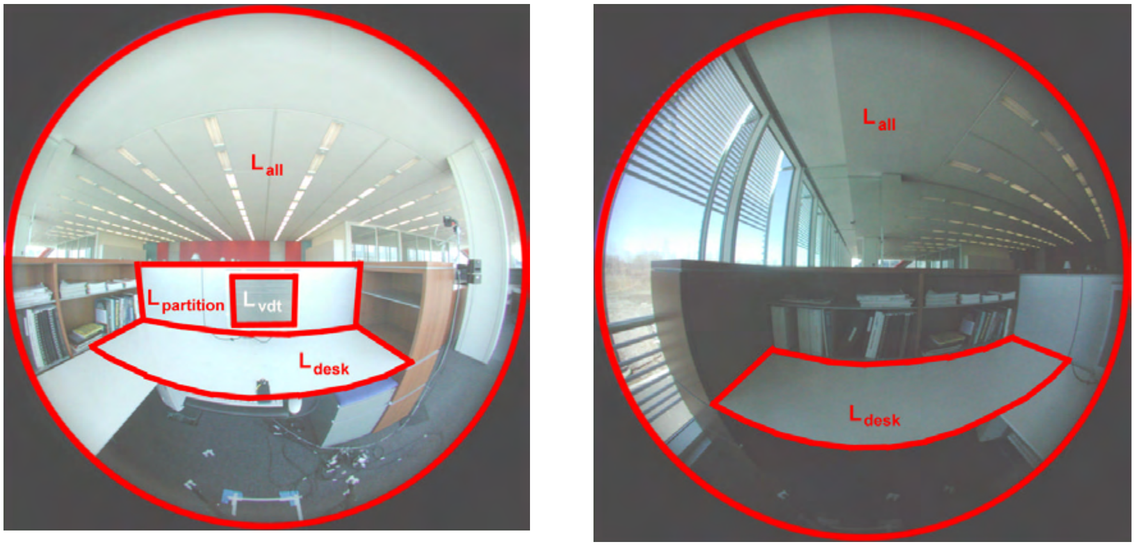


Figure 6-2. Photographs showing the desk and partition surfaces that were monitored by the shielded sensors facing east (left) and north (right) in Area A.

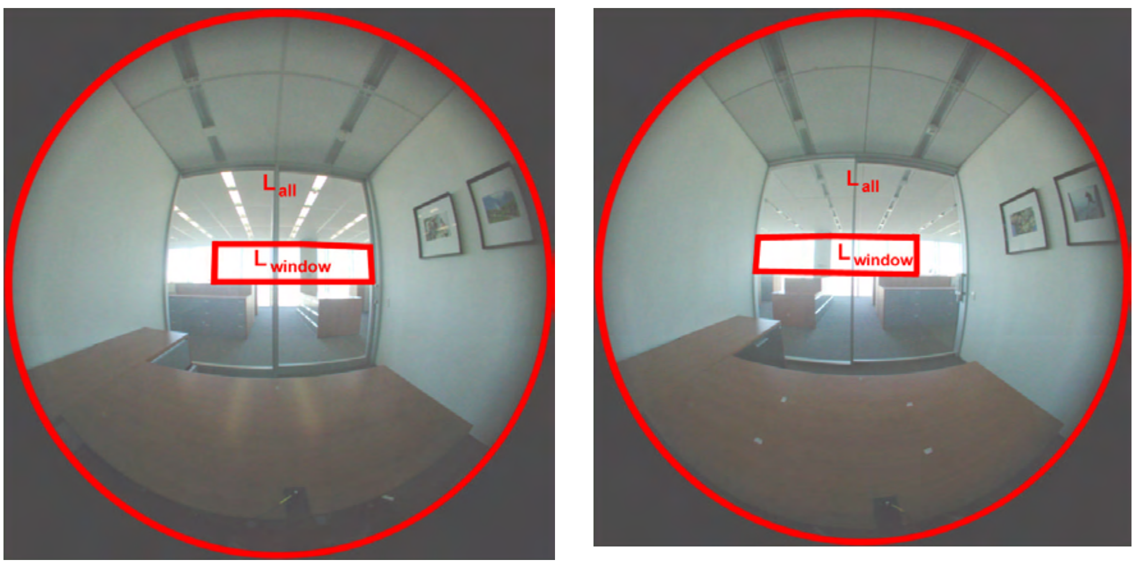


Figure 6-3. Photographs showing the surfaces that were monitored by the shielded sensors facing west in private office 106 Area A (left) and office 108 Area B (right).

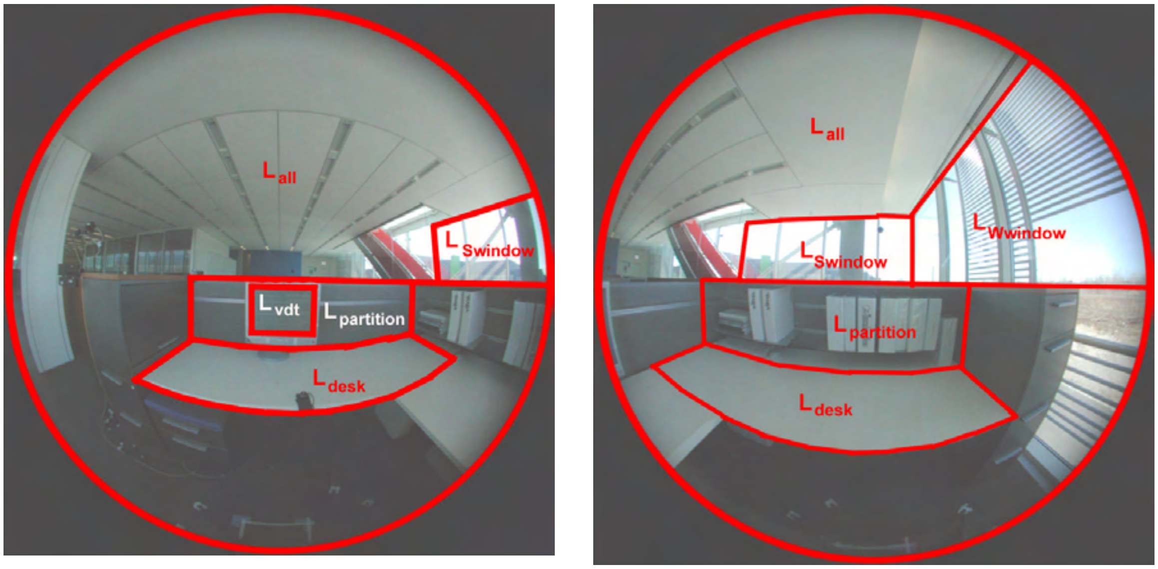


Figure 6-4. Photographs showing the surfaces that were monitored by the shielded sensors facing east (left) and south (right) in Area B. The south and west luminance were included in the luminance ratio and discomfort glare calculations.

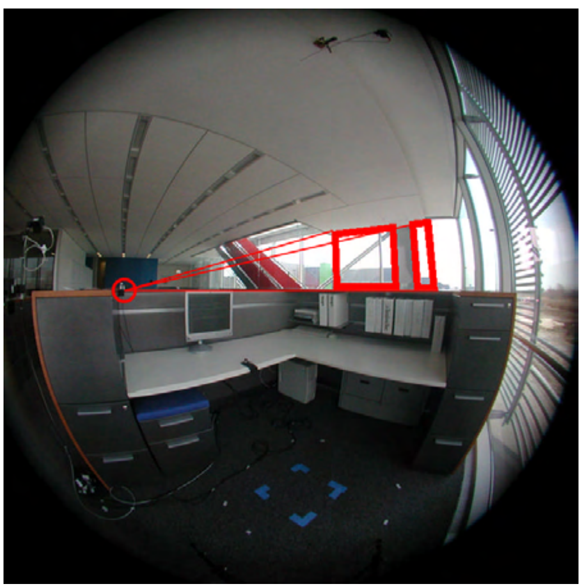


Figure 6-5. Shielded sensor looking at south window wall – view includes the column between the two areas delineated in red.

With the VDT as the task, the partitions, desk, and south window for the south side (area B) of the open plan area are potential large adjacent surfaces which fall within the 3:1 or 1:3 luminance ratio guidelines. The south window can also be considered to be an adjacent surface when the south wall bookcase (partition) is the task view area. These ratios are computed as Lvdt/Lpartition, Lvdt/Ldesk, and Lvdt/Lwindow.

Paper tasks are also relevant. For the open-plan offices, the luminance of a task on the desk (white paper) was measured to have nearly the same luminance as the background (desk surface) because the desk was white. In the private offices the desks are brown and black. Reflectances were not measured directly, but are assumed to be in the range from 20 to 30%. White paper is known to have a background reflectance of about 80%, while newsprint and colored papers have lower values. Print, which is nearly black (5-10% reflectance) can cover 20-30% of the surface area of the paper, so overall task reflectance can be as low as 60%. Based on the assumed reflectances for the desk, only an extremely tidy person would be likely to exceed the 3:1 task-to-immediate-surround luminance ratio, and only if their task had little writing on it. Unless there is direct sun or shadow on the desk, the luminance ratio between a paper task and the desk itself will be mainly determined by the relative reflectances of the surfaces, and will not change significantly with time. No direct monitoring of desk to paper luminance ratios was made for either the open plan or private offices.

To compute luminance ratios for task versus remote surfaces it is first necessary to estimate a remote luminance (Lremote). The global vertical sensors measure the illuminance from the entire facing hemisphere. Subtracting the illuminance from the shielded sensors that are used to compute the partition luminances gives the illuminance from the area above the partition. These illuminances are divided by the appropriate field factor for the remote area to give its weighted average luminance. The luminance above the partition is not directly adjacent to the VDT, and can be considered a remote view luminance. For the east view, the ratio Lvdt/Lremote(east) should be in the 10:1 or 1:10 range. The south window can also be considered a remote view for this orientation, so Lvdt/Lwindow(south) should also be in this range. For the south or north view, ratios can be computed for the task view being the bookcase partition wall, and remote view being the west window luminance, or overall remote luminance as described earlier (Lpartition/Lwindow(west), Lpartition/Lwindow(south), and Lpartition/Lremote).

Luminances were measured every minute, so the luminance ratios can be computed at the same frequency. The data is summarized by computing the fraction of time the ratios exceed the recommended levels.

The digital luminance maps provide a more direct estimate of the spatial luminance patterns. In analyzing the digital luminance maps we defined adjacent surfaces as within a 30° cone centered on the task, but excluding the task (3:1 or 1:3 ratio). Remote, or non-adjacent surfaces were defined as falling within a 30-60° cone of view (10:1 or 1:10 ratio). Everything outside the 60° cone can be assumed to fall under the restriction that it should be within a 40:1 or 1:40 ratio with the task.

6.2.3. Daylight glare index (DGI)

The daylight glare index (DGI) is a metric that evaluates discomfort glare for large-area sources of glare such as windows. Disability glare causes temporary blindness such as roadway glare from on-coming cars.

Discomfort glare is the visual discomfort that over time causes headaches, eye strain, fatigue and other physical discomforts. While disability glare is an issue in this evaluation, discomfort glare was considered to be the metric of greatest relevance to this study.

The DGI is computed from a formula that was developed to account for the effects of source brightness, size, location relative to line of sight, and adaptation luminance. Daylight Glare Index dates back to 1960, and is based on glare studies conducted under controlled laboratory conditions. The experimental setup consisted of a large illuminated diffusing screen (the light from the closely packed fluorescent lamps was diffused by an opal plastic screen) which had provided a uniform luminance condition. The source size was varied from 10^{-3} sr to the whole field of view, and the source luminance was varied between 3.5 and 15,500 cd/m^2. Subjects reported their subjective impressions of glare on a scale ranging from "just perceptible" to "just intolerable". A formula, known as the Hopkinson-Cornell large-source glare index, was derived and correlated to these subjective impressions [Hopkinson and Bradley, 1960; IES 1962].

In later studies, Hopkinson [1972], Chauvel et. al. [1982], and Boubekri et. al. [1992] have shown that although the ranking of the subjective impressions suggested by the Cornell formula (IES GI or DGI) is reasonably robust, the absolute level of the response depends upon the environment. Glare from windows, as measured by the Cornell formula, is judged to be less annoying than it was in the original laboratory experiments. Table 6-1 lists the mean subjective response to values from the Cornell formula as measured in a simple environment (laboratory, windowless office, etc.) (IES GI) and in environments with windows (DGI).

Table 6-1.
Subjective correlation to IES GI and DGI

Glare criterion	IES GI	DGI
Just imperceptible	10	16
Just acceptable	16	20
Just uncomfortable	22	24
Just intolerable	28	28

Throughout the analysis, the term DGI (not IES GI) was used for simplicity but the threshold values differed according to Table 6-1 depending on whether the field of view included a view of the window(s). The DGI computation used here is the large-source modification of the original glare formula, and includes the adaptation luminance effect.

$$DGI = 10\log 0.478\sum_{i=1}^{n}\frac{L_s^{\ 1.6}\cdot\Omega^{0.8}}{L_b + 0.07\cdot\omega^{0.5}\cdot L_s} \quad (2)$$

L_s Source luminance (cd/m^2)

L_b Background luminance (cd/m^2)

Ω Solid angular subtense of source modified for the effect of the observer in relation to the source (sr)

ω Solid angular subtense of source at the eye of the observer (sr)

For very large sources, Chauvel noted that the formula becomes practically independent of the size of the source, with the DGI instead depending primarily on the luminance.

As described in the above section on luminance ratios, luminances were measured once per minute by the shielded and unshielded illuminance sensors. This makes it possible to compute DGI values for each of the view directions covered by these sensors on a once per minute basis. Average values do not provide an appropriate way to summarize this data; as a 50 – 50 mix of imperceptible and intolerable does not produce a just acceptable environment. The summary is instead presented in terms of the percentage of the day when the DGI values exceed target DGI category values (i.e., 20, 24, and 28).

Occupants in the private offices (Office 106 in Area A or 108 in Area B) face the west window walls. DGI was computed with the west window as the glare source and the remaining surfaces (all except the window) as the adaptation luminance. The glare source is viewed head-on.

In the public space, the DGI was computed for a person seated at the workstations located closest to the west window wall with their view either to the east or to the north (in Area A) or south (in Area B). The DGI values computed were:

- In Areas A, facing east, a computation assigned the VDT as the glare source luminance and the average luminance of remaining field of view as the adaptation luminance. The glare source is centered in the view.
- In Areas A and B facing east, a computation assigned the VDT and back panel as the glare source luminance and the average luminance of remaining field of view as the adaptation luminance. The glare source is centered in the view.
- In Areas A and B facing east and looking down, the computation assigned the desk as the glare source luminance, and all other surfaces as the adaptation luminance. The glare source is centered in the view.
- In Area A facing north and Area B facing south, a computation assigned the partition wall as the glare source luminance, and all other surfaces as the adaptation luminance sources. The west window is in the remote field of view, but was not evaluated as a separate glare source.

- In Area B facing south, a computation assigned the west and south windows as the glare source luminances and all other surfaces (bookcase partition wall and desk) as the adaptation luminance. One had a direct view of the south window glare source, but neither it nor the west window are centered in the view.
- In Area A facing north and down, and Area B facing south and down, the computation assigned the desk as the source luminance and all other surfaces (bookcase partition wall) as the adaptation luminance. The west window was within one's remote field of view, but this luminance was not included as a glare source in the DGI computation because the glare potential of a source is very low for a source at a large angle from the direct line of sight. The glare source is centered in the view.

The computation was subject to the following limitations.

- Since the shade was dynamically operated, the monitored window luminance was an average across both the shaded and unshaded portions of the window. In the case where the direct sun orb was within the field of view, the use of average luminances reading diminished the final DGI index relative to what it would have been if the sun orb had been treated as a separate glare source.
- The south window luminance sensor included a view of an exterior structural column. The solid angle computation corrected for this area however the exterior column created a shadow on the surface of the interior shade, when it was drawn, and therefore skewed the measurement of the window luminance for oblique sun angles.
- Diffuse shadows were cast across the desk and partition work surfaces causing a non-uniform luminance distribution. The luminance measurement averaged this non-uniformity.

6.2.4. Window luminance

Window luminance is a major determinant of glare and excessive luminance ratios. There were two questions regarding window luminance in the building. The first was simply to determine what luminances can be obtained with different shade control algorithms and shade densities. The second was to determine to what level window luminances should be controlled to maintain a comfortable and productive environment, while maximizing views and conserving energy.

Window luminances were monitored by the shielded illuminance sensors in the private offices for the west windows and by a separate shielded sensor for the south window, as described above. As noted above, these values are averages, and do not take into account extreme spatial deviations. We nonetheless expect significant correlation between them and the problems of glare and excessive luminance ratios.

The measurements were taken every minute. The monitored window luminance levels for each day were then binned in 200 cd/m^2 increments to give the cumulative distribution over the course of a day. These distributions were then grouped according to solstice and equinox conditions, sky condition, and shade control algorithm. Sky conditions were determined by the average daily global horizontal exterior illuminance which generally indicates whether it was a predominantly clear or overcast sky condition. Percentages of day that a target value was exceeded can be derived from these data as a function of the sky condition, or for a composite year composed of different sky conditions.

To determine a target control level we looked at calculations of discomfort glare, luminance ratios, reflections on monitors, and subjective appraisals, as a function of window luminance:

1) For discomfort glare we assumed that a person faces the window. At the mockup the windows occupy a substantial fraction of the field of view (0.1 to 1 steradian) depending on the distance to them. If one assumes typical office background adaptation levels of 50 to 100 cd/m^2, and desires a DGI of 20 or less ("just acceptable") then the calculated maximum window luminance is about 2000 cd/m^2.
2) For the luminance ratio calculations we assumed that the person was looking east at their VDT, which with the modern flat screen displays in use at The Times will have an average luminance of 200 cd/m^2. For adjacent surfaces the limitation is 3:1, so the luminance of the adjacent surround should be 600 cd/m^2 or less. If the window is assumed to fill one steradian of view from the adjacent surface, and the surface is assumed to have a reflectance of 50%, then the window luminance should be 3500 cd/m^2 or less. This restriction is less limiting than the glare restriction. However, in Area B of the mockup subjects facing east have a non-adjacent (remote) view of the south windows. For a non-adjacent view the recommended luminance ratio limit is 10:1, which again directly leads to a limit of 2000 cd/m^2.
3) To determine a criteria for reflections on monitors we first calculated that there is a 20% loss of contrast (see end notes) from light scatter in the eye from a luminance pattern distribution that just meets the IES luminance ratio guidelines of 3:1 from 2° to 30°, 10:1 from 30° to 60°, and 40:1 for 60° to 90°. A 20% loss of contrast requires a veiling luminance of 50 cd/m^2 for a monitor with a white luminance of 200 cd/m^2. If we assume a diffuse plus specular monitor reflectance of 5%, and a window size of one steradian, this gives a window luminance restriction of 3000 cd/m^2, which is a little less restrictive than the glare and luminance ratio limits.
4) Finally, in addition to the calculations described above, we have some information in the form of user preferences for pulling blinds as a function of the luminance of the window just before the blinds were pulled. The data comes from a study of 43 subjects doing normal work in a large windowed environment [Clear et al. 2005]. Table 6-2 shows that the 50% probability point is approximately 2000 cd/m^2, which is consistent with our calculations.

Table 6-2.
Probability of pulling blinds versus luminance of window

Probability	Luminance (cd/m^2)
25%	1200
50%	2100
75%	3000

The 2000 cd/ m^2 limit was used as a threshold value below which comfortable conditions would likely be attained. All the level constraints described above treat the window as a whole, which is consistent with our monitoring equipment.

6.2.5. View

While some view was discernible through the shade fabric during some periods of the day, “view” was defined in this study as the area of the window that was unobstructed by both the exterior ceramic tubes and the interior roller shade. The ceramic tubes partially obstruct the view below 86.4 cm (34 in) and above 201 cm (79.125 in). The vision or view window in between is obstructed when the shades are dropped. Given the preset shade heights that aligned with the ceramic tubes, the percentage of day when the shade was lower than 201 cm (79.1 in) above the floor (no view) was computed.

6.2.6. Interior brightness levels

The average daily illuminance was computed for each day at each sensor location. The illuminance includes both daylight and fluorescent lighting contributions and as such the daily average should always exceed the maximum fluorescent-only lighting levels at each sensor. These averages give a general indication of interior brightness levels and the distribution one can expect over the course of the year at different depths from the window walls. A significant difference in interior illuminance between the area closest to the window wall and the area furthest from the window wall can give the room a cave-like gloomy quality. The Radiance study indicated that the illuminance distributions were fairly uniform if direct sun was controlled by the interior shade. Monitored data was used to fill out this dataset. The back of the room (illuminance sensors Aldist5 and Bldist5) are generally going to have the most even illuminances because they are the farthest from the windows. Ratios can also be computed against these locations on a per minute basis (with filters for missing points) and then can be summarized in terms of fractions of the day that target ratios are exceeded. Gloom appears to be related to vertical surface luminance distributions, which were not directly measured in the east portion of the room, but should be related to the horizontal illuminances that were measured [Shepard et al. 1989]. Reflectances over large areas are fairly uniform throughout the space, so illuminance ratios are roughly equivalent to luminance ratios. A target ratio of 10:1 is consistent with the IESNA guidelines for non-adjacent surface luminances, and is likely to be indicative of a potential for gloom.

6.2.7. Illuminance ratios

Non-uniform lighting across a work surface or task can be a source of annoyance. Using digital luminance maps, luminance ratios were measured across various task surfaces. Sharp shadows caused by illuminance ratios, particularly if they are of magnitude of 3:1 or more, can be mistaken as information, and therefore can cause a degradation of visual performance. The luminance maps were examined to see if there are locations with this degree of shadowing.

6.2.8. End notes: Luminance contrast

Luminance contrast quantifies the visibility of foreground relative to its immediate background. Reduction in luminance contrast occurs when a "veiling" luminance is superimposed on the target and the background. Luminance contrast can be calculated in three different ways.

The luminance contrast for uniform luminance targets viewed against uniform luminance backgrounds are calculated as shown in Equation 3.

$$C = \left| \frac{(L_t - L_b)}{L_b} \right| \tag{3}$$

Equation 3 was used for the calculations of contrast loss in the text. When the background luminance is very low relative to the task luminance, it is often ignored in the numerator. Equation 4 is mostly used for self-luminous displays, such as VDT screens.

$$C = \frac{L_t}{L_b} \tag{4}$$

Equation 5 is used in bipartite patterns such as sine wave or square wave test patterns where there is no clear distinction between the target and background. This contrast is usually referred as Michelson contrast or modulation contrast.

$$C = \left| \frac{(L_{\max} - L_{\min})}{L_{\max} + L_{\min}} \right| \tag{5}$$

The common assumption and simplification in all calculations is that the target and the background have uniform luminances. There is a significant body of work on visibility as a function of contrast, size, and the adapatation luminance level (the denominator in equations 3 and 4, and the denominator/4 in equation 5). Unfortunately, there is no generally accepted method for measuring the luminance contrast for complex luminance patterns, but the general visibility trends versus the luminance difference that are found in the laboratory situations are thought to be valid.

6.3. EXPERIMENTAL RESULTS

The environmental quality data was analyzed from graphs of the data as a function of the day of the year, or time of day. Graphs of data versus the day of the year also generally contain information on the shade control algorithm or configuration (see Tables 4-1 and 4-2 for definitions) along the top of the graph with its own right-hand vertical axis. The luminance ratio graphs also include the exterior vertical illuminances, while the DGI graphs show whether the lights were on. These were all factors which are potentially correlated with the environmental variables with which they were graphed. The graphs were examined visually to see if there were any potentially significant correlations.

6.3.1. Area A

In Area A, occupants will experience glare associated with transient adaptation when looking north at the bookcase partition wall with the west window also in the field of view. The luminance value of the west window wall exceeded the partition luminance by a factor of 10 or more for up to 40% of the day when the shades were controlled for daylight or for up to 23% of the day when the shades were controlled for glare (Figure 6-6). However, the occupant is anticipated to work facing east for the majority of the day. Work tasks that involve the bookcase or shallow desk surface located on the north-facing leg of the workstation are anticipated by the building owner to be short in duration: e.g., telephone or paper-based tasks.

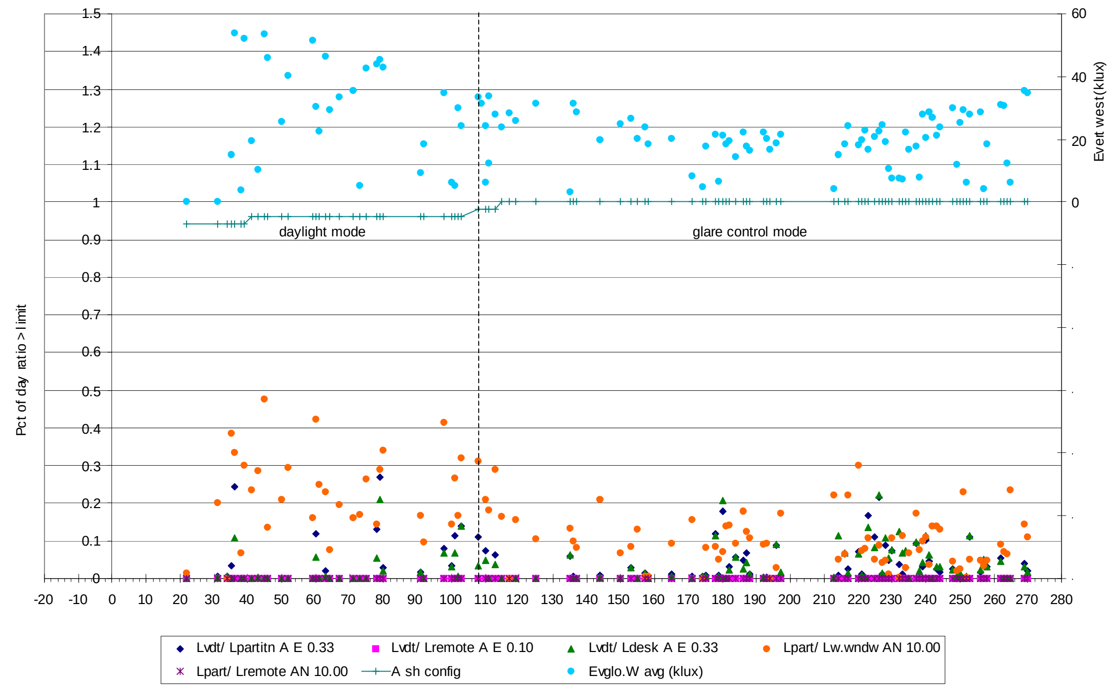


Figure 6-6. Percentage of day that the luminance ratio exceeded the IESNA recommended limits at workstation A1 facing east or north. Legend: L=luminance, vdt=visual display terminal, partitn=partition wall, remote=remote luminance of facing hemisphere minus task surface luminance, A sh config=shade configuration number, Evglo.W avg=average exterior vertical illuminance on west façade. Numbers following the ratios are IESNA recommended limits.

Luminance ratios facing east indicated that there were less significant visual comfort problems. Excluding outliers, the luminance of the desk or partition wall was greater than the luminance of the VDT by a factor of 3 or more for up to 11% of the day when the shades were controlled for daylight or for up to 9% of the day when the shades were controlled for glare.

Comparison of the vertical illuminance and the north partition/window luminance ratio variable suggests a moderately strong correlation. However, the luminance ratios is also likely to be related to the shade fraction and sun angle (time of year), and it was not clear that there was sufficient data to give a meaningful quantitative analysis of the effect of the vertical illuminance on the luminance ratios. We are particularly concerned that the results of an analysis which did not properly take into account sun angles effects would have no meaning for any of the other facade orientations. We therefore have not attempted any further quantitative analysis at this time.

Examples of when these luminance ratios were exceeded are given in Figures 6-7 and 6-8 (2/14, 6/28). For the north view, the luminance of the north partition wall remained low throughout the majority of the day being lit obliquely by diffuse daylight while the west window luminance was relatively high. The bookcase at the west end of the partition tended to shade the partition wall, lowering the partition luminance. In the late afternoon, when the sun was in the plane of the window, the partition luminance increased to levels that were near comparable to the west window luminance. For the east view, the desk and partition wall surfaces faced the west window wall so the luminance levels of these surfaces were greater than the north partition wall but were still sufficiently well controlled throughout the majority of the day so as not to present significant problems with transient adaptation as the eye moved from the desk or partition to the VDT screen.

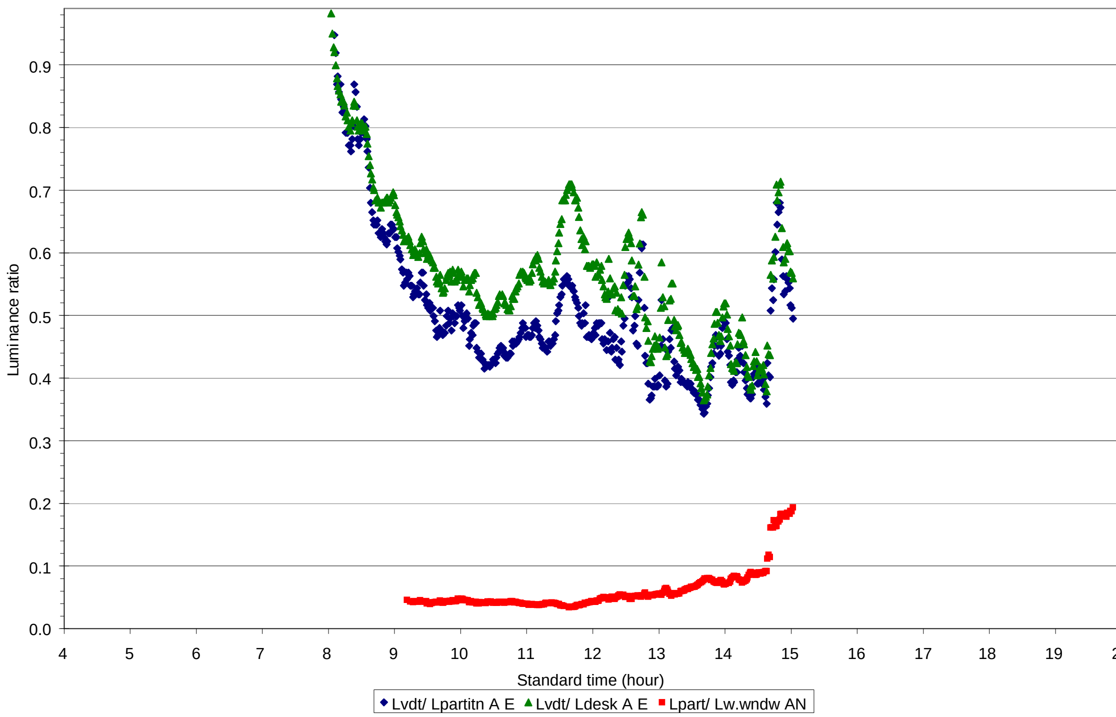


Figure 6-7. Luminance ratios on 2/14/04. Daylight control.

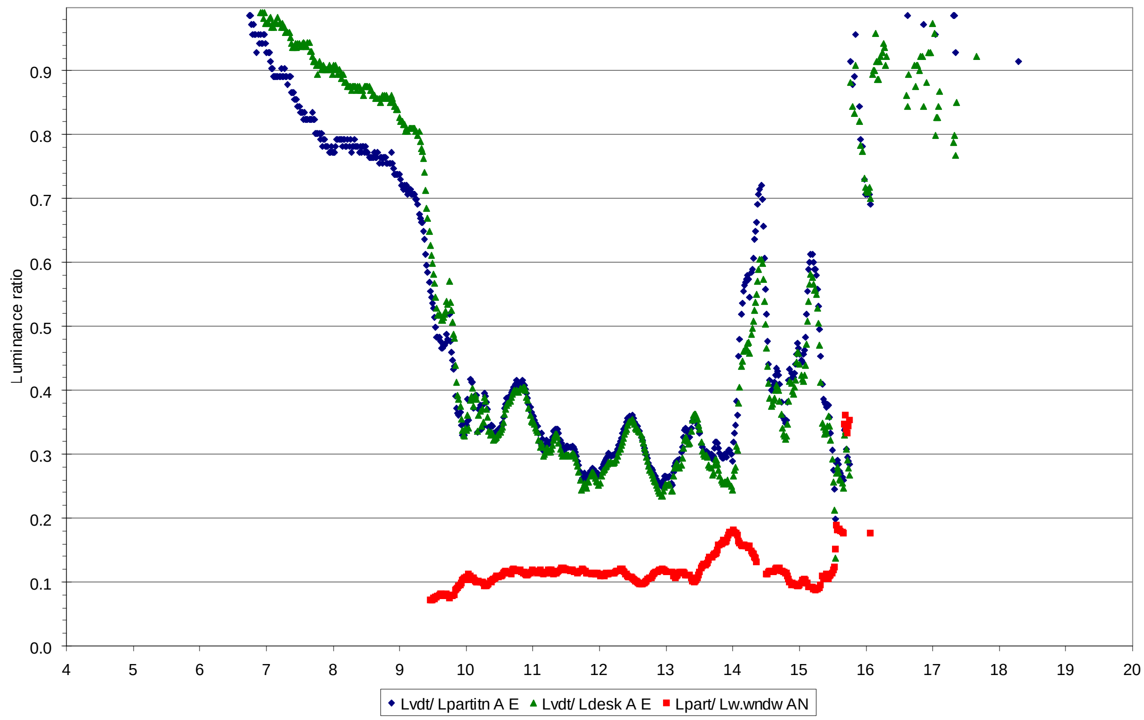


Figure 6-8. Luminance ratios on 6/28/04. Glare control mode.

These data, being averaged over a broad surface, did not detect the effect of shadowing produced by the backlit roller shade. The sharp contrast between the sunlit and shadowed areas across the task surfaces can be a source of annoyance. When direct sun passed through the interstitial spaces in the roller shade fabric, distinct shadows from the furniture, ceramic tubes, or the occupant's body were cast over the work surfaces. These shadows were most evident in the first workstation adjacent to the west window wall and occurred on the upper surfaces of the partitions in the other workstations further from the window wall as well (Figure 6-9). Stripes of direct sun were also evident. These were due to sunlight passing through the 2.5-cm (1-in) gap between the shade bands (Figure 6-10).

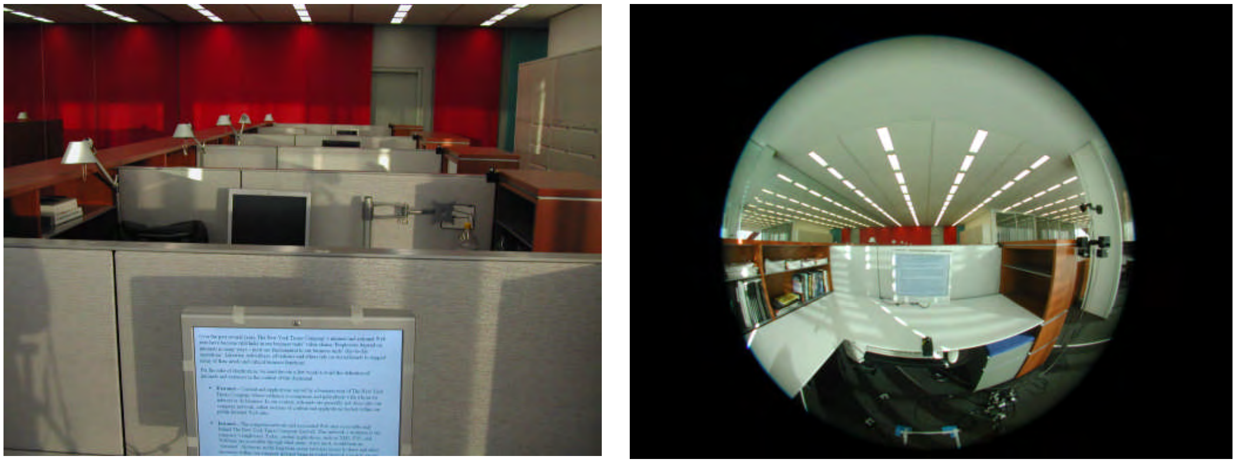


Figure 6-9. Photograph showing shadowing of surfaces when shade is down and backlit by direct sun.

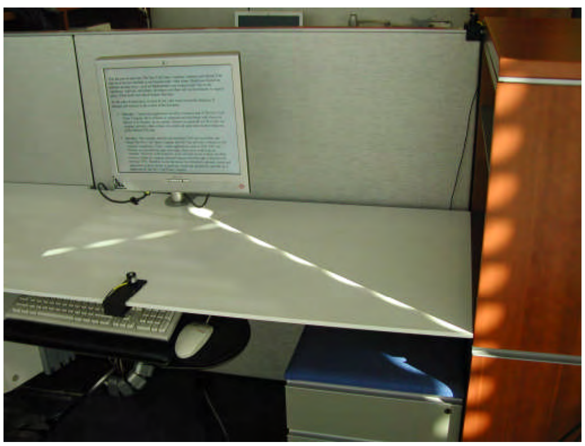


Figure 6-10. Photograph of sunlight passing through the gap between the shade bands.

The west window luminance caused occasional discomfort glare when viewed directly by occupants in the private office. On a few days over the nine-month monitored period, the daylight glare index (DGI) was between values of 20 ("just acceptable") and 24 ("just uncomfortable") for 2-40% of the day for the horizontal view in the private office facing the west window (Figure 6-11). There were lower percent values (20% of day maximum) when the shades were controlled for glare. For all days when DGI was between 20 and 24, the lights in the private office were not on so the adaptation luminance was low. Increasing the interior office luminance would decrease the DGI.

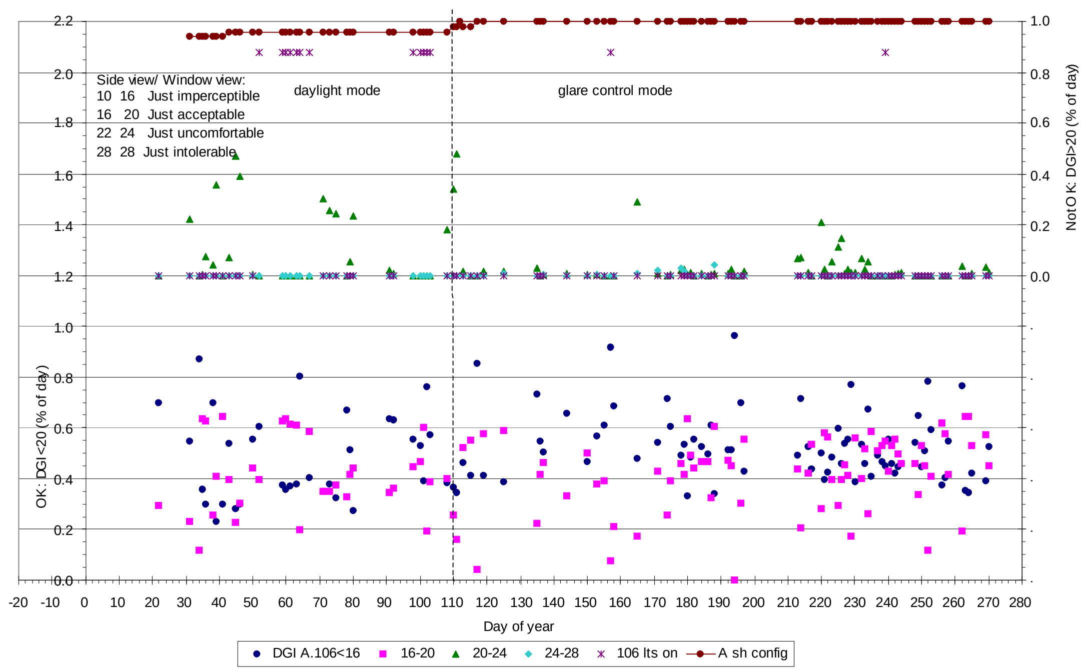


Figure 6-11. Area A. Percentage of day that the daylight glare index was within a specified range. View of the west window wall from inside the private office (Room 106).

The discomfort glare experienced in the private office will be similar to or less than the discomfort glare experienced at the same distance from the window in the open plan office area. In Area A, the occupant seated in the fifth workstation from the west window wall has their primary view toward their VDT screen facing west. This view position will cause discomfort glare to the occupant (direct view of the sun orb will also be a significant problem), so the building owner was advised not to configure the furniture layout so that occupants faced the west window (unless some means was used to block direct sun). Alternatively, the furniture layout could be changed so that the primary VDT viewing direction is to the north. The north window wall may cause less discomfort glare for a smaller percentage of the day.

For all other view locations, there was minor to no discomfort glare throughout the day. The DGI (excludes window view so threshold values for IES GI were used) was between 10 ("just imperceptible") and 16 ("just acceptable") for the desk view facing east for 30-70% of the day and less than 10 for the remainder of the day (Figure 6-12). Desk luminance levels tended to be high in the first workstation closest to the west window wall but sufficiently controlled for glare. For all remaining view locations computed, the DGI was less than 10 or 16 ("just imperceptible") for 100% of the day.

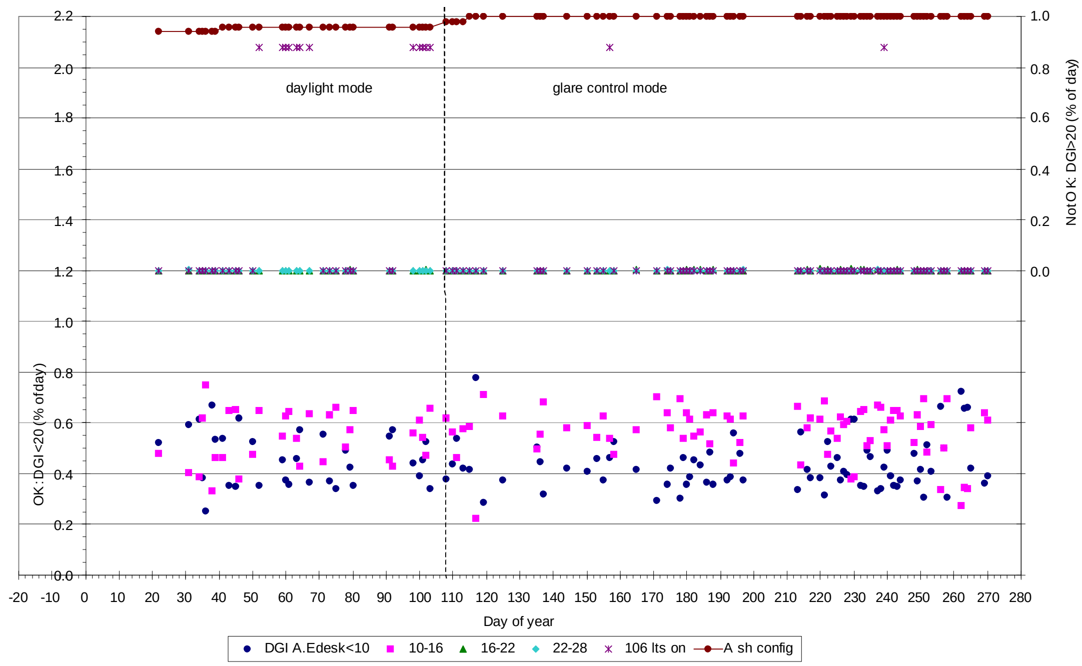


Figure 6-12. Area A. Percentage of day that the daylight glare index was within a specified range. First workstation nearest the west window, facing the desk looking east.

The average west window luminance very infrequently exceeded the 2000 cd/m^2 limit throughout the nine-month monitored period. For 10 days out of the 186 usable monitored days, the window luminance was greater than 2000 cd/m^2 for 10-54 min of the day (sun up). See Figure 6-13. The west window luminance was monitored over the vision and upper portion of the window wall and did not exclude periods when direct sun (with the shade up or down) struck the sensor directly.

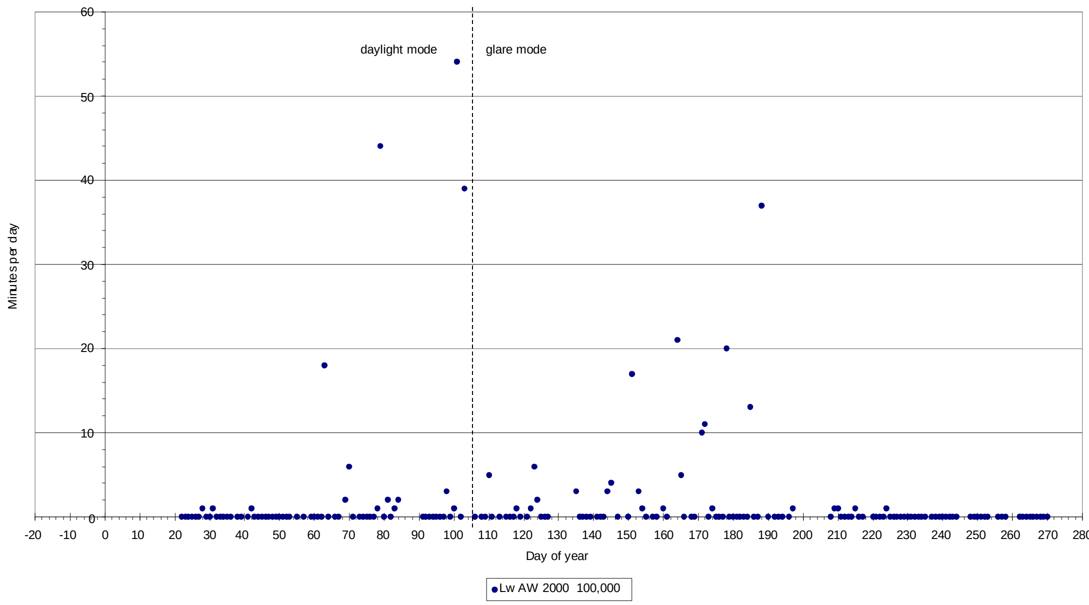


Figure 6-13. Area A. Minutes per day that the west window luminance exceeded 2000 cd/m².

Daily cumulative distributions of the average west window luminance are shown in Figures 6-15 and 6-16. On sunny days around the vernal equinox with daylight control, the peak of the distribution was approximately 30% of the day between the 1600 and 1800 cd/m² bins. With glare control, the peak was shifted to lower values: west window luminance levels peaked at the 1400 cd/m² bin at ~30% of the day for the same conditions. These two graphs nicely demonstrate the manufacturer's ability to fine-tune the setpoints of the control system to balance daylight and glare control requirements in response to building owner feedback. For the vernal equinox period on cloudy days and for the summer solstice period on sunny days, the west window luminance was well controlled below the 2000 cd/m² bin.

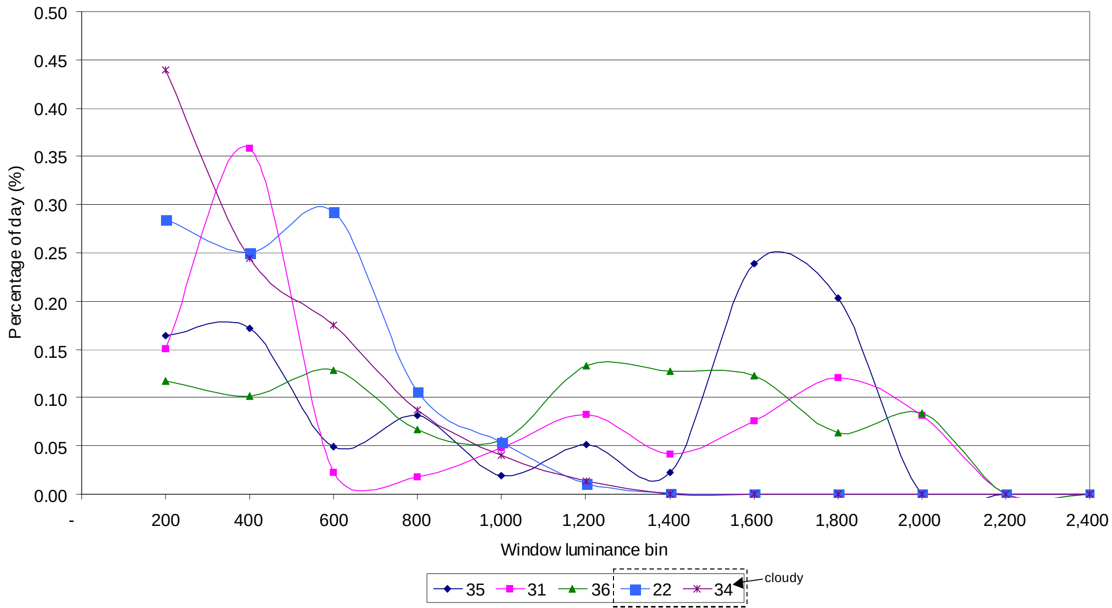


Figure 6-14. Area A. Percentage of day when the west window luminance (cd/m^2) is within a range of binned values (bin 200 = 0-200 cd/m^2). Daylight mode 1. Winter solstice, sunny conditions, average global exterior illuminance is between 8-36 klux.

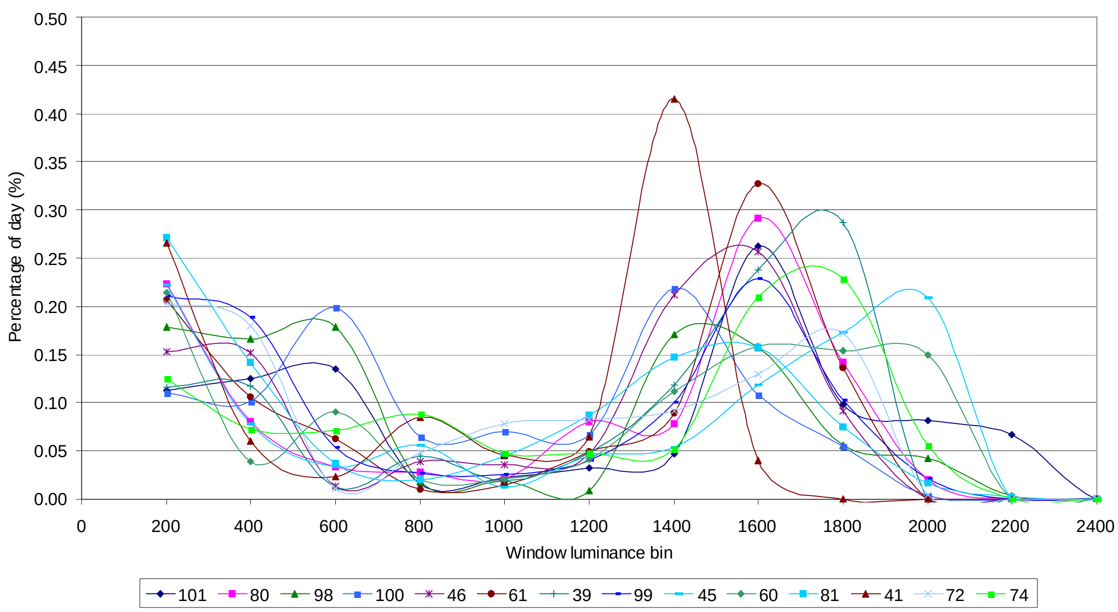


Figure 6-15. Area A. Percentage of day when the west window luminance (cd/m^2) is within a range of binned values (bin 200 = 0-200 cd/m^2). Daylight mode 1 and 2. Vernal equinox, sunny conditions, average global exterior illuminance is between 35-53 klux.

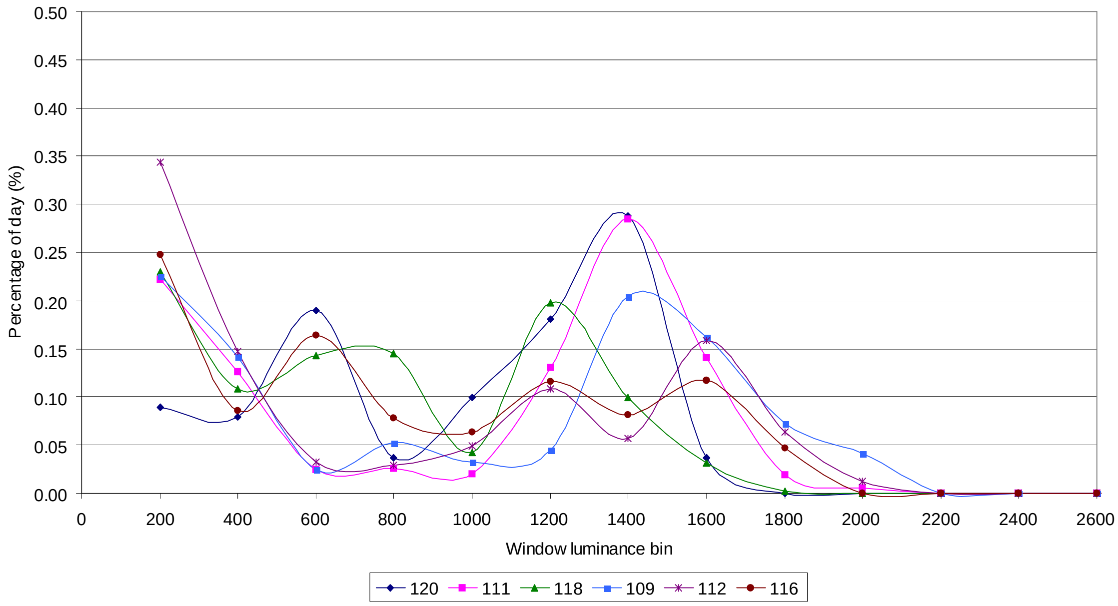


Figure 6-16. Area A. Percentage of day when the west window luminance (cd/m²) is within a range of binned values (bin 200 = 0-200 cd/m²). Glare mode 3 or 4. Vernal equinox, sunny conditions, average global exterior illuminance is between 35-53 klux.

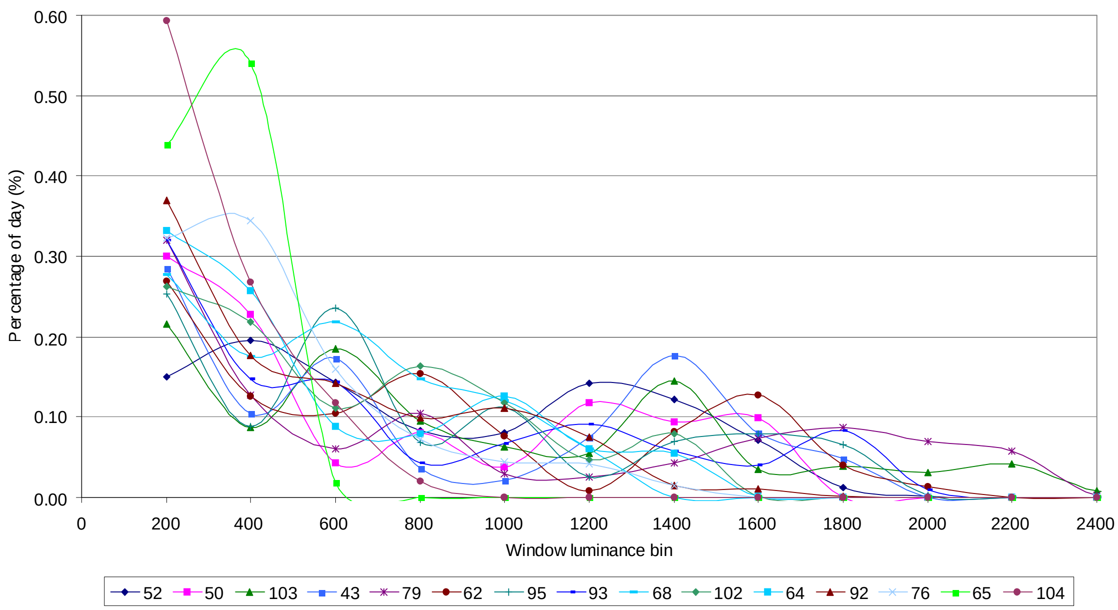


Figure 6-17. Area A. Percentage of day when the west window luminance (cd/m²) is within a range of binned values (bin 200 = 0-200 cd/m²). Daylight mode 1 and 2. Vernal equinox, cloudy conditions, average global exterior illuminance is between 6-26 klux.

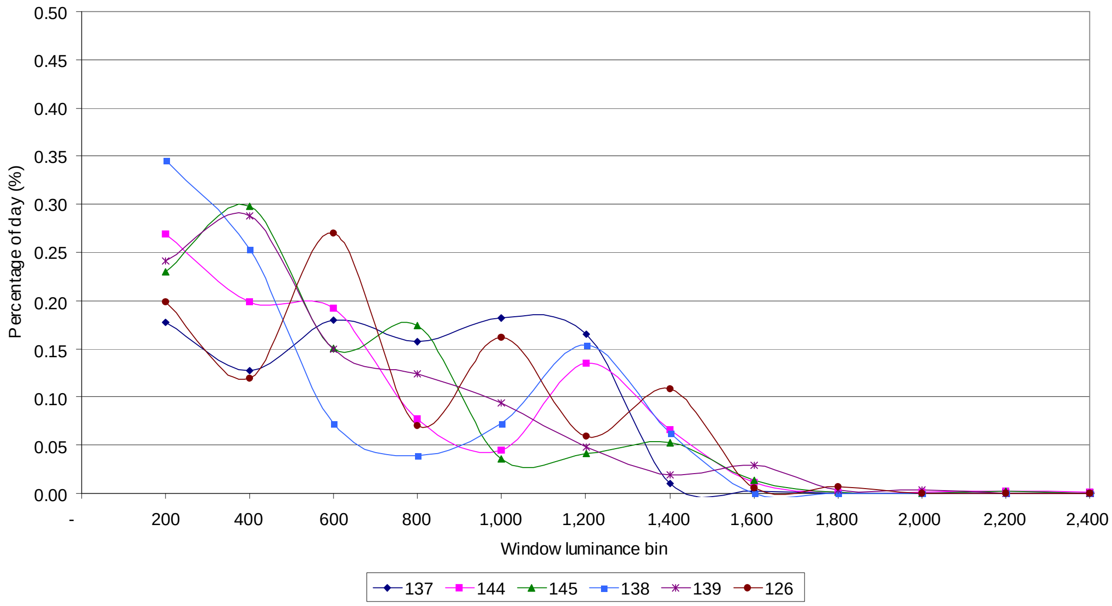


Figure 6-18. Area A. Percentage of day when the west window luminance (cd/m^2) is within a range of binned values (bin 200 = 0-200 cd/m^2). Glare mode 4. Summer solstice, sunny conditions, average global exterior illuminance is between 32-55 klux.

Average daily interior horizontal illuminance levels are given in Figure 6-19 at various distances from the window wall. The workplane illuminance level at the first workstation ("A Iwpi1") nearest the west window wall is most indicative of the interior daylight levels because the fluorescent lighting is of sufficient distance from this sensor to not contribute much flux (104 lux maximum) and because the fluorescent lighting is typically dimmed down to a low level during the day. The average daily interior illuminance levels at this location (Iwpi1) were between ~800-1200 lux during the monitored period. The change from daylight to glare control mode did not appear to significantly influence this average – the change in algorithm and solar conditions confounded this analysis. However, changes in shade operations between the two control modes occurred only in the afternoon (see Section 5.3), so the overall daily average illuminance is unlikely to reveal the subtle changes in daylight illuminance levels. By anecdotal observation, the shades were down more frequently and therefore daylight illuminance levels were less with the glare control mode.

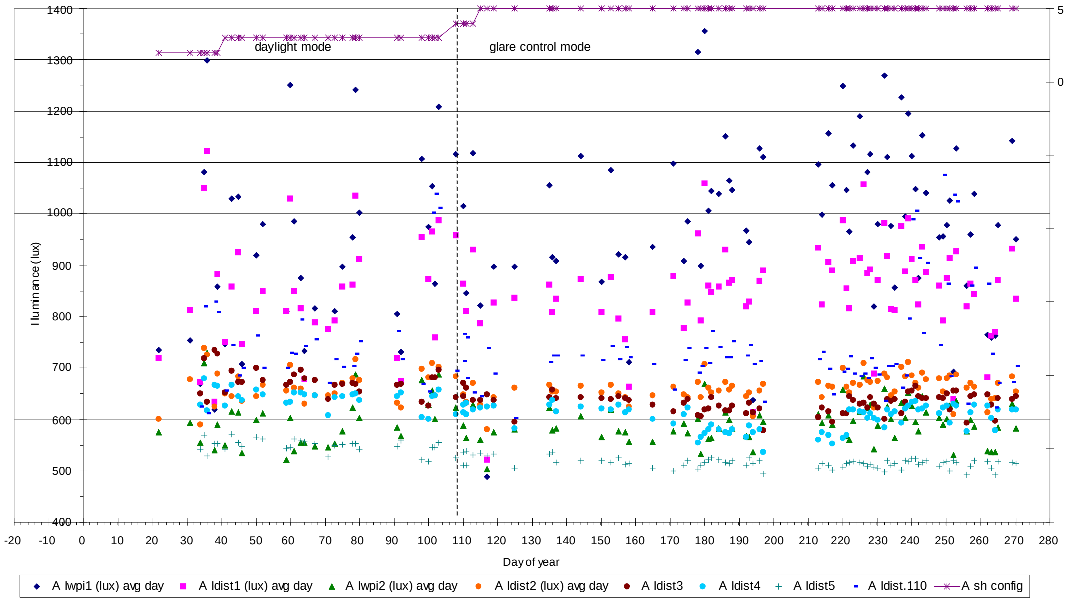


Figure 6-19. Area A. Average daily illuminance (lux) at various distances from the window wall.

As expected, interior illuminance levels decreased with distance from window wall (compare data from "Idist" sensors which are all at the same 1.2 m or 4 ft height). Lateral distribution across the window wall (compare "Idist2" to "Idist.110" which are the same distance from the window wall) was fairly uniform. The daily average illuminance was no lower than 500 lux, where this lower bound was defined by the fluorescent lighting setpoint.

Throughout the nine-month period, view to the exterior was maintained for at least 65% of the day (Figure 6-20). "No view" was defined by shade heights that blocked the vision and upper portion of the window wall. The large percentage of day with view, even in the glare control mode, was due in part to the control system design which restricted window shade movement during the morning hours (shades were always fully raised during this period). Generally, less view occurred during the summer months on sunny days while more view was available during cloudy days and during equinox or winter months for this west window orientation. The shade analysis section provides more detailed on shade operations and percentage of day values that the shade was positioned at each preset height (Section 5.3).

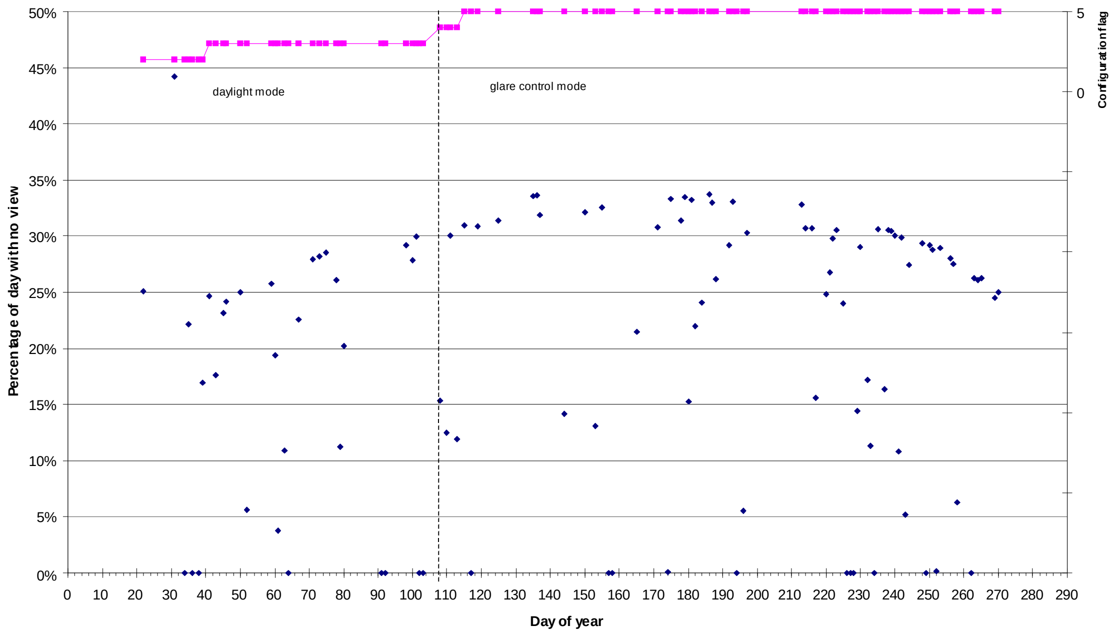


Figure 6-20. Area A. Percentage of day that view out the window is blocked by the shade.

6.3.2. Area B

Similar to Area A, occupants will experience glare associated with transient adaptation when viewing either the VDT or bookcase partition tasks with the south window wall in their adjacent or remote field of view. The IESNA recommended limits on luminance ratios were exceeded for a significant percentage of the day (40-85%) for these cases (Figures 6-21 and 6-22). South window luminance levels were significantly brighter than the VDT and bookcase partition wall luminance levels throughout the day. Control of the depth of direct sun penetration alone was not sufficient to provide visual comfort for these tasks. Control of window luminance is warranted. For the later period, a new window brightness control mode was tested (control configuration 5 after day 210) on the west façade only. If brightness control had been implemented on the south window wall, we would expect to see a significant change in performance. Examples showing when the luminance ratios were exceeded are given in Figures 6-23 to 6-26.

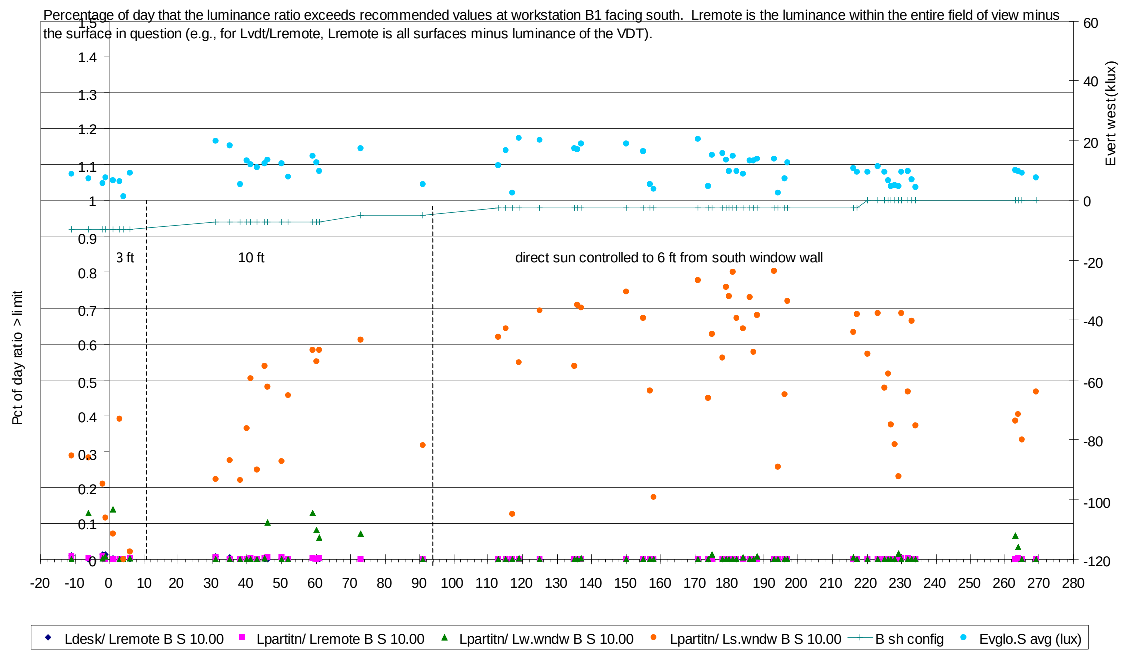


Figure 6-21. Percentage of day that the luminance ratio exceeded the IESNA recommended limits at workstation B1 facing south.

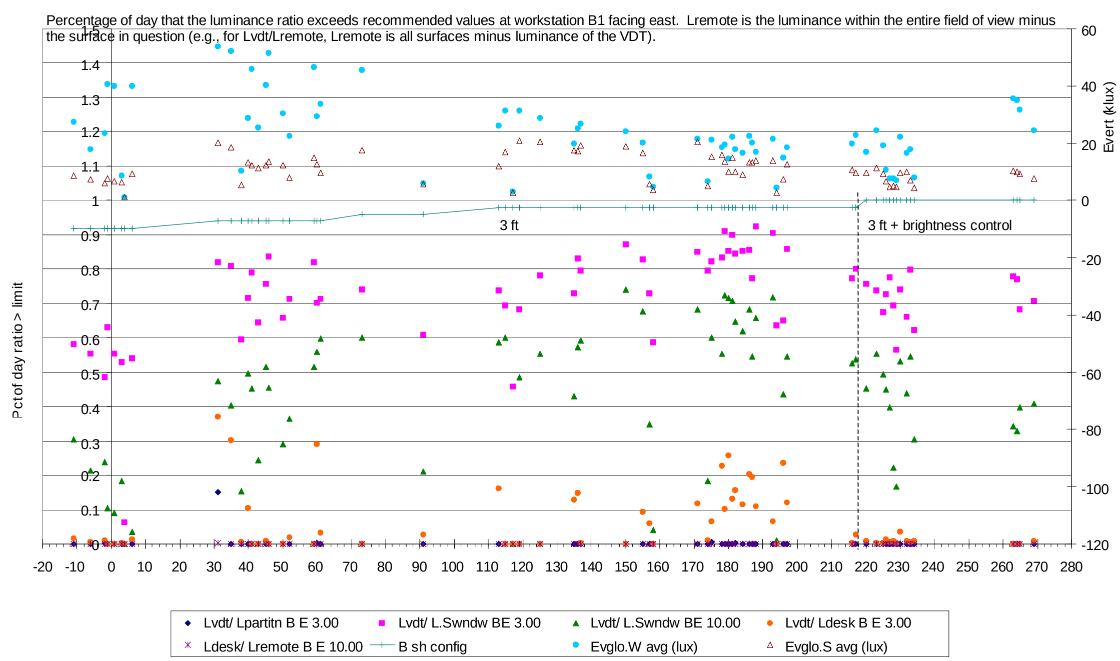


Figure 6-22. Percentage of day that the luminance ratio exceeded the IESNA recommended limits at workstation B1 facing east.

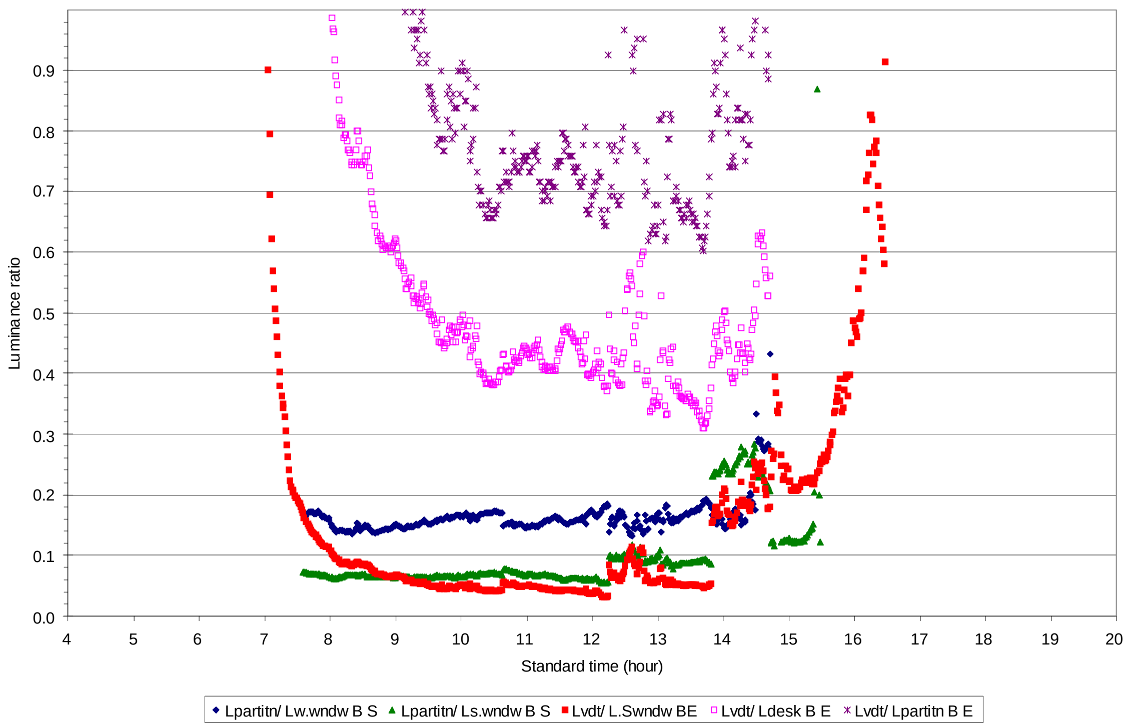


Figure 6-23. Area B. Luminance ratios on 2/14/04. Luminance ratios that have the window luminance in the denominator should not be below 0.1. Lvdt/Ldesk and Lvdt/Lpartition should not be below 0.33.

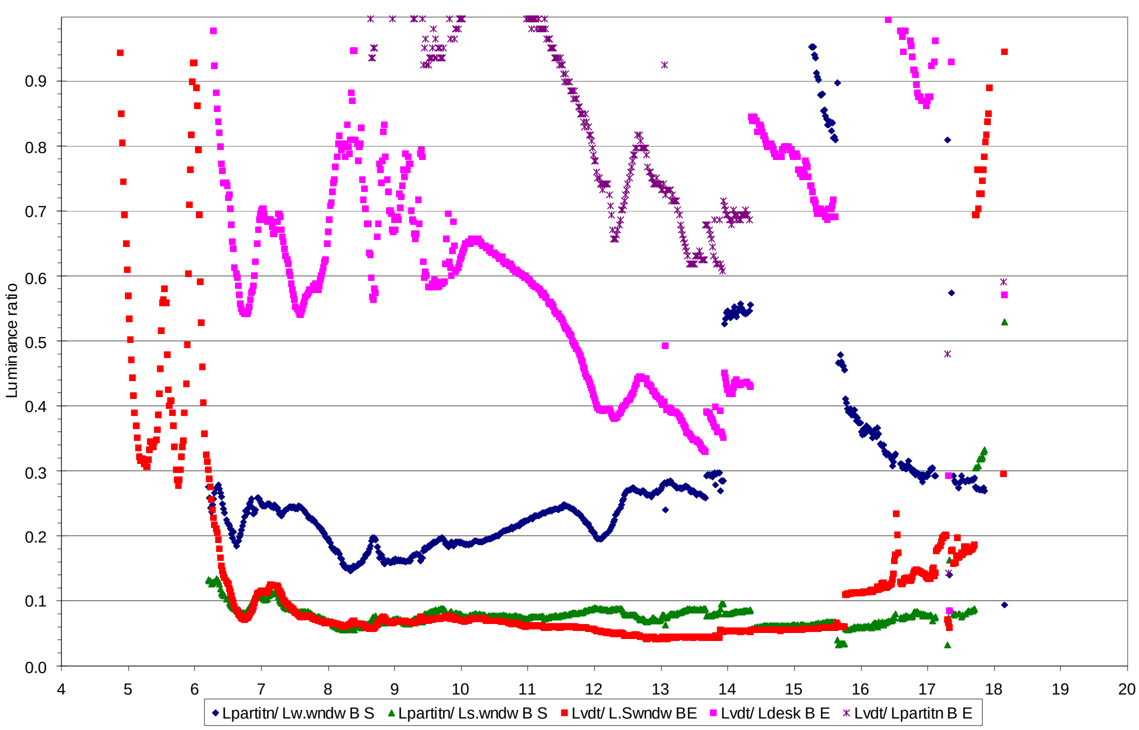


Figure 6-24. Area B. Luminance ratios on 5/16/04.

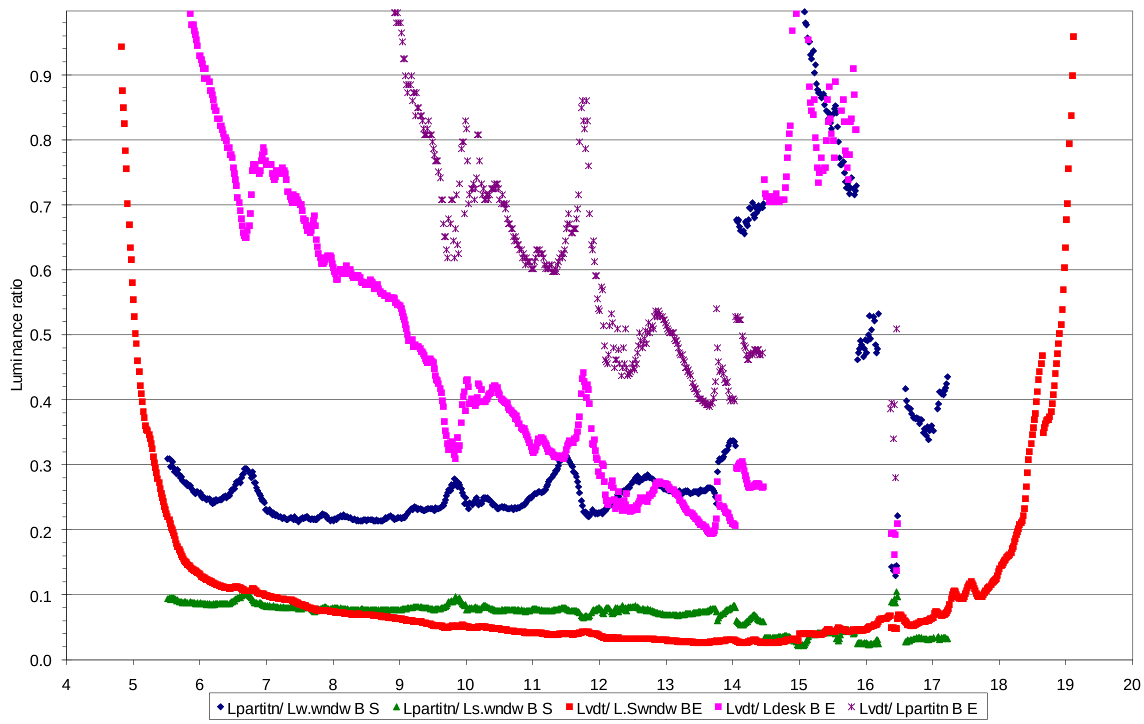


Figure 6-25. Area B. Luminance ratios on 7/4/04.

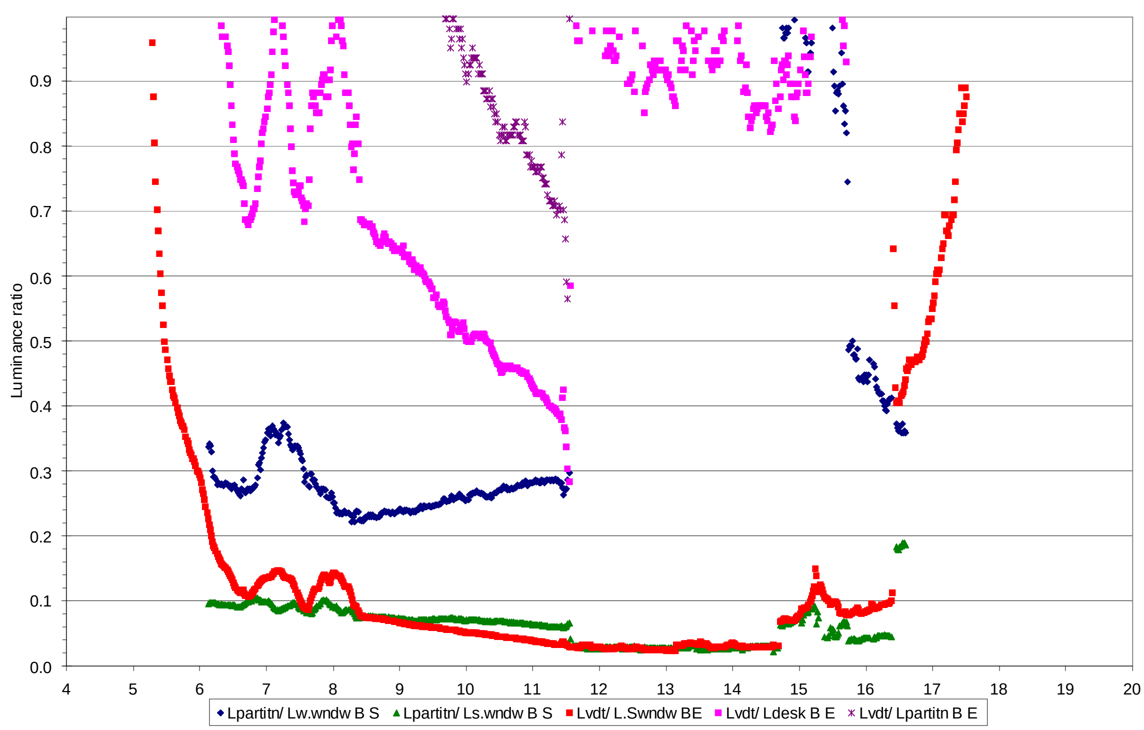


Figure 6-26. Area B. Luminance ratios on 8/10/04.

The west window luminance caused discomfort glare when viewed directly by occupants in the private office. South window luminance also caused discomfort glare when occupants faced south and were seated in the first workstation closest to the west window wall. The DGI was between 20 (“just acceptable”) and 24 (“just uncomfortable”) for 2-55% of the day for the occupant in the private office facing the west window (Figure 6-27). As explained for Area A, the adaptation luminance was low in the private offices compared to the bright west window causing discomfort glare. Turning on the electric lights in the private office would decrease discomfort. Comparable levels of discomfort glare may be experienced in the fifth workstation from the west window wall, where the occupant also faces the west window wall. Direct view of the sun orb from the west and south will also occur at this location. The DGI facing the south window wall was between 20-24 for 2-25% of the day between April and August (Figure 6-28). The adaptation luminance was high for the occupant due to the close proximity of the south and west window walls so even though the absolute window luminances were high, all surrounding luminances were also high so discomfort glare tended not to be severe. For other seated locations farther from the window with the same view, discomfort glare levels are expected to increase. For all other computed views, the DGI was below “just acceptable” levels.

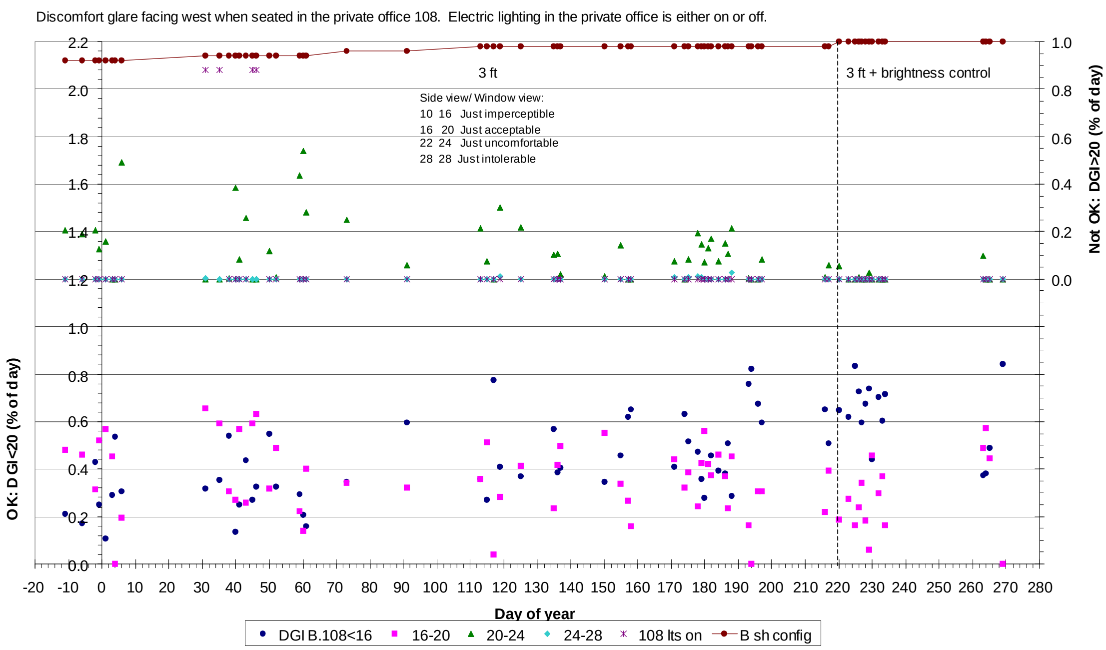


Figure 6-27. Area B. Percentage of day that the daylight glare index was within a specified range. View of the west window wall from inside the private office (Room 108).

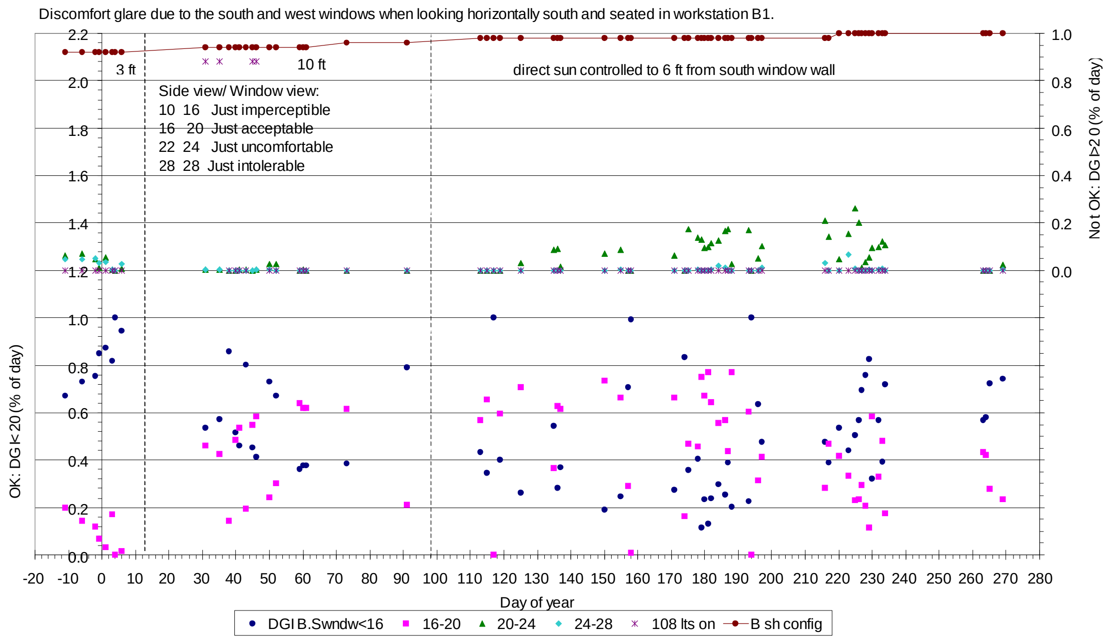


Figure 6-28. Area B. Percentage of day that the daylight glare index was within a specified range. View of the south window wall from the first workstation closest to the west window wall.

The average west window luminance very infrequently exceeded the 2000 cd/m² limit throughout the nine-month monitored period (Figure 6-29). For 15 days out of the 144 usable monitored days, the window luminance was greater than 2000 cd/m² for 10-71 min of the day (sun up). However, the average south window luminance did frequently exceed the 2000 cd/m² limit. For example, after mid-April when direct sun was controlled to 1.83 m (6 ft) from the window wall, this limit was exceeded for 300-650 min per day. Trends given changes in control mode over this nine-month period cannot be properly characterized because of the parallel changes in solar conditions. Note that unlike the west window, the south window was unshaded by ceramic tubes so luminance levels were significantly greater than the west. The measurement of window luminance included both the vision and upper region of the window wall (from 1.2 m or 4 ft above the floor to ceiling height).

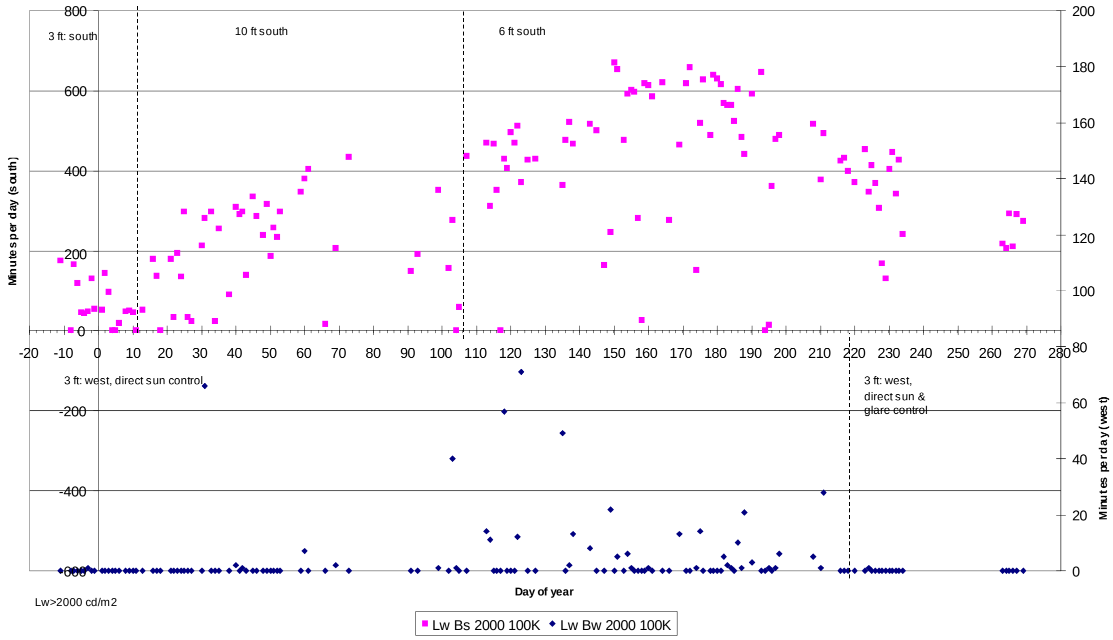


Figure 6-29. Area B. Minutes per day that the west (lower) or south (upper) window luminance exceeded 2000 cd/m^2.

Daily cumulative distributions of the average west window luminance are shown in Figures 6-30 to 6-33. On sunny days around the winter solstice, the peak of the distribution was approximately 25% of the day around the 1800 cd/m^2 bin. On sunny days around the vernal equinox, the peak shifted slightly downwards to 1600 cd/m^2 for 25% of the day. On sunny days around the summer solstice, the peak is further reduced to ~1200 cd/m^2 for 15% of the day. These changes in the daily cumulative luminance distribution are due to changes in solar conditions since the control algorithm was not changed throughout these periods. For cloudy conditions during the vernal equinox, the west window luminance was well controlled below 2000 cd/m^2 for the majority of the day.

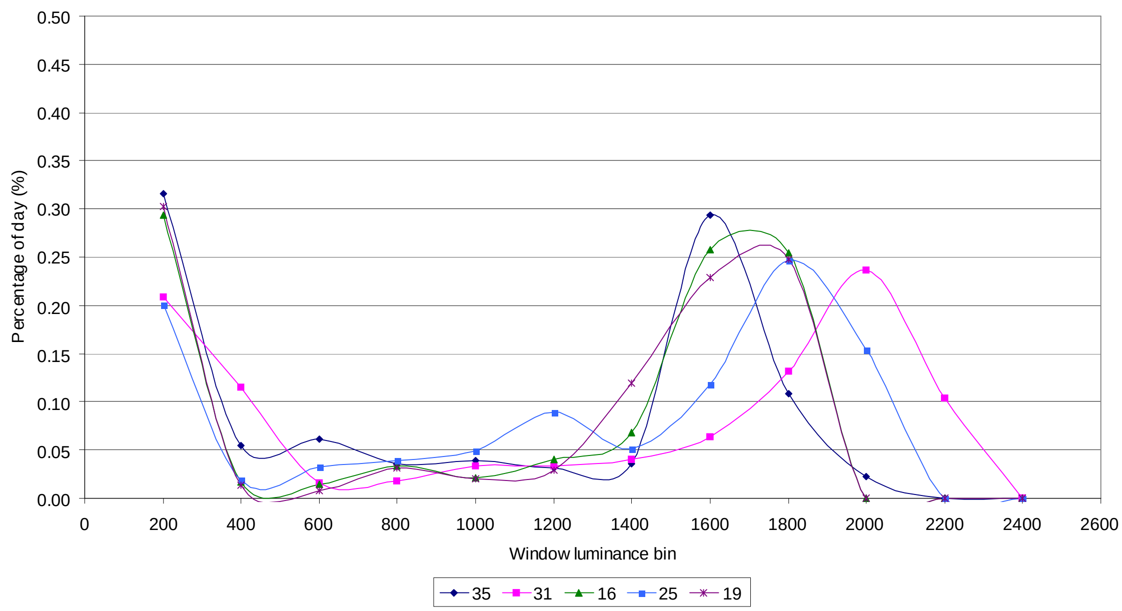


Figure 6-30. Area B. Percentage of day when the west window luminance (cd/m^2) is within a range of binned values (bin 200 = 0-200 cd/m^2). Winter solstice, sunny conditions, average global exterior illuminance is between 25-36 klux.

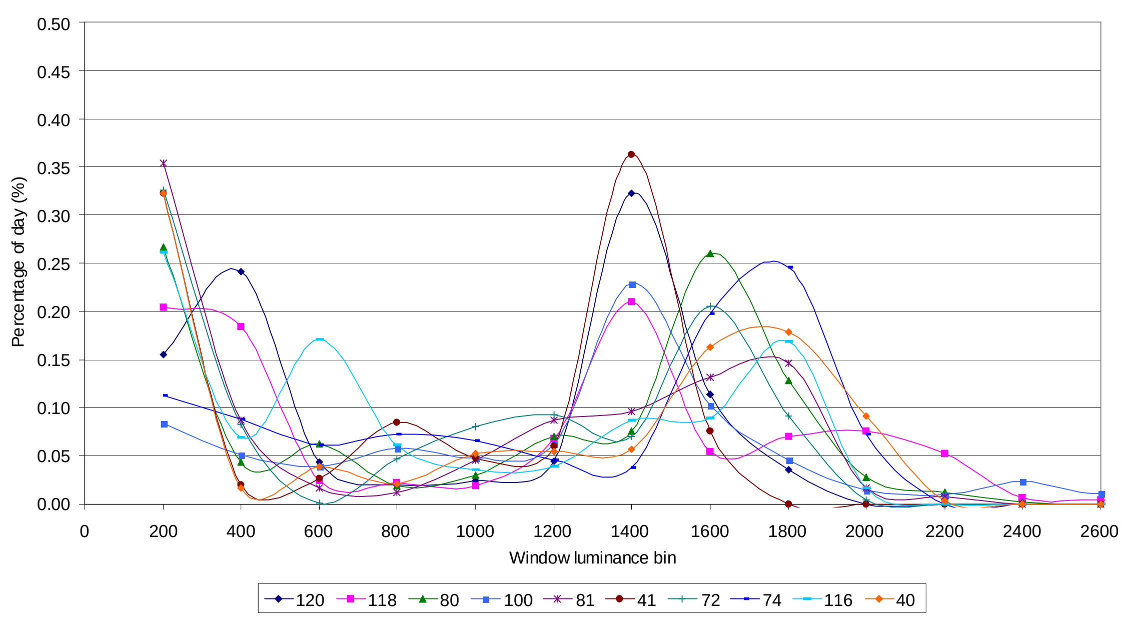


Figure 6-31. Area B. Percentage of day when the west window luminance (cd/m^2) is within a range of binned values (bin 200 = 0-200 cd/m^2). Vernal equinox, sunny conditions, average global exterior illuminance is between 30-57 klux.

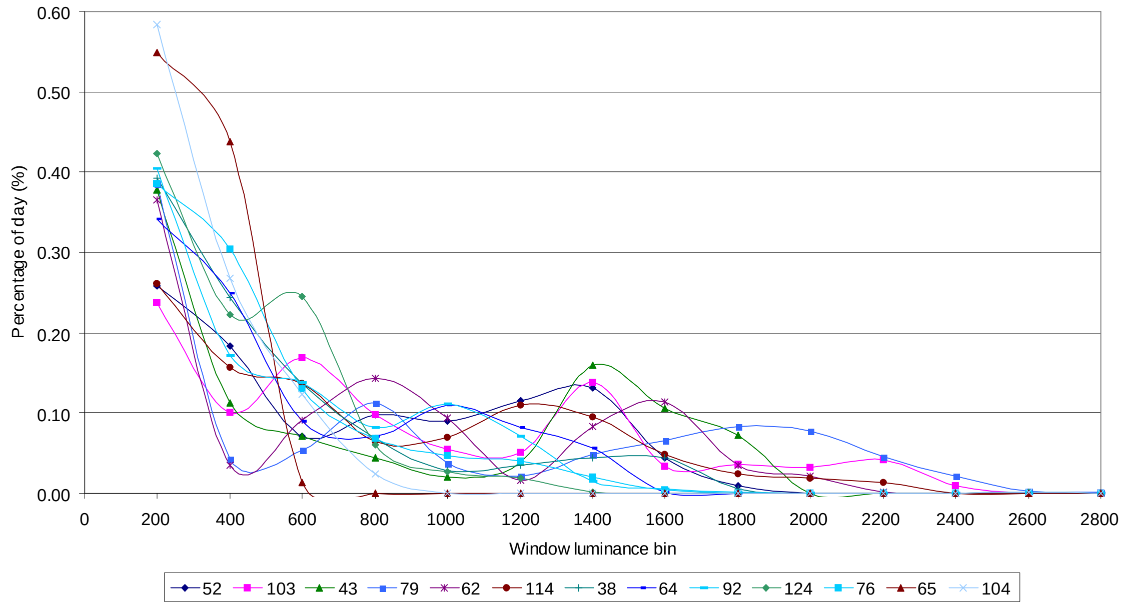


Figure 6-32. Area B. Percentage of day when the west window luminance (cd/m^2) is within a range of binned values (bin 200 = 0-200 cd/m^2). Vernal equinox, cloudy conditions, average global exterior illuminance is between 6-25 klux.

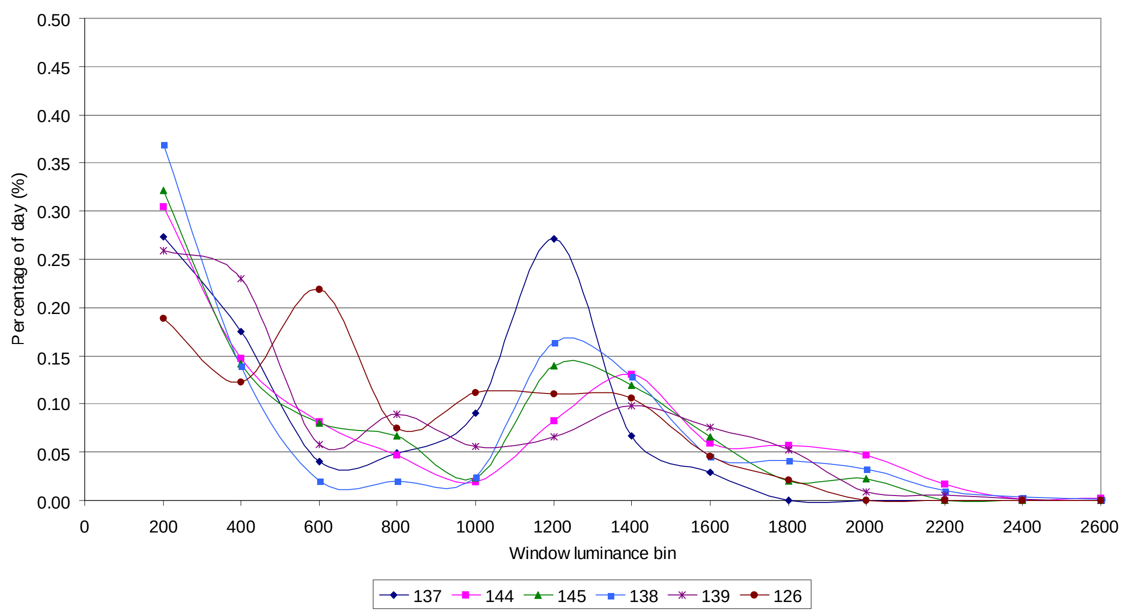


Figure 6-33. Area B. Percentage of day when the west window luminance (cd/m^2) is within a range of binned values (bin 200 = 0-200 cd/m^2). Summer solstice, sunny conditions, average global exterior illuminance is between 30-57 klux.

For sunny days around the winter solstice, the daily cumulative distribution of south window luminance was broader than that on the west (Figure 6-34). Bin levels were computed up to 5200 cd/m^2. Window luminance levels were significantly greater than 2000 cd/m^2 for significant percentages of the day with 3.04 m (10 ft) direct sun control. The graph includes two days where direct sun was controlled to 0.91 m (3 ft) from the window. The remaining days shown have direct sun controlled to 3.04 m (10 ft) from the window. For the 0.91 m (3 ft) control, window luminance levels were generally less than 1400 cd/m^2 (day of year (DOY)=-4 had 43 min when levels exceeded 2000 cd/m^2 while DOY=11 had zero min).

On cloudy conditions around the vernal equinox, south window luminance continued to pose problems due to the bright sky conditions (Figure 6-35). The shades were raised throughout the day since there was no direct sun. Window luminance levels exceeded 2000 cd/m^2 for 90-310 min on these days.

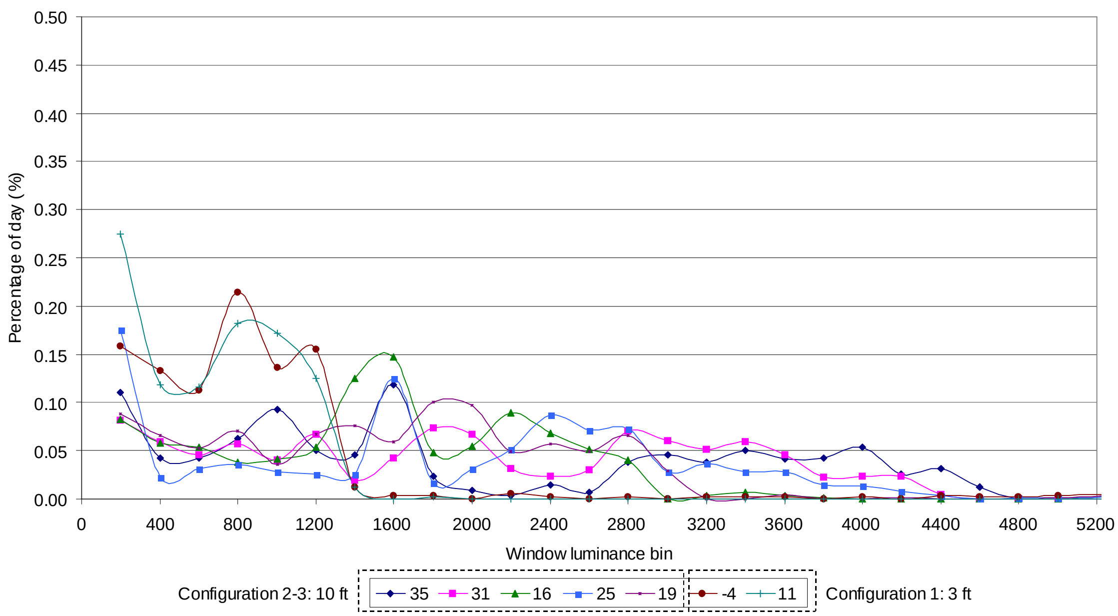


Figure 6-34. Area B. Percentage of day when the south window luminance (cd/m^2) is within a range of binned values (bin 200 = 0-200 cd/m^2). Winter solstice, sunny conditions, average global exterior illuminance is between 25-36 klux.

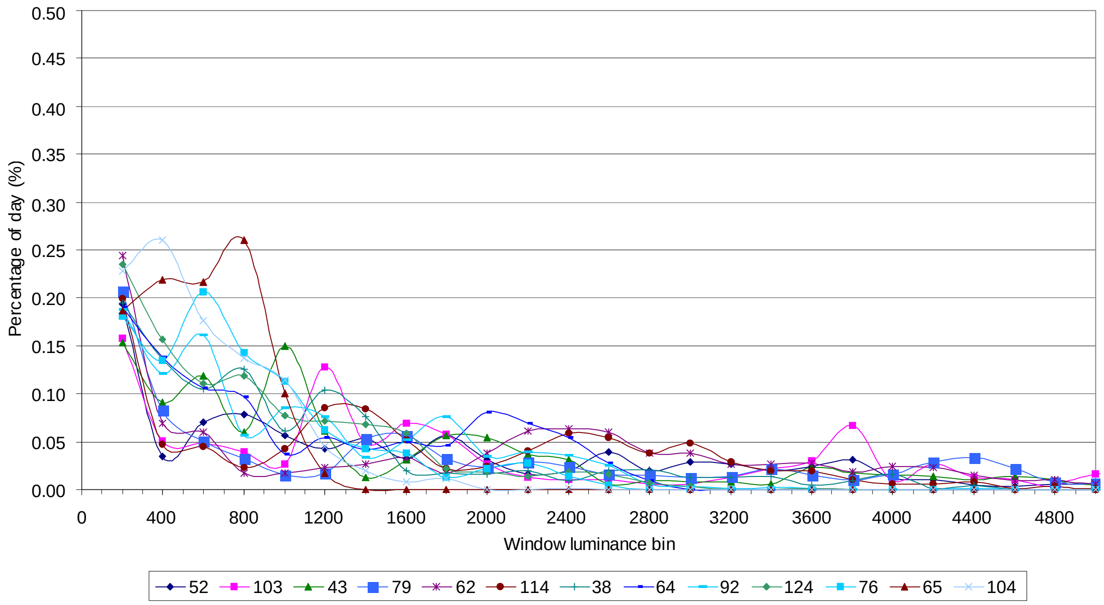


Figure 6-35. Area B. Percentage of day when the south window luminance (cd/m^2) is within a range of binned values (bin 200 = 0-200 cd/m^2). Vernal equinox, cloudy conditions, average global exterior illuminance is between 6-25 klux.

Average daily interior horizontal illuminance levels are given in Figure 6-36 at various distances from the west window wall and at the same distance from the south window wall. The stair to the south tended to shadow the sensors to varying degrees depending on solar conditions. At the corner workstation closest to the west window wall, total illuminance was between 1000-1500 lux over the monitored period. There was a significant drop in illuminance in this first workstation when the brightness control mode was tested in August and September (DOY=218 onwards). Given the bilateral condition, daylight levels tended to drop with distance from the west window but this trend is slightly muddled given contributions from the south window wall. The building owner was quite satisfied with the brightness level in this area of the daylighting mockup throughout the test period.

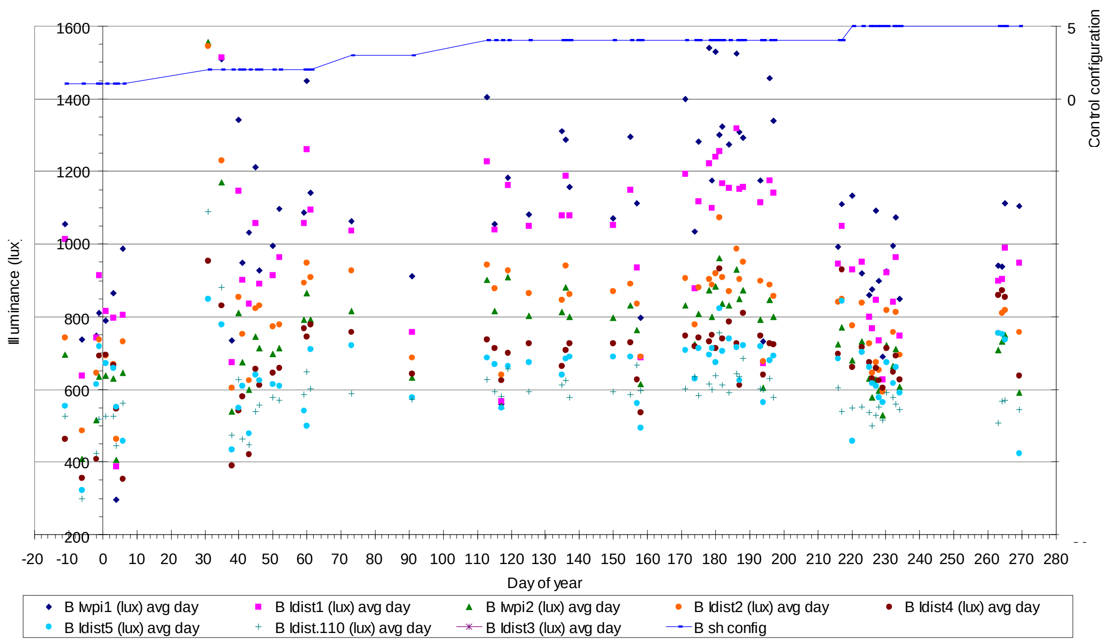


Figure 6-36. Area B. Average daily illuminance (lux) at various distances from the window wall.

Throughout the nine-month monitored period, view to the exterior was maintained for at least 75% of the day on the west facade (Figure 6-37). On the south, view was maintained for at least 80% of the day when direct sun was controlled to 1.83 m (6 ft) from the window (after DOY 107). When controlled to 0.91 m (3 ft) during the period around the winter solstice, there was no view for 80-90% of the day due to the low winter sun angles. View was defined in the same manner for the south and west facades (shade height greater than 76 cm (30 in) above the floor). Note the distinct upper boundary of points for the west facade and see the analysis in the shading analysis (Section 5.3) that explains this trend in more detail.

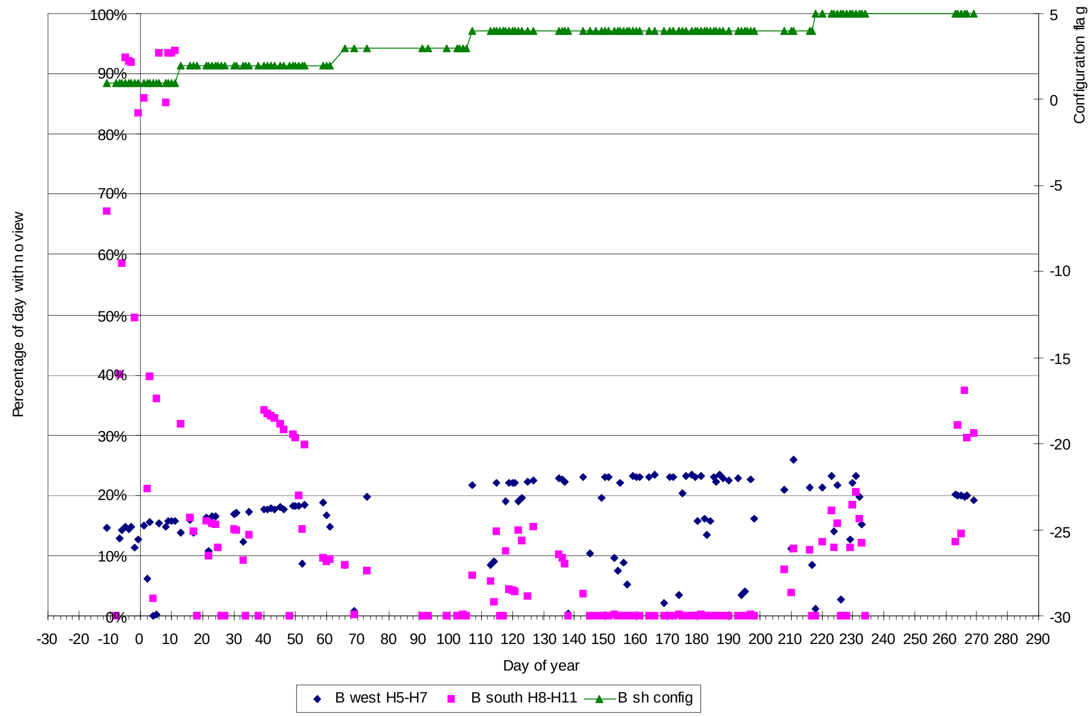


Figure 6-37. Area B. Percentage of day that view out the window is blocked by the shade.

Examples of how window luminance, daylight illuminance, and view varies with solar conditions and shade control algorithm are given in the shade controls analysis (Section 5.3).

6.4. DISCUSSION OF EXPERIMENTAL RESULTS

6.4.1. Will occupants be comfortable

For the main viewing direction toward the east, occupants will be visually comfortable performing VDT tasks in Area A for the majority of the day throughout the year, particularly if the shades are controlled for glare (as in glare control mode 4). No discomfort glare is anticipated in the open plan area or private offices unless one faces the west window wall. Even so, discomfort glare facing the window was within "just uncomfortable" levels for a few days over the monitored period and below "just acceptable" levels for the remaining period. The average west window luminance was maintained below 2000 cd/m^2 for the majority of the day (maximum exceedance was 54 min/day). Average daily interior illuminance levels were within ~800-1200 lux at a distance of 3.35 m (11 ft) from the window wall. Unobstructed outdoor view was available for at least 65% of the day. Overall, the shading system in Area A demonstrated excellent overall performance and was able to balance or tune the various performance variables to an acceptable degree.

With direct sun control to 0.91 m (3 ft) from the window wall, the performance in Area B on the west façade was nearly comparable to that in Area A. Luminance ratios were maintained to acceptable levels for the majority of the day throughout the year for the east viewing direction and for tasks involving the VDT. Discomfort glare levels facing the window from within the private office were within "just acceptable" to "just uncomfortable" levels for 2-55% of the day and below these levels for the remainder of the day. The average west window wall luminance was maintained below 2000 cd/m^2 for the majority of the period (maximum of 71 min when this limit was exceeded in a day). View was available for at least 75% of the day.

The shading system in Area B did not provide acceptable comfort conditions primarily due to the lack of control over the south window wall luminance during diffuse sky conditions as well as during periods when the shade was backlit by direct sun. Occupants performing VDT tasks with the south window in the field of view will experience glare because the luminance ratio limits between the VDT and south window were exceeded for a significant percentage of the day (>40% of the day throughout the monitored period). South window luminance levels well exceeded 2000 cd/m^2 for the majority of the day (>200 minutes per day). Discomfort glare (DGI) was not significant in the first workstation closest to the west window wall: the eye was adapted to the bright surroundings so the bright south window wall caused between "just acceptable" and "just uncomfortable" levels of glare for no more than 20% of the day.

6.4.2. Reviewing the balance between glare and daylight

Ideally with dynamic window systems, one would like to achieve control of glare and direct sun while providing sufficient daylight to the interior to combat gloom and reduce lighting energy consumption at all times throughout the day and year. This is difficult to achieve with automated roller shades when a perforated fabric is used and an economic solution is desired. Roller shades cannot block direct sunlight completely so the orb of the sun seen through the fabric causes direct source glare if viewed directly. For view positions where one cannot reposition the task or one's eye, direct source glare poses intolerable viewing conditions and leads to occupant complaints. The building owner recognized this problem immediately upon completion and startup of the daylighting mockup during the winter solstice. The 3%-open fabric backlit by the sun had the appearance of a thin veil and the intense orb of the sun was within direct view (Figure 6-38). Use of a black-out shade to block the orb would completely eliminate useful daylight but was not acceptable to the building owner. The building owner decided to specify a lower-density fabric for facades that were subject to these conditions for a significant percentage of the year (south, floors unshaded by urban obstructions). As mentioned in Section 2, use of a Venetian blind was not considered primarily for aesthetic reasons.

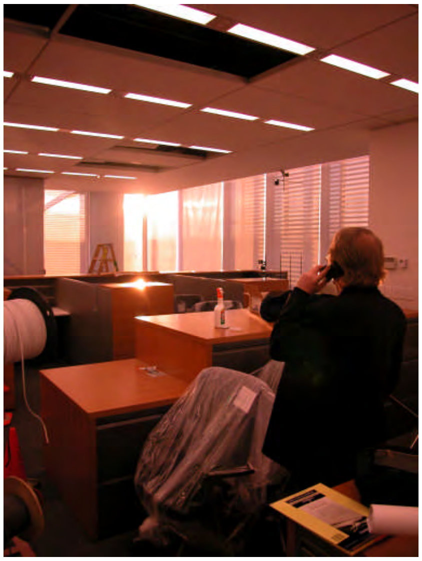


Figure 6-38. View of shaded south façade. The sun orb was within view throughout this winter solstice day.

It also became apparent to the building owner that controlling direct sun to 0.91 m (3 ft) from the south window wall caused the shades to be closed for the majority of the day during winter solstice conditions. This gave the building owner and design team the distinct impression of gloom, a closed-in feeling since view was blocked, and a sense of dreariness in the mockup on winter days. The gray tone of the fabric towards the interior contributed to this sense of dreariness. So while a denser fabric was needed for direct sun control, the interior daylit environment was not acceptable from an aesthetic point of view. The 0.91 m (3 ft) criteria was lifted on the south and pushed to 3.04 m (10 ft) because there were no workstations close to the window wall – a circulating stair was immediately adjacent to the south window wall. Later this control depth was reduced to 1.83 m (6 ft) to reduce window glare. To control window luminance, we expect that the shades on the south window wall will be closed for the majority of the day, particularly during sunny winter solstice conditions.

Early on, the building owner found that the lighting levels in Area B were brighter than Area A. This was attributed not only to the south window wall but also the difference in control algorithms between the two Areas on the west facade. In Area A during the winter season (a glare control mode was implemented initially in the first month of testing but not included in the dataset), the west shades were down even when the sun was not in the plane of the window. This contributed to a sense of gloom and dreariness in Area A while Area B was perceived as brighter and more acceptable. The daylight mode in Area A resulted from early discussions between LBNL, The Times, and the manufacturer. Later, the glare mode (control configuration 3 and 4) in Area A was also implemented in response to feedback from LBNL and the building owner. Both manufacturers recognized that further adjustments to their control system were needed to meet the complex performance demands of The Times.

After analysis with the digital luminance maps, we recognized that the large-area glare source on the west window wall should be defined by the vision portion of the window wall not by the vision and upper portion of the window wall. The upper portion of the window wall was shaded by the ceramic tubes so its luminance rarely presented problems with glare unless low direct sun could be viewed through the tubes and shade fabric. The procurement specifications reflected this approach and further work on the shade control algorithm and shade fabric selection was directed towards control of window luminance in the vision portion of the window wall (the clear unobstructed glazed region between 0.76-2.13 m or 2.5-7.0 ft above the floor). The impact of such glare control will be negative on daylight, view, and energy savings. However, each building wing is glazed on three sides due to the cruciform shape of the floor plan, so view and unobstructed daylight will be available through at least one side of the building throughout the day.

A set of high-resolution time-lapse images were taken by a professional photographer in both Area A and B every half hour from different viewpoints on 2/23/04. These images can be viewed at the project website: http://windows.lbl.gov/comm_perf/newyorktimes.htm.

6.5. CONCLUSIONS

The environmental quality resulting from the shading systems was evaluated over a nine-month period as the shade control system's threshold setpoints were tuned given feedback from the building owner and LBNL. For each area, several comfort metrics were computed: percentage of day that luminance ratios between task surfaces and window were exceeded, percentage of day that the daylight glare index was within specific ranges, minutes per day that the window luminance exceeded 2000 cd/m^2, percentage of day when the window luminance was within specific binned values, average daily total daily illuminance at various distances from the window wall, and percent of day that the view was blocked by the shade. Time-of-day plots were given to illustrate how these values varied over the course of the day. Photographs were used to illustrate shadowing patterns cast by direct and diffuse sunlight.

Overall, Area A demonstrated excellent performance and was able to balance or tune various performance variables to an acceptable degree. For the main viewing direction toward the east, occupants will be visually comfortable performing VDT tasks in Area A for the majority of the day throughout the year, particularly if the shades are controlled for glare. No discomfort glare is anticipated in the open plan area or private offices unless one faces the west window wall – in which case discomfort glare was within "just uncomfortable" levels for a few days over the monitored period. The average west window luminance was maintained below 2000 cd/m^2 for the majority of the day. Average daily interior illuminance levels were within 800-1200 lux at a distance of 3.35 m (11 ft) from the window wall.

The shading system in Area B demonstrated nearly comparable performance on the west, but was not able to deliver comfortable conditions due to lack of control over the south window wall luminance during diffuse sky conditions as well during periods when the south shade was backlit by direct sun. Luminance ratio limits between the VDT and south window were exceeded for a significant percentage of the day (>40% of the day throughout the monitored period). South window luminance levels exceeded 2000 cd/m^2 for the majority of the day (> 200 min per day). Discomfort glare in the first workstation closest to the west window wall facing both the west and south windows was minimal due to the eye's adaptation to the bright surroundings. In both areas, there will be disability glare if the occupant looks towards the sun orb, even with the shade down. The building owner recognized this problem and decided to specify a lower-density fabric for facades that were subject to this condition for a significant percentage of the year.

Both manufacturers should be commended for tackling the difficult problem of managing a shading device to balance the client's desire for daylight, view, and interior brightness against the need to control discomfort glare, particularly in an open plan work environment. Discomfort glare results from a complex mix of luminous sources (overhead lighting being dimmed or fully on, window sky light or direct sun), size of the sources, and position of the source relative to the occupants' eyes. The problem of quantifying glare and controlling for glare is difficult to solve and highly dependent on the occupants' main viewing position and task. Further work is clearly needed in developing more robust fundamental discomfort glare models and control systems.

Section 7
SUBJECTIVE APPRAISALS IN THE DAYLIGHTING MOCKUP

7.1. INTRODUCTION

A subjective appraisal study of the automated roller shades and daylighting control systems installed in The New York Times Daylighting mockup was conducted in 2004. The objectives of this study were to identify potential problems associated with the use of these systems and to compare subjective appraisals between the two areas of the mockup: 1) Area A in the north half of the mockup daylight with west-facing windows and installed with one manufacturer's roller shade and daylighting control system; and 2) Area B in south half of the mockup daylit bilaterally with a south and west-facing windows installed with different roller shade and daylighting control systems provided by two separate manufacturers.

The analysis is based on survey results from 53 subjects who filled out questionnaires at the New York Times mockup. The subjects were staff volunteers from the New York Times or volunteers from outside organizations. There were seven groups of subjects (1-11 subjects per group) where each "group" visited on a separate day. Subjects in each group were randomly divided into two sub-groups, one of which evaluated Area A, and the other Area B. Four of the groups (totaling 26 subjects) visited the space between April 30 and June 11, 2004. The other three groups (27 subjects) visited the space on September 15, 16, and 17, 2004.

Subjects were requested to visit the mockup in the afternoon so as to experience the space when direct sun (if it was sunny) was in the plane of the south- and west-facing windows. All but two subjects began work at the mockup at or after the noon hour. One subject visited the mockup at 8:00, and a second began work at 11:00. Upon arrival at the mockup, subjects were assigned a desk location, given an overview of the space, and requested to fill out a brief background and attitude questionnaire (see Appendices A and B for the entire questionnaire and experimental procedure). The remaining experimental period was broken into two sessions lasting one to three hours each. Subjects brought their own work. At the end of each session, subjects filled out a questionnaire giving their reactions to the space, with an emphasis on the windows and lights. All questionnaires were returned to the experimenter in sealed envelopes and mailed directly to the Lawrence Berkeley National Laboratory team for analysis.

Illuminance and luminance data were also collected and averaged to give an overall session and spatial average for workplace illuminance, and adaptation and view luminance. Session averages were also computed for the outdoor horizontal global illuminance (which includes the sun contribution), the diffuse horizontal illuminance (which excludes the sun contribution), and the global vertical illuminance (including the sun contribution) on the west and south facades. Appendix C provides detailed information on monitored conditions during the tests. See related project reports for a full description of the The New York Times Daylighting mockup and instrumentation.

7.2. TYPES OF ANALYSIS

The questionnaire results provide a measure of whether the two automatic window shade control systems that were installed in the mockup provide an acceptable environment. The background and attitude data on the subjects provide information on how representative the study group is, and thus how well these results can be generalized from the study group to the New York Times' workforce as a whole. The attitude data also provides general data on the subject's perception of the relative importance of different environmental attributes. In addition, correlations between factors were examined to see if there are particular subgroups with different responses, or conditions that were particularly problematic. Correlations which appear causal are useful in extending the results to populations which are not identical to the study population. Correlations were examined to see if they were logically consistent, and thus an indication of cause and effect, or if they were ambiguous in interpretation. Ambiguities can occur if more than one variable is correlated to a result, and there is no clear a priori reason for one to be more probable than the other. For example, although the data was examined to see if there were differences in response between the north and south work-stations, these results should not be interpreted as implying differences in the shade systems. The two locations do not have the same views, so it is difficult to determine if differences in response are due to the shade system. A lesser problem with ambiguity arose with the examination of the results versus the illuminances and luminances. The physical data vary by date, and session, but the ages of the subjects and their use of time was also strongly correlated with the date, and thus there is an inherent ambiguity in the interpretation of the cause of variations found in the subjective responses by date. Multi-variate fits of the data suggest that both sets of factors are important in determining subject response.

7.3. RESULTS

7.3.1. Subject background data

The subject group was classified by gender, age, and by whether the subjects wore glasses at work. There were significantly (probability 4%) more men than women in the study group. The group was evenly divided by age and the use of glasses (Table 7-1).

Table 7-1
Background characteristics of study group

Characteristic	Fraction
Female	0.36
Male	0.64
40 and over	0.47
Under 40	0.53
No glasses	0.53
Glasses	0.47

All three of these factors correlate to some of the other factors in the study, and for age and gender the correlations appear as if they are causal. These correlations are described in conjunction with the description of the other variables.

7.3.2. Subject attitudes

Subjects were asked to rank the importance of ten environmental attributes in making a pleasant and productive office environment, rank their sensitivity to six environmental factors, and indicate their preferred light level. All the rankings were on a scale of 1 to 5, with 1 being unimportant, least sensitive or very low for the three types of questions respectively, and 5 being very important, very sensitive, or very bright.

The environmental attributes were generally all considered to be moderately important to very important, and every one of them had at least one person who gave it the maximum ranking. However, for some of the attributes, even the minimum score was moderately important (3) or above, while for the other attributes the minimum scores were lower. An analysis of variance (ANOVA) showed that there were statistically significant differences in the mean scores. An analysis of the differences (Tukey's multiple comparison test) showed that the ten attributes could be divided into seven overlapping groups. A given attribute will be a member of one or more groups. There is no statistically significant difference in the responses for attributes that are members of a given group. There is a statistically significant difference between attributes that do not share a group. Table 7-2 lists the ten attributes, their rated mean level of importance, the lowest rating given, and their group memberships.

Table 7-2
Perceived importance of environmental attributes to making a pleasant and productive environment

Attribute	Mean rating	Minimum	Group(s)
Good lighting	4.45	3.50	1
Temperature control	4.40	3.00	1,2
Comf. Ergo furniture	4.29	3.00	1,2
Good computer monitor	4.18	3.00	1,2,3
Windows	4.03	2.75	1,2,3
Attractive environment	3.96	2.00	2,3,4
Controllable light	3.80	2.00	3,4,5
Latest comp/ op. system	3.52	1.00	4,5,6
View	3.42	1.50	5,6,7
No noise	3.40	1.65	5,6,7

Of particular significance to The New York Times is the finding here that subjects rated a view as significantly less important than the mere presence of windows, or good lighting. The difference between the importance of good lighting and the importance of windows was not statistically significant in this study, however the trend found is nearly identical to what was found by LBNL in a related study on electrochromic windows [Clear et al. 2005]. When the data is combined, this difference is statistically significant.

The subject's perception of the importance of the different environmental attributes was not related to their age, or their use of glasses. Women rated attributes significantly (mean difference = 0.34) higher than men did, but the relative rankings of the different attributes was nearly the same for the two genders.

On average, subjects were moderately sensitive to sensitive to the environmental conditions, but individual responses varied over the entire range from 1 to 5 for all but glare. The least sensitive glare rating was 1.5. An ANOVA showed that there were statistically significant differences in sensitivities to the different factors, and Tukey's test showed that there were three overlapping groups for the six factors. Table 7-3 shows that glare and gloominess were the two most important factors in this group, while visual distractions were the least. However it was also found that women rated sensitivity to cold significantly higher than did men (4.4 versus 3.2). Sensitivity to cold would have ranked slightly above glare if there had been equal numbers of men and women in the two groups.

Table 7-3
Sensitivity to environmental factors

Factor	Mean rating	Group
Glare	3.8	1
Gloominess	3.7	1
Cold	3.6	1,2
Heat	3.6	1,2
Noise	3.3	1,2
Visual distractions	3.1	2,3

Preferred light levels ranged from 2 to 5, with an average of 3.4, which is slightly above moderate. The preferred levels were not correlated with any of the other subject background or attitude variables.

7.3.3. Illuminances and luminances

Luminance measurements were made at the north and south workstations adjacent to the west window wall. Global average (overall adaptation) luminance measurements were made for a subject facing the back wall, or the side wall (north in the north corner, and south in the south corner). The measurements were made by dividing the illuminance on a vertically oriented sensor by π. The result is the luminance of a field of view of constant luminance which yields the illuminance found.

View luminance measurements were made at the same locations as the global average luminances. Four view luminances were measured at each corner: one aimed at the back panel, one aimed at the desk below the back panel, one aimed at the side panel, and the last aimed at the desk below the side panel (Figure 7-1). The measurements were made by placing a cut-out mask in front of an illuminance sensor, and dividing the measured illuminance by the appropriate calibration factor to get the "average" luminance as described for the adaptation luminance (Figure 7-2).


Figure 7-1. Shielded sensors used to measure adaptation and view luminances in Area B (south area) of the mockup. These sensors were placed in the first workstation and were undisturbed by occupants during the subjective appraisals.

Figure 7-2. Detailed view of shielded sensors. The unshielded sensor in the left image is used to measure adaptation luminance. The sensors mounted behind the slotted opening (below unshielded sensor in the left image or lower sensor in the right image) measures view luminances.

Workplace illuminances were made at the top corner of the partitions for five workstations in each of the two Areas (shown in Figure 7-3 as sensors AId1-AId5 and BId1-BId5), plus the second workstation in from the window wall for the two center workstations (AId6, BId6).

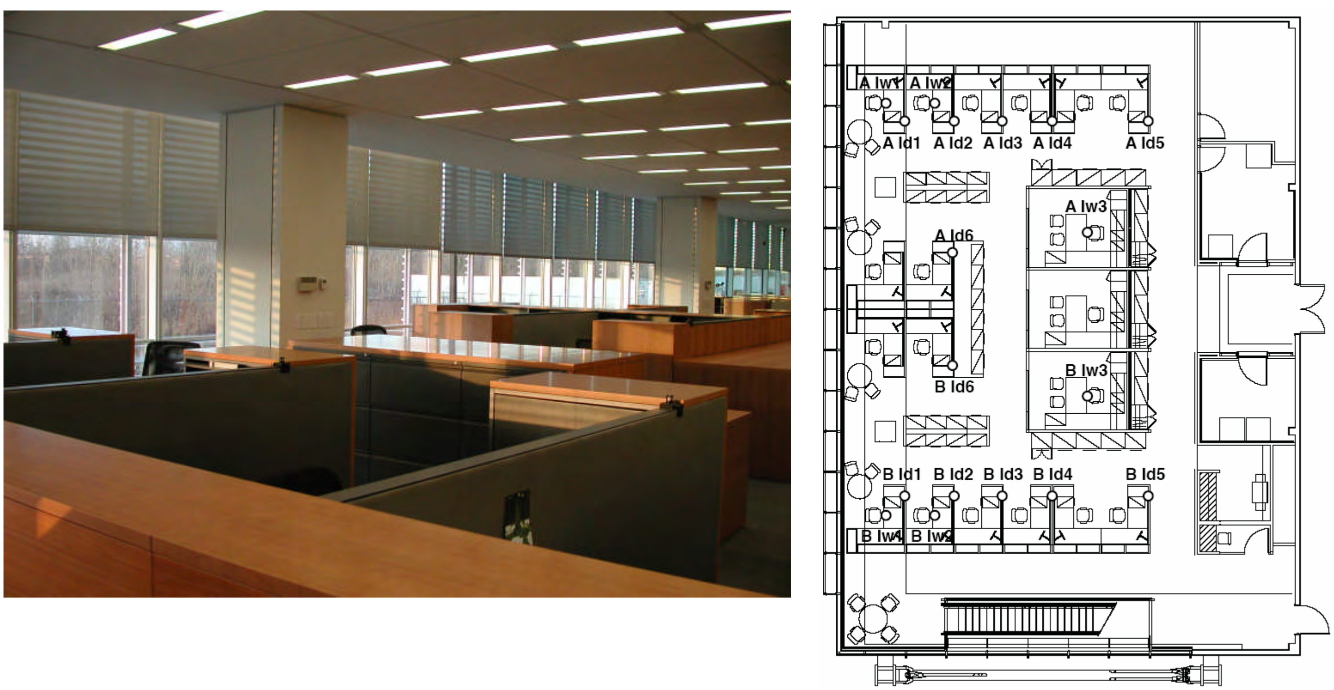


Figure 7-3. Detailed view of shielded sensors. The unshielded sensor in the left image is used to measure adaptation luminance. The sensors mounted behind the slotted opening (below unshielded sensor in the left image or lower sensor in the right image) measures view luminances.

Subjects recorded the time at which they started the experiment, and the times which they ended each session. The sensors described above, plus the outdoor sensors, recorded measurements once a minute. Averages were calculated for each session based on the approximate start and stop times for each group of subjects. The stop time for session 1 was used as an estimate for the start time of session 2. Start and stop times for the two sessions were on average approximately 12:00 to 14:30, and 14:30 to 16:30. Correlations between the four individual view luminances and two adaptation luminances averaged over 96% within the two groups. Correlations between the six illuminances were closer to 80%, but even this is still fairly high. Subjects were not constrained to a fixed view direction, but analysis showed that subject's subjective responses were not correlated to the fractions of time spentfacing the different view directions. The combination of this lack of effect and the high correlation between the values led us to simplify the analysis by averaging over the different orientations and locations. This results in a single average view luminance, global luminance, or illuminance, for each session and zone, or twenty-eight values each in total. Table 7-4 lists the averages and ranges over these 28 values, and over the 14 values for the outdoor illuminance measurements, which are independent of zone. There were no significant differences in average workplace illuminance or view luminance as a function of north/south location or session, although they was a marginally significant interaction between the two. Only the overall average for these variables are reported. There were significant differences by session and location for the global average luminances, and a significant difference by session (location is not a factor for the outdoor values) for the outdoor measurements. These results are reported in the appropriate detail.

Table 7-4
Illuminances (lux) and luminances (cd/m^2) during the experimental sessions

	Average	Minimum	Maximum
View luminance	230	30	850
Adaptation luminance	360		
North (session 1)	290	120	570
North (session 2)	210	90	560
South (session 1)	610	140	1600
South (session 2)	340	120	980
Workplace illuminance	780	190	2700
Outdoor illuminances: session 1			
Global illuminance	45,000	6,000	108,000
Diffuse illuminance	25,000	5,100	44,000
South vertical illuminance	24,000	2,500	72,000
West vertical illuminance	12,000	1,800	35,000
Outdoor illuminances: session 2			
Global illuminance	32,000	6,500	94,000
Diffuse illuminance	17,000	5,100	34,000
South vertical illuminance	22,000	2,500	61,000
West vertical illuminance	18,000	1,300	64,000

Examination of the physical data indicated that sky conditions ranged from a near clear condition on two days (maximum illuminances near 100,000 lux), to partly cloudy or overcast conditions on the other days. Luminances and illuminances average 1.5 to 2.5 times more than would be recommended in a non day-lit space, and are far more variable, especially in the south. Interestingly, there is a trend, just missing statistical significance, for people's judgments of the importance of a view to decline with increasing workplace illuminance.

7.3.4. Subject activity and orientation

Surprisingly, computer use was a distant fourth in terms of fraction of time spent on an activity. As shown in Table 7-5, the three major activities at over 20% each were meeting (including listening or talking), reading and handwriting. The “other” office category consisted of drawing, cutting and model building. Walking, touring, guiding and hand-holding were included in the tour/guide category.

Table 7-5
Subject use of time during the study period

Activity	Percent of study period (%)
Meeting	25.8
Reading	22.2
Writing (by hand)	22.1
Computer	11.6
Cell phone	7
Other office	5.3
Tour/guide	2.1
Unspecified	2.1
Eating	1.9

Subjects' use of time varied by age and gender, and was different for the different groups on different days. For example, formal meetings were confined to only 3 of the 7 days. A full 60% of subject's time was reported as meeting on the first test day (April 30). About 34% of subject's time was reported as talking or listening on September 15. The remaining days averaged about 10%, for both formal and informal meetings. Subjects under 40 averaged only 3% of their time on formal meetings, while older subjects averaged over 30% of their time on meetings. There may also be gender difference, but it was not quite statistically significant. The gender difference that was statistically significant was the time spent on writing by hand, with a mean percentage of 36% for women versus only 18% for men.

Subjects spent approximately one-third of their time facing each of the two desk orientations: east and north in zone A, and east and south in zone B. Approximately 23% of their time was spent facing the window wall, while only 9% of their time was spent facing the center (south from zone A, and north from zone B). Subjective responses to the space were not significantly correlated with the fraction of the time subjects spent facing any given direction.

7.3.5. Subjective responses: Overall level of response

Subjects answered the subjective response questions twice, once for each session. Table 7-6 below lists the average response (mean), the standard deviation (sigma) and the minimum and maximum (min and max) for each question. The table also lists the percentage of subjects who overrode the automatic blind control. The summary statistics for the separate sessions are listed below the question for those few questions where the difference between sessions was significant at the 5% level for a single comparison, however because there were 16 comparisons (one for each dependent variable) there is an 18% probability that there are two differences meeting the 5% single test criteria by chance. Four variables showed a difference that was significant at the 5% single test level. The difference in use of manual override is significant under a multiple comparison test. The difference in the annoyance level for dimming of electric lights is probably not real, and the other two “significant” differences should be considered as trends, and not established differences.

Table 7-6
Subjective responses to environment

	mean	sigma	min	max
Ratings: 3 is best, 1 & 5 are extremes				
Temperature	2.44	0.72	1	3.4
Light level at task	3.04	0.39	2	4.25
Rating: 5 is nicely distributed, 1 is poorly distributed				
Overall lighting distribution	3.77	0.85	1.5	5
Level of glare: 1 is not perceptible, 5 is intolerable				
From windows	2.53	0.95		
session 1	2.67	1.08	1	5
session 2	2.39	1.04	1	5
From electric lights	1.96	0.84	1	3.8
From bright vertical surfaces	2.01	0.86	1	4
Bright light on task makes it difficult to see: 1 is disagree, 5 is agree				
Computer	1.98	1.03	1	5
Other tasks	1.83	1.01	1	5
Lighting is comfortable: 1 is disagree, 5 is agree				
Comfortable lighting	4.06	0.93	1	5
Level of agreement: 1 is best, 5 is worst				
Gloomy room	1.7	0.91	1	4.5
Noisy shades	1.49	0.69	1	3.75
Shade operation was annoying	1.47	0.65	1	3.375
Light dimming was annoying	1.31	0.49		
session 1	1.21	0.38	1	2.35
session 2	1.4	0.73	1	4
Shades blocked view	2.29	1.13		
session 1	2.02	1.28	1	5
session 2	2.5	1.32	1	5
Satisfaction: 1 is very dissatisfied, 5 is very satisfied				
Overall satisfaction	4.06	0.63	1	5
Fraction				
Manual override of shade position?				
session 1	0.23	0.06		
session 2	0.37	0.07		

Single comparison significance level for session differences listed:	
Glare from windows:	1.60%
Light dimming was annoying	5%
Shades blocked view	1%
Manual override of shade position?	0.06%

The general level of response as indicated in Table 7-6 looks encouraging, although there are individuals who found one or more aspects of the lighting annoying, intolerable or very unsatisfactory. The average subject judged the light as being “just right”, glare as being between perceptible and acceptable, somewhat disagreed with the statement that bright lights made tasks difficult to see, or that the room was gloomy, or that the operation of the lights or shades was annoying or blocked the view, and finally judged the level of comfort as high and the lighting satisfactory. One discordant note in this general response was that a significant fraction of the subjects (about 30%) reported overriding the automatic shade algorithm. A second disturbing note is that one subject did not just slightly disagree with the generally rosy assessment of the space, but instead found the glare intolerable and the room uncomfortable, felt that the shades blocked the view, and was very dissatisfied with the lighting. Furthermore, examination of the variations in response, described below, suggest that there are some concerns that are not immediately obvious in the overall results given in Table 7-6.

7.3.6. Subjective responses: Correlations with other variables

An attempt was made to find first single variable fits, and then multi-variable fits of the dependent variables, described in the section above, against the independent variables, which were described earlier. Parameters included in the multi-variable fits were those that were significant at a 5% level, but because multiple fits were examined the fit as a whole was not judged wholly significant until it reached the 0.25% probability level. The adjustment to the lower probability compensates for the chance of spuriously getting what appears to be a significant fit if there are multiple chances to do the fit. Using the lower probability level decreases the chance of labeling a fit significant when it isn't, but increases the chance of ignoring fits which are real. We therefore examined the fits between the two probability levels for logical consistency and physical plausibility. Fits which fail these two tests were dropped from further consideration. Fits which are plausible but are above the 0.25% probability level should be considered as probable, but not proven. Fits below the 0.25% level are fairly secure.

Of the 16 dependent subjective response measures described above, 5 showed no statistically significant correlation at the 5% probability level to any of the summary luminances or illuminances, the date, or to the background or attitude responses. One of these response measures, overall satisfaction, being an overall measure, seemed logically to be potentially dependent upon the other response measures. It was found that it had a low, but significant correlation ($R^2 = 26\%$, $P < 0.01\%$) to the difficulty of seeing "other tasks" because of bright light on them. Not surprisingly, given the lack of correlation between overall satisfaction and the independent variables, the difficulty of seeing other tasks is also uncorrelated to the independent parameters. The other three parameters that share this lack of correlation were the lighting distribution, the glare from bright vertical surfaces, and the "comfort" of the lighting.

Of the remaining 11 parameters, another five of them fit with a probability between 0.25% and 5%. The least likely of these, the judgment of whether a room seemed gloomy, was only dependent on date, and had a single fit probability of 3.4%. A examination of the data showed that subjects rated June 11 as significantly more (1 step or more) gloomy than the other days, despite the fact that the various illuminances and luminances measured for that day were either near or above average. Given this lack of consistency it is likely that this fit is due to chance and is not causal.

The response as to whether the shades blocked the view also showed an inconsistent and unlikely pattern. In session 1, but not session 2, subjects without glasses had a higher level of agreement that the shades blocked the view. In session 2, but not session 1, subjects facing the south window wall were more likely to report that the shades blocked the view. These regressions too, are probably due to chance.

Of the remaining three tentative fits, two, the fit to whether bright light on the computer made it unreadable, and the fit to the glare rating from the electric lights, were primarily dependent on the workstation location. This is a plausible causal factor, but the fits need to be viewed with caution, given the small number of subjects at each workstation (range 1 to 7, average 4).

Table 7-7 gives the degree of fit (R^2) and the single fit significance level for the 9 dependent parameters that remained after the winnowing process above. The significant independent parameters and their values are listed below each dependent parameter, except for the one case when the parameter is just the date. In this case it appears that date is acting as a stand-in for subject variability, and has no intrinsic interest by itself. The date parameter is therefore listed without values. The fits are listed in order of their statistical significance level and the degree of fit, with the most significant fits first. All of the fits in the table are linear regressions of the parameters. Binary parameters, such as Female or Male, have a value of 1 if true, and 0 if false. Thus, for example, the mean temperature rating for a female subject for a June test with a self-reported sensitivity to heat of 3 is: $2.017 - 0.224 + 0.027 * 3^2 + 0.347 = 2.38$. All of the dependent variables, except for the ln(odds ratio) for manual override of the blinds, are for subjective ratings, and are therefore limited to the range of from 1 to 5. Two of the fits can give values below 1, but these should be interpreted as being equal to 1.

Table 7-7
Best fits to subjective response variables & override of blinds

Dependent/independent variable	R^2 or value	Significance level
Temperature	0.504	<.0001
Intercept	2.017	
Female	-0.224	
Male	0.224	
Sensitivity to heat (squared)	0.027	
April - June participants	0.347	
September participants	-0.347	
Glare from windows	0.363	<.0001
Intercept	1.815	
40 years old or over	0.284	
Under 40 years old	-0.284	
view luminance (see note)	0.0022	
date	N/A	

Table 7-7 (continued)
Best fits to subjective response variables & override of blinds

Dependent/independent variable	R^2 or value	Significance level
Manual override of shade position	0.331	<.0001
log (base e) odds ratio of no to yes		
% time other	-0.019	
40 years old or over	0.844	
Under 40 years old	-0.844	
Eglo	5.62E-05	
Operation of shades is annoying	0.277	<.0001
Intercept	1.942	
Female	0.279	
Male	-0.279	
North	-0.216	
South	0.216	
Ediff	-1.90E-05	
Dimming of lights was annoying	0.235	<.0001
Results for session 2 only, session 1 showed no significant correlations		
North	-0.246	
South	0.246	
Attractive environment	0.349	
Light level at task	0.167	0.0024
Intercept	3.903	
Preferred light level?	-0.251	
Bright light makes computer unreadable	0.3	0.0029
% time working on computer	0.012	
Workstation		
A1	2.16	
A2	1.98	
A3	1.28	
A4	2.69	
A5	1.62	
A6	2.65	
B1	2.08	
B2	1.18	
B3	2.22	
B4	1.31	
B5	no data	
B6	1.65	
SW Corner	3	

Table 7-7 (continued)
Best fits to subjective response variables & override of blinds

Dependent/independent variable	R^2 or value	Significance level
Shades are noisy	0.103	0.0194
North	1.27	
South	1.71	
Glare from electric lights	0.403	0.0274
Workstation		
A1	1.13	
A2	2.17	
A3	1.66	
A4	2.99	
A5	1.99	
A6	3	
B1	1.38	
B2	1.67	
B3	2.04	
B4	1.64	
B5	2	
B6	2.66	
SW Corner	1	

Essentially equivalent fits for glare from windows can be obtained by using global average luminance, or average window luminance, in place of view luminance with the glare rating = 1.895 + 0.228* (age) + 0.0012 * adaptation luminance, or glare rating = 1.901 + 0.278*(age) + 0.00069 * average window luminance.

7.4. DISCUSSION OF REGRESSION ANALYSIS

7.4.1. Temperature

The results in Tables 7-6 and 7-7 suggest that temperature needs to be controlled more carefully in the mock-up, and probably should be warmer. The overall mean level from Table 7-6 is closer to "just right" than it is to "too cold", but Table 7-7 shows that female subjects were colder than male subjects, and subjects in September were distinctly colder than those in the period from the end of April to June. The mean rating for a woman in September was below 1.9, which is closer to "too cold" than to "just right". The mean rating for men in the April to June period, which is the other extreme, is almost exactly "just right". Sixty percent of the difference between the two extremes was due to the change of season, which suggests that the heating/cooling system could be controlled more carefully.

7.4.2. Glare from windows

The values from Table 7-6 suggest that overall glare from the windows is under control, as the mean value 2.5, is below the value of 3, which was labeled acceptable. Table 7-7, however, suggests that for older subjects it will be possible for glare from the windows to rise to an uncomfortable level. The fits show that to maintain the glare rating to 3 or less, the view luminance for older subjects has to be kept under 410 cd/m^2, the average window luminance has to be kept below 1200 cd/m^2, and/or the global average luminance has to be kept under 740 cd/m^2. Maximum view luminances exceeded the view luminance limit for both sessions and for both north and south workstations. Maximum global average luminances and average window luminances exceeded the limit on the south end of the mock-up. The problem is less severe for the younger subjects, with the allowable luminances being 670 cd/m^2, 2000 cd/m^2, and 1110 cd/m^2, respectively. These allowances were exceeded by both the view and global average luminances at the south location during session 1, and the view luminance criteria was exceeded on the north end of the mockup during session 2. This limit was not exceeded by the average window luminance at any time. A limit of 2000 cd/m^2 window luminance was identified as a potential problem for discomfort glare by Daylight Glare Index calculations and luminance ratio calculations, which is consistent with the results above. Thus, it appears that particularly at the south end of the mockup, where there are windows on two sides, there was a potential glare problem at the time of the testing.

7.4.3. Manual override of shade position

This variable essentially measures how well the automatic system is controlling the shades. When the global outdoor illuminance level is high, the subjects almost always agree with the decision of the shade control algorithm. The fraction of subjects who pulled the blinds is estimated to drop by a factor of 300, as the outdoor illuminance level rises. The main disagreement occurs at the lowest illuminance levels, but there was not sufficient data to determine if the maximum might actually occur at an intermediate level. The type of disagreement was self recorded, and we have not attempted to determine whether subjects raised or lowered the blinds.

There is no obvious utility to knowing that subjects under 40 were more likely to override the automatic shade control. The propensity for subjects in meetings to override the controls suggests that it might be best to provide a meeting space that does not have significant visual access to windows.

7.4.4. Operation of shades is annoying

There was significantly more agreement with this statement by women on the south end of the mockup than by the average subject. However, at its worst, the predicted value was only 2.34, with a value of 1 = disagree, and 3 = somewhat agree. Thus there seems to be some room for improvement, especially in the corner area where there are shades on two sides, but it is a relatively low priority, as the level of agreement is low even at its worst.

7.4.5. Dimming of lights was annoying

The comments for variable are very similar to those above. Again, there is more of a problem on the south side of the mockup, but again the maximum predicted level of agreement that there is a problem, 1.99, is very low.

7.4.6. Light level at task

The only variable affecting the rating of the light level was individual preference. Since the mean rating was "just right" the only thing that can be done is to provide more individual control.

7.4.7. Bright light makes computer unreadable & Glare from electric lights

Subjects didn't tend to be concerned about computer readability unless they were spending significant amounts of time on the computer. This suggests that subjects who spend only a little time on the computer simply compensate for the glare, but that this tends to be an annoyance if subjects spend a lot of time on the computer.

Both questions show a correlation to the workstation location. Although this may be just a chance correlation, a plot of the data (Figure 7-4) shows what appears to be a distinct trend with distance along the west-east axis (distance from the west window). For the visibility on the computer, the trend is U-shaped, with the locations in the middle being the most readable. For glare from the electric lights, the trend is linear, and statistically significant, with the glare being worst at the east side (farthest from the window). Light levels near the window (west) are significantly higher than farther back (1100 lux versus 600 lux for the illuminance sensor for the first and sixth workstation illuminance sensors respectively). A tentative interpretation of the result is that higher adaptation luminances near the window reduce the level of glare from the electric lights, but can make the computer less readable for the first two workstations nearest the window. The level of glare from the electric lights reaches a rating of 3, which is still "acceptable". The difficulty of reading the computer reaches a level of 4 at the southwest corner table, but this should not be expected to be a normal workstation. It reaches a level of 3.5 on the North-East, which is higher than is desirable, and suggests that the electric lighting system was not optimal for computer use. These are both tentative conclusions, as the significance level of these results was marginal. Nonetheless, it may be advisable to consider the use of task lights with more aggressive dimming, a change in fixture choice, or possibly the addition of added fill light to reduce glare and improve readability.

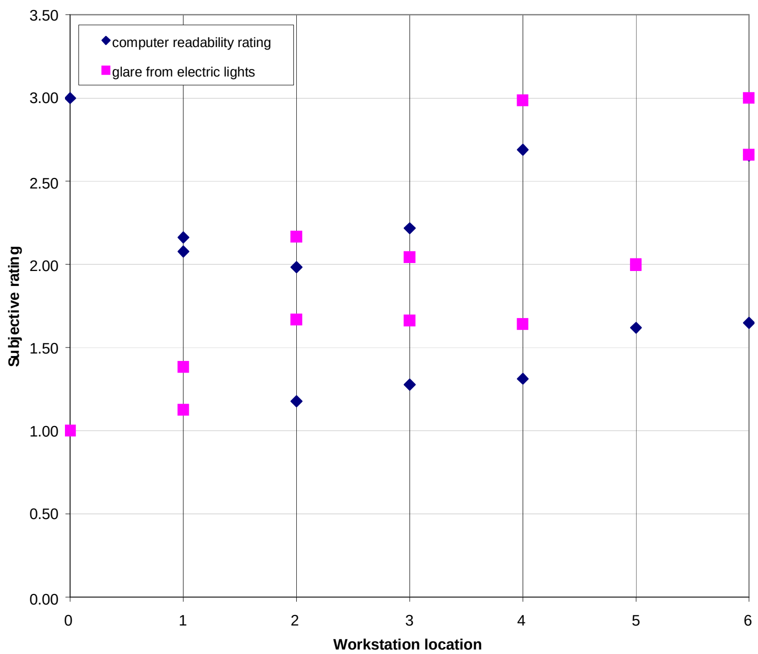


Figure 7-4. Rating versus nominal workstation distance from window.

7.4.8. Shades are noisy

As with several other of the variables a more negative response to shade operation is evident on the south edge of the mock-up where there are more shades. However, even on the south edge of the building, the level of agreement with this statement, 1.7, is closer to "disagree" than to "somewhat agree", so shade noise is not likely to be a major issue - at least as long as there is something else to complain about.

7.5. CONCLUSIONS

There were four significant findings of interest, three of them firm, and one of them more tentative. Glare from windows reached the "uncomfortable" level when luminances in the space became high. This apparently happened despite the operation of the shades. This is a firm finding. Automatic operation of the shades was overridden a significant fraction (30%) of the time. This was much more likely to occur at relatively low exterior light levels than at high exterior light levels. It was also far more likely to occur when people spent a significant fraction of their time in meetings, which suggests that meeting rooms should possibly be set aside away from the windows, or possibly on the north side. This is a firm finding. Subjects, especially women, and especially during September, rated the space as being too cold. The problem was much less during the summer, and for men. This is a firm finding. There was a distinct trend for increased glare from electric lights for work stations farthest from the west window. There was a noticeable increase in difficulty in reading computer screens adjacent to the window, and, consistent with the trend in glare from electric lighting, farthest from the window. The problem nearest the window is presumably due to glare from the windows themselves, while the problem in readability farthest from the windows is presumably due to glare from the electric lighting. Improvements in the electric lights may therefore be helpful. This is a tentative finding.

We want to reemphasize here that no firm conclusions are possible about differences between the two window shade systems. Subjects rated shade operation in the south zone as more annoying and noisier, and also were more annoyed by the electric light dimming, but conditions in the north and south zones were different, so the differences in the ratings may not be due to differences in the window shade systems. Conversely, the fact that no statistically significant difference was found in the perception of glare and visibility between the two zones does not mean that the window shade systems are equivalent in this respect.

Section 8
PROCUREMENT SPECIFICATIONS

8.1. LIGHTING CONTROLS SPECIFICATIONS

The lighting controls scope of work is based upon the philosophy that occupants of commercial office buildings prefer natural light to electric light. The lighting controls system specified by The New York Times for its new headquarters building is a DALI (Digital Addressable Lighting Interface) based system with dimmable fixtures throughout the interior space. This allows the system to dim down the electric lighting in response to daylight admittance. It also provides for variable target set points for illuminance levels at the work plane. The New York Times intends to establish and adjust target set points on a departmental basis. The lighting control sequences are described within the specification 16575. These sequences utilize occupancy sensors, photosensors, switches and a time clock to control the lighting in the interior space on each floor. The emergency lighting system is also described within the specification. The lighting control sequences are tied to Control Intent Diagrams that divide up the space on each floor into its various control zones. The overall intent is to provide electric light only when the space is occupied and to provide as little electric light as is necessary to achieve the target set point for the work plane in a given department. A department usually occupies multiple floors.

This specification has been made public in order to assist design professionals by providing an example of a daylight harvesting, fully dimmable lighting controls system that has been market tested. This specification combined with reflected ceiling plans, lighting fixture layouts and DALI ballast specifications was competitively bid and led to the award of the lighting controls system contract on October 4, 2004. The DALI ballasts (refer to specification 16510) were awarded as an integral part of the lighting controls contract.

The full specifications can be found in Appendix D. See updated versions of the specification on the website: http://windows.lbl.gov/comm_perf/newyorktimes.htm

8.2. ROLLER SHADES AND SHADE CONTROLS SYSTEM SPECIFICATIONS

The shades and shade controls scope of work is based upon the philosophy that occupants of commercial office buildings prefer natural light to electric light. The shade system goals for The New York Times Building are:

- Maximize natural light
- Maximize occupant connectivity with the outdoors, i.e. external views
- Intercept sunlight penetration so as to avoid direct solar radiation on the occupants
- Maintain a glare free environment
- Provide occupant manual override capability
- On any given façade the shades are as a general rule expected to be controlled together to the same bottom-of-hem height

The overall intent is to keep the shades up as much of the time as is possible without causing thermal or visual discomfort. Thermal comfort is assured by solar tracking and the geometry of the external sun screens. Visual comfort is assured by managing the luminance on the window wall. The manual override system has been specified based upon post occupancy evaluations of office building occupants with automated shade systems. The number one recorded complaint in these studies was the inability of an occupant to operate a shade or group of shades when necessary.

This performance specification has been made public in order to assist design professionals by providing an example of an automated shade system that has been market tested. This specification combined with reflected ceiling plans, furniture layouts, perimeter architectural typologies and details was competitively bid and led to the award of the shades and shade control system contract on September 30, 2004.

The full specifications can be found in Appendix E. See updated versions of the specification on the website: http://windows.lbl.gov/comm_perf/newyorktimes.htm

Section 9
ENGINEERING STUDIES USING RADIANCE

9.1. INTRODUCTION

Four types of engineering studies were conducted on The New York Times new headquarters building using the Radiance visualization tool (http://radsite.lbl.gov/radiance/framew.html). These studies were used to assist the selected manufacturers with the practical aspects of defining zones and sensor locations on shop drawings and selecting fabrics for various floors and façade orientations for engineering shop drawings that needed to be submitted to The Times in the first quarter of 2005. The data was also provided to help the manufacturers understand if their control systems would be reliable under the specific daylighting conditions within a complex urban environment. Images were also produced to help both The Times and the manufacturers understand the dynamics of the daylight within the space over different days throughout the year and on different floors of the building. The four studies consisted of:

1. Daylight illuminance distribution studies which included time-lapse images of the shade operations
2. Shadow studies of the exterior façade, including time-lapse images of each façade
3. Time-lapse visualizations of the interior from various viewpoints
4. Annualized analysis of window luminance and illuminance for the selection of shade fabrics

9.2. DAYLIGHT ILLUMINANCE DISTRIBUTION STUDY

Radiance images were provided to the building owner and shading and lighting manufacturers showing daylight illuminance levels for floors 26 and 6 under overcast sky and clear sky conditions on the solstice and equinox days (see examples in Figure 9-1 and 9-2 below). The primary purpose of these data was for the lighting manufacturer to determine the configuration of the daylighting control zones for The New York Times Headquarters building. These images can also be used by the shading manufacturer to visualize what the patterns of sunlight will be in the space for a specific control algorithm and grouping of shade zones. They may also help the building owner understand relative levels of interior daylight illuminance that may be expected over the course of the year.

The illuminance images are given from a floor plan view. Illuminance levels are given at the varying heights of the furniture or at floor level as seen from this plan view. The format of the images are iso-contour falsecolor images showing plan illuminances in lux on a log scale. All images are given with the same range of scale: 0-26,000 lux. The maximum value may exceed this range.

The average illuminance at each work station and the ceiling-mounted photosensor signals for various locations in the tower (for floors 26 and 6) were also computed for the lighting manufacturer. These data were to assist the lighting manufacturer in locating their photosensors.

Finally, to troubleshoot the automated shade control algorithm developed for the Radiance simulations, interior images of each façade on the 15th floor were generated. These images will help the building owner and shade manufacturer visualize the shade controls.

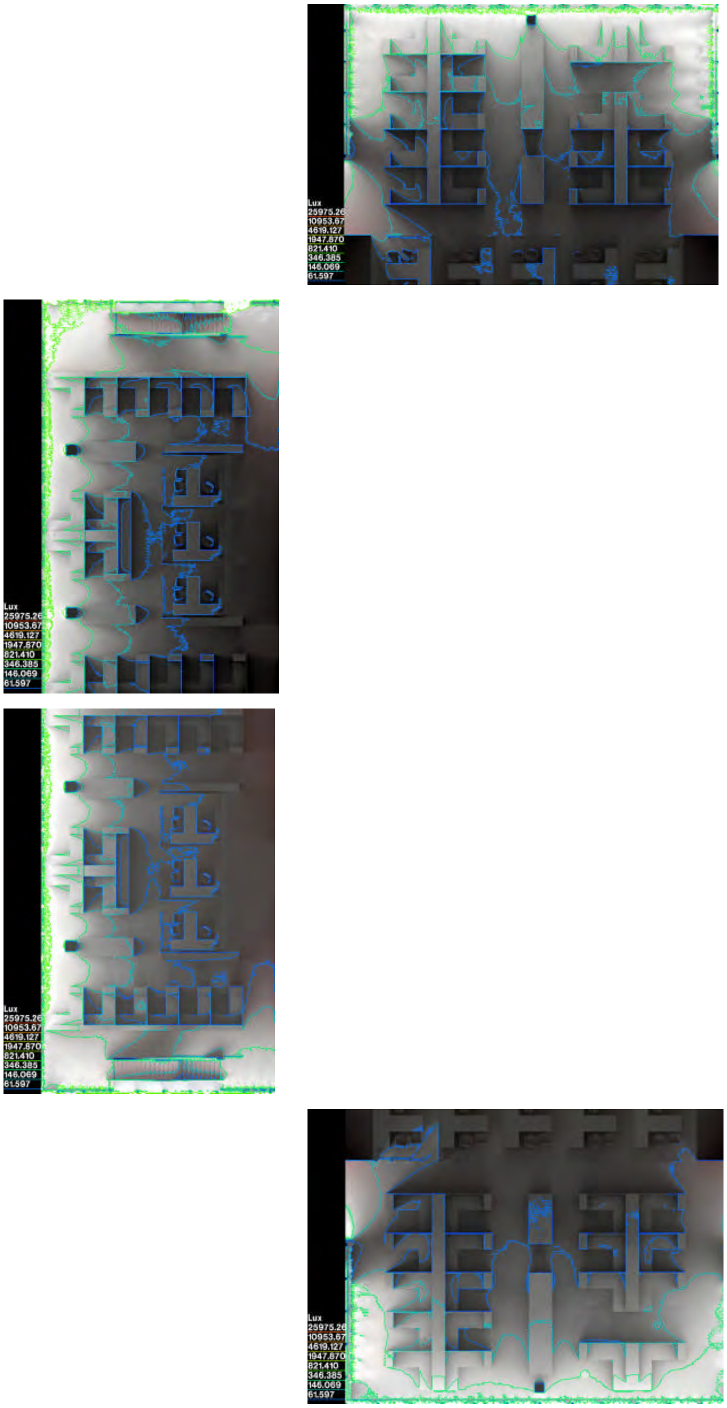


Figure 9-1. Isocontour image of the 6th floor on December 21 (CIE clear sky) at 10:00 with shade control algorithm “d”.

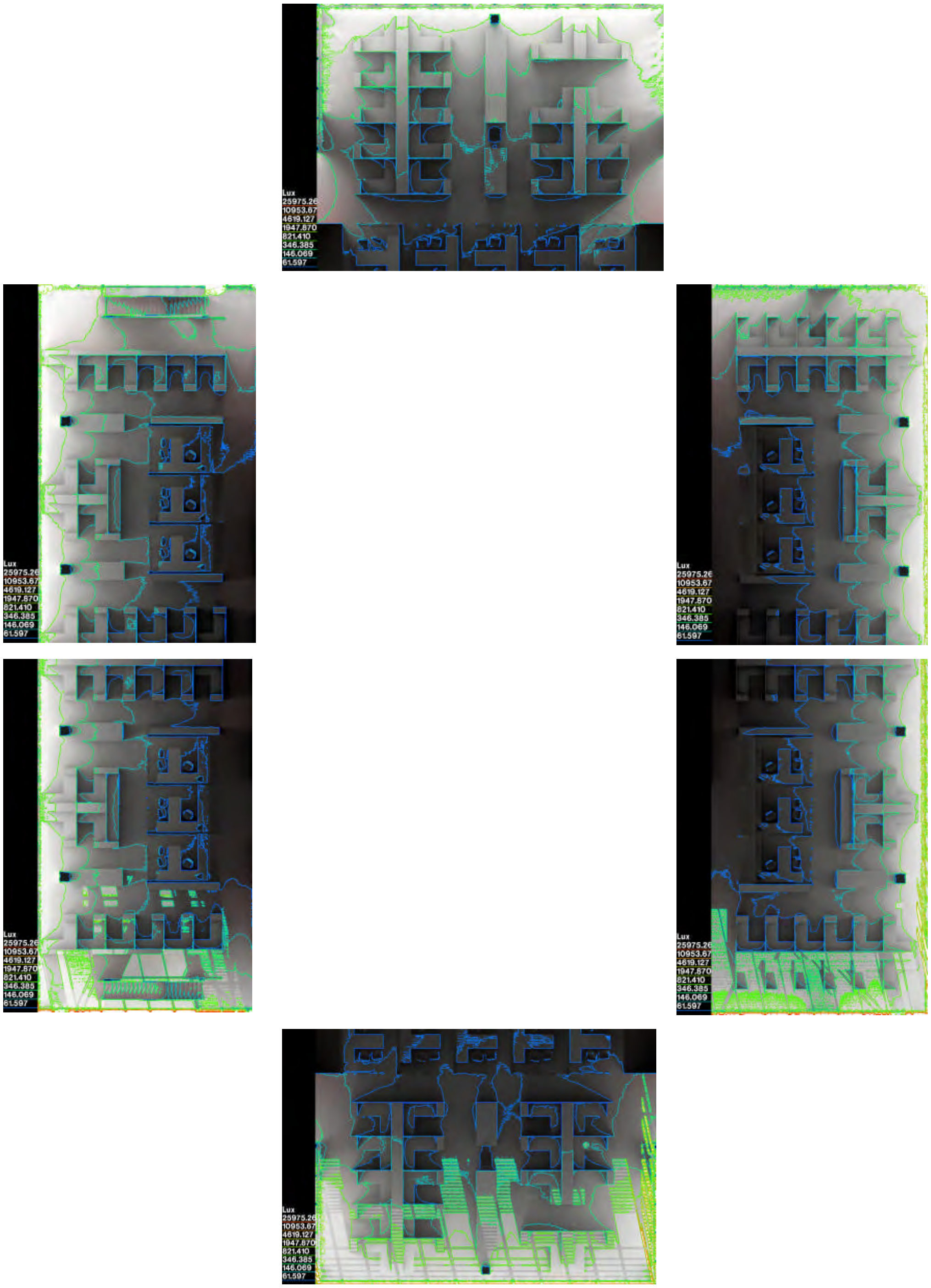


Figure 9-2. Isocontour image of the 26th floor on December 21 (CIE clear sky) at 13:00 with shade control algorithm “d”.

9.2.1. Radiance modeling assumptions and other relevant details

Floor numbers:

- Floor 26 (the highest floor level for The Times with typical layout).
- Floor 6 (the lowest floor level for The Times with typical layout).

Sky condition and month-day-time:

- CIE clear sky (table below) and CIE overcast sky.
- Renderings for Floor 6 and 26 include the dates and times marked in Table 9-1 below for the CIE clear sky condition. Designations for "c" and "d" are given for the control algorithm modeled and are explained below. For the overcast sky condition, daylight factors are provided and are applicable to any day or time of the year.

Table 9-1
Control algorithm for Radiance renderings

	CIE Clear Sky		
EST	June 21	Sept 21	Dec 21
5:00	d		
6:00	d		
7:00	d	c	
8:00	d	c	d
9:00	d	c	d
10:00	d	c	d
11:00	d	c	d
12:00	d	c	d
13:00	d	c	d
14:00	d	c	d
15:00	d	c	d
16:00	d	c	d
17:00	d	c	
18:00	d	c	
19:00	d		

Shade type:

- Mechoshade black/white 2% openness factor with white side in (#99745).

Shade preset heights:

- Shades at ceiling
- Shades to mid way of upper ceramic tubes
- Shades to top of vision window
- Shades to 1.2 m (4 ft) above floor
- Shades to bottom of vision window
- Shades to floor

For the stair condition:

- At the south and north facades with the stair, shades were modeled for the floor above and below with the same position as the simulated floor.

9.2.2. Shade control algorithm

For shade control algorithm "c", the shades were controlled so that direct sun penetration was no more than 0.91 m (3 ft) from all facades except for the facades immediately adjacent to the stairs. The stairs are located in the west wing on the north and south facades. Direct sun was allowed to penetrate 3.65 m (12 ft) from the window wall at these stairs. The shade control zones were "wrapped" at the corners of the west and east wings due to the unshaded 2.13-m (7-ft) glazed section along the east and west facades. For example, the shade control zone on the southwest corner of the west wing includes a 2.13 m (7 ft) unshaded window module on the west façade and a 3.81 m (12.5 ft) west-most section of windows on the south façade. The other three corners are symmetrical to this one. If the entire west façade (including the clear glazed section on the south and north ends) was controlled to 0.91 m (3 ft), then the shades would be down during some times of the year even though the majority of the west façade was already shaded by the ceramic tubes. With the definition of the corner zones, the shades lower to be the most protective considering the two elevations but the rest of the west and east facades are controlled according to the façade shaded by the ceramic tubes.

Shade control algorithm "d" was defined in the same way as "c" except that at the stairs, the depth of sun penetration was decreased to 0.91 m (3 ft) in the portions of the façade that were not immediately adjacent to the stairwell. The shades at the five window modules at the stairwell were controlled to allow 3.65 m (12 ft) depth of sun penetration. See Figure 9-3.

The equinox simulations use shade control algorithm "c" and the solstice simulations use algorithm "d". This was a correction/change to the control algorithm that Glenn Hughes at The Times had requested after the equinox simulations and photosensor ratio computations had already been completed. The equinox simulations were not recomputed due to computing/ time constraints and to keep the illuminance images consistent with the photosensor ratio computations. For the overcast sky condition, the shades were modeled as fully up.

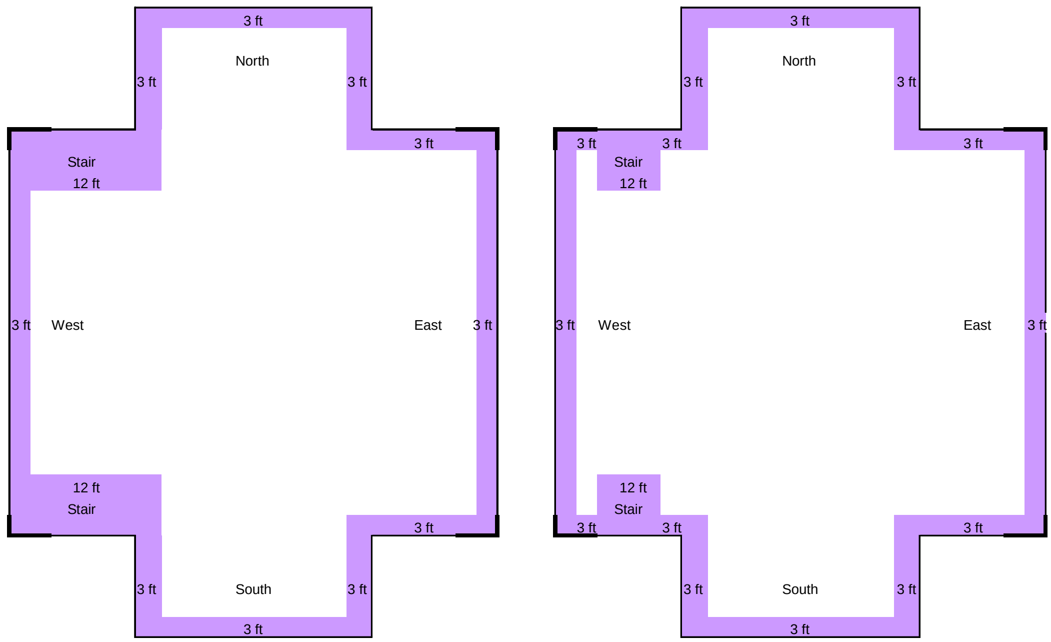


Figure 9-3. Diagram of tower floor plan showing allowable depth of direct sun penetration from the face of the façade for algorithms "c" (left) and "d" (right). The wrapped shade control zones are shown with heavy black lines.

A web-based image database (Figure 9-4) was created to check the shade operations for control algorithm "d" for each façade. This database can be found at the project website: http://windows.lbl.gov/comm_perf/newyorktimes.htm.

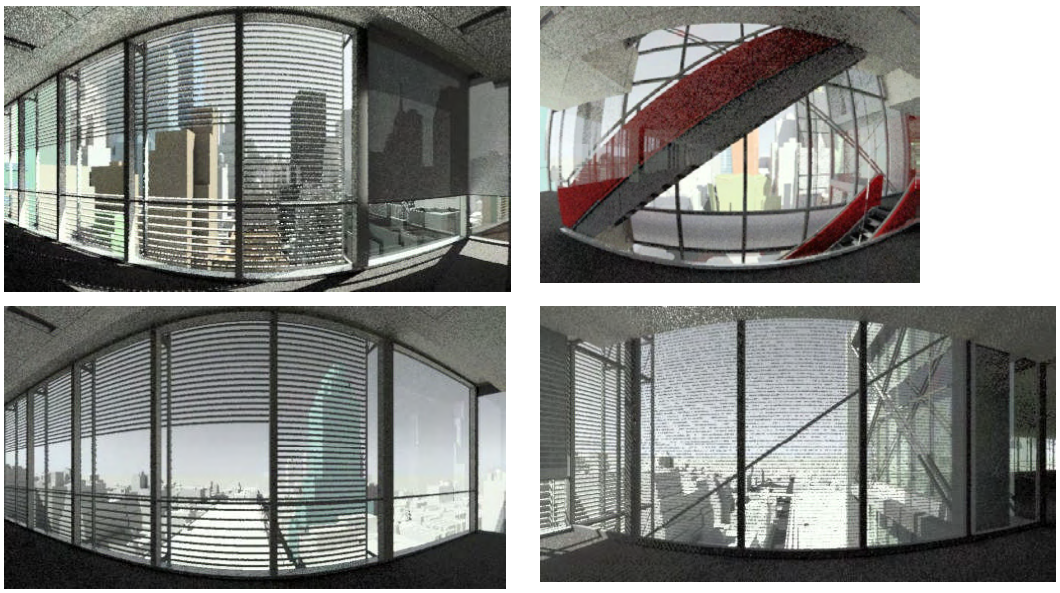


Figure 9-4. Time-lapse images for the fall equinox (September 21) were generated for each section of the façade at floor level 15. The above example images are given for 12:00 EST.

9.2.3. Some words on accuracy

The illuminance values should be taken as a rough guide. Though the relative distribution of illuminance in the space should correspond reasonably well with clear sky conditions for the corresponding date and time, the absolute level of daylight varies substantially from one day to the next. We did not calibrate these runs with New York weather data to establish an appropriate average external illuminance, and we expect the actual values to differ by a factor of two (if the value is 100 lux, then the values can be as much as 200 lux or little as 50 lux). Again, the distribution should not change very much with an absolute change in daylight level, so what is significant in these results is the relative pattern of illuminance.

Updates, modifications, and corrections to model and simulations since November 2004 (date of last set of transmitted images) were made. These included the following:

- The surface reflectances of the urban environment were modified. Previously the generic reflectances ranged as high as 50%. These reflectances were scaled down to a more reasonable, realistic 20%. Reflectances for individual known buildings were kept the same.

- The shade controls were updated. Previously the shades operated under control algorithm “b”, which had Mechoshade #99745 blocking direct sun so that the sun did not penetrate more than 0.91 m (3 ft) from the window wall at the floor level or 1.8 m (6 ft) from the window wall across the facades at the stairwells. There were no shades for the floors above and below the simulated floor. There were also no wrapped corner zones in algorithm “b” as occur in algorithms “c” and “d”. The current control algorithms are “c” and “d”, as explained above.
- The number of images rendered was increased. Previously submitted set of images included clear sky for Level 26 but not Level 6, and overcast/dayfactor images for Level 6. Current set of images includes clear sky for both levels along with overcast/dayfactor images for Level 26.
- In addition, more hours were rendered for June 21st and September 21st. June 21st previously included 7:00 to 17:00 hours. Now it includes 5:00 to 19:00 hours. September 21st previously included 7:00 to 17:00 hours. Now it includes 7:00 to 18:00 hours.
- The format of the images was changed. The previous set of clear sky images was rendered in falsecolor and the dayfactor images had iso-contour lines. The current set of images all use iso-contour lines.

9.2.4. Urban model

The New York Times Headquarters building is bound by 40th and 41st Streets and 8th and 7th Avenues. The urban model includes four blocks to the west, approximately 6 blocks to the north, two blocks to the east, and approximately eight blocks to the south. See Figure 9-5.

Materials of buildings in the surrounding blocks were assigned based on estimates using the photos provided by NYT. The blocks farther away and not shown on the photographs were given generic surface reflectances of 20%. Tall and notable buildings (such as the Empire State building) which could be visible or shade NYT were assigned approximate materials based upon photographs found from the internet.

The New York City urban model. The building site is here.

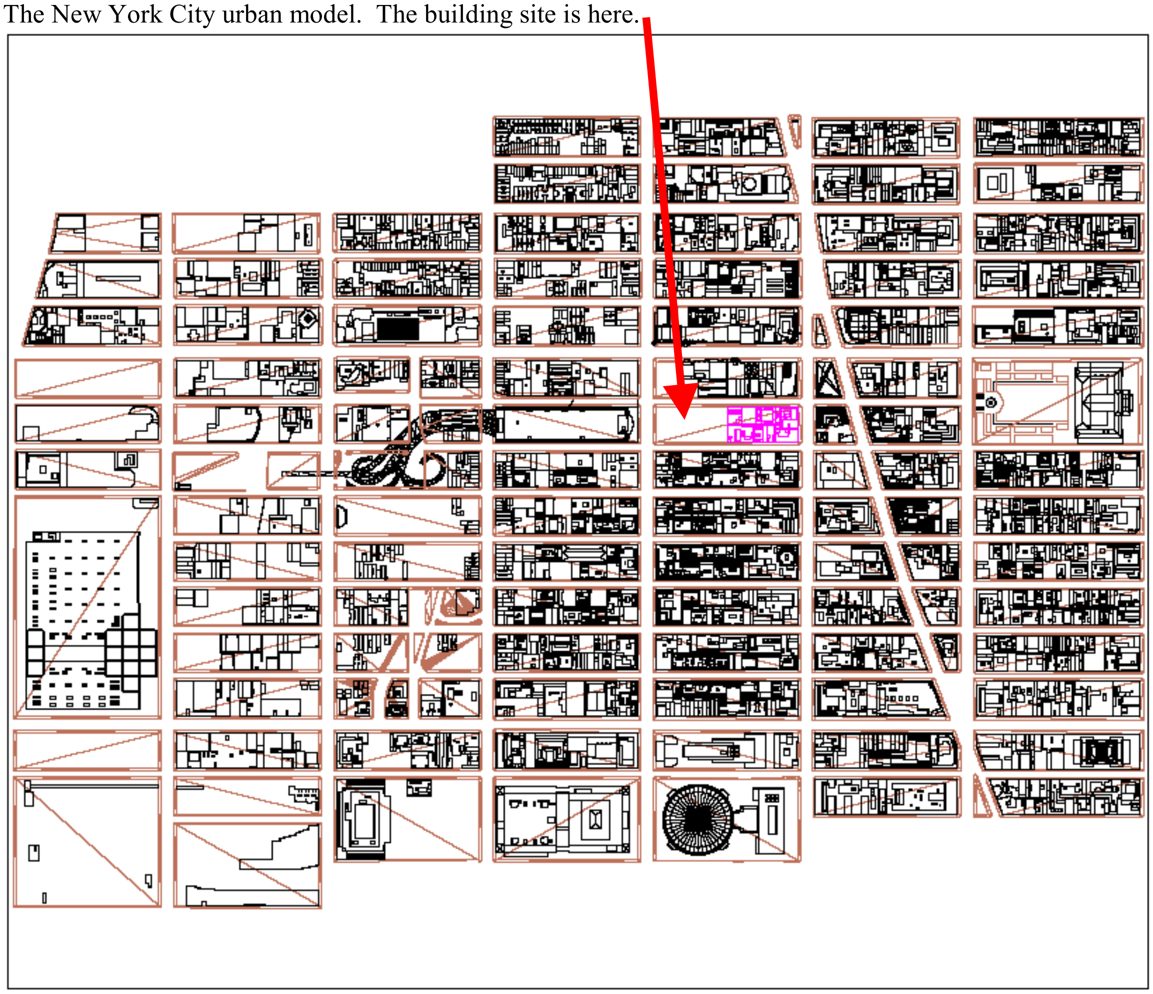


Figure 9-5. Map of the Radiance New York city urban model.

Images were transmitted via CDROM. The file name convention for the images and the location of the images are given in Appendix F.

9.2.5. Photosensor data

Photosensor data were generated for the same dates and times of the year and control algorithms given in Table 9-1. The manufacturer provided hemispherical spatial response characteristics for a ceiling-mounted photosensor. These data were used to modify the computed global illuminance data at selected locations on the ceiling (Figure 9-6). For example, if the photosensor shield design blocked light incoming from a specific area of its view, light from this area would not be included in the computed value. These data were used by the manufacturer to determine how well work plane illuminance levels correlated to planned photosensor locations. These data were transmitted directly to the manufacturer. The location of the numbered photosensors are given in Appendix B where the arrow is in the direction of highest sensitivity, not the location of the sensor (location is centered on the number).

9.2.6. Average work plane illuminance data

The average work plane illuminance was computed for each workstation in the tower floor plan. These averages were computed using 100 random points across each L-shaped work surface. These data were transmitted via CDROM as well. The location of the numbered workstations are given in Figure 9-7. Example illuminance data are given in Table 9-2 below.

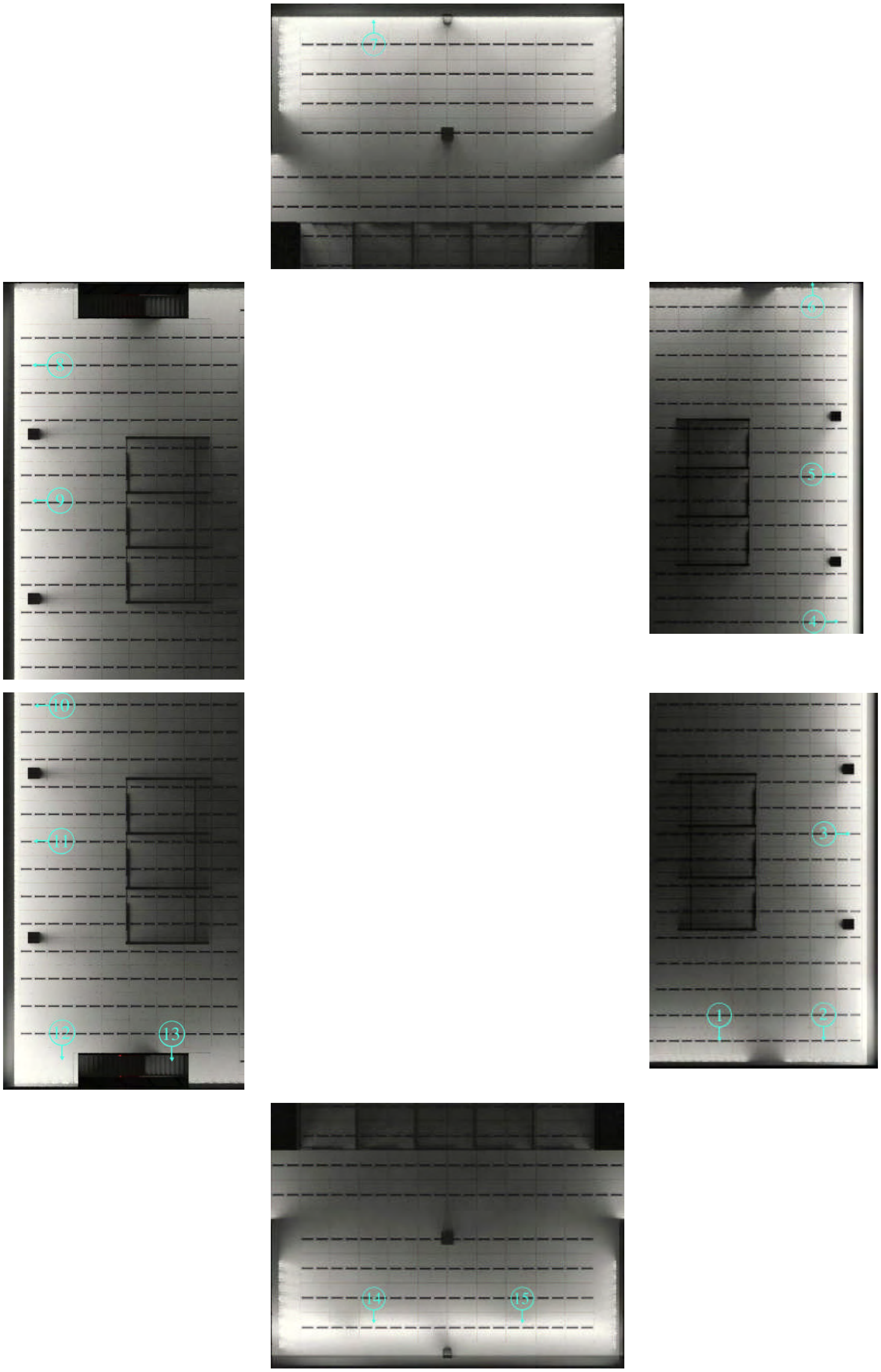


Figure 9-6. Location of ceiling-mounted photosensors The arrow is pointed toward the direction of greatest sensitivity and is not the location of the sensor (location is centered on the number).

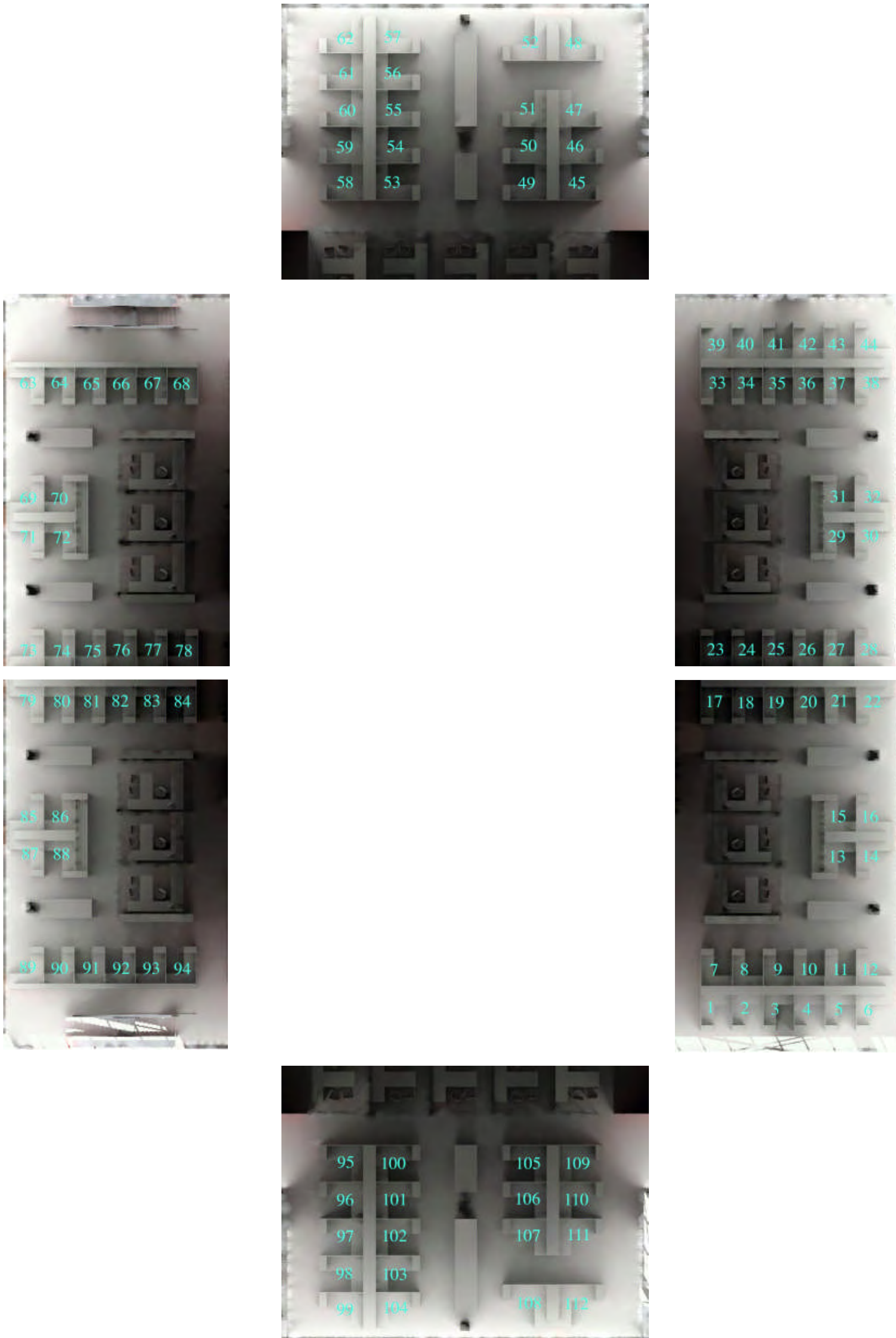


Figure 9-7. Location of numbered workstations.

Table 9-2
Average workplane illuminance on the 26th floor on December 21 from 8:00-17:00 under CIE clear sky conditions with control algorithm “d”. Data are given in lux.

Desk	I26_12-21@8d	I26_12-21@9d	I26_12-21@10d	I26_12-21@11d	I26_12-21@12d	I26_12-21@13d	I26_12-21@14d	I26_12-21@15d	I26_12-21@16d	I26_12-21@17d
1	117	146	255	414	450	426	283	160	126	93
2	109	136	247	398	403	379	317	155	119	86
3	89	113	189	360	359	296	259	140	99	64
4	107	147	225	338	438	408	312	176	125	81
5	161	247	397	406	459	527	441	266	189	133
6	288	570	766	785	772	645	635	451	314	223
7	54	62	70	75	80	81	77	65	57	43
8	56	65	73	77	83	85	108	69	59	44
9	58	71	76	78	89	89	105	76	59	43
10	72	100	98	98	119	115	128	100	74	50
11	123	177	268	169	206	184	249	175	128	78
12	284	466	482	495	450	477	674	495	339	184
13	113	147	234	136	198	168	200	154	106	74
14	293	488	557	423	396	451	598	439	293	177
15	120	153	184	137	208	170	193	157	108	73
16	316	473	467	367	412	460	594	472	309	181
17	39	39	39	38	42	42	47	44	37	37
18	42	44	44	42	48	50	55	52	40	37
19	50	55	55	52	64	66	71	63	46	38
20	69	85	78	73	102	101	103	87	62	44
21	116	144	215	130	193	166	198	158	104	69
22	315	484	528	433	390	436	572	440	289	172
23	39	39	39	38	41	42	45	42	37	37
24	43	45	46	44	48	50	55	51	41	38
25	51	56	57	54	64	67	74	80	46	38
26	71	85	79	75	103	99	106	98	62	45
27	124	153	189	138	205	170	201	167	110	73
28	343	492	511	437	430	495	655	524	324	190
29	121	148	241	133	200	174	221	181	109	72
30	319	498	541	425	391	447	598	464	292	174
31	125	156	192	142	216	180	232	314	115	72
32	314	469	452	386	402	450	641	574	293	167
33	57	71	74	84	99	100	103	88	55	39
34	61	76	79	89	105	107	112	98	58	41
35	65	81	87	94	118	120	131	109	61	42
36	82	104	107	111	153	149	169	142	76	49
37	132	165	264	165	231	206	295	256	126	76
38	342	547	614	526	445	486	715	614	318	179
39	131	199	222	265	303	315	313	267	124	74
40	127	176	180	206	237	243	244	219	115	71
41	100	144	158	184	225	232	247	213	91	57
42	124	181	220	254	330	338	371	319	122	68
43	193	267	340	328	441	417	508	451	194	100
44	348	525	535	475	697	646	927	872	380	184
45	53	62	79	94	105	105	103	83	55	38
46	62	71	181	161	182	189	181	138	70	42
47	131	164	363	337	373	377	366	290	150	76
48	375	491	574	639	682	683	660	569	340	191
49	46	54	70	82	88	89	86	71	50	39
50	55	66	90	108	119	120	116	92	60	41
51	115	152	181	214	238	235	231	186	119	68
52	345	465	502	575	620	618	595	502	326	181
53	42	52	65	75	79	78	74	62	49	37
54	50	64	83	97	105	102	95	78	58	40
55	70	91	124	146	159	155	144	116	80	51
56	123	161	214	248	273	269	252	206	132	85
57	350	441	553	628	683	677	646	538	358	211
58	54	68	84	97	101	98	106	71	56	41
59	71	90	115	132	143	138	135	99	72	48
60	126	165	212	243	259	247	220	178	123	75
61	185	237	311	356	380	370	334	272	186	109
62	361	464	583	653	701	685	644	538	370	213

Table 9-2 (continued)

Desk	I26_12-21@8d	I26_12-21@9d	I26_12-21@10d	I26_12-21@11d	I26_12-21@12d	I26_12-21@13d	I26_12-21@14d	I26_12-21@15d	I26_12-21@16d	I26_12-21@17d
63	376	473	593	665	742	725	720	268	274	271
64	136	181	246	289	315	294	274	134	125	100
65	83	113	155	183	187	177	169	91	83	63
66	66	87	115	134	136	131	269	77	67	53
67	62	77	100	114	121	115	522	80	65	48
68	58	70	93	108	116	112	640	81	64	44
69	378	473	571	635	675	639	616	275	275	235
70	131	171	225	258	272	247	225	123	120	91
71	374	470	570	647	685	683	685	267	272	272
72	129	167	219	253	265	252	237	117	117	97
73	394	487	585	657	673	654	627	286	288	252
74	128	165	218	252	258	237	217	117	116	90
75	70	92	122	137	136	124	111	65	65	52
76	53	68	85	92	90	82	75	48	47	41
77	44	55	64	68	66	61	58	39	39	37
78	39	48	54	55	54	52	55	37	37	36
79	377	471	569	644	676	676	680	268	273	274
80	125	162	212	248	254	242	228	115	116	96
81	69	91	120	135	135	126	116	64	66	55
82	53	67	84	91	89	83	79	48	48	45
83	45	56	65	69	68	64	61	40	40	39
84	40	49	55	57	55	53	55	37	38	36
85	384	480	581	647	666	648	626	277	278	244
86	127	164	218	248	250	234	217	117	117	90
87	383	479	580	651	684	695	712	278	281	282
88	126	164	216	242	246	238	234	118	118	96
89	399	484	572	654	683	674	660	313	303	249
90	140	179	235	253	287	308	260	147	136	98
91	88	118	161	149	164	167	170	108	91	68
92	70	90	121	109	128	122	121	91	79	58
93	64	83	112	88	98	124	123	93	76	53
94	66	85	116	80	91	101	139	94	77	55
95	53	66	78	74	81	82	85	64	55	45
96	72	91	114	121	137	145	149	83	71	62
97	127	166	210	229	262	267	313	128	111	94
98	176	226	285	331	477	487	450	216	182	135
99	281	346	440	566	768	1004	963	592	384	318
100	42	51	57	59	63	63	63	53	48	39
101	51	61	71	77	83	83	82	70	59	44
102	67	82	100	113	128	125	156	98	81	57
103	107	130	160	254	340	336	303	176	141	92
104	260	317	469	634	809	972	905	513	351	263
105	48	56	61	64	67	69	70	58	52	42
106	55	68	72	76	82	84	86	75	61	46
107	101	121	136	155	166	224	312	197	119	102
108	250	307	397	507	583	763	827	552	338	281
109	52	62	137	86	79	78	81	68	58	41
110	64	165	261	100	123	150	130	107	79	48
111	115	234	346	180	244	251	434	268	152	99
112	267	375	474	597	730	825	887	546	349	248

9.3. RADIANCE SHADOW STUDY

A shadow study was conducted to determine the pattern of shadows from urban obstructions on:

- exterior tower façades in elevation
- podium courtyard facades in elevation
- podium in plan view

9.3.1. What the views show

The tower façade images show the exterior in elevation from in front of the ceramic tubes and do not intersect any part of the building complex. Buildings to the sides and beyond the New York Times block have been clipped out of view.

The podium courtyard images show the four courtyard façades in elevation from finished floor 1 to finished floor 4.

The podium in plan view has a blue square representing the courtyard ground and a green rectangle in place of the skylight glass.

Hourly images from 7:00 to 21:00 EST for the 21st day of every month has been rendered. Reference grid lines have been omitted from the individual renderings because of time constraints. For the tower, each façade has a corresponding gridline overlay image drawings (refer to drawings A-3001 through A-3004) and for the courtyard there is one gridline overlay image (courtyard is square, refer to drawing A-3231).

9.3.2. Radiance modeling details

The 3D model of the New York Times building complex was taken from the AutoCAD drawing file *3d typology dia.dwg* supplied through The Times via the project architect. The 3D model of New York City was supplied by EarthData Solutions LLC. The two models were combined to form the model for this shadow study (Figure 9-8). The images were saved in directories named tower, courtyard, and podium. The tower and courtyard directories each have four subdirectories for the façade orientations.

The naming convention for the images is as follows:
dayMM-DD-HH_[tower|court|pod]_orientation.jpg
MM-DD-HH being month-day-hour designations for the image.

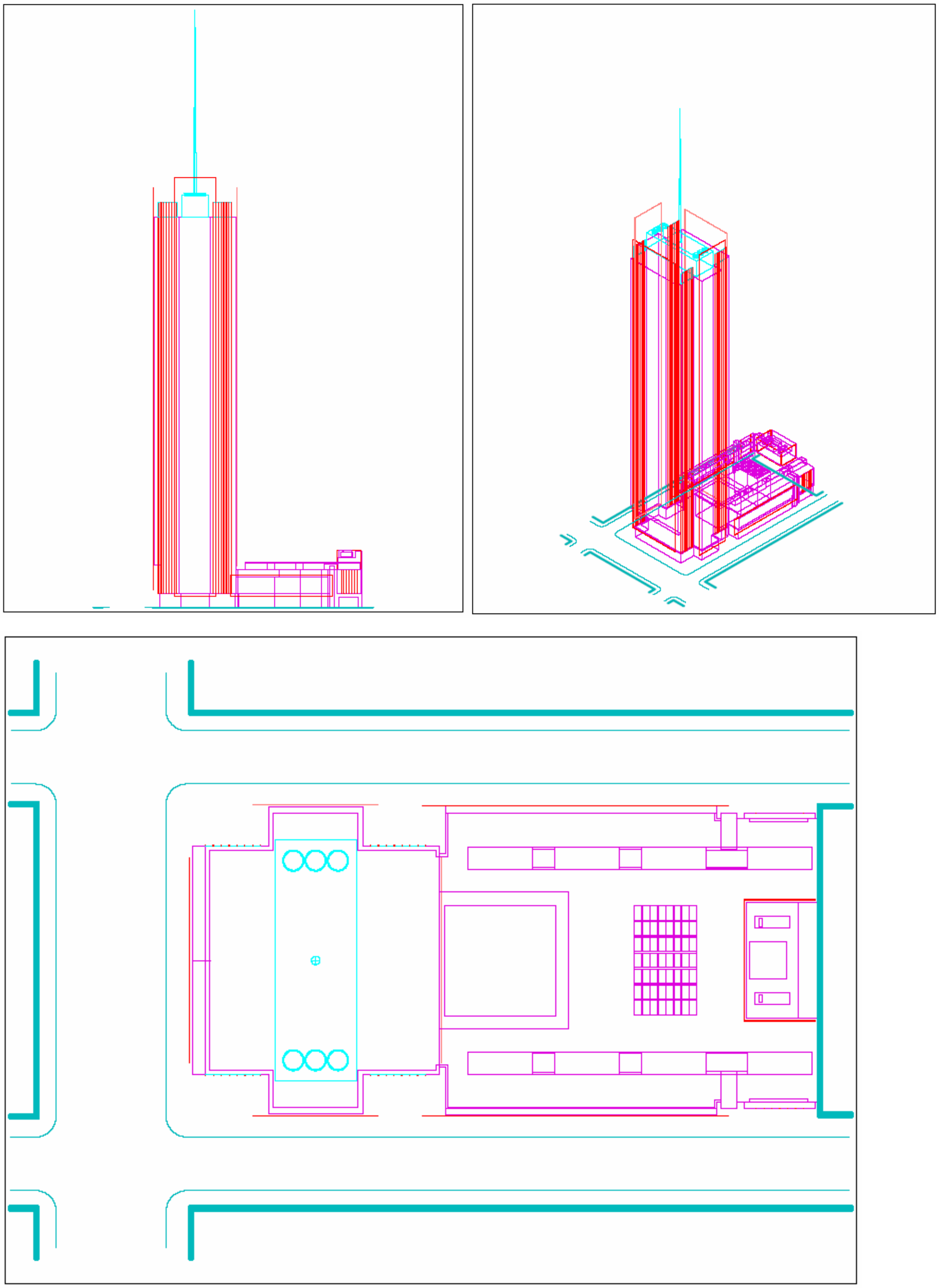


Figure 9-8. The New York Times tower (top) and podium (bottom) model from 3d typology drawing.

9.3.3. How to read the images

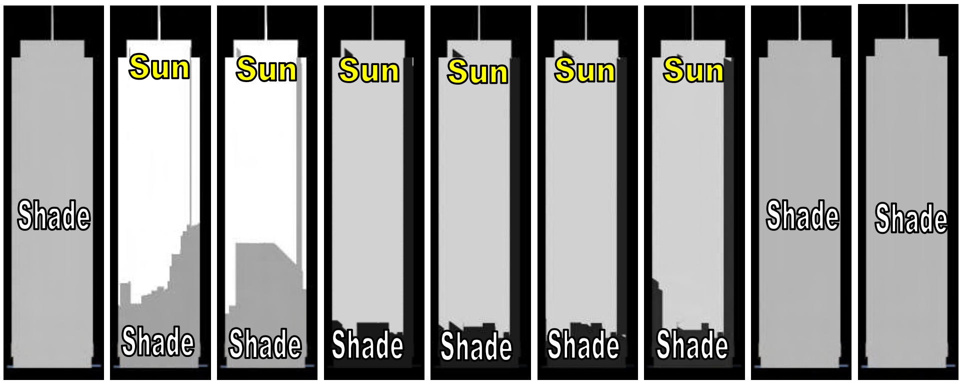


Figure 9-9. January 21st east façade, 7:00 through 15:00.

Note that the light gray can mean either sun or shade depending on the image.

- In images with white and light gray, light gray means shade.
- In images with two tones of gray, the lighter gray means sun.
- In images with only light gray, light gray means shade.

This variance is due to the availability and intensity of daylight throughout the times of day. The first image above shows full shade because it is too early. The next six images show the façade to be in partial sun but the second and third images show the sunny areas to be whiter because those are times of relatively stronger sun as compared to the next four images (the sun is hitting the building at an almost normal angle compared to more and more oblique angles). The last two images return to full shade because the east façade does not receive sun at those times. Note also that there is never a case of full sun on any tower façade at any time of day since the building complex sits within an urban environment.

Figure 9-10. January 21st interior courtyard south elevation, 7:00 through 15:00 hour.

The above courtyard images have been rendered in the same way as the tower images. The first four images show the façade to be in full shade. The next four images show the courtyard façade in partial sun and with varying contrast depending on sun angle. The last image returns to full shade.
Note that there is ONE case of full sun in the courtyard, happening on July 21st at 10:00 on the east façade. The sun at this time is perpendicular to the east facade and high enough in the sky that no obstructions are able to shade it. As a visualization, the façade at this time has been rendered as a uniform light gray.

Figure 9-11. January 21st podium plan view, 7:00 through 15:00 hour.

The podium plan images look at the courtyard and skylight. In the examples above, the first three show the podium to be in full shade while the rest receive varying degrees of sun.

Table 9-3 shows the hours when a tower façade is fully shaded across the full Times-occupied floors (floor 27 and below) and when tubes (ceramic screen) shades the full façade (cut-off angle of 65°). Table 9-4 summarizes the shade conditions for the podium skylight.

Table 9-3
Hours when tower façade is fully shaded

East Façade **Hour**

date	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1.21						T	T								
2.21						T	T								
3.21						T	T								
4.21					T	T									
5.21					T	T									
6.21					T	T									
7.21					T	T									
8.21						T									
9.21						T	T								
10.21							T								
11.21							T								
12.21							T								

South Façade **Hour**

date	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1.21															
2.21		T													
3.21			T	T											
4.21				T	T	T									
5.21				T	T	T	T								
6.21					T	T	T								
7.21					T	T	T								
8.21				T	T	T									
9.21			T	T											
10.21		T													
11.21															
12.21															

West Façade **Hour**

date	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1.21								T							
2.21								T							
3.21								T							
4.21							T	T							
5.21							T	T							
6.21							T	T							
7.21							T	T							
8.21							T	T							
9.21								T							
10.21								T							
11.21								T							
12.21								T							

North Façade **Hour**

date	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1.21															
2.21		T													
3.21		T													
4.21			T												
5.21			T												
6.21			T	T											
7.21			T												
8.21			T												
9.21		T													
10.21															
11.21															
12.21															

Shaded boxes = Façade receives sun
T= tubes casting shadow onto façade

Table 9-4
Hours when direct sun is incident on part or all of the podium skylight

	7	8	9	10	11	12	13	14	15	16	17	18	19	20
jan					sun									
feb				sun	sun	sun	sun	sun	sun					
mar			sun	sun	sun	sun	sun	sun	sun	sun	sun			
apr			sun	sun	sun	sun	sun	sun	sun	sun	sun			
may			sun	sun	sun	sun	sun	sun	sun	sun	sun			
jun				sun	sun	sun	sun	sun	sun	sun	sun			
jul				sun	sun	sun	sun	sun	sun	sun	sun			
aug			sun	sun	sun	sun	sun	sun	sun	sun	sun	sun		
sep			sun	sun	sun	sun	sun	sun	sun					
oct				sun	sun	sun	sun	sun	sun					
nov				sun	sun	sun								
dec					sun									

9.4. TIME-LAPSE VISUALIZATIONS

A web page was created that links to 23 QuickTime movies corresponding to 6 plan views and 17 perspectives of the New York Times tower building, with split views showing the 6th and 26th floors, simultaneously. These images provides one with an understanding of the lighting quality, direct sun control, window brightness, and illuminance distribution throughout the space resulting from daylight as managed by the automated shades. The time-lapse movies can be found at the project website: http://windows.lbl.gov/comm_perf/newyorktimes.htm.

Each animation runs through a timelapse daylight simulation of the Summer solstice, Fall equinox, and Winter solstice (6/21, 9/21, and 12/21) at hourly intervals. Images and illuminance values were generated using Radiance. Shades were controlled to prevent direct solar from penetrating more than 0.91 m (3 ft) from the window wall at any point except the north and south stairwells, where direct solar was allowed 3.65 m (12 ft) penetration. (This algorithm was modified slightly between the equinox and solstice runs, such that the equinox animations also permitted 3.65 m (12 ft) penetration at the windows adjacent to the stairwell. This made little actual difference to the results, so the equinox runs were not recomputed after the change.) One clicks on a view to see the corresponding time-lapse animation.

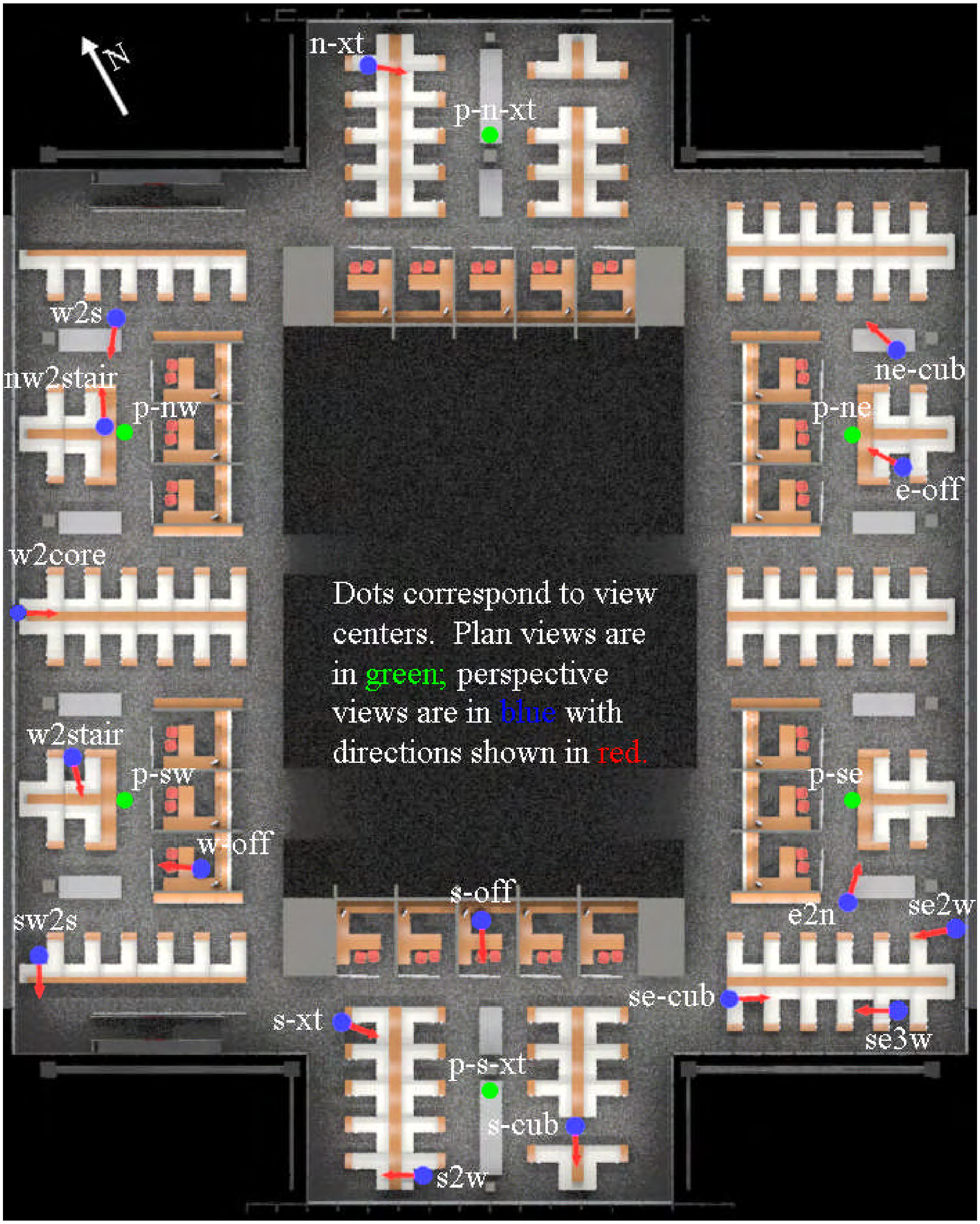


Figure 9-12. Location of view points.

9.5. ANNUALIZED ANALYSIS

9.5.1. Method

9.5.1.1. Daylight

The quantity and character of daylight is subject to regular daily and seasonal patterns of variation together with irregular meteorological events. Conditions may be overcast or clear, or some intermediate of the two. The luminance of the sky and sun varies continuously depending on the instantaneous meteorological conditions. The pattern of luminance of the sky vault is dependent on the degree of cloud cover and the time of day. Actually occurring sky luminance patterns often possess random features due to clouds. These features cannot, in general, be accounted for because of their random nature. However, the prevailing patterns of luminance across the sky vault can be reproduced fairly accurately using sky models. A sky model generates a pattern of brightness across the sky vault based on a measurement of the total horizontal illuminance due to the sky. There are sky models for overcast, intermediate and clear sky conditions. Good agreement between modelled and measured luminance patterns has been demonstrated. See Figure 9-13 below for a comparison of a measured and a modelled sky luminance pattern (clear sky conditions).

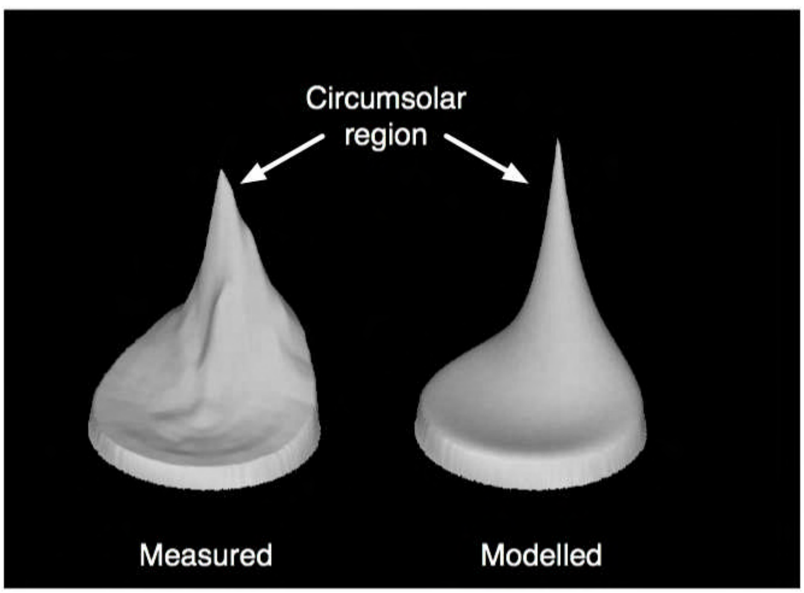


Figure 9-13. Measured versus modeled clear sky luminance pattern.

9.5.1.2. Climate-based analysis

The visual environment inside The Times building will depend on the instantaneous external conditions, e.g. clear, overcast, bright, dull, etc. A period of a full year at short time-step is needed to capture in the simulation the full range of both short-term and long-term (i.e. seasonal) variations in the sky and sun conditions. Consideration of any period shorter than a full year would select only some of the possible range in sky and sun conditions, and introduce unpredictable biases into the analysis. Furthermore, it is not possible to make meaningful daily or monthly averages of daylight quantities because they typically exhibit large changes in direction and magnitude throughout the course of the day.

Thus the analysis for The Times building was founded on hourly climate data for a full year. The TMY2 (Typical Meteorological Year) data file for New York City (TMY 94728) was identified as the most suitable of the available New York climate datasets for the location of the NYT building. The TMY2 climate file contains a record of the variation in climate that was measured at the location. For example, steady clear (or overcast) sky conditions maintained for several days. The pattern of hourly values in a climate file is unique and, because of the random nature of weather, it will never be repeated in precisely that way. However, climate files are representative of the prevailing conditions at the site, and they do exhibit the full range in variation that typically occurs. Diffuse horizontal and direct normal irradiation data from the TMY2 climate file for New York are shown below (Figure 9-14). These data were used to generate the hour-by-hour sky and sun conditions for the analysis. The hourly data was interpolated to give values every 15 minutes, and the instantaneous sun/circumsolar position was based on a 7.5 degree grid for the sky vault. This gives a better representation of the continuous movement of the sun across the sky vault than hourly values which result in a 15 degree movement of the sun at each (hour) time-step.

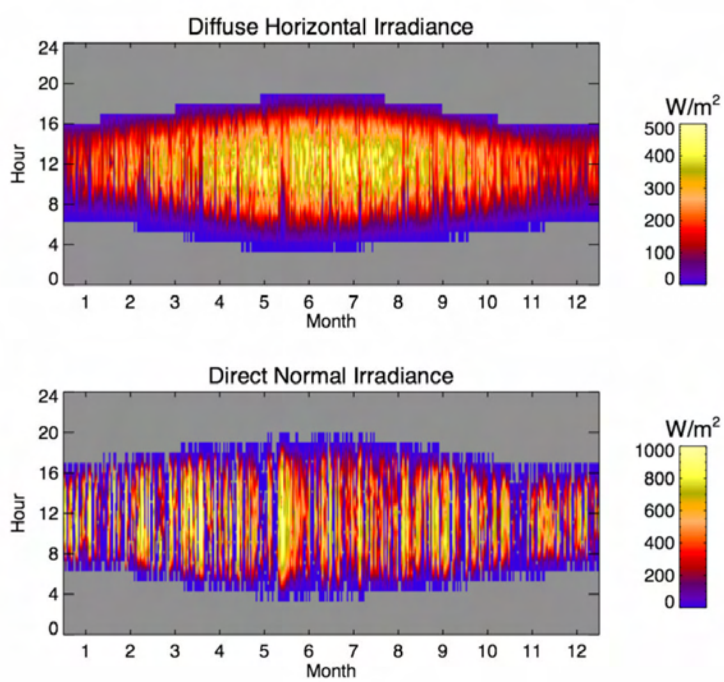


Figure 9-14. Irradiation data for New York City (TMY 94728)

9.5.1.3. Generate hourly sky and sun conditions based on the TMY2 climate data

The TMY2 climate data for New York were processed to determine the sky and sun conditions at each 15 minute time-step for the daylight period of the year. The parameters that determine the sky and sun conditions were: diffuse horizontal irradiance; direct normal irradiance; sun azimuth; and, sun altitude. The sun luminance was based directly on the value for direct normal irradiation. Daylight quantities at each 15 minute time-step were synthesised from a set of pre-computed renderings generated under normalized conditions. The full geometrical complexity of the 3D model assembled by LBNL - building and context - was used in the simulations. Figure 9-15 below shows a rendering of the NYT tower and surrounding buildings. Precise modelling of the façade and interior was carried out for floors 6 and 26 (shown).

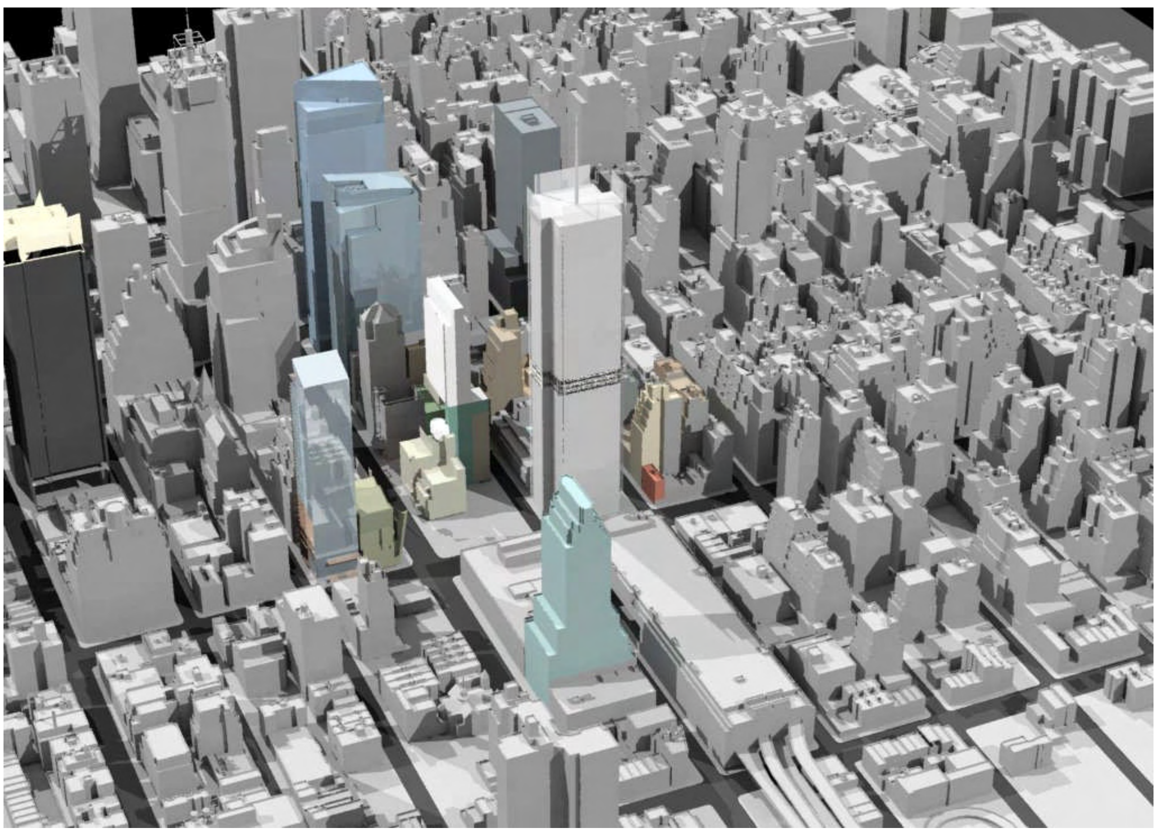


Figure 9-15. Urban context of The Times building.

The following daylight related quantities were predicted in the simulations:

- The luminance in the field of view for 12 viewpoints each on floors 6 and 26 with no shades deployed.
- As above with fabric material 99745 covering the window.
- Vertical (external) illuminance on the four principal facades of the building at floor 6 and 26.

The parameters (position, direction, angles, etc) for the twelve window views were selected so that there was one view from each of the four principal and eight minor facades. Annual metrics for the occurrence of high luminance in the field of view was the focus for this study. Vertical illuminance was predicted because this quantity will be used as one of the conditions to control the operation of the shades.

9.5.1.4. Luminance in the field of view

Luminance images were generated for views looking out from each of the principal and minor facades at floor levels 6 and 26 for unshaded and fully shaded windows. A total of ~450 normalized luminance images – with the sun position based on the 7.5 degree grid – were needed per view. Note that the technique accurately synthesizes the absolute luminance for the ~4500 daylight hours from the normalized images, i.e. ~ten times faster than a brute-force method. Figure 9-16 below shows the predicted luminance for a view from floor 26 on the principal East façade for one instant in the year (clear sky conditions).

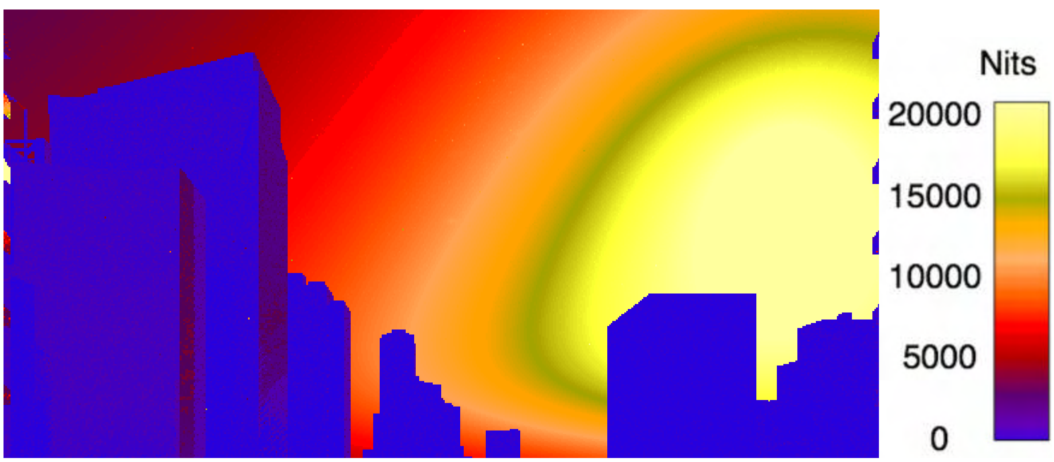


Figure 9-16. Predicted luminance for a view from Floor 26 on the east façade (clear sky conditions).

9.5.1.5. Spatio-temporal maps of solar exposure

Clear sky conditions can occur for any sun position. Spatio-temporal maps reveal the propensity for exposure to the sun throughout the year by setting clear sky conditions at every hour. The spatial map shows the distribution in exposure across the facade. The temporal map reveals when in the year the exposure can occur for a selected point.

Spatio-temporal maps of exposure to direct solar radiation were generated for each of the major facades of the building at floor levels 6 and 26. Figures 9-17 to 9-19 provides some examples of these data.

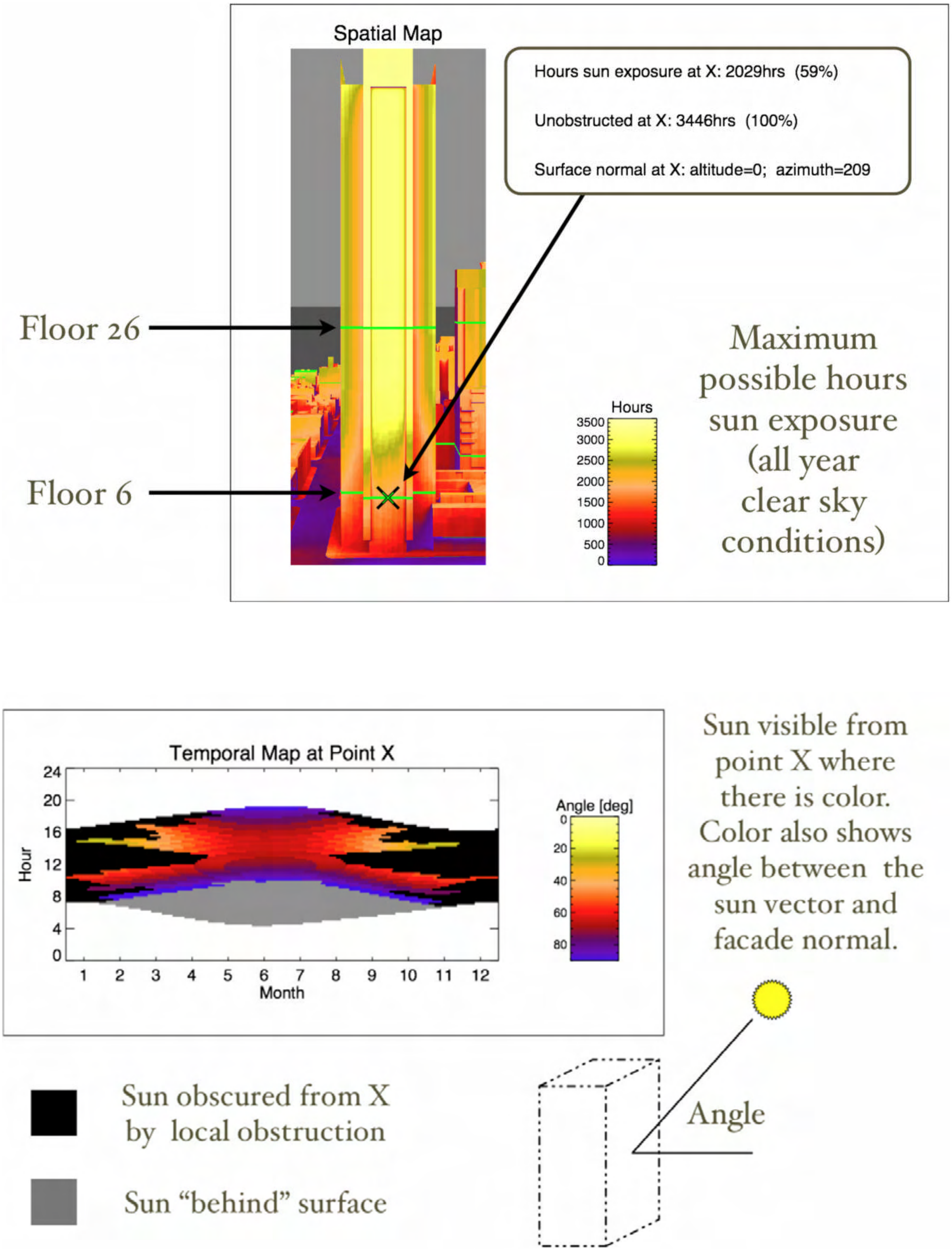


Figure 9-17. Diagram explaining how to read spatio-temporal maps

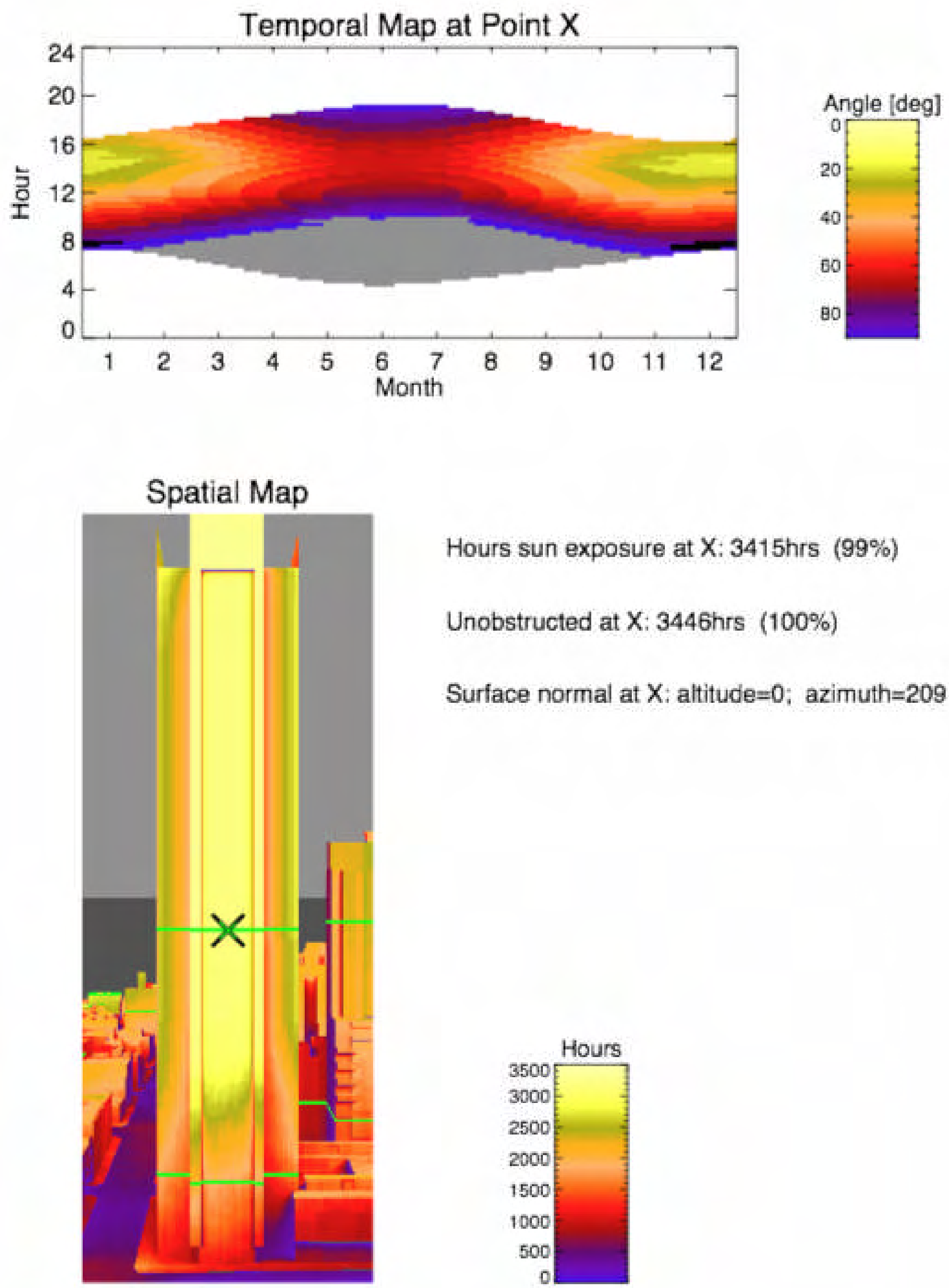


Figure 9-18. Spatio-temporal maps for the south façade, floor 26.

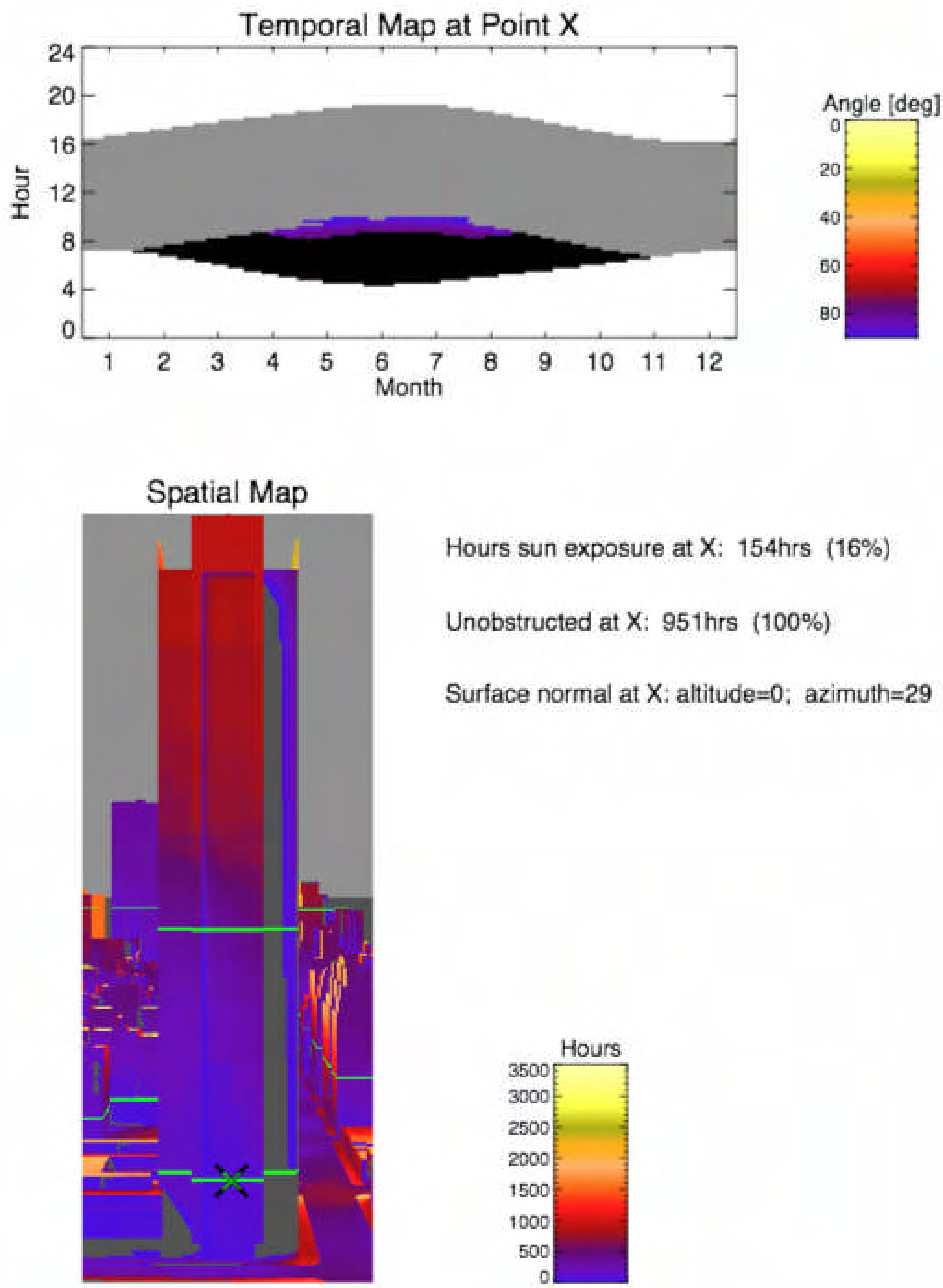


Figure 9-19. Spatio-temporal maps for the north façade, floor 6.

9.5.1.6. Daylight glare

Discomfort from daylight glare does not yet have a standard definition that is widely accepted by all researchers. The earliest glare metrics for daylight were based on extrapolations from glare studies of artificial lighting. These have since been discovered to be largely inapplicable because of the enormous differences in scale, quantity and character between artificial lights and typical daylight glare sources (i.e. sky and sun viewed through windows).

A consensus is however emerging that a key factor in daylight glare is the average luminance in the field of view. Any view of direct sun will be important also. Positional factors appear to be of less significance than they are with the much smaller source artificial lights. In the first instance, the field of view was set to be the above-horizon view through the glazing for each of the twelve viewpoints noted earlier.

9.5.1.7. Processing the simulation data

The annual occurrence of high average luminances in the field of view was determined from the thousands of images generated for each view. A record was made of the average luminance in the mask area at each hour (actually, interpolated 15 min time-step). A plot showing the annual frequency of occurrence was generated from this data. The annual occurrence is expressed as the occurrence on a daily basis, e.g. if a particular average luminance was predicted to occur for 365 hours in the year, then it would be shown as occurring for one hour per day. An example plot is shown in Figure 9-20 below. For example, with the shades always up, a mean luminance of 2000 cd/m^2 is exceeded for ~7 hr per day (on average across the year). With the shades fully down. 2000 cd/m^2 is exceeded for only a few minutes (on average across the year).

The annual occurrence of high luminance is presented as a daily value for convenience. However, that value should not be taken to be the maximum time per day for which the high luminance will occur. It will always be the case that high luminances will be more likely to occur at certain times of the day and year, and lower luminances at other times. This is evident from the temporal maps, which indicate the propensity for occupants ‘seeing’ the bright circumsolar region (and sun).

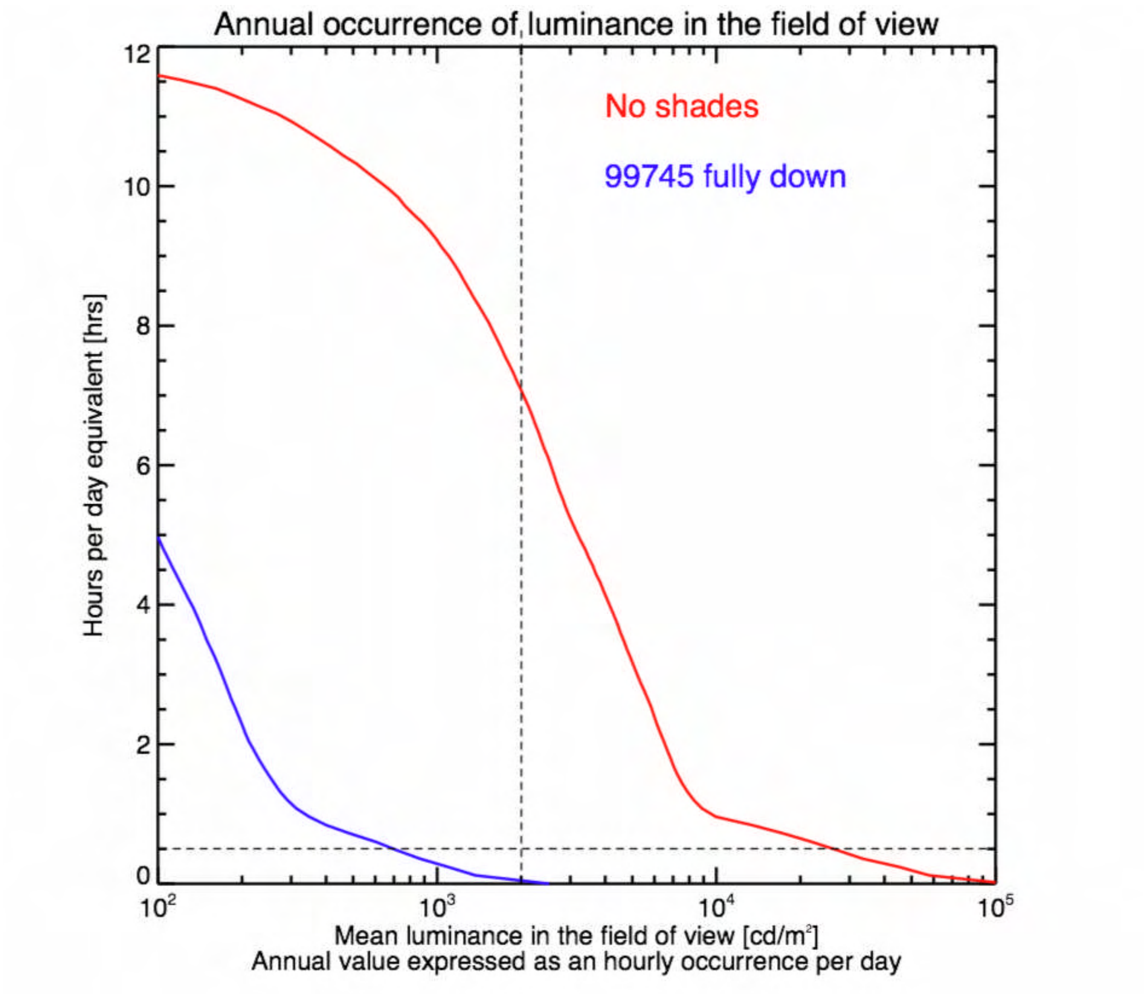


Figure 9-20. Example graph showing annual occurrence of high average luminances in the field of view. South, Floor 26.

9.5.1.8. Shade control algorithm

The annualized luminance plots have been presented for the unshaded and fully shaded scenarios separately. This is to determine the limits of what can be reasonably expected.

The next stage in the analysis is to post-process the luminance images from the unshaded and shaded scenarios together to mimic the operation of a shade control algorithm. A schematic is given in Figure 9-21 below.

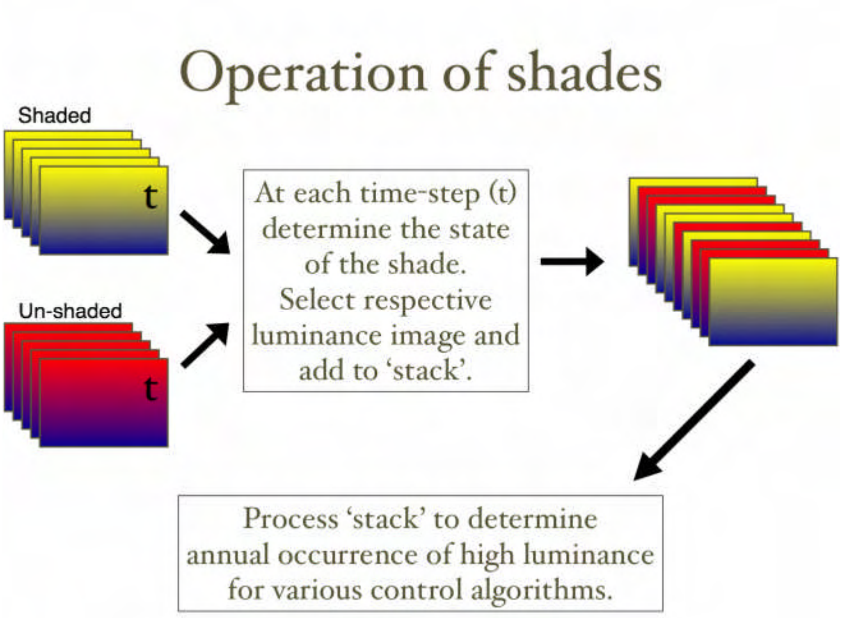


Figure 9-21. Schematic showing how images were post-processed to mimic the control algorithm

The following shade control algorithms were investigated. In each case the control of the shades was governed by one of the following conditions:

- Altitude of the sun
- Vertical illuminance
- Mean field of view luminance

9.5.2. Results

9.5.2.1. Sun altitude condition

In this example view (Figure 9-22), the altitude of the sky just visible at the top of the window is 38 degrees. For this first test, the shades were lowered whenever the sun altitude was less than 38 degrees. This stringent condition makes no allowance of sun and sky conditions. Note: the curves for the shades open-all-the-time and shades closed-all-the-time conditions are repeated in all the plots.

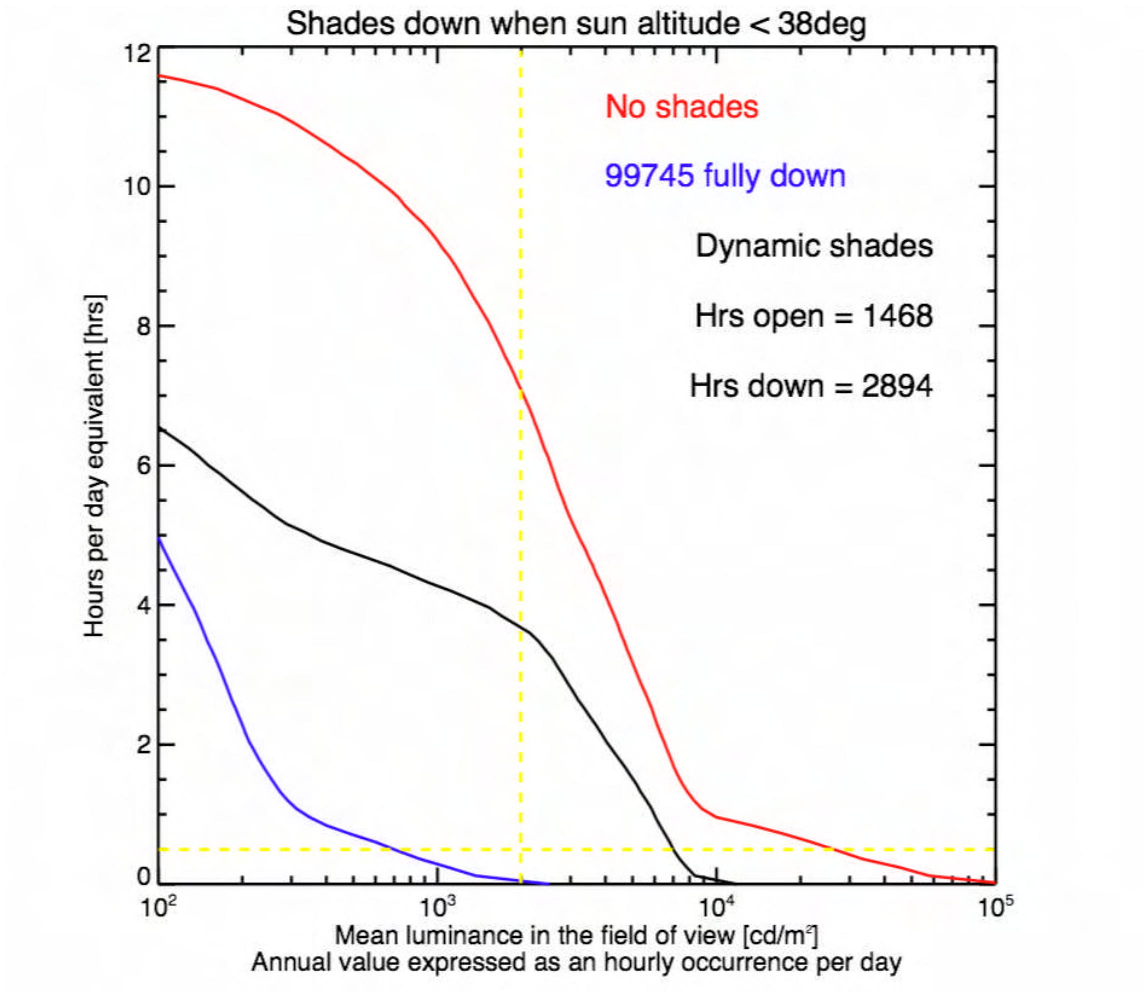


Figure 9-22. Annual occurrence of high average luminances in the field of view. South, Floor 26. Control algorithm: Shade lowered when solar altitude is less than 38 degrees.

Luminances of 2000 cd/m^2 and greater occur daily (on average throughout the year) for approx. 4 hr. The shades will be open for ~30% of daylight hours. This condition fails to exclude visible patches of high luminance sky, e.g. low altitude circumsolar region on clear days and bright overcast skies. Furthermore, the shades will be lowered by this condition when the sun position is visible even though the sky may be very overcast and cloud cover totally obstructs the sun.

9.5.2.2. Vertical illuminance condition

The vertical illuminance incident on the building facade at a point depends on the sky brightness distribution, the sun position and brightness, and the degree and shape of local obstructions. For this series of tests, the shades are lowered whenever a vertical illuminance threshold value is exceeded. Vertical illuminance thresholds covering the range 2klux to 10klux in 2klux steps were tested. The vertical illuminance was that predicted on the exterior of each of the four principle facades at the mid-point for floors 6 and 26. We expect this illuminance to be well correlated with vertical illuminance measurements from the photocells that will installed on the inside of the glass façade. The plots are shown in Figure 9-23 to 9-27 below.

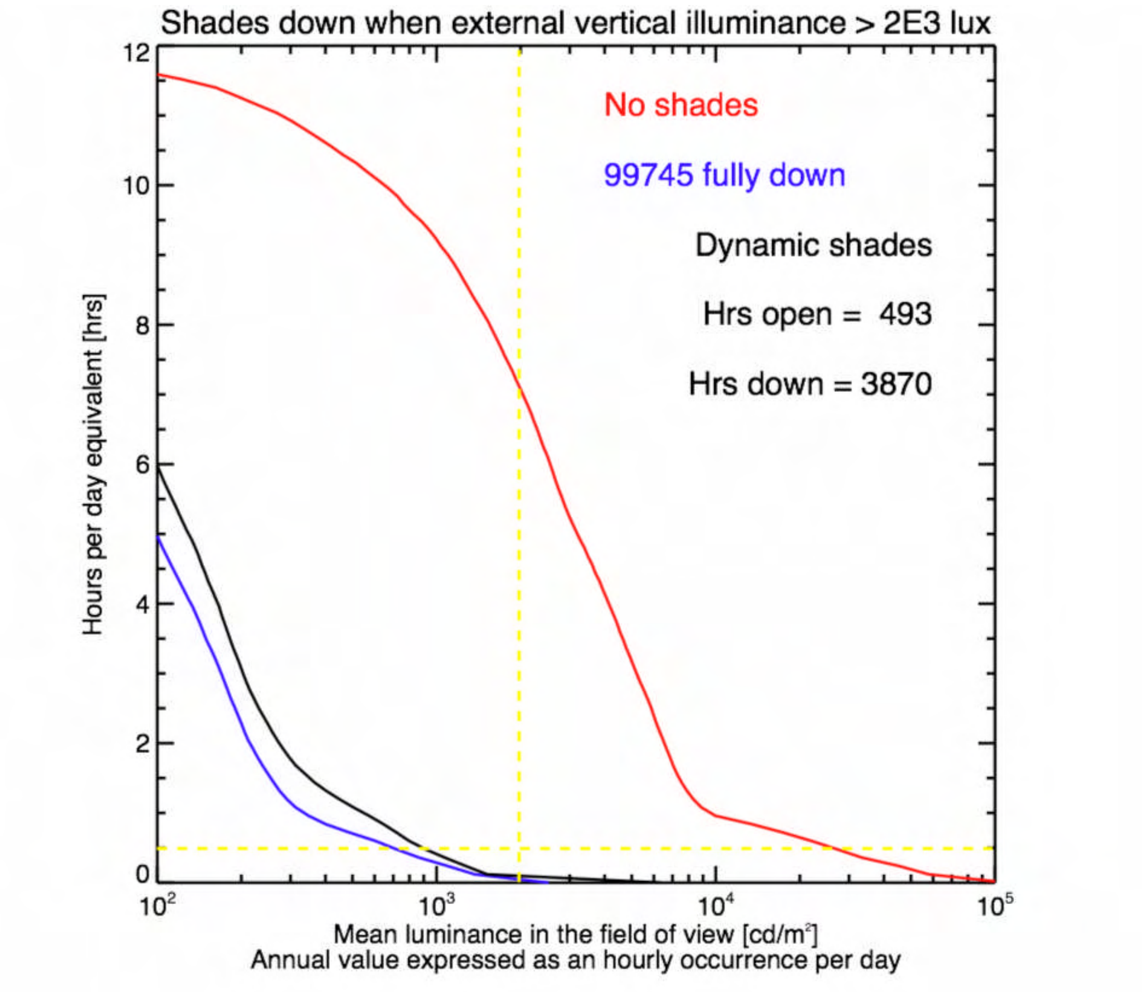


Figure 9-23. Annual occurrence of high average luminances in the field of view. South, Floor 26. Control algorithm: Shade lowered when external vertical illuminance is greater than 2000 lux.

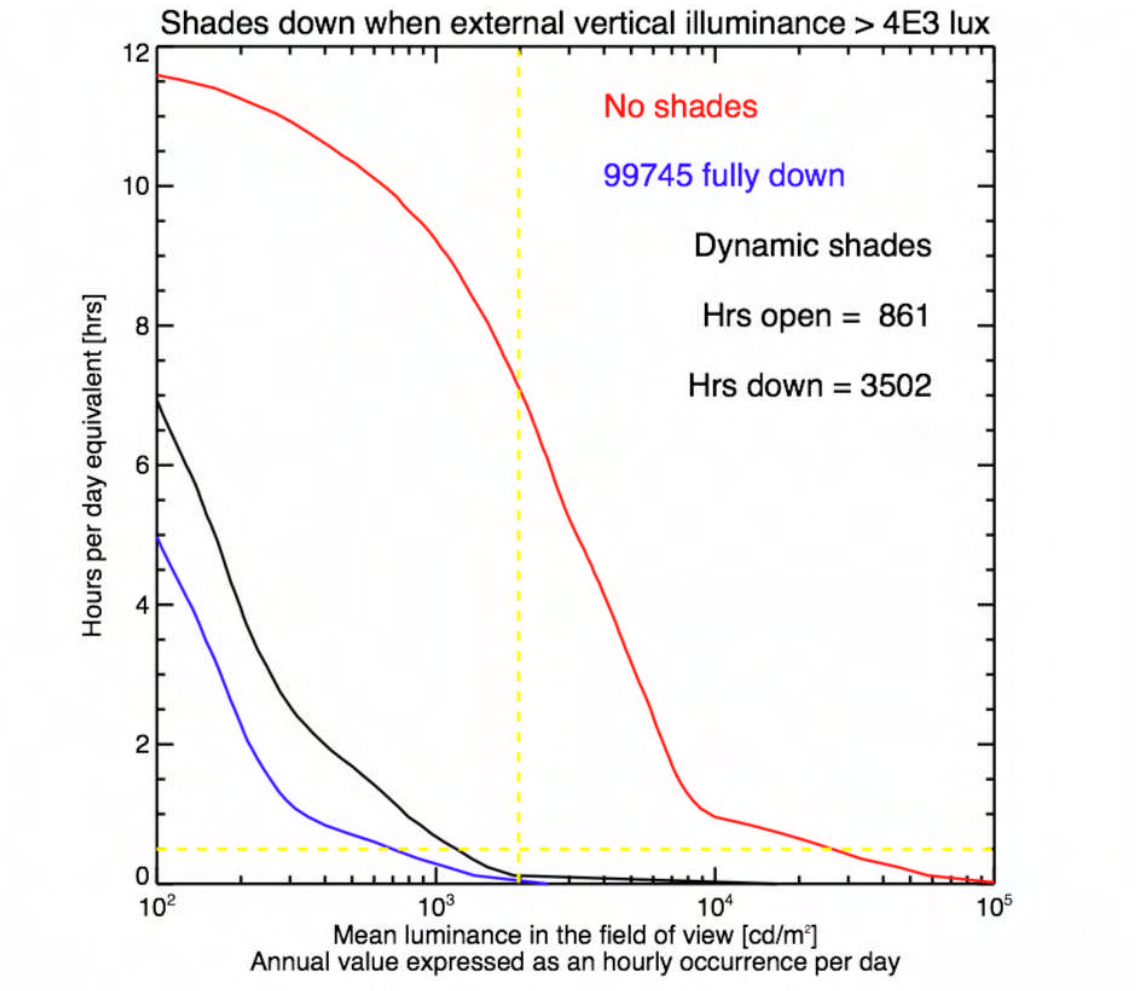


Figure 9-24. Annual occurrence of high average luminances in the field of view. South, Floor 26. Control algorithm: Shade lowered when external vertical illuminance is greater than 4000 lux.

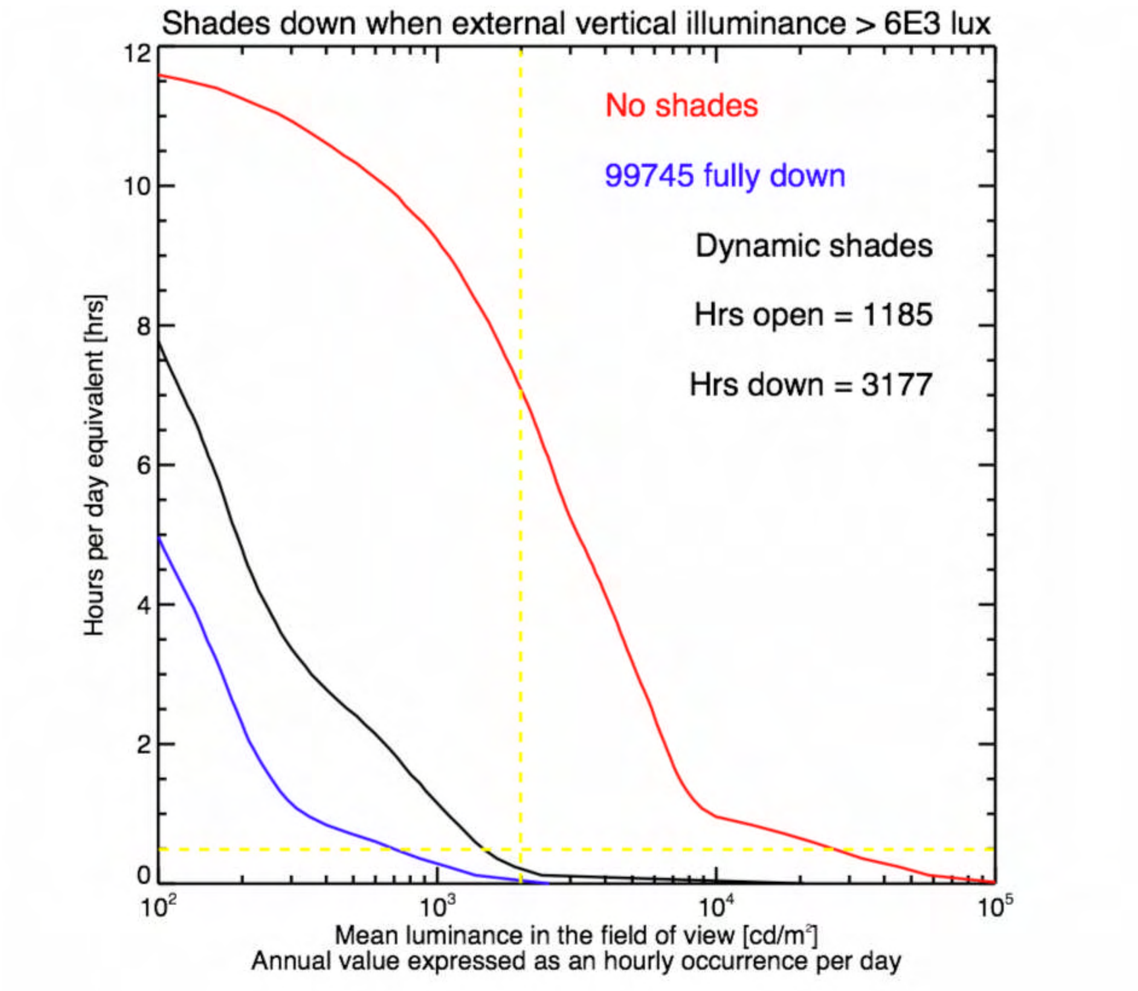


Figure 9-25. Annual occurrence of high average luminances in the field of view. South, Floor 26. Control algorithm: Shade lowered when external vertical illuminance is greater than 6000 lux.

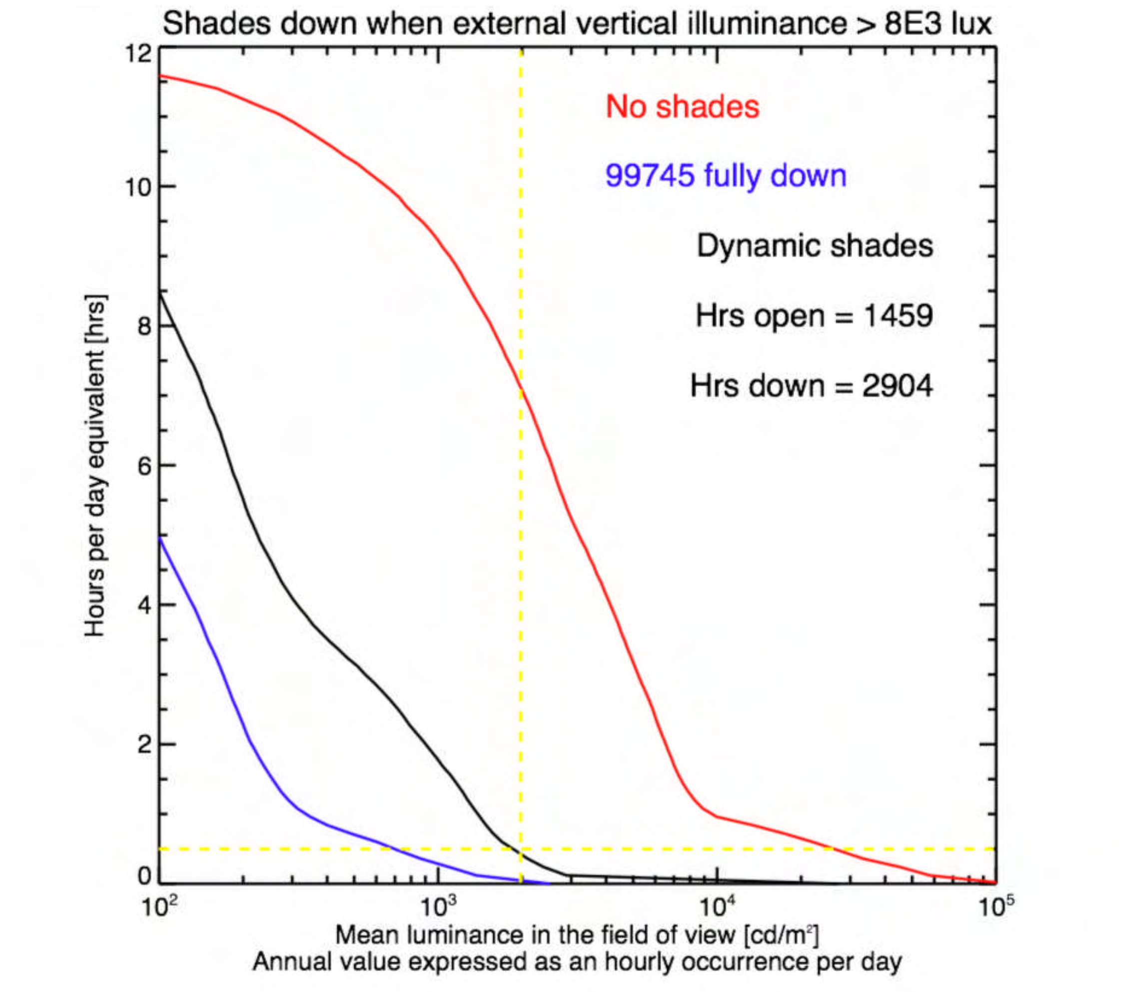


Figure 9-26. Annual occurrence of high average luminances in the field of view. South, Floor 26. Control algorithm: Shade lowered when external vertical illuminance is greater than 8000 lux.

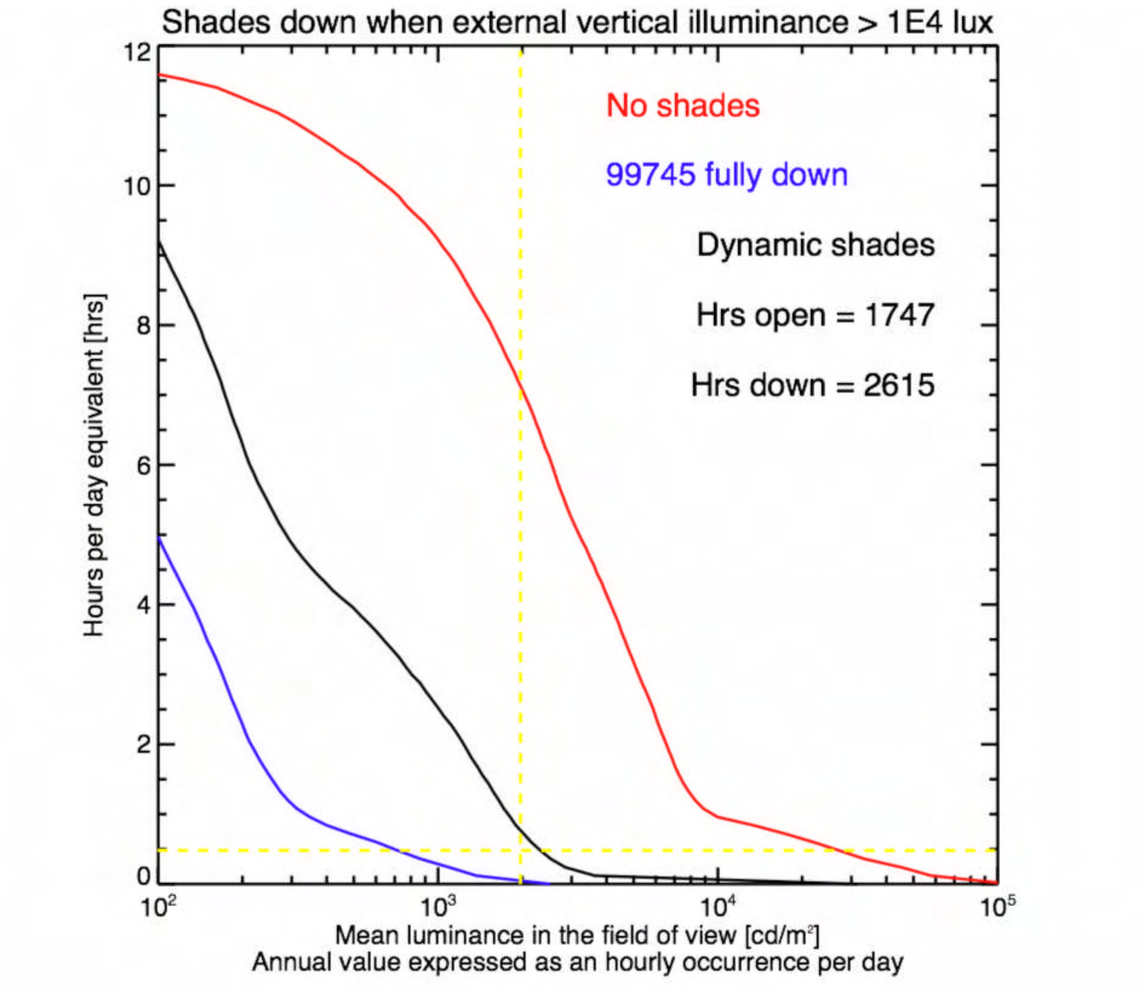


Figure 9-27. Annual occurrence of high average luminances in the field of view. South, Floor 26. Control algorithm: Shade lowered when external vertical illuminance is greater than 10,000 lux.

The 2000 lux threshold is exceeded for ~90% of daylight hours – the shades are down most of the time. There were few instances when the average luminance exceeded 2000 cd/m^2.

The 4000 lux threshold is exceeded for ~80% of daylight hours. Marginal increases in high luminances over the 2000 lux condition.

The trend continues for the 6000 lux and 8000 lux thresholds. For the 8000 lux threshold, an average luminance of 2000 cd/m^2 occurs daily for ~1/2 hour (on average throughout the year). For 10,000 lux, the occurrence is greater (~3/4 hr).

9.5.2.3. Field-of-view luminance condition

For this test, the shades are lowered whenever the (predicted) average luminance in the field-of-view (i.e. mask area) exceeds a threshold value (Figures 9-28 to 9-30). This mechanism can be termed 'ideal' since the shade action is in direct response to the magnitude of the parameter we wish to control. It is included for comparison with the sun altitude and vertical illuminance conditions.

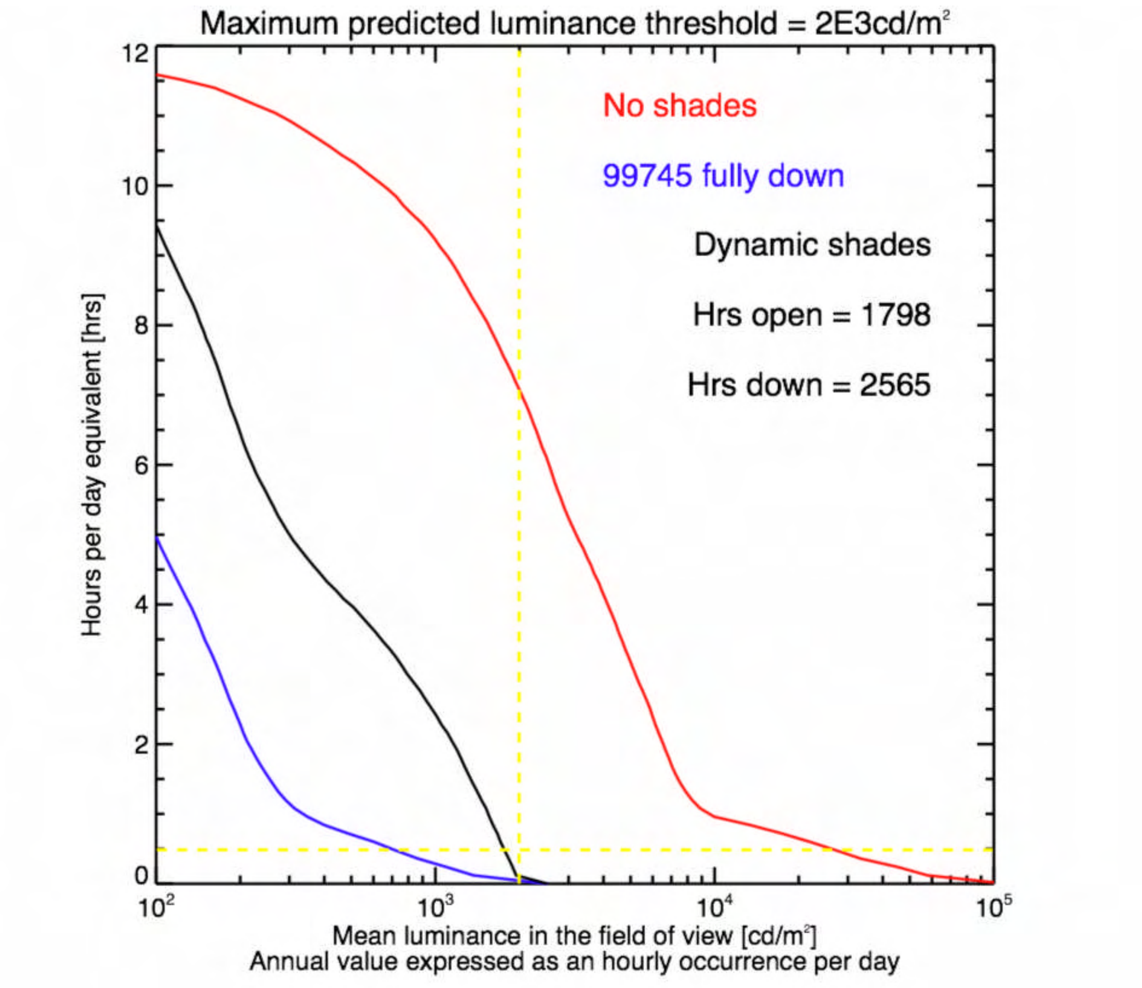


Figure 9-28. Annual occurrence of high average luminances in the field of view. South, Floor 26. Control algorithm: Shade lowered when the average field-of-view luminance is greater than 2000 cd/m^2.

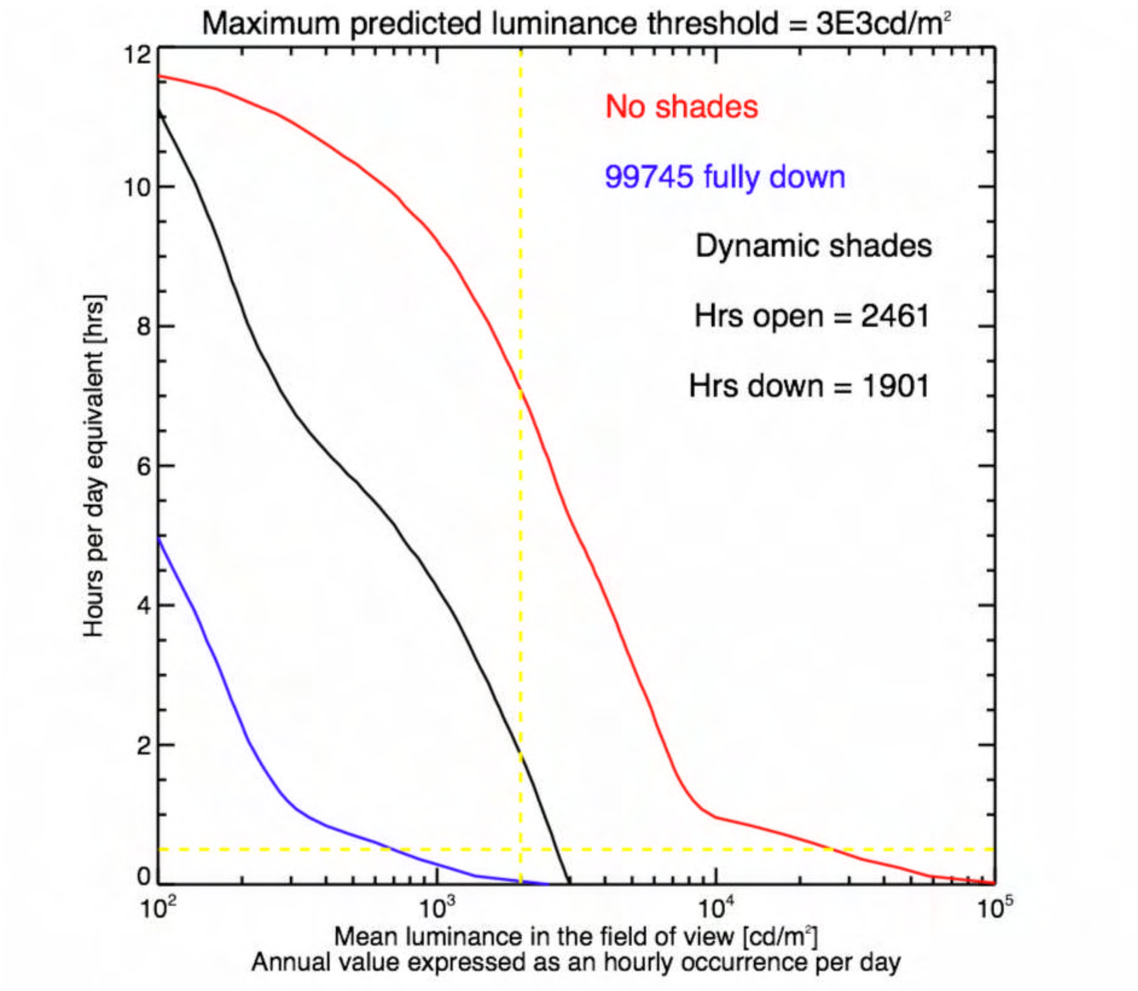


Figure 9-29. Annual occurrence of high average luminances in the field of view. South, Floor 26. Control algorithm: Shade lowered when the average field-of-view luminance is greater than 3000 cd/m^2.

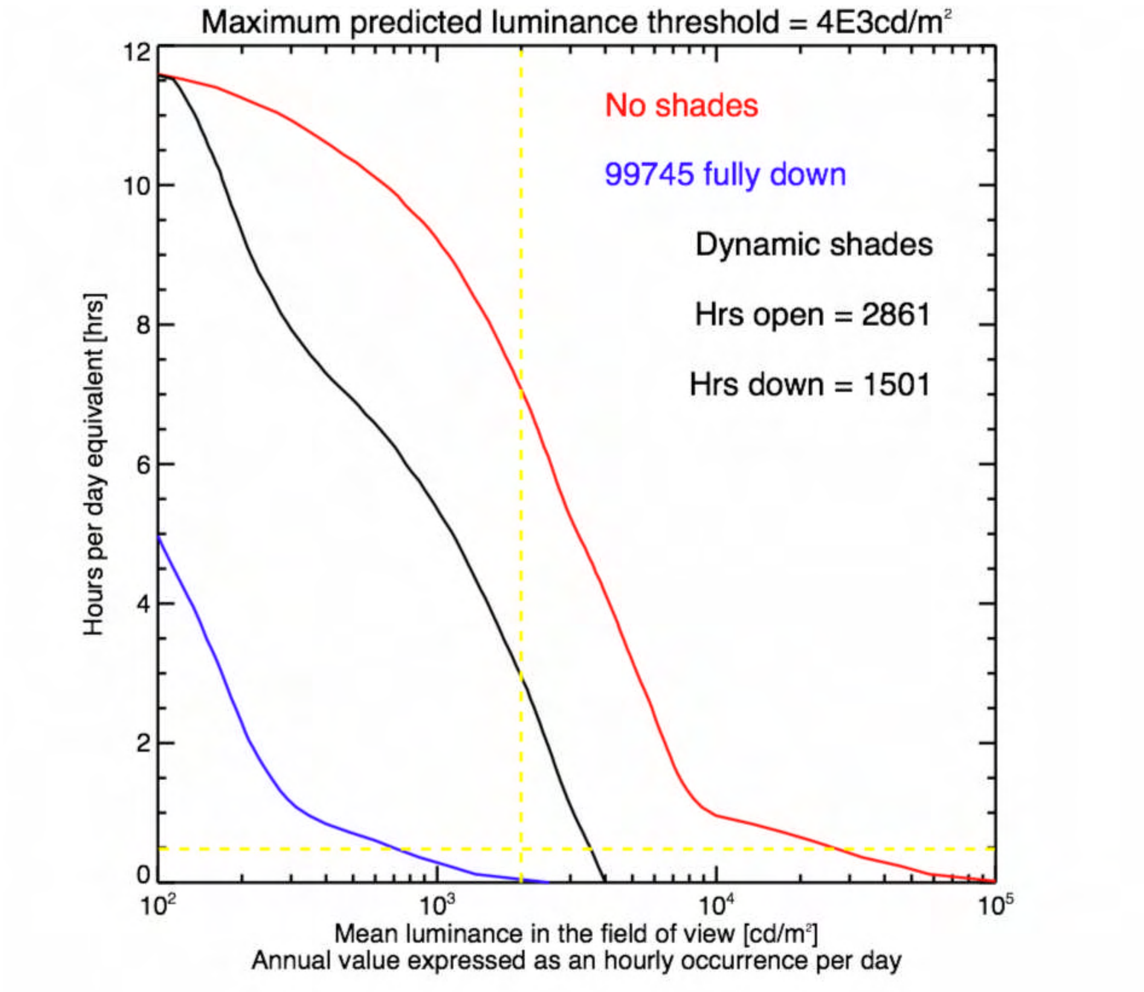


Figure 9-30. Annual occurrence of high average luminances in the field of view. South, Floor 26. Control algorithm: Shade lowered when the average field-of-view luminance is greater than 4000 cd/m^2.

The 2000 cd/m^2 condition offers comparable control to that for the shades continually lowered, but with the shades raised for ~40% of daylight hours.

Relaxing the condition to 3000 cd/m^2 results in the shades open for ~56% of daylight hours. The 2000 cd/m^2 average luminance value is exceeded daily for 2hrs, but it is never larger than 3000 cd/m^2.

There is a similar trend for the 4000 cd/m^2 condition.

9.5.3. Summary

Sun altitude alone seems an ineffective control parameter for the operation of the shades – it fails to minimise the occurrence of predicted high luminance.

The vertical illuminance condition seems to be a reliable parameter with which to control the lowering of shades to minimise the occurrence of high luminance in the field of view.

Section 10
MARKET TRANSFER

10.1. INTRODUCTION

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.

10.2. 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.

10.3. 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 must look 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 should be 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. In the future, 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.

10.4. 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 documented the performance of these systems and partnered with manufacturers to improve performance and reduce costs. The field test data resulted 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.

10.5. PROJECT DISSEMINATION

Tours were given to over 100 visitors to The New York Times Daylighting mockup over a two-year period.

Technical Publications

Market Transformation Opportunities for Emerging Dynamic Facade and Dimmable Lighting Control Systems, ACEEE 2004 Summer Study on Energy Efficiency in Buildings: Breaking Out of the Box, August 22-27, 2004, Asilomar, Pacific Grove, CA. LBNL-55310.

Popular Press Articles

The New York Times Building: Designing for energy efficiency through daylighting research
Science Beat, Berkeley Lab, February 17, 2004.
http://www.lbl.gov/enews/2-17-04.html

The New York Times and EETD advance energy-efficient building design
Environmental Energy Technologies Division News Vol. 4(5): Winter 2004
Lawrence Berkeley National Laboratory
http://eetd.lbl.gov/newsletter/nl16/NYTimes.html

A Day in the Light: The New York Times's radical around-the-clock experiment in lighting design
Metropolis Magazine, May 2004
http://www.metropolismag.com/cda/archives.php

Blueprint for daylighting at The New York Times
Daylight! Daylight! Read all about it
Architectural Lighting, June 2004
http://www.archlighting.com/architecturallighting/al/search/article_display.jsp?vnu_content_id=1000526940

Day of the sun: Energy savings result from testing a mock-up of The New York Times' new headquarters
Glass Magazine, November 2004

Green grows up… and up and up and up
Sustainable high-rises are sprouting from Manhattan's bedrock
Architectural Record Innovation, November 2004
http://www.archrecord.com/innovation/2_Features/0411Green.asp

The costs and benefits of high performance buildings: lessons learned
Earth Day New York
The New York Times: A melding of high design and performance
Getting it right: Providing energy efficiency and comfort in an all-glass building
http://www.earthdayny.org/costsandbenefits.html

Copies of all articles are included in the Appendix G.

Presentations

- AESP Lighting Conference, Albany, NY, May 25-26, 2005.
- LightFair Daylighting Institute, New York, New York, April 11, 2005.
- Managing energy use, daylight, and glare with dynamic facades in highly glazed buildings. ICBEST, Bath, England, April 7-8, 2005.
- SOM Building Science and Design Research Symposium, New York, New York, November 19-20, 2004.
- Center for Environmental Design Research, Invited Lecture, Berkeley, California, November 12, 2004.
- Illuminating Engineering Society Convention, Gold Coast, Australia, November 4-6, 2004
- Center for the Built Environment Annual Meeting, Berkeley, California, October 25, 2004
- ACEEE Emerging Technologies Conference, San Francisco, California, October 14-15, 2004.
- Glass Symposium, Syracuse, New York, October 21, 2004
- International Symposium on Daylighting Buildings (IEA SHC TASK 31), Torino, Italy, September 21, 2004.
- LightFair Daylighting Institute, Las Vegas, Nevada, March 29, 2004.

- Advanced Facades for Energy Efficient Buildings: From Design Intent through Verified Performance. ICBEST, Sydney, Australia, 2004.
- Perspectives on Advanced Facades with Dynamic Glazings and Integrated Lighting Controls. CISBAT 2003, Innovation in Building Envelopes and Environmental Systems, International Conferences on Solar Energy in Buildings, October 8, 2003, École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland.
- Integrating Automated Shading and Smart Glazings with Daylight Controls. International Symposium on Daylighting Buildings (IEA SHC TASK 31), Tokyo, Japan.

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Appendix A

PARTICIPANT INFORMATION

COST EFFECTIVE DAYLIGHTING SOLUTIONS SURVEY

Thank you for taking the time to visit this mockup of the new headquarters building for the New York Times (NYT). **Please read this letter explaining your rights as a research subject before filling out any of the survey.** You are being asked to participate in a research study on advanced energy-efficient window and lighting systems conducted by Eleanor Lee of Lawrence Berkeley National Laboratory (LBNL). The objective of this study is to find out how commercially available off-the-shelf automated window shade and dimmable electric lighting systems can be used to increase the occupant comfort while decreasing energy use. Your input will help us make this assessment.

Procedure

- The NYT experimenter will explain to you all the necessary logistical items when you first arrive at the mockup: location of your desk, your computer set-up, location of the bathrooms, etc.
- The NYT experimenter will explain how to override the automated shades using a push button controller mounted on the wall in the space.
- A questionnaire will be given to you. To ensure anonymity of your response, do not write your name down.
- The NYT experimenter will ask you to spend 5 minutes to fill out Part A (background section) of the questionnaire at the start of the test period.
- You will then be asked to work at your normal work activities for 3 hours.
- At the end of this period, you will be asked to spend 5 minutes to fill out Part B of the questionnaire.
- You will be asked to work at your normal work activities for another 3 hours.
- At the end of this period, you will be asked to spend 5 minutes to fill out Part C of the questionnaire (identical to Part B).
- To ensure confidentiality of your responses, you will place the questionnaire in an LBNL-addressed, stamped envelope and seal the envelope prior to returning it to the NYT experimenter. There will be no identifying marks on the envelope exterior. You will be asked to put the envelope in a designated box upon leaving the mockup. The NYT experimenter will mail the unopened envelopes to LBNL.
- The following data will be monitored while you are working: interior illuminance, lighting energy use, and height of the shade.
- Please do not discuss your impressions with anyone else either before or after the study because you could bias other participants or prospective subjects.

Participation in research is VOLUNTARY. You have the right to not take part in this study or to stop taking part at any time. Simply seal the unfilled or partially-filled questionnaire in the LBNL-stamped envelope and place it in the box when you leave.

Participating in this study poses no known risks to you. The data will be analyzed and summarized by an outside group (LBNL) that does not know your identity. Any raw data to released to the New York Times will have the dates and times removed so that they cannot identify subjects either. No individuals will be quoted in final reports.

There is no direct benefit to you from the research, although it is possible that some participants may find the mockup office to be a more pleasant work environment than their normal office. We hope that the research will benefit society by helping us develop automated window systems and lighting systems which provide a better, more energy efficient work environment.

For each participant, the following information will be kept by LBNL: coded dates and times, coded desk location and light measurements, and responses to the questionnaire. No names are associated with the questionnaires. This material will be stored in a locked file cabinet in the office of the lead researcher, Eleanor Lee (LBNL, Building 90, Room 3090). No names or other individual identifiers of subjects will be included in project reports.

Lawrence Berkeley National Lab is not offering any payment or remuneration for completing the survey.

Any further questions you have about taking part in this study can be answered by Eleanor Lee at (510) 486-4997. If you have any questions about your rights or treatment as a participant in this research project, please contact the Berkeley Lab Human Subjects Quality Assurance Committee at (510) 486-5507 or the University of California at Berkeley's Committee for the Protection of Human Subjects at (510) 642-7461 or subjects@uclink.berkeley.edu.

Please take this cover sheet with you to keep.

Thanks again for your help towards our goal of attaining a more energy-efficient and pleasant work environment!

Eleanor Lee, Scientist
Building Technologies Program
Lawrence Berkeley National Laboratory

Appendix B

THE NEW YORK TIMES: OCCUPANT'S SATISFACTION SURVEY

INSTRUCTION

We would like you to answer the questions in this questionnaire. Please fill out this questionnaire as completely as possible. If there is any question you are unable to answer or do not want to answer, just skip it and go on to the next one. Please respond to all of the items as openly and honestly as possible. Try to answer all the questions based on your immediate impression. There are no right or wrong answers; it is only your opinions that are important.

There are three ways to answer the questions in this survey.

1. Circle the appropriate response,
2. Fill in the blank with appropriate answer, and
3. Mark **X** on the scale provided.

The following are examples that show how each of the different questions should be answered. For example:

Q1) What is your gender?
a) Male
b) Female

Q2) During this session, what percentage of your time was spent on each of the following tasks?

Task	**Percent**
Reading	_**20**_%
Computer	_**80**_%

Q3) When you perform your work tasks, what is your preferred light level in your workspace?

	Very Low	**Low**	**Moderate**	**Bright**	**Very Bright**
	1	**2**	**3**	**4**	**5**

Light level |----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|

PART A: BACKGROUND INFORMATION

1) Today's Date (mm/dd/yy)____________ Start Time ______________

2) Have you read the attached participant information form?
   a) Yes
   b) No

3) Please enter your workstation ID# _______
   (The workstation ID number can be found on your desk)

4) What is your gender?
   a) Male
   b) Female

5) How old are you?
   a) Under 40 years old
   b) 40 or over

6) Do you wear glasses at work?
   a) Yes
   b) No

7) Please assign a rating from 1 to 5 for what you feel the importance of the following items are in making a pleasant and productive office environment, with 1 being the least important and 5 being the most important.

Item	**Rating**				
	Unimportant				**Very Important**
	1	**2**	**3**	**4**	**5**
a) Good temperature Control	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
b) Good lighting	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
c) Windows	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
d) A view	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
e) Comfortable (ergonomics) furniture	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
f) The latest computer/ operating system	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
g) No noise	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				

Item	Rating				
	Unimportant				Very Important
	1	2	3	4	5
h) Controllable lights or shades	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
	1	2	3	4	5
i) An attractive environment	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
	1	2	3	4	5
j) A good computer monitor	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
	1	2	3	4	5
k) Other (specify) ____________________	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				

8) Please assign a rating from 1 to 5 for your sensitivity to the following items, with 1 being not sensitive, 3 being moderately sensitive, and 5 being very sensitive.

Item	Rating				
	Least Sensitive		Moderately Sensitive		Very Sensitive
	1	2	3	4	5
a) Glare	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
	1	2	3	4	5
b) Cold	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
	1	2	3	4	5
c) Heat	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
	1	2	3	4	5
d) Gloominess	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
	1	2	3	4	5
e) Noise	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
	1	2	3	4	5
f) Visual distractions	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				

9) When you perform your work tasks, what is your preferred light level in your workspace?

	Very Low	Low	Moderate	Bright	Very Bright
	1	2	3	4	5
Light level	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				

- End of questionnaire Part A -

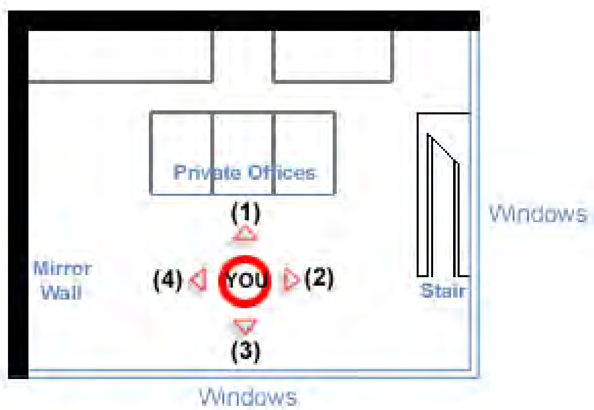
PART B: FIRST SESSION

1) Current Time_______________

2) During this session, what percentage of your time was spent on each of the following tasks?

Task	**Percent**
Reading	____%
Computer	____%
Writing (by hand)	____%
Cell phone	____%
Other (please specify)________________________	____%

3) During this session, what percent of your time were you facing the following directions (please refer to the orientation specified in the plan view diagram of the workspace below):



Direction	**Percent**
(1) Toward the private offices	____%
(2) Toward the stair & windows	____%
(3) Toward the windows	____%
(4) Toward the mirror wall	____%

4) Please assign a rating from 1 to 5 with the following lighting/temperature conditions at your workspace during the past three hours.

Item **Rating**

Too Cold **Just Right** **Too Hot**

1 2 3 4 5

a) Temperature |----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|

Too Dark **Just Right** **Too Bright**

1 2 3 4 5

b) Light level at the task |----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|

Poorly Distributed **Nicely Distributed**

1 2 3 4 5

c) Overall lighting distribution (shadows, bright spots, etc.) |----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|

5) Please rate the level of glare.

Not Perceptible **Perceptible** **Acceptable** **Un-comfortable** **Intolerable**

1 2 3 4 5

a) From the windows |----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|

1 2 3 4 5

b) From the electric lights |----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|

1 2 3 4 5

c) From bright vertical surfaces (walls & partitions) |----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|

6) Bright light on my task made it difficult to read or see.

Disagree **Somewhat Agree** **Agree**

1 2 3 4 5

a) Computer |----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|

1 2 3 4 5

b) Other tasks |----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|

7) Please indicate your level of agreement/disagreement (disagree =1 , agree = 5) with the following statements:

	Disagree 1	2	Somewhat Agree 3	4	Agree 5
a) The lighting was comfortable	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
b) The room was gloomy	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
c) The shades were too noisy	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
d) The operation of the shades was annoying	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
e) The dimming of lights was annoying	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
f) The shades blocked the view	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				

8) Did you manually override the shade position at any time?

a) Yes

b) No

9) Overall, how satisfied are you with your window shade control and lighting control system at your workspace in this session

	Very Dissatisfied 1	Dissatisfied 2	Just Satisfied 3	Satisfied 4	Very Satisfied 5
Overall Satisfaction	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				

10) Please add any additional comments about shading and lighting control system in this session that you think would be helpful in making this a better workspace.

- End of questionnaire Part B -

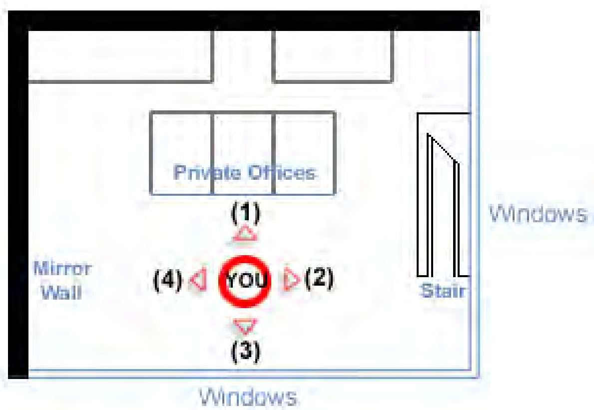
PART C: SECOND SESSION

1) Current Time_______________

2) During this session, what percentage of your time was spent on each of the following tasks?

Task	**Percent**
Reading	____%
Computer	____%
Writing (by hand)	____%
Cell phone	____%
Other (please specify)______________________	____%

3) During this session, what percent of your time were you facing the following directions (please refer to the orientation specified in the plan view diagram of the workspace below):



Direction	**Percent**
(1) Toward the private offices	____%
(2) Toward the stair & windows	____%
(3) Toward the windows	____%
(4) Toward the mirror wall	____%

4) Please assign a rating from 1 to 5 with the following lighting/temperature conditions at your workspace during the past three hours.

Item	Rating				
	Too Cold		Just Right		Too Hot
	1	2	3	4	5
a) Temperature	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
	Too Dark		Just Right		Too Bright
	1	2	3	4	5
b) Light level at the task	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
	Poorly Distributed				Nicely Distributed
	1	2	3	4	5
c) Overall lighting distribution (shadows, bright spots, etc.)	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				

5) Please rate the level of glare.

	Not Perceptible	Perceptible	Acceptable	Un-comfortable	Intolerable
	1	2	3	4	5
a) From the windows	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
	1	2	3	4	5
b) From the electric lights	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
	1	2	3	4	5
c) From bright vertical surfaces (walls & partitions)	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				

6) Bright light on my task made it difficult to read or see.

	Disagree		Somewhat Agree		Agree
	1	2	3	4	5
a) Computer	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				
	1	2	3	4	5
b) Other tasks	|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|				

7) Please indicate your level of agreement/disagreement (disagree =1 , agree = 5) with the following statements:

	Disagree 1	2	Somewhat Agree 3	4	Agree 5
a) The lighting was comfortable	|----|----|----|----|	----|----|----|----|	----|----|----|----|	----|----|----|----|	
b) The room was gloomy	|----|----|----|----|	----|----|----|----|	----|----|----|----|	----|----|----|----|	
c) The shades were too noisy	|----|----|----|----|	----|----|----|----|	----|----|----|----|	----|----|----|----|	
d) The operation of the shades was annoying	|----|----|----|----|	----|----|----|----|	----|----|----|----|	----|----|----|----|	
e) The dimming of lights was annoying	|----|----|----|----|	----|----|----|----|	----|----|----|----|	----|----|----|----|	
f) The shades blocked the view	|----|----|----|----|	----|----|----|----|	----|----|----|----|	----|----|----|----|	

8) Did you manually override the shade position at any time?

a) Yes

b) No

9) Overall, how satisfied are you with your window shade control and lighting control system at your workspace in this session

	Very Dissatisfied 1	Dissatisfied 2	Just Satisfied 3	Satisfied 4	Very Satisfied 5
Overall Satisfaction	|----|----|----|----|	----|----|----|----|	----|----|----|----|	----|----|----|----|	

10) Please add any additional comments about shading and lighting control system in this session that you think would be helpful in making this a better workspace.

- **End of questionnaire Part C –**

PLEASE PUT THE QUESTIONNAIRE IN THE STAMPED ENVELOPE, SEAL THE ENVELOPE AND HAND IT TO THE EXPERIMENTER.

Appendix C
MONITORED CONDITIONS

This appendix provides more detailed information about the test conditions and monitored data while the subjective appraisals were being performed.

SCHEDULE OF VISITS TO DAYLIGHTING MOCKUP

Table C1
Subjective appraisal visits

Date	Start time of test*	End time*	Number of subjects
April 30	13:00	17:20	11
May 3	9:00	14:45	1
June 7	13:00	15:30	5
June 11	14:30	17:00	9
September 15	14:30	15:00	11
September 16	13:00	16:30	7
September 17	10:30	16:00	9

CONTROL SYSTEM CONFIGURATIONS

Area A:
Shading system was set to “glare mode 2”: shades adjusted to control window glare. All fluorescent lighting was dimming according to daylight availability as intended with no ballast failures. Lighting setpoint was 538 lux (50 fc).

Area B:
Shading system set to block direct sun 0.91 m (3 ft) from the west window and 1.8 m (6 ft) from the south window with no brightness override. Most fluorescent lights according to daylight availability as intended. Lighting setpoint was 538 lux (50 fc). One or two intermittent ballast failures occurred in zones S3 and S6.

For full description, see Section 4.

MANUAL SHADE OVERRIDES

Table C2
Manual shade override

Date	Area A west façade	Area B south façade	Area B west façade
April 30	none	none	none
May 3	none	none	none
June 7	none	none	none
June 11	15:00-17:15	14:00-15:00, 16:45-17:00	14:00-15:00, 16:00-17:00
September 15	11:15-12:20, 13:50-15:50	no data	no data
September 16	12:15-15:45	13:45-15:10, 15:30-16:20	13:40-14:20, 14:40-18:00
September 17	12:15-18:00	14:15-14:30	14:15-14:30, 15:00-15:10

COMPUTER VISUAL DISPLAY TERMINAL TYPE (VDT)

Computers were provided in the three workstations closest to the west window wall on the far north (Area A) and south ends (Area B) of the mockup (total of six computers). Each computer was equipped with a new CCD screen (white area on screen was ~200 cd/m^2). These workstations were used primarily for internet access. Internet access was provided to everyone at their work stations and the majority of the subjects took advantage of this opportunity. Those that did write and read documents, used their own laptops but they were a minority.

TASK LIGHTS

Task lights were available on four of the Area A workstations (north end, second through fifth from the west window wall) and on two of the Area B workstations (south end, second and third from the west window wall). The experimenters did not notice any subject use the task lights for work purposes but occupants did experiment with the lights.

FIGURES

The following figures show the monitored conditions in the daylighting mockup for each date that subjective appraisals were conducted. The figure legend is explained in Table C3 below.

Table C3
Description of variables plotted in Figures

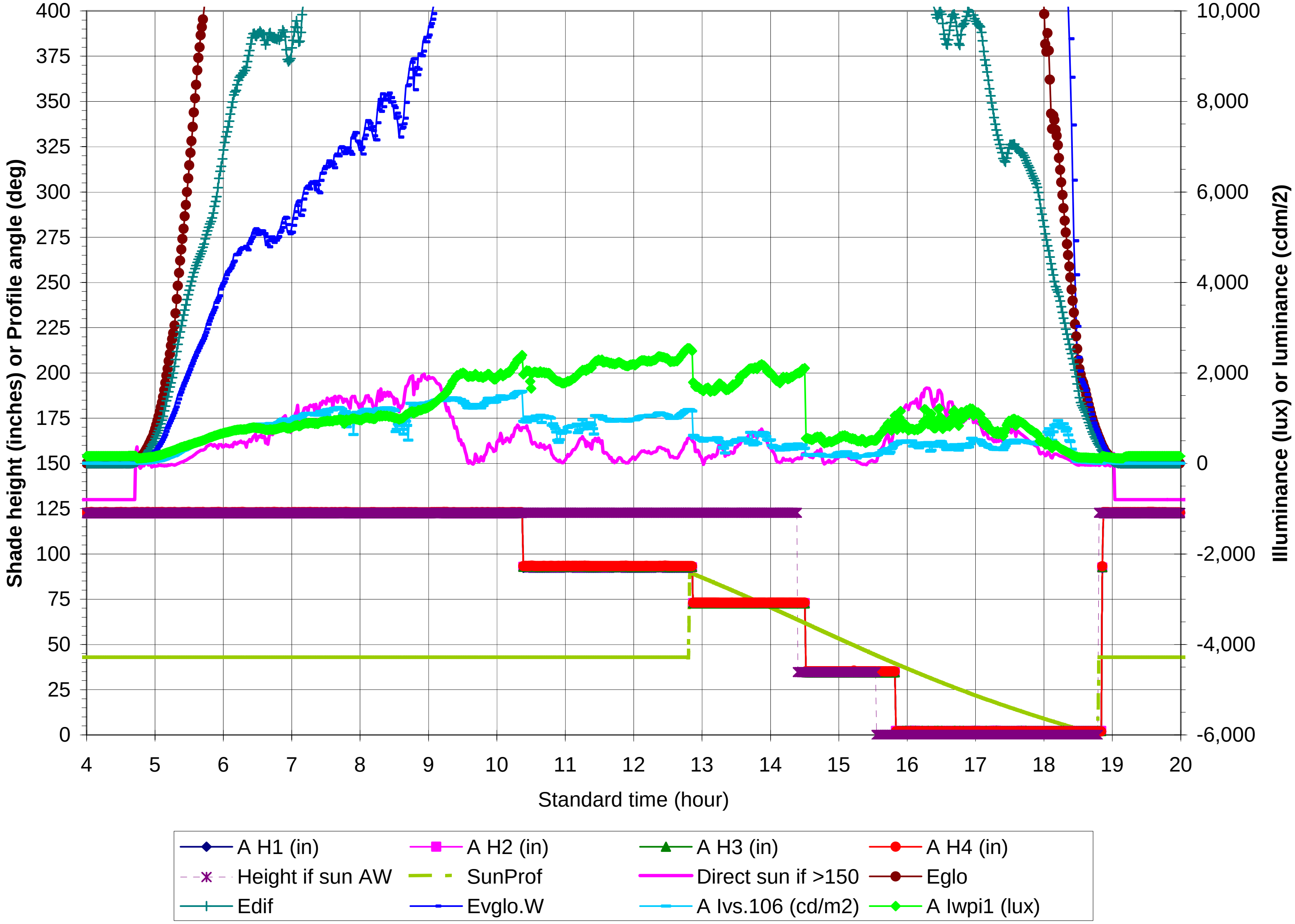
Variable	Units	y-axis	Description
A H1 (in)	inches	left	Height of shade group in Area A at west-facing window
A H2 (in)	inches	left	H1 is the northernmost shade
A H3 (in)	inches	left	H4 is the southernmost shade
A H4 (in)	inches	left	If the shade height is ~124 inches, the shade is up fully.
Height if sun AW	inches	left	If there is direct sun, then this is the height the shade should be at if direct sun penetration is to be limited to 3 ft from the window.
SunProf	degree	left	Sun profile angle for west façade
Direct sun if > 150	unitless	left	If this value is greater than 150, then there is direct sun (orb of the sun is not blocked by clouds). This assumes that if the ratio of global to diffuse exterior horizontal illuminance is greater than 1.5, there is direct sun. The 1.5 value is derived from physical observations.
Eglo	lux	right	Exterior horizontal global illuminance
Edif	lux	right	Exterior horizontal diffuse illuminance
Evglo.W	lux	right	Vertical global illuminance on the west façade
A Ivs.106 (cd/m2)	cd/m2	right	Average west window luminance (from 4 ft above the floor to the ceiling)
A Iwpi1 (lux)	lux	right	Total workplane illuminance (daylight+electric light) at the first workstation nearest the west window wall (29 inches above finished floor)
B H5.M1w (in)	inches	left	Height of shade group in Area B at west-facing window
B H6.M2w (in)	inches	left	H5 is the northernmost shade in Area B
B H7.M3w (in)	inches	left	H7 is the southernmost shade in Area B
Height if sun BW	inches	left	If there is direct sun, then this is the height the shade should be at if direct sun penetration is to be limited to 3 ft from the window.
SunProf	degree	left	Same as above
Direct sun if > 150	unitless	left	Same as above
Eglo	lux	right	Same as above
Edif	lux	right	Same as above
Evglo.W	lux	right	Same as above
B Ivs.108 (cd/m2)	cd/m2	right	Average west window luminance (from 4 ft above the floor to the ceiling)
B Iwpi1 (lux)	lux	right	Total workplane illuminance (daylight+electric light) at the first workstation nearest the west window wall (29 inches above finished floor)
B H8.M4s (in)	inches	left	Height of shade group in Area B at south-facing window
B H9.M7s (in)	inches	left	H8 is the westernmost shade in Area B
B H10.M9s (in)	inches	left	H11 is the easternmost shade in Area B
B H11.M5s (in)	inches	left	If there is direct sun, then this is the height the shade should be at if direct sun penetration is to be limited to 6 ft from the window.
Height if 6' BS	inches	left	If there is direct sun, then this is the height the shade should be at if direct sun penetration is to be limited to 6 ft from the window.
South profile	degree	left	Sun profile angle for south façade
Direct sun if > 150	unitless	left	Same as above
Eglo	lux	right	Same as above
Edif	lux	right	Same as above
Evglo.S	lux	right	Vertical global illuminance on the south façade
B Ivs.dist1.S (cd/m2)	cd/m2	right	Average south window luminance (from 4 ft above the floor to the ceiling)
B Idist5	lux	right	Total workplane illuminance (daylight+electric light) at the sixth workstation from the west window wall (48 inches above finished floor)

Variables plotted in the exterior solar conditions plots are defined similarly to above.

4/30/04

Area A

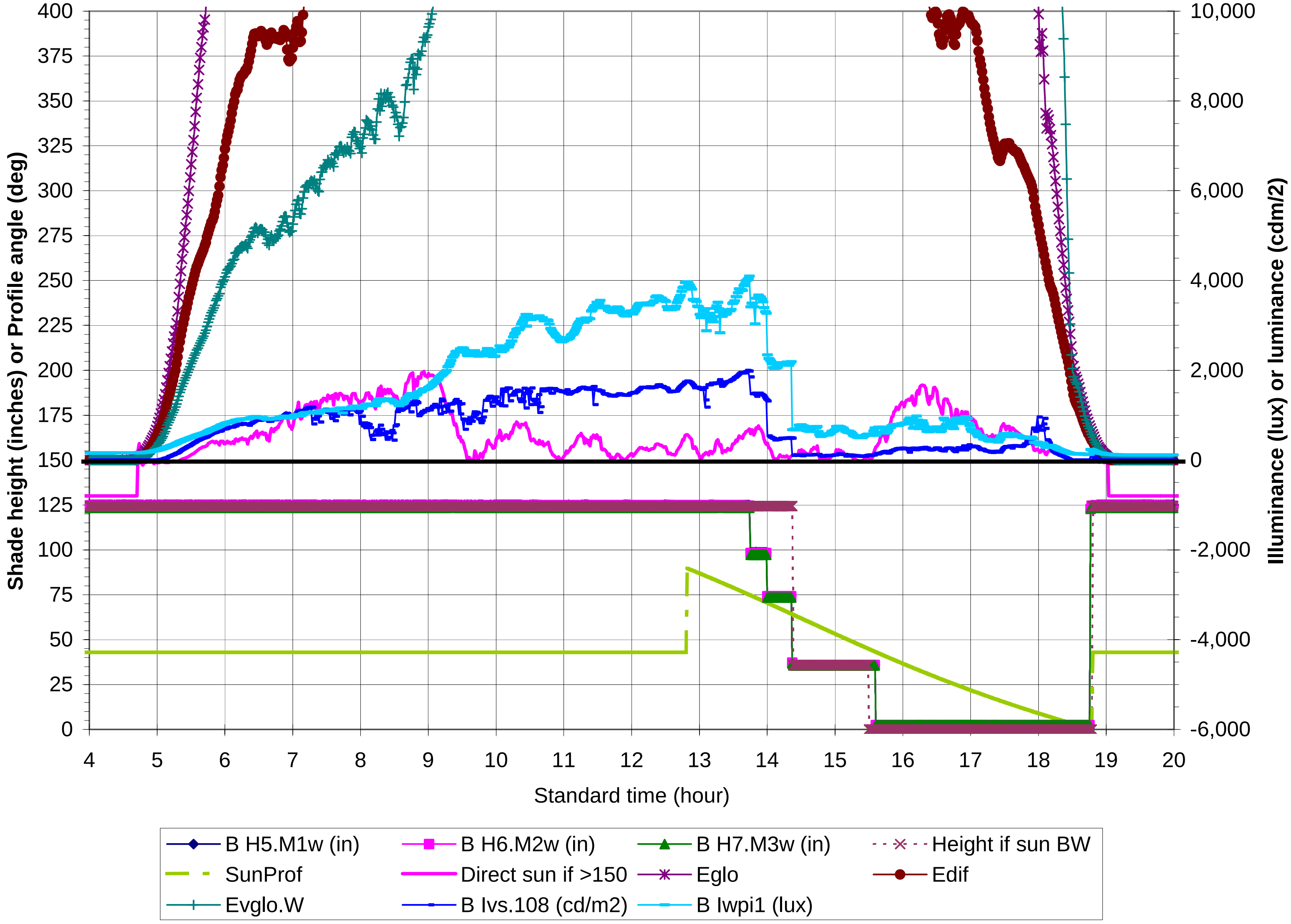
West



4/30/04

Area B

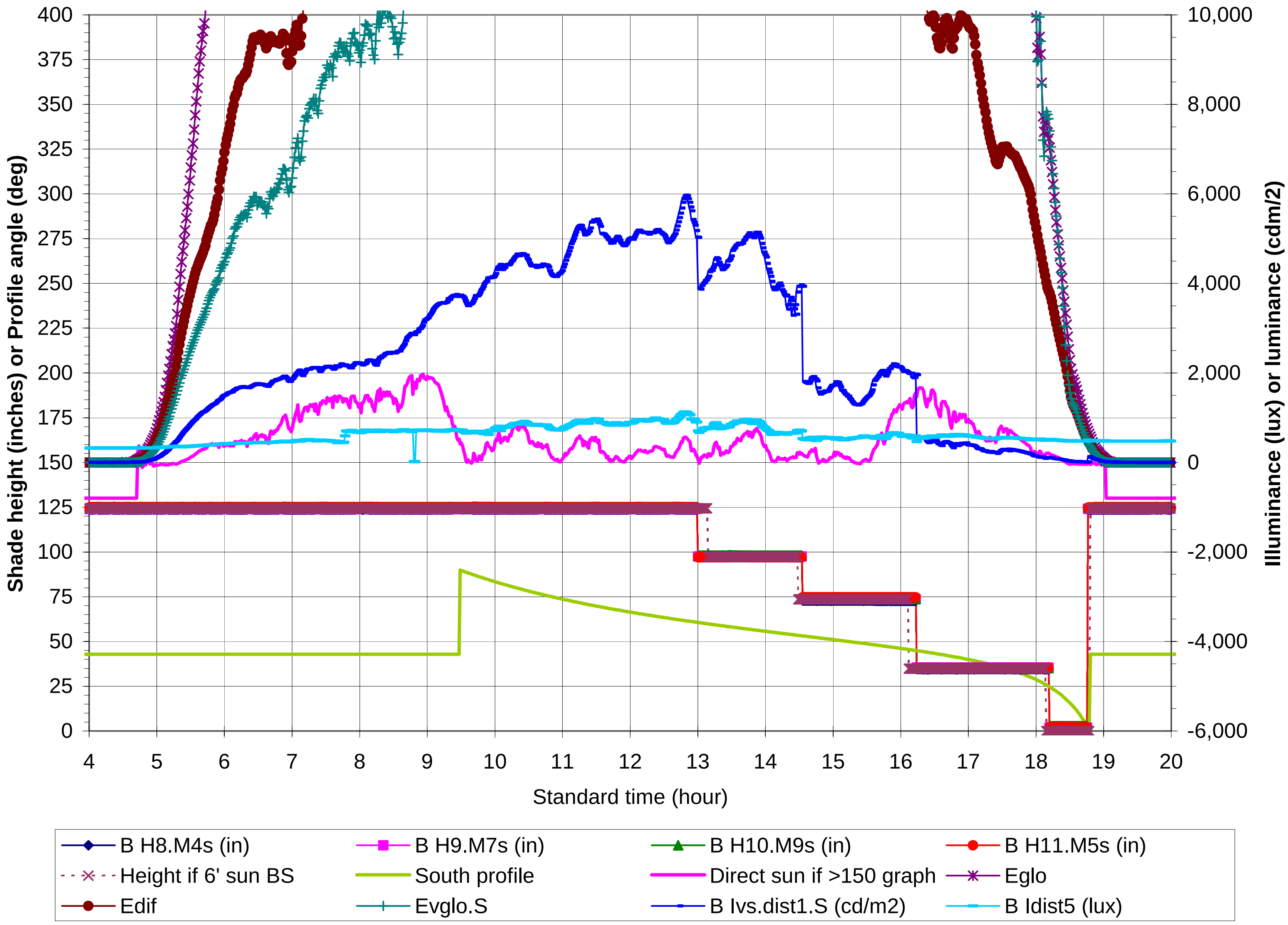
West



4/30/04

Area B

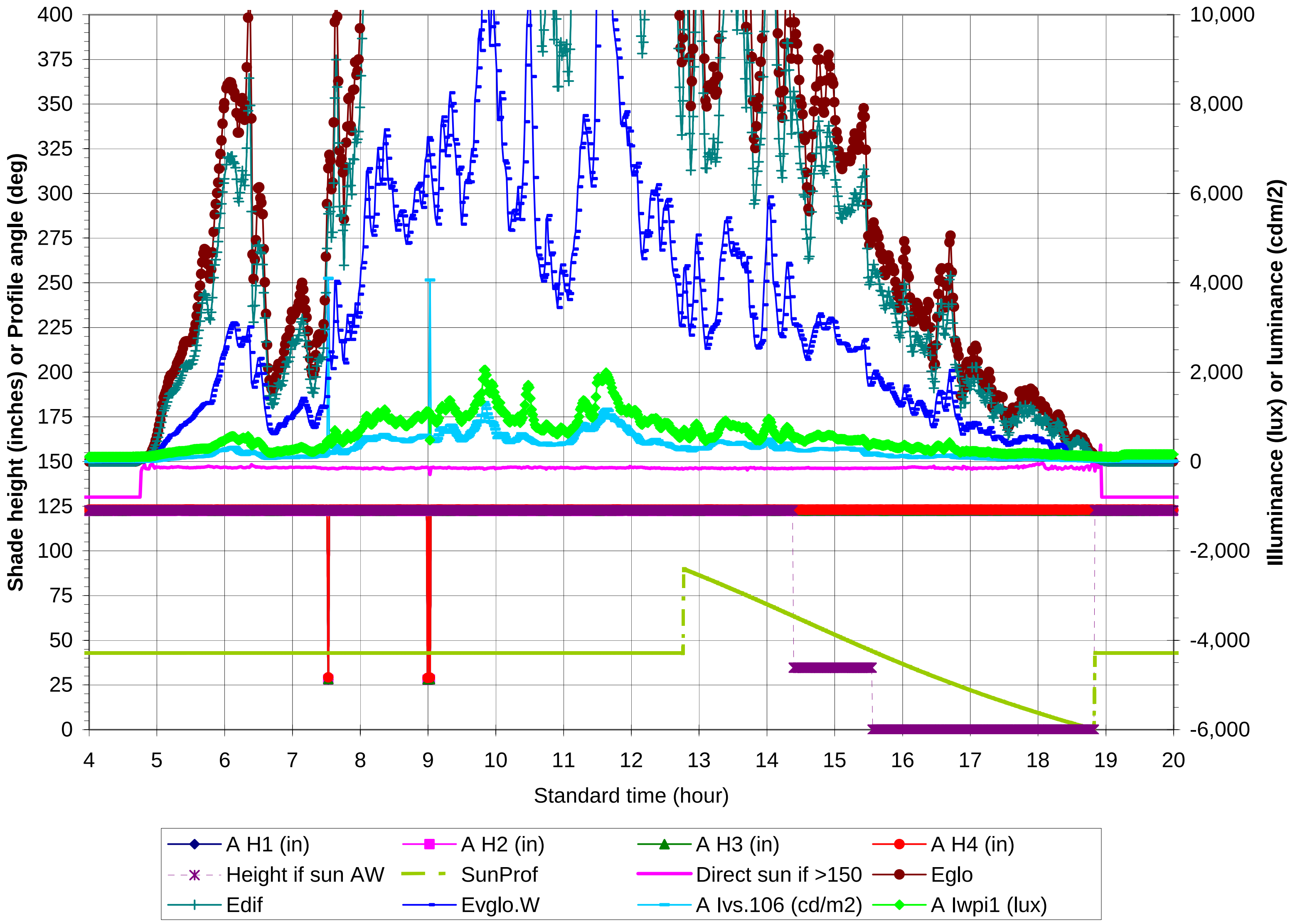
South



5/3/04

Area A

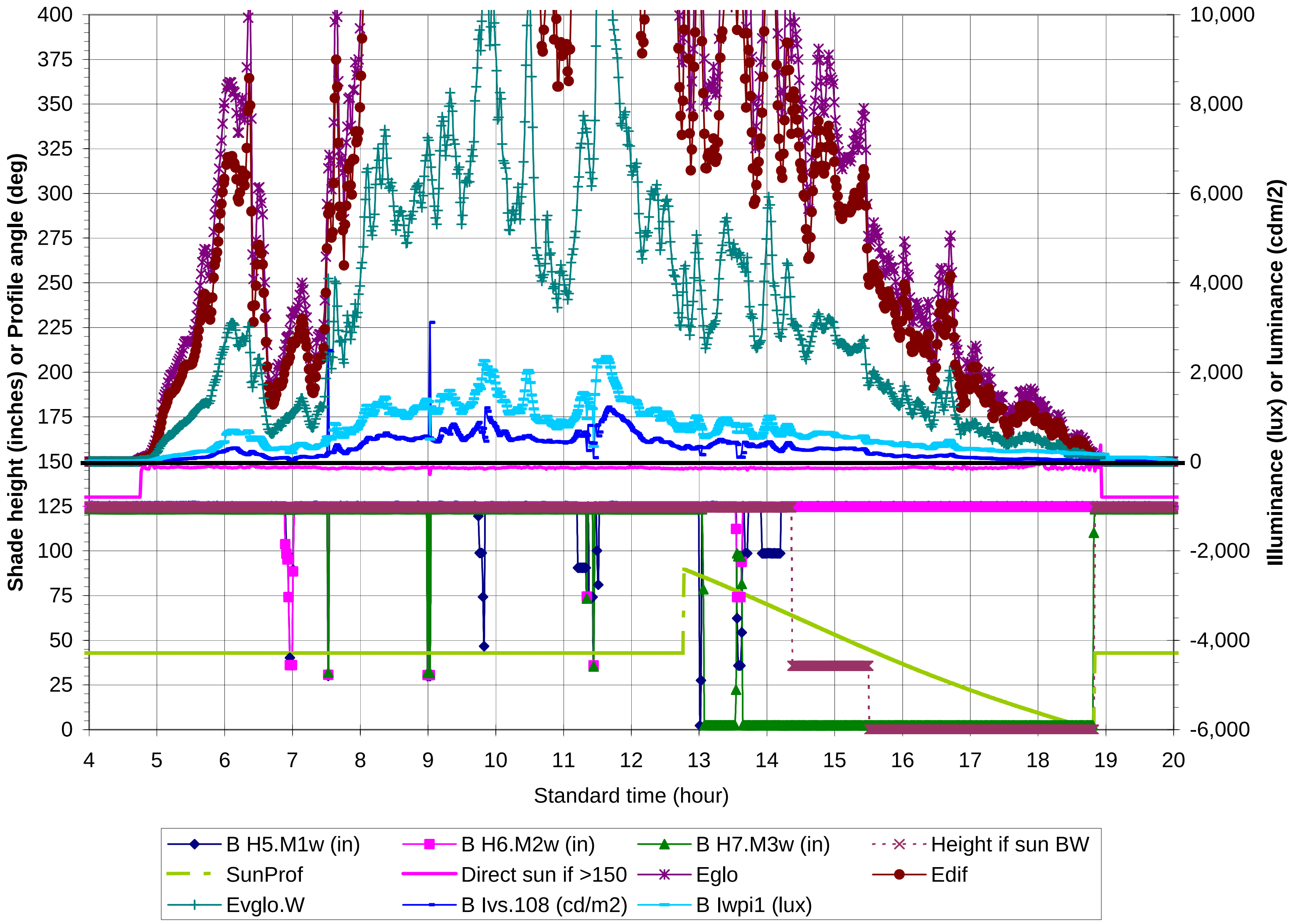
West



5/3/04

Area B

West



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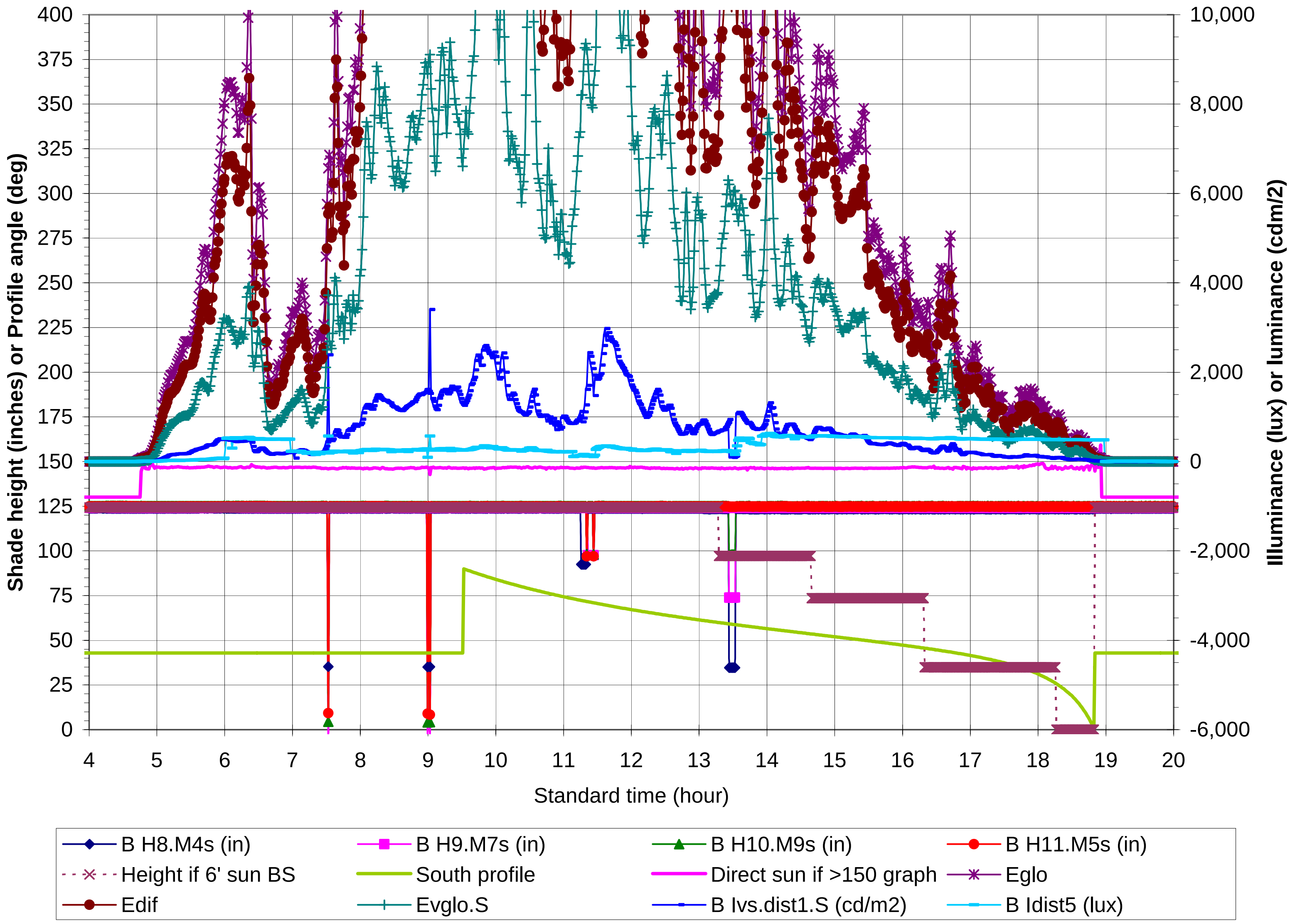
Area B

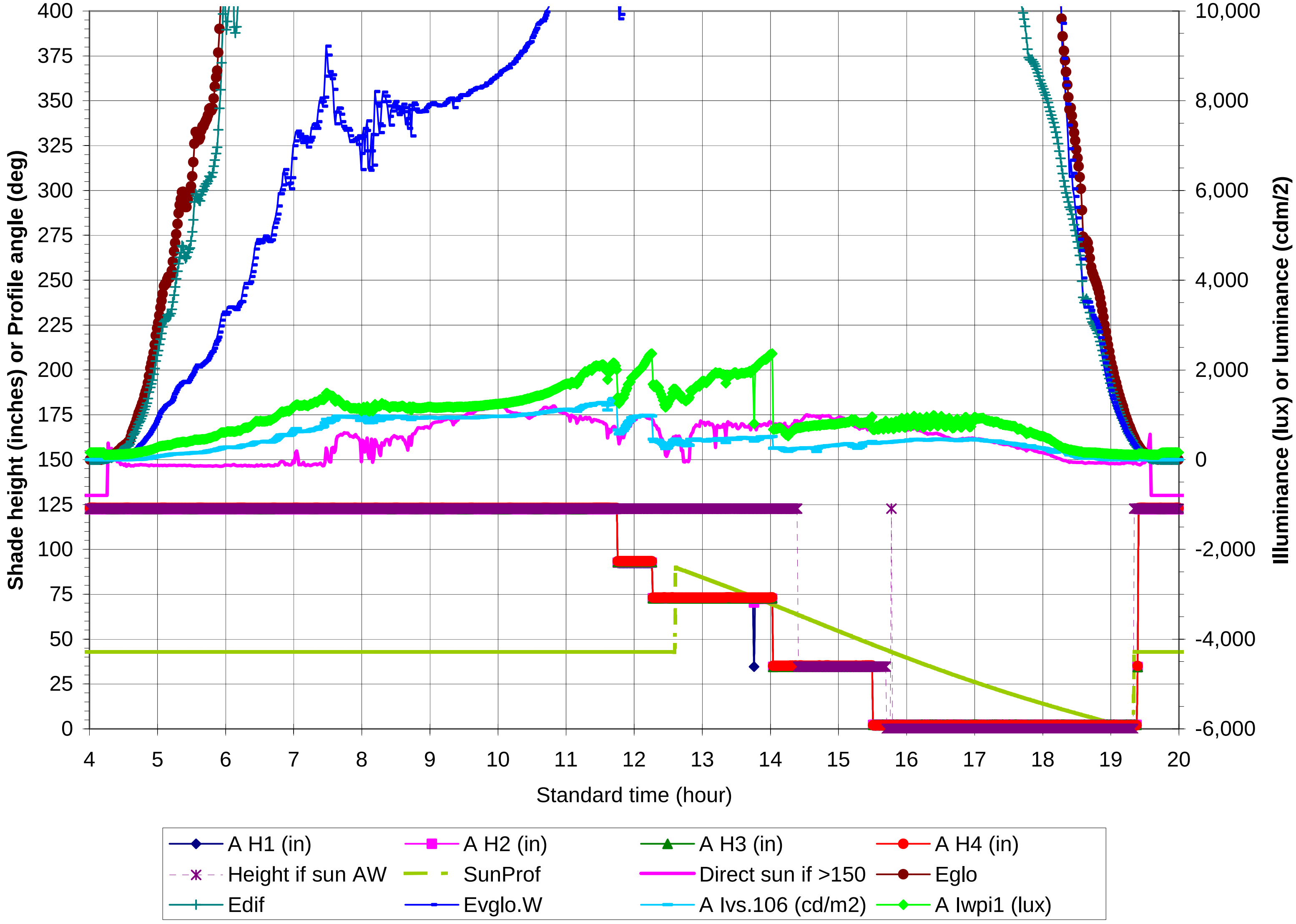
South



6/7/04

Area A

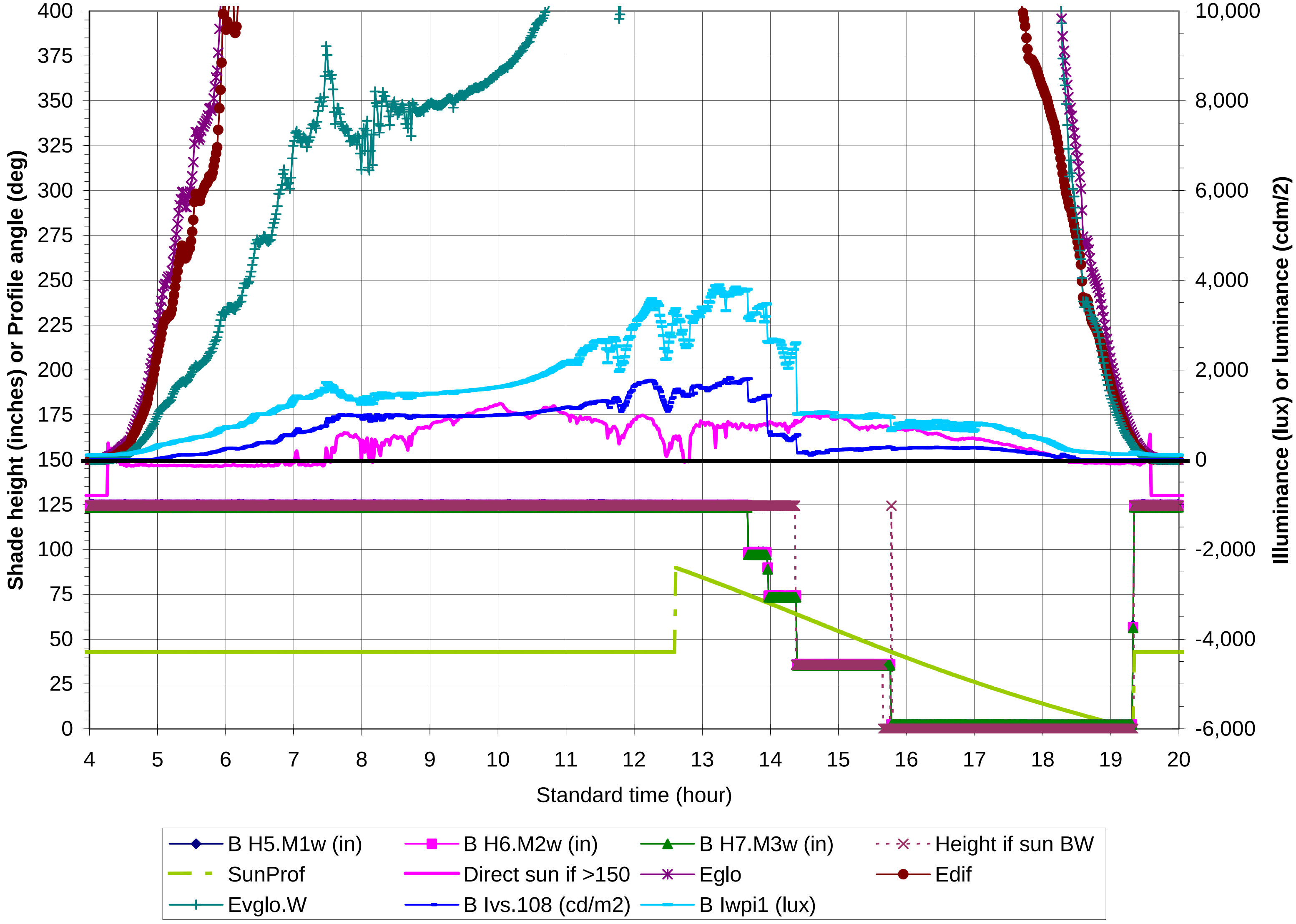
West



6/7/04

Area B

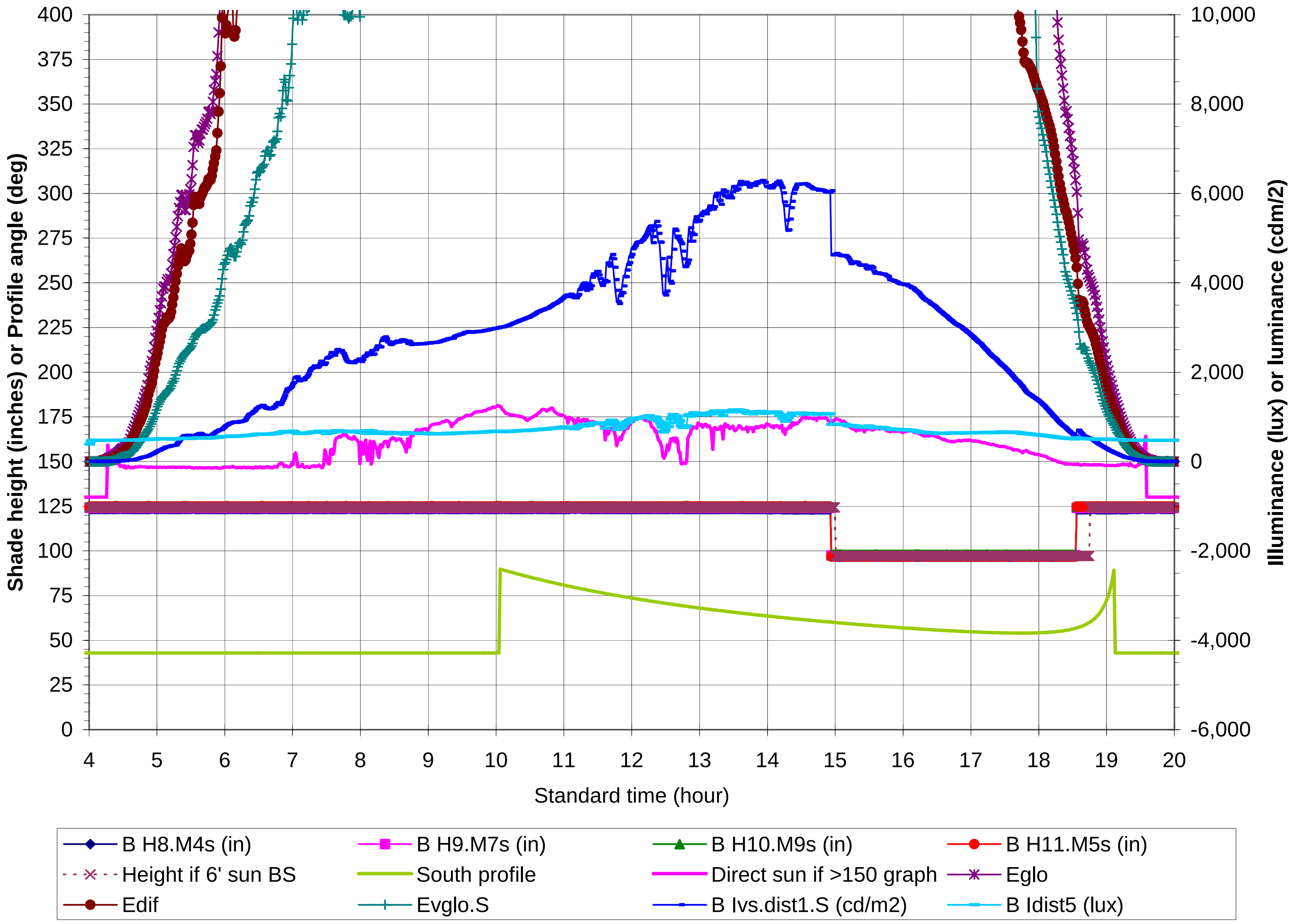
West



6/7/04

Area B

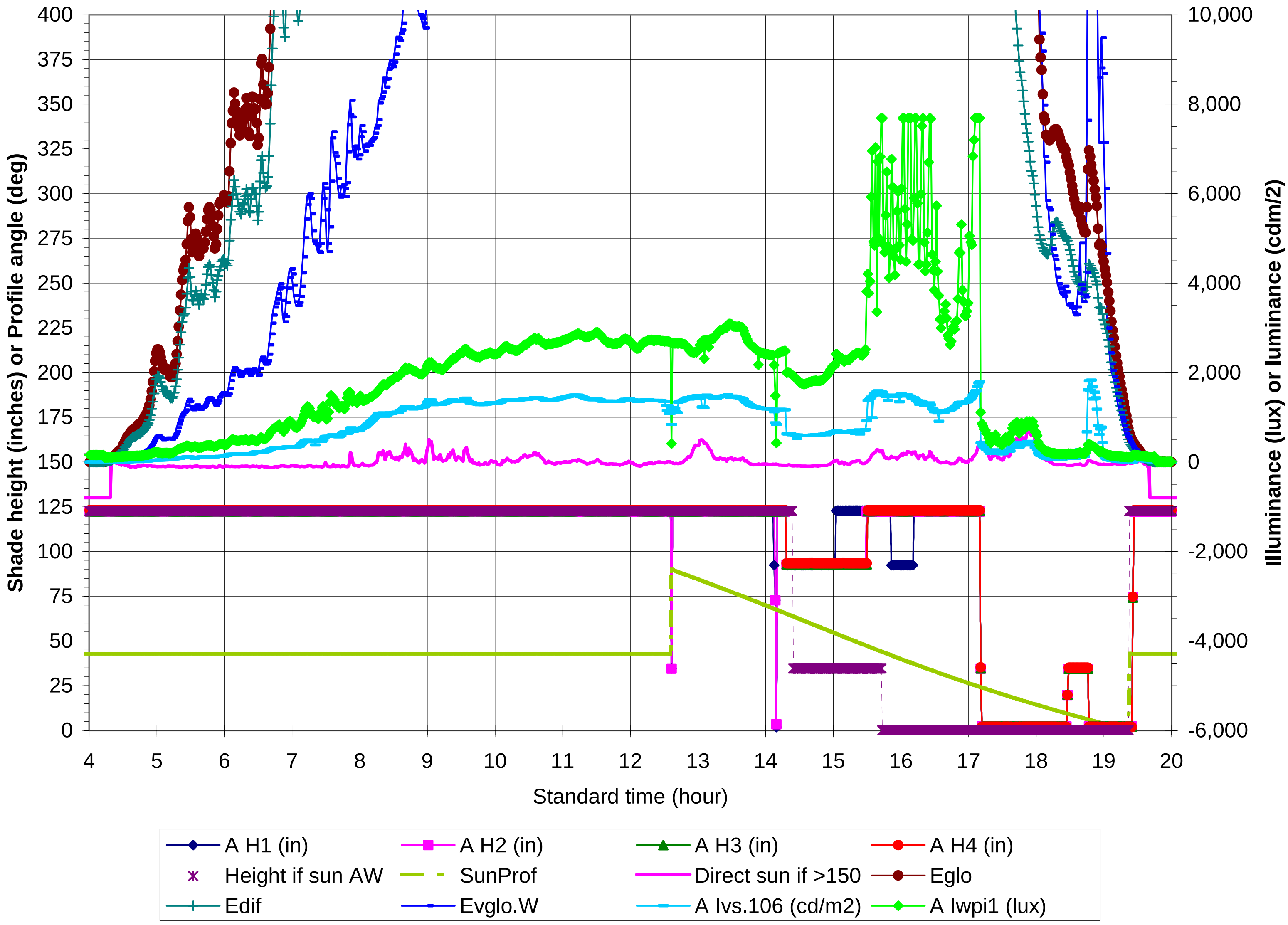
South



6/11/04

Area A

West



6/11/04

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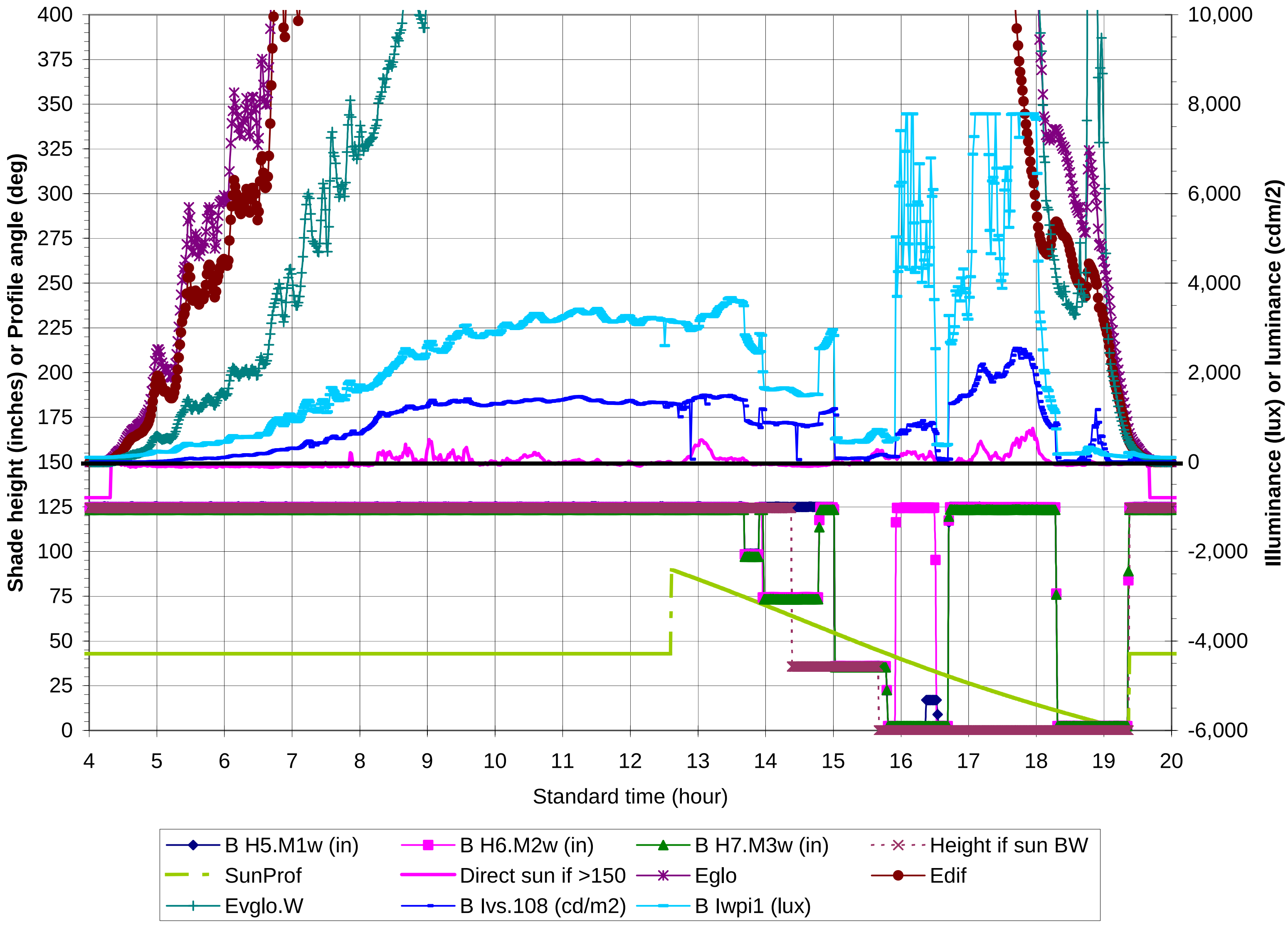

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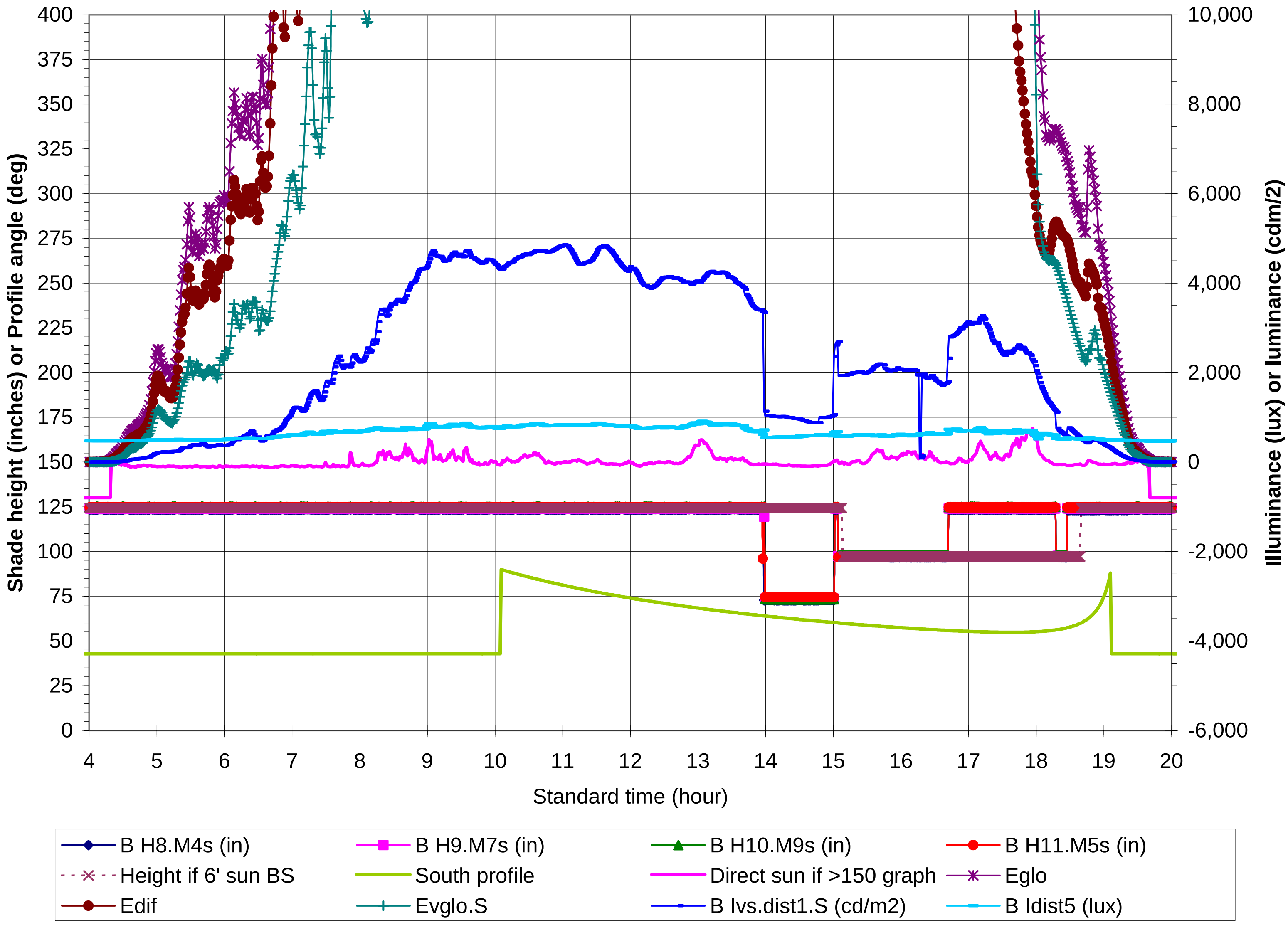

9/15/04

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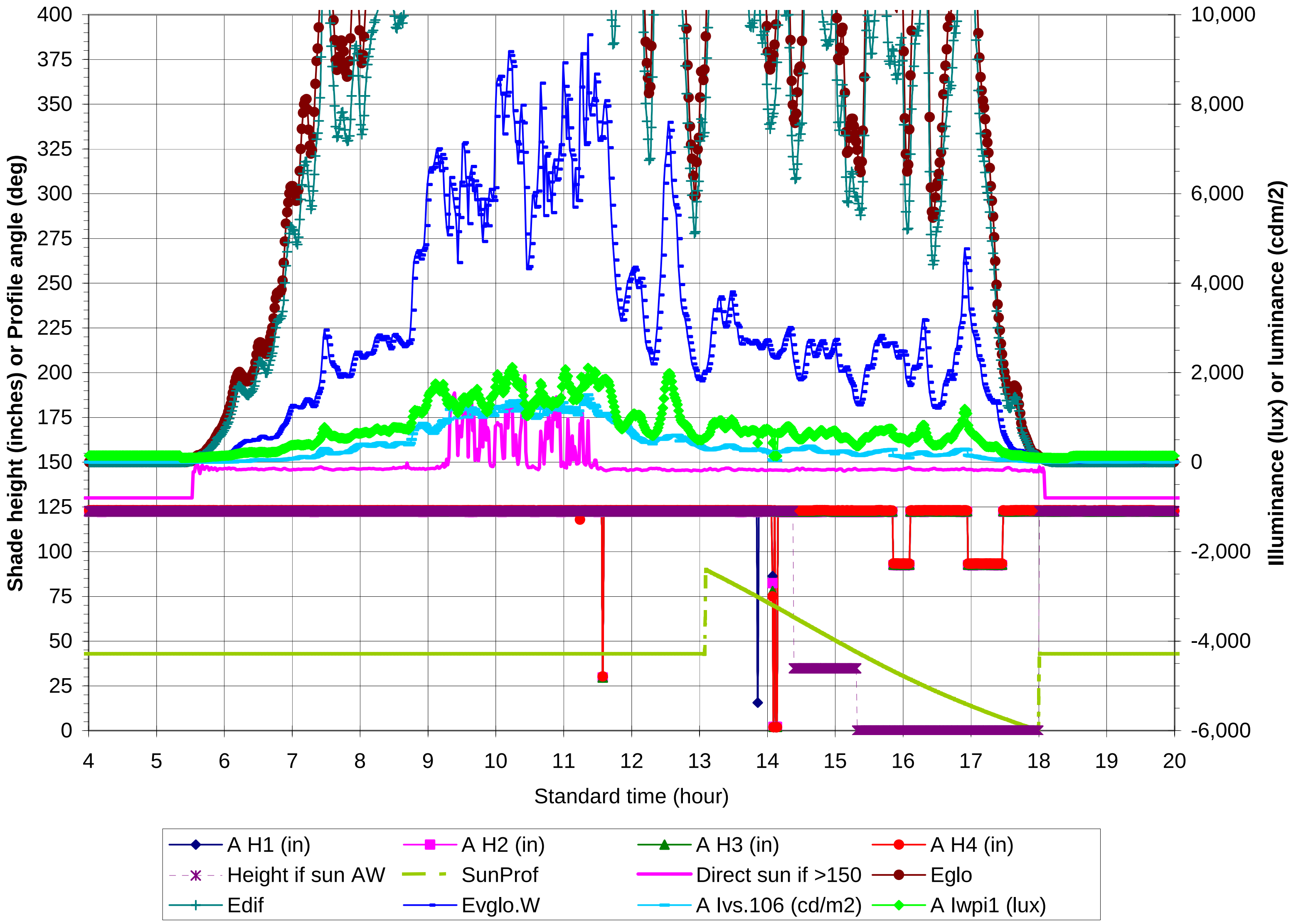
West



9/15/04

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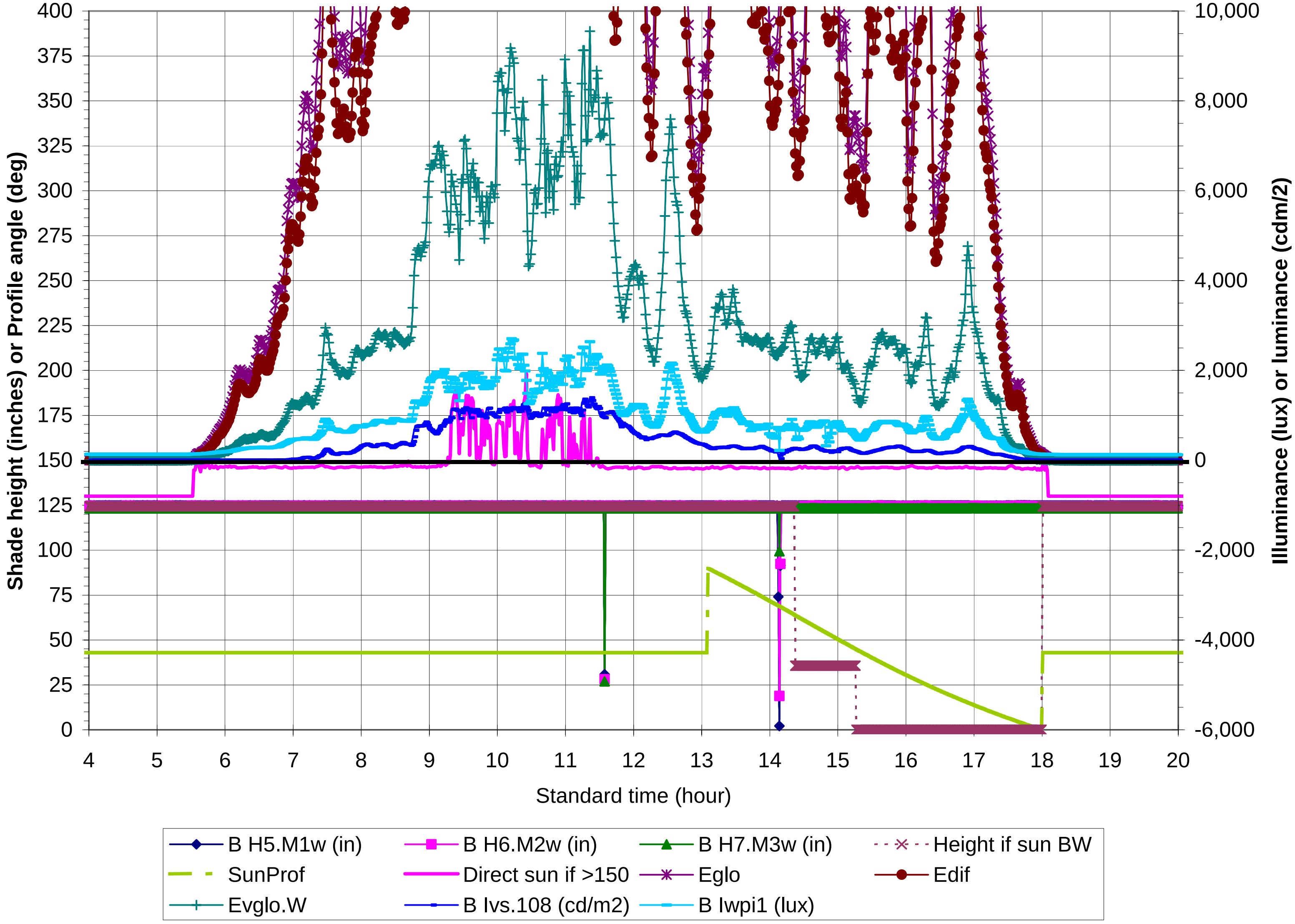

9/15/04

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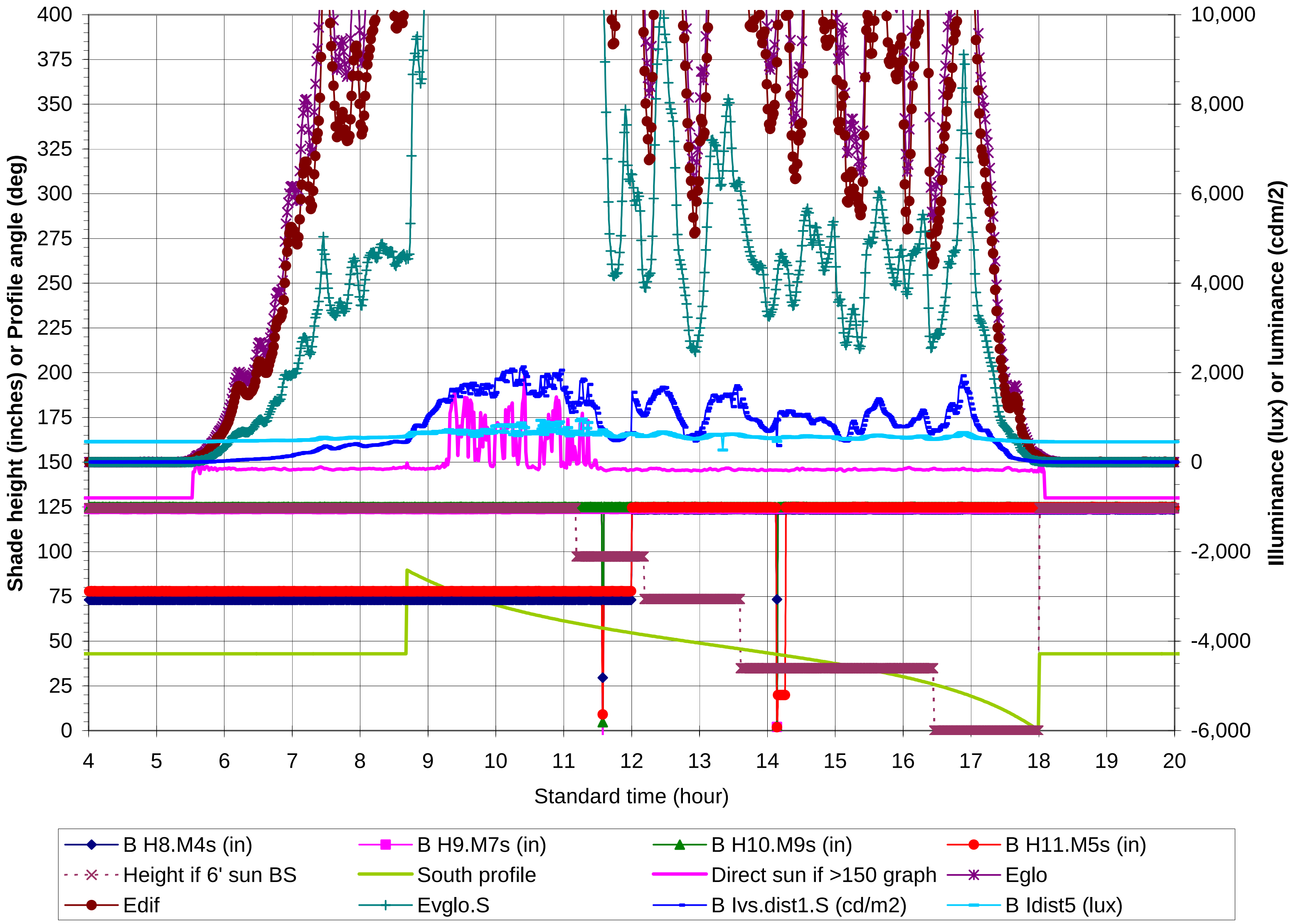

9/16/04

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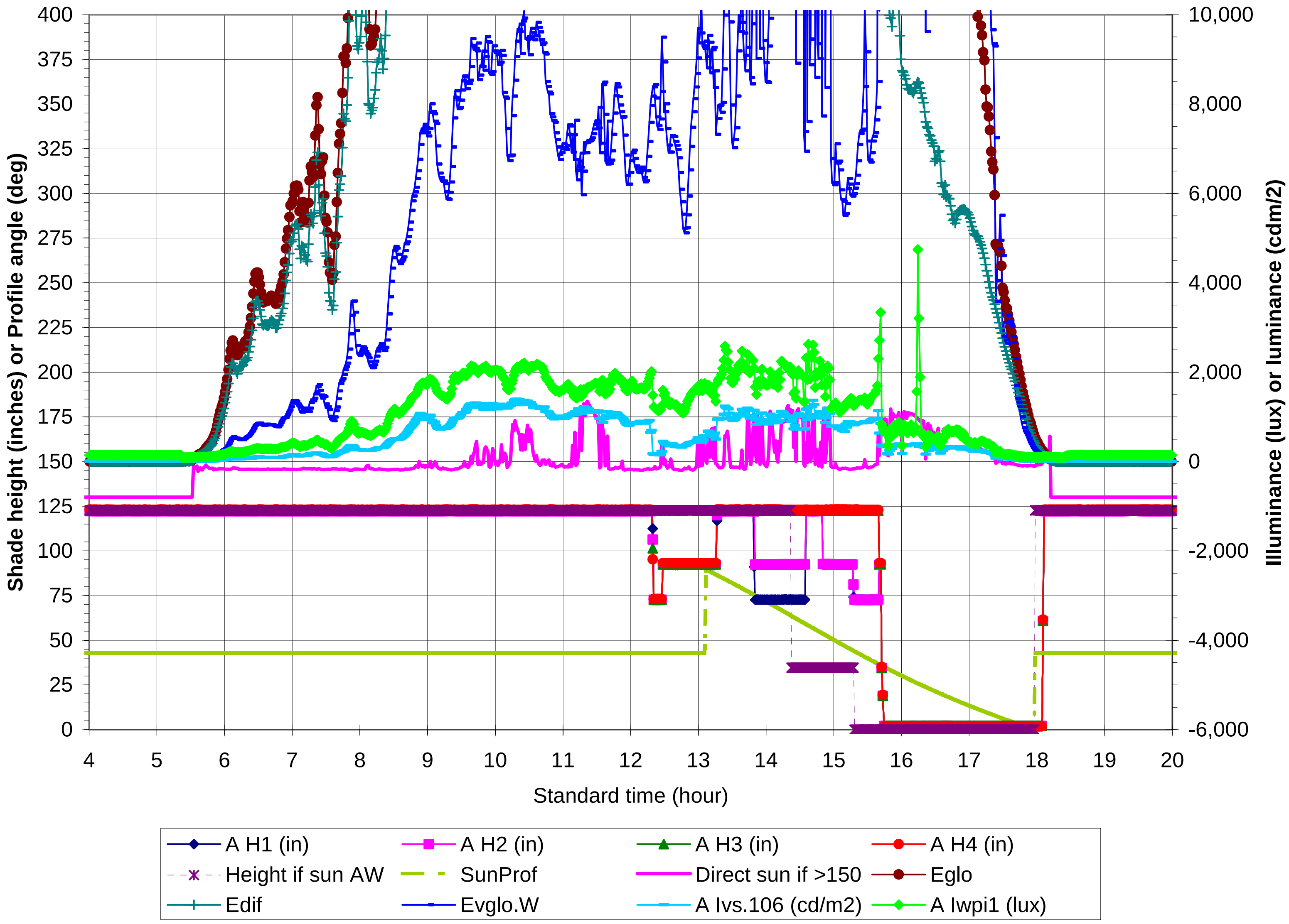

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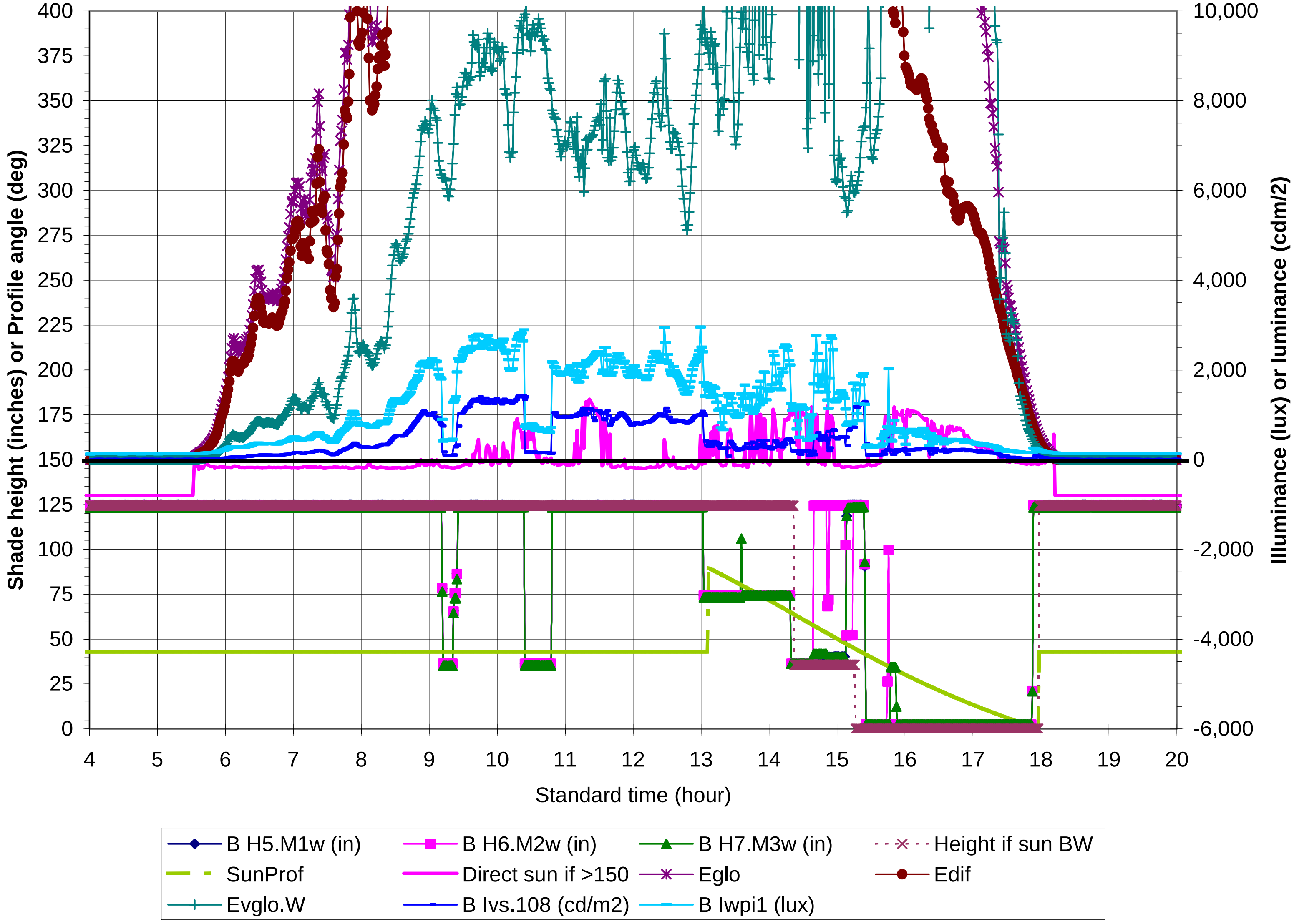

9/16/04

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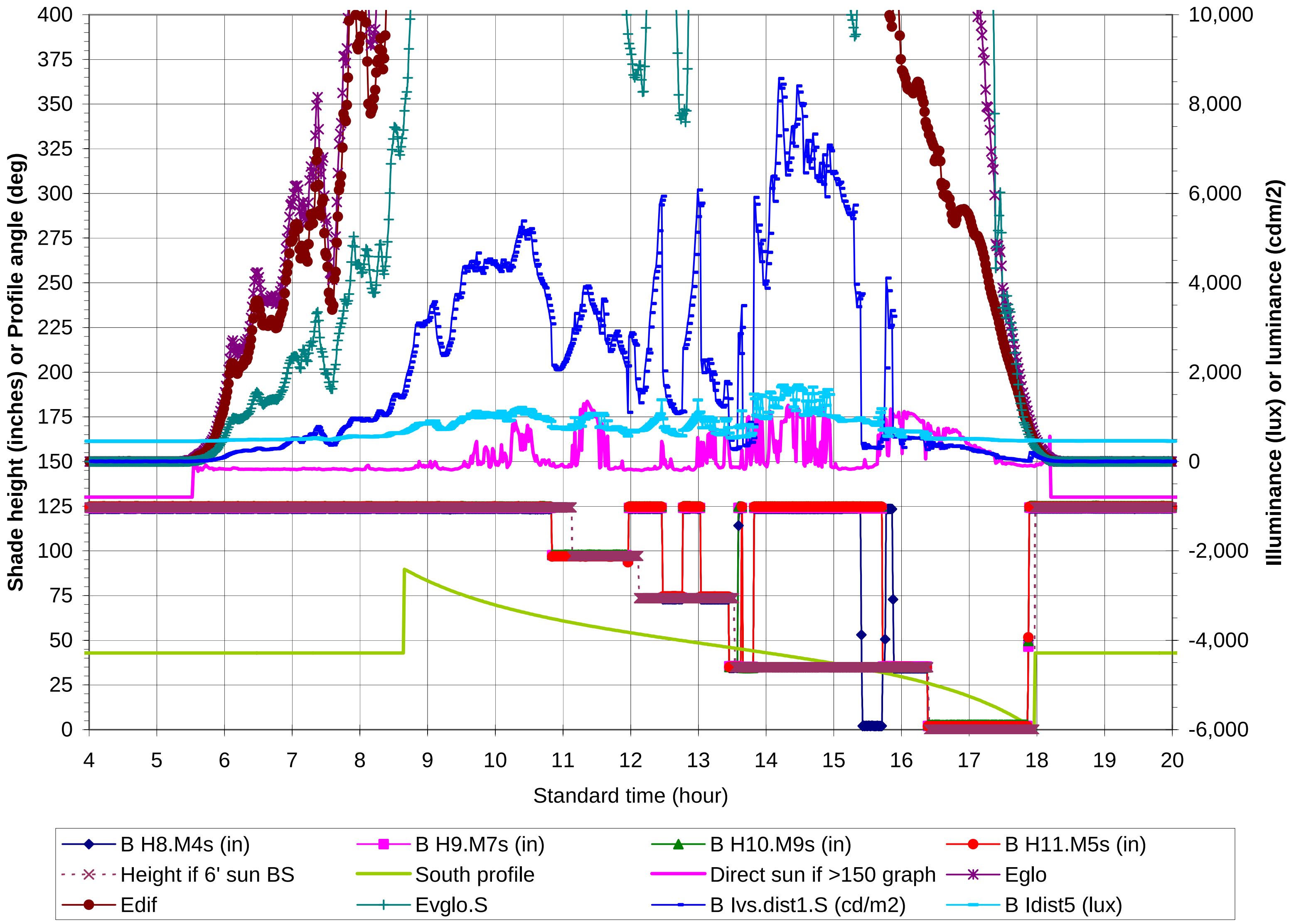

9/17/04

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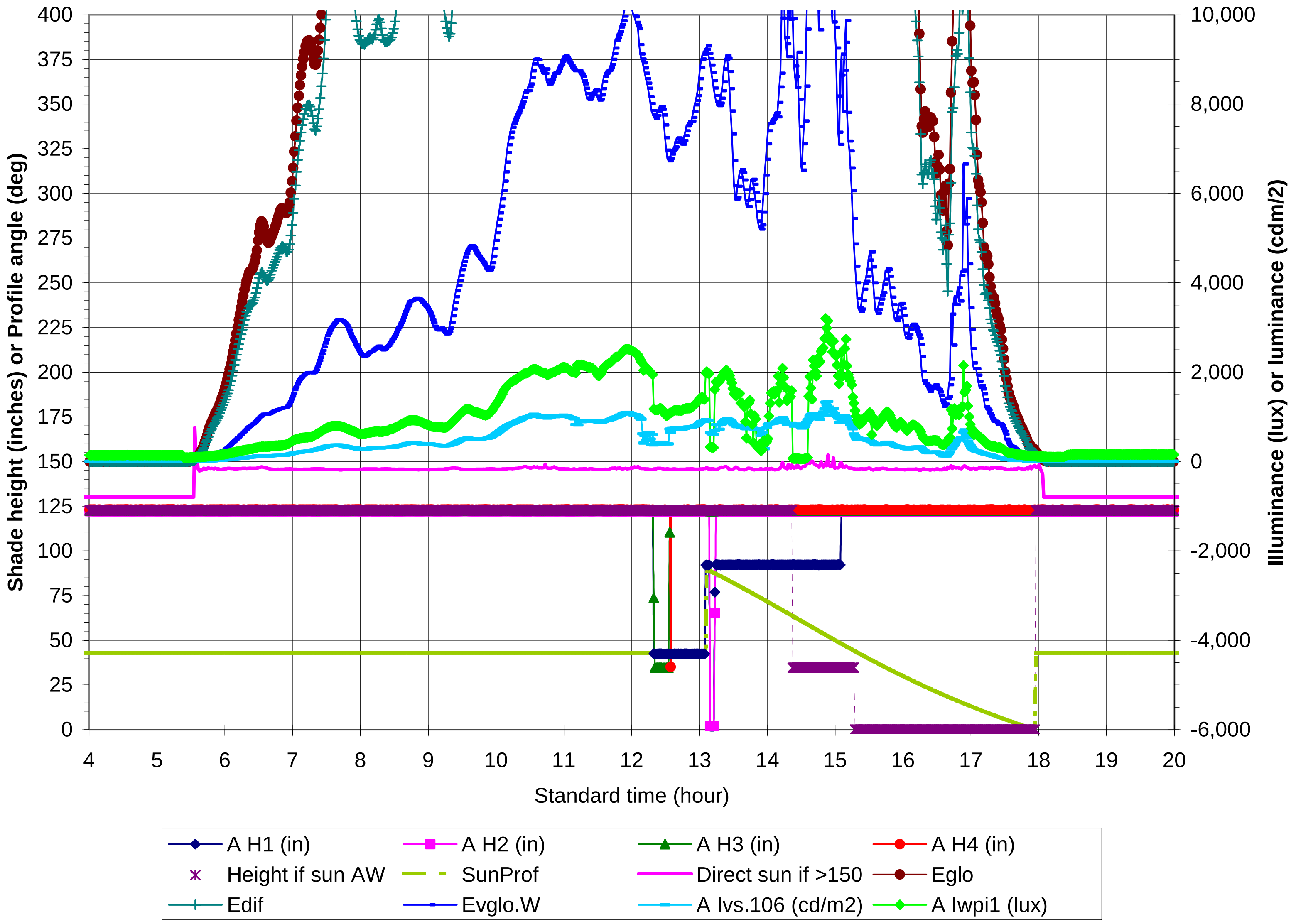
West



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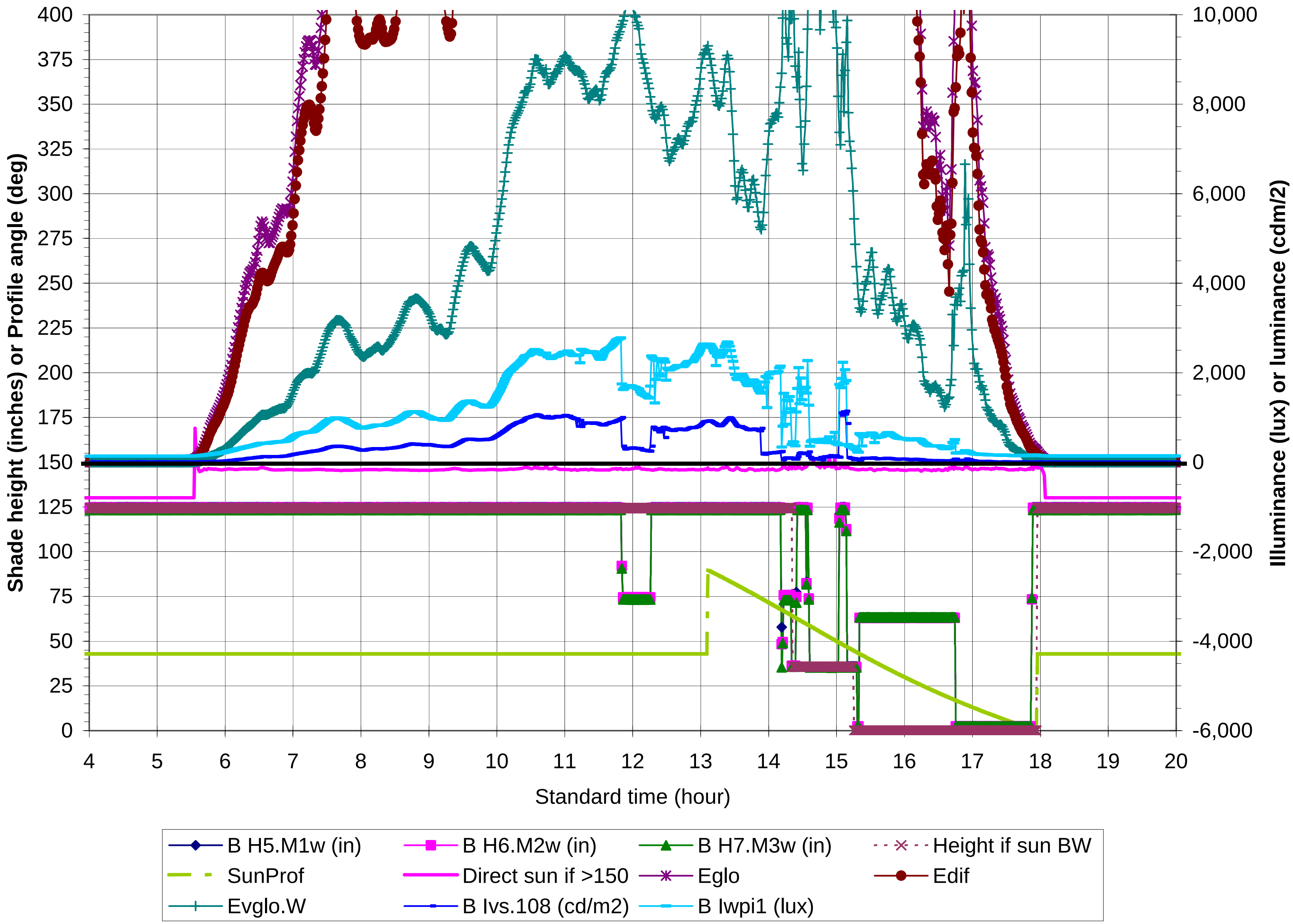
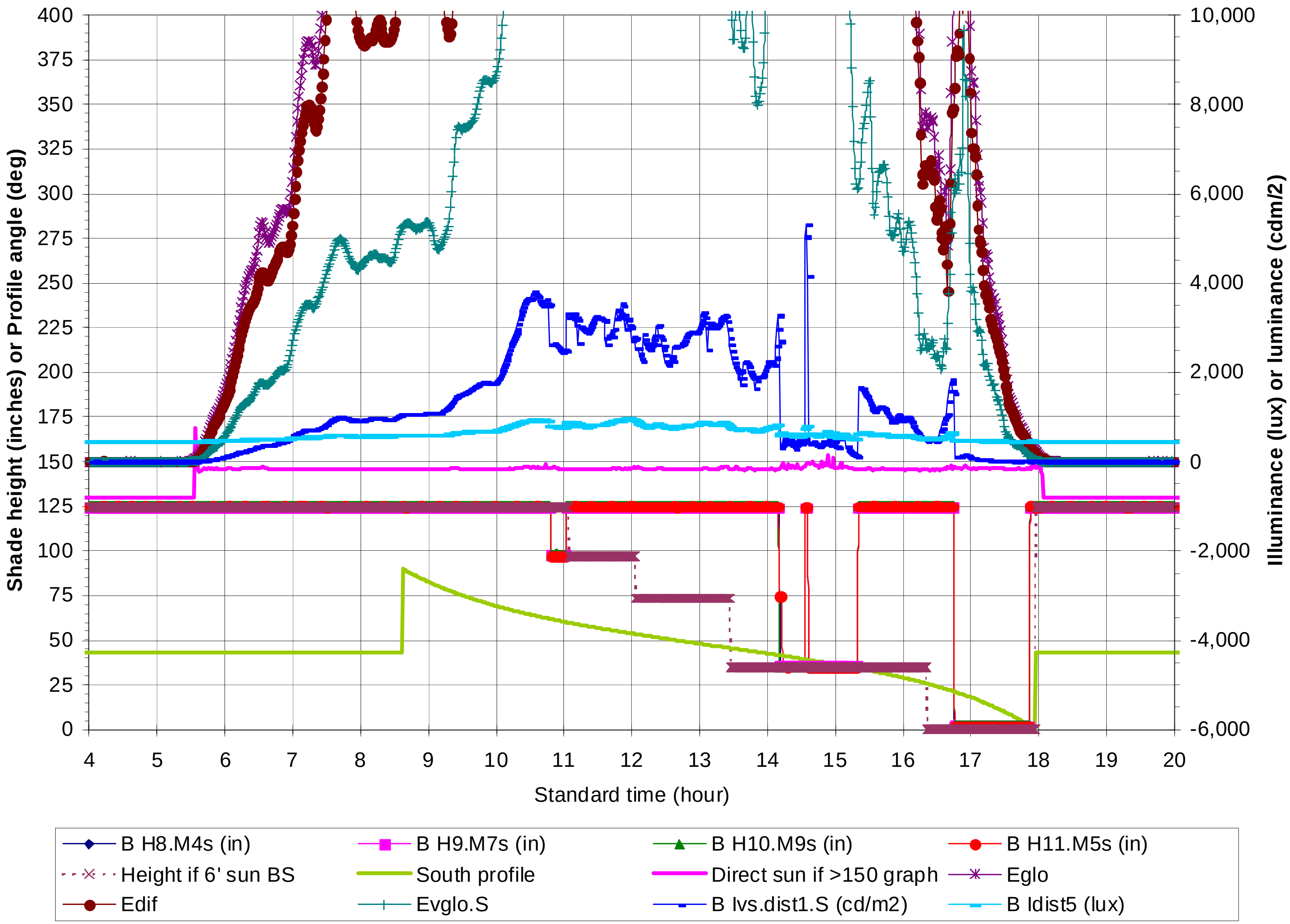


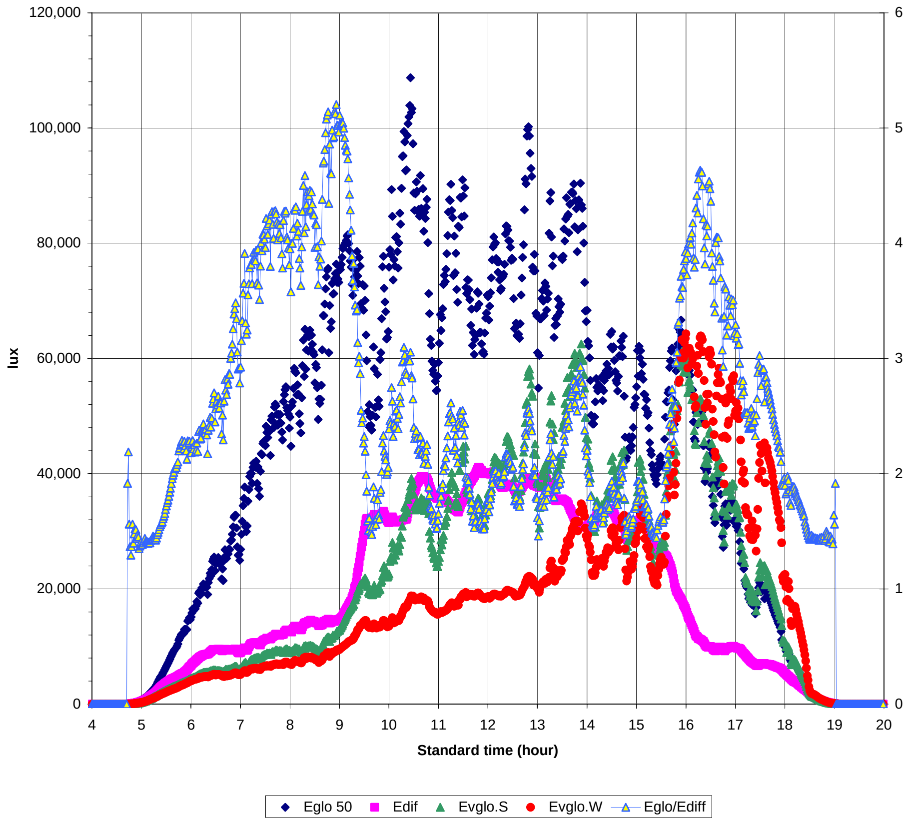
9/17/04

Area B

South



4/30/04



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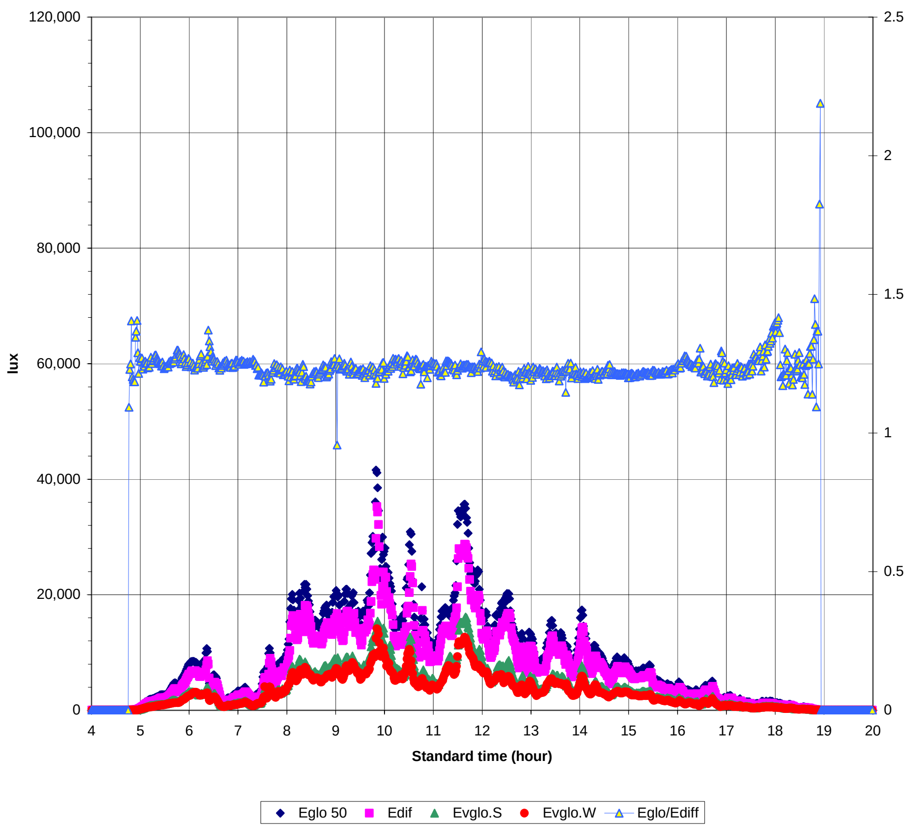
Evglo.S
Evglo.W
Eglo/Ediff

5/3/04



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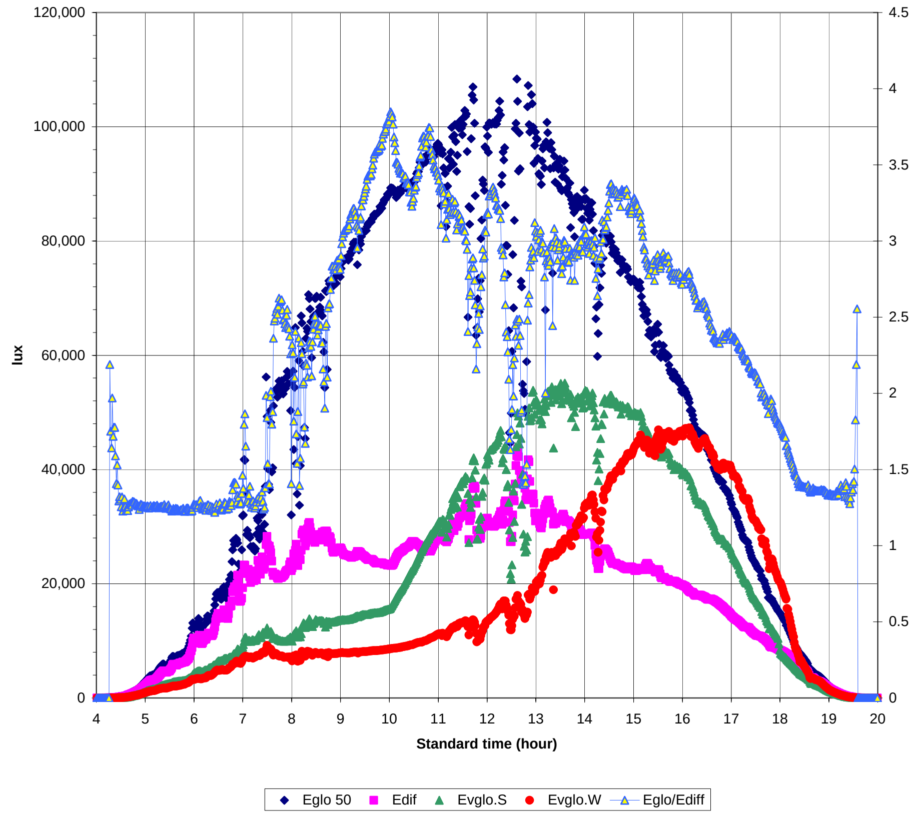
Evglo.S
Evglo.W
Eglo/Ediff

6/7/04



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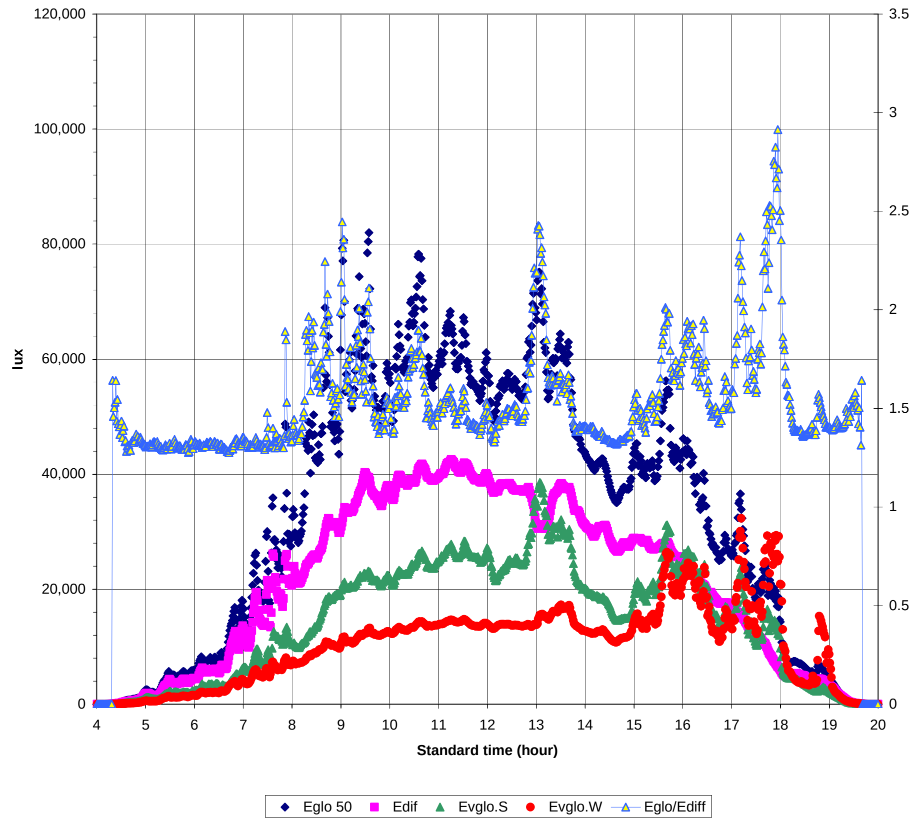
Evglo.W
Eglo/Ediff

6/11/04



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Standard time (hour)
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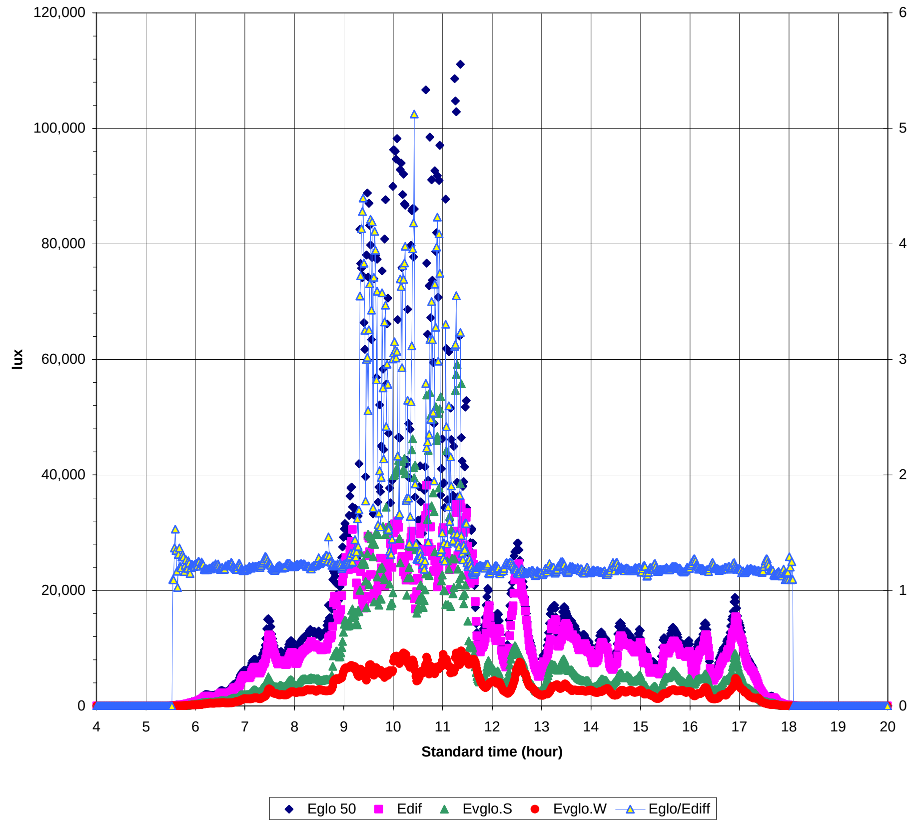
Evglo.W
Eglo/Ediff

9/15/04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Standard time (hour)
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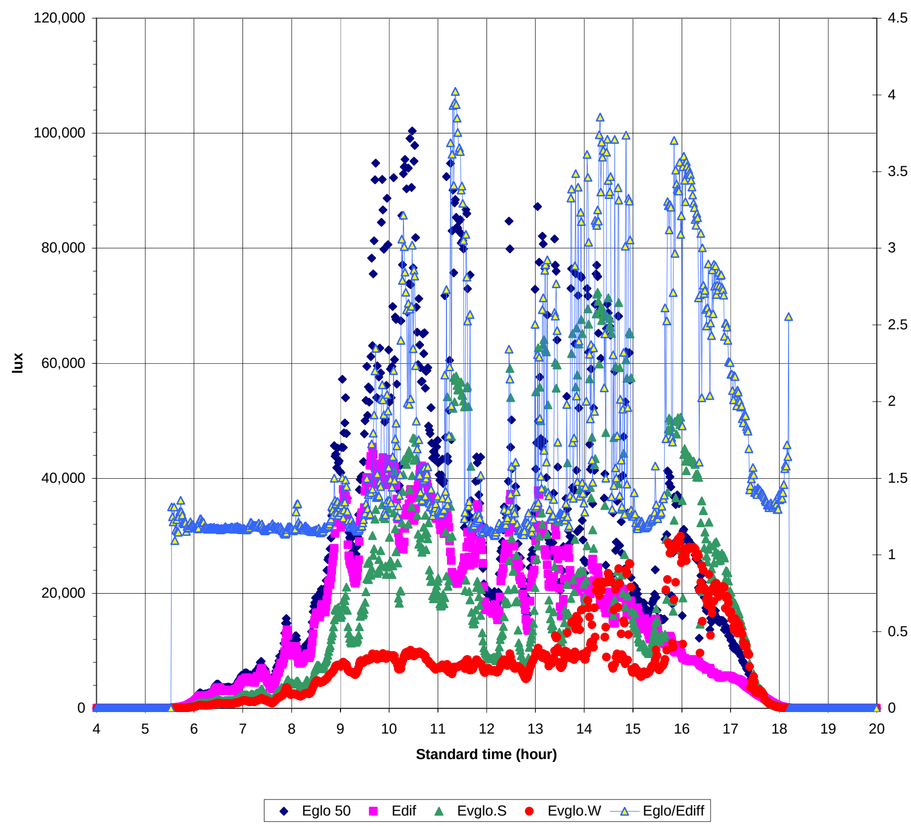
Edif
Evglo.S
Evglo.W
Eglo/Ediff

9/16/04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Standard time (hour)
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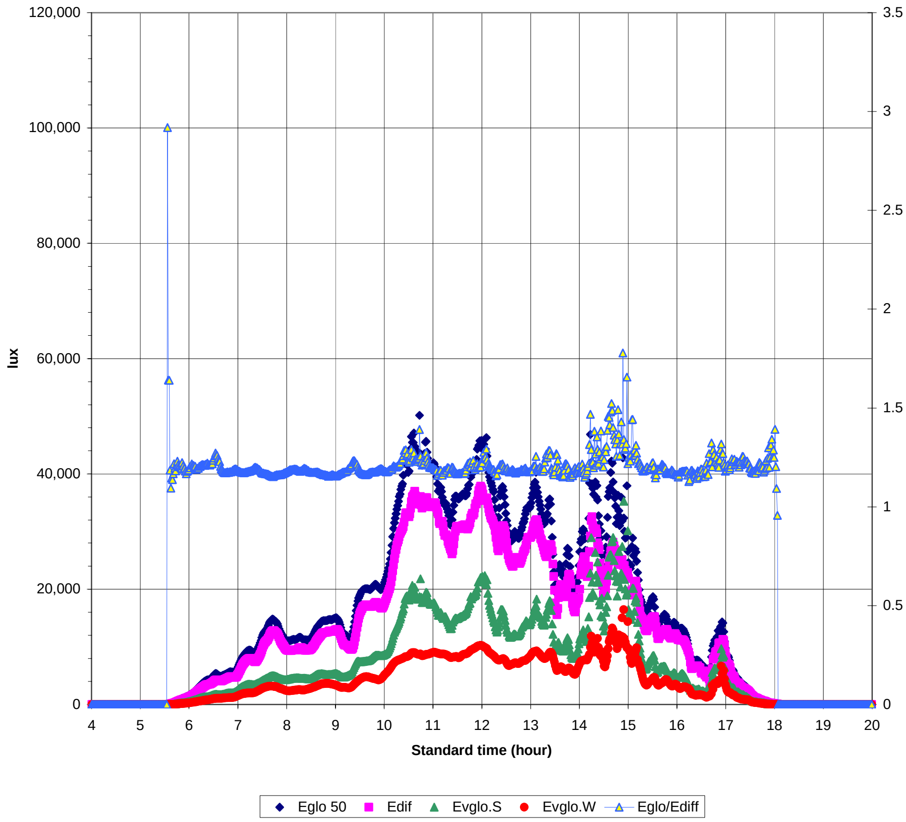
Edif
Evglo.S
Evglo.W
Eglo/Ediff

9/17/04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Standard time (hour)
Eglo 50
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Evglo.W
Eglo/Ediff

Appendix D

LIGHTING CONTROLS SPECIFICATIONS

PART 1 -

PART 2 - GENERAL

2.1 RELATED DOCUMENTS

A. Drawings and general provisions of the Contract, including General and Supplementary Conditions and Division 1 specification sections, apply to this Section.

B. Sequence of Operation as shown on the Drawings and in this Specification.

C. Lighting Control Schedule as included in this Specification.

D. LCS Supplier shall coordinate all of the work in this Specification with all trades covered in other sections of the specifications.

E. Related Sections to include the following:
   1. Division 16, Section 16510, Lighting Fixtures and Ballasts
   2. Division 12, Section 12494, Roller Shades
   3. Division 1, Sections 01100, 01270, 01330, 01400, 01600 and 01700

2.2 SUMMARY

A. Scope: This Specification includes the following:
   1. Furnish a fully functional digital addressable lighting control system for the general control, configuration, and management of designated lighting fixtures via local area network and lighting control network in accordance with this Specification and the project construction documents.
   2. Furnish all hardware.
   3. Furnish all system engineering, programming, testing, start-up and commissioning required for a complete and operational system.

B. By others: The Electrical Installation Contractor shall furnish and install the following under separate contract:
   1. All wiring installation requirements including, but not limited to cables, conduits, raceways, electrical boxes, fittings and supports for these wiring installation requirements.

2.3 DEFINITIONS

A. **Address:** A way of identifying a specific device or groups of devices. Digital Lighting Interface Interface (DALI) systems have three levels of addresses: broadcast, group, and individual. Individual addresses are required to perform most queries and to make group assignments. Messages can be sent to individual devices, groups of devices, or to all devices (broadcast).

B. **BMS**: Building management system.

C. **Broadcast Command**: A command that is received by all devices on the network. As an example, a broadcast off command will turn off every device that receives the command and is able to process it.

D. **Channel**: A fixture or group of fixtures controlled simultaneously as a single entity. Also known as a "zone."

E. **DALI**: Digital Addressable Lighting Interface: IEC Standard 60929, Annex E & G or most recent revision or equivalent ANSI standard.

F. **Fade**:
  1. Fade Override: The ability to temporarily set fade times to zero for all lighting scenes.
  2. Fade Rate: The time it takes each channel to arrive at the next scene, depending on the degree of change in lighting level.
  3. Fade Time: The time it takes a channel to fade from one lighting scene to another.

G. **FC**: Footcandle.

H. **Group**: A designated group of luminaries that will turn on and off and dim in unison. Also called a zone.

I. **LAN**: Local Area Network.

J. **LCS**: Lighting Control System.

K. **LCS Supplier**: Lighting Control System Supplier

L. **LED**: Light-Emitting Diode indicator light.

M. **Lighting Control Network**: A digital network.

N. **DALI Lighting Control Network**: Also called a Loop. A powered digital communication network with 64 DALI addresses.

O. **Loop**: A powered Lighting Control Network conforming to the DALI standard.

P. **Monitoring**: Acquisition, processing, communication, and display of equipment status data, metered electrical parameter values, power quality evaluation data, event and alarm signals, tabulated reports, and event logs.

Q. **NRTL**: Nationally Recognized Testing Laboratory.

R. **PC**: Personal Computer using IBM protocols and Microsoft operating system, sometimes plural as "PCs."

S. **PIR**: Passive Infrared.

T. **Scene**: A lighting state or effect created by adjusting several channels of lighting to the desired intensity.

U. **Site**: The New York Times new building location at 620 8th Avenue, New York, NY.

V. **Specification**: Lighting Controls System Specification 16575

W. **TVSS**: Transient voltage surge suppressor.

X. **Zone**: A designated group of lighting fixtures that can be controlled in unison.

2.4 SUBMITTALS

A. General: Submittals shall be in hard-copy and electronic format.

  1. Hard-copies shall be in quantities consistent with that specified in Division 1 of these specifications.
  2. Electronic format shall be on a CD-ROM in the following file types:
     a. MS Office Word 2003
     b. MS Office Excel 2003
     c. MicroStation version J DGN

d. AutoCAD 2002 DWG
e. Adobe Acrobat PDF

B. Product Data: List of components for LCS, including dimensions and manufacturers' technical data on features, performance, electrical characteristics, ratings, and finishes. Include a complete Bill of Materials for each type of product indicated.
1. Dimming control components
2. Photo sensors, occupancy sensors
3. LAN components
4. Lighting control network devices
5. Ballasts and lamp combinations compatible with dimmer controls – ballasts and lighting fixtures shall be furnished under separate contract(s)
6. Sound data including results of operational tests of dimming controls
7. Control wire and cable connectors to include identification where each type will be used – wire and connectors shall be furnished and installed by the Electrical Installation Contractor in accordance with LCS Supplier Product Data requirements
8. Control wire and cable to include color and insulation type – wire and connectors shall be furnished and installed by the Electrical Installation Contractor in accordance with LCS Supplier Product Data requirements

C. Shop Drawings: Detail assemblies of standard components, custom assembled for specific application on this Project. Shop drawings shall be delivered in accordance with a schedule developed in consultation between the Owner and the LCS Supplier.

1. Outline Drawings: Indicate dimensions, weights, location arrangement of LCS components for each floor from the cellar to floor 28, inclusive.
2. Floor plans: Show location, orientation, and coverage area of each sensor for each floor including floors 2 through 28 and the NYT spaces in the cellar.
3. Riser Diagrams: Show interconnections throughout the building between components specified in this Section and devices furnished under other Sections. This includes vertical risers in the tower from the cellar to floor 28, inclusive; and, in the podium including floors 2, 3 and 4. Include power, control, data and emergency lighting system on the riser diagrams.
4. Block Diagrams: Indicate data communication paths and identify networks, data buses, data gateways, concentrators, and other devices to be used. Describe characteristics of network and other data communication lines.
5. Point List and Network Load: List all control devices, sensors, ballasts, and other loads connected to each lighting control network and total connected load for each lighting control network. Include percentage of rated connected load and network addresses.
6. Wiring Diagrams: Detail specific power, control, data, emergency and night-light wiring for each floor from the cellar to floor 28, inclusive. Clearly differentiate between manufacturer-installed and field-installed wiring. Show interconnecting signal and control wiring and interfacing devices. Field-installed wiring shall be performed under a separate contract by the Electrical Installation Contractor.
7. Control Wiring Termination Drawings: Provide wire numbers and termination points for all control wiring on a separate drawing for each floor.
8. Panel Schedules: Show all lighting panels and branch circuits including all emergency lighting circuits and their sources.

9. Nomenclature: Coordinate all devices within a master naming convention for the lighting system. A hierarchy of LCS components shall be developed by floor.

D. Installation Coordination Drawings: Reflected ceiling plan(s) and other details, drawn to scale, on which the following items are shown and coordinated with each other.

1. Suspended ceiling components
2. Structural members to which lighting-fixture suspension systems will be attached
3. Items in finished ceiling, including the following:

a. LCS components and wiring
b. Light fixtures, power and control wiring
c. Shade system control components, power and control wiring
d. Sound masking and/or Public Address speakers and wiring
e. Sprinkler heads and piping
f. Access panels
g. Supply air diffusers and return air inlets
h. Fire alarm system devices and wiring

E. Network Communications Drawings: Submit evidence that lighting controls are compatible with connected monitoring and control devices and systems specified in other sections of the specifications.

F. Samples: One for each type of wall switch, sensor device and wall plate specified, in each color specified.

G. Software and Firmware Operational Documentation:

1. Software operating and upgrade manuals.
2. Program Software Backup: On a magnetic media or optical compact disc, complete with data files.
3. Device address list.
4. Printout of software application and graphic screens.

H. Software Upgrade Kit: For Owner to use in modifying software to upgrade and to allow system expansion.

I. Record Documents: Drawings in electronic format, preferably MicroStation version J, showing the actual installed wiring, control device identification and locations, and schedules of control functions, loop number and address of all ballasts and other addressed devices.

J. Field Test Reports: Indicate and interpret test results for compliance with performance requirements.

1. Submit printed points list.
2. Submit representative trend data for a minimum of 25 zones chosen by Owner that verify compliance with the written sequence of operation.

K. Maintenance Data: For LCS equipment components to include in maintenance manuals specified in Division 1 of the specifications.

L. Operation and Maintenance Data: For lighting controls to include in emergency, operation and maintenance manuals. In addition to items specified in Division1 include the following:

1. Software manuals.
2. Adjustments of scene preset controls, adjustable fade rates, and fade overrides
3. Operation of adjustable zone controls
4. Testing and adjusting of emergency lighting and night lighting feature
5. Methodology for revising target set points
6. Methodology for revising zones make-up
7. Methodology for revising time clock functions and settings
8. Methodology for enabling and disabling occupancy sensors

2.5 QUALITY ASSURANCE

A. Source Limitation: Obtain all lighting control components and final commissioning from the LCS Supplier.

B. Lighting control components shall include all operating elements of the lighting control system such as: occupancy sensors, wall controls, photo sensors, routers, computer(s), software and other devices and software that are an integral part of the LCS. All control equipment shall be tested and burned-in at the factory prior to delivery to the Site. Lighting fixtures, lamps, digitally controlled ballasts, and passive components such as wire, conduit, and connectors are not included.

C. LCS Supplier Qualifications: A firm experienced in sourcing a complete and integrated package of control equipment similar to that indicated for this Project and with a record of successful in-service performance.

D. Installer Qualifications: An electrical contractor licensed for work in New York City with IBEW labor. The Electrical Installation Contractor will be managed under a separate contract by Turner Construction Company for the Owner. The LCS Supplier has a supervisory role with respect to the installation of the LCS components and the interconnection wiring.

E. Startup Personnel Qualifications: The LCS Supplier shall engage specially trained personnel to perform final start-up, configuration, and system testing and commissioning.

F. Electrical Components, Devices, and Accessories: Listed and labeled as defined in NFPA 70, Article 100, by a testing agency acceptable to authorities having jurisdiction, and marked for intended use.

G. Control Panels: Tested and listed under UL and CSA.

H. Comply with 47 CFR, Subparts A and B, for Class A digital devices.

I. Comply with NFPA 70.

J. Comply with 2002 National Electric Code with New York City amendments.

K. Comply with NEMA for types of equipment enclosures.

L. Comply with State and Local electrical codes and approved for use in New York City.

2.6 PROJECT CONDITIONS

A. Interruption of Existing Electrical Service: Do not interrupt electrical service to facilities occupied by Owner or others unless permitted under the following conditions and then only after arranging to provide temporary electrical service according to requirements indicated:

1. Notify Owner and Owner’s Rep no fewer than seven days in advance of proposed interruption of electrical service.
2. Do not proceed with interruption of electrical service without Owner's written permission.

2.7 COORDINATION

A. The LCS Supplier shall coordinate the design layout of the ceiling-mounted devices with other engineered systems in the ceilings including light fixtures, HVAC equipment, fire-suppression system, sound masking system and shade controls with Architect.

B. The LCS Supplier The Electrical Installation Contractor shall coordinate the field layout and installation of ceiling-mounted devices with other construction that penetrates ceilings or is supported by them, including light fixtures, HVAC equipment, fire-suppression system, and shade controls.

C. Coordinate lighting control components to form an integrated interconnection of compatible components.

1. Match components and interconnections for optimum performance of lighting control functions.
2. The LCS is independent of the BMS.
3. Design display graphics showing building areas controlled by the LCS; include the status of lighting controls in each area.

2.8 WARRANTY

A. Materials Warranty - Manufacturer agrees to repair or replace components of lighting controls that fail in materials or workmanship within the specified warranty period.

1. Failures include, but are not limited to, the following:

a. Software: Failure of input/output to execute switching or dimming commands.
b. Failure of modular relays to operate under manual or software commands.
c. Damage of electronic components due to transient voltage surges.
d. Failure of photo sensors to: (i) detect changes in ambient lighting level, (ii) provide feedback to its respective control unit on target illuminance levels.
e. Failure of occupancy sensor to: (i) detect presence or non-presence of occupant(s) in the occupancy zone, (ii) provide feedback to its respective control unit on occupancy status.

2. Warranty Period: Two years from date of Final Acceptance.
3. Coverage: Cost to repair or replace malfunctioning parts including labor at the prevailing union rates in New York City.

B. System Warranty (Single Point of Responsibility)

1. LCS Supplier shall provide a full system warranty covering operation of all components and software in accordance with contract documents.
2. Warranty Period: Five years from date of Final Acceptance.
3. Coverage to include:
   a. Cost to repair or replace malfunctioning parts including labor, at the prevailing union rates in New York City.
   b. Written certification that entire system is working properly.

C. Post Occupancy Evaluation report one year after Final Acceptance – this is for mutual benefit of the Owner and LCS Supplier to ensure the LCS is operating according to the original design intent.

1. Analysis of the lighting energy usage
2. Analysis of the integrity of the zones
3. Analysis of target set points compliance
4. Analysis of lighting sequences and their application in the various spaces
5. Status of emergency lighting

2.9 EXTRA MATERIALS

A. Furnish extra materials described below that match products installed and that are packaged with protective covering for storage and identified with labels describing contents.

1. Software: One CD-ROM version of the lighting control operating software
2. System Management Software Updates
3. Record Drawings: Two of each type submitted in hard copy and one electronic file for each drawing, preferably in MicroStation version J
4. Line Drivers: Three of each type furnished
5. Communication Power Supplies: Three of each type furnished
6. Network Interface Cards: Three of each type furnished
7. Repeater Units: Three of each type installed
8. Data Line Surge Suppressors: One for every 10 of each type furnished. Furnish at least one of each type.

9. Relays: Equal to two percent of amount furnished, but no fewer than two relays
10. Fuses: Equal to two percent of amount furnished for each size installed, but no fewer than three.

PART 3 - PRODUCTS

3.1 LIGHTING CONTROL SYSTEM SUPPLIER

A. Subject to compliance with requirements, LCS Supplier offering complete digital lighting control systems are limited to:
   1. Lutron – Coopersburg, PA
   2. Siemens Energy & Automation, Inc. - Pine Brook, NJ
   3. Starfield Controls, Inc. - Westminster, CO
   4. Tridonic Inc. – Norcross, GA

3.2 SYSTEM REQUIREMENTS

A. Expansion Capability: Adequate to increase the number of control functions in the future by 20 percent. This expansion capability applies as applicable to equipment ratings, housing volumes, spare relays, terminals, number of conductors in control cables, network addresses, device connected load, and control software.

B. Line-Voltage Surge Suppression: Factory installed as an integral part of 120vac and 277vac, solid-state control panels and control components.

   1. Alternative Line-Voltage Surge Suppression: Field-mounted surge suppressors that comply with UL 1449 and with IEEE C62.41 for Category A locations.

C. Manual switch operation or automatic sensor actuation sends a digital signal to its corresponding relays and ballasts to perform the intended function, such as on, off, dim, fade and the like.

3.3 LIGHTING CONTROL SYSTEM

A. General
   1. Lighting management software shall be MicroSoft Windows based with multiple security levels.
   2. Controls components include: ballasts (furnished by the Ballast Supplier), photo sensors, occupancy sensors, dimming switches, control panels and other interface electronics required to create a comprehensive lighting control system with a central system console. All type F1 lighting fixtures shall be DALI.
   3. A database management system shall be provided that logs all commands emerging from the LCS. The database shall be protected and shall be easily backed up regularly onto a CD. The database shall be subdivided into annual database buckets.
   4. System architecture shall include:
      a. System console/PC
      b. Backbone communications network

c. DALI networks for DALI devices
d. Separate networks for non-DALI and DALI-compliant devices
e. Refresh rate shall be less than 30 seconds on the system
f. Diagnostic and commissioning tools

B. Scheduling of scenes by location and by time of day

C. Emergency lighting system – a number of lighting fixtures on each floor shall be designated emergency fixtures. These fixtures shall provide a 2 (two) FC egress path for occupants. Refer to the Control Intent Diagrams for Typical Emergency Fixtures. The emergency fixtures shall be on separate emergency power circuits. Under normal conditions these emergency fixtures will operate during daytime hours (sunrise to sunset) at the output level required by the daylight dimming sequence in that space or at a pre-specified output level where no dimming sequence is required. Under normal conditions at night 9sunset to sunrise) these emergency fixtures will operate at a pre-specified output level. When emergency power is initiated via energization of the life-safety generator, normal controls shall be overridden and the emergency lights shall revert to the emergency power setting. The emergency power setting (output level) shall be 100%. The LCS shall be restored to full auto mode upon recovery from an emergency power event. Recovery shall occur immediately after the life-safety generator is deenergized. The emergency control units must be UL listed, approved for use in New York City and MEA (Materials Equipment and Acceptance) approved. The Engineer shall certify all emergency lighting fixture locations.

D. Night-light system – each emergency light fixture on each floor shall remain on at night at a pre-specified output level regardless of occupancy.

E. Lighting system energy usage shall be measured at the high voltage (HV) panel on each floor. These measurements shall be used to check energy usage calculations and reports. A split bus HV panel shall be provided (typically) by the Electrical Installation Contractor, which shall keep all lighting loads separate from other loads on the HV panel.

F. Lighting Controls System searchable database
1. An archived log file shall be maintained in the system drive(s).
2. The log file shall provide deterministic values including, but not limited to: photo sensor data, occupancy sensor state and system control mode (auto, manual and maintenance).
3. The system shall monitor and store all requisite change-of-value data needed to troubleshoot control operations including: date, time of day, lighting control zone ID, ballast output levels, sensor output values, time delay set points and time delay values.
4. Data shall be stored on a daily basis.
5. Data shall be exportable to a MicroSoft Excel or Access database format.
6. Data shall be automatically archived.
7. System reports shall be available to the System Operator and all security levels above System Operator. The system shall trend real-time and historical data.

G. Reporting
1. Energy usage
2. Failure report (lamp & ballast)

3. Target set point map
4. Switching events (ballast on/off)
5. Lamp hours
6. Commands usage
7. System failures
8. Trend

H. Load shedding program to include relative power shaving feature.

I. Self-diagnostic and self-corrective features shall be included in the system using the following defined rules. The system shall interrogate itself with respect to these rules and where mismatch between the anticipated condition and the measured condition is identified, then the system will create an alarm and attempt a reset. If the system does not correct itself upon reset, then another higher level alarm condition shall be initiated.
   1. If lights are on in a zone that the photo sensor indicates the target light level is exceeded by more than 25 FC for five (5) minutes.
   2. If one ballast in a zone is at an output level in variance (more than 20%) with the other ballasts in the zone.
   3. Recovery from power failures – the system shall set itself to the state required by the conditions in the space at the point of time of restoring power.

J. Timeclock - the time switch shall function to prevent lighting from being energized at preset periods each day. The time switch shall permit different “ON-OFF” settings for each day of the week, with provision for omitting selected days. The time switch shall have at least four (4) inputs. Unit shall be capable of retaining memory for no less than 90 days. When permitted by the time switch, photoelectric controls shall operate to energize lighting whenever natural lighting falls below twenty five (25) FC.

K. Daylighting Control
   1. If sufficient daylight is available in the space to achieve target illumination level at the work plane, then the lights shall be turned off.
   2. If the target illumination level at the work plane is not achieved, then electric lights will be turned on and dimmed to achieve the target illuminance level.
   3. The fade rate for the electric lights will be from 2 to 5 minutes so that dimming is imperceptible to the occupants.

L. Larger zones may be created than defined in the Control Intent Diagrams in Part 4 of this specification. The larger zones may be controlled with offsets for subset(s) of the fixtures. Optimize the number of sensors and zones.

M. The light fixtures and all other lighting devices shall be identified within the master lighting controls system console/PC. The methodology for establishing fixture nomenclature shall include floor, sector and zone designations. A hierarchy shall be established that facilitates the location of any specific fixture physically and within the system (virtually). All ballast addresses shall be bound to a specific fixture or device.

N. Graphic User Interface (GUI) shall be customized to this project through easy-to-use applications and shall include:
   1. Map of each floor showing all zones with active target set points

2. Map of each floor with illuminance levels as measured by the system photo sensors
3. Device parameters shall be displayed. What is to be displayed is dependent upon the application.

O. Target set points – the system shall allow for variable target set points. The set points for any zone or combination of zones shall be adjustable by the System Operator at the main lighting control system console/PC.

P. DALI system capacity – the layout shall allow for expansion within each DALI group. It shall limit the number of addressable units in a DALI group to 48. It shall limit the system current to 80% of maximum allowable connected load. The maximum allowable connected load is 190 milliamperes (mA).

Q. Single master mode of operation shall be the basis for the connectivity of all lighting system components. The non-DALI and DALI-compliant devices such shall be connected directly to the DALI control unit, not through the DALI ballasts.

R. Stand-alone system shall be the basis for the design.

3.4 SOFTWARE

A. Lighting Control Software: Features and functions include the following:

1. Password Protection: minimum of two configurable security levels – (i) System Operator and, (ii) System Administrator
2. Operates in multitasking, multi-user environment. Windows NT or compliant.
3. On-Line help with on-line monitoring by LCS.
4. Coordinates the communications of the network.
5. Provides mouse-driven graphic interface with devices depicted on the floor plan and single-line diagram screens.
6. Provides interactive color-graphics to show status and properties of individual control devices on both floor plans and single-line diagrams.
7. Logs user-defined power monitoring and control and power distribution system events including log on/off; attempted log on/off; alarms; and, equipment operations; with date and time stamps.
8. Exports and imports data to and from commonly used Windows spreadsheet, database, and other applications; uses dynamic data exchange technology.
9. Reports Trends: Instantaneously, in a real-time or historical tabular format, bar chart, or user-defined time, trend plots of monitored parameters; unlimited as to interval, duration, or quantity of trends.
10. Manages Maintenance Function: Annunciates and logs maintenance messages from discrete input and controls outputs, according to programmable security access protocol using the communication network.
11. Programs: Provide custom program for the operation of the LCS based upon the sequences of operation and control schedules for the project. Utilize industry standard software that is modifiable by the end user.
12. Display: Single graphic display for programming lighting control panelboards if applicable.

13. System Memory: Nonvolatile. System shall reboot program and reset time automatically without errors after power outages up to 90 days' duration.
14. Software: Lighting control software shall be capable of linking switch and sensor inputs to relay and ballast outputs, retrieving links, viewing relay and ballast output status, controlling relay and ballast outputs, simulating switch and sensor inputs, setting device addresses, and assigning switch and sensor inputs and relay and ballast output modes.
15. Automatic Time Adjustment: System shall automatically adjust for leap year and daylight saving time and shall provide weekly routine and annual holiday scheduling.
16. Astronomic Control: Automatic adjustment of sunrise and sunset switchingbased on location of the Site and time of year.
17. Remote Communication Capability: Allow programming, data-gathering interrogation, status display, and controlled command override from a PC at a remote location over the Internet. System shall include firewalls and control software, and remote computer compatibility verification for this purpose.
18. System Override Capability: System Operator may override programmed shutdown of lighting and may override other programmed control for intervals that may be duration programmed.
19. Automatic battery backup shall provide power to maintain program and system clock operation for 90 days' minimum duration when power is off.
20. Compatibility with dimmer controls shall permit commands that change preset scenes and dimmer settings according to programmed time signals.
21. Daylight Balancing Dimming Control: Control components shall interpret variable analog signal from photoelectric sensor and shall route dimming signals to selected groups of fixtures containing dimming fluorescent ballasts. Signal shall control dimming of fixture in accordance with the sequence of operation.
22. Diagnostics: When system operates improperly, software shall initiate factory-programmed diagnosis of failure and display messages identifying problem and possible causes.

3.5 WORKSTATION/SERVER

A. Central-Processing Workstation/Server: Desktop PC installation capable of communicating with a minimum of 20 percent greater than the number of lighting control devices on this project, and including the following minimum peripherals, accessories, and features:

1. RAM: 256 MB
2. Hard-Disk Drive: 30 GB
3. CPU: 1,000 MHz
4. CD-RW/DVD-ROM Drive: not less than 16 X
5. Monitor: 17 inch flat screen LCD monitor, HP Flat Panel Monitor L1730
6. Video Memory: 2 MB
7. Operating System: Window XP Pro or as required by manufacturer. Include license, documentation and storage media
8. Keyboard: Standard
9. Mouse: Two button with roller wheel
10. Two serial ports: RS232 serial communicator

11. One parallel port: with Windows printer driver
12. Two USB ports
13. Two Network Interface Cards: Compatible with building LAN system. 100/10basT Ethernet, computer operated, with two-way communication transmitter-receiver chip
14. Modem: Internal, 56K baud, minimum
15. Automatic Reboot Capability: When power is restored after an outage
16. Power Supply: Internal, sized to serve all peripherals with a minimum of 25% spare capacity
17. Printer: Color ink jet
18. Backup Battery-Inverter Power Supply: Automatic, rated 650-VA output for 10 minutes. Arranged to supply computer, accessories, and peripherals, not including a printer. Include transient voltage surge suppressor and electromagnetic-interference filters.

3.6 CONTACT INPUTS

A. The control system shall support dry contact inputs and these inputs shall be software linkable to any number of relays for override control.

B. The control system shall support digital/switch inputs, momentary toggle inputs and maintained contacts.

3.7 RELAY CONTROL

A. Factory assembled with modular single-pole relays, power supplies, and accessory components required for specified performance. On/off function may be provided by relays or with internal on/off circuitry in ballasts and similar devices listed for that function. Mechanical on/off operation may be either distributed or grouped into relay panels as consistent with the manufacturer's design concept. The control system shall employ an all-modular design for easy addition or replacement of input or relay output modules.

1. Grouped Relay Enclosure:

   a. NEMA class 1 or as required by local jurisdiction and for the installation location.
   b. Lockable enclosure.
   c. Steel enclosure per UL916.
   d. Barriers separate low-voltage and line-voltage components.
   e. Identification: Mounted on cover. Identify each relay as to address and load groups controlled.

2. Grouped Single-Pole Relays:

   a. Low-Voltage Leads: Plug connector-to-connector strip in cabinet and pilot light power where indicated with mechanical or electrical latching.

b. Rated Capacity: 20A, 125vac for tungsten filaments; 20A, 277vac for electronic ballasts.
c. Endurance: 1,000,000 cycles at rated capacity.
d. Mounting: Provision for easy removal and installation in relay enclosure.
e. Local Control: Provide means to manually actuate the relay at the relay enclosure even in the absence of control power to the relay module.
f. Indicator Light: Provide a local indicator light to indicate the closed status of the relay at the relay enclosure.
g. Relay output timer: Provide output timer capable of various durations for each relay.
h. Two pole loads: two relay outputs may be switched for two pole loads.

3. Distributed Relays:
a. Same capacity and ratings as grouped relays.
b. Designed to be mounted locally in lighting zone and in accordance with local jurisdiction requirements.
c. Indicator Light: may be local or remotely queried and displayed by lighting system management computer.
d. Identification: Identify each relay with lighting control network and device address.

3.8 Panels

A. Panels shall be wall mounted NEMA grade, constructed of sheet steel plates not less than #16 U.S. gauge. Contractor shall reinforce wall as required for wall-mounted panels.
B. Panels shall be completely pre-wired by the manufacturer. The installation contractor shall be required to provide input feed wiring, load wiring, and control wiring. No other wiring or assembly by the installation contractor shall be permitted.
C. Unless otherwise indicated, panels shall contain branch circuit protection for all lighting circuits. Branch circuit breakers shall have the following performance characteristics:
1. U.L. listed under U.L. 489 as a molded case circuit breaker for use on lighting circuits.
2. Contain a visual trip indicator and shall be rated at 10,000AIC (120V) or 14,000 AIC (277V), unless otherwise noted.
3. Thermal-magnetic in construction for both overload and dead short protection. The use of fully magnetic breakers shall not be acceptable, even when used in conjunction with individual dimmer thermal cutouts.
4. Switching duty (SWC) rated so that the loads can be switched off via the breakers.
D. Panels shall be cooled via free-convection, unaided by fans, and capable of continuous operation to all of these section specifications within an ambient temperature range of 0°C (32°F) to 40°C (104°F).
E. Panels shall have the following additional performance characteristics:
F. Be designed to prevent any foreign objects from coming in contact with any part of the panel, which would be at an elevated temperature.
G. Be designed to provide airflow across the heat sink areas and through the dimmer chassis. Panel sections, which provide airflow only across heat sinks, shall not be mounted one above another in order to allow for adequate heat dissipation.

H. Panel shall provide capability to electronically assign each fixture to any zone in the dimming system.
I. Multiple panels shall be capable of operating in one system. Provide as many panels as necessary to house the required control units and main lighting control system. Operating voltage shall be 277 volts. Panels shall be provided with main circuit breakers. Branch circuit breakers shall be 20A.

3.9 DALI LIGHTING CONTROL NETWORK POWER SUPPLY

A. Lighting Network power supply shall comply with DALI or equivalent requirements.

B. Power supply shall be fully regulated to maintain operating voltage within full range of rated connected load and during charging cycle.

C. Rated connected load shall be no less than 80% of rated charging load.

D. Power supply shall be Class 2.

3.10 FLUORESCENT DIGITAL DIMMING BALLASTS

A. Ballasts shall conform to DALI standard and protocol and as required in section 16510 of the specifications.

B. Voltage: 277 vac

C. Ballasts shall be controlled individually or as a zone. Each ballast or group shall be addressable and shall include on/off, fade, sweep, dimming, and other standard DALI control functions and as required to meet the sequence of operation.

D. Fade time, grouping, power-on, system power-on, and other similar settings shall be configurable over the digital network and stored in non-volatile memory at the device or in system node panels in accordance with system architecture. The data shall be protected against power interruptions. The data storage shall be maintenance-free.

3.11 DIGITAL CONTROL NETWORK

A. Dimmers, scene, and other controls shall be peer-to-peer or receive digital signals from digital network control stations linked through a dimmer cabinet.

B. Functions of digital network control stations shall be set up to include indicated number and arrangement of scene presets, channels, and fade times.

3.12 MANUAL DIMMING SWITCHES AND PLATES

A. Switches: Modular, momentary push-button, low-voltage type.
   1. Office switches shall digitally communicate with the LCS or peer-to-peer to control light fixtures assigned to that switch. The switch shall be able to actuate

the following functions based upon the described sequence of operation and intended functions, and interact with its related photo-sensors and occupancy-sensors:

- On
- Off
- Dim up
- Dim down
- Restore (illuminance level upon reentry to the office shall be the same level when last occupied, i.e. restore to prior occupied setting)

2. Conference Room switches shall digitally communicate with the LCS or peer-to-peer to control light fixtures assigned to that switch. The switch shall be able to actuate the following functions based upon the described sequence of operation and intended functions, and interact with its related photo-sensors and occupancy-sensors:
   - On
   - Off
   - Dim up
   - Dim down
   - Go to multiple presets

B. Preset light levels shall be user settable.

C. Maximum light levels shall be user adjustabler for each dimmer.

D. Where a switch is in a daylighting controls area, then each switch shall override daylighting controls when manually operated.

E. Switches may be wall mounted push buttons or touch panels.

F. Color: NEMA WD-1 white, unless indicated otherwise.

G. Integral Pilot Light or Indicator LED: Indicates that control is active by being on continuously when powered or when pushbuttons are actuated.

H. Switch faceplates shall be of metal a minimum 1/8th inch thick, finish as designated by Architect and Engineer. Painted finishes shall be matched to sample provided by Architect. Paint to be polyurethane enamel type equal to Polane in quality. Faceplates shall securely attach to their electrical wall box with mechanical fasteners, but without visible screws or fasteners on the face of the switch. The faceplate shall be grounded. Switch shall be capable of withstanding without impairment of function or loss of memory, electrical surges due to static electricity discharge of a user touching the switch, electrical noise and line voltage surges. Switches shall be mounted directly to the metal faceplate or rigid metal subassembly and shall be rated for a minimum 100,000 operations. Buttons supported only by their connection to a printed circuit board or flexible membrane type switches are not acceptable. Faceplates shall be engraved or silk screened with identifying legends as noted in the drawings. Size and style of engraving or silk screening shall be determined by the Architect. Silk screening shall chemically bond to the faceplate so as to resist removal by scratching, cleaning, etc.

3.13 INDOOR PHOTO SENSORS

A. Manufacturers: Subject to compliance with requirements within the Specification, manufacturers and their product(s) shall be selected by the LCS Supplier.

B. Photo sensors shall detect changes in ambient lighting level, provide dimming range as required by sequence of operation, and provide feedback on the target illuminance setpoints.

1. The location and number of all photo sensors shall be optimized by the LCS Supplier in accordance with the requirements of the Specification.
2. Ceiling-mounted with range and viewing angle to meet requirements of sequence of operation and Contract Documents. The cone of view shall be limited to 110 degrees (55-degree half angle).
3. The sensor shall incorporate a photodiode to provide light level measurement that can be correlated to the desktop illuminance. The photodiode shall be optically filtered to measure light to closely match the human photopic response.
4. There shall be different photo sensors for different tasks, i.e. skylight, open plan areas, offices, conference rooms, perimeter and other interior spaces as defined in the Contract Documents. Optimize for each application to optimize resolution for the expected range of light.
5. Fully adjustable response in the range between 0 and 250 FC minimum with ±1% accuracy with eight (8) bit minimum resolution at 21°C. The photo sensor shall be demonstrated to be accurate under the following three conditions: (i) 100% electric light, (ii) 100% daylight, and (iii) various combinations of electric light and daylight.
6. All adjustments with exception of sensor range shall be made via the communication line or wireless devices. Units that require the use of unit mounted manual adjustments or which must be programmed at the unit are not acceptable.
7. Resolution enhancement shall be capable of supporting a variety of target set points from 10 FC to 50 FC.
8. The photo sensor output value shall be available for reporting and graphic user interface.
9. Outputs shall be 4-20 mA, 0-10 volts or 8-bit digital.
10. Power supplies shall accept 120vac or 277vac.
11. The photo sensor shall be fully temperature compensated.
12. The photo sensor shall have a cover that protects the photodiode and diffuser from dust.
13. All sensors shall be installed in the 6 inch center plate in the type F1 lighting fixtures. Sensors shall be low profile, flush mounted to the greatest extent possible.
14. The sensor shall communicate with the LCS panels, not directly with the ballasts.
15. The photoelectric device shall be a Class 2, low voltage type.
16. The housing shall be constructed from flame-retardant material and meet UL984 HB standards.

3.14 INDOOR OCCUPANCY SENSORS

A. Manufacturers: Subject to compliance with requirements within the Specification, manufacturers and their product(s) shall be selected by the LCS Supplier.

B. General Description: Ceiling mounted, solid-state units with direct connection to LCS or separate relay unit.
   1. Operation - General
      a. The selection of the type(s) and locations of the occupancy sensors shall be the responsibility of the LCS Supplier.
      b. Manual-on function shall not override occupancy sensor delay timer.
      c. Delay timers shall be adjustable.
      d. All occupancy sensor control functions may be temporarily overridden by network commands.
      e. Occupancy sensors for small zones, i.e. enclosed offices, small conference rooms shall have a manual override switch in the control zone. Refer to the Control Intent Diagrams - Manual DALI Dimming (Wall Box Switch) and Occupancy Control Zones.
   2. Operation - Dimming Ballasts:
      a. Refer to the space dimming requirements in the Specification.
      b. Refer to the Control Intent Diagrams - Occupancy Control Zones.
      c. Refer to the Control Intent Diagrams - Manual DALI Dimming (Wall Box Switch) And Occupancy Control Zones.
      d. All operating modes shall be selectable via the communication network using either broadcast or individually addressed command.
   3. Operation – Non-dimming Ballasts
      a. When covered area is unoccupied, lights turn off. Lights turn back on when occupancy detected.
      b. Refer to the space dimming requirements in the Specification.
      c. Refer to the Control Intent Diagrams - Occupancy Control Zones.
   4. Sensor Output: Direct input to LCS or interface rated to operate the connected relay and complying with UL 773A.
   5. Sensor Power: Sensor shall be powered directly from the control system or from the relay unit.
   6. Relay Unit: Dry contacts rated for 20A ballast load at 277vac, for 13A tungsten at 120vac, and for 1 hp at 120vac.
   7. Device Color unless required otherwise: white.
   8. Mounting:
      a. Sensor: Suitable for mounting in a removable 6 inch square plate located in the center of the F1 lighting fixtures.
      b. Relay: Externally mounted though a 1/2-inch knockout in a standard electrical enclosure, concealed in the fixture or ceiling cavity.
      c. Time-Delay and Sensitivity Adjustments: Set via digital communication network.
      d. Settings made via digital network shall be queriable unless accessible through a sensor display.
   9. Indicator: LED, to show when motion is being detected during testing and normal operation of the sensor.
   10. Bypass Switch: Override the on function in case of sensor failure.
   11. No nuisance outages in occupancy zones shall be accepted by Owner.

C. PIR Type: Ceiling mounted; detect occupancy by sensing a combination of heat and movement in area of coverage.
      a. Detector Sensitivity: Detect occurrences of 6-inch minimum movement of any portion of a human body that presents a target of at least 36 sq. in.

b. With daylight filter and lens to afford coverage applicable to space to be controlled.
c. Detection Coverage (Rooms): Achieve the coverage(s) as described in the Control Intent Diagrams when mounted on a 115-inch high ceiling.
d. Detection Coverage (Open Plan Areas): Achieve the coverage(s) as described in the Control Intent Diagrams when mounted on a 115-inch high ceiling.
e. Detection Coverage (Corridors): Achieve the coverage(s) as described in the Control Intent Diagrams when mounted on a 115-inch high ceiling.

D. Ultrasonic Type: Ceiling mounted; detect occupancy by sensing a change in pattern of reflected ultrasonic energy in area of coverage.
   a. Detector Sensitivity: Detect a person of average size and weight moving at least 12 inches in either a horizontal or a vertical manner at an approximate speed of 12 inches/second.
   b. Crystal controlled with circuitry that causes no detection interference between adjacent sensors.
   c. Detection Coverage (Rooms): Achieve the coverage(s) as described in the Control Intent Diagrams when mounted on a 115-inch high ceiling.
   d. Detection Coverage (Open Plan Areas): Achieve the coverage(s) as described in the Control Intent Diagrams when mounted on a 115-inch high ceiling.
   e. Detection Coverage (Corridors): Achieve the coverage(s) as described in the Control Intent Diagrams when mounted on a 115-inch high ceiling.

E. Dual-Technology Type: Ceiling mounted; detect occupancy by using a combination of PIR and ultrasonic or acoustical detection methods in area of coverage. Particular technology or combination of technologies that controls on and off functions shall be selectable in the field by operating controls on unit.
   a. Sensitivity Adjustment: Separate for each sensing technology.
   b. Detector Sensitivity: Detect occurrences of 6-inch minimum movement of any portion of a human body that presents a target of at least 36 sq. in., and detect a person of average size and weight moving at least 12 inches in either a horizontal or a vertical manner at an approximate speed of 12 inches/s.
   c. Detection Coverage (Rooms): Achieve the coverage(s) as described in the Control Intent Diagrams when mounted on a 115-inch high ceiling.
   d. Detection Coverage (Open Plan Areas): Achieve the coverage(s) as described in the Control Intent Diagrams when mounted on a 115-inch high ceiling.
   e. Detection Coverage (Corridors): Achieve the coverage(s) as described in the Control Intent Diagrams when mounted on a 115-inch high ceiling.

2.14 LIGHTING NETWORK CONDUCTORS AND CABLES

A. Low voltage DALI digital network control wire, also called “loop wiring”, shall meet the requirements of the Specification, the local jurisdiction, or LCS Supplier recommendations, whichever is more stringent.
B. Network wire between fixtures may be free-run Class 2 in accordance with NEC Article 725 and allowed by local jurisdiction.

C. Network wire shall be stranded copper cable, plenum rated with yellow jacket and a minimum size of 18 AWG.
D. Jumpers between fixtures shall plug into a bulkhead type connector mounted in the fixture and be removable.
E. Homeruns to lighting network power supply shall be run in conduit.
F. Class 2 Free-Run Control and Sensor Connections: Stranded copper cable, plenum rated with yellow jacket and a minimum size of 18 AWG.
G. Splices and Taps: Insulation displacement or wire trap connectors shall be used to splice all Class 1 and Class 2 control wiring. Twist-on wire-nut type connectors are not allowed.
H. A five conductor cable system is required for power and control wiring of all DALI devices. The DALI communication conductors shall be #18 AWG minimum.
I. Maximum voltage drop of 2 volts from the point of supply to the device.
J. No wire may exceed 1000 feet in length.
K. Wire shall be furnished and installed by a separate contractor.
L. Junction and Mounting Boxes: All ceiling mounted digital control network junction and mounting boxes shall be NEMA deep 4-11/16" with ½" knock-outs unless required otherwise for specific equipment.
M. Homeruns for emergency lighting circuits shall be kept separate from normal powered lighting circuits.

2.15 ETHERNET LAN

A. Primary Ethernet LAN: Furnish network receptacles located in each LCS closet, at Lighting System Computer, and as shown on Construction Documents.
B. Provide and install patch cables and Ethernet switch hubs as required for independent LCS Ethernet LAN.
C. Provide a TCP/IP modem capable of maintaining a secure and firewall protected Internet connection using VPN or equivalent protocol acceptable to Owner.

2.16 SPACE DIMMING SCHEDULE & LIGHTING CONTROL SEQUENCES

A. Non-dimming spaces, **lighting control sequence #1:** lights are off when the space is unoccupied, as occupancy is registered the lights turn on to 100%. As the space is evacuated, when no occupancy is detected the lights turn off after a pre-specified delay. Refer to Control Intent Diagrams:
    i. Occupancy Control Zones
        1. 3rd Floor East, CSK-1
        2. 3rd Floor West, CSK-1
        3. 13th Floor, CSK-1
        4. 14th Floor, CSK-2
        5. 15th Floor, CSK-2
        6. 19th Floor, CSK-1
    ii. Typical Emergency Fixtures
        1. 3rd Floor East, CSK-5
        2. 3rd Floor West, CSK-5
        3. 13th Floor, CSK-5
        4. 19th Floor, CSK-5

1. Cellar Mailroom – occupancy sensor, no dimming
2. Photo archives - occupancy sensor, no dimming
3. Cold storage – occupancy sensor, no dimming
4. Elevator lobby – occupancy sensor, the fluorescent ceiling mounted light shall be on the emergency/night-light scheme, no dimming
5. Service corridors – occupancy sensor, one fixture on the emergency/night-light scheme, no dimming
6. Privacy rooms - occupancy sensor, one fixture on the emergency/night-light scheme, no dimming
7. Copy rooms, Equipment Rooms, Support Rooms, and lockable closets- occupancy sensor, one fixture on the emergency/night-light scheme, no dimming
8. File rooms - occupancy sensor, one fixture on the emergency/night-light scheme, no dimming
9. Technology rooms (IDF closets) - occupancy sensor, one fixture on the emergency/night-light scheme, no dimming
10. Vending machine areas – occupancy sensor and one light on the emergency/night-light scheme, no dimming
11. Pantries – occupancy sensor, one light on the emergency/night-light scheme, no dimming
12. Toilets - occupancy sensor, two lights on the emergency/night scheme, no dimming

B. Dimming with switches, no daylight control, **lighting control sequence #2**: sequence is lights are off when the room is unoccupied, as occupancy is registered the lights turn on to 70%. At any time the lights may be manually controlled by the occupant(s) from the wall mounted dimming switch with presets. As the room is evacuated, when no occupancy is detected the lights turn off after a pre-specified delay. It is not necessary for the last person out of the room to manually turn off the lights even if the lights were manually controlled during occupancy. Refer to Control Intent Diagrams:
   i. Occupancy Control Zones
      1. 3rd Floor East, CSK-1
      2. 3rd Floor West, CSK-1
      3. 13th Floor, CSK-1
      4. 14th Floor, CSK-2
      5. 15th Floor, CSK-2
      6. 19th Floor, CSK-1
   ii. Manual DALI Dimming (Wall Box Switch) And Occupancy Control Zones
      1. 3rd Floor East, CSK-3
      2. 3rd Floor West, CSK-3
      3. 13th Floor, CSK-3
      4. 19th Floor, CSK-3
   iii. Typical Emergency Fixtures
      1. 3rd Floor East, CSK-5
      2. 3rd Floor West, CSK-5
      3. 13th Floor, CSK-5
      4. 19th Floor, CSK-5

1. Conference rooms in the open plan areas – occupancy sensor with manual override wall mounted dimming switch with multiple presets
2. Training rooms (except on 15th floor) - occupancy sensor with manual override wall mounted dimming switch with multiple presets

3. Libraries (except on the 28th floor) – occupancy sensors and manually operated wall mounted dimming switch with multiple presets, one fixture on the emergency/night-light scheme
4. Pulitzer project room – occupancy sensor and manually operated wall mounted dimming switch with multiple presets, one fixture on the emergency/night-light scheme
5. Offices in open plan areas – occupancy sensor, manual override wall mounted dimming switch with multiple presets, auto-restore to the last setting upon reentry
6. Exam rooms - occupancy sensor, manually operated dimming switch with multiple presets, one fixture on the emergency/night-light scheme
7. WQXR studios - occupancy sensor with manual override wall mounted dimming switch with multiple presets, one fixture on the emergency/night-light scheme

C. Dimming, daylight control with manual override switches, **lighting control sequence #3**: sequence is lights are off when the room is unoccupied, as occupancy is registered the lights turn on based upon daylight available. At any time the lights levels may be controlled by the occupant(s) at the wall mounted dimming switch. The manual dimming switch overrides the daylight control scheme. As the room is evacuated, when no occupancy is detected the lights go out after a pre-specified delay. It is not necessary for the last person out of the room to manually turn off the lights even if the lights were manually controlled during occupancy. Refer to Control Intent Diagrams:
   i. Manual DALI Dimming (Wall Box Switch), Daylight Sensor (Photocell) And Occupancy Control Zones
      1. 13th Floor, CSK-6
      2. 15th Floor, CSK-3
   ii. Typical Emergency Fixtures
      1. 3rd Floor East, CSK-5
      2. 3rd Floor West, CSK-5
      3. 13th Floor, CSK-5
      4. 19th Floor, CSK-5

1. Conference rooms on the perimeter – occupancy sensor, daylighting dimmable controls via independent DALI zone(s) with manual override wall mounted dimming switch with multiple presets
2. Offices on the perimeter – occupancy sensor, daylighting dimmable controls via independent DALI zone with manual override wall mounted dimming switch with multiple presets
3. Executive offices - occupancy sensor, daylighting dimmable controls via independent DALI zone with manual override wall mounted dimming switch with multiple presets
4. Network Operations Center on the 12th floor - occupancy sensor, daylighting dimmable controls via independent DALI zone with manual override wall mounted dimming switch with multiple presets, three fixtures on the emergency/night-light scheme
5. Physical therapy room on the perimeter - occupancy sensor, daylighting dimmable controls via independent DALI zone with manual override wall mounted dimming switch with multiple presets, one fixture on the emergency/night-light scheme
6. Library on the 28th floor - occupancy sensor, daylighting dimmable controls via independent DALI zone(s) with manual override wall mounted dimming switch with multiple presets, one fixture on the emergency/night-light scheme
7. Private dining rooms - daylighting dimmable controls via independent DALI zone with manual override wall mounted dimming switch with multiple presets

8. Training rooms on the 15th floor - daylighting dimmable controls via independent DALI zone with manual override wall mounted dimming switch with multiple presets
9. Boardroom - occupancy sensor, daylighting dimmable controls via independent DALI zone with manual override wall mounted dimming switch with multiple presets

D. Dimming, automatic daylight control, no dimming switches or manual override switches, **lighting sequence #4**: sequence is lights are off when the occupancy zone is unoccupied, as occupancy is registered the lights turn on in all daylight zones within the occupancy zone based upon daylight available. The target set point illuminance level at the work plane (29.5" above finished floor) is maintained as a minimum by adding electric light output to whatever daylight is available. When sufficient daylight is available to achieve the target set point or more than enough daylight is available, then the light fixtures in that daylight zone(s) shall be off. At night the light fixture output levels shall achieve the target set point illuminance level at the work plane. There simply will not be any daylight contribution. As the open plan area various occupancy zones are evacuated, when no occupancy is detected the lights go out after a pre-specified delay. Refer to the Control Intent Diagrams:
   i. Occupancy Control Zones
      1. 3rd Floor East, CSK-1
      2. 3rd Floor West, CSK-1
      3. 13th Floor, CSK-1
      4. 19th Floor, CSK-1
   ii. Daylight DALI Dimming Zones
      1. 3rd Floor East, CSK-2
      2. 3rd Floor West, CSK-2
      3. 13th Floor, CSK-2
      4. 19th Floor, CSK-2
   iii. Typical Emergency Fixtures
      1. 3rd Floor East, CSK-5
      2. 3rd Floor West, CSK-5
      3. 13th Floor, CSK-5
      4. 19th Floor, CSK-5

1. Open work plan areas – daylighting dimmable controls via multiple DALI daylight control zones, with multiple fixtures on the emergency/night-light scheme
2. Data Center server rack area on the 12th floor - daylighting dimmable controls via multiple DALI daylight control zones, with multiple fixtures on the emergency/night-light scheme.

E. Dimming without switches, no daylight control, **lighting sequence #5**: sequence is lights are off when the corridor is unoccupied, as occupancy is registered the lights in the corridor turn on to the output level based upon the pre-specified target set point. Refer to Control Intent Diagrams:
   i. Occupancy Control Zones
      1. 3rd Floor East, CSK-1
      2. 3rd Floor West, CSK-1
      3. 13th Floor, CSK-1
      4. 19th Floor, CSK-1
   ii. Typical Emergency Fixtures
      1. 3rd Floor East, CSK-5

2. 3rd Floor West, CSK-5
3. 13th Floor, CSK-5
4. 19th Floor, CSK-5

1. Core corridors – each corridor is an independent DALI zone on its own target set point with multiple fixtures on the emergency/night-light scheme

F. Non-dimming, time clock control only, **lighting sequence #6**: sequence is lights come on at 100% at sunset, the lights turn off at 1:00 am, the lights come back on at 100% one hour before sunrise and go off at sunrise. Refer to Control Intent Diagrams:
   i. Time Clock Control Zones
      1. 3rd Floor East, CSK-4
      2. 3rd Floor West, CSK-4
      3. 13th Floor, CSK-4
      4. 19th Floor, CSK-4

1. Perimeter cove architectural lighting on floors 2 through 28 inclusive. Refer to the Control Intent Diagrams – Time Clock Control Zones.

G. Conference Center – **lighting sequence #7**, preset dimming control system for the Conference Center shall meet or exceed the following capabilities:
1. Refer to Control Intent Diagram: 15th FL Control Diagram, CSK-1
2. There are 3 conference rooms that can combined in six different space scenarios. These include: 3 individual conference rooms, all 3 rooms combined as one, and two different combinations of two rooms combined as a double.
3. System shall be configured such that the touch screen control station in each of the 3 conference rooms can operate as the master control station.
4. Door switches or infrared connectivity between control stations shall determine the room configurations. These shall be inputs to the system.
5. Depending upon room size (conference center walls are removable) there shall be a number of spaces to be selected at the touch screen control stations. Each selectable room shall have four preset scenes and on/off for up to 8 control zones. The touch screen control station in each room shall only be able to control the zones in its configured space.
6. One raise/lower switch with visual display shall be available for each zone.
7. A temporary master raise/lower switch shall move all light levels up or down.
8. System shall have smooth fade mode. Switching time between scenes shall be adjustable from 1 second to 5 minutes.
9. A temporary zone override shall be provided.
10. Multiple touch screen control stations shall be capable of activating each of the preset scenes and shall not interfere with each other.

H. Cafeteria – **lighting sequence #8**, preset dimming control system for the cafeteria shall meet or exceed the following capabilities:
1. Refer to Control Intent Diagram: 14th FL Control Diagram
2. System shall have four preset scenes and on/off for up to 13 control zones.
3. System shall be mountable in a standard 2, 3, or 4 gang metal wall box.
4. One master raise/lower dimming switch with visual display shall be available and connected to all 13 zones.

5. System shall have smooth fade mode. Switching time between scenes shall be adjustable from 1 second to 5 minutes.
6. A temporary zone override shall be provided.
7. The 13 zones cover the cafeteria seating area and servery on the 14th floor and the cafeteria balcony on the 15th floor.

I. Special conference rooms with audio visual connectivity – audio visual equipment interface for manual dimming and preset control. This is overlaid on top of typical lighting sequence #3 including dimming and daylight control with manual override wall box dimming switches, **lighting sequence #9**: sequence is lights are off when the room is unoccupied, as occupancy is registered the lights turn on based upon daylight available. At any time the lights levels may be controlled by the occupant(s) at the wall mounted dimming switch. The manual dimming switch overrides the daylight control scheme. As the room is evacuated, when no occupancy is detected the lights go out after a pre-specified delay. It is not necessary for the last person out of the room to manually turn off the lights even if the lights were manually controlled during occupancy. Refer to Control Intent Diagrams:
   i. Manual DALI Dimming (Wall Box Switch), Daylight Sensor (Photocell) And Occupancy Control Zones
      1. 3rd Floor West, CSK-3
      2. 15th Floor, CSK-1

1. Page One conference room on 3rd floor
2. Conference Center - 3 main room on the west side of the 15th floor

PART 4 - EXECUTION

4.1 EXAMINATION

A. FIELD QUALITY CONTROL

1. LCS Supplier Field Service: Provide factory-authorized service representative to inspect, test, and adjust field-assembled components and equipment installation, including connections, and assist with field testing. Report results in writing.

2. Perform the following field tests and inspections and prepare test reports:

   a. Complete installation and start-up checks according to manufacturer's written instructions.
   b. Test for circuit continuity, open, shorts and other tests recommended by the manufacturer.
   c. Check operation of local control devices.
   d. Verify that the control system features are operational.
   e. Test system diagnostics by simulating improper operation of several components selected by Owner/Architect/Engineer.
   f. After installing sensors, and after electrical circuitry has been energized, adjust and test for compliance with requirements.
   g. Operational Test: Verify actuation of each sensor and adjust time delays.
   h. Electrical Tests: Use particular caution when testing devices containing solid-state components. Perform the following according to manufacturer's written instructions:
      i. Continuity tests of circuits.
      ii. Operational Tests: Set and operate controls at PC workstations and at monitored and controlled devices to demonstrate their functions and capabilities. Use a methodical sequence that cues and reproduces actual operating functions as recommended by the manufacturer. Note response to each test command and operation
   i. Remove and replace lighting control devices where test results indicate that they do not comply with specified requirements.
   j. Correct deficiencies, make necessary adjustments, and retest. Verify that specified requirements are met.
   k. Reports: Prepare written reports of tests, inspections, verifications and observations indicating and interpreting results. Record defective materials and workmanship and unsatisfactory test results. Record repairs and adjustments.
   l. Additional testing and inspecting, at Contractor's expense, will be performed to determine compliance of replaced or additional work with specified requirements.
   m. Verify normal operation of each fixture after installation.
   n. Test for Emergency Lighting: Interrupt power supply to demonstrate proper operation. Verify normal transfer to backup source and retransfer to normal.
   o. If adjustments are made to lighting system, retest to demonstrate compliance with standards.

4.2 TRAINING

A. A trainer shall be provided by the LCS Supplier to train Owner's maintenance personnel to adjust, operate and maintain the LCS and all of its components.

B. The minimum of 40 hours training session shall be provided and shall include:
   1. General description of the system and operational functions of its components.
   2. Hands on training for each of the hardware components (performance, maintenance, repair, part replacement)
   3. Hands on software training (programming, operation, modem connection)
   4. At least two Owner representatives, two representatives from the electrical maintenance group and two representatives from the Engineer shall be present for the training.
   5. Manufacturer shall provide a minimum of 6 complete operation manuals for use during the training session.
   6. The System Administrator training shall be carried out in a separate one-on-one session.

C. Train Owner's management and maintenance personnel in interpreting and using monitoring displays and in configuring and using software and reports. Train them in troubleshooting, servicing, adjusting, and maintaining equipment.

D. Training Aid: Use the approved final versions of software and maintenance manuals as training aids.

E. Schedule training with Owner with at least thirty days advance notice.

4.3 ON-SITE ASSISTANCE

A. Occupancy Adjustments: Within one year of date of Final Acceptance, provide up to three Site visits, when requested by Owner, to adjust and calibrate components and to assist Owner's personnel in making program changes and in adjusting sensors and controls to suit actual conditions.

B. Post Occupancy Evaluation: one year after the date of Final Acceptance, provide an evaluation of the system using trend reports, energy usage and system failure reports.

4.4 OFF-SITE TECHNICAL SUPPORT

1. Hardware and Software: For the entire System Warranty Period, provide unlimited response to Owner questions regarding software use and hardware and communication link troubleshooting, reconfiguring, and adjusting.
2. Availability: Eight hours per day, weekdays.
3. Responder Qualifications: Engineer or technician thoroughly familiar with the LCS.
4. Provide telephone, Internet, or other communication connection that allows off-site query, troubleshooting, control, monitoring, and configuration of the system by an authorized off-site technician.
5. Communication channel shall be provided by Owner.

4.5 SYSTEM COMMISSIONING

A. The LCS shall be commissioned on a floor by floor basis and then finally as an entire system.
B. Final Acceptance of the LCS shall be contingent upon successful commissioning of each floor and the entire system.
C. As the LCS installation is completed on individual floors by the Electrical Installation Contractor, a partial system start up, testing and commissioning plan shall be implemented by the LCS Supplier factory-trained engineer(s).
D. Upon completion of the entire LCS installation by the Electrical Installation Contractor, the system shall then be commissioned by the LCS Supplier as a whole system. The commissioning will be performed upon notification by the Electrical Installation Contractor that the system installation is complete and that all loads have been tested live for continuity and freedom from defects and that all control wiring has been connected and checked for proper continuity. The LCS Supplier shall perform supervisory functions during the Electrical Installation Contractor final checkout.
E. The LCS Supplier shall provide the Owner, Architect and Engineer with ten working days advance notice of the scheduled final commissioning start date.
F. Upon completion of the final system checkout, the LCS Supplier shall demonstrate the functionality of the LCS to the Owner.
G. The LCS Supplier shall demonstrate the operation of the LCS to the Owner. Each lighting sequence shall be fully demonstrated to be in accordance with the Specification.
H. The LCS Supplier shall demonstrate the reliability of the LCS to the Owner. Compliance with the Specification shall be demonstrated over a 30 day test period.
I. The LCS Supplier shall demonstrate the flexibility of the LCS to the Owner. Rezoning of daylight zones and independent zones shall be demonstrated solely with the use of the PC/console. No physical wiring may be moved, added or removed during these demonstrations.
J. The LCS Supplier shall demonstrate the self diagnostics and self-corrective features of the LCS to the Owner.
K. The LCS Supplier shall demonstrate the emergency lighting and night-light features of the LCS to the Owner. A power outage shall be scheduled during this part of the commissioning program.
L. The LCS Supplier shall demonstrate the occupancy zone integrity of the LCS to the Owner.
M. The LCS Supplier shall demonstrate full reporting capabilities and system refresh rate of 30 seconds or less.
N. During commissioning the following shall be measured to determine system performance:
   1. Work plane illuminance for various target set points in the open plan areas at any work stations in the daylighting zones as selected by Owner
   2. Luminance at the interior of the perimeter window wall
   3. Lighting system energy usage
O. The LCS Supplier shall correlate daylight dimming with natural light levels.
P. System must be demonstrated to perform 90% of the time in accordance with work plane illuminance targets under daylight conditions over a 30 day test period.

Q. Final commissioning shall be completed prior to The New York Times first move-in date.

PART 5 - LIGHTING SEQUENCES AND CONTROL INTENT DIAGRAMS

4.1 Lighting sequences

A. Exterior lighting – there shall be no exterior lighting controlled by the LCS.

B. Normal business hours are defined as follows:
   1. Monday – Friday: 7 AM – 10 PM
   2. Saturday, Sunday and Holidays: 8 AM – 5 PM
   3. Newsroom business hours are distinct and shall be programmed separately by floor (this applies to floors 2 through 7 inclusive)

C. Lighting sequences – there are eight distinct lighting sequences. Each sequence shall apply to one or more spaces as defined in the Space Dimming Schedule in paragraph 2.16 of the Specification.

4.2 Control Intent Diagrams

1. CSK-1, 19th Floor, Control Intent Diagram, Occupancy Control Zones
2. CSK-2, 19th Floor, Control Intent Diagram, Daylight DALI Dimming Zones
3. CSK-3, 19th Floor, Control Intent Diagram, Manual DALI Dimming (Wall Box Switch) And Occupancy Control Zones
4. CSK-4, 19th Floor, Control Intent Diagram, Time Clock Control Zones
5. CSK-5, 19th Floor, Control Intent Diagram, Typical Emergency Fixtures
6. CSK-1, 13th Floor, Control Intent Diagram, Occupancy Control Zones
7. CSK-2, 13th Floor, Control Intent Diagram, Daylight DALI Dimming Zones
8. CSK-3, 13th Floor, Control Intent Diagram, Manual DALI Dimming (Wall Box Switch) And Occupancy Control Zones
9. CSK-4, 13th Floor, Control Intent Diagram, Time Clock Control Zones
10. CSK-5, 13th Floor, Control Intent Diagram, Typical Emergency Fixtures
11. CSK-6, 13th Floor, Control Intent Diagram, Manual DALI Dimming (Wall Box Switch), Daylight Sensor (Photocell) And Occupancy Control Zones
12. CSK-1, 3rd Floor West, Control Intent Diagram, Occupancy Control Zones
13. CSK-2, 3rd Floor West, Control Intent Diagram, Daylight DALI Dimming Zones
14. CSK-3, 3rd Floor West, Control Intent Diagram, Manual DALI Dimming (Wall Box Switch) And Occupancy Control Zones
15. CSK-4, 3rd Floor West, Control Intent Diagram, Time Clock Control Zones
16. CSK-5, 3rd Floor West, Control Intent Diagram, Typical Emergency Fixtures
17. CSK-1, 3rd Floor East, Control Intent Diagram, Occupancy Control Zones
18. CSK-2, 3rd Floor East, Control Intent Diagram, Daylight DALI Dimming Zones
19. CSK-3, 3rd Floor East, Control Intent Diagram, Manual DALI Dimming (Wall Box Switch) And Occupancy Control Zones
20. CSK-4, 3rd Floor East, Control Intent Diagram, Time Clock Control Zones
21. CSK-5, 3rd Floor East, Control Intent Diagram, Typical Emergency Fixtures
22. CSK-1, 14th Floor, 14th FL Control Diagram
23. CSK-1, 15th Floor, 14th FL Control Diagram
24. CSK-2, 14th & 15th Floor, 14th & 15th FL FL Control Load Schedule

PART 6 - COLLEGE POINT MOCK UP

6.1 Manufacturer shall support a comprehensive lighting and shade control system in the mock up at College Point. The mock up is a replica of the southwestern corner of a typical floor of the The New York Times Headquarters Building as designed by Renzo Piano Building Workshop and Gensler.

A. Owner shall provide electrical installation services for the mock up lighting control system.
B. LCS Supplier shall furnish all lighting control components including, but not limited to: central control panel(s), distributed control units, photo sensors, occupancy sensors, PC, software and hardware with lighting control program.
C. DALI ballasts, lighting fixtures, shades and shade control system shall be furnished by others.

6.2 MOCK UP SCHEDULE

A. Delivery of lighting control system components for electrical subcontractor installation by January 4, 2005.
B. System PC installation by LCS Supplier by January 17, 2005.
C. Initial commissioning of the LCS by January 21, 2005.
D. Continuing commissioning efforts and system refinements through May 31, 2005.

PART 7 - ALTERNATES

7.1 Provide add alternate for extended warranty for additional one year, two years and three years.

END OF SECTION 16575

OCCUPANCY CONTROL ZONES

LIGHTING SEQUENCE
#1,#3, #4,#5

TOTAL OF 23 ZONES

OCCUPANCY CONTROL ZONES

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Architect
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22 West 19th Steet New York, NY
11001

Interior Architect
GENSLER ARCHITECT
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10020

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NEW YORK, NEW YORK

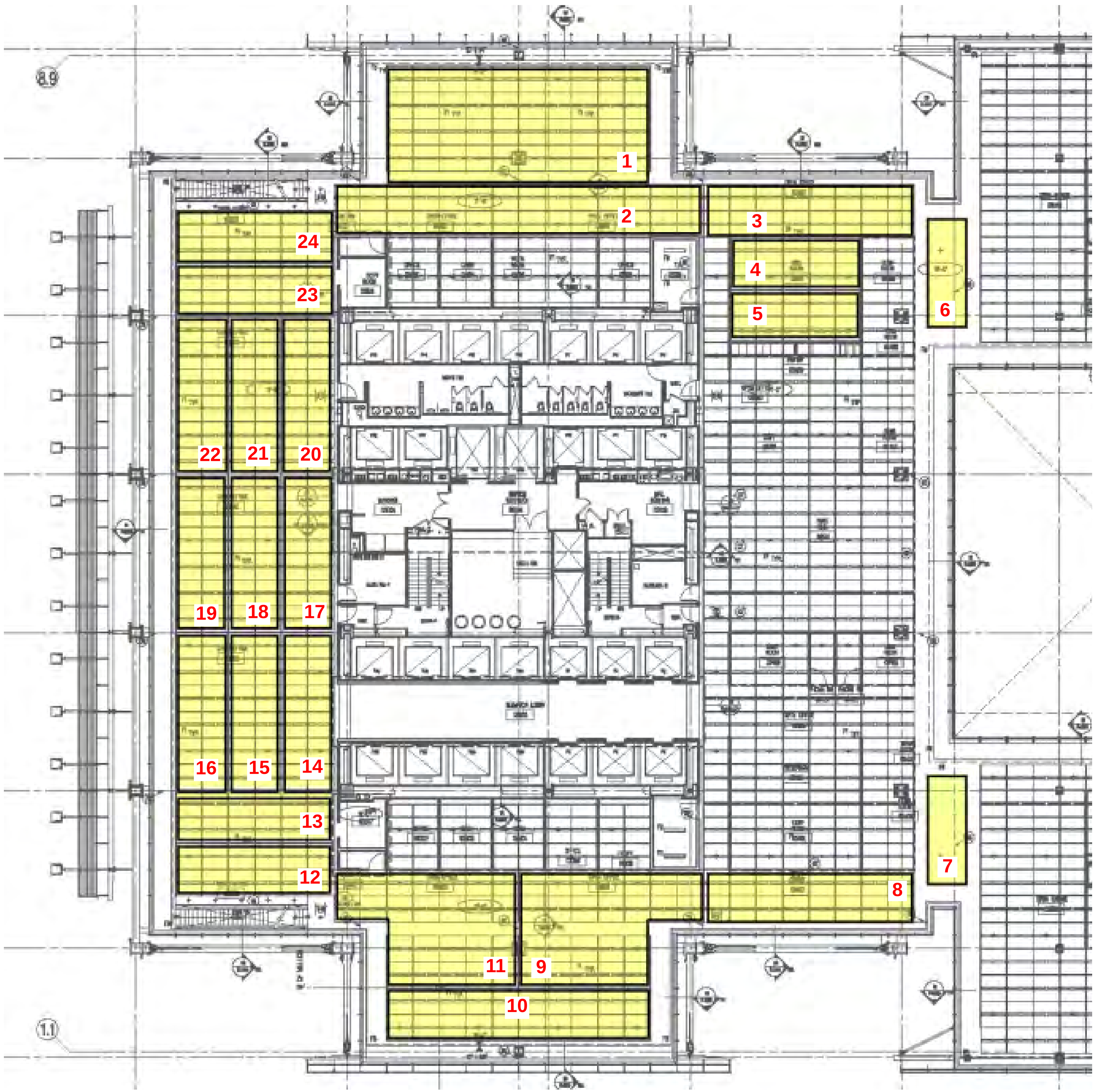
LIGHTING DESIGN

3rd Floor West

Sept. 22nd, 2004

Control Intent Diagram

CSK-1



LIGHTING SEQUENCE #3, #4
TOTAL OF 24 ZONES

DAYLIGHT DALI DIMMING ZONES

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22 West 19th Steet New York, NY
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GENSLER ARCHITECT
One Rockefeller Plaza, New York, NY
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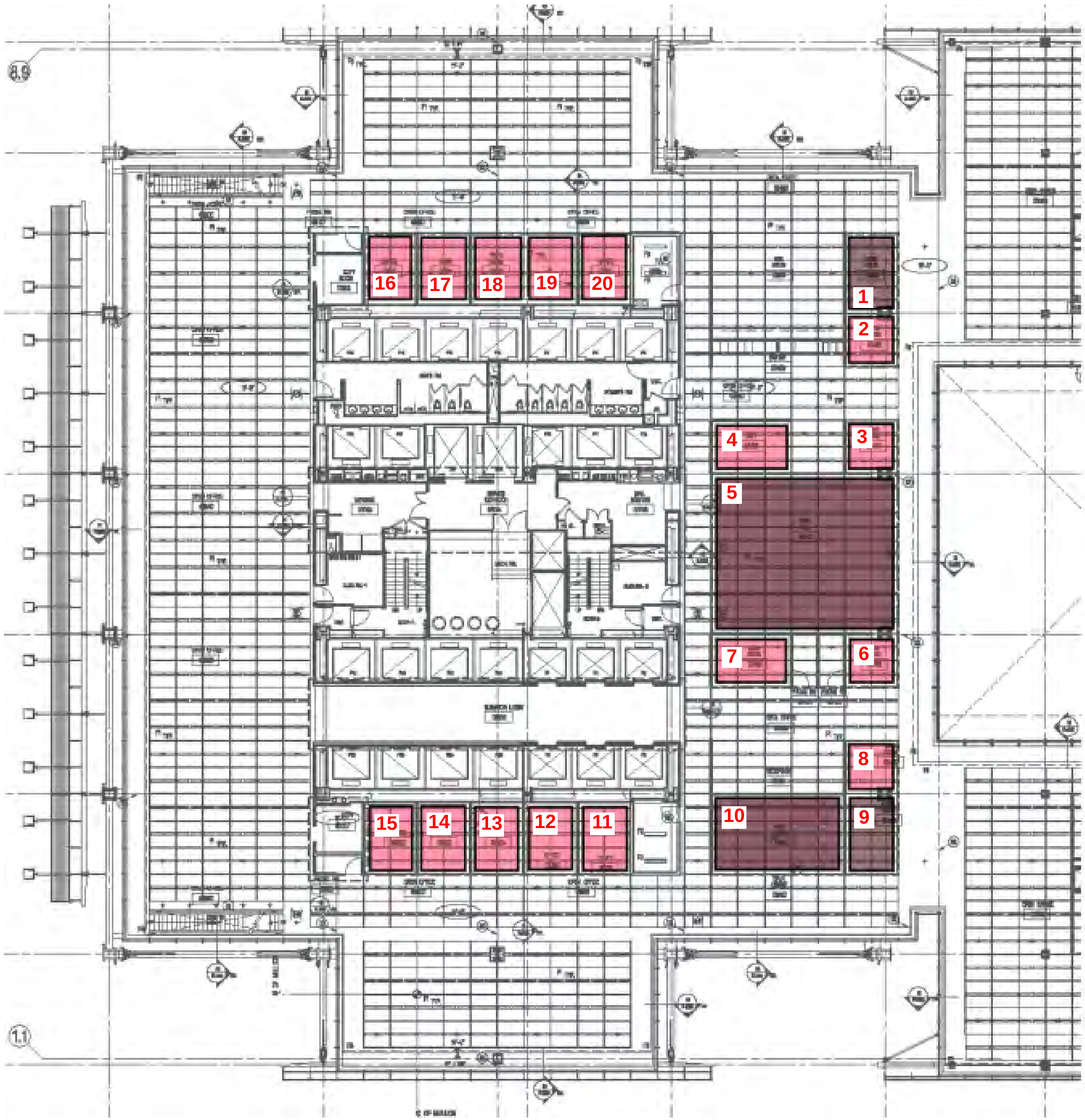
Sept. 22nd, 2004

Control Intent Diagram

CSK-2



WITH MULTIPLE PRESET DIMMER CONTROL LIGHTING SEQUENCE #9

TOTAL OF 20 ZONES
LIGHTING SEQUENCE #2, #3, #9

MANUAL DALI DIMMING (WALL BOX SWITCH) AND OCCUPANCY CONTROL ZONES

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212.391.4330 T
212.391.4331 F
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Architect
RENZO PIANO BUILDING WORKSHOP
34,Rue Des Archives 75004 PARIS

FOX & FOWLE ARCHITECTS, P. C.
22 West 19th Steet New York, NY 11001

Interior Architect
GENSLER ARCHITECT
One Rockefeller Plaza, New York, NY 10020

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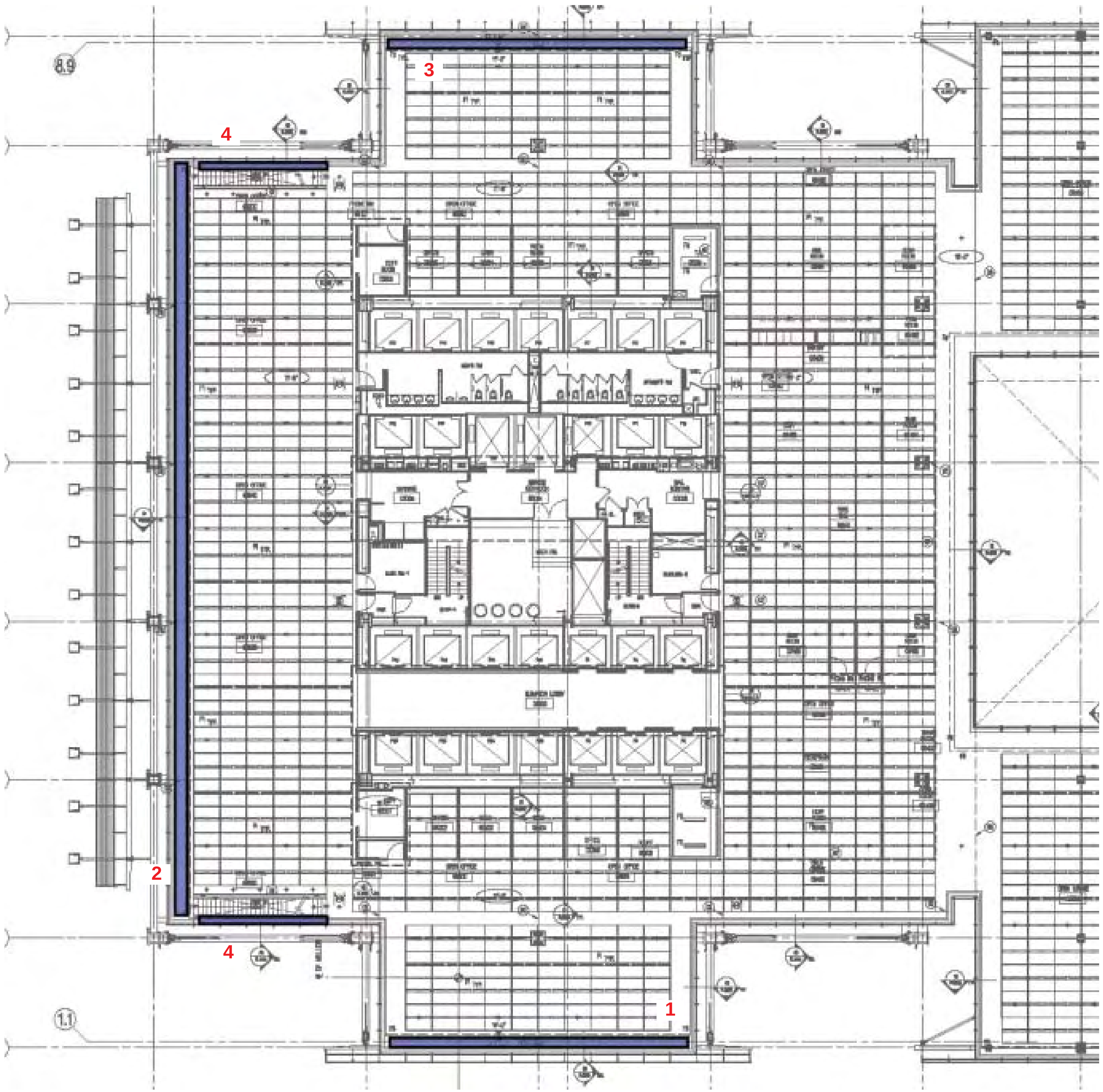
Sept. 22nd, 2004

Control Intent Diagram

CSK-3



LIGHTING SEQUENCE #6
TOTAL OF 4 ZONES

TIME CLOCK CONTROL ZONES

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NY NY 10018
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Architect
RENZO PIANO BUILDING WORKSHOP
34,Rue Des Archives 75004 PARIS

FOX & FOWLE ARCHITECTS, P. C.
22 West 19th Steet New York, NY 11001

Interior Architect
GENSLER ARCHITECT
One Rockefeller Plaza, New York, NY 10020

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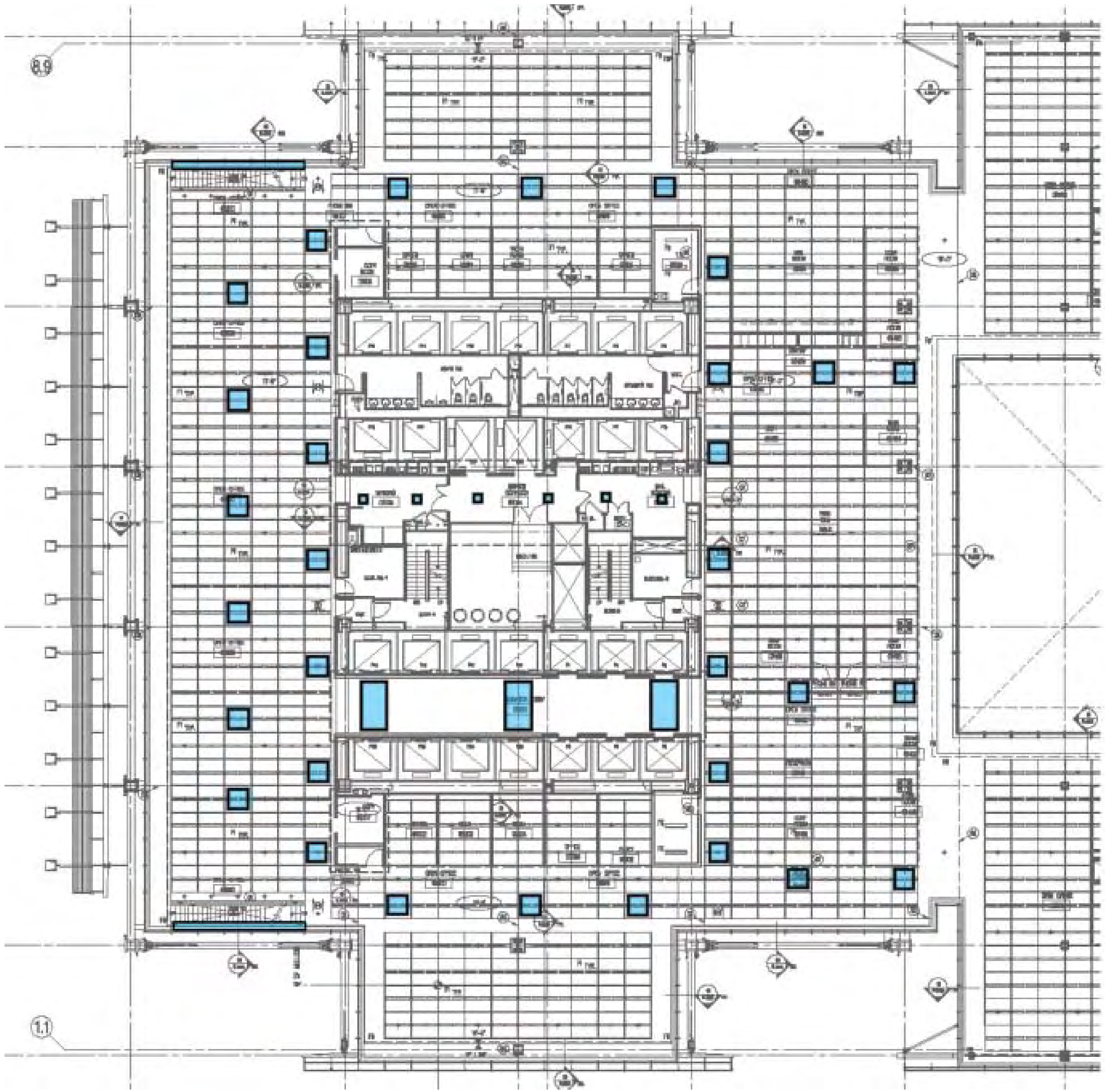
Control Intent Diagram

CSK-4



LIGHTING SEQUENCE #1, #2, #3, #4, #5
TOTAL OF 47 FIXTURES

TYPICAL EMERGENCY FIXTURES

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Architect
RENZO PIANO BUILDING WORKSHOP
34,Rue Des Archives 75004 PARIS

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22 West 19th Steet New York, NY 11001

Interior Architect
GENSLER ARCHITECT
One Rockefeller Plaza, New York, NY 10020

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3rd Floor West

Sept. 22nd, 2004

Control Intent Diagram

CSK-5

OCCUPANCY CONTROL ZONES

LIGHTING SEQUENCES #1,#3,#4,#5

TOTAL OF 13 ZONES

OCCUPANCY CONTROL ZONES

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Architect
RENZO PIANO BUILDING WORKSHOP
34,Rue Des Archives 75004 PARIS

FOX & FOWLE ARCHITECTS, P. C.
22 West 19th Steet New York, NY 11001

Interior Architect
GENSLER ARCHITECT
One Rockefeller Plaza, New York, NY 10020

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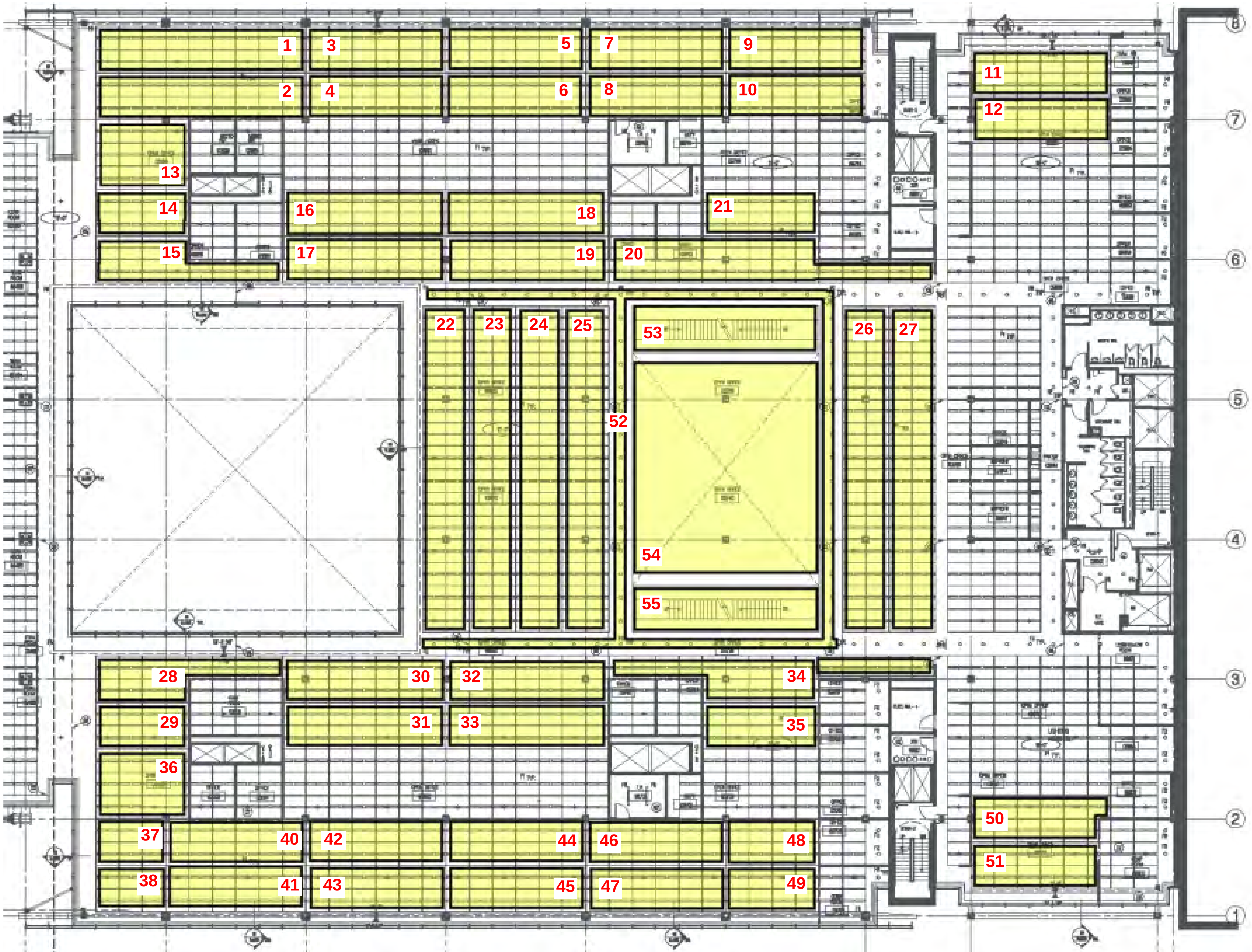
LIGHTING DESIGN

3rd Floor East

Sept. 22nd, 2004

Control Intent Diagram

CSK-1



LIGHTING SEQUENCES #3, #4

TOTAL OF 55 ZONES

DAYLIGHT DALI DIMMING ZONES

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22 West 19th Steet New York, NY 11001

Interior Architect
GENSLER ARCHITECT
One Rockefeller Plaza, New York, NY 10020

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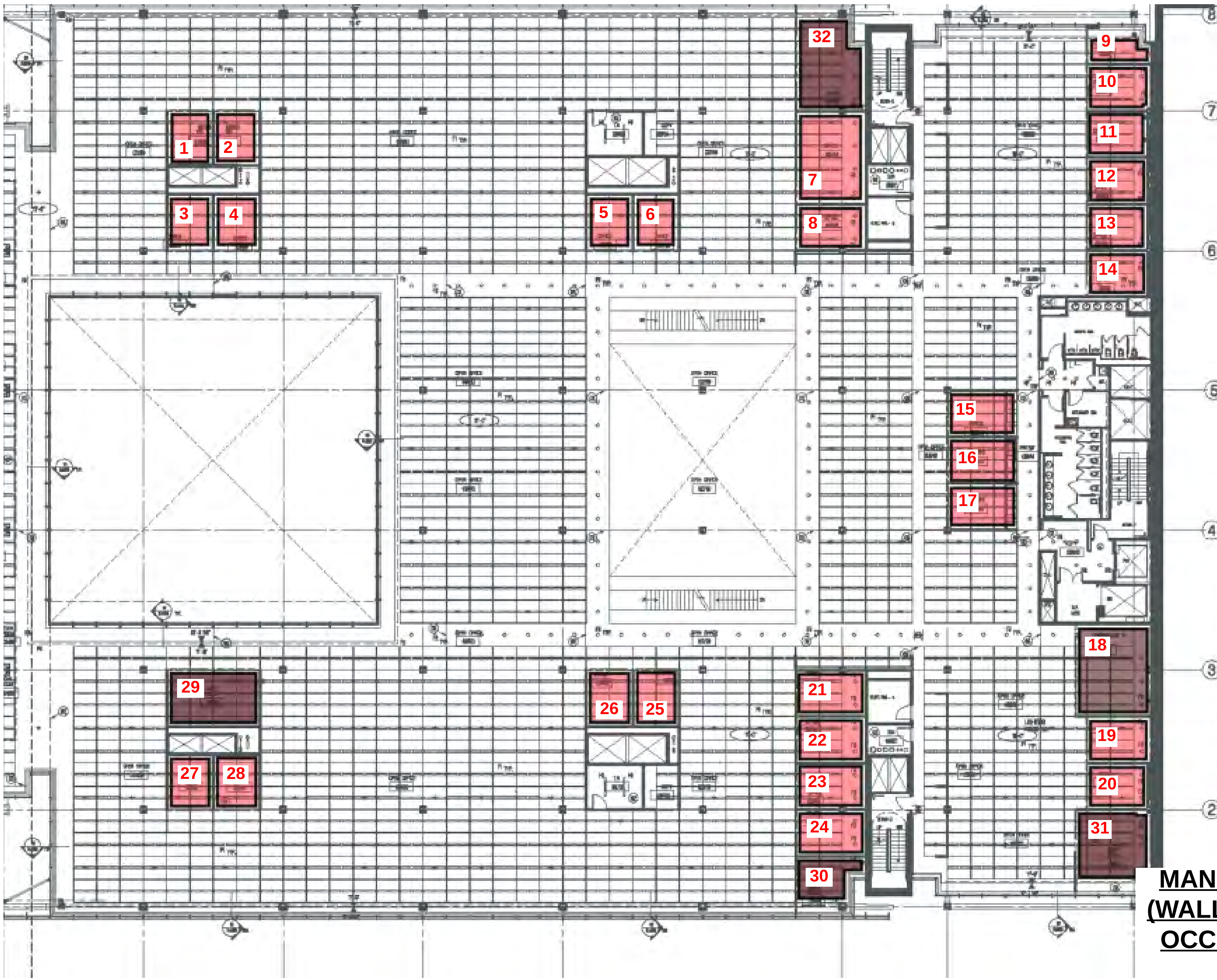
LIGHTING DESIGN

3rd Floor East

Sept. 22nd, 2004

Control Intent Diagram

CSK-2



WITH MULTIPLE PRESET DIMMER CONTROL

TOTAL OF 32 ZONES
LIGHTING SEQUENCE #2,#3

MANUAL DALI DIMMING (WALL BOX SWITCH) AND OCCUPANCY CONTROL ZONES

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212.391.4231 F
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Architect
RENZO PIANO BUILDING WORKSHOP
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22 West 19th Steet New York, NY 11001

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One Rockefeller Plaza, New York, NY 10020

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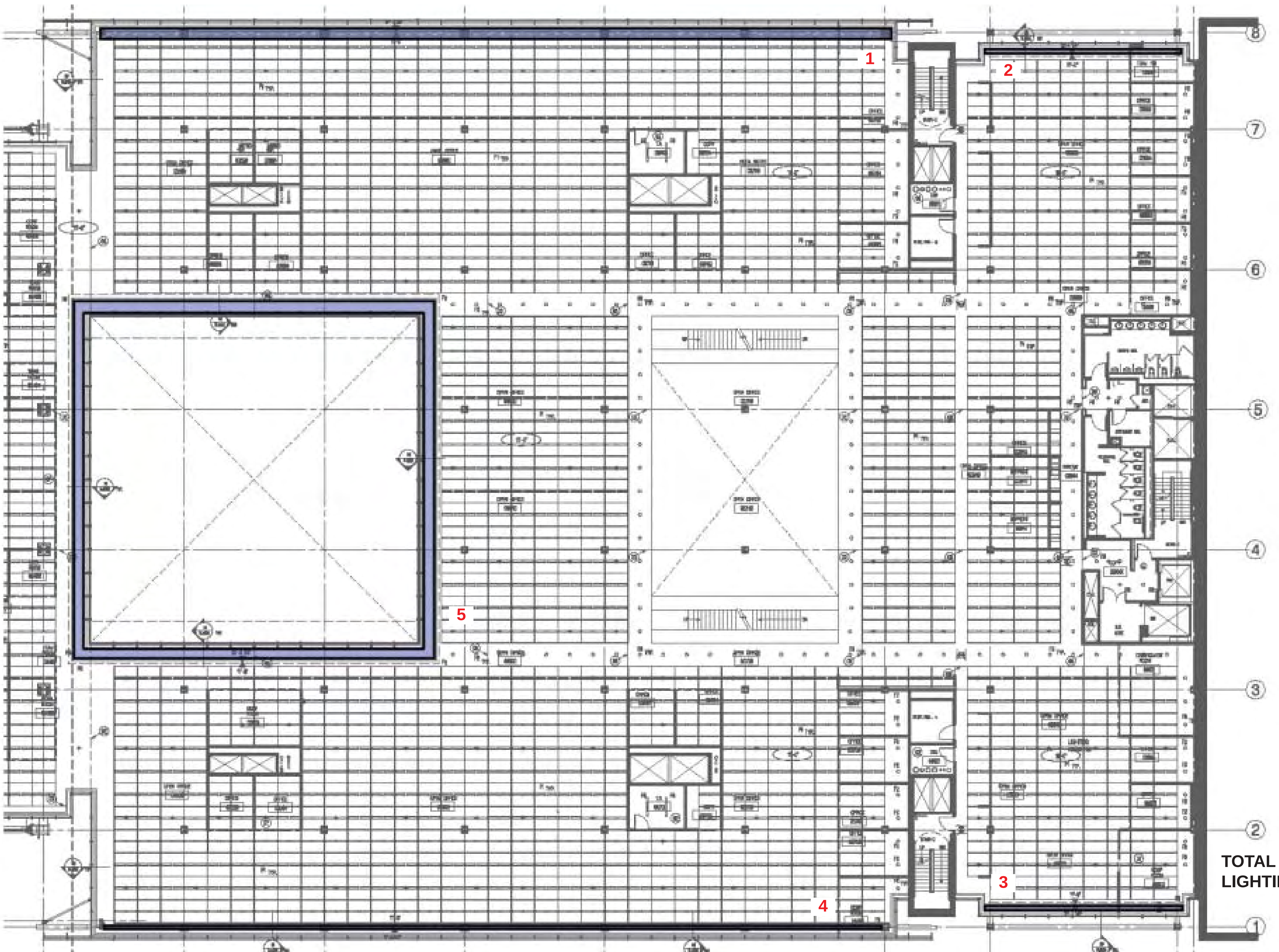
Control Intent Diagram

CSK-3



TOTAL OF 5 ZONES
LIGHTING SEQUENCE #6

TIME CLOCK CONTROL ZONES

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22 West 19th Steet New York, NY 11001

Interior Architect
GENSLER ARCHITECT
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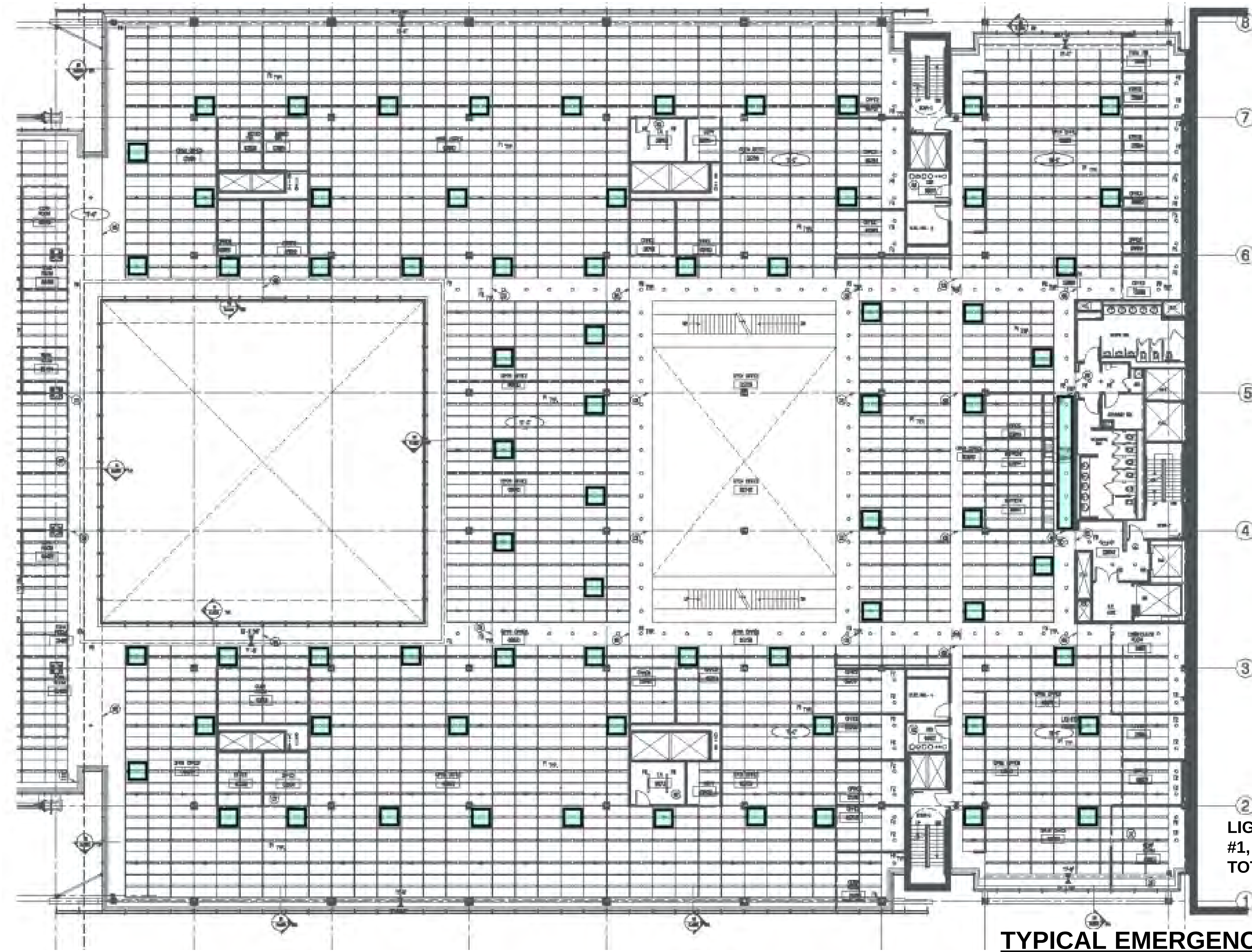
Control Intent Diagram

CSK-4



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22 West 19th Steet New York, NY 11001

Interior Architect
GENSLER ARCHITECT
One Rockefeller Plaza, New York, NY 10020

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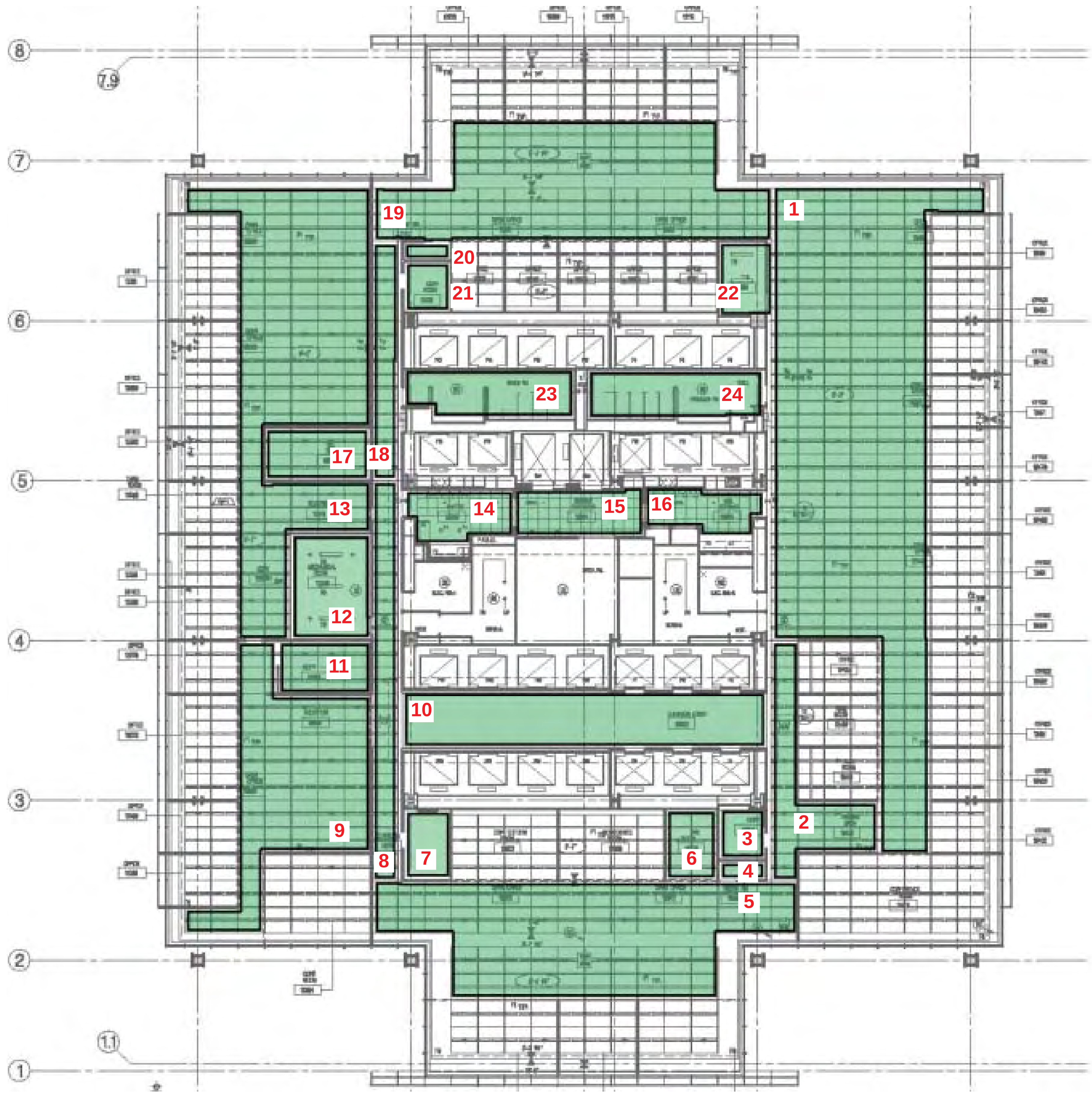
LIGHTING DESIGN

3rd Floor East

Sept. 22nd, 2004

Control Intent Diagram

CSK-5



OCCUPANCY CONTROL ZONES

LIGHTING SEQUENCE
#1,#3,#4,#5

TOTAL OF 24 ZONES

OCCUPANCY CONTROL ZONES

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Architect
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22 West 19th Steet New York, NY
11001

Interior Architect
GENSLER ARCHITECT
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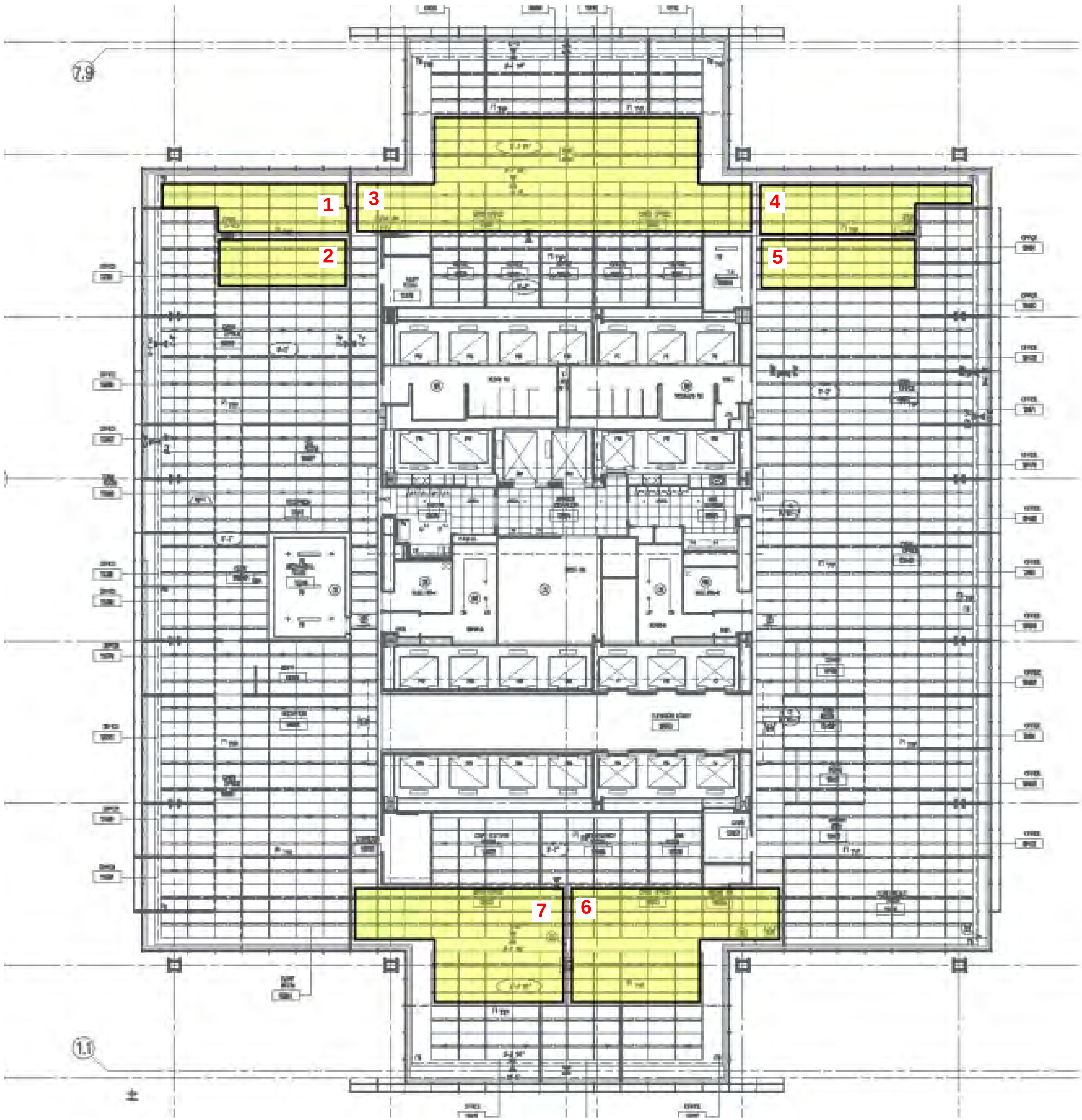
13th Floor

Sept. 22nd, 2004

Control Intent Diagram

CSK-1



LIGHTING SEQUENCE #3, #4
TOTAL OF 7 ZONES

DAYLIGHT DALI DIMMING ZONES

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11001

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GENSLER ARCHITECT
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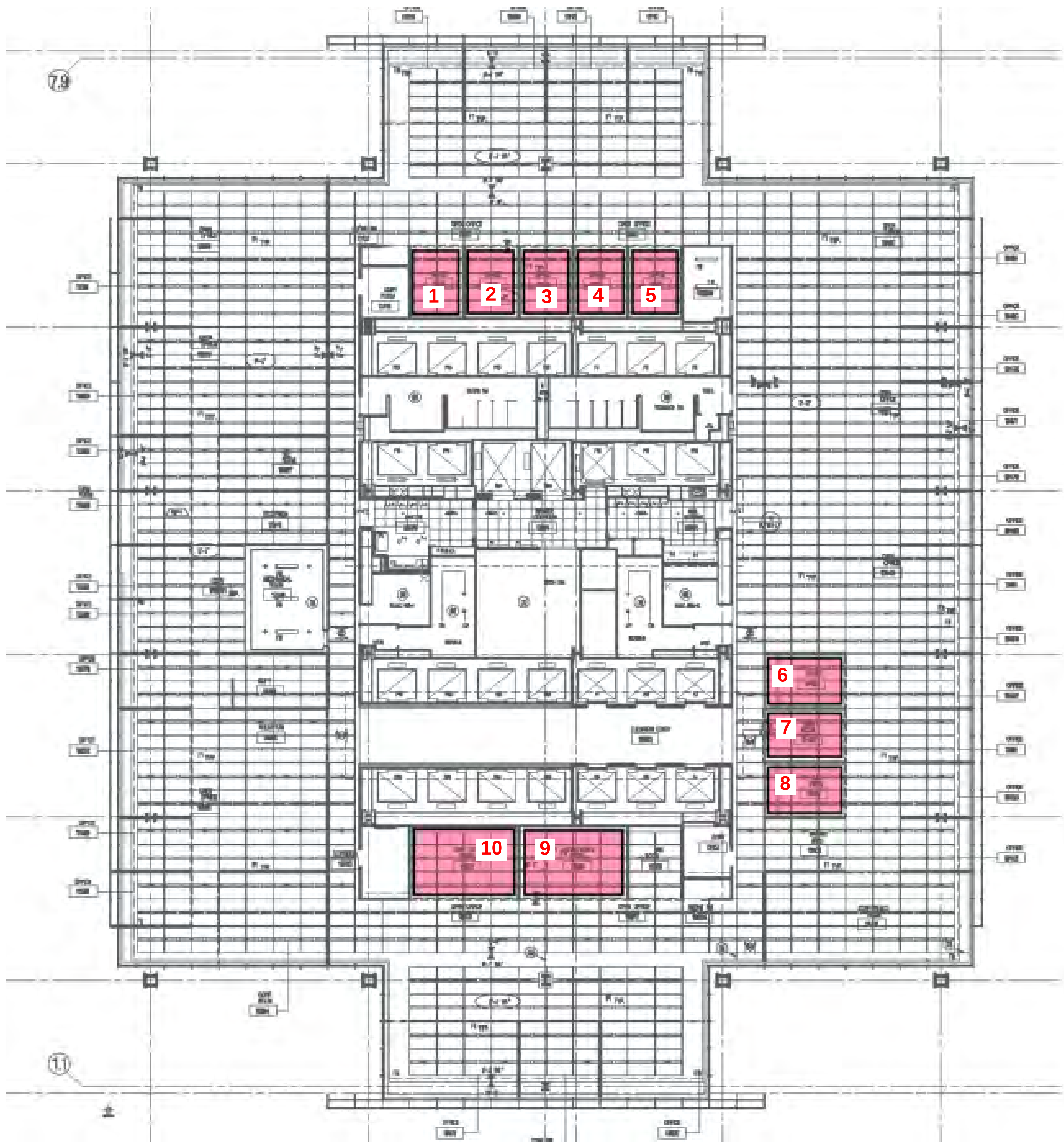
13rd Floor

Sept. 22nd, 2004

Control Intent Diagram

CSK-2



LIGHTING SEQUENCE #2, #3
TOTAL OF 10 ZONES

MANUAL DALI DIMMING (WALL BOX SWITCH) AND OCCUPANCY CONTROL ZONES

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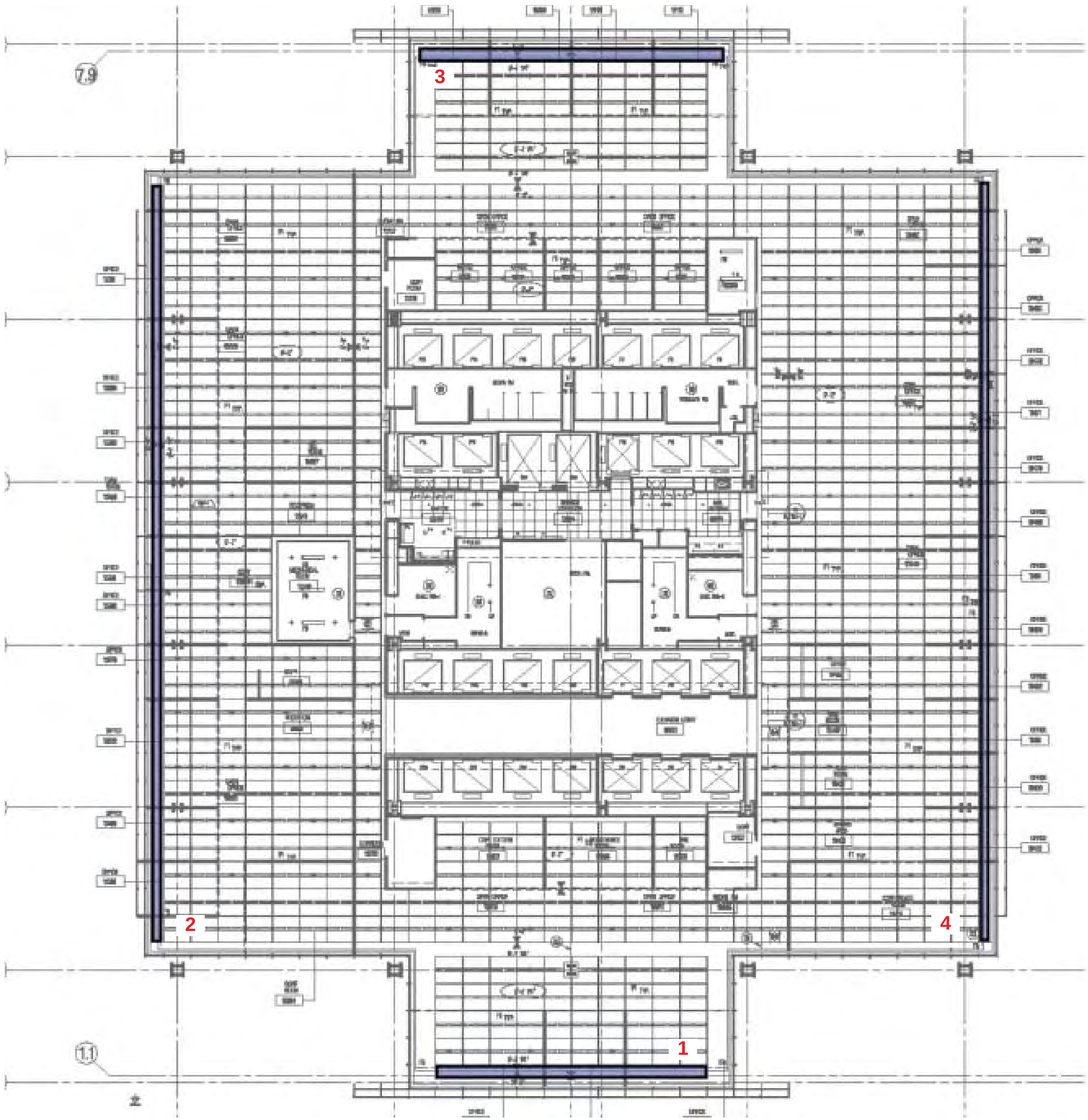
13th Floor

Sept. 22nd, 2004

Control Intent Diagram

CSK-3



LIGHTING SEQUENCE #6
TOTAL OF 4 ZONES

TIME CLOCK CONTROL ZONES

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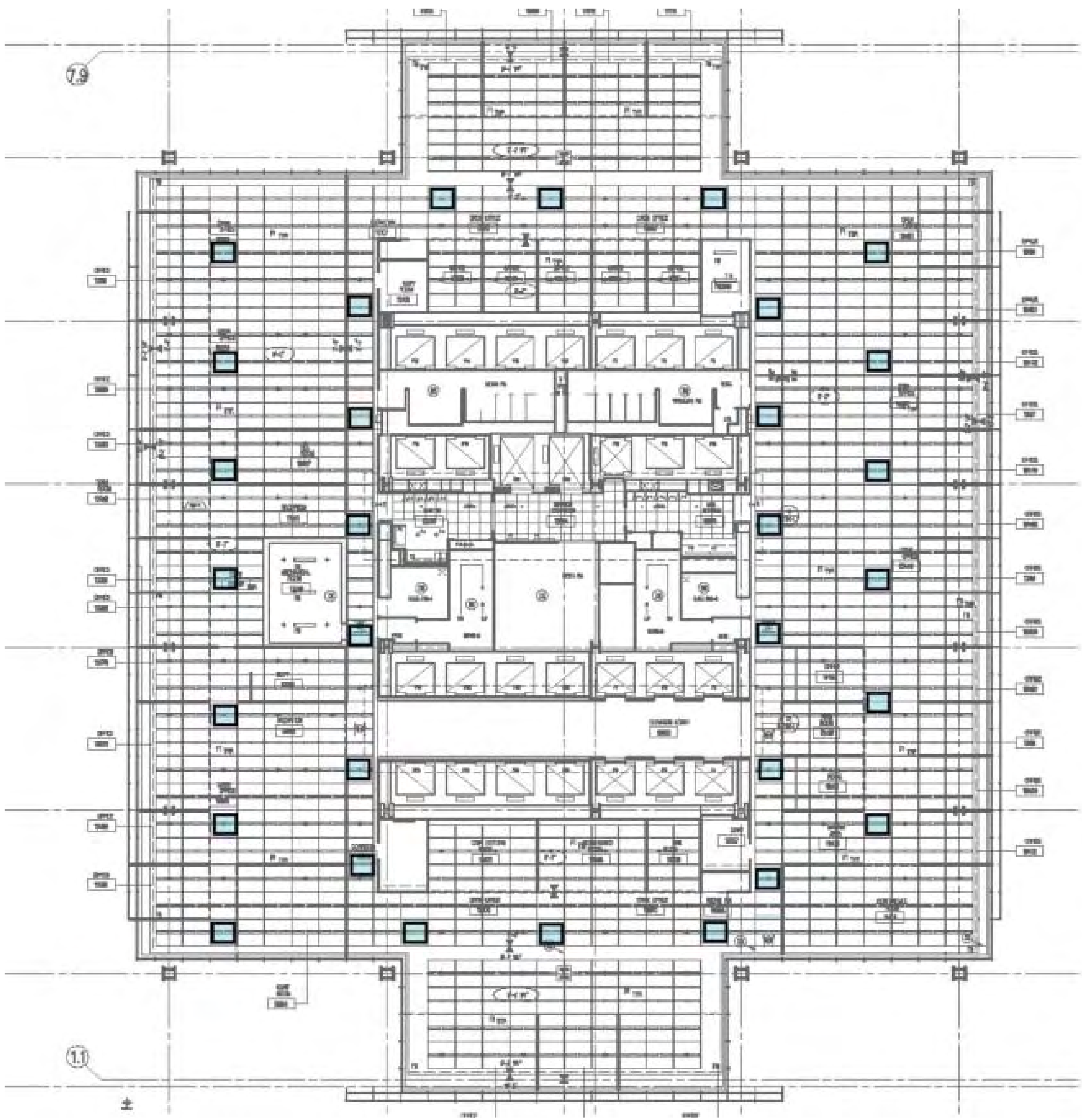
LIGHTING DESIGN

13th Floor

Sept. 22nd, 2004

Control Intent Diagram

CSK-4



TYPICAL EMERGENCY FIXTURES

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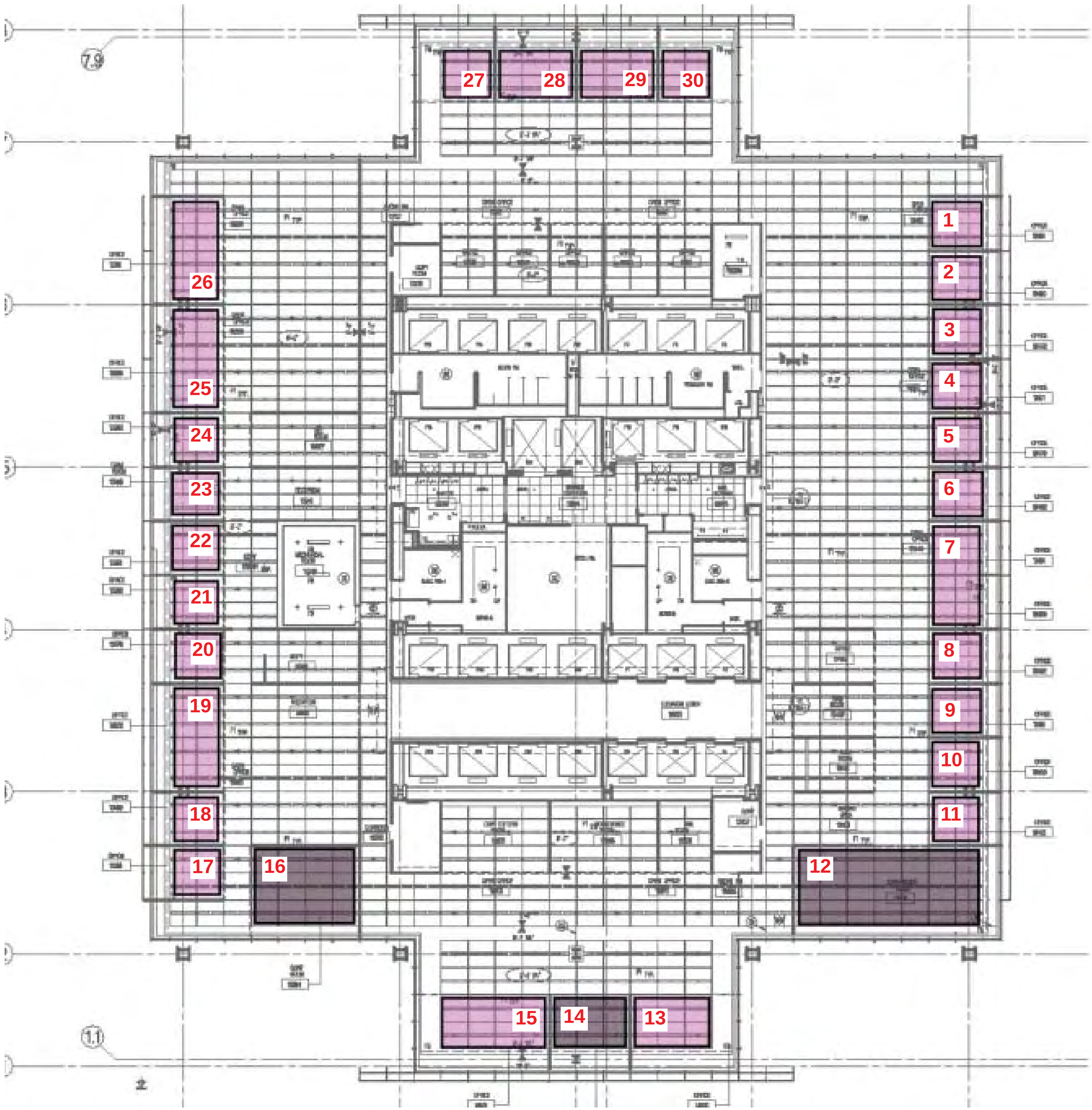
LIGHTING DESIGN

13th Floor

Sept. 22nd, 2004

Control Intent Diagram

CSK-5



WITH MULTIPLE PRESET DIMMER CONTROL

LIGHTING SEQUENCE #2, #3

MANUAL DALI DIMMING (WALL BOX SWITCH), DAY-LIGHT SENSOR (PHOTOCELL) AND OCCUPANCY CONTROL ZONES

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22 West 19th Steet New York, NY 11001

Interior Architect
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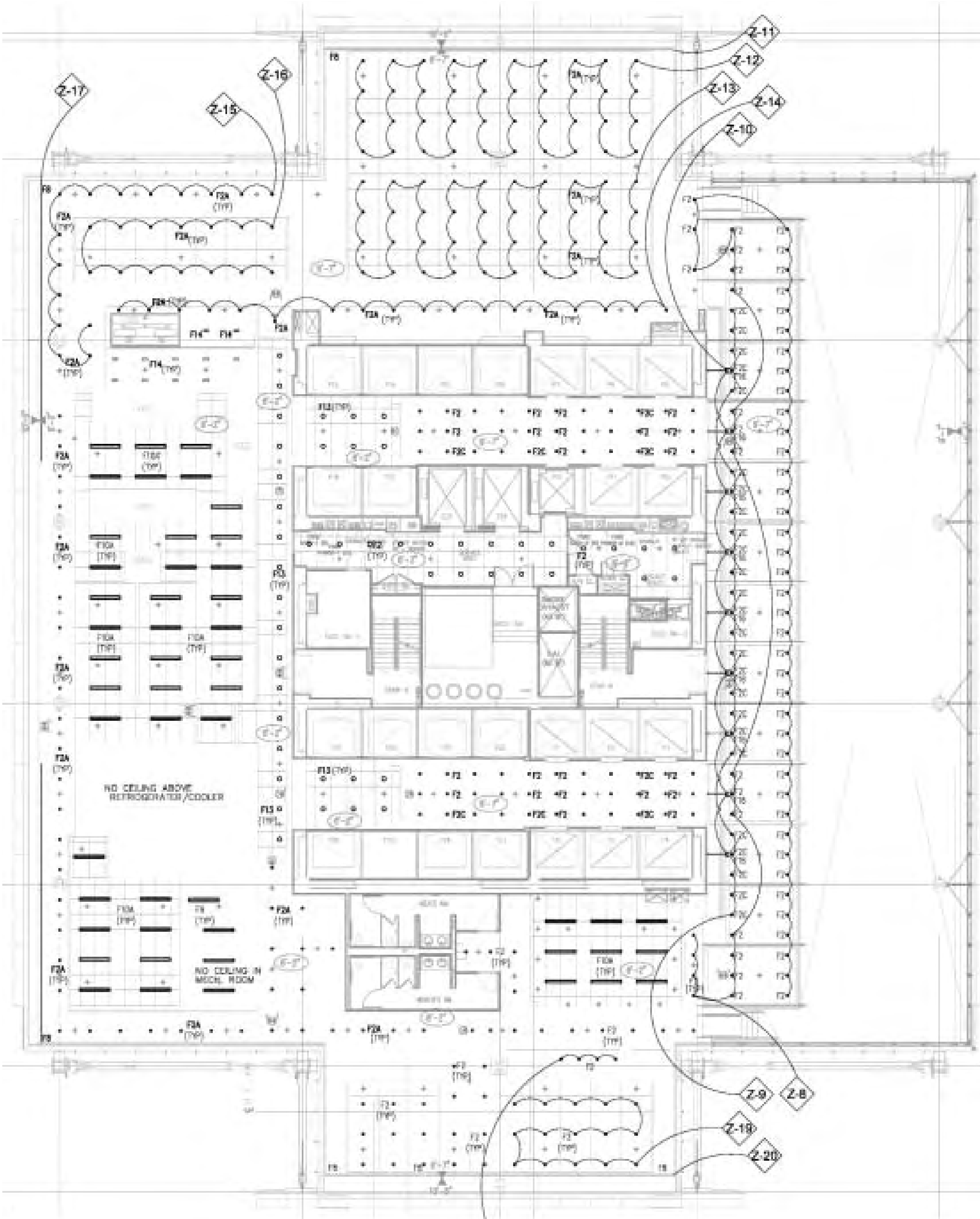
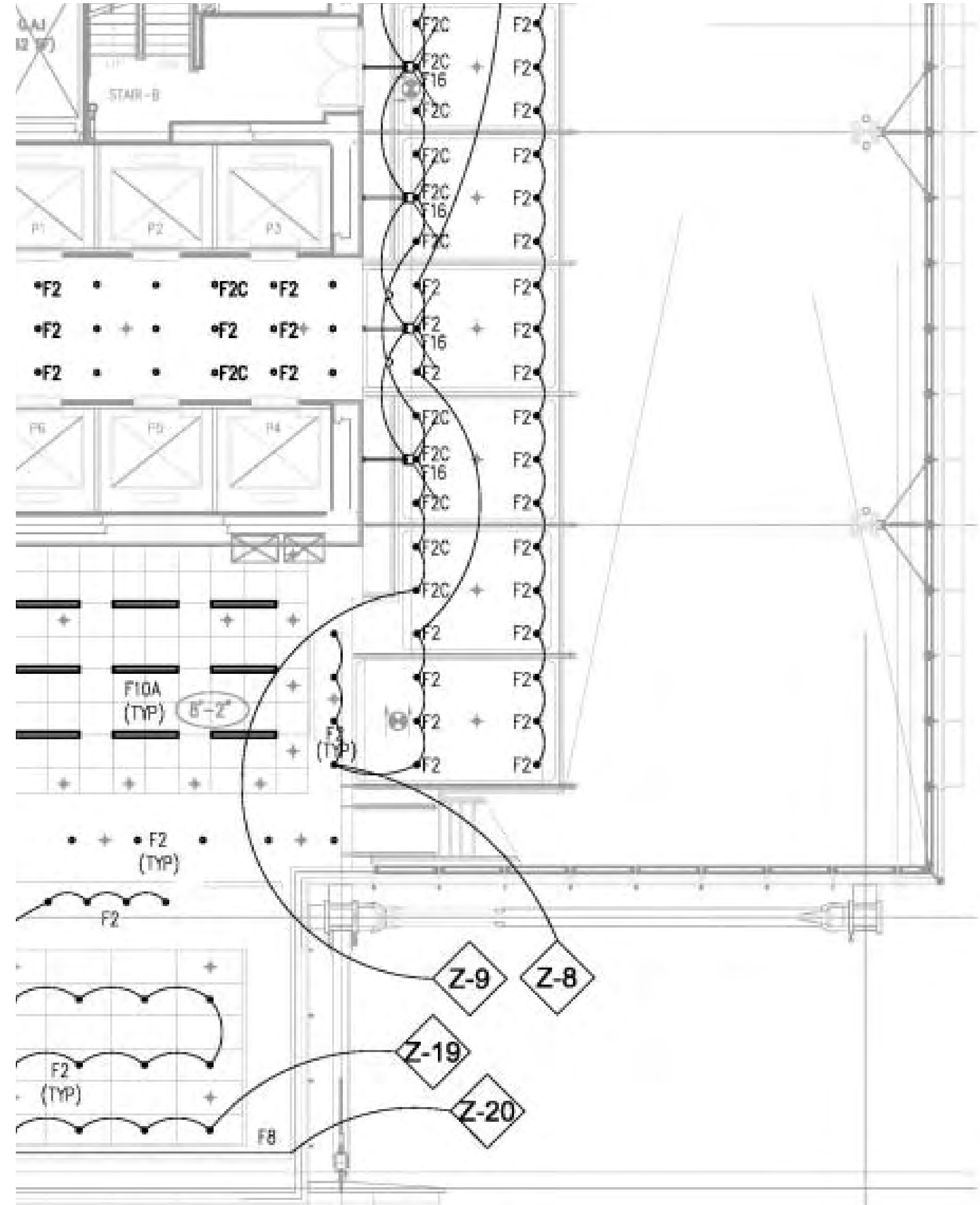
13th Floor

Sept. 22nd, 2004

Control Intent Diagram

CSK-6





LIGHTING SEQUENCE #8
TOTAL OF 13 ZONES

14th FL CONTROL DIAGRAM

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RENZO PIANO BUILDING WORKSHOP
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Interior Architect
GENSLER ARCHITECT
One Rockefeller Plaza, New York, NY 10020

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LIGHTING DESIGN

14th Floor

Sept. 22nd, 2004

Control Intent Diagram

CSK-1

LIGHTING SEQUENCE #1, #3, #4, #5
TOTAL OF 16 ZONES

OCCUPANCE CONTROL

ADDENDUM #1 Revised Sep. 02nd, 2004

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22 West 19th Street New York, NY 11001

Interior Architect
GENSLER ARCHITECT
One Rockefeller Plaza, New York, NY 10020

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LIGHTING DESIGN

14th Floor

Sept. 22nd, 2004

Control Intent Diagram

CSK-2

DIMMING LOAD SCHEDULE

14th Floor

Zone	Type	Description	Volts	No. of Fixtures	Watts / Fixture	Total Watts	Location/ Focus
Z-8	F-2	Recessed downlight with (1) 50Watt low voltage MR16 lamp and magnetic transformer	12	57	50	285+0	Cafeteria - Perimeter
Z-9	F-2C	Recessed downlight with (1) 50Watt low voltage MR16 lamp and magnetic transformer	12	25	50	1250	Cafeteria - Perimeter
Z-10	F-16	Wall bracket uplight with (1) 300t low voltage T-3 lamp and magnetic transformer	120	9	300	2700	Cafeteria - Perimeter
Z-11	F-8	Perimeter T-5 Fulorescent uplight cove with non dim ballast	277	11x4'-0"	28W/4'-0"	308	Servery - Perimeter
Z-12	F-2A	Recessed downlight with (1) 50Watt low voltage MR16 lamp and magnetic transformer	12	40	50	2000	Servery
Z-13	F-2A	Recessed downlight with (1) 50Watt low voltage MR16 lamp and magnetic transformer	12	40	50	2000	Servery
Z-14	F-2A	Recessed downlight with (1) 50Watt low voltage MR16 lamp and magnetic transformer	12	18	50	900	Servery - Perimeter
Z-15	F-2A	Recessed downlight with (1) 50Watt low voltage MR16 lamp and magnetic transformer	12	15	50	750	Servery - Perimeter
Z-16	F-2A	Recessed downlight with (1) 50Watt low voltage MR16 lamp and magnetic transformer	12	14	50	700	Servery
Z-17	F-8	Perimeter T-5 Fulorescent uplight cove with non dim ballast	277	7x4'-0"	28W/4'-0"	196	Servery - Perimeter
Z-18	F-2	Recessed downlight with (1) 50Watt low voltage MR16 lamp and magnetic transformer	12	4	50	200	Annex Private Dinning
Z-19	F-2	Recessed downlight with (1) 50Watt low voltage MR16 lamp and magnetic transformer	12	15	50	750	Annex Private Dinning
Z-20	F-8	Perimeter T-5 Fulorescent uplight cove with non dim ballast	277	5x4'-0"	28W/4'-0"	140	Annex Private Dinning

DIMMING LOAD SCHEDULE

General Notes:

All Fluorescent circuit should have 277V. See following dimming graphs for detail.

1. Loads are calculated for lamps only; electrical engineer to calculate for wattage input of ballasts and step-down transformers.
2. Emergency requirements to be designed and specified by Electrical Engineer, Electrical Contractor to coordinate.
3. All fluorescent run lengths and loads to be verified in field by the Contractor.

15th Floor

Zone	Type	Description	Volts	No. of Fixtures	Watts / Fixture	Total Watts	Location/ Focus
Z-1	F-8	Perimeter T-5 Fulorescent uplight cove with non dim ballast	277	28x4'-0"	28W/4'-0"	784	Cafeteria - Perimeter
Z-2	F-2	Recessed downlight with (1) 50Watt low voltage MR16 lamp and magnetic transformer	12	40	50	2000	Cafeteria
Z-3	F-12	Surface mounted adjustable downlight with (1) 75Watt Par30 lamp	120	56	75	4200	Cafeteria
Z-4	F-12A	Surface mounted adjustable downlight with (1) 75Watt Par30 lamp	120	28	75	2100	Cafeteria
Z-5	F-11	Pendant with (1) 100 Watt low voltage T-6 lamp and magnetic transformer	12/120	24	100	2400	Cafeteria
Z-6	F-2C	Recessed downlight with (1) 50Watt low voltage MR16 lamp and magnetic transformer	12	29	50	1450	Cafeteria - Perimeter
Z-7	F-2	Recessed downlight with (1) 50Watt low voltage MR16 lamp and magnetic transformer	12	24	50	1200	Cafeteria - Perimeter

LIGHTING SEQUENCE #7 & #8
TOTAL OF 7

14th & 15th FL CONTROL LOAD SCHEDULE

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Architect
RENZO PIANO BUILDING WORKSHOP
34,Rue Des Archives 75004 PARIS

FOX & FOWLE ARCHITECTS, P. C.
22 West 19th Steet New York, NY 11001

Interior Architect
GENSLER ARCHITECT
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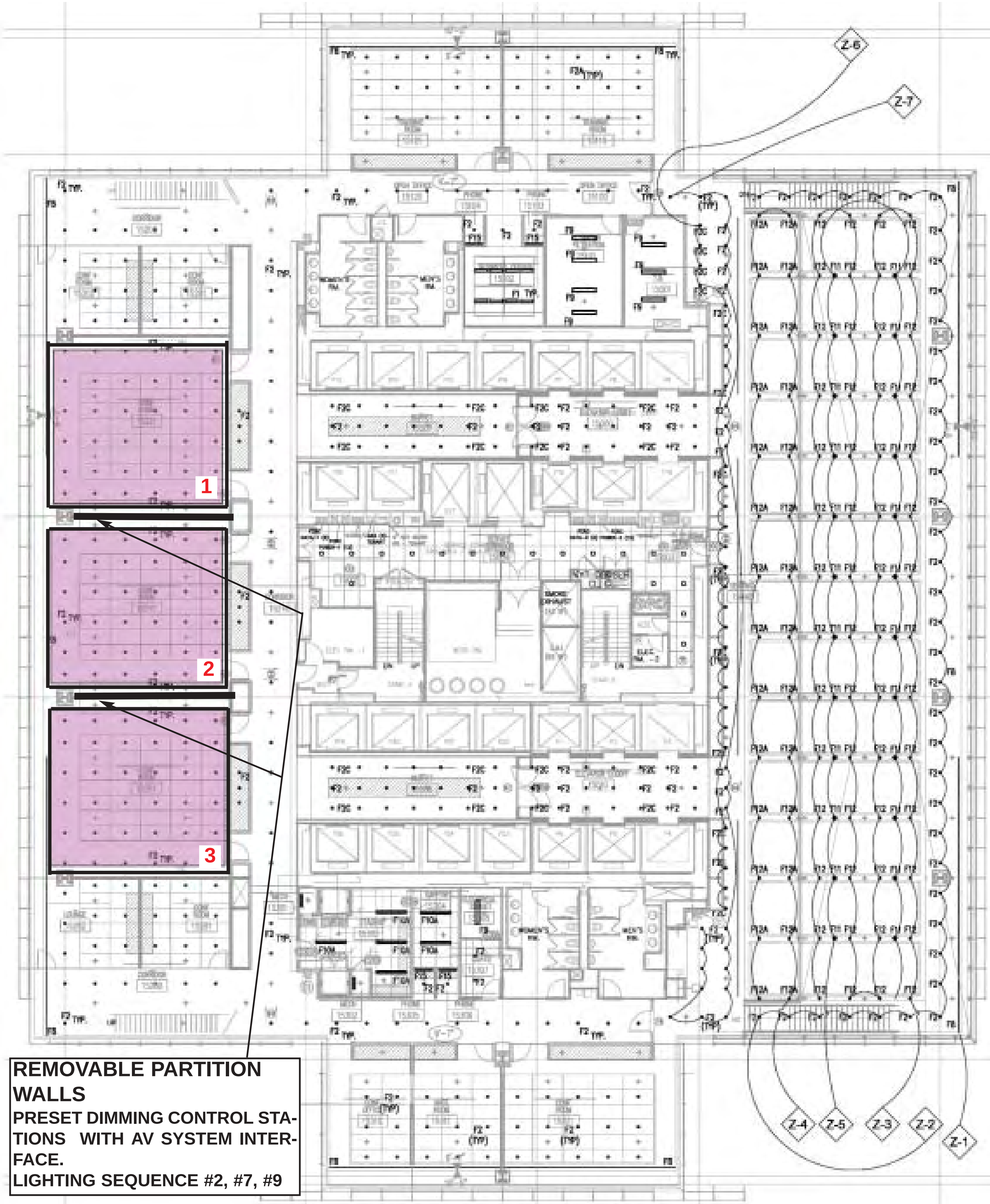
14th & 15th Floor

Sept. 22nd, 2004

Control Intent Diagram

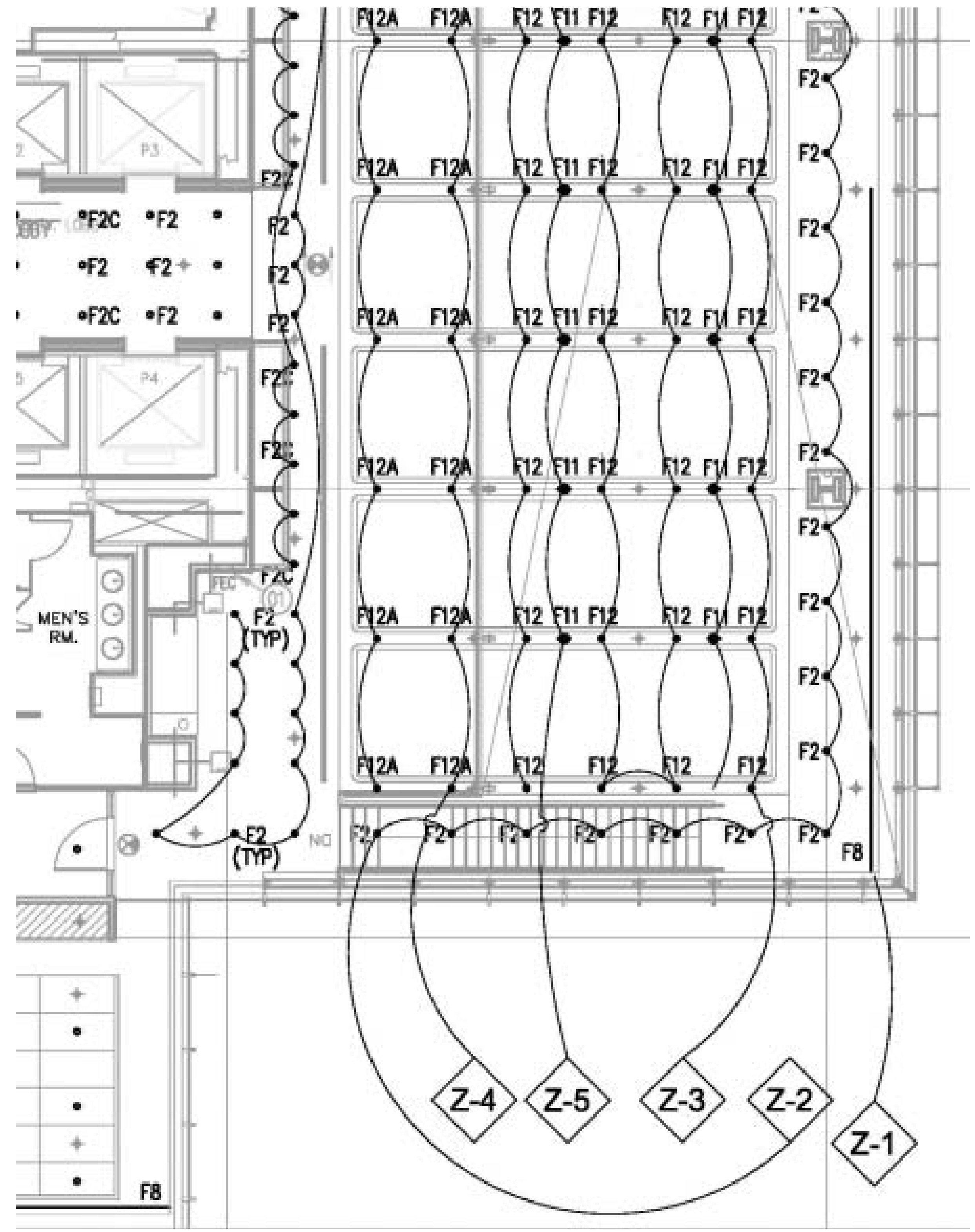
CSK-2



REMOVABLE PARTITION WALLS

PRESET DIMMING CONTROL STATIONS WITH AV SYSTEM INTERFACE.

LIGHTING SEQUENCE #2, #7, #9



LIGHTING SEQUENCE #2, #7, #8 & #9

TOTAL OF 7 ZONES AT CAFETERIA

15th FL CONTROL DIAGRAM

ADDENDUM #1 Revised Sep. 02nd, 2004

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RENZO PIANO BUILDING WORKSHOP
34,Rue Des Archives 75004 PARIS

FOX & FOWLE ARCHITECTS, P. C.
22 West 19th Steet New York, NY 11001

Interior Architect
GENSLER ARCHITECT
One Rockefeller Plaza, New York, NY 10020

NEW YORK TIMES BUILDING
630 EIGHT AVENUE, NEW YORK, NEW YORK

LIGHTING DESIGN

15th Floor

Sept. 22nd, 2004

Control Intent Diagram

CSK-1

LIGHTING SEQUENCE #1, #3, #4 & #5

TOTAL OF 19 ZONES

OCCUPANCY CONTROL ZONES

ADDENDUM #1 Revised Sep. 02nd, 2004

SBLD studio
132 W 36th St
NY NY 10018
212.391.4230 T
212.391.4231 F
sbldstudio.com

Clients:
THE NEW YORK TIMES
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Architect
RENZO PIANO BUILDING WORKSHOP
34,Rue Des Archives 75004 PARIS

FOX & FOWLE ARCHITECTS, P. C.
22 West 19th Steet New York, NY 11001

Interior Architect
GENSLER ARCHITECT
One Rockefeller Plaza, New York, NY 10020

NEW YORK TIMES BUILDING

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NEW YORK, NEW YORK

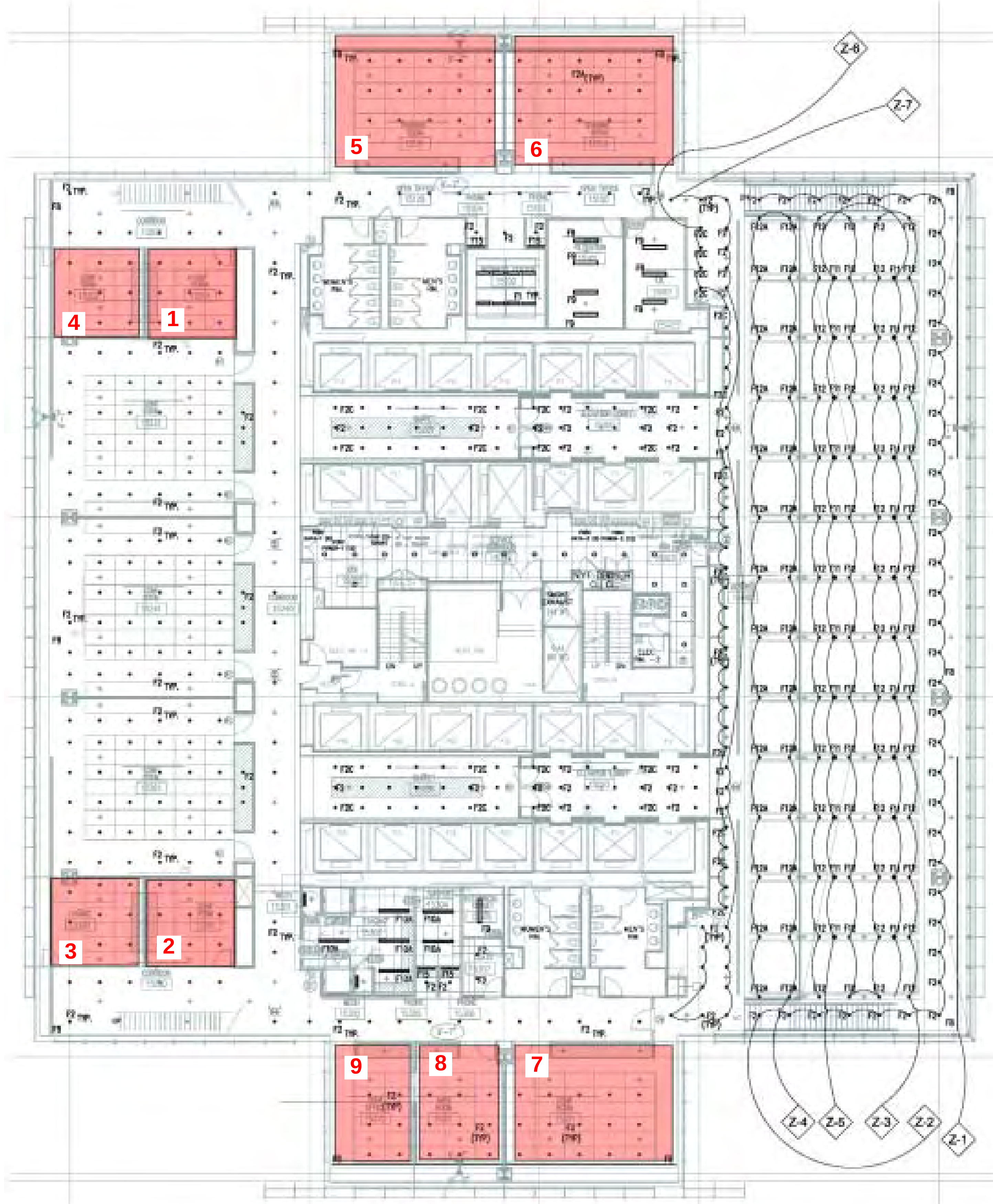
LIGHTING DESIGN

15th Floor

Sept. 22nd, 2004

Control Intent Diagram

CSK-2



LIGHTING SEQUENCE #2, #3
TOTAL OF 9 ZONES

MANUAL DALI DIMMING (WALL-BOX SWITCH) DAYLIGHT SENSOR (PHOTOCELL) AND OCCUPANCY CONTROL ZONES

ADDENDUM #1 Revised Sep. 02nd, 2004

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132 W 36th St
NY NY 10018
212.391.4230 T
212.391.4231 F
sbldstudio.com

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229 W. 43rd St. New York, 10036

Architect
RENZO PIANO BUILDING WORKSHOP
34,Rue Des Archives 75004 PARIS

FOX & FOWLE ARCHITECTS, P. C.
22 West 19th Steet New York, NY 11001

Interior Architect
GENSLER ARCHITECT
One Rockefeller Plaza, New York, NY 10020

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15th Floor

Sept. 22nd, 2004

Control Intent Diagram

CSK-3

OCCUPANCY CONTROL ZONES

LIGHTING SEQUENCES
#1, #3, #4, #5
TOTAL OF 19 ZONES

OCCUPANCY CONTROL ZONES

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NY NY 10018

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Architect
RENZO PIANO BUILDING WORKSHOP
34,Rue Des Archives 75004 PARIS

FOX & FOWLE ARCHITECTS, P. C.
22 West 19th Steet New York, NY 11001

Interior Architect
GENSLER ARCHITECT
One Rockefeller Plaza, New York, NY 10020

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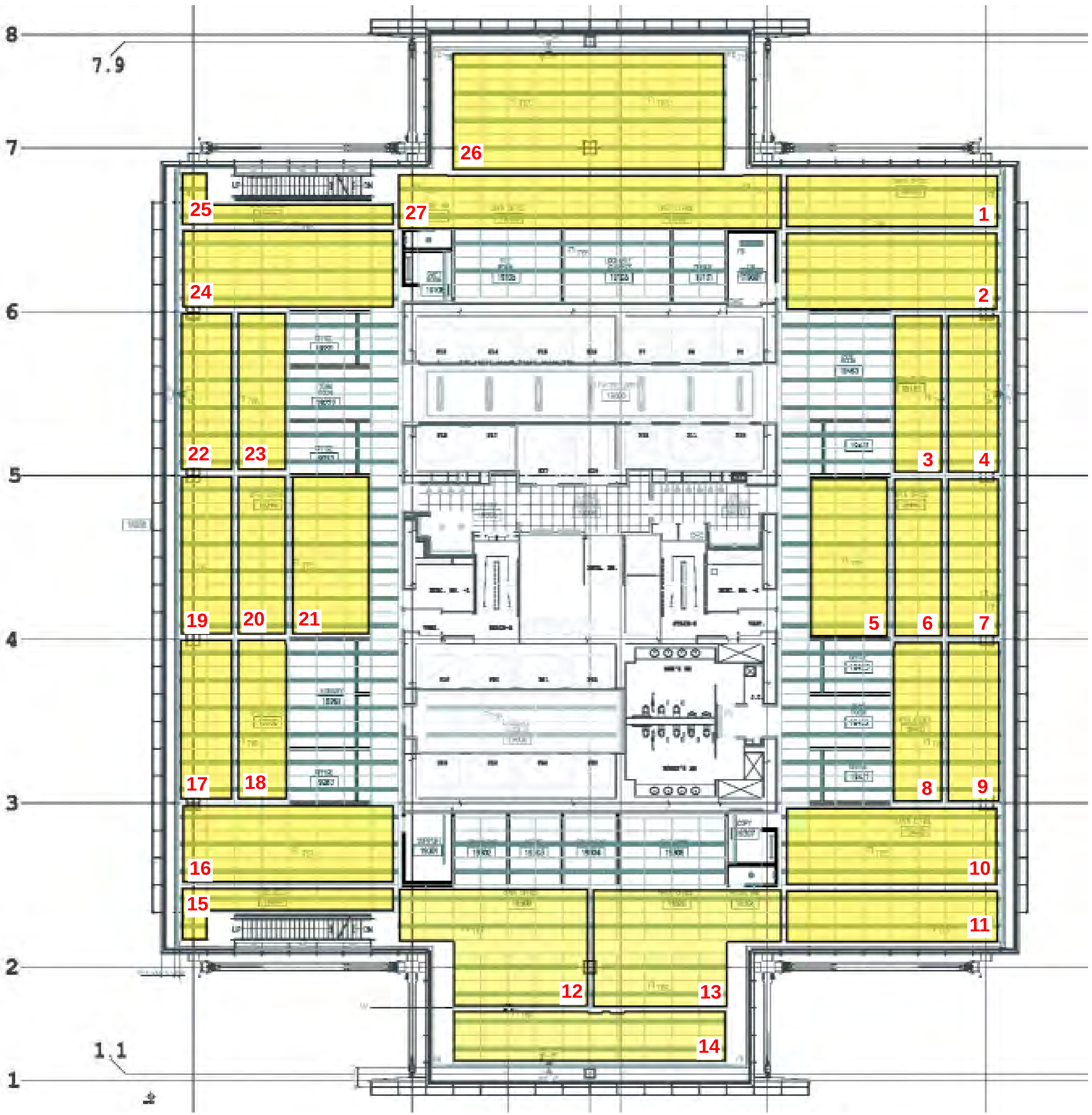
LIGHTING DESIGN

19th Floor

Sept. 22nd, 2004

Control Intent Diagram

CSK-1



LIGHTING SEQUENCE #3, #4
TOTAL OF 27 ZONES

DAYLIGHT DALI DIMMING ZONES

SBLD studio
132 W 36th St
NY NY 10018
212.391.4230 T
212.391.4231 F

Clients:
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229 W. 43rd St. New York, 10036

Architect
RENZO PIANO BUILDING WORKSHOP
34,Rue Des Archives 75004 PARIS

FOX & FOWLE ARCHITECTS, P. C.
22 West 19th Steet New York, NY 11001

Interior Architect
GENSLER ARCHITECT
One Rockefeller Plaza, New York, NY 10020

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NEW YORK, NEW YORK

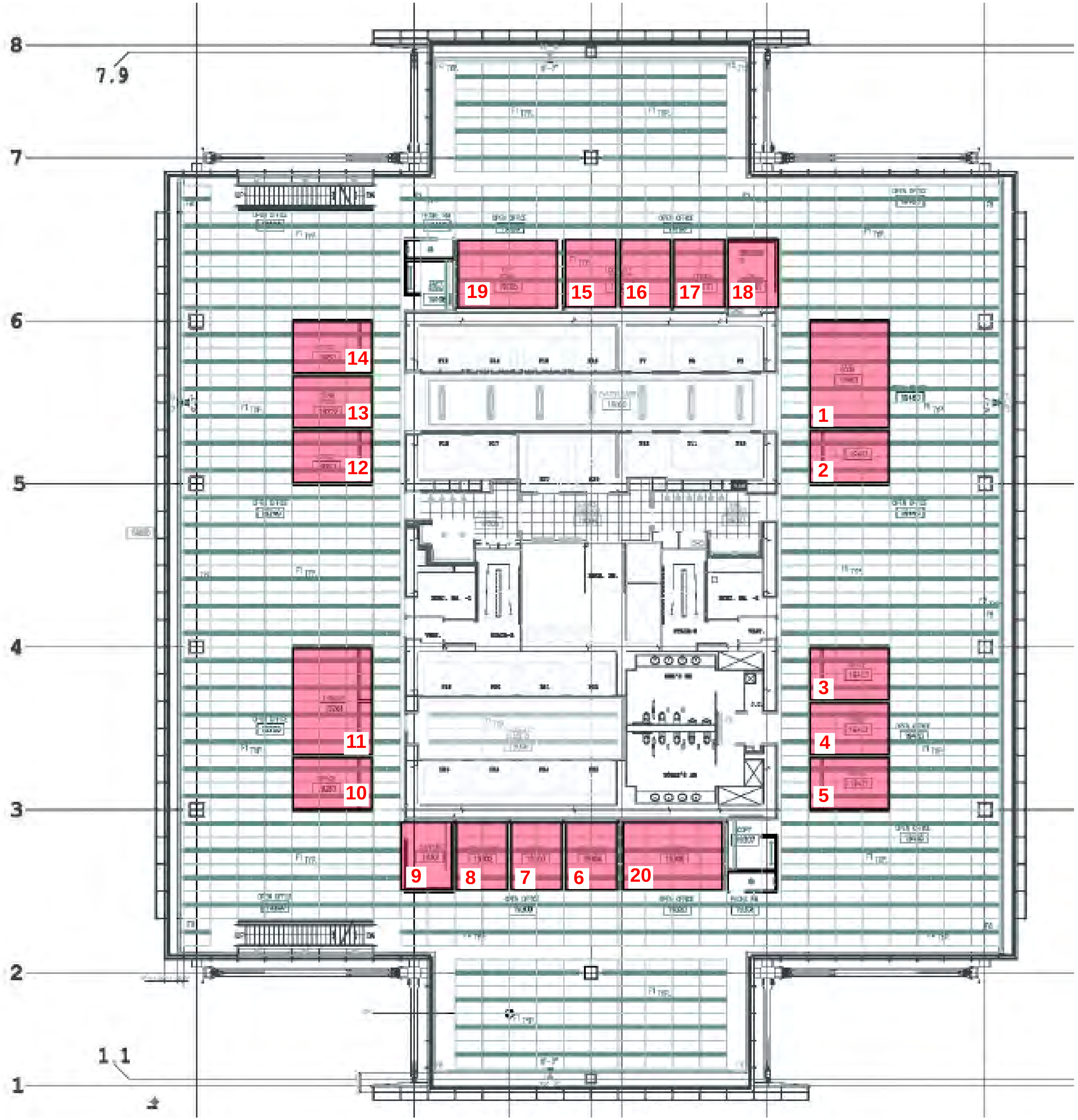
LIGHTING DESIGN

19th FLoor

Sept. 22nd, 2004

Control Intent Diagram

CSK-2



LIGHTING SEQUENCE #2, #3
TOTAL OF 20 ZONES

MANUAL DALI DIMMING (WALL BOX SWITCH) AND OCCUPANCY CONTROL ZONES

SBLD studio
132 W 36th St
NY NY 10018
212.391.4236 T
212.391.4231 F
sbldstudio.com

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229 W. 43rd St. New York, 10036

Architect
RENZO PIANO BUILDING WORKSHOP
34,Rue Des Archives 75004 PARIS

FOX & FOWLE ARCHITECTS, P. C.
22 West 19th Steet New York, NY 11001

Interior Architect
GENSLER ARCHITECT
One Rockefeller Plaza, New York, NY 10020

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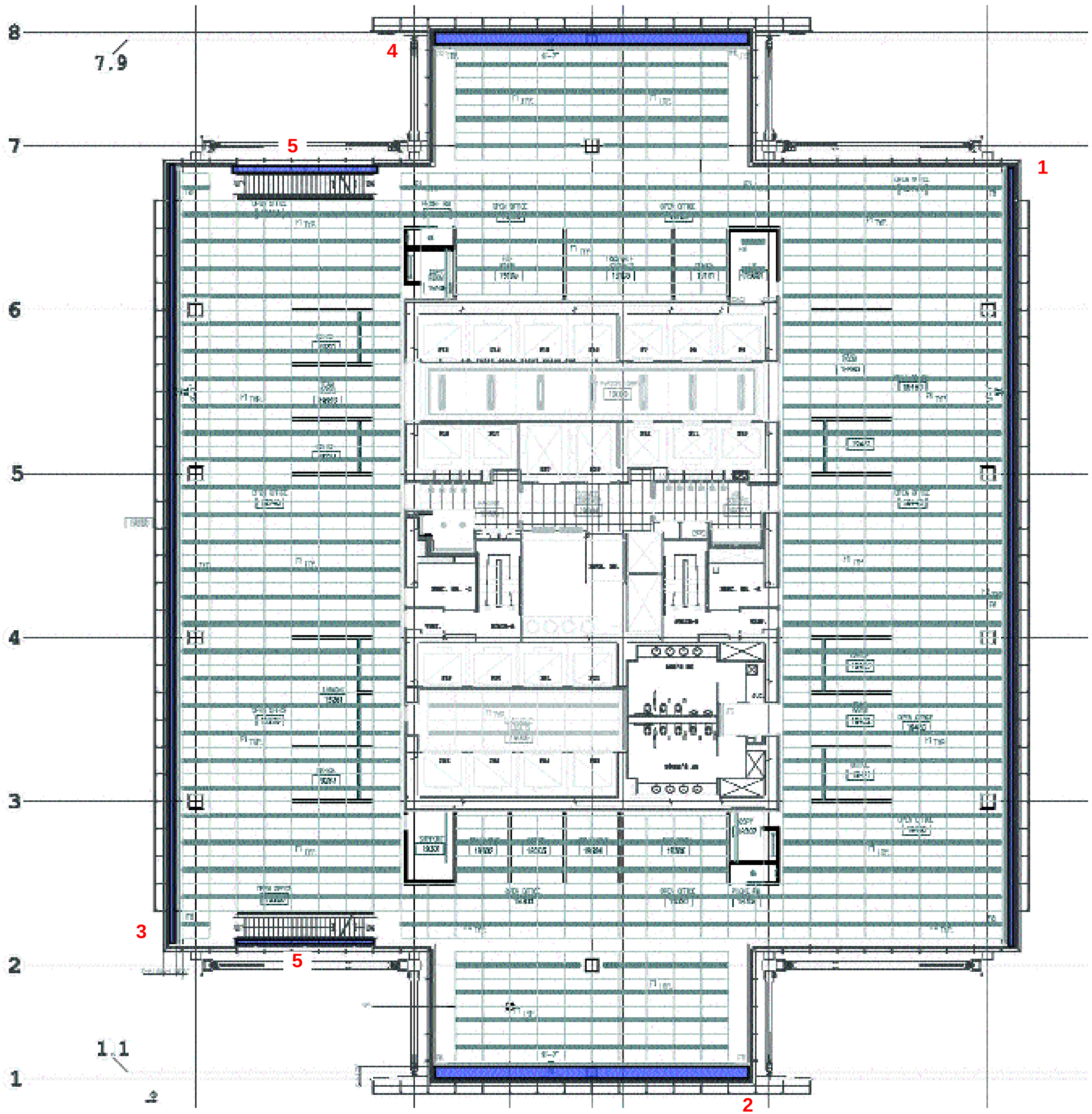
Sept. 22nd, 2004

Control Intent Diagram

CSK-3



LIGHTING SEQUENCE #6
TOTAL OF 5 ZONES

TIME CLOCK CONTROL ZONES

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132 W 36th St
NY NY 10018
212.391.4230 T
212.391.4331 F
sbldstudio.com

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Architect
RENZO PIANO BUILDING WORKSHOP
34,Rue Des Archives 75004 PARIS

FOX & FOWLE ARCHITECTS, P. C.
22 West 19th Steet New York, NY 11001

Interior Architect
GENSLER ARCHITECT
One Rockefeller Plaza, New York, NY 10020

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NEW YORK, NEW YORK

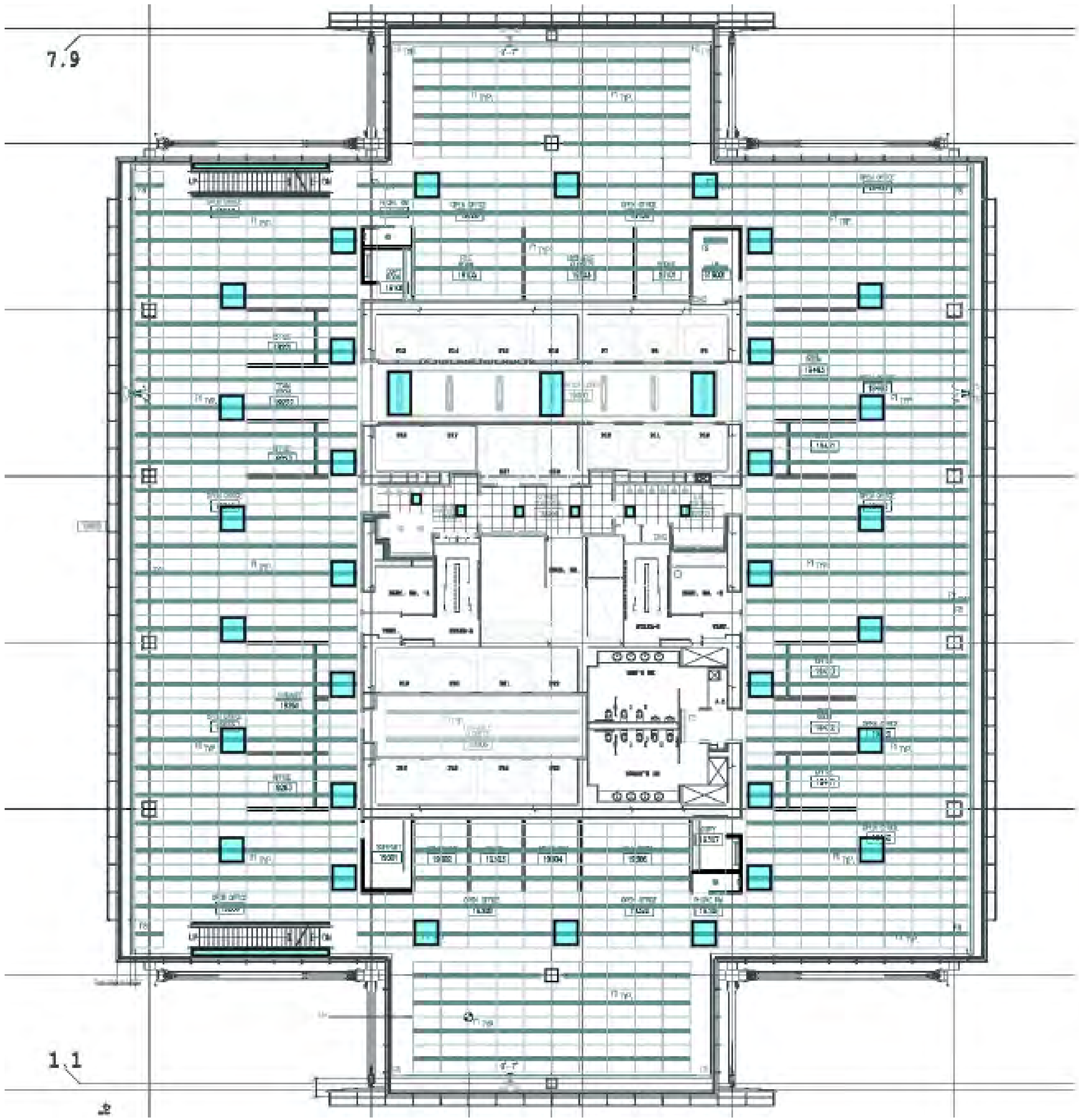
IGHTING DESIGN

19th Floor

Sept. 22nd, 2004

Control Intent Diagram

CSK-4



LIGHTING SEQUENCE #1, #2, #3, #4, #5
TOTALLY OF 46 FIXTURES

TYPICAL EMERGENCY FIXTURES

SBLD studio
132 W 36th St
NY NY 10018
212.391.4230 T
212.391.4231 F
sbldstudio.com

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THE NEW YORK TIMES
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Architect
RENZO PIANO BUILDING WORKSHOP
34,Rue Des Archives 75004 PARIS

FOX & FOWLE ARCHITECTS, P. C.
22 West 19th Steet New York, NY 11001

Interior Architect
GENSLER ARCHITECT
One Rockefeller Plaza, New York, NY 10020

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LIGHTING DESIGN

19th Floor

Sept. 22nd, 2004

Control Intent Diagram

CSK-5

Appendix E

ROLLER SHADES AND SHADE CONTROLS SYSTEM SPECIFICATIONS

SECTION 12494 - ROLLER SHADES

PART 1 - GENERAL

1.1 SUMMARY

A. This Section includes interior roller shades, motorized shade operators and an automatic shade controls system for the entire glazed perimeter of The New York Times Building for floors 2 through 28 including the garden court on floors 2, 3 and 4.

B. See Division 16 Sections for electrical service and connections for motorized shade operation.

1.2 SUBMITTALS

A. Product Data: For each type of product indicated.

B. Shop Drawings: Include: plans, elevations, section views, details of installation, operational clearances, wiring diagrams, and relationship to adjoining Work.

1. Verify dimensions by field measurements before fabrication and indicate measurements on Shop Drawings.

2. Submit shop drawings in electronic format, MicroStation version J.

C. Coordination Drawings: Drawn to scale and coordinating penetrations and ceiling-mounted items.

D. Samples: For each exposed finish and for each color and texture required.

E. Window Treatment Schedule: Use same room designations indicated on Drawings.

F. Maintenance data.

G. Shop drawings shall be delivered in accordance with a schedule established in consultation between Owner and Shade Controls System Supplier.

1.3 QUALITY ASSURANCE

A. Installer Qualifications: A qualified installer, approved by Shade Controls System Supplier to install shade products.

B. Roller Shades Fire-Test-Response Characteristics: Provide products passing flame-resistance testing according to NFPA 701 by a testing agency acceptable to authorities having jurisdiction.

C. Electrical Components, Devices, and Accessories: Listed and labeled as defined in the 2002 National Electric Code with New York City amendments, and NFPA 70, Article 100, by a testing agency acceptable to authorities having jurisdiction, and marked for intended use.

D. Corded Window Covering Product Standard: Comply with WCMA A 100.1.

PART 2 - PRODUCTS

2.1 ROLLER SHADES

A. Available Products: Subject to compliance with requirements, products that may be incorporated into the Work include, but are not limited to, the following:
1. Lutron Electronics Co., Inc.
2. MechoShade Systems, Inc.
3. Nysan Shading Systems

B. Fabric manufacturers: Subject to compliance with requirements, provide products from one of the following:

1. MechoShade Systems, Inc.
2. VIMCO
3. Hexcel
4. Mermet

C. Finishes:
1. Metal and Plastic Components Exposed to View: Color shall be RAL 9003.

D. Shade fabric: PVC-coated fiberglass, PVC-coated polyethylene or non-PVC coated “yarn”

1. Material width shall suit window widths, typically five feet wide bands.
2. Material optical transmittance properties shall be consistent with the unobstructed portion of the window wall (the glazing area not shielded by the exterior ceramic rods) luminance criteria.
3. For each shade control zone the Supplier shall determine the proper density and weave of the fabric to meet the luminance requirements. Shade fabrics may thus vary from façade to façade and for different elevations (floors) of the building. Owner reserves the right to change the fabric OF and color at no cost prior to installation.
4. Material Safety Data Sheets shall be provided.
5. Shades shall be washable with soap and water.
6. The twill and fill colors and geometry shall be approved by the Architect.
7. Shade fabric may be made of different face colors.
8. Black out shades shall be opaque. Architect shall approve color(s) and geometry.

E. Rollers: Electrogalvanized or epoxy primed steel or extruded-aluminum tube of diameter and wall thickness required to support and fit internal components of operating system and the weight and width of shade band material without sagging; designed to be easily removable from support brackets.

1. Shade Material Attachment: Shade Controls System Supplier's standard method for attaching shade material to roller.
2. Direction of Roll: Regular, from back of roller.

F. Mounting Brackets: Galvanized or zinc-plated steel.

G. Pocket-Style Head Box: U-shaped, formed-steel sheet or extruded aluminum; long edges returned or rolled; with bottom open.

1. Corner Section: Factory formed and welded.

H. Bottom Bar: Steel or extruded aluminum with plastic or metal capped ends and with concealed weight bar as required for smooth, properly balanced shade operation.

1. Type: Concealed, by pocket of shade material, internal.

I. Shade Operation: Motorized operator AC or DC with capability of operating up to six (6) each coupled five ft. wide shades.

J. Mounting: Recessed in ceiling pocket, permitting easy removal and replacement without damaging roller shade or adjacent surfaces and finishes. At corner conditions the mounting system shall allow a minimal light gap not to exceed ¼” while ensuring that the perpendicular shade bands do not touch.

2.2 FABRICATION

A. Product Description: Roller shade consisting of roller, a means of supporting roller, flexible sheet or band of material carried by roller, a means of attaching material to roller, bottom bar, and operating mechanism that lifts and lowers the shade.

B. Concealed Components: Non-corrodible or corrosion-resistant-coated materials.

1. Lifting mechanism with permanently lubricated moving parts.

C. Unit Sizes: Obtain units fabricated in sizes to fill window and other openings as follows, measured at 74 deg F (23 deg C):
1. Shade Units Installed Outside Jambs: Width and length as indicated, with terminations between shades of end-to-end installations at centerlines of mullion or other defined vertical separations between openings.
2. The gap between five ft. wide shade bands in a motor group, i.e. coupled together, shall not exceed one inch.
3. The gap between shade motor groups shall not exceed one inch.

D. Installation Brackets: Designed for easy removal and reinstallation of shade, for supporting head box, roller, and operating hardware and for hardware position and shade mounting method indicated.

E. Installation Fasteners: Not fewer than two fasteners per bracket, fabricated from metal non-corrosive to shade hardware and adjoining construction; type designed for securing to supporting substrate; and supporting shades and accessories under conditions of normal use.

2.3 MOTORIZED ROLLER SHADE OPERATORS

A. General:

1. Factory-assembled motorized shade operation systems designed for lifting shades of type, size, weight, construction, use, and operation frequency indicated and of size and capacity and with features, characteristics, and accessories suitable for Project conditions and recommended by shade manufacturer.
2. Include electric motors and factory pre-wired motor controls, remote-control stations, remote-control devices, power disconnect switches, enclosures protecting controls and all operating parts, and accessories required for reliable operation without malfunction.
3. Wiring shall be provided by the Electrical Installation Contractor
   a. Power and controls to the motors
   b. Power and controls to the sensors
   c. Power and controls to the manual override touch screens
   d. System interconnections
4. Coordinate wiring requirements and electrical characteristics with the building electrical system.
5. Provide supervision during the wiring installation to ensure the wiring is being performed in accordance with the shop drawing details.
6. Comply with NFPA 70.

B. Control Equipment: Comply with NEMA ICS 1, NEMA ICS 2, and NEMA ICS 6 with NFPA 70 Class 2 control circuit, maximum 24-V ac or dc. Control boxes shall be located in central core closets on the floors to the extent possible. Control boxes in the ceilings are to be minimized. The as-built location of any ceiling mounted control boxes shall be clearly defined on the record drawings, specifically on reflected ceiling plans.

C. Electric Motors: UL-approved or -recognized, asynchronous, totally enclosed, insulated, capacitor-start motors, complying with NEMA MG 1, with thermal-overload protection, brake, permanently lubricated bearings, and limit switches; sized by shade manufacturer to start and operate size and weight of shade considering service factor or considering Project's service conditions without exceeding nameplate ratings.

1. Service Factor: According to NEMA MG 1, unless otherwise indicated.
2. Motor Characteristics: AC Single phase, coordinate voltage rating with Engineering Drawings, 60 Hz; or, DC.
3. Motor Mounting: Within manufacturer's standard roller enclosure.
4. Motor warranty shall be 5 years from the date of Final Acceptance.

2.4 SHADE CONTROL SYSTEM

A. Primary goals of the shade control system are:
   1. Maximize natural light
   2. Maximize occupant connectivity with the outdoors, i.e. external views
   3. Intercept sunlight penetration so as to avoid direct solar radiation on the occupants
   4. Maintain a glare free environment
   5. Provide occupant manual override capability
   6. On any given façade the shades are as a general rule expected to be controlled together to the same bottom-of-hem height.

B. Sensors
   1. Interior sensors shall primarily be located in the lighting fixtures within a 6" removable center plate centered in the 5 ft. ceiling mounted lighting fixtures. A secondary interior sensor location shall be flush mounted on the perimeter side of the dry wall clad columns.
   2. Any other interior locations must be coordinated with the Architect. Architect reserves the right to refuse positions that are aesthetically displeasing.
   3. Exterior sensors may be located on the mast platform or on the roof ceramic rods screen steel support structure. Exterior sensors installed on the roof ceramic rods screen steel support structure but must be coordinated with window washing tracks and equipment.
   4. Exterior sensors may not be located on the ceramic rods, ceramic rods supports or windows on any floors.
   5. Radiometers may be installed on the mast platform located approximately 130 above the base of the mast.
   6. Analog to digital converters and amplifiers may be located in the NYT radio room on the 51st floor.
   7. Sensors shall determine sky conditions, boundary conditions for each shade control zone and average luminance in the unobstructed portion of the window wall (the glazing area not shielded by the exterior ceramic rods).
   8. The types, locations (within the constraints identified herein) and number of sensors shall be determined by the Shade Controls System Supplier.
   9. Architect shall approve sensor appearance.
   10. Exterior sensor signals shall be available to Owner and Owner's contractor as an input to the podium skylight control system.

C. Shade alignment
   1. All shade heights within a shade control zone shall be bottom-of-hem matched within ½ inch.
   2. All shade heights within a shade motor group shall be bottom-of-hem matched within ¼ inch.
   3. The accuracy of shade alignment shall be maintained over a period of five years from the date of Final Acceptance.

D. Control algorithms and the automatic control system mode
   1. The shades shall block direct sun so that the depth of direct sun penetration is no greater than a specified horizontal depth from the face of the window wall at floor level. The specified maximum penetration distance may vary for different perimeter areas and on different floors. The shades shall not be deployed to block direct sun if the sun is blocked

by nearby buildings within an entire shade control zone. The exterior ceramic rods provide direct sun shading. Automated shade control shall account for this shading. The profile angle and solar surface azimuth angle shall be determined by the Shade Controls System Supplier based upon the geometries of the curtain wall.

2. The shades shall control glare so that the window luminance viewed from any angle within the work space is no greater than a specified level during the day. This includes all periods throughout the day when there is or is not direct sun in the plane of the window. When there is no direct sun in the plane of the window wall, the average luminance of the unobstructed portion of the window wall (the glazing area not shielded by the exterior ceramic rods) shall not exceed 2000 cd/m2 (candelas per square meter). When there is direct sun in the plane of the window but the orb of the sun is not within the immediate field of view, the average luminance of the unobstructed portion of the window wall shall not exceed 2000 cd/m2. When there is direct sun in the plane of the window and the orb of the sun is within the immediate field of view, the average luminance of any portion of the window wall shall not exceed 2000 cd/m2 for more than 30 minutes.
3. Daylight admittance shall be maximized by raising the shades when sun control and glare control are not required.
4. View to the outdoors shall be maximized by opening the shades so that the shades do not block the unobstructed vision portion of the window wall when sun control and glare control are not required.
5. Variable sky conditions in a given day shall cause shade operations as the unobstructed portion of the window wall (the glazing area not shielded by the exterior ceramic rods) luminance varies.
6. Response to variable luminance at the unobstructed portion of the window wall (the glazing area not shielded by the exterior ceramic rods) shall be limited so as to avoid shade movement hysteresis. As the unobstructed portion of the window wall (the glazing area not shielded by the exterior ceramic rods) luminance increases, shade movements shall respond at normal system response speed. As the unobstructed portion of the window wall (the glazing area not shielded by the exterior ceramic rods) luminance decreases shade movements shall respond after a predetermined delay of five minutes minimum. If shades are in a position in which sunlight penetration would exceed the specified distance for that area, but cloudy conditions are present and the system is allowing view and increased natural light levels to occur, then as the cloudy condition changes to a sunny condition immediate shade movement shall occur to intercept the sunlight.
7. Response to variable sky conditions shall be immediate as the conditions change from cloudy to sunny, that is the shades shall go to the appropriate preset position immediately without stopping at intermediate preset positions. Response shall be staged one preset at a time with a delay of five minutes minimum between successive shade movements when sunny conditions change to cloudy.
8. Multiple shade control zones may be controlled by a sensor or group of sensors. Boundary conditions for shade control zones shall be factored into the system.
9. Shade positions shall be limited to a predetermined set of presets. On all facades with ceramic tubes these presets are: fully retracted, half way between the fully retracted position and the top of the vision window, top of the vision window, 4 feet above finished floor, bottom of vision window and down to the floor.
10. The presets for façade typologies without ceramic tubes shall be numerically the same and shall match the heights described in subparagraph 2.4.D.9 of this section of the

specifications except where the façade is a louver in which case no shades shall be provided.

11. In automatic mode the shades shall move to the 6 preset positions at the specified vertical heights. The system shall enable additional preset heights to be inserted or existing preset heights to be revised by the System Operator or System Administrator.
12. Sunset and sunrise conditions shall be programmed as separate controlled events. For the fifteen minutes after sunrise, the shades on all facades shall be fully open. For the fifteen minutes before sunset the shades on all facades shall be fully open.
13. The different building elevations and façade orientations will experience different urban conditions such as shading by other buildings and reflections off of other buildings depending upon the time of year and time of day. The shade control zones and sensor locations shall enable the shade control system to carry out the primary goals as identified in paragraph 2.4.A of this section of the specifications.
14. Seasonal modes of operation that address the highest luminance sunpath conditions on the various facades shall be programmed.
15. At night the shades shall be fully retracted.
16. System universal commands shall enable the System Operator and all security levels above System Operator to perform the following activities from the shade system main console/PC:
    a. Lower all shades to floor height with a single command
    b. Raise all shades to open position with a single command
    c. Lower all shades on a specific floor to floor height with a single command
    d. Raise all shades on a specific floor to fully retracted position with a single command
17. The shade control motors shall move the shades within a shade control zone with delays on the order of milliseconds so that the shades in the zone appear to move to a new preset together.
18. The shades on the southern façade have multiple conditions to manage and as such these shade control zones may not match heights throughout an entire day. The southern central zone with ceramic tube screen may not match the shades on the notches where there are no ceramic tube screens or by the convenience stairs.
19. The shades for the cafeteria seating area on floor 14 shall operate in a double height space. There shall be two shades vertically aligned to cover the double height perimeter curtain wall condition. The top and bottom shades in each of these vertically aligned pairs shall operate as one continuous shade with a minimal horizontal light gap between top and bottom shade not to exceed ½”.
20. The shades for the library on the 28th floor shall operate in a double height space. There shall be two shades vertically aligned to cover the double height perimeter curtain wall condition. The top and bottom shades in each of these vertically aligned pairs shall operate as one continuous shade with a minimal horizontal light gap between top and bottom shade not to exceed ½”.

E. Manual control system mode

1. Occupant override shall be provided via a touch screen panel mounted on each perimeter column in the space. The touch screen shall be enabled by the touch of a finger and a map of the shades by shade motor for the local area on that floor shall be brought up onto the screen. Each shade motor when touched shall provide a drop down menu showing

the presets. When a preset is selected that shade motor shall move that shade to the manually selected preset position.

2. Manual occupant override shall maintain the shade position at the selected preset until: (i) the next system command to further lower the shades in that control zone at which time the shade will rejoin the shade control zone at the lower height determined by the automatic control system for that shade control zone, or (ii) if the shade was lowered by the manual override activity, then the system will check the window luminance after the override was accomplished and it will remain in that position until the system can assure the same window luminance with the shade raised. Irregardless the shades shall go back to automatic control no later than 15 minutes prior to sunset.
3. Manual override in the area beside the southern convenience stair cases shall have special features.
4. Each manual override in the open plan and in the perimeter offices shall be reported as an alarm. Other manual overrides such as in conference rooms shall not be reported as alarms. All manual override activities shall be trended.

F. Maintenance mode

1. When in maintenance mode the shades selected shall no longer be under the control of the automatic controls or occupant override. This shall remain so until maintenance mode is deselected at which time the automatic control system shall regain control.
2. The entire system may be placed in maintenance mode from a single command at the main shade control system console/PC. This command places every shade in maintenance mode.
3. Each floor may be selected and placed in maintenance mode. This command places every shade on that floor in maintenance mode.
4. Each shade control zone may be selected and placed in maintenance mode. This command places every shade in that shade control zone in maintenance mode.
5. Each shade motor group may be selected and placed in maintenance mode.
6. A web browser for the System Operator shall be provided on a wireless network or on a network provided by Owner.

G. Program mode

1. When in program mode the predetermined adjustable parameters in the system may be revised by the System Administrator.
2. Parameters that shall be adjustable are:
   a. delay time for system response to a change from sunny to cloudy condition
   b. delay time for system response to a reduction in average luminance in the unobstructed portion of the window wall (the glazing area not shielded by the exterior ceramic rods)
   c. sun light penetration distance by shade control zone
   d. maximum average luminance of the unobstructed portion of the window wall (the glazing area not shielded by the exterior ceramic rods) by shade control zone

H. Shade control system database

1. An archived log file shall be maintained in the system drive(s).
2. The log file shall provide deterministic values including, but not limited to: position of shades, glare photo sensor data, profile angles, radiometer readings and system control mode (auto, manual and maintenance).

3. The system shall monitor and store all requisite change-of-value data needed to troubleshoot control operations including: date, time of day, solar condition, profile angle, shade motor group ID, shade control group ID, zone azimuth, sensor output values, shade height, control trigger (direct sun light penetration, glare, local manual override, system override), modified output values for the luminance of the unobstructed portion of the window wall (the glazing area not shielded by the exterior ceramic rods), time delay setpoints and time delay values.
4. Data shall be stored on a daily basis.
5. Data shall be exportable to a MicroSoft Excel or Access database format.
6. Data shall be automatically archived.
7. System reports shall be available to the System Operator and all security levels above System Operator. The system shall trend real-time and historical data. Reports shall include, but are not limited to: trend reports on the variables described in paragraph 2.4.H.3 of this section of the specifications. For example the manual override by shade motor group shall be trended so that a consistent override activity in a specific shade control zone is highlighted to the System Operator.

I. Interface compatibility with Building Management System (BMS)
   1. The shade control system shall be capable of receiving and acting in accordance with universal commands from the BMS. The universal commands shall include, but are not limited to: lower all shades to floor height; raise shades to fully retracted position and, return to automatic control mode.
   2. The protocol for these messages may be BacNet or LON Works.

J. Graphical User Interface (GUI) shall be customized to this project through easy to use applications and shall include:
   1. The main shade control console/PC shall provide a map of each floor showing the shade motor groups, shade control zones and sensor locations with the real-time position of each shade motor group.
   2. The main shade control console/PC shall provide a chart of all adjustable parameters with their current values.
   3. All reports shall be viewed on the main shade control console/PC.

K. System architecture shall include, but not be limited to:
   1. Windows based head end system with main shade control system console/PC located in the System Operator's office.
   2. Vertical distribution cables shall be Ethernet or category 6E throughout the building.
   3. Shade motor group control unit(s) may be centrally located in the Shade Controls Closet or distributed in the ceiling . All ceiling mounted controls components shall be located so as to be accessible for maintenance activities. Above the ceiling is a return air plenum on all floors. On each floor where a centrally located system is proposed, a sketch of the wall space required to mount the control unit(s) shall be submitted with the proposal.

PART 3 - EXECUTION

3.1 INSTALLATION

A. Install roller shades level, plumb, square, and true according to manufacturer's written instructions. Allow clearances for window operation hardware.

1. Shade band shall be positioned not further than 1 inch from the inside of the interior curtain wall mullion on all façade typologies and the garden court.

B. Adjusting: Adjust roller shades to operate smoothly, easily, safely, and free from binding or malfunction throughout entire operational range.

C. Cleaning: Clean roller shade surfaces after installation, according to manufacturer's written instructions.

3.2 DEMONSTRATION

A. Shade Controls System Supplier shall train Owner's maintenance personnel to adjust, operate and maintain systems. A minimum 40 hours of one-on-one training shall be provided to the System Operator and a separate 40 hours training shall be provided one-on-one to the System Administrator. Refer to Division 1 Section "Closeout Procedures Demonstration and Training."

B. All building occupants on floors 2 through 28 inclusive shall receive a paper-based educational guide on the general workings of the shade control system and specific instructions on how to use the manual override feature. An electronic version of the same guide shall be stored in the database and also displayed on the manual override touch screen panels.

3.3 COMMISSIONING

A. The shade control system will be commissioned on a floor by floor basis and then finally as an entire system. Final commissioning shall be successfully completed prior to the first move-in date for The New York Times occupants.

B. Final Acceptance of the shade control system shall be contingent upon successful commissioning of each floor and the entire system.

C. During commissioning the following will be measured to determine system performance:
1. Average luminance of the unobstructed portion of the window wall (the glazing area not shielded by the exterior ceramic rods) shall not exceed 2000 cd/m2.
2. Sunlight penetration distance shall not exceed the Owner specified distance for each shade control zone.

3. Response to variable external conditions including, but not limited to: partially sunny days; shading from other buildings in the neighboring urban landscape; and, reflections from other buildings in the neighboring urban landscape
4. Matching heights of adjacent shades
   a. within each shade motor group
   b. within each shade control zone
5. Proper consistent action of all shade groups on each façade for a 30 day period
6. The shade log shall be plotted for each shade motor group for the 30 day period. The log shall be used to demonstrate to the Owner that the automated shade movement meets the specified criteria in these specifications.
7. Return from manual override to automatic mode shall be demonstrated to be in accordance with these specifications using the log and also through direct observation under partly cloudy conditions.
8. All aspects of rezoning, control monitoring, logging, fault diagnostics and reporting shall be demonstrated to the Owner.
9. Vertical light gaps between shades at corner conditions and horizontal light gaps in the cafeteria seating area shall not exceed specified ¼”.

D. Final Acceptance shall be upon successful demonstration of all commissioning requirements described in section 3.3.C of these specifications.

3.4 WARRANTY

A. The shade fabric shall have a lifetime warranty.

B. The motors and control system components shall have a 5 year labor and material warranty.

3.5 SPARE PARTS

A. Ten each shade bands, five feet wide, shall be provided.

B. Ten shade band couplers shall be provided.

C. Ten motors shall be provided.

D. One shade control mother board shall be provided.

3.6 PRE-COMMISSIONING ACTIVITIES AT THE COLLEGE POINT MOCK UP

A. Product testing to finalize shade fabric criteria, openness factor and optical transmittance properties

B. Luminance measurements at various sun angles on each façade typology

C. Predefined potential problem times shall be investigated

D. Sensor locations

E. The size of various shade control zones and the possibility of multiple shade control zones on one sensor shall be investigated.

PART 4 - ALTERNATES

4.1 A web browser based manual override system in lieu of the touch screen panels mounted on columns throughout the space. The web browser alternate shall provide a system for occupants to select a shade or group of shades and then manually override the automatic mode and set the shade(s) at a preset to their liking on their desktop PC. The program application must be easily downloaded onto both McIntosh and Windows based desktop computers. A user profile database will be required to be established. Based upon the user's location limits shall be placed upon which shades or shade groups may be selected for manual override. These limits include, but are not limited to: only shades on the user's floor may be selected for override; and, only shades within neighboring shade control zones of the user's location may be selected. The system must include logical constraints to prevent abuse, i.e. an inordinate number of shade overrides by a single user in a brief period of time; and, to prevent hysteresis by conflicting commands from two or more users within the same shade control zone. Messages to users shall be provided by the system explaining why a shade cannot be selected or conflicting commands that cannot be carried out.

4.2 Shade fabric alternates may be offered that include non-PVC coated "yarn" and/or sustainable fully recyclable materials. All optical properties must be provided with the bid proposal.

4.3 Provide a full deduct for removal of the shade installation from the proposal.

4.4 Provide a full deduct for furnish and install of the shades on all 4 sides of the garden court on floors 2, 3 and 4.

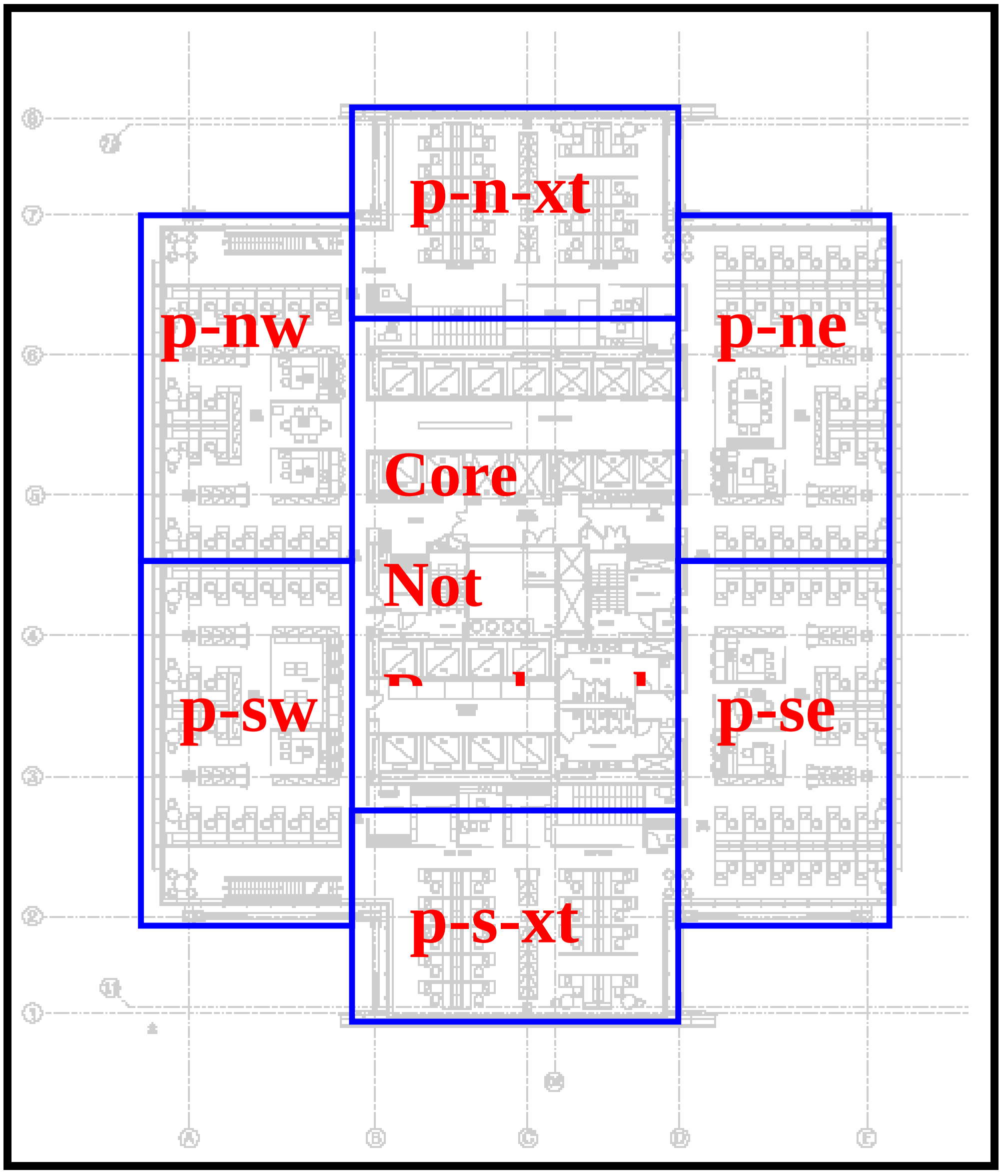
4.5 Provide an add alternate for furnishing black out shades in the private dining rooms on the 15th floor.

4.6 Provide an add alternate to furnish and install black out shades in tracks provided by the curtain wall contractor on the glass wall at the back of the auditorium stage.

END OF SECTION 12494

Appendix F

FILE NAMING CONVENTION FOR RADIANCE ILLUMINANCE FILES



The views that have been rendered are:

Plan view of South extrusion = p-s-xt

Plan view of North extrusion = p-n-xt

Plan view of Southwest offices = p-sw

Plan view of Southeast offices = p-se

Plan view of Northeast offices = p-ne

Plan view of Northwest offices = p-nw

File naming convention:

Sample image name looks like this:

L26_9-21@17c_p-n-xt_iso.tif where:

L26 = Level 26

9-21@17 = Sept 21st at 17:00 hours (all times EST)

c = mechoshade #99745, shade blocks direct sun but allows for 12' penetration on the stairwell walls

p-n-xt = plan view of north extrusion (the part that sticks out)

iso = iso-contour lines format

tif = tiff image format

Appendix G

PUBLISHED ARTICLES

This appendix includes the following articles:

The New York Times Building: Designing for energy efficiency through daylighting research
Science Beat, Berkeley Lab, February 17, 2004.
http://www.lbl.gov/enews/2-17-04.html

The New York Times and EETD advance energy-efficient building design
Environmental Energy Technologies Division News Vol. 4(5): Winter 2004
Lawrence Berkeley National Laboratory
http://eetd.lbl.gov/newsletter/nl16/NYTimes.html

A Day in the Light: The New York Times's radical around-the-clock experiment in lighting design
Metropolis Magazine, May 2004
http://www.metropolismag.com/cda/archives.php

Blueprint for daylighting at The New York Times
Daylight! Daylight! Read all about it
Architectural Lighting, June 2004
http://www.archlighting.com/architecturallighting/al/search/article_display.jsp?vnu_content_id=1000526940

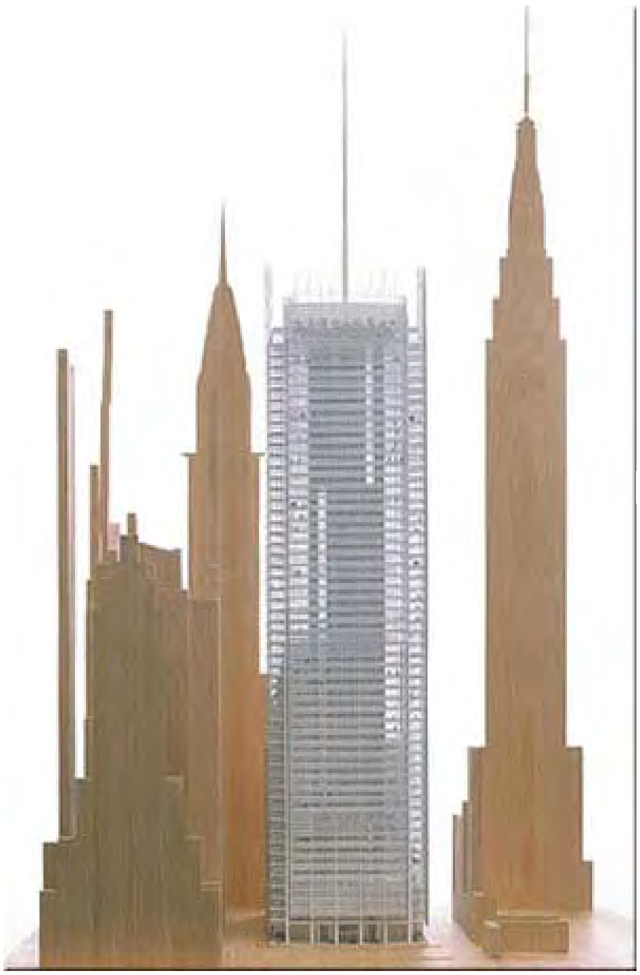
Day of the sun: Energy savings result from testing a mock-up of The New York Times' new headquarters
Glass Magazine, November 2004

Green grows up… and up and up and up
Sustainable high-rises are sprouting from Manhattan's bedrock
Architectural Record Innovation, November 2004
http://www.archrecord.com/innovation/2_Features/0411Green.asp

The costs and benefits of high performance buildings: lessons learned
Earth Day New York
The New York Times: A melding of high design and performance
Getting it right: Providing energy efficiency and comfort in an all-glass building
http://www.earthdayny.org/costsandbenefits.html

The New York Times Building: Designing for Energy Efficiency Through Daylighting Research

Contact: Allan Chen, a_chen@lbl.gov



As their new headquarters, the New York Times Company will soon build a 52-story glass tower near Times Square.

Soon the venerable *New York Times* will have a new home in the heart of Manhattan, its first new headquarters office building since the current one was completed in 1913. The transparent glass tower, 52 stories high, will overlook the Times Square Redevelopment area on Eighth Avenue between Fortieth and Forty-first Streets.

Early in 2003, a group of visitors from the New York Times Company and its design and engineering contractors paid a visit to Berkeley Lab's Environmental Energy Technologies Division (EETD) to talk about making buildings energy-efficient, comfortable, and productive places to work. They spent a day learning about the Lab's research in commercial-buildings energy efficiency, glazing, daylighting, lighting, and thermal comfort from EETD's Stephen Selkowitz, Mary Ann Piette, Francis Rubinstein, Eleanor Lee, and others. As a result of that visit, the New York Times Company and Berkeley Lab's EETD are beginning a cooperative research project to test new technologies to increase the energy-efficiency of the new building and to improve the indoor environment for the comfort of its occupants.

As a major building owner, the Times found it difficult to specify with confidence a cost-effective, fully integrated glazing (window) and lighting control system. Berkeley Lab's Building Technologies staff has been researching these topics for several years with Department of Energy and California Energy Commission support. The new Times building is an opportunity to extend and apply Berkeley Lab's prior research, making available more efficient and cost-effective systems not only to the Times Company but to other owners and design teams.

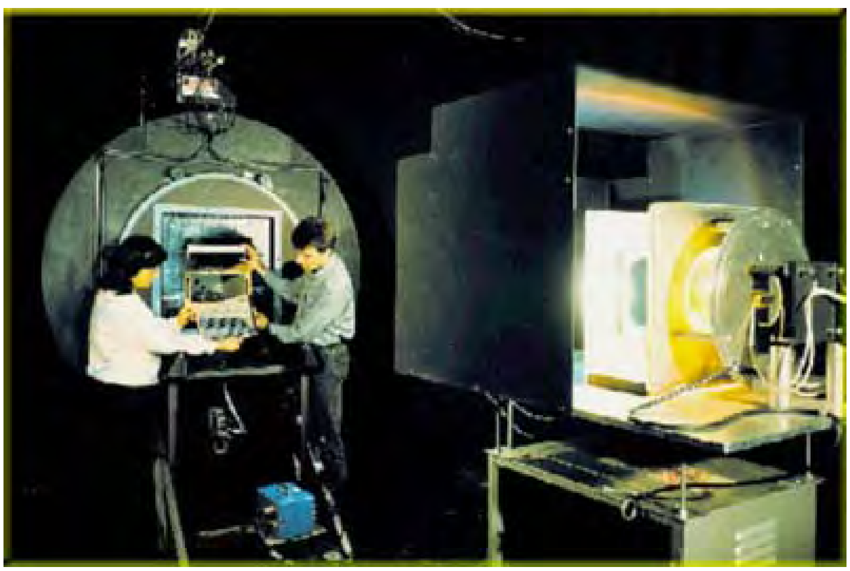
The research focuses on integrated technologies to reduce electric lighting energy use through daylighting, while controlling glare and cooling loads in this highly glazed building. Researchers are testing alternative hardware and control solutions in a newly constructed, 4,500 square foot mockup of a portion of the building.

The research program will not only quantify performance alternatives, but will provide the New York Times Company with critical performance information so that it can publish a procurement specification for the technology solutions for the entire building. The project is being funded by the New York Times Company and the New York State Energy Research and Development Authority, with costs shared by the U.S. Department of Energy and the California Energy Commission.

Pushing the daylighting envelope

"We've known since the 1970s that daylighting can reduce lighting energy use," says Building Technologies Department Head Stephen Selkowitz. "But the mere use of large glass areas is not in itself a guarantee that energy savings or comfort will be achieved, because there are so many trade-offs involved."

Selkowitz notes that "it's been difficult to make as much progress in the use of daylighting as we have in other areas of lighting and glazing technology for a variety of reasons. For one, daylighting requires a high level of system integration. Designers have to design the building from the start to incorporate daylight into office spaces, there has to be a flexible and responsive control strategy to lower or turn off electric lights when daylight is available, and visual and thermal comfort must be maintained at all times."



Researchers in Berkeley Lab's Environmental Energy Technologies Division have long studied daylighting as a means to more efficient interior lighting.

Adds Selkowitz, "The cost of components for successful daylighting can be high, like dimmable electronic ballasts" — which control fluorescent lights — "and the systems with their sensors and controls require careful calibration after they are installed, something that is not done very often in buildings today."

Berkeley Lab research suggests that proper daylighting can reduce perimeter-zone lighting energy by as much as 60 to 70 percent of the annual electric lighting energy with additional reductions in electric demand. Overall building energy use can be reduced by 10 to 30 percent compared to a similar nondaylit building, depending on such factors as the fraction of total building area that can be effectively daylit.

Additional savings come from reducing building air conditioning and heating loads through the selection of efficient glazings and automatic shading.

"The project will contribute to Berkeley Lab's longer term energy efficiency research goals in several ways," says Selkowitz. "Simulation and field testing will provide a measured database of performance quantifying the benefits of an optimized solution for this building's design. The project will include a calibration and commissioning task, which will help lower costs and improve the operation of the installed systems."

Selkowitz also points to the involvement of numerous manufacturers in the field test program, which will "directly involve the manufacturers with the design integration and calibration strategies. And finally, the very large procurement of an integrated daylighting system based on open, performance-based specifications should help move the market towards greater availability and lower costs for these energy-saving building systems."

The building as a contribution to civic life

When the New York Times Company decided to erect a new building, creating a comfortable working environment for its employees was one of its highest priorities, along with energy-efficiency. The building was designed to have transparency, both to bring in the daylight, and to serve as a reminder of the mission of the newspaper: providing information "transparency" about the civic life of the nation and the city. To help create a connection to the community, the building will have an auditorium at the ground floor for civic and cultural events. The newsroom will occupy floors two through seven.

Low-emissivity glass screened by ceramic tubes will reduce the building's cooling loads.

An unusual feature of the building, one more common in Europe than in U.S., will be its fully glazed curtain wall. Thin horizontal ceramic tubes placed on a steel framework one and a half feet in front of the glass will screen the double glazed, spectrally selective, low-emissivity, full-height glass wall around the building, thus reducing the building's cooling loads. (Low-emissivity glass is an energy-efficient material that helps reduce heating and cooling use.) The ceramic tubes provide an aesthetic bonus, taking on the changing color of the sky during the course of the day as light diffuses through them from different angles. Above the top of the building, the screen of tubes becomes less dense, and its lace-like appearance will permit a view of roof garden foliage.

The building will unite most of the 2,500 Manhattan-based employees of the Times Company, which currently has offices at seven locations in New York City. "This building is designed from the ground up to reinforce the values of the New York Times Company," said Michael Golden, vice chairman of the Times Company, when the plan was announced late in 2002. "The open plan and ease of communication, both vertically and horizontally, will enhance collaboration. Our new physical environment will improve the way we work, which is the highest calling of architecture."

The building was designed by architect Renzo Piano, a winner of the prestigious Pritzker Prize in 1998, in collaboration with Fox & Fowle Architects. Construction will start later in 2004, and its expected completion date is mid-2006.

Piano is well-known for his design of the Centre Georges Pompidou in Paris, Osaka's Kansai International Airport, and Berlin's Potsdamer Platz, among many others. Fox & Fowle received a National Honor Award for Design from the American Institute of Architects in 2000 for their design of the Condé Nast Building at 4 Times Square, which emphasizes state-of-the-art energy efficiency and other environmentally responsible features.

The Energy-Efficient New York Times Building, part 2

Top

The Energy-Efficient New York Times Building, part 2

Contact: Allan Chen, a_chen@lbl.gov

A testbed for advanced daylighting

The transparent design of the New York Times building not only brings in daylight; it symbolizes the newspaper's mission to shed light on the life of the city and the nation.

The New York Times Company's engineering staff was seeking a set of integrated technologies that could effectively dim electric lighting and automatically deploy shading when appropriate, to take advantage of daylight benefits while providing comfort. They were unable to find a system on the market that they believed would meet their requirements.

David Thurm, Real Estate Vice President for the New York Times Company, says, "We were excited to find that LBNL's prior work was relevant to our project. As an owner/operator, our primary interest is ensuring that the working environment in our building meets the comfort needs of our employees. The solutions we are developing in the mockup will verify that the control systems and operating strategies will function effectively and provide the productive work environment needed by our employees under a wide range of climate conditions."

Selkowitz notes that "the New York Times, as a motivated and concerned owner, has provided us with a great opportunity to advance the use of daylighting as an energy efficiency strategy. In partnership with our team, lead by Eleanor Lee, they designed and have just completed a 4,500 square-foot south and west quadrant of one floor of the building on the grounds of their printing plant in College Point, New York. This full size mockup will allow us to demonstrate and test the key hardware, calibration and operational controls issues, allowing the team to specify a technological solution that meets both comfort and energy-saving goals."

Although it was originally intended to be a conventional furniture mockup in a dark warehouse, says Selkowitz, with its glass curtain wall and exterior shading "the test structure has become a working daylighting laboratory, complete with lighting controls and interior automated shading, as well as furniture and interior finishes, to solve a design challenge that has eluded building owners throughout the country."

One floor of the New York Times Company's printing plant in College Point, New York has been modified as a fully equipped, 4,500-square-foot mockup of the planned new building's interior.

After the Times had offered to cover the cost of constructing the outdoor mockup, the Berkeley Lab/Times team successfully competed in a solicitation from the New York State Energy Research and Development Administration for the additional funding required to carry out its extensive instrumentation and monitoring and the associated analysis. The Department of Energy and the California Energy Commission also provided a share of the costs, as did the hardware vendors, making this a national partnership.

Berkeley Lab will direct the 12-month, state-of-the-art performance evaluation in the testbed, and working with the Times Company will use project results to develop performance specifications, which should stimulate the building industry to provide lower cost technologies and systems that meet the needs of the building. Using this approach, the industry's experience with the Times building will help proliferate daylighting to other buildings.

"We think that demonstrating these technologies in a landmark building will gain them far more attention among manufacturers and specifiers than through more conventional lab-based research," says Selkowitz.

The New York Times Company, its architecture and engineering firms, and a Berkeley Lab team led by Eleanor Lee—consisting of Selkowitz, Francis Rubinstein, Dennis Dibartolomeo, Christian Kohler, Robert Clear, Greg Debra Ward, Judy Lai, David Watson, Howdy Goudey, Robin Mitchell, and Danny Fuller—have been working together to develop the R&D project plan and launch the project. They have held a series of design "charrettes" on the East and West Coasts and meetings with the building-supply industry. (Charrette, French for cart, is a term that originated among architecture students at the École des Beaux Arts, slang for piling on the work to meet project deadlines.)

The mockup facility and final calibration of the instrumentation are now complete. Testing began on schedule on December 21, the winter solstice. While most of Berkeley Lab celebrated the holidays at home, Lee and her team were anxiously monitoring the data flow from the mockup. Watch the pages of Science Beat

for the test results as they become available.

Additional information

- More about the planned New York Times building
- More about the design by architect Renzo Piano
- More about EETD's Building Technologies Department

Instruments in the mockup facility gauge the effectiveness of lighting controls, automated shading, furniture designs, and even interior finishes for the working environment of the New York Times building to come.

The Energy-Efficient New York Times Building, part 1

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EETD Newsletter
Winter 2004
pg. 5

The *New York Times* and EETD Advance Energy-Efficient Building Design

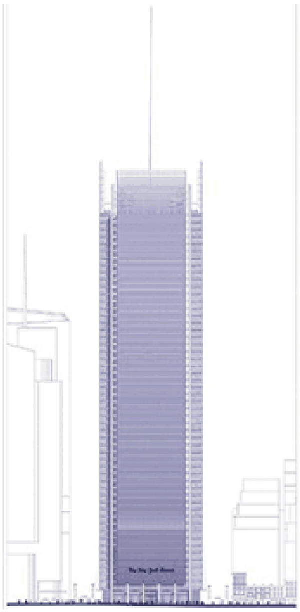

Figure 1. Artist rendering of the *New York Times'* new headquarters in Manhattan.

The New York Times is building a new headquarters, the company's first new office building since its current one was completed in 1913. The new transparent glass tower, 51 stories high, will overlook the Times Square Redevelopment area on 8th Avenue between 40th and 41st Streets in the heart of Manhattan (see Figure 1).

In preparation for construction of the new building, a group of visitors from the New York Times Company and its design and engineering contractors visited the Environmental Energy Technologies Division (EETD) at Lawrence Berkeley National Laboratory (Berkeley Lab) in early 2003 to talk about how to make buildings energy efficient, comfortable, and productive places to work. They spent a day learning about Berkeley Lab's research in commercial-building energy efficiency, glazing, lighting, daylighting, and thermal comfort from EETD's Stephen Selkowitz, Francis Rubinstein, Eleanor Lee, Mary Ann Piette, and others.

As a result of that visit, the New York Times Company and EETD have begun a cooperative research project to test new technologies that will increase the energy efficiency of the new headquarters. Because the Times found it difficult to specify a cost-effective, fully integrated window and lighting control system for the building, which will have an extensive glass façade, the research project will focus on integrated technologies to reduce electric lighting energy use through daylighting while controlling glare and cooling loads. Berkeley Lab's Building Technologies staff has been researching these topics for years. The new Times building is an opportunity to extend and apply the Lab's research, making efficient and cost-effective systems available not only to the Times but to other building owners and design teams.

"We think that demonstrating these technologies in a landmark building will gain them far more attention among manufacturers and specifiers than through more conventional lab-based research," says Building Technologies Department Head Stephen Selkowitz.

Researchers will test alternative hardware and control solutions in a newly constructed 4,500-square-foot mockup of a portion of the building. The research program will quantify performance alternatives and provide the Times with critical information so that it can publish a procurement specification for the technology solutions for the entire building. The project is being funded by the New York Times Company and the New York State Energy Research and Development Authority (NYSERDA), with cost sharing from the U.S. Department of Energy (DOE) and the California Energy Commission (CEC).

Pushing the Daylighting Envelope

"We've known since the 1970s that daylighting can reduce lighting energy use," says Selkowitz. "But the mere use of large glass areas is not in itself a guarantee that energy savings or comfort will be achieved because there are so many tradeoffs involved. It's been difficult to make as much progress in the use of daylighting as we have in other areas of lighting and glazing technology for a variety of reasons. Daylighting requires a high level of system integration; architects and engineers have to design the building from the start to incorporate daylight into office spaces, there has to be a flexible and responsive control strategy to lower or turn off electric lights when daylight is available, and visual and thermal comfort must be maintained at all times.

"The cost of components, like dimmable electronic ballasts (which control fluorescent lights), for successful daylighting can be high, and the systems, with their sensors and controls, require careful calibration after they are installed, something that is not done very often in buildings today," Selkowitz notes. The Times project "will include a calibration and commission task, which will help lower component costs and improve the operation of the installed systems."

Berkeley Lab research suggests that proper daylighting can reduce lighting energy use in building perimeter zones by as much as 60 to 70 percent of annual perimeter-zone electric lighting energy use. Overall building energy use can also be reduced by 10 to 30 percent compared to energy use in a similar non-daylit building, depending on factors such as the fraction of total building area that can be effectively daylit. The additional savings come from reducing building air conditioning and heating loads as a result of selecting efficient glazings and automatic shading.

Figure 2. A shading system candidate for the new *New York Times* building undergoes testing in College Point.

This project "will contribute to Berkeley Lab's longer-term energy-efficiency research goals in several ways," says Selkowitz. "Simulation and field testing will provide a measured database of performance, quantifying the benefits of an optimized solution for this building's design. The participation of numerous manufacturers in the field test program will involve them with design integration and calibration strategies. And finally, the very large procurement of an integrated daylighting system based on an open, performance-based specification should help move the market towards greater availability and lower costs for these energy-saving building systems."

The New Building as a Contribution to Civic Life

When the New York Times Company decided to erect the new building, creating a comfortable working environment for its employees was one of its highest priorities, as was energy efficiency. The building was designed to be highly "transparent," both to bring in daylight and to underscore the mission of the newspaper: providing information—transparency—about the civic life of the nation and the city. There will be an auditorium on the ground floor for civic and cultural events. The newsroom will occupy floors two through seven.刧刧

An unusual feature of the building, more commonly seen in Europe than in the U.S., will be its fully glazed curtain wall. Thin horizontal ceramic tubes placed on a steel framework one and a half feet in front of the glass will screen the building's full height wall of double-glazed, spectrally selective, low-emissivity glass, thus reducing the building's cooling loads. The ceramic tubes provide an aesthetic bonus, taking on the changing color of the sky during the course of the day as light diffuses through them from different angles. Above the top floor of the building, the screen of tubes becomes less dense, so its lace-like appearance will permit a view of roof-garden foliage.

The building will unite most of the 2,500 Manhattan-based employees of the Times Company, which currently has offices at seven locations in New York City. "This building is designed from the ground up to reinforce the values of The New York Times Company," said Michael Golden, vice chairman of the Times Company, when the plan was announced late in 2002. "The open plan and ease of communication, both vertically and horizontally, will enhance collaboration. Our new physical environment will improve the way we work, which is the highest calling of architecture." Construction will start later in 2004, and the expected completion date is mid-2006.

The building was designed by architect Renzo Piano, a winner of the prestigious Pritzker Prize in 1998, in collaboration with Fox + Fowle Architects. Piano is well-known for his design of the Centre Georges Pompidou in Paris, Osaka's Kansai International Airport, and Berlin's Potsdamer Platz, among many others. In 2000, Fox + Fowle received an American Institute of Architects National Honor Award for Design for the CondŽ Nast Building at 4 Times Square. That building emphasizes state-of-the-art energy conservation and other environmentally responsible features.

A Testbed for Advanced Daylighting

The New York Times Company's engineering staff had been trying to find a set of integrated technologies that would effectively dim the electric lighting and automatically deploy shading when appropriate in the new building, to take advantage of the daylight benefits but provide comfort. They were unable to find a system on the market that they believed would meet their requirements.

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"The solutions we are developing in the mockup will verify that the control systems and operating strategies will function effectively and provide the productive work environment needed by our employees under a wide range of climate conditions," says Thurm. (See Figure 2.)

Figure 3. Measuring light levels at the *New York Times* test facility.

Although it was originally intended to be a conventional furniture mockup in a dark warehouse, the test structure will now become a working daylighting laboratory with its glass curtain wall and exterior shading, complete with lighting controls, interior automated shading, as well as furniture and interior finishes, to solve a design challenge that has eluded building owners throughout the country.

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Berkeley Lab will direct the 12-month state-of-the-art performance evaluation in the mockup and, working with the Times, will use project results to develop performance specifications to stimulate the building industry to provide lower-cost technologies and systems that meet the building's needs. Using this approach, the industry's experience with the Times building will help proliferate daylighting to other buildings.

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Stay tuned. Later in the year, EETD News will report on results from these tests.

—Allan Chen

Stephen Selkowitz
(510) 486-5064; fax (510) 486-4096

This research is funded by the New York State Energy Research and Development Authority, the Department of Energy and the California Energy Commission, with a significant costshare from the New York Times Company.

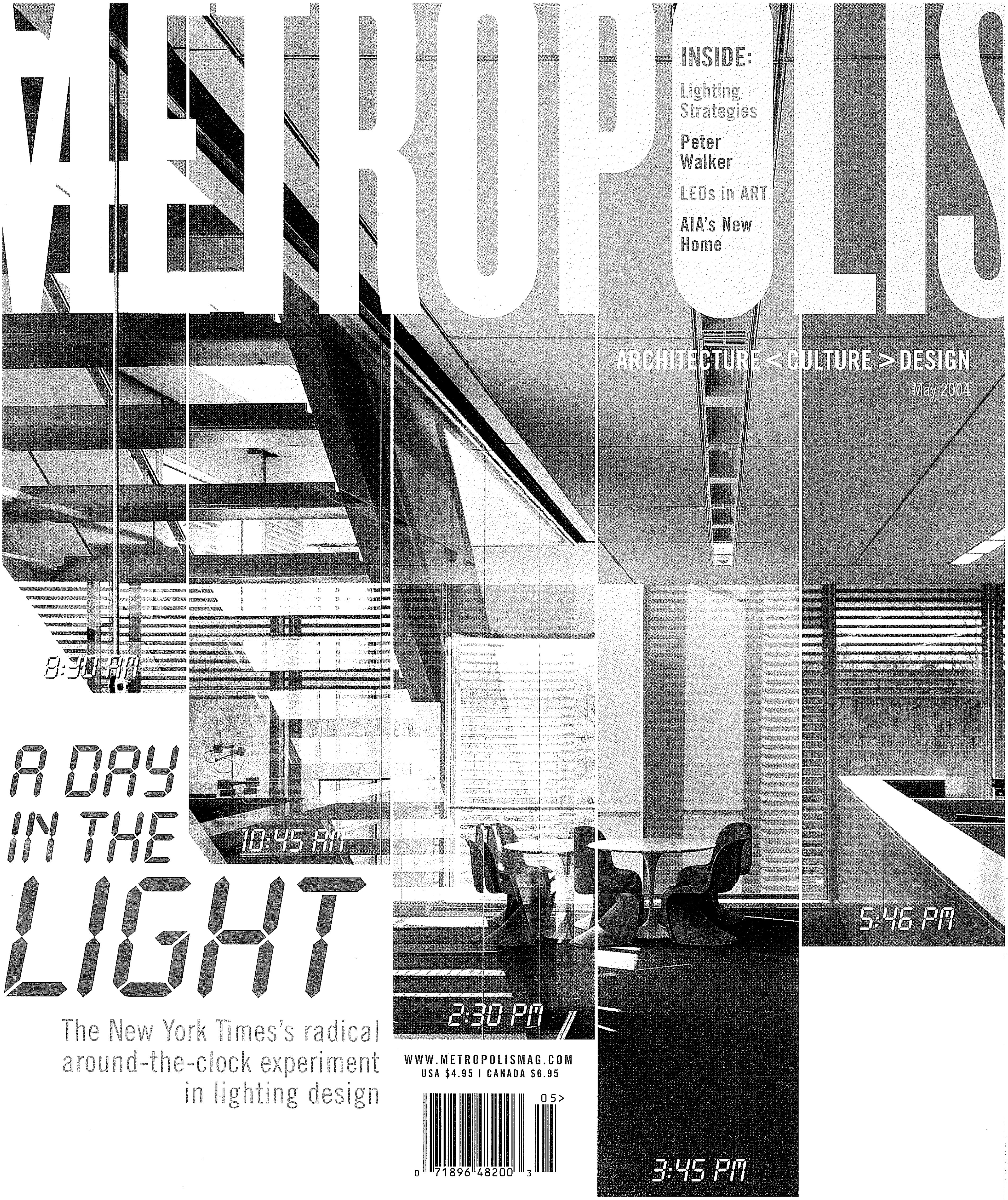
EETD Newsletter Home Page
CBS Newsletter Home Page

METROPOLIS

INSIDE:
- Lighting Strategies
- Peter Walker
- LEDs in ART
- AIA's New Home

ARCHITECTURE < CULTURE > DESIGN

May 2004

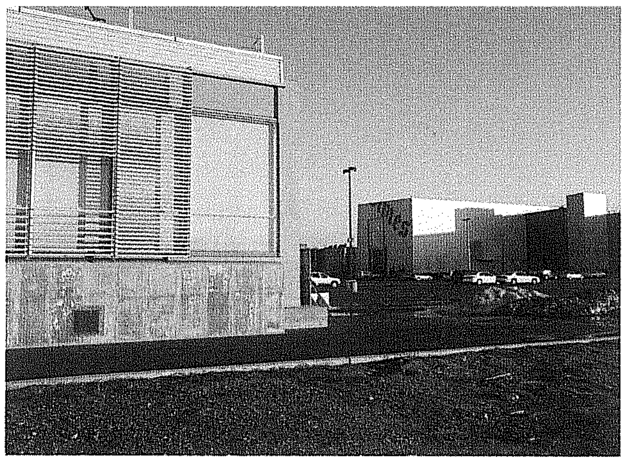


A DAY IN THE LIGHT

The New York Times's radical around-the-clock experiment in lighting design

WWW.METROPOLISMAG.COM
USA $4.95 | CANADA $6.95

Several types of sensors are placed throughout the mock-up including: (1) photocells that measure light for the dimming control systems; (2) occupancy sensors; (3) cameras; (4) and brightness sensors, which determine glare. "Early indications suggest we'll have to deploy the mechanized shades on the south-west wall [by the stairs] earlier than we thought," says lighting designer Attila Uysal. Here they're not deployed even though sensors are detecting glare.

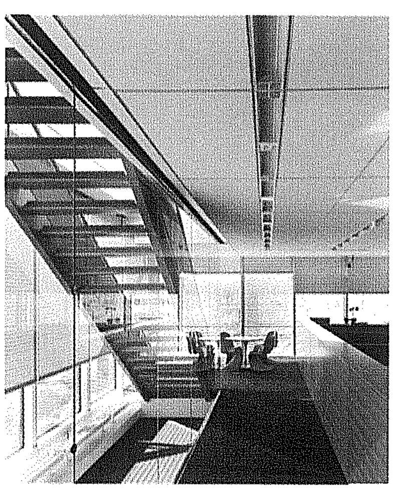


Photography by David Joseph

To test the groundbreaking scheme for its new headquarters, the New York Times has launched an elaborate building study: a 24-hour experiment in lighting design.

A DAY IN THE LIGHT

By Martin C. Pedersen



2:30

Top: The mock-up, with the Times printing plant in the background. Left: At 2:30 p.m. the sun has shifted to the west, causing the shades on that side of the mock-up to close. There is still enough daylight, however, for the overhead lights to be off. Above: Fifty minutes later, the sunlight becomes more direct and the shades lower still further. Note: the two lit fixtures near the curtain wall should be off, since there is enough natural light in the space.

The most ambitious lighting experiment in American commercial real estate is currently being conducted in the parking lot of the New York Times's printing plant in Queens. Sitting in the northwest corner of the lot is a gray flat-roofed structure that hardly resembles world-class architecture or cutting-edge research. But inside that building is a glimpse into the not-so-distant future: a luminous 4,300-square-foot office mock-up—a prototype for the Times's new Manhattan headquarters, by Renzo Piano. The design for the 51-story tower, featuring a shimmering 800-foot glass curtain wall, promises to bathe notoriously cranky reporters and editors in natural light. Here in Queens, interior architects and designers are testing workstations, private offices, a glass facade sheathed in Piano's sun-shielding ceramic rods, and one of the architect's other signature touches for the building, a set of stairs in the southwest corner of the space that will link the paper's 28 floors and create a transparent stage show for its Midtown neighbors.

The mock-up is the culmination of a meticulous, near maniacal two-year effort by the newspaper and its consulting designers to thoroughly trouble-shoot any and all building issues prior to construction. "The Queens facility really serves four purposes," says David Thurm, vice president of real estate development for the Times. "It's a furniture mock-up, an extensive lighting experiment, a constructability review, and

THIS MIGHT BE THE MOST STUDIED BUILDING IN THE COUNTRY. PREVIOUS MOCK-UPS INCLUDED A TWO-STORY STRUCTURE BUILT IN ITALY AND LATER SHIPPED TO NEW YORK.

a tool for talking to employees and getting their input."

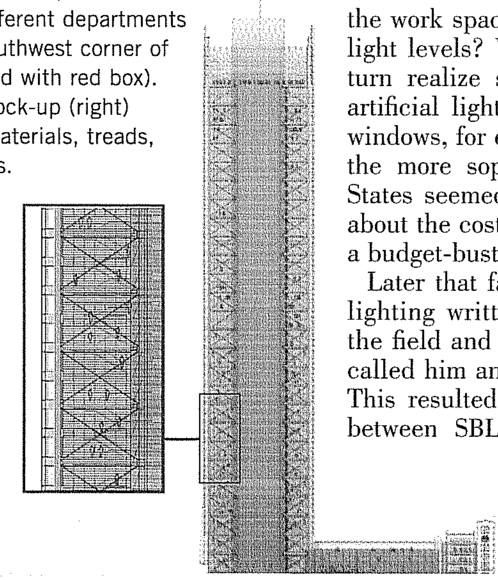
This might be the most analyzed, tested, and studied building scheme in the country. The Times has already commissioned previous mock-ups for furniture (in the basement of its current 43rd Street headquarters), the ceramic facade (including a two-story structure built in Italy and later shipped to New York), floors, under-floor air, and lighting, among other things. Countless studies have been completed, even an extensive one on ice and snow formation on the ceramic rods. "They have a lot of different systems going into this building, and for each one they have a research team looking into cost, performance, and impact on the tenants," says Eleanor Lee, a scientist with the Lawrence Berkeley National Laboratories (LBNL) who is overseeing the lighting experiment. "It's a whole array of technologies they're looking into to make sure that everything goes well."

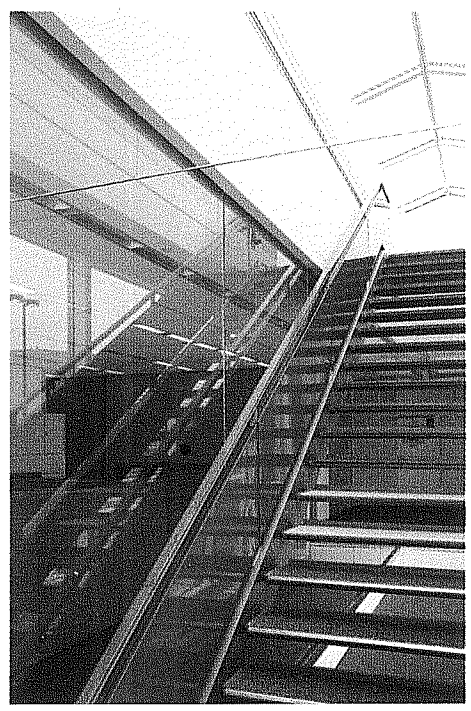
The idea of harvesting the abundant natural light intrinsic to the Piano design was an early and obvious idea. "During the furniture mock-up in fall 2002 we asked our lighting consultants [SBLD Studio] to analyze lighting controls," says Glenn Hughes, director of construction real estate at the Times. Could dimming systems improve the quality of the work space by allowing each department to set its own light levels? Was this economically viable? Could they in turn realize substantial energy savings by reducing the artificial light in areas where it wasn't needed—near the windows, for example? What they quickly learned was that the more sophisticated dimming systems in the United States seemed prohibitively expensive. "We were worried about the cost," he says. "We were not prepared to get into a budget-busting situation."

Later that fall Thurm happened to find a paper on daylighting written by Steve Selkowitz, a leading expert in the field and head of building technologies at LBNL. "We called him and had a fabulous conversation," Thurm says. This resulted in a January meeting at the California lab between SBLD Studio; Gensler, the interior architects; Flack and Kurtz, the engineers; and a corporate team led by Michael

Left to right: At 3:45 p.m. the sun continues to set, creating glare conditions that the shades react to. At 5:18, the sun is setting on the horizon; the intensity of the direct sunlight causes the shades to close completely, and artificial lights go on to make up for the loss of natural light. At 5:46, roughly dusk, the sun disappears beyond the horizon and the shades go up.

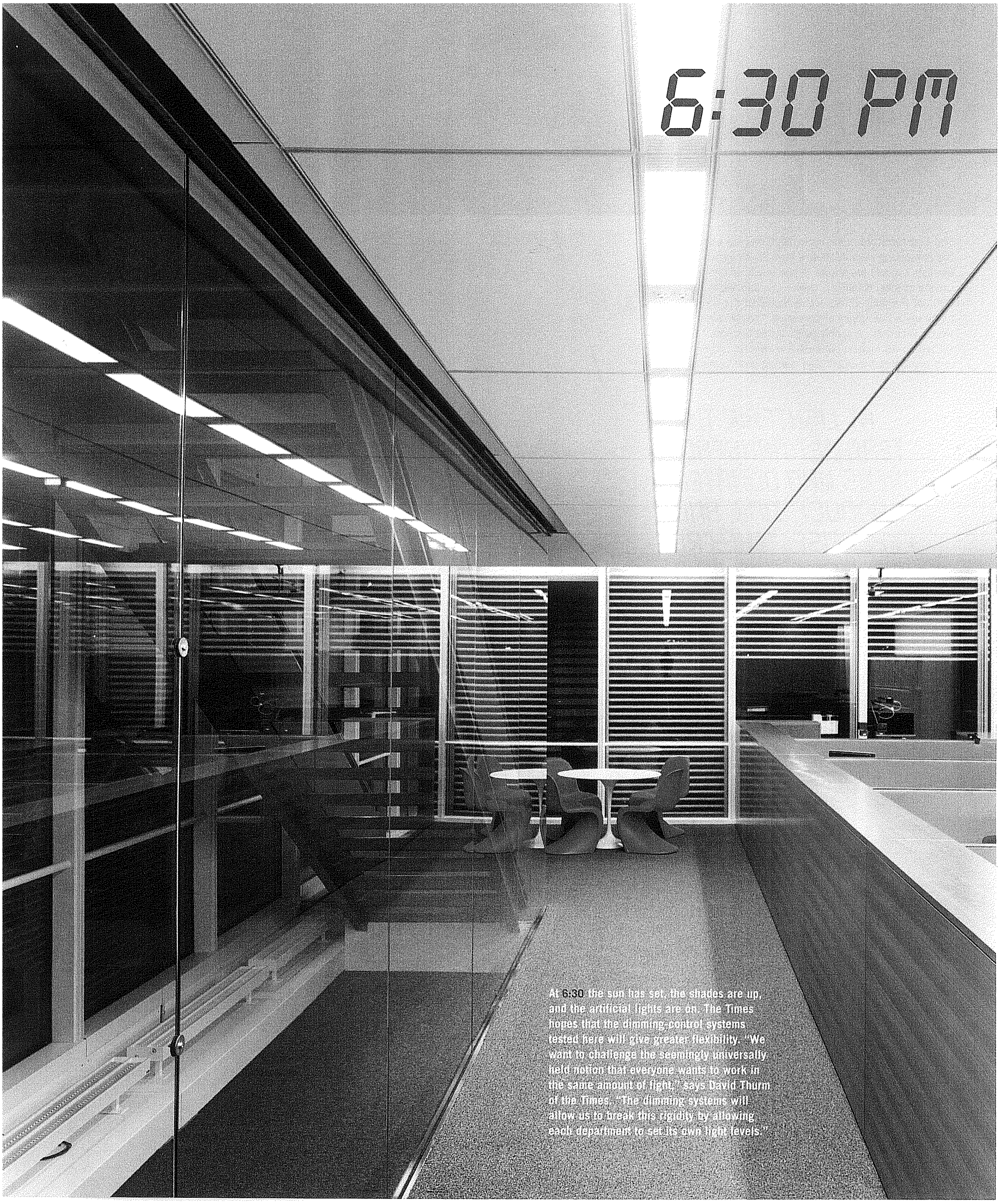
A rendering of the south elevation of the building (below). The Times will occupy the first 28 floors; the staircase linking the different departments is located at the southwest corner of the building (marked with red box). The stairs in the mock-up (right) were built to test materials, treads, handrails, and steps.



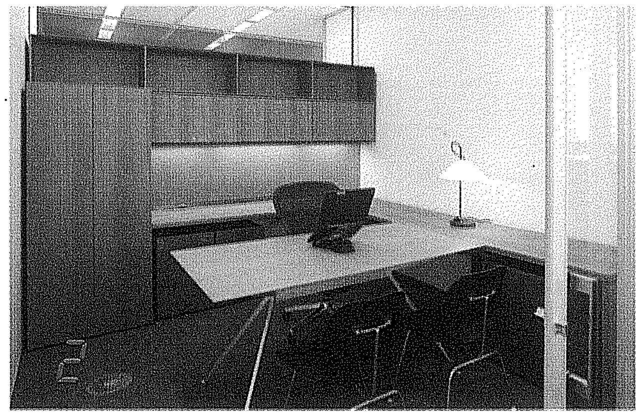


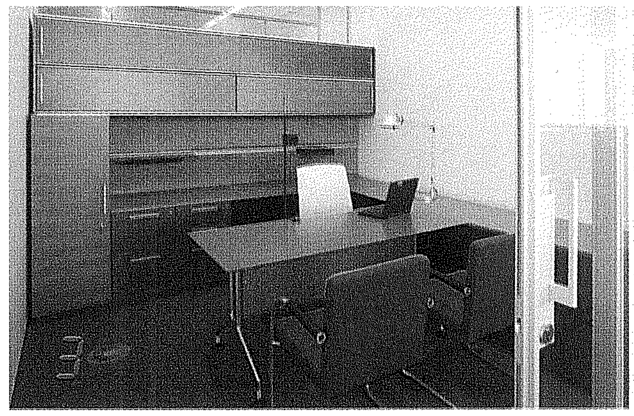
Renderings courtesy Fox & Fowle Architects

6:30 PM



At **6:30** the sun has set, the shades are up, and the artificial lights are on. The Times hopes that the dimming-control systems tested here will give greater flexibility. "We want to challenge the seemingly universally held notion that everyone wants to work in the same amount of light," says David Thurm of the Times. "The dimming systems will allow us to break this rigidity by allowing each department to set its own light levels."





The first furniture mock-up in 2002 helped narrow the competing manufacturers from six to three. The finalists (above) are shown in the mock-up's three private offices: Knoll (1), Unifor (2); and Vitra (3). "One of the main things we've tested in the furniture mock-up is the height of partitions," (right) says Rocco Giannetti, a senior associate at Gensler. "We settled on 48 inches, because it allows for privacy but still maintains the open plan seating arrangement."

AT LIGHTFAIR THE TEAM MET MANUFACTURERS WHO DONATED PRODUCT, TIME, AND EXPERTISE. "THEY'RE TREATING THIS AS A LABORATORY FOR THEIR OWN PURPOSES," THURM SAYS.

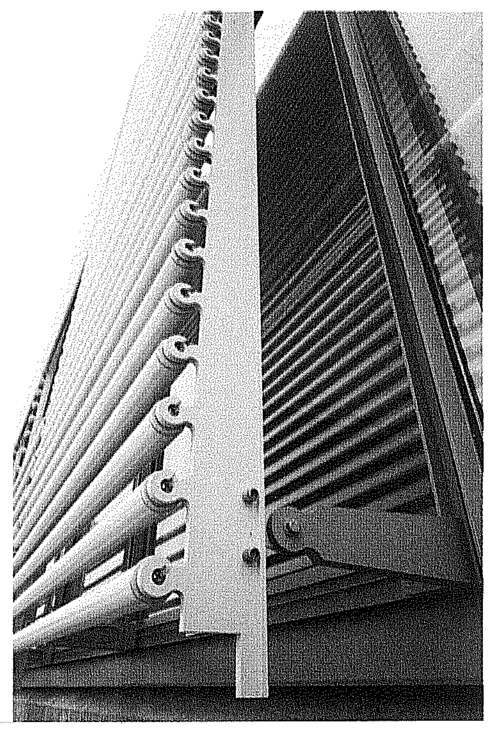
Golden, vice chairman of the New York Times Company.

"About a month earlier we'd had some brief moments of enlightenment," Hughes recalls. "While trying to make up our minds about which dimming system we wanted, I said I thought we had the wrong question in front of us. We needed to talk about what kind of shade system we were going to purchase and then we would be able to understand the lighting system we needed. When we went out to Lawrence Berkeley, that is exactly the message they gave us. We started out telling them about the low-iron Star Fire glass, and they said, 'Oh, that's the highest transmittance of any type of curtain wall. You've got to manage your facade.'"

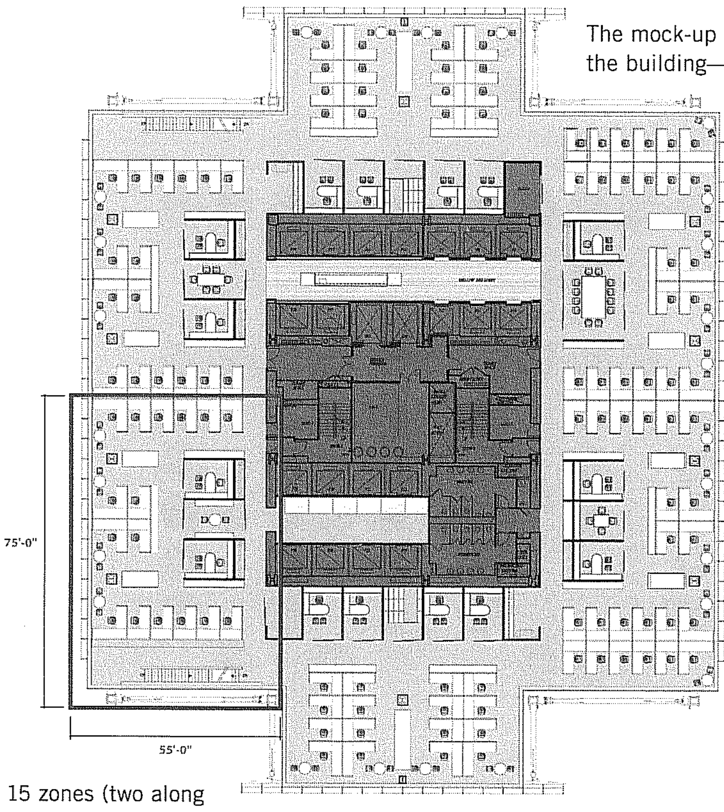
Thurm told Selkowitz that they were looking to rent space in Manhattan for a second furniture mock-up (the first one had narrowed the manufacturers to Knoll, Vitra, and Unifor). There they would also test lighting controls. "Steve said, 'Gee, this mock-up you're about to build—it's too bad you couldn't build it outside because that would be a perfect way to test what we've been talking about,'" Thurm recalls. "It was one of those 'aha' moments. Later in the conversation Steve says, 'It's really too bad it's already January because there's a NYSERDA [New York State Energy Research Development Authority] grant we could apply for, but the deadline is April and we'll never make it.' And we said, 'Hold that thought...'"

In very short order—less than a week—the Times had committed to the freestanding mock-up. In mid-June LBNL was awarded a $250,000 daylighting grant. (All of the NYSERDA money went into research; the Times paid

The Times has conducted several tests for the building's facade. "At one point," Thurm says, "to demystify the curtain wall for potential bidders we hired four different firms to engineer and build prototypes." In the latest iteration (below) the ceramic rods are held in place by an aluminum frame.



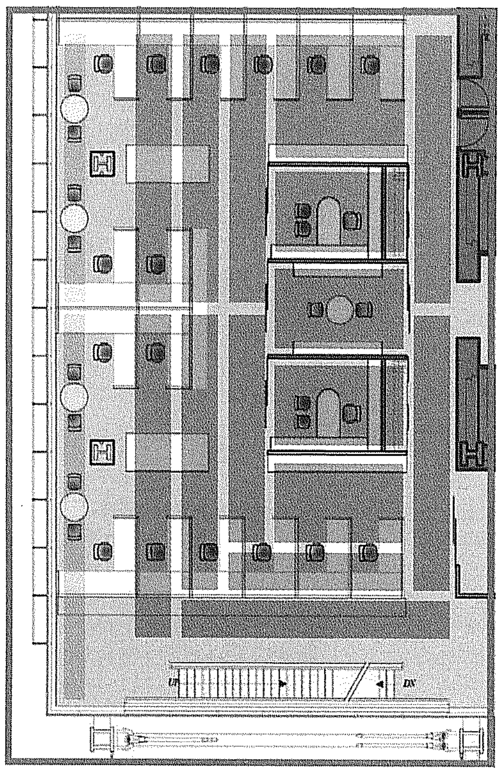
"EVERY MINUTE WE SAMPLE WHAT'S GOING ON IN THE SPACE, AND WE DO IT TWENTY-FOUR HOURS A DAY," LEE SAYS.



The mock-up recreates the southwest corner of the building—roughly one-sixth of one floor.

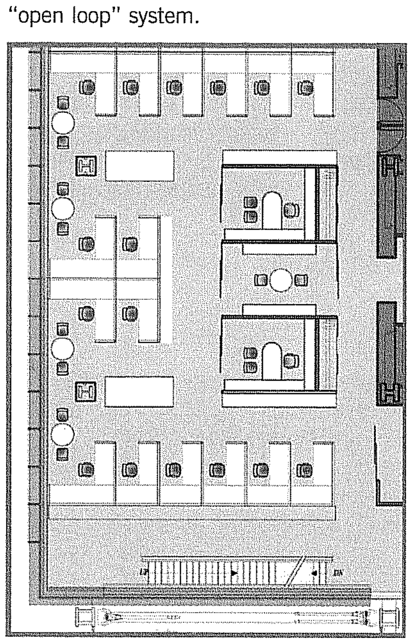
LIGHTING ZONES

The space is divided into 15 zones (two along the curtain wall are for decorative night-time lighting of the facade). The blue section operates on Lutron shades and lighting controls. The red uses a MechoShade system and Siemens dimming controls; this half of the mock up is larger to accommodate more intense sunlight.



SHADES

On the Lutron side, the shades respond to ambient light in the space. This is a "closed loop" system. The MechoShade system reacts to the position of the sun and sky conditions outside. This is an "open loop" system.



an undisclosed seven-figure-plus amount for construction.) The interior architects produced the design and construction documents for the mock-up. "We also worked with Fox & Fowle [the local architecture firm collaborating with the Renzo Piano Building Workshop] to get the curtain-wall information and the level of detail required for that," says Edward Wood, the principal in charge at Gensler. "This whole job has been about understanding the architecture, understanding the interior, and exploring how they relate to one another."

The mock-up was also an opportunity to explore construction issues. "We worked hard with Turner, our construction manager, to do full debriefings, and we had the architects sit in on those conversations," Thurm says. "What about the stairs? What made them expensive? We get a huge benefit by having already built them because that one stair is going to be replicated many times over."

Armed with recommendations from Selkowitz, the Times team attended Lightfair last year and met with a number of manufacturers eager to participate in the lighting experiment; all donated product, time, and expertise. "To their great credit, they're treating this as a laboratory for their own purposes," Thurm says. Testing complex products often leads to simplification—and market acceptance. "Obviously it works better for us if these systems are truly commercial products," he adds. "If it looks like they have legs in the marketplace, then they'll be supported and that will be reflected in the price."

In order to measure all sun angles, the lighting experiment began on December 21 (the shortest day of the year) and will end on June 21 (the longest). "Solstice to solstice," Thurm says. "Sounds very pagan." The ultimate goal is the seamless integration of the dimming-control systems, which regulate the artificial lights, and the mechanized shades. "You want to provide a homogeneous light level throughout the space, regardless of the conditions outside," says Attila Uysal of SBLD Studio, who designed the two schemes for the mock-up.

The mock-up recreates the southwest corner of the building, which will experience the most sun exposure. It is divided roughly in half; each side operates with different dimming-control systems and shades. The southwest wall (by the stairs) and half of the western facade is the MechoShade side; here Siemens dimming controls operate on the DALI (Digital Addressable Lighting Interface) system, a state-of-the-art computer protocol popular in Europe that allows light sources to be individually controlled. Because lighting zones can be changed without rewiring, this provides great flexibility. The shades on this half of the mock-up don't respond to the light in the space but react to the position of the sun and prevailing sky conditions continued on page 135

Floorplan courtesy Gensler

A Day in the Light

continued from page 95

using a rooftop measurement device called a radiometer. "The computer already knows the position of the sun," explains Jan Berman, president of MechoShade. "That's a predictable event programmed into the software. The radiometer determines whether it's a sunny, cloudy, or bright condition, and then the shades move up or down accordingly."

On the other side of the mock-up the dimming controls and mechanized shades are made by Lutron. Their integrated scheme uses a 0-to-10-volt system where groups of lights are adjusted in predetermined zones. Less flexible than DALI, it's still more advanced than anything used in the United States, where less than two percent of office space has dimming capabilities (and that's largely confined to conference rooms and high-end executive suites). In contrast to MechoShade, Lutron's shades are controlled by ceiling-mounted sensors, which react to the light inside the space.

LBNL and the manufacturers have placed 107 sensors in the mock-up to measure light conditions on a minute-by-minute basis. This data is fed via a special Times Web site to a computer at LBNL, where scientists in turn send information back to the manufacturers on the performance of their equipment. "Every minute we sample what's going on in the space, and we do it twenty-four hours a day," Lee says. "Then we have a second set of information. We go out to the site and do human-factors surveys. If you get a majority of people saying they don't like something, that is probably even more important than the measurements you're taking."

Although the directional orientation of the Queens facility is identical to the future home of the Times, the mock-up represents just one-sixth of the future building's floorplate. LBNL is using daylighting software called Radiance to adjust for the other sides of the building and the surrounding environment. Developed by the lab about ten years ago, the modeling program has since become popular with architecture firms and game designers (and can be downloaded for free on the LBNL Web site). "Using the mock-up data you construct a computer simulation," Lee explains. "Then you take the field data and ask, 'Are the field numbers and computer simulation aligned?' You have to calibrate them because you can only model to a limited degree of accuracy. Then you take that calibrated model to the Manhattan site and model the exterior surroundings—no trivial task—and go about predicting the light conditions for the different floors."

In March LBNL provided the Times with preliminary numbers showing some significant energy savings, but the full range of questions they need answered won't be available until all the data is collected. "By the end of the mock-up period we'd like to know which systems are working best," Hughes says. "It's not about picking manufacturers yet but understanding what the requirements are and being able to write those down so they can be put into the marketplace for bid. Ultimately we need to know which shade systems are operating without glare, how much energy we're saving by harvesting daylight, how much direct penetration of daylight we want."

Groundbreaking for the new building, which will be located on Eighth Avenue between 40th and 41st Streets, is imminent. In the meantime the Times is not only bringing employees out to Queens to test the space but also conducting tours of the mock-up for real estate developers and builders to promote the glories and long-term economic benefits of natural light. "For the past year David Thurm and I have been out there telling the world that daylighting needs to come at a reasonable price, and that we're prepared to help provide some of the solutions to make that happen," Selkowitz says. "In this business the classic term is *market transformation.*"

"One of the principles of innovation is that you share your information," Thurm says. "Daylighting should be universal. And if manufacturers can figure out a way to bring the price down, then I think builders will say, 'Of course we have to do this!'" ◘ **www.metropolismag.com**

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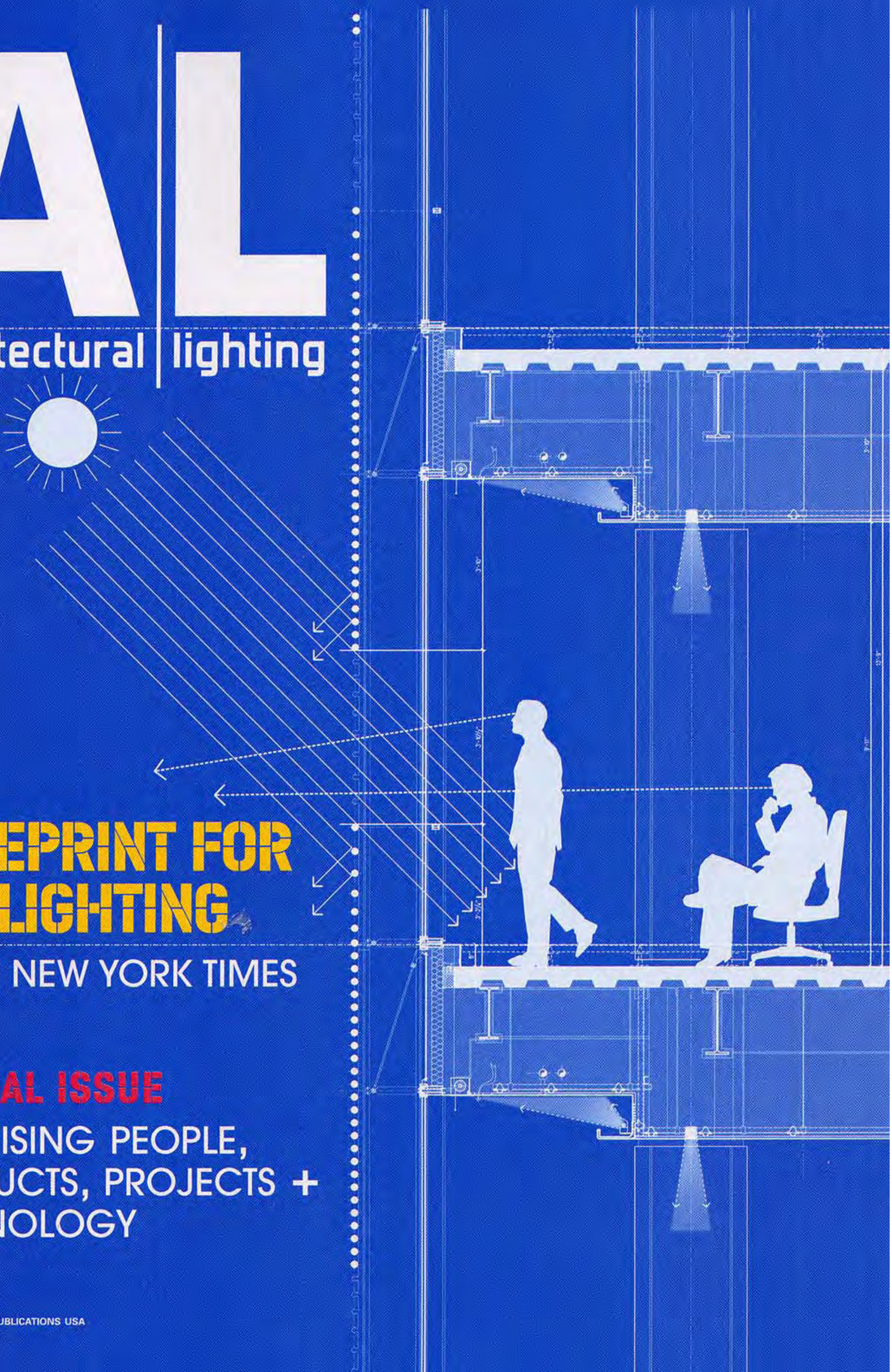

BLUEPRINT FOR DAYLIGHTING

AT THE NEW YORK TIMES

SPECIAL ISSUE

PROMISING PEOPLE, PRODUCTS, PROJECTS + TECHNOLOGY

JUNE 2004
VNU BUSINESS PUBLICATIONS USA
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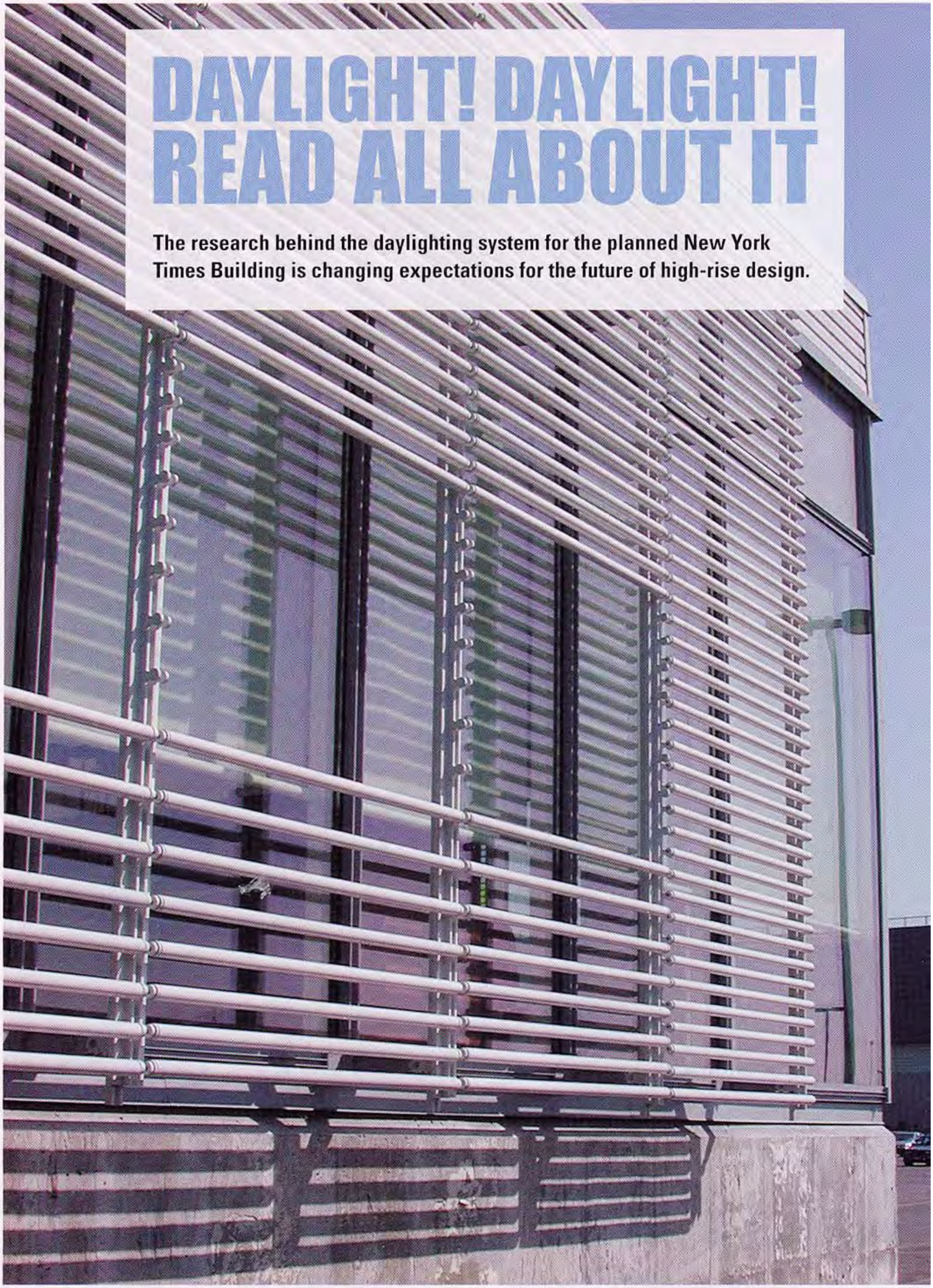
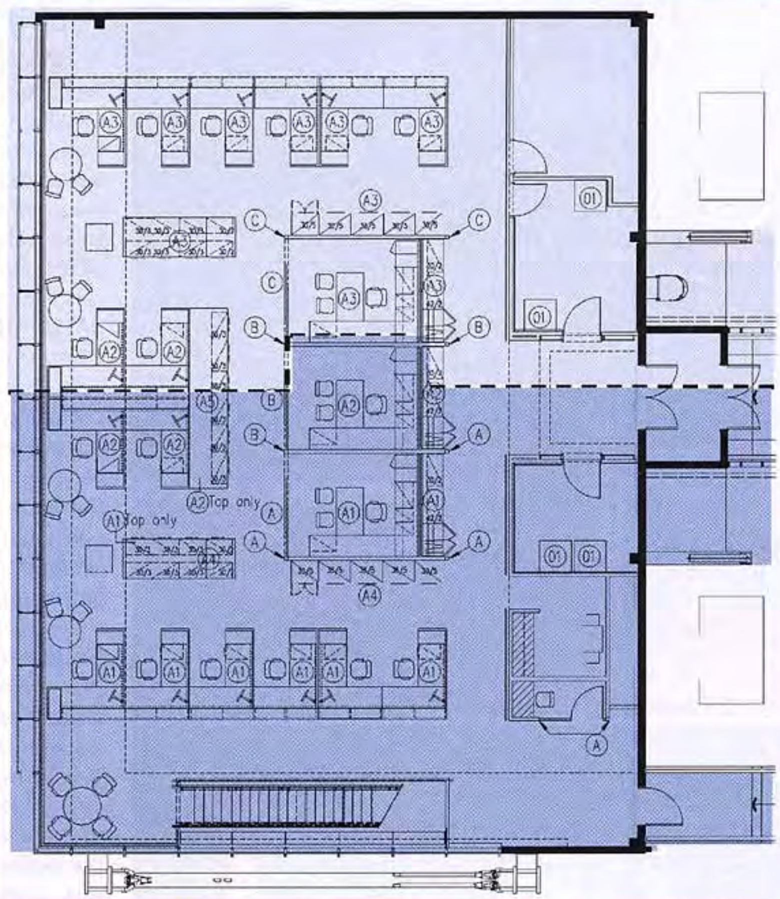
DAYLIGHT! DAYLIGHT! READ ALL ABOUT IT

The research behind the daylighting system for the planned New York Times Building is changing expectations for the future of high-rise design.



THE NEW YORK TIMES IS NOT YOUR AVERAGE CLIENT, AND NEITHER IS ITS new 51-story headquarters to be located on 8th Avenue between 40th and 41st Streets. What makes the Times stand out as a client is its research approach (it is a news organization after all) and its project management style, which it developed as a result of building two major printing facilities over the last 20 years. The new building's design is complex, and the process to create it has been even more so. While the project will be home to a whole host of technologically advanced building systems, it is the daylighting mock-up that has garnered particular attention.

In the parking lot of its College Point, Queens, printing facility, the Times has constructed a one-story, 4,500-square-foot, full-scale mock-up of the southwest corner of the planned building. Its purpose has evolved well beyond its original function as a furniture mock-up and constructability exercise; it is a comprehensive investigation of daylighting in combination with shading systems, not paired in this way before, or for a project of this scale. The findings are certain to influence how lighting and the integration of daylighting will be incorporated in future high-rise office buildings around the world.



The southwest corner of the building will receive the greatest amount of daylight; therefore, it was chosen as the portion of the building to study. The plan of the 4,500-square-foot mock-up (above, courtesy Gensler) is divided into two areas to test different shading and dimming systems. Lutron equipment occupies the north side of the space (light blue), while MechoShade and Siemens components are installed on the south side of the testing area (dark blue). The ceramic tube screen wall (facing page) acts as both an aesthetic element and an architectural shading device.

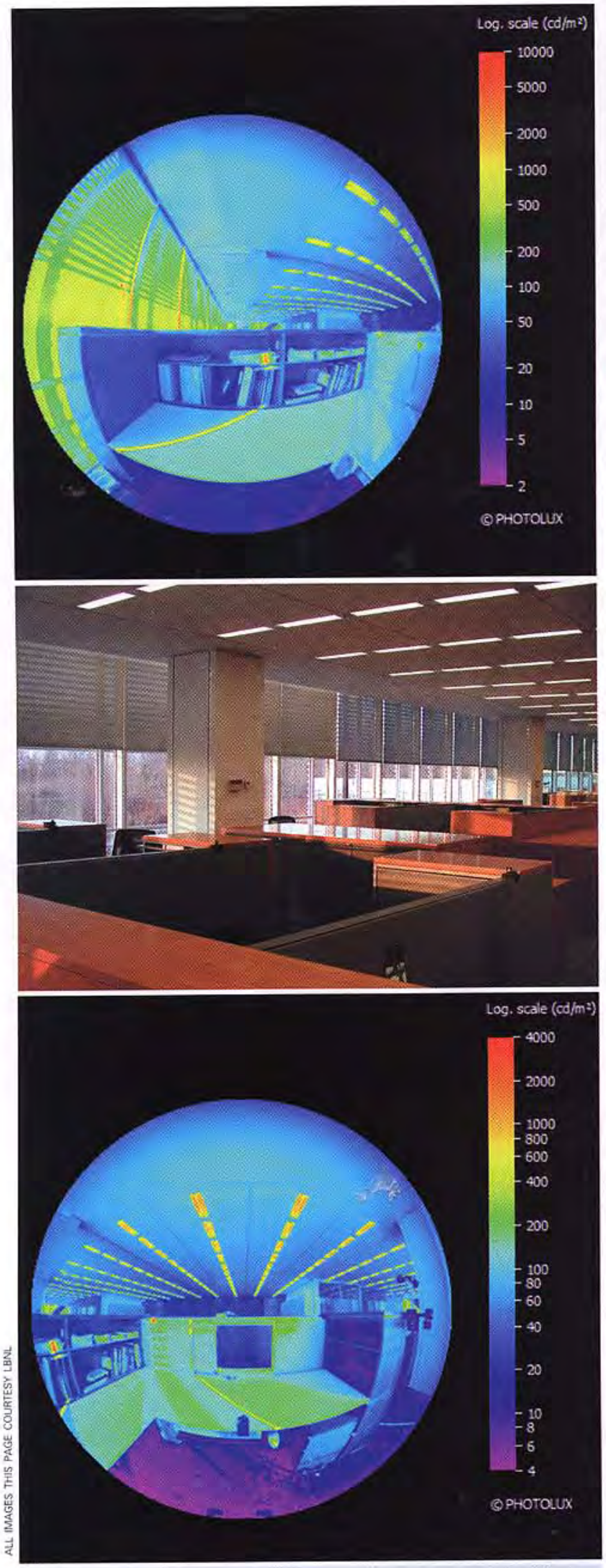
TO SHADE OR NOT TO SHADE?

From the outset, the building's design *parti* has been the expression and thorough incorporation of light and transparency. The building's "skin" is a double-layer system comprised of a clear, low-iron-glass curtain wall with a screen of ceramic tubes in front supported by an aluminum armature. The challenge created by this system has been how to control daylight levels so that the work environment is not overly illuminated (brightness and glare), yet maintains a connection to the outside.

The Times was interested in daylighting and energy-efficiency issues related to the building's design early on, which automatically implicated the need for a control system. The organization understands efficient control systems (its printing plants produce over a million copies of the newspaper on a daily basis), so it asked interior architect Gensler Associates, and Susan Brady Lighting Design (SBLD), responsible for the interior lighting, to design an equally systematic interior. The Times also required that each department be able to adjust the lighting according to its needs.

Despite an abundance of natural light in the building, electric light is still necessary to compensate for the very bright contrast at the building's perimeter. The client's desire to implement a lighting control system translated into three possible options: an easy on/off system, a 0-10 volt programmable dimming system, or DALI. But before committing to one, the Times needed more information. To figure out which control system was a viable option, SBLD began a detailed investigation into light sensors. The firm discovered that there were no such systems of note in the United States, and while double curtain walls are prevalent in Europe, the combination of dimming and shading controls in one system is not.

In keeping with the organization's thorough research methodology, David Thurm, vice president of corporate real estate development, had also been looking into daylighting and come across a paper written by Stephen Selkowitz, head of the building technologies program at Lawrence Berkeley



ALL IMAGES THIS PAGE COURTESY LBNL

Digital luminance maps taken in the north zone of the mock-up facing east (top) and north (above) indicate the light levels on every surface. Both shading systems—MechoShade to the right and Lutron to the left—are installed on the western elevation (center) and respond to the amount of light entering the building at 4:30 PM during the spring equinox in sunny conditions.

National Laboratory (LBNL). Still not sure how to implement a dimmable lighting system or even if it should use one in the new building, the Times decided to visit Lawrence Berkeley. Client, interior architect, lighting designer and engineer made the trek to LBNL in January 2003. During the course of that visit and the discussion that ensued, Glenn Hughes, director of construction for the Times, asked the question everyone seemed to be skirting around: What was the best way to manage the façade and could it be done with a shade system? "The parody of the space is that it allows connectivity to the world and the beauty of natural light to come into the building, but it needs to be tempered in order for people to enjoy it," says Hughes. With that question asked, the visit to LBNL confirmed that both a shading and a dimming system were the answer to the daylight conundrum. Then, serendipitously, a conversation between Thurm and Selkowitz resulted in the mock-up—already in development to review the final three furniture vendors and the lighting control systems—becoming an advanced daylighting study. For this, the team received support from NYSERDA (the New York State Energy Research Development Authority), the California Energy Commission and the Department of Energy.

DAYLIGHTING MOCK-UP 101

Glenn Hughes is very clear about the purpose of this mock-up: "We are not collecting data to compare vendors. We are collecting data to find energy savings, to learn about shade control and to figure out the best possible system." Three vendors are involved in the mock-up: Lutron, MechoShade and Siemens. Further neutralizing the playing field, the data collection has occurred under the watchful eye of LBNL, a leader in the field of daylighting and building systems research for the last decade.

A separate set of construction documents, prepared by Gensler and coordinated with LBNL, indicates the location of all the sensors and measuring devices. "The rigging of the measuring equipment was an entire exercise unto itself," says Gensler senior associate Rocco Giannetti. Data is being collected over a six-month period—December 21, 2003, to June 21, 2004. The two shading systems being studied measure daylight in fundamentally different ways. MechoShade's system responds to exterior conditions like the solar path of the sun, while Lutron's system responds to the immediate conditions of the space. The issue is not which is a better method, but which is the best solution for the New York Times application.

The south side of the mock-up and half of the western façade is divided into seven zones and outfitted with MechoShade's equipment. Three radiometers are strategically placed on the rooftop to coordinate the building's location with the direct solar angle. A total of 10 photo sensors—two on the exterior façade and eight inside, including three on the south wall and one in the open-plan area—monitor the brightness level as it changes across the window wall. The shading system maintains a luminance ratio of 10:1, which is a comfortable level for distinguishing visual task surfaces from the background. The notable characteristics of the MechoShade system are that it is both proactive (the system is already set to acknowledge the solar path of the sun) and reactive (the system responds to changes in sky condition and reflecting surfaces).

The MechoShade system is paired with Siemens' Instabus protocol control system, so that the team can test a DALI interface and how the brightness override could be incorporated. To study the DALI system, light level sensors are installed at the work plane. The Siemens system is responding to the general amount of daylight in the space, and dimming

The dual-lamp ceiling fixtures (above) have a multi-purpose center area to incorporate sensors and sprinklers, and the end compartments take the air return back into the ceiling plenum. The result is a clean and taught ceiling plane of light slots. Shades on the different elevations of the building respond to the daylight conditions at the southwest corner of the mock-up, while sensors mounted to the ceiling and the floor take illuminance readings (left).

the electric lights accordingly so that the overall luminance level never exceeds 50 footcandles.

Lutron's integrated motorized roller shade and dimming ballast system is installed on the north side of the mock-up and along the second half of the western façade. It has one exterior sensor and eight interior sensors distributed throughout the five zones of its testing area. Lutron is using a closed-loop shield photo sensor system, meaning that the shades are responding to the measurement of light from within the space. The sensors, which read the window luminance, are placed in the ceiling plane near the windows. The goal is to strike a balance between glare and energy savings. Both systems are set so that at night the shades are fully raised. There is also a manual override feature.

There is a combined total of 107 sensors between the manufacturers' and LBNL's testing equipment. Web cams monitor the lighting conditions around the clock, so LBNL can confirm the testing conditions for the actual data collected. From a computer hub in the mock-up, the data is transmitted to the Times printing plant across the parking lot via an optical dish on two secure systems, and that in turn is sent to LBNL, who in turn has secure communication with the manufacturers. LBNL is also conducting a human factor study where a statistically representative group of 60 people will work in the space and then fill out questionnaires.

LBNL's goal is to provide the New York Times with parameters—the best features culled from each system—for its performance specifications. Results should also clarify how the shade system performed and indicate whether the technology of the system is robust enough for continuous use. Data regarding glare has already been analyzed. The Times will issue a performance specification at the end of July, and LBNL will issue its final report in September 2004.

THE FUTURE IS CLEAR

The study is a milestone opportunity for all parties involved. The Times hopes its daylight investigation will stimulate the marketplace to offer this technology cost-effectively. For the manufacturers, it is a way to test and confirm their systems via an independent third party, who also happens to be a world-renowned laboratory. Ultimately, this daylight investigation gives building owners, architects, lighting designers and manufacturers an accurate reference point, so they know that a daylighting-shading-dimming combination is a viable option for future buildings, and not just for commercial office high-rise design. **ELIZABETH DONOFF**

more information at
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DETAILS

PROJECT The New York Times Daylighting Mock-Up, Queens, New York
ARCHITECT Renzo Piano Building Workshop, Paris, in association with Fox & Fowle Architects, New York City
INTERIOR ARCHITECT Gensler Associates, New York City
INTERIOR LIGHTING DESIGN Susan Brady Lighting Design, New York City
PHOTOGRAPHER Elizabeth Donoff, except where noted

MANUFACTURERS	APPLICATION
MOCK-UP AREA A (NORTH)	
Mark Lighting	Lighting fixtures
USG	Ceiling system
Lutron	Lighting controls: 0-10 Volt dimming (T8), shades and Eco-10 ballasts
Advance Transformer	Mark VII ballasts
MOCK-UP AREA B (SOUTH)	
Zumtobel	Lighting fixtures
Armstrong	Ceiling system
Siemens	Lighting controls: DALI digital dimming (T8)
MechoShade	Shades
Advance Transformer	ROVR T8 ballasts

Day of the Sun

Energy savings result from testing a mock-up of The New York Times' new headquarters

By Sahely Mukerji

Owners of The New York Times Co., along with researchers at the Environmental Energy Technologies Division of Lawrence Berkeley National Laboratories in Berkeley, Calif., constructed a 4,500-square-foot mock-up of the paper's new headquarters in the parking lot of its College Point, Queens, printing facility. The researchers used the model of the southwest corner of the headquarters for testing daylighting and shading systems.

"No prior studies looked in this detail at field performance in a facility of this size with as many hardware systems," says Stephen Selkowitz, head of LBNL's Building Technologies Department.

In March, the researchers provided Times' owners with preliminary numbers showing significant energy savings. Typically, building owners find minimal energy savings from daylighting beyond a 10-15-foot deep perimeter, Selkowitz says. However, in the mock-up, the average daily lighting energy savings in the February-to-May test period ranged from 76 percent at 10 feet from the glass to 37 percent at 25 feet.

"Photo-cell-controlled dimmable lighting reduces electricity use in response to available daylight," Selkowitz says. "Daylight levels are influenced by glazing and external shading, [and] dynamic operation of the motorized shades to control glare.

"Measurements reinforced direct observation

Sources

Stephen Selkowitz, Lawrence Berkeley National Laboratory, Building Technologies Department, Building 90-3111, 1 Cyclotron Road, Berkeley, Calif. 94720, SESelkowitz@lbl.gov

Glen Hughes, The New York Times, 220 W 43rd St., New York, N.Y. 10036, hughegd@nytimes.com

Christine Shaffer, Viracon, 800 Park Drive, Owatonna, Minn. 55060, cshaffer@ viracon.com

A rendition of the 51-story New York Times headquarters that the quality of daylight in the space enhances the occupants' experience," Selkowitz says. The full range of answers, however, won't be available until all the data is analyzed. Data collection ended in August.

The design

The 51-story headquarters will feature an 800-foot curtain wall, a glass façade sheathed in sun-shielding ceramic rods and stairs linking 28 floors. The all-glass building, to be complete in mid-2006 at Eighth Avenue between 40th and 41st streets, was designed by Renzo Piano to embody transparency, lightness, strength and integrity.

The original tower design, with its exterior shading provided daylight, views and outdoor contact, but did not control glare and sun penetration, according to an LBNL report. The design also did not make provisions to dim electric lights to take advantage of daylighting, the report states. Consequently, the Times design team approached LBNL to assist in solving the challenge of integration and cost.

"The mock-up was built for four reasons," says Glenn Hughes, director of construction at The New York Times. "First, we needed a furniture mock-up. Second, we realized there were not sufficient tools available to model natural light admittance, glare and daylight harvesting with certainty. Third, we wanted to perform analyses on some of our interior designs such as the communicating stairs. Fourth, we were able to take hundreds of our employees through the mock-up and gather many comments."

It's unusual for a building owner to invest this

Top, the Radiance simulation of the mock-up at night; and bottom, an interior veiw of the mock-up on a hazy day last December.

The science of daylighting

Daylighting improves the quality of indoor spaces and has huge potential for energy savings and electric-load reduction. However, as an architectural strategy, it has not yet achieved widespread use. Three obstacles limit applications, says Stephen Selkowitz, head of the Building Technologies Department at Lawrence Berkeley National Laboratories in Berkeley, Calif. These include:

- High cost of dimming electronic ballasts that allows electric light to slowly and proportionately reduce as daylight increases. The price difference between conventional and dimming ballasts is 500 percent.
- Difficulty of controlling sunlight and glare without sacrificing daylight
- Challenge of integrating sensors, controls, lights and shades into systems that reliably meet occupant and owner needs over time

During the last decade, LBNL researchers have been testing and analyzing integrated façade and lighting systems that can provide these benefits, Selkowitz says.

"One-third of all energy used in commercial buildings is used for lighting, and most [of it] during the day when the sun and the sky provide light 20 to 200 times brighter than typical indoor levels," Selkowitz says. "The best architects have always used daylight to enhance buildings and spaces."

Glass transmits daylight, but also produces solar heat and glare. Electrochromic glass (see story, Glass Magazine, October, p. 50), dimmable lights, and automated motorized shades and blinds, however, can improve thermal and visual comfort, as well as reduce peak cooling and annual energy use, Selkowitz says. "The U.S. Department of Energy strongly supports this approach, although it will take some time before the products reach full commercialization and low costs.

"There is renewed interest in daylighting because of the potential energy savings, because people prefer rooms with windows and they like views," Selkowitz says. Some evidence, such as improved productivity in schools, points to other performance attributes, but debate continues on the meaning of these studies.

much time and money to get the technical details right, Selkowitz says. "It is also unusual for a research-and-development group and an owner to collaborate."

A goal of the study is to change the paradigm for dimmable lighting controls in buildings, Selkowitz says. "Today, only about 2 percent of fixtures use dimmable ballasts. They are a low-volume, high-cost product [that is] difficult to integrate into a working system with sensors and controls. They are found in executive offices and a few daylighted spaces. The project seeks to change that paradigm, to make dimming ballasts the standard choice, to allow light levels to be tuned to workers' needs, to harvest daylight and to control emergency electric demand.

"This requires solving all the integration issues and convincing manufacturers that a market of enlightened owners will pay 'reasonable' premiums for a product that delivers the function," Selkowitz says. "Our final goal is to get other large firms like the Times to ask for the same smart technologies."

The test

Times' owners paid an undisclosed amount to construct the mock-up. The research was funded by a $250,000 grant from the New York State Energy Research Development Authority and $75,000 each from the U.S. Department of Energy and the California Energy Commission.

"The plan was to collect data over six months [winter solstice to summer solstice] that encompasses all the sun angles," Selkowitz says.

Researchers installed more than 100 sensors to record lighting energy, shade height, interior illumination and luminance, sky conditions, and general lighting conditions using webcams. Limited occupancy surveys were also administered. The researchers used Radiance, a daylighting software, to develop detailed ray-tracing lighting simulation models to predict how the space will perform in different exposures and climates, and how daylight changes as shade fabric or fixtures change. They attempted to develop and validate procedures for the automated shading and dimmable lighting that provide visual comfort and enhance performance for occupants, while providing energy savings.

"The automated blind sensor location, calibration and operating logic are all critical, as are the sensor issues related to the dimmable lighting," Selkowitz says. "The goal was to verify or improve performance [and] use the data gathered to write a performance specification."

The specification was put out to bid this summer so that companies, including ones that did not participate in the tests, could respond. Times owners are currently reviewing the bids.

"A key goal of this project was to develop performance specifications, so that companies can more readily specify and procure these technology packages," Selkowitz says. "At the same time, the manufacturers are being asked to rethink how they offer their products to owners in terms of procurement practices and pricing."

"The New York Times has gained tremendous value from the experiment," Hughes concludes. "The gift of natural light has been beautifully integrated with the interior architecture, creating a space that really feels good." ▣

The contract goes to ...

Viracon of Owatonna, Minn., has been chosen as the supplier of glass for The New York Times' headquarters; the glazing contractor is Benson Industries of Portland, Ore.

"The glass is a combination of Viracon's VE-2M coating on low-iron glass, combined with a custom silk-screen pattern in a white ceramic frit," says Christine Shaffer, marketing manager of Viracon. "The glass blends the aesthetics of a custom silk screen with solar controlling properties of the low-emissivity coating.

"The use of low-iron glass substrates continue to increase in popularity," Shaffer adds "Low-iron glass is being used on the [World Trade Center] Tower Seven. The VE-2M coating is Viracon's most popular coating today. The custom silk screen is similar in design of another Renzo Piano building, the Aurora Place in Sydney, Australia." ▣

The uniform shape of the headquarters brings more light in and gives employees near-panoramic views.

Green grows up...

Sustainable high-rises are sprouting from Manhattan's bedrock.

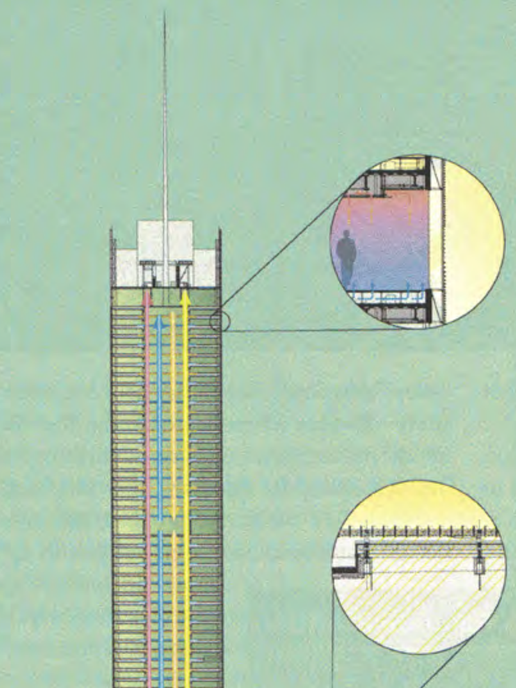
and **up** and **up** and **up**

By Deborah Snoonian, P.E.

Tall buildings are getting greener. Or green buildings are getting taller. Either way you slice it, the sustainability movement in the U.S. has gone large-scale and skyward, and nowhere is this more apparent than in New York City. By the end of this decade, several green high-rises now planned or under construction will pepper the Manhattan skyline, including a headquarters for the nation's leading newspaper, the Freedom Tower, apartment buildings, and office towers for a financial institution and a major publisher.

Why the surge? New York owners and developers say they've discussed green design for years, but no one wanted to be the first to take the plunge—that is, until the Durst Organization hired Fox & Fowle Architects to design the Condé Nast Building at Four Times Square. Within a year's time from 1999 to 2000, Four Times Square opened, Battery Park City's environmental guidelines for residential construction were passed, and the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) certification program was established. "Those three events changed everything," says one developer who wished to remain anonymous. "Before that, we said, 'Why bother?' No one understood green design or what its advantages were. But after Four Times Square, everyone thought, 'We can do that too.' And LEED gave us a blueprint for understanding how to get there."

The projects underway involve committed clients who've hired architects capable of leading multidisciplinary and often international teams through the confusing choreography of standards, guidelines, and best practices for sustainable design. Though the technologies and strategies they employ aren't always new, many are rare in tall buildings in the U.S.—a situation that will change as more cities embrace density and draft their own sustainability principles.



New York Times Tower

Among the green features of the building (clockwise from top, diagram at right) are a solar screen of ceramic rods, automated skylights, onsite cogeneration, and a courtyard garden. The lowest levels of the building (inset, top and bottom) offer full transparency, with views out and in. Extensive lighting studies were performed at a full-scale mock-up (inset, middle), which was also used to test furniture layouts and the constructability of the facade. The tower's high-tech lighting and shading system will be commissioned at the mock-up before installation.

The Grey Lady's green makeover

When Renzo Piano Building Workshop and Fox & Fowle Architects were chosen as the winning team for the new headquarters of the *New York Times*, critics swooned over its facade of ultra-clear glass shaded by a scrim of white ceramic tubes. As owners, though, the *Times* was concerned about glare and heat gain. Would eye-strained reporters literally sweat over their deadlines as they cranked the air-conditioning to budget-busting levels? In late 2002, lighting consultants SBLD Studios and interior architect Gensler were already evaluating lighting and shading systems when David Thurm, vice president of facilities for the *Times*, happened upon a technical paper written by Stephen Selkowitz, a lighting expert and head of the building technologies department at the Lawrence Berkeley National Laboratory in California.

So began a one-of-a-kind research project. The *Times* design team met with Berkeley Lab researchers, who recommended an integrated facade management system of dimmable lights and mechanized shades that would respond to the sun's angle and intensity. Just weeks later, the *Times* decided to build a freestanding mock-up of the tower [RECORD, March 2004, page 169] that would let them test real-world conditions for such a system, and by mid-June, Berkeley Lab secured a grant from the New York State Energy Research Development Authority (NYSERDA) to collect data they'd need to design it. By the first day of winter 2003—less than a year since the initial meeting—the mock-up stood complete and over 100 sensors began collecting data for a solstice-to-solstice study that allowed researchers to model light conditions year-round. The zones and control schemes were tweaked continually as data were collected. "We didn't want fixtures going on and off, or shades going up and down constantly," says firm principal Bruce S. Fowle, FAIA. The study showed that enough daylight penetrated the 44-foot perimeter zone of the building to permit lights in that area to be dimmed, if not turned off entirely, and lighting energy savings in winter ranged from 10 to 70 percent.

The design team issued solicitations based on detailed performance specifications written during the study. Just last month, Mecho Shade, Lutron, and Zumtobel were selected to provide shades, dimmable ballasts and controls, and custom fixtures, respectively. A second NYSERDA grant will allow these suppliers to commission their systems in the mock-up before installation. "This will reduce the chance of poor performance and cost overruns," says Thurm, problems that have plagued wider adoption of these technologies.

The design also calls for underfloor air distribution (UFAD) on the floors occupied by the *Times*. Though it's known to improve indoor air quality, UFAD hasn't been used much in U.S. high-rises. "There's a false perception that raised floors sound cheap," says Fowle. "That may have been true years ago, but not anymore." To plan its implementation, the *Times* gathered nearly 40 architects, engineers, and consultants involved with the new tower and a building for another paper they own, the *Sarasota Herald-Tribune*. "We worked out construction sequencing and other details that would have been difficult to do in one-on-one meetings," including measures to keep the plenums clean, says Glenn Hughes, director of construction for the *Times*.

One Bryant Park

Rainwater will be collected, stored in four different locations (diagram, right), and reused for toilet flushing and as makeup for the cooling towers. Raised floors for cabling and underfloor air distribution (middle right, top) eliminates ductwork and improves indoor air quality. The podium entry on Sixth Avenue will feature photovoltaics (middle right, bottom). The building's angular, faceted form was inspired by Bryant Park's Crystal Palace of 1853, the first glass-and-steel building in America. One triangular "face" of the building (far right) will be double-glazed to vent excess heat.

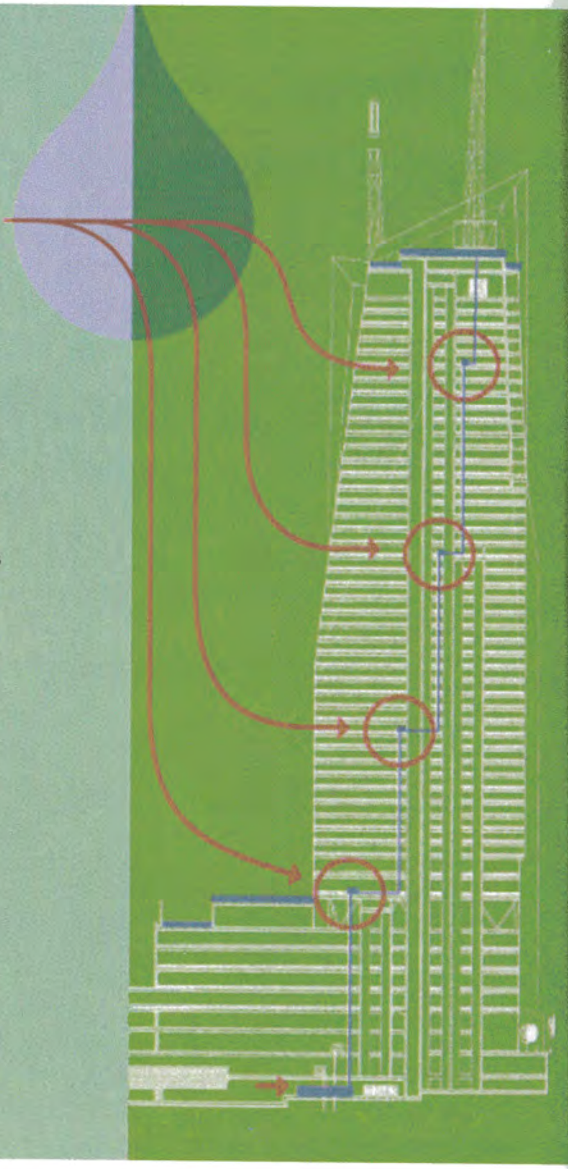
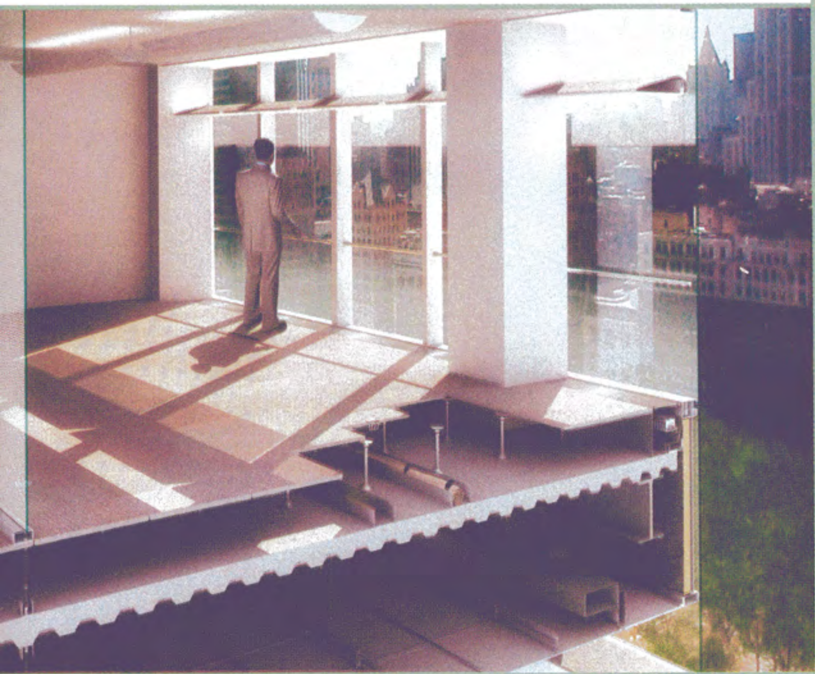


IMAGE COURTESY COOK + FOX ARCHITECTS

PROJECT	ARCHITECT	HEIGHT	#FLOORS	COMPLETION
The Solaire	Cesar Pelli & Associates	250'	27	2003
The Helena	Fox & Fowle	405'	37	2004
211 Murray Street	Cesar Pelli & Associates	230'	24	2005
The Hearst Tower	Foster and Partners	597'	41	2006
New York Times Tower	Renzo Piano Building Workshop/Fox & Fowle	748' (1140' with mast)	52	2007
One Bryant Park	Cook + Fox	945'	54	2008
Freedom Tower	SOM	1,776'	70	2008

A bank invests in efficiency

Just a few blocks east of where the *Times* broke ground in August, another glazed tower began construction. Designed by Cook + Fox Architects, One Bryant Park is being codeveloped by its main tenant, Bank of America, and the Durst Organization. The project team is gunning for LEED platinum—a first for an office high-rise.



IMAGES COURTESY DBOX FOR COOK + FOX ARCHITECTS

Though European architects have turned to double-walled glazing systems for efficiency, such a system wouldn't have worked here because of New York's hot, humid summers, says partner Robert Fox, AIA. Still, one "face" of the building, which looks south toward Bryant Park, will be double-glazed to prevent heat gain, and floor-to-ceiling glass will be fritted at the top and bottom for interior comfort but left clear in the middle to preserve views.

A variety of energy-saving technologies are planned, including an onsite 4.6-megawatt cogeneration system, geothermal heating and cooling, and building-integrated photovoltaics (BIPVs) installed in three places—atop a glass roof that floats over the subway entrance, along the entry pavilion on the southeast corner, and on spandrels that support a 10-story notch on the eastern facade. Though they won't produce large amounts of electricity, "we used BIPVs near the ground so people could see them and learn the importance of renewable energy," says partner Richard Cook.

Fox says sustainable design has taken leaps and bounds in the years since he and former partner Fowle designed the Condé Nast Building and helped draft Battery Park City's guidelines. "Back

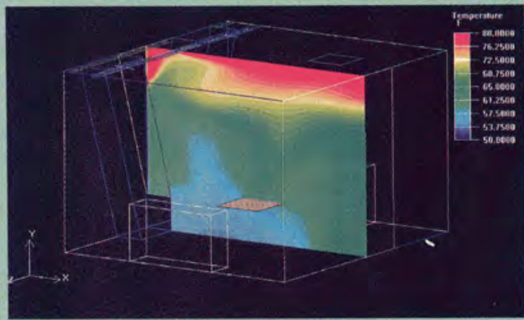
then the architects and owners really led the process, but now we're used to teaming up with engineers and consultants earlier on. And for Bank of America, we challenged ourselves to make the best use of everything that's available for free: air, sunlight, rainfall."

As in the *Times* building, UFAD will be used on floors occupied by Bank of America. Other features include a one-acre planted roof on the podium and an air filtration system that removes 95 percent of particulates, compared to 35 percent for most buildings and 85 percent at Four Times Square.

A publisher puts its magazines under one roof

In the mid-1990s the Hearst Corporation, whose titles include magazines like *Esquire* and *Cosmopolitan*, began looking at its real-estate operations in New York with an eye toward consolidation. After analyzing the rental market and crunching the numbers, they decided to build their own space—sustainably. "Buildings have such a huge impact on the environment and health, so having our own green building was a way to recognize this and put our employees first,"

IMAGES COURTESY FOSTER AND PARTNERS (LEFT AND OPPOSITE, BOTTOM) AND FLACK + KURTZ (ABOVE AND OPPOSITE, TOP)



Hearst Tower
When finished, the building will house all of Hearst's magazine-publishing operations in New York. Irregular corners and angles of the structural diagrid posed a challenge to engineers designing the HVAC system, who used computational fluid dynamics (graph, top right) to analyze airflow patterns on each floor. In a twist on double-walled construction, the spaces between the new structure and the preserved facade as well as a neighboring apartment building will be used to move and vent air. Rainwater will also be collected and reused onsite for irrigation and as cooling tower makeup.

says Brian Schwagerl, director of real estate and facilities planning for Hearst. Foster and Partners won the commission for its first major work in the U.S. With his usual technical rigor, Lord Norman Foster designed a glazed tower that's being inserted—where else?—into the shell of the original 1927 Hearst Building, to which a planned high-rise was never added.

The building's 856,000 square feet will contain a skylit atrium with a cafeteria and auditorium, a water feature (still under consideration) fed by harvested rainwater that would provide cooling in summertime and help with humidification, and space for all of Hearst's magazine employees in New York. The project is expected to garner the first LEED gold rating for a commercial office tower in New York State.

After analyzing several HVAC options, including UFAD, engineers Flack + Kurtz opted for slab-integrated heating and cooling with low-temperature air. Temperatures can be controlled from stations located on each floor, and in lieu of floor-by-floor mechanical rooms, central air handling units will be housed on the 28th floor to make it easier to flush them with outside air. Engineer Paul Reitz says they found the dips and angles of the diagrid a serious challenge in analyzing the system's performance. "We relied heavily on computational fluid dynamics (CFD) to determine how air would move on each floor," he says. "Without CFD, the entire system would have been guesswork—and we could have guessed wrong." CFD also enabled clever use of the building's tight site; the space between the preserved six-story facade and the new structure, as well as between the structure and the apartment high-rise to its west, are being used as plenums to move and vent air.

Reliance on such high-tech analysis is increasingly common in sustainable design, and this project has benefitted from a partnership between a world-class architect fluent in technology and an engineering firm that's been intimately involved with the sustainable-design movement in New York City through projects and standards-setting. "I'm hard-pressed to find a firm that cares about the details more than they do," says Reitz of Foster's staff, who express the same sentiment about their partners. That trust has proven necessary to achieve any measure of success with green building.

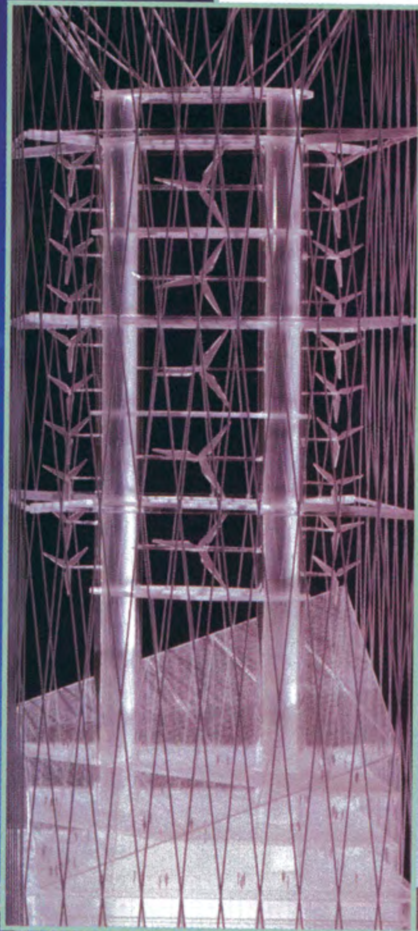
A tower powered by wind

If all goes as planned, the most scrutinized high-rise of our time will be the first in the world to harvest wind. Last year, London engineering firm Battle McCarthy was tapped to design an integrated wind-turbine system for the Freedom Tower. The firm has worked on similar schemes for other buildings, but none have been realized.

Though turbines are a well-developed technology, concerns about noise, vibration, and safety have kept them off buildings in densely-populated areas. That will change. "Wind turbines make sense particularly for tall buildings, where you don't have to pay for the structure to put them up," says Guy Battle, principal of Battle McCarthy. Engineers are finding ways to make them quieter, he says, and despite common perceptions, there's little risk that turbine blades will fly off or dismember birds in midflight.

DEVELOPERS WHO ONCE ASKED "WHY BOTHER?" ARE NOW SAYING "WHY NOT?"

It's unclear whether architect Skidmore, Owings & Merrill will pursue LEED certification for the Freedom Tower, but the firm



Freedom Tower

Battle McCarthy is designing an integrated wind-turbine farm to top the world's most scrutinized skyscraper. Preliminary estimates indicate the turbines could provide as much as 10 to 15 percent of the building's energy demand. Other sustainable amenities are typical of those in other high-rises: rainwater capture and reuse, use of recycled-content and low-VOC building materials, and recycling of debris during construction.

maintains that LEED criteria are guiding the design. More green towers can be expected to rise in lower Manhattan, too: Following Battery Park City's lead, sustainable design guidelines have been drafted, and developer Silverstein Properties is seeking a new type of LEED certification for the exterior structure of Seven World Trade Center, slated to open in 2005. The core-and-shell LEED program was established in 2003 to encourage sustainability for developer projects built on spec, a market several times larger than that of owner-occupied buildings. A companion program, LEED for Commercial Interiors, will allow tenant fit-outs to be certified as well.

Greening the sky-high home

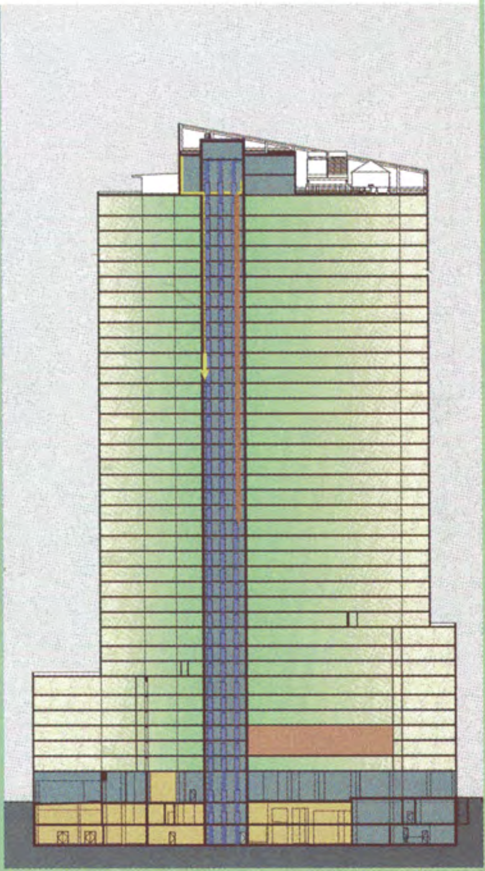
It was just west of the WTC site, in Battery Park City, where sustainability took root. Last year, the Solaire became the first residential high-rise completed under the neighborhood's green guidelines; now a second tower, also designed by Cesar Pelli & Associates, is under construction at 211 Murray Street. The new building will share a blackwater treatment system located in the Solaire's basement. Treated water from both buildings will be used as makeup water for cooling towers and will feed clean water to a nearby park.

Similar projects are underway in Battery Park City, and now neighborhoods like midtown and Hell's Kitchen are building green residential towers even in the absence of mandates. The first to open will be The Helena, a 37-story tower on West 57th Street, designed by Fox & Fowle and expected to achieve LEED gold.

IMAGES COURTESY DBOX FOR SKIDMORE, OWINGS & MERRILL (LEFT); SKIDMORE, OWINGS & MERRILL (RIGHT TWO); FOX & FOWLE ARCHITECTS (OPPOSITE TWO)

The Helena

Fox & Fowle Architects's 580-unit tower sits on the Hudson River at West 57th Street, an area undergoing explosive growth in residential construction. The building will be the first voluntarily sustainable residential high-rise in New York, but others planned throughout the city will soon follow. It is expected to achieve a LEED gold rating, with features including a green roof and graywater recycling.



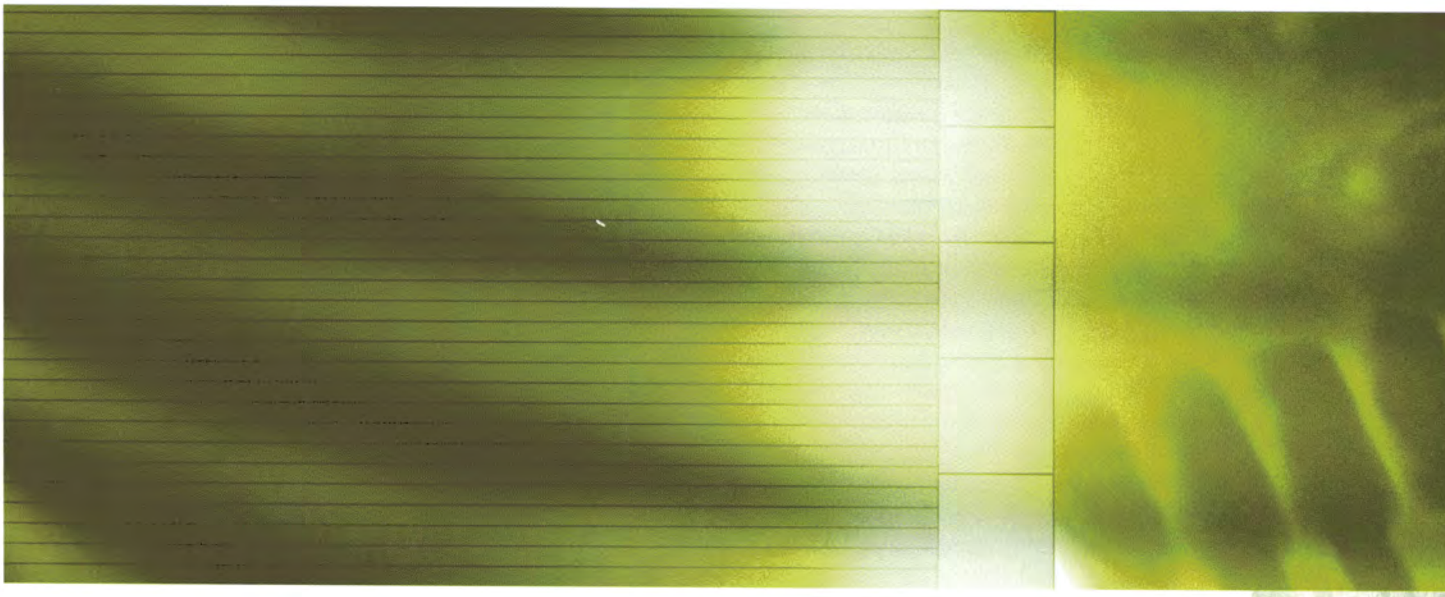
Green residential high-rises might be even hotter than the commercial market in New York. "There are bigger opportunities for implementing sustainability in residential tall buildings," says Gary Pomeranz, senior vice president of Flack + Kurtz. "People don't interview for a job and wonder, 'What's the air quality like in here?' But when they're looking for an apartment, they want clean air, clean water—and they'll pay extra for those amenities." That's proved true at the Solaire, where rents have averaged about 10 percent higher than at conventional buildings.

Beyond ratings and ribbon-cuttings

Accolades aside, the true test of sustainability will begin when the dust settles at these construction sites. Any building can be operated inefficiently, and this is especially true of large structures with complex systems, multiple tenants, and mixed uses. Each of these towers will be fully commissioned before opening to head off operating problems, and developers like the Durst Organization have even been successful at securing grant funds from NYSERDA and other agencies to periodically test and commission their existing buildings. LEED also aims to correct this situation by requiring projects to be reevaluated after five years to maintain their rating.

Though even American architects agree they lost ground to designers bound by higher energy prices, "the U.S. has been taking cues from high-rises in Europe and Asia, particularly in curtain-wall design, for efficiency," says Paul Katz, principal at Kohn Pedersen Fox in New York, which is building multiple high-rises in Shanghai and Hong Kong. Future U.S. projects will see even more melding of architecture and engineering to meet sustainability goals through formal means, and the most innovative examples might occur outside New York. "The city's zoning laws are based so much on the street grid that they're totally contrary to green design. They almost predetermine form and orientation," says Fowle.

But for now, the Big Apple's green towers represent the best in U.S. practice. And they point up the growing influence of LEED and local sustainability mandates, despite the inevitable limitations and flaws of such criteria. Peer pressure helps too. As one Manhattan developer put it, "It would have been nice to have been the first to build this way, but that's okay—we'll just set higher goals the next time." Exactly. ■



GETTING IT RIGHT: PROVIDING ENERGY EFFICIENCY AND COMFORT IN AN ALL-GLASS BUILDING

Stephen Selkowitz,
Lawrence Berkeley National Laboratory

Transparent Buildings: Background and Context

The growing interest in sustainable design in the U.S. has fostered a renewed interest in the role of glazing in building facades. Highly glazed building façades have always had a dramatic architectural and aesthetic impact, embodied most notably over the last 30 years in the iconic smooth reflective glazed façades of many low-rise and high-rise buildings. With monolithic glass and no external shading, the tinted and reflective glass typically selected has a very low solar heat gain coefficient and low daylight transmittance.

Even with large HVAC systems, thermal comfort is often a problem in spaces adjacent to such glazings. These façades allow views into the building interiors only at night; during the day they provide virtually no insight into the inner workings of the buildings, instead reflecting images of the surroundings. On cloudy days the occupants' views can be unsatisfactory and the spaces gloomy. They rely almost entirely on electric lighting to brighten the interior.

The traditional reflective glass commercial building is being challenged by a growing interest in the use of highly-glazed, transmissive façades. These façades have relatively clear, high transmittance glazing systems, and are typically outfitted with some form of sun control. With origins in Europe, the trend is expanding to other regions, including the United States. The stated rationale varies but often includes occupant benefits as well as sustainable design attributes associated with daylighting and energy savings.

A number of technological advances have facilitated these new architectural approaches. Low-e glass and related thermal improvements have made glazed façades more efficient in cold climates. Spectrally selective glazings have made it possible to maintain high daylight transmittance while reducing unwanted solar heat gain and cooling loads. Both approaches contribute to improving thermal comfort. Innovations in sealants and structural use of glass have made a wider range of architectural solutions feasible and cost effective. There has been an increased use of daylighting both as an energy saving strategy and to provide other occupant amenities and benefits.

Despite this growing interest, "getting it right" remains a challenge. Elegant images in architectural magazines don't automatically translate into sustainable designs with proven comfort and energy performance. Controlling thermal heat loss and gain can be largely addressed with highly insulating glazing technologies on the market today. However, controlling solar gain and managing daylight, view and glare is at a much earlier stage in terms of cost-effective, available solutions.

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 or can be added to the façade either on the interior or exterior of the glazing. In all cases, sensors, actuators, and control logic are needed 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 glass optical properties and can be activated either manually or by automated control systems. In each case, electric lighting should be adjusted 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 (software or occupant preference) that determines what action should be taken under each set of conditions.

Some combination 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 effectively under all environmental conditions and meets subjective occupant desires and objective performance requirements. Finally, these rigorous performance goals must be achieved with cost effective, long lasting solutions that require minimal maintenance.

The building systems that would achieve these performance results do not exist today, at least not as readily specifiable and cost-effective options. While daylighting strategies can be successfully implemented in buildings with skylights and with some success in buildings with modest fenestration, highly-transparent buildings present a unique challenge. They provide an opportunity to advance the market for emerging, smart, dynamic shading and windows and for dimmable daylighting control technologies.

Without such systems, the architectural design intent is at risk for glare and overheating, and is subject to the ad hoc manual control of interior shades and light switches, with results that are usually less than satisfying. The integration of these two technologies will increase the cost-effectiveness of both. This may renew interest in designing floor plates and interiors to optimize daylight utilization throughout a greater percentage of the building's floor area.

It will take time and effort to change the marketplace but it is possible to accelerate the process by which technical solutions are improved and advanced. The interests of innovative owners and motivated manufacturers are converging.

Strange Bedfellows: Building Owners and Researchers

The New York Times headquarters building, described in some detail by Bruce Fowle, utilizes a state-of-the-art high transmittance, double glazed, low-e, spectrally selective glazing assembly with an innovative fixed external shading system comprised of ceramic rods. However, due to the floor to ceiling glass, and the use of a rod-free vision strip, there will still be unavoidable periods of glare.

The Time's design team had the foresight to begin addressing these critical lighting quality and façade issues early while there was sufficient time to explore potential design options and implement them in the final building. One major challenge was finding solutions that addressed the thermal and luminous issues as an integrated, cost-effective and reliable package. Through the internet, the owner found 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

Emerging Technology: *Research continues on coated glass whose properties can be electrically switched from highly transparent (65%) to very low transmission (4%) in a matter of minutes. A test facility at LBNL is used to quantify energy performance and to better understand occupant response to the control strategies and the comfort levels in the space.*

Prototype electrochromic "smart glass" in a test facility at LBNL. Three sequential views of one test room in the LBNL façade test facility, showing the darkening sequence. Left: high transmission under overcast conditions; Center: sun emerges from clouds; Right: glazing switched to low transmission state to control glare and reduce cooling loads. The visible transmittance of these prototypes can be switched from 65% to 4% in several minutes.

new directions. Dimming ballasts had been dismissed as viable options based on 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 much lower prices (e.g., $20-30/ballast). Direct contacts with key manufacturers confirmed these possibilities. The LBNL team also proposed using dimming ballasts throughout the building, simplifying replacement logistics and allowing tuning of light levels to variable task and personal requirements and providing the owner with peak electric demand control at all building locations. It was still unclear how all the shading and lighting hardware would be integrated, controlled, commissioned and operated as well as how that operation would influence light and occupant response in the space.

To address issues of glare, lighting quality and hardware integration, LBNL recommended that the Times alter their plans for a conventional furniture mockup (typically built full-scale indoors in a warehouse) and build an outdoor mockup instead. This would allow them 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 reduced uncertainty and provided another key strategy to ultimately lower costs.

In addition, The Times wanted feedback from future occupants in advance of construction to provide input on some critical interior design issues. After weighing potential costs and benefits, The Times decided to construct a 401 m^2 (4318 ft^2) mockup of approximately one quarter of a typical floor. Located in a parking lot at their Queens printing plant the mockup was oriented precisely as it would be at the final location in Times Square. Construction was completed in December 2003 and testing began immediately at the winter solstice, continuing until the summer solstice in June 2004.

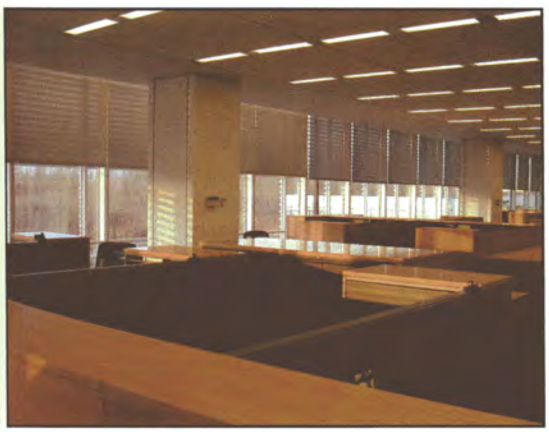
Performance Assessment: New York Times Daylighting Mockup

It is highly unusual for an owner to build a mockup at the scale and complexity of this one. The Times paid the direct costs but the measurement and evaluation work by LBNL was supported by NYSERDA with co-support from DOE and California Energy Commission. The results are directly assisting The Times in critical investment decisions, but will also be shared industry-wide to benefit others.

When building owners research technology options, the usual questions surface: how will it work, are the vendor claims valid, what risks are incurred, and will performance benefits be sustained? Most designers and owners can't answer these questions and thus slow the pace of innovation. The New York Times mockup test program accomplished several objectives: 1) to enable vendors to prove their claims and fine tune their systems to meet the building owner's evolving requirements, and 2) understand the benefits and limitations of each manufacturer's approach to shade management and daylighting controls.

The fully furnished mockup was divided into two test areas. Two roller shade companies and two manufacturers of dimmable lighting systems installed commercially-available systems with different types of sensors and control strategies. The objective was not to do a side-by-side comparison of "competing" systems but to understand how vendor decisions regarding control infrastructure and design might impact actual field operation. The end goal was not product selection but rather the development of a detailed performance specification that would be open for bid by any vendor.

Monitored data was collected by LBNL from December 21 to June 21, capturing the full range of



Photos: LBNL

Photograph of mockup (left) and RADIANCE nighttime rendering of the same space (right) solar conditions. During this time, the manufacturers were permitted to tune their systems to obtain optimal performance and improve their designs. The building owner was able to adjust some control settings to obtain a system that better met their needs. Manufacturers were able to alter their systems to better meet the owner's specifications. A subjective "occupant satisfaction" study was conducted to assess the lighting environment and acceptance of the automated technologies, and to explore how occupants might override the automated control strategies. Detailed luminance maps of work stations with computer monitors were taken at various locations within the mockup at different days and times to better understand the visual environment.

RADIANCE simulations (a ray-tracing computer tool for lighting and daylighting design) allowed the building owner to explore and visualize the impact of design options on glare, visual display terminal (VDT) visibility, illuminance and luminance distribution. The optical properties of the shades, all interior furnishings, curtainwall finishes including the ceramic rods, and the VDT were measured as inputs to the modeling work.

Initial project results have met or exceeded the team's expectations. First, the full size mockup provided hands-on, iterative testing and refinement of complex sensor/control/software systems allowing the owner to assess not only engineering data (e.g., kWhs saved) but also lighting quality issues.

The mockup showed that useful daylighting savings can be achieved throughout all the typical floor space, far deeper than originally planned. The notched corners provide large energy savings as daylight reaches the adjacent workspace from two directions.

Selecting the shade materials and control algorithms was one of the more challenging tasks. Low-transmission shades deployed frequently will control glare but limit daylight admittance. The shade fabrics used in the mockup control sky glare and enhance computer screen visibility under most typical conditions, while still providing energy savings. Additional test and simulation studies are underway with alternative shade materials to explore their performance in different parts of the building throughout the year.

A series of performance specifications for the key hardware purchases have been circulated to potential vendors and the ballast, shading and controls industry are now responding to them. Successful hardware bidders will be invited to install their systems in the mockup prior to bidding for installation and commissioning so that uncertainty and risk can be reduced, leading to more realistic and lower cost bids.

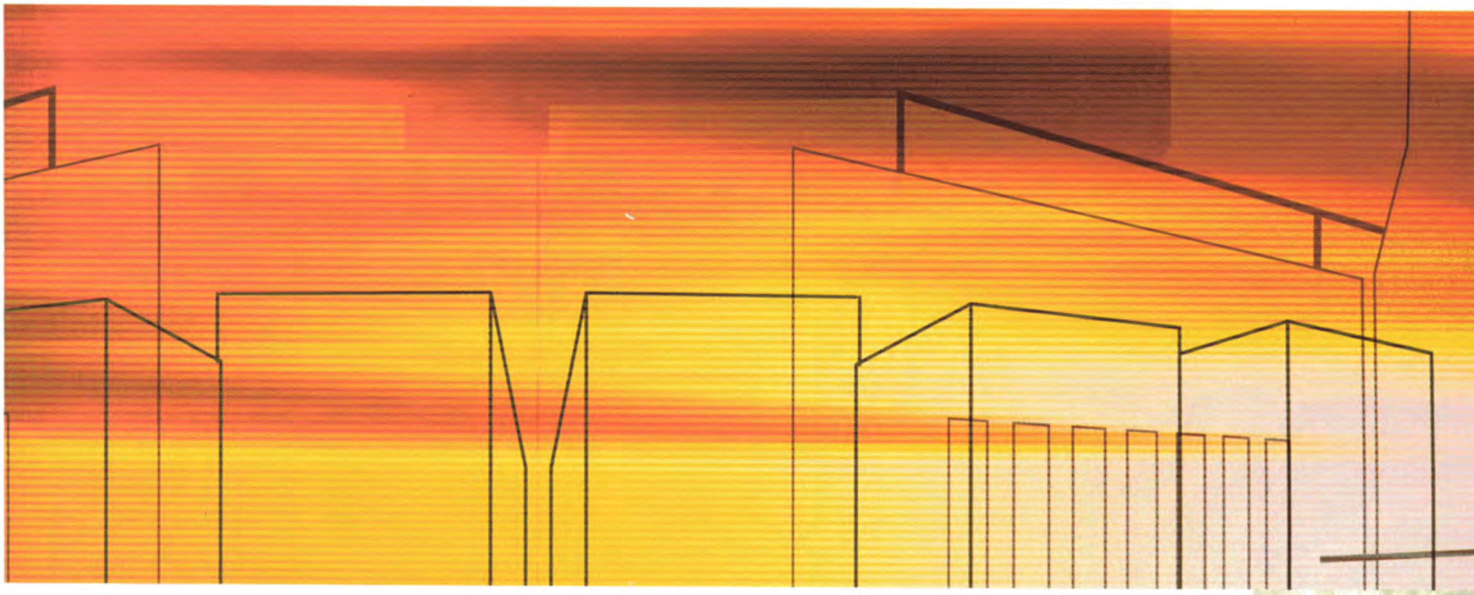
In addition to its value in resolving the façade and daylighting issues, the mockup also allowed The Times to better understand and refine critical construction details before the tower was built, reducing errors and cost. Problems caught at this stage can be solved far more effectively than when full scale construction is underway.

All participants are very pleased with results to date. The New York Times will get a building that will better meet its staff's needs, with fewer performance problems and at lower cost. The LBNL team and the public agencies that supported the research study have benefited because the R&D results are already influencing manufacturer's business practices and awakening other owners and design teams to the potential benefits of these design approaches. The cumulative market pressure from additional projects like this one will ultimately cause accelerated change in a marketplace that has been notoriously slow to adapt to emerging environmental needs.

Acknowledgements: The project was initiated at the New York Times by David Thurm, VP, Real Estate, and Glenn Hughes, Director of Construction, with assistance from a large team of designers and consultants. The LBNL research team is led by Eleanor Lee, with financial support from New York State Energy Research and Development Authority, and with co-support from the California Energy Commission and the U.S. Department of Energy.

For more info: see pages 126-129

Stephen Selkowitz *is Department Head of the Building Technologies Department, Lawrence Berkeley National Laboratory, LBNL, where he manages 80 technical staff in a buildings R&D program encompassing Windows and Daylighting, Lighting Systems Research, Computer Simulation Tools and Commercial Buildings Performance. He has 30 years of experience in the field of building energy performance, with an emphasis on research, development and deployment of energy efficient technologies and design practices. Projects range from near term demonstrations of emerging technology to basic materials research intended to influence the next generation of building products, and include development of the new computer tools and information technologies needed to change the practice of building design and operations. The program balances a state-of-the-art research effort with an aggressive technology transfer and implementation effort so that results of the R&D program are effectively utilized by industry and the building community. Selkowitz participates in a wide range of building industry, government, and professional activities in the U.S. and internationally. He is a frequent invited speaker on the topic of building energy efficiency, and is the author of over 150 publications and holds 2 patents. His accomplishments are recognized by several awards, the most recent being the 2002 ACEEE Champion of Energy Efficiency Award. Before joining LBNL he was a principal in a consulting engineering firm and taught courses in Environmental Controls and Alternative Energy Systems.*



THE NEW YORK TIMES: A MELDING OF HIGH DESIGN AND PERFORMANCE

Bruce Fowle, FAIA
Fox & Fowle Architects

The New York Times Building combines design and environmental excellence with a vital corporate mission and commercial opportunity. The New York Times, that will occupy the lower half of the building, wanted a memorable, yet timeless new home that would very distinctly express its mission of transparency and service to the public for the next hundred years. Forest City Ratner, the developer of the project, is planning to lease the other half of the project's 1.6 million square feet and needed a marketable speculative development that would be viable in the city's currently challenging economic environment.

The approach to meeting this programmatic challenge began with a multi-faceted design team. Renzo Piano Building Workshop (RPBW), the winner of the design competition for the project, brought a sensitive and exemplary concept, a spirit of European innovation and an artisan-based approach to the project. RPBW looked to Fox & Fowle Architects (FFA) for large-scale urban experience, knowledge of the New York City construction industry and leadership in sustainable design. The team was bonded through a synergy of working styles and a steadfast dedication to design excellence.

In the winning competition entry, RPBW imagined a slender, diaphanous tower with several innovations untested in the New York market, such as the intricate curtainwall and exterior sunshading system. The main challenge was developing a feasible, economically viable building, while preserving the nobility of the design concept and carrying it through the details. Maintaining environmental responsibility within the many urban constraints and complex programming presented another challenge. In translating the design concept to the scale of a commercial 52-story building, the team was able to unitize the building materials, control the cost, and provide constructability within the rapid development schedules of New York City. The team's unwavering dedication to elegant, innovative and mission-oriented design resulted in a building that balances design, programmatic and environmental excellence.

In contrast to the solid aesthetic of many urban office buildings, the New York Times Building is sheathed entirely in low-iron clear glass. This transparency, revealing the activity within, embodies the paper's mission of transmitting an unclouded, lucid report of the news to its public.

The most innovative feature of the curtainwall design is an exterior veil of ceramic tubing that functions as both an aesthetic device and provides critical sunshading. Aesthetically, the tubing serves as a canvas for the environmental conditions, changing color with the sun and weather. This extra exterior layer allows for the use of floor-to-ceiling glass, by deflecting the sun and mitigating the loss of energy efficiency expected in a clear glass building. The cruciform shape of the tower floorplate, with a maximum distance of 42 feet from perimeter to core, allows daylight to penetrate deeply into every floor. The tubular layer is critical to limiting the building's energy consumption, reducing solar heat gain by 30% and energy costs by approximately 13%. In addition, in the Times space there will be an automated roll-down window shade system to supplement the

for their newsrooms, which are provided in the four-story "podium" at the base. At the center of the podium's 60,000 square foot floors, there is a 4,000 square foot exterior courtyard set on earth. Designed by landscape architect HM White Site Architects and Cornelia Oberlander, its garden emulates a moss glen indigenous to New York State featuring a bosque of native birch trees. Besides enhancing the working environment of the newsroom and the public spaces at grade, the garden reduces stormwater runoff and heat island effect while absorbing carbon. A high-efficiency moisture-sensing drip irrigation system provides water only when necessary. Visible at street level from three sides of the building, through the multiple layers of the lobby's transparent glass, the garden contributes a calming community amenity to a neighborhood with little public space. The selection and positioning of the plant materials resulted from an extensive daylight and shadow computer modeling study.

tubes and control early morning and late afternoon direct sunlight and glare. These controls, in tandem with daylight dimming systems, have been studied extensively in a full-sized mockup of one-fifth of a typical tower floor. The New York Times, with a generous investment by the New York State Environmental Research and Development Agency (NYSERDA), contacted the Lawrence Berkeley Laboratory to work with them and the interior architectural design team (which includes Gensler, Susan Brady Lighting Design, Flack+Kurtz and Turner) to develop the first large scale proposal of automated roll-down window shades and daylight dimming in a commercial office building. The refinement of the system that has evolved through this process will have a significant effect on the cost and efficiency of the installation, and should benefit the industry at large going forward.

The team tested many different types of materials for the tubing, including traditional terra cotta, clay, aluminum and various ceramics from around the world. Aluminum silicate, an extremely dense and high-quality ceramic used for special manufacturing purposes, was chosen for its long-term durability and cost-effectiveness. The silicate tubes will be glazed with a finish similar to terra cotta to reflect light, self-clean and ensure its resistance to weather. The team also conducted testing to determine the distance necessary between the glass curtain wall and the tubing to allow for efficient window washing and façade maintenance. It is anticipated that this tubing will have the added benefit of reducing migrating bird impact – a major concern on the East Coast fly-way.

The New York Times required extremely large floorplates

Natural light is brought into the eastern end of the podium through a large skylight above a two-story atrium that serves as the nucleus of the newsroom activity. The skylight is shielded by an external automated louver system that adjusts to the solar angle and intensity, thus minimizing solar radiation and glare while maximizing light and reducing the cooling loads of the space below.

In the notched corners of the building's tower, the structure is exposed to the exterior, contributing to the aesthetic and furthering the display of transparency. Working with Thorton-Tomasetti, the structural engineers for the project, the team was challenged to find a method to fireproof the steel and make its exterior appropriate without expensive cladding. Through collaboration with steel fabricators and many other related trades, the problem was solved by using exposed steel members with intumescent coating and careful detailing of the components.

The New York Times Building incorporates a cogeneration plant which will power its 24-7 operation and provide virtually all of the Times' hot water needs for the building. Located in a mechanical room at the far end of the podium's top floor, the cogeneration plant consists of two natural gas-fired reciprocating engine generators with a total capacity of 1.5 megawatts of electrical power. The cogeneration plant, designed by Flack+Kurtz, the mechanical engineers for the project, recovers the heat produced by combustion and converts it into useable energy in the form of hot water.

The recovered hot water serves the Times' portion of the building's heating loop to provide warmth during the winter. In summer, it will serve the hot water absorption refrigeration machine to provide cooling during the warm seasons. The heat recovered from the generators is 8.3 million btus per hour, sufficient to heat 50% of the building on a typical winter day. Extensive measures to isolate the equipment were implemented to address the normal acoustic and vibration issues with cogeneration. Putting the plant in the basement could have alleviated some of these measures, but would have required the use of more ductwork and enlargement of the building volume. Although the team ultimately negotiated a satisfactory agreement with Con Ed for the power required from the grid, projects hoping to replicate this dual approach must start as early as possible to avoid disruption in the design schedule.

As part of the team's effort to enhance the indoor environmental quality and energy efficiency, the project will incorporate the first major underfloor air distribution system in New York City. By investigating installations of underfloor air around the country and in Europe, The Times became convinced that the system would benefit the company and its employees, through enhanced air quality, comfort, individual control and increased energy conservation. A great deal of thought and study went into the design of this system. A series of off-site think-sessions with the entire team, including extensive laboratory tests, were required. The pre-purchase of the underfloor system and the use of a comprehensive commissioning process to ensure its proper functioning were essential components of the decision.

The design of the interior environment, developed under the leadership of Gensler, the project's interior architects, in collaboration with RPBW and FFA, continues the physical embodiment of the New York Times' mission. Accessible interconnecting stairs between office floors promote interaction among employees, ease internal movement, reduce elevator load, and are a potent symbol of the Times' organizational commitment to breakdown barriers between departments. Positioned at the exterior walls, movement along these stairways will be visible from the exterior and adds to the feeling of openness as one moves through the space and views the building from street level. The assembly of the stairs was studied as part of the full-scale mockup; since they are an integral component of the building, the lessons learned from the pre-construction mockup continue to unfold exponentially, justifying its cost many times over.

Just as the mock-up tested the curtainwall and interior assemblies, an installation at the newspapers' current location has provided valuable information on the benefits and liabilities of various waterless urinals. The Times installed two types of waterless urinals from two different manufacturers and conducted a health study and user survey over nine months. Providing this information to the City allowed the team to get unprecedented approvals from both the Department of Buildings and the Department of Health for incorporation throughout the new building. However, as a result of employee feedback, the Times has decided not to use these urinals in the building.

An application for LEED certification of the project is pending. The level of commitment has not been finally determined as of this writing.

When complete in early 2007, the New York Times Building will bring a fresh new character to the New York City skyline, a vibrant piece of crystalline architecture that treads lightly on the natural environment and provides inspiration for many years to come.

Bruce S. Fowle *is a founding Principal of Fox & Fowle Architects and has been the firm's visionary leader since its inception twenty-six years ago. The architecture, planning, and interior design firm, based in New York City and employing one hundred people, has received numerous prestigious awards. As a long time proponent of environmental conservation, Mr. Fowle helped guide the firm to a leadership position in sustainable design. Among its achievements are the design of the first green skyscraper in the country, the first green guidelines for residential high-rises in New York, and green guidelines for a number of institutions and regional transportation systems.*