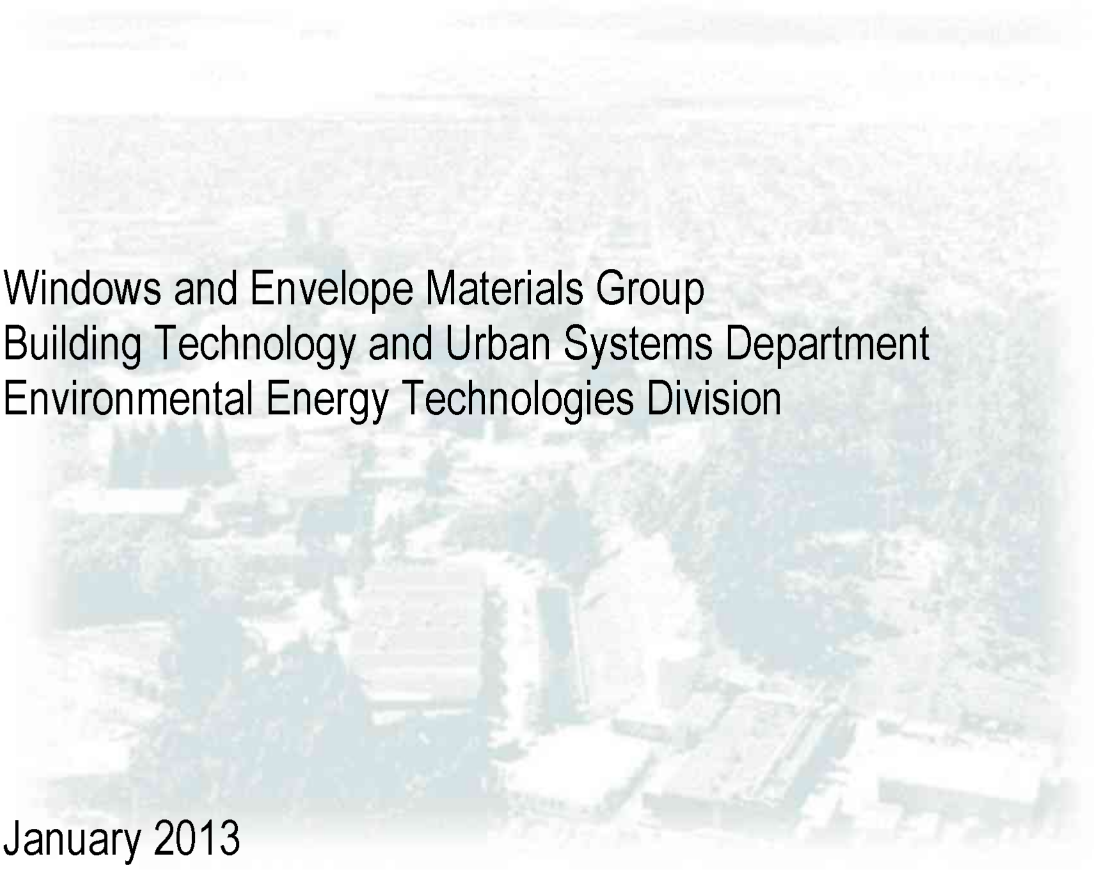
Ernest Orlando Lawrence
Berkeley National Laboratory

A Post-Occupancy Monitored Evaluation of the Dimmable Lighting, Automated Shading, and Underfloor Air Distribution System in The New York Times Building

E.S. Lee, L.L. Fernandes, B. Coffey, A. McNeil, R. Clear
Lawrence Berkeley National Laboratory

T. Webster, F. Bauman, D. Dickerhoff, D. Heinzerling, T. Hoyt
University of California Berkeley



Windows and Envelope Materials Group
Building Technology and Urban Systems Department
Environmental Energy Technologies Division

January 2013

Disclaimer

Acknowledgments

The authors would like to thank Angelo Salvatore, Executive Director of Building Operations, and Patrick Whelan, Facilities Director, at The New York Times for their generous support and dedication to this collaborative effort; Arah Schuur, Alan Schroeder, Marc LaFrance, and Patrick Phelan, US Department of Energy; Dustin Davis, California Energy Commission; Adam Hinge, Sustainable Energy Partnerships (SEP), for inviting involvement on analysis of the post-occupancy survey data that SEP gathered; Liam Sillery, Lead Engineer, First New York Partners, for assistance on technical issues concerning the underfloor air distribution system; industry partners Joel Berman, Jan Berman, Steve Hebeisen, and Alex Greenspan from MechoShade Systems, Inc. and Michael Jouaneh and Brian Courtney from Lutron Electronics, Inc. for their technical support in providing access to data sources, equipment, and additional information needed to conduct this analysis; and LBNL colleagues, Cindy Regnier, Stephen Selkowitz, Dennis DiBartolomeo, Francis Rubinstein, Thierry Nouidui, and Daniel Fuller for their technical, administrative, and editorial assistance on this project.

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Program, of the U.S. Department of Energy, under Contract No. DE-AC02-05CH11231 and by the California Energy Commission through its Public Interest Energy Research (PIER) Program on behalf of the citizens of California. In-kind support was provided by The New York Times Company. The New York State Energy Research and Development Authority supported Sustainable Energy Partnerships, who worked with the Times Company to conduct the occupant survey prior to the start of this project.

Table of Contents

Summary

With aggressive goals to reduce national energy use and carbon emissions, the US Department of Energy will be looking to exemplary buildings that have already invested in new approaches to achieving the energy performance goals now needed at a national level. The New York Times Building, in New York, New York, incorporates a number of innovative technologies, systems and processes and could become a model for widespread replication in new and existing buildings. Post-occupancy data are invaluable in establishing confidence in innovation. A year-long monitored study was conducted to verify energy performance, assess occupant comfort and satisfaction with the indoor environment, and evaluate impacts on maintenance and operations. Lessons learned were derived from the analysis; these lessons could help identify and shape policy, financial, or supporting strategies to accelerate diffusion in the commercial building market.

Together with the Lawrence Berkeley National Laboratory (LBNL) and the Center for the Built Environment (CBE) at the University of California, the Times Company collaborated in 2011-2012 to conduct a monitored evaluation of three installed energy efficiency measures – dimmable lighting, automated interior roller shades, and an underfloor air distribution system (UFAD). The headquarters of The New York Times Corporation is a new, 52-story, 1.5 million gross square feet commercial office building located in Manhattan, New York, where floors 2 through 21 totaling 628,000 gross square feet have been fully occupied by the Times Company since July 2007. The post-occupancy study focused on evaluating a typical floor in the high-rise tower and relied on several sources of information:

- operational characteristics data for the automated shading system, dimmable lighting system, and under floor air distribution system;
- occupant survey data including ratings of satisfaction to posed questions and written comments;
- energy use data derived directly from measurements (lighting) or from a calibrated EnergyPlus model (HVAC); and
- cost data derived from the manufacturer and from experts in the field.

Energy use and peak demand savings

- Annual monitored lighting energy use savings due to dimmable lighting control strategies (setpoint tuning and daylighting) were 3.94 kWh/ ft^2-yr (56%) compared to the ASHRAE 90.1-2001 compliant system with an installed lighting power density of 1.3 W/ft^2 and scheduling and occupancy controls implemented with on-off relay switching. Annual lighting energy use was 3.15 kWh/ft^2-yr on average for the daylit zones of the 6th, 11th, and 20th floors of the tower.
- Annual total electricity use savings from all three measures combined for a typical tower floor were 2.58 kWh/ft^2-yr (24% reduction from the code compliant base case). Total heating energy was reduced by 1.36 kBtu/ft^2-yr (51%). Total site and source energy use intensity for heating,

cooling, ventilation, lighting, and equipment end uses for the Times Building was 29 kBtu/ft^2-yr and 94 kBtu/ft^2-yr, respectively, assuming a site-to-source conversion factor of 3.34 for electricity and 1.05 for natural gas. The Times Company energy use was simulated using a calibrated EnergyPlus model. Monitored lighting and plug energy use were input via schedules and monitored data were used to calibrate the AHU and UFAD models in EnergyPlus. The 90.1-2001 compliant model had an overhead VAV system, smaller windows, no exterior fixed attached shading, and scheduled lighting.

- Total peak electric demand was reduced from 3.73 to 2.65 W/ft^2 for a savings of 1.08 W/ft^2 (22%) on a peak day in July and by 21-25% during summer months from June through September. Lighting electric peak demand reductions were an average of 0.49 W/ft^2 during summer months.

Occupant satisfaction and comfort

- Surveys were issued to all employees in 2010 in an independent study, where 665 responses were received (35% of total). A more detailed analysis of this dataset was conducted to determine causes of occupant responses in this study.
- Satisfaction with overall lighting quality in the workspace and the belief that lighting quality enhances the occupants' ability to get their job done were significantly correlated to overall satisfaction with the building. 78% of the occupants were satisfied with the overall quality of the lighting in their workspace (average rating was 5.53). 61% of occupants believed that the new building enhanced their ability to get their job done (average rating for all floors was 5.02, where 4 is "neutral").
- 57% of the occupants responded with greater than neutral satisfaction with the automatic lighting controls (occupancy sensors, dimming in response to daylight conditions). The average rating was 4.77 on a 7-point scale.
- 41% of the occupants responded with greater than neutral satisfaction with the automatic window shades, with an average rating on all 20 floors of 4.12 on a 7-point scale.
- 66% were satisfied with the visual comfort of the lighting (average was 5.00, source could be from the window or overhead lighting).
- Manual override of the automated shading system occurred infrequently for the majority of the occupants located on all floors: for the motor groups that were overridden at least once, 80% of these motors were overridden an average of 18 times per year (1.5% of the year) for an average total time of 38 hours per year during primary work hours. The remaining 20% were overridden more frequently, on average 29% of the year. Of all actions taken, 70% were to lower the shade. Primary reasons cited were to lower the shade to reduce sunlight (42%) while the second most cited reason was to raise the shade to maximize view (25%).
- 206 out of the 318 comments (65% of the total comments, 31% of all survey participants) were related to visual discomfort due to window shade operation. The most common concern with the

window shades was that they failed to control glare. The Times Company is currently working with the manufacturer to implement upgrades to the control system to account for reflected glare from nearby buildings, particularly since several new buildings were constructed after occupancy and initial shade commissioning.

- 46% of the occupants responded with greater than neutral satisfaction with the temperature in their workspace, with an average rating on all 20 floors of 4.06 on a 7 point scale. 68% of the occupants responded with greater than neutral satisfaction with the humidity level in their workspace, with an average rating on all 20 floors of 5.26 on a 7 point scale.
- Temperature measurements in the interior zone indicate that a reasonable amount of air stratification was achieved in the occupied zone (2-3°F difference between standing head height (67 in.) and ankle height (4 in.)).

Return on investment

- Assuming the time-of-use rates schedule for the New York area, and an added installed cost of \$2.12/ft^2 for dimmable lighting, energy savings due to setpoint tuning and daylight dimming yielded a simple payback of 4.1 years and an internal rate of return (IRR) of 25%.
- For all three measures combined, a simple payback of 8 years and IRR of 12% was calculated, assuming an added installed cost of \$1.39/ft^2 for shading and \$3.50/ft^2 for the UFAD raised floor, \$0.19/kWh, \$1.20/therm, a life of 30 years for all measures, and a discount rate of 6%.

Lessons learned

- This study confirms that office buildings in an urban environment can deliver measured energy performance that substantially beats a similar code compliant building by using a combination of smart design, efficient technology and properly integrated building systems, with a process that starts in design and continues through to construction and commissioning, and into operations.
- The key lesson for replicating the success of this building on a large scale is that the required technologies and systems solutions are largely available, but there are gaps in the traditional design-construct-operate sequence that slow widespread implementation. It is essential to start with a sound, integrated building design, and then to pay attention to details such as procurement of building equipment, and verifying the proper performance of the equipment after it is installed. The Times Company did its homework in 2004 well before construction began on the building, evaluating and optimizing the shading and daylighting technologies in a 4500 ft^2 full-scale mockup to anticipate the challenges of installation in the actual building. Data from this study, coupled with improved design tools and evolving building systems, will allow designers to capture these performance benefits in future projects without the use of such sophisticated studies or mockups. The building owners also dedicated the time to verify that the systems were properly

commissioned prior to move-in, provided educational materials to the occupants, and then followed through in the initial period of occupancy to troubleshoot and fine-tune operations.

- Motivated and committed building owners and facility managers will always be an essential element to capture persistent measured savings in an energy efficient, occupant friendly building. We believe the measured results from the Times Building post occupancy study, the tools and processes developed and demonstrated, and continuous improvements in the performance and cost of the systems studied suggest that these savings are scalable and replicable in a wide range of commercial buildings nationwide.

A post-occupancy monitored evaluation of the dimmable lighting, automated shading, and underfloor air distribution system in The New York Times Building

Eleanor S. Lee, Luis L. Fernandes, Brian Coffey, Andrew McNeil, Robert Clear
Building Technology and Urban Systems Department, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, Mailstop 90-3111, 1 Cyclotron Road, Berkeley, CA 94720

Tom Webster, Fred Bauman, Darryl Dickerhoff, David Heinzerling, Tyler Hoyt
Center for the Built Environment, University of California, Berkeley, CA 94720

1. Introduction

1.1. Overview

With aggressive goals to reduce national energy use and carbon emissions, the US Department of Energy will be looking to exemplary buildings that have already invested in new approaches to achieving the energy performance goals now needed at a national level. One such project that has attracted attention nationally is The New York Times Building in New York, New York, which incorporates a series of innovative technologies, systems and processes. Some of these innovations can become a model and prototype for larger scale implementation and replication in new and existing buildings, but it is critical first, to fully document the measured energy performance of the innovations employed, and second, to explicitly address the process and technical challenges of scalable replication in new construction and adaptation to retrofit the nation's existing building stock.

Innovative building systems are rarely evaluated after occupancy due to lack of resources, lack of interest on the part of the owner, or concerns regarding inconvenience to the occupants, impositions on privacy, or liability or defamation of the owner's or architect and engineer's reputation. On-going real time measurement and feedback on energy use and occupant satisfaction as part of building operations is not yet standard practice. And yet, post-occupancy data are invaluable to the building industry, providing factual, non-anecdotal feedback on whether innovative systems work as claimed: delivering energy and demand savings to the degree predicted, meeting occupant requirements, and running smoothly under facility management. Without well documented performance data, opportunities to maximize the impact of the lessons learned are lost.

There is a growing global effort to document and make available to the public the energy performance of buildings. This is a requirement for all buildings in Europe, now being implemented in New York City and several other cities, and is now required in California at the time of lease or sale as of 2013. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) announced they intend to develop a labeling and certification program in the US as well. The US Green Building Council's Leadership in Energy and Environmental Design (LEED) is developing requirements to verify and report building performance after occupancy. All of these efforts are directed towards making building performance more transparent to end users of buildings. Unfortunately, accurately measuring and interpreting building energy performance at a level that encourages others to invest in innovative systems, e.g., dimmable lighting, is not yet standard practice or easily implemented.

A New York State Energy Research and Development Authority (NYSERDA) R&D investment with substantial cost share from The New York Times Company, the US Department of Energy (DOE), and the California Energy Commission Public Interest Energy Research (CEC PIER) program made possible the research needed to realize a set of efficiency features in the Times Building during its design and construction from 2003 to 2006. Throughout that design development process leading to occupancy in 2007 the Times Company staff shared design concepts, testbed results, and commissioning processes widely in the New York community in a manner that has already impacted several other buildings. To further assist in promoting the benefits of energy efficient strategies, in 2011 the Times Company agreed to participate in a post-occupancy evaluation as a partner in the US Department of Energy's Commercial Building Partnership program.

Given the world-wide publicity on the Times Building and the increased interest in innovative solutions for addressing energy-efficiency, greenhouse gas emissions, and sustainability goals, there is tremendous interest within the building community to better understand quantified performance outcomes of each of the major innovative measures used in the Times Building. Without that knowledge, the risk-averse nature of the buildings industry will limit the scope and speed at which potential national impacts might be obtained.

1.2. Purpose of this document

Together with the Lawrence Berkeley National Laboratory (LBNL) and the Center for the Built Environment (CBE) at the University of California, the Times Company has collaborated to conduct a monitored evaluation of three installed energy efficiency measures – dimmable lighting, automated interior roller shades, and an underfloor air distribution system (UFAD).

The headquarters of The New York Times Company is a new, 52-story, 1.5 million gross square feet commercial office building located in Manhattan, New York, where floors 2 through 21 totaling 628,000 gross square feet have been fully occupied by the Times Company since July 2007 (Figure 1). The Times Company incorporated innovative energy efficiency measures (EEMs) that were designed to create a high quality, comfortable workplace environment for their employees while minimizing energy use, demands on the utility grid, and greenhouse gas emissions. Summary data from this study are given in Table 1.

This document provides an analysis of the energy consumption and level of occupant satisfaction that were achieved in the final occupied building. A typical Times Company floor of the 52-story tower was monitored in detail in order to determine lighting energy use, UFAD operations, and other loads within the open plan office zones. A detailed, calibrated EnergyPlus building energy simulation model was then developed in order to derive annual total energy use. Occupant surveys were issued to evaluate user satisfaction with the workplace environment. The facility managers were interviewed to understand how maintenance and operations were affected by the systems. Over the course of this evaluation, the Times Company has deepened their understanding of how the installed energy efficiency measures performed while the project team has learned lessons that can be shared with the broader industry.

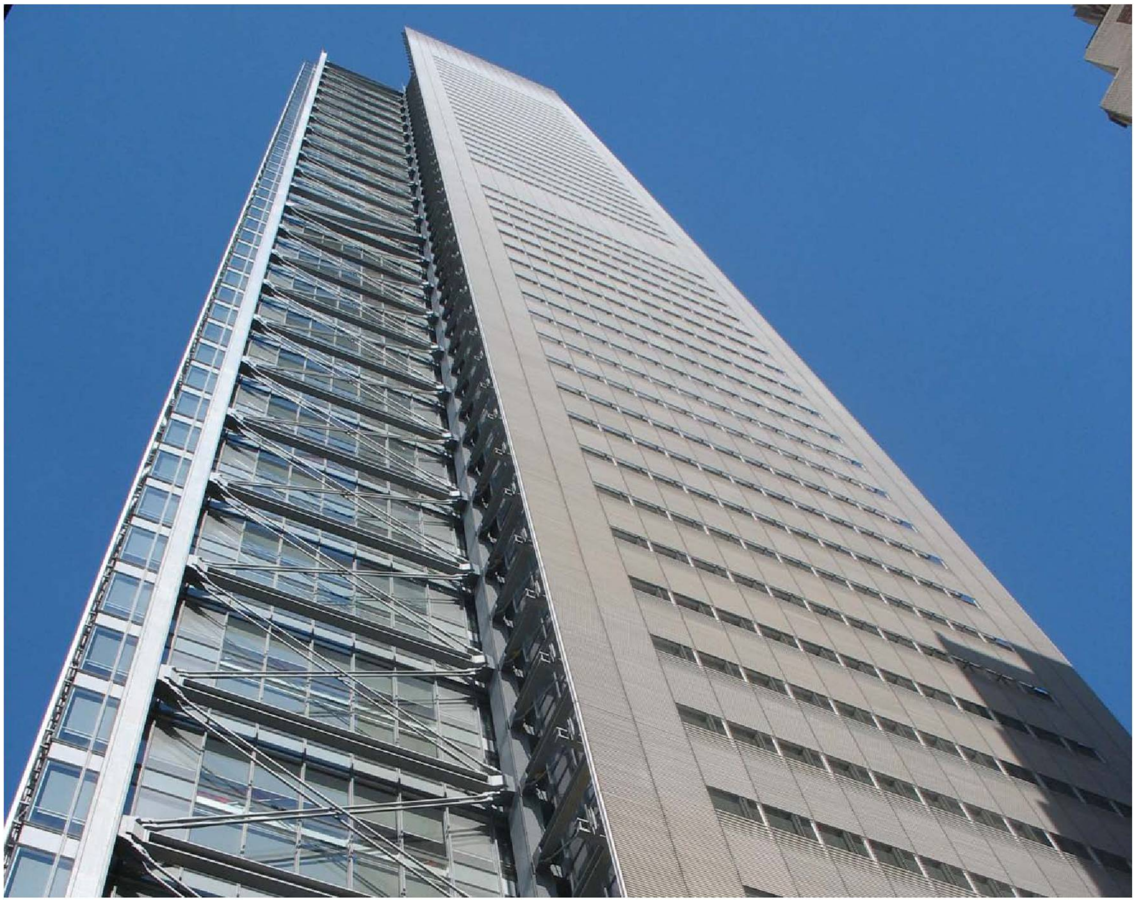


Figure 1. Exterior of the tower portion of the Times Building. Copyright: The Times Company.

Table 1. Summary statistics

Project	Offices
Climate Zone and Type	ASHRAE Zone 4A, hot and cold and humid
Ownership Type	Owner Occupied
Barriers Addressed	Integrated design practices Dimmable electronic ballasts and daylighting Automated interior shading Underfloor air distribution system
Gross Square Footage of Project	25,784 ft^2 (20th floor); 628,000 ft^2 (The Times Company portion of the building)
Monitored Energy Savings – 20th floor (vs ASHRAE 90.1-2001 baseline)	66,623 kWh/yr electricity 35,120 kBtu/yr natural gas
Energy Cost Savings – 20th floor	$13,081/yr
Project Payback	8 years, IRR 12%

Assuming $0.19/kWh and $1.20/therm

2. On the benefits of designing buildings as integrated whole building systems

Achieving a high level of building performance is the result of careful, informed design and execution so that building subsystems – the building envelope, lighting system, and space conditioning systems – work together synergistically to achieve an acceptable, energy-efficient, and comfortable indoor environment.

A simple example of this concept is a conventional façade designed to only minimize heat gains as dictated by the energy efficiency code. This may at first glance reduce the HVAC energy use in a commercial building, but may also result in a lost opportunity to enhance daylighting. Daylighting not only reduces electric lighting demand but can also improve the quality of the indoor environment. With reduced use of electric lighting, heat gains are reduced, further reducing HVAC demands. HVAC capacity is typically based on peak load conditions, so simultaneous reduction of both window and lighting heat gains, when mid-day summer solar radiation and outdoor temperatures tend to be at their highest levels, can also reduce the capital costs of the central plant. Demands on the utility grid can be reduced, which is particularly important in urban areas like New York City where capacity is limited.

As the US makes progress towards meeting ambitious greenhouse gas emission and energy use reduction goals, architects and engineers will need to rely increasingly on design and engineering strategies that maximize building performance while minimizing energy use and peak demand. Systems integration is a key strategy, enabling us to meet these goals. The concept of integration is not new, but it wasn't until recently that we were able to begin to see the full realization of this concept, enabled by low cost, digitally addressable, reconfigurable, and dynamic components supported by powerful software that facilitates diagnostics and fine-tuning of the systems over the life of the building. Combinations of static, efficient technologies can go a long way toward achieving aggressive energy efficiency goals. Combinations of dynamic, efficient technologies can provide the added benefit of further optimization on a seasonal or even minute-to-minute basis in response to weather, occupant demands, or regional grid demands.

Facile reconfiguration of systems is particularly important for buildings with high churn rates where speed and cost is of utmost importance or for owners with a vested interest in providing comfortable and productive indoor environments that are tailored to their occupants. An underfloor air distribution system with its raised floor access system enables cost efficient reconfiguration of air diffusers and power, voice, and data outlets. Digitally addressable lighting can be reconfigured at the touch of a button when a new work group moves in with different lighting preferences. The initial investment into dynamic systems may pay off in the long term due to both reduced energy costs and long-term operating costs.

3. How did the Times Company make it happen?

One cannot argue that the realization of such optimized solutions is routine, even today. When the Times Company embarked on their journey to explore use of these systems in their new building, digital systems were only starting to emerge on the market and use of dynamic components was certainly a significant risk with many unknowns. But the Times Company invested time to learn about the systems, test and witness them in a full scale 4318 ft^2 outdoor mock-up of the southwest corner of their new building prior to purchase to understand their limitations and feasibility (Figure 2), and then followed through from design through commissioning and operations to ensure that initial intentions were realized in the final occupied building. The Times Company received significant in-kind assistance in the investigation of the shading and lighting options. As mentioned above, NYSERDA, DOE and CEC PIER provided direct funds to LBNL to support third-party field testing of these measures prior to purchase. This work is documented in [1,2].

Figure 2. College Point Mockup, Queens, New York. Copyright: David Joseph.

The Times Company took calculated risks, made the largest direct procurement of innovative lighting and shading technologies in the US, shared knowledge with the buildings industry by making their procurement specifications and commissioning tools available to all, which has since led to significant investments in the industry and major improvements to product offerings. Instead of working with their subcontractors with a punitive mindset of "What can you do for me?", the Times Company maintained an open collaborative attitude of "What can we do together?" throughout the entire design and construction process. The result is arguably a building that not only is more energy efficient and easier to reconfigure, but is also a place where people can work with a greater sense of amenity and comfort, the ultimate goal of the Times Company.

The added cost of the innovative systems was a critical issue in the decision making process. Like all building owners, the Times Company was constrained to a fixed capital budget for construction but because occupancy was for the long-term, they were willing to make the investments. Innovative systems often cost more when first introduced to the market because the manufacturer must recover large initial capital investments to design and produce new products. As the market matures, the cost of the system is usually reduced significantly, particularly as competitive products emerge on the market. As an early adopter, the Times Company was able to purchase the systems at a near mature market rate not only because of the sheer volume of the purchase but also because they took the time to understand the incremental differences between the innovative and conventional products then independently determine the added costs associated with those differences. As an informed consumer, the Times Company was able to negotiate more effectively with vendors in their competitive bid process. At the time, USGBC LEED certification was not part of the Times Company's decisionmaking criteria.

Construction costs in New York City are heavily influenced by labor costs. To reduce costs, the Times Company tasked their architectural and engineering (A/E) teams to design the systems to minimize labor in the field. Lighting fixtures were designed to be placed end to end so that power and communications cabling could be integrated as part of the fixture, then installed in the field using simple quick connectors. Sensors could be installed in a standard pre-wired port located on each fixture. Fixtures were shipped with lamps and ballasts already in place. When the Times Company requested bids for installing the automated shading system, they prepared full-scale layouts of the hardware in diagrammatic form showing how the various components of the system should be wired together, then conducted a mandatory pre-bid meeting at the full-scale outdoor mockup building to demonstrate how the system would need to be wired and installed. By demystifying the unknowns of a new technology, the Times Company was able to avoid the conservative bids that usually accompany the installation of "innovative" technologies.

To avoid the added cost and inconvenience of trying to fix systems that didn't work properly after the space was occupied, the Times Company included provisions in their procurement specification that the systems be commissioned by the vendor and proven to perform per the specifications prior to final sign-off and payment. After selection of the vendors, the final shading and lighting systems were field tested by LBNL in the full-scale building mockup for six months to work out any remaining feasibility issues and to verify system performance before installation in the final building. LBNL also designed and built commissioning tools and protocols for their use so that the Times Company could verify shading and lighting system performance in the final building (Figure 3). CBE was commissioned to build a measurement system to verify UFAD operations. The Times Company used these tools to conduct systematic checks as the systems were installed on a floor-by-floor basis in the final building, providing the vendors with non-compliant items that were to be addressed by the following weekly meeting. In the final sign-off, the vendors were required to provide training on all the systems' features so that the building could be operated without continued dependence on the vendor for day-to-day operations. The specifications also required that status data be logged and stored on a database maintained by the Times Company to facilitate diagnostics on all systems. As-built drawings were also required for all systems once the job was complete.

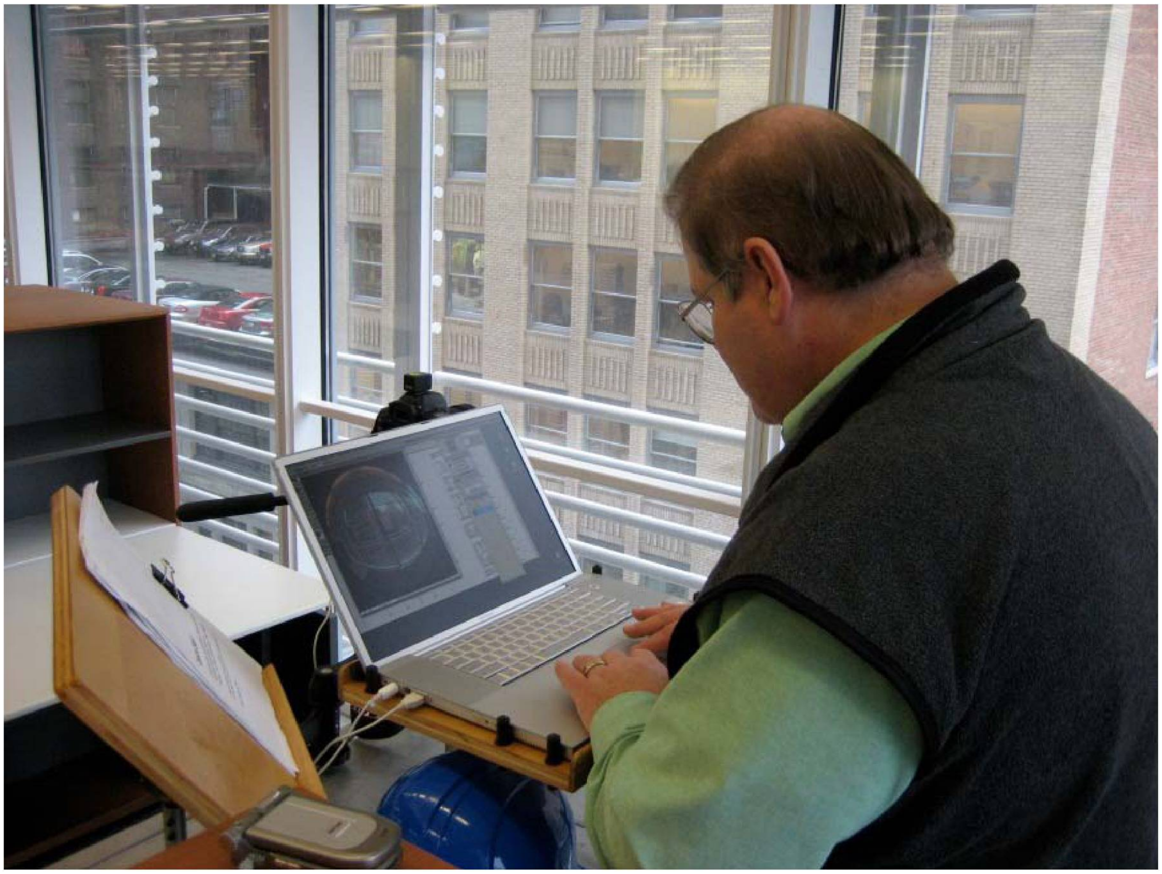


Figure 3. Commissioning cart for the automated shading system being used in the Times Building. Copyright: LBNL.

4. How did the innovative systems really perform?

In this section, we provide a summary of the findings from the post-occupancy monitored study conducted in the Times Building in 2011-2012. The energy performance of the lighting system was monitored directly using sensors on the circuit panels supplemented with control status data from the manufacturer to determine the strategy in effect at the time. Automated operation of the interior motorized roller shade was logged by the manufacturer. HVAC energy use was determined by combining a series of measurements and operations data with a calibrated EnergyPlus model. HVAC energy savings are therefore presented as an aggregated value not broken down by energy efficiency measure since all three EEMs worked together to produce the resultant thermal environment and therefore HVAC energy use in the zone. Total annual energy use was compared to a baseline defined by the mandatory and prescriptive code in effect at the time of design: ASHRAE 90.1-2001 [3].

The Times Building is a high-rise building located at the intersection of 8th Avenue and West 41st Street, a block southwest of Times Square in Manhattan. The building is set amongst a fairly dense urban environment with high-rise buildings immediately to the north, east and south, but relatively clear toward the west with the low-rise Port Authority building and views to the Hudson River. Data were monitored on the 20th floor of the high-rise tower portion of the building where occupants performed office computer-based tasks over a typical eight-hour day. The cruciform floor plate of the tower enables all occupants to have views out through three segments of the façade. Obstructions are minimal across the floor plate: open plan work settings with low height partitions (4 ft) are located near the windows while private offices are located near the core (Figure 4).

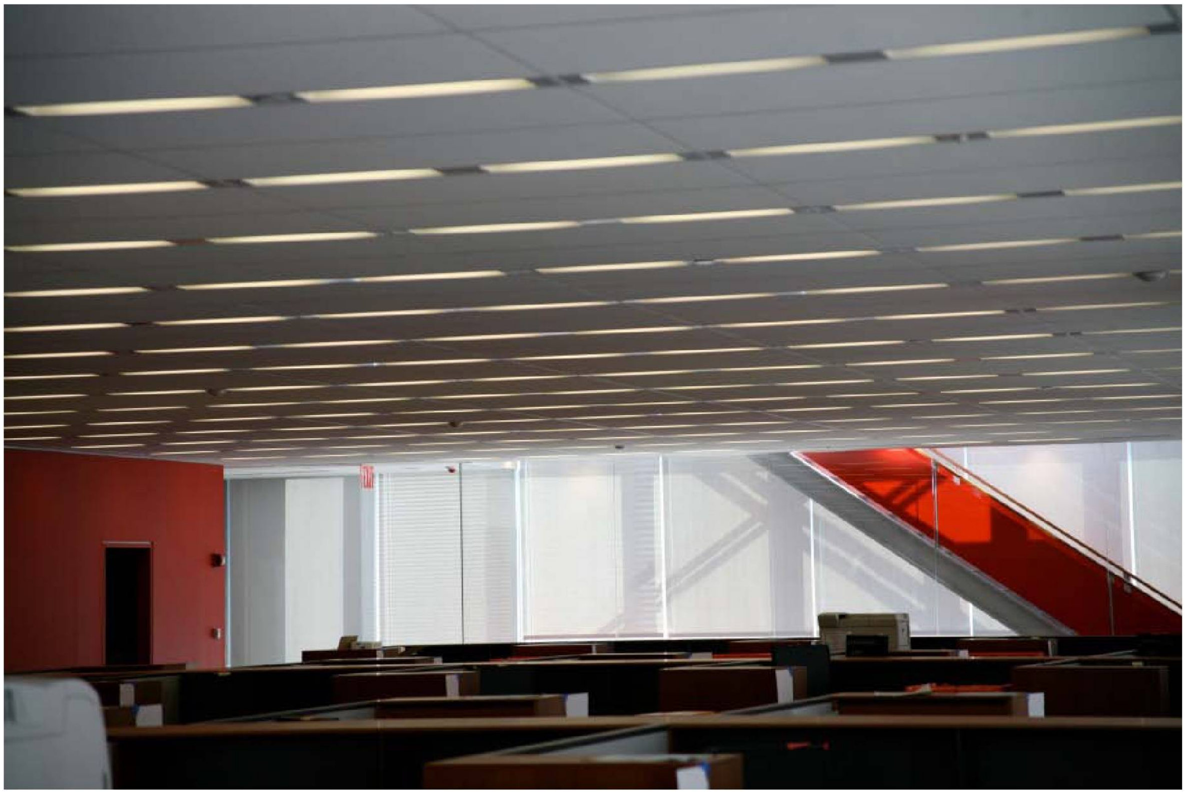


Figure 4. View across the open plan work areas toward the facade. Private offices are located at the core (off the left hand side of the image). Copyright: LBNL.

The façade consists of floor-to-ceiling, clear, double-pane low-emittance windows shaded for the most part by a vertical plane of irregularly spaced, exterior, horizontal, ceramic tubes set off 18 inches from the face of the windows. A horizontal section of this scrim was left open so that occupants could have unobstructed views out when sitting or standing (Figure 5). The ceiling height at the window wall was set at 10.3 ft to allow for greater daylight admission then stepped down to 9.58 ft high after a setback of 3.5 ft from the window. Interior, motorized roller shades are automated so that direct sun is allowed to penetrate only a user-defined distance from the window, glare is minimized, and daylight is admitted within the constraints of glare control. The electric lighting system is dimmed or shut off in response to occupancy, setpoint tuning, and available daylight. Because direct sunlight penetration and lighting loads are being actively managed, the UFAD system is tasked with providing a comfortable environment within a deep perimeter zone where a comparatively modest variation in loads occurs over the course of the day. Occupants are served by floor diffusers located in each work station and are able to adjust air volume.

The following sub-sections describe the intent behind each of the three systems in more detail and then provide an analysis of performance. A discussion follows thereafter in Section 5 on the lessons learned that may enable successful implementations in other buildings.

Figure 5. The view section of the window wall is the open portion between the upper and lower exterior shading elements (photo from the daylighting mockup at College Point, New York). Copyright: LBNL.

4.1. Lighting System

4.1.1. The challenge and the Times Company solution

In 2010, primary source electric lighting energy use was 3.2 Quads (Btu x 10^{15}) or 17% of the total energy use attributable to US commercial buildings [4]. In typical US commercial office buildings [5], lighting energy use intensity is 6.77 kWh/ft^2-yr, representing 25% of total building energy use. Indoor lighting is a significant fraction of this energy use and much of this can be reduced using a combination of strategies, including efficient hardware, automated controls, and informed space design.

Automated dimmable lighting has been commercially available for over two decades, but the analog ballast made it difficult to cost-effectively commission and reconfigure lighting zones over the life of the installation. Electronic, digital-addressable dimming ballasts were a relatively new, unproven technology in the mid-2000s when the Times Building lighting installation was specified. To address the risk and uncertainty of this innovation, a detailed monitored evaluation of the lighting system was conducted in a full-scale outdoor mockup, after which the Times Company issued a procurement specification for dimmable lighting to be installed throughout the Times Company floors in the building [1].

The final system was designed to meet the maximum installed lighting power density (LPD) specified by the ASHRAE 90.1-2001 code: 1.3 W/ft^2 with the intent to consume less through dimming strategies. Lighting equipment consisted of custom, 6-inch by 5 ft long ceiling-recessed fixtures with two 14 W T5 lamps per fixture and a digital electronic ballast. Dimming control enabled a light output range of 10-100% with a power range of 35-100%. Standby power use was 3% of full power when the lights were shut off. At full power, the desk or work plane illuminance was measured to be between 45 and 52 fc. Each fixture was digitally addressable and the manufacturer commissioned and zoned the fixtures to best suit the functions of the lighting control strategies. The Times Company and the 90.1-2001 baseline conditions are summarized in Table 2.

The automatic controls enabled three strategies to be implemented in the open plan areas:

a) Occupancy-based control turned off light fixtures after an 8 minute delay (there were a total of 26 ultrasonic/ passive infrared sensors in 14 open plan zones (typically 30x40 ft in size) on a typical floor in the tower portion of the building);
b) setpoint tuning was enabled via dimmable electronic ballasts, where the Times Building Operations Department defined the setpoint level (30 fc for all zones except for one small work group who preferred a lower setpoint level); and,
c) photosensor-based daylight dimming was enabled via one ceiling mounted photosensor for each of the 14 open plan zones, with the daylight setpoint matching the setpoint tuning level of 30 fc; the

14 open plan zones were further subdivided into daylight zones (typically by row(s) of lighting fixtures from the windows); lights were dimmed in proportion to available daylight and turned off if there was sufficient daylight in the daylit zone to fully meet the setpoint illuminance level.

Energy use data in this section focuses on the ambient lighting in the open plan work areas and does not include lighting in the private offices or support areas, nor personal task lamps on desks or accent lighting.

Table 2. Definition of Lighting System in Open Plan Office Zones

ASHRAE 90.1-2001	
Lighting power density	1.3 W/ft^2
Work plane illuminance at full power	45 to 52 fc
Scheduling (automatic shut off)	
Weekdays	1:00 AM to 6:00 AM
Weekends and Holidays	Off
Occupancy	
If occupied after scheduled hours, lights were turned on via relay to full power.	

The Times Company	
Lighting power density	1.3 W/ft^2
(2) 14 W T5 lamps per fixture	
1 DALI digital ballast per fixture	
Light output range	10-100%
Power output range	35-100%
Standby power when off	3% of full power
Occupancy sensors	
Open plan zones: 30 ft x 40 ft deep typical	
Passive infrared, ultrasonic sensors	
8-minute delay before shut off	
Setpoint tuning	30 fc
Daylight dimming	30 fc setpoint
Open plan zones: 30 ft x 40 ft deep typical with subdivided daylight zones	
1 photosensor per zone	
Each fixture dimmed to appropriate dimming level	

4.1.2. What were the energy savings?

Lighting energy use was monitored by LBNL using sensors that enabled an accurate measurement to within 1% of reading – sensors were placed directly via the main circuit panels for a year, while the lighting control modes were determined from energy management control system (EMCS) data provided by the manufacturer (Figure 6). Since the EMCS data were more comprehensive, the monitored power data were correlated to EMCS data in order to determine energy use on alternate floors and for different time periods and to independently verify the data from the manufacturer. The EMCS data were available for only the open plan zones ranging in depth from 20 to 40 feet from the window; characterizing energy use as a function of daylight zone or depth from the window wall was not feasible.

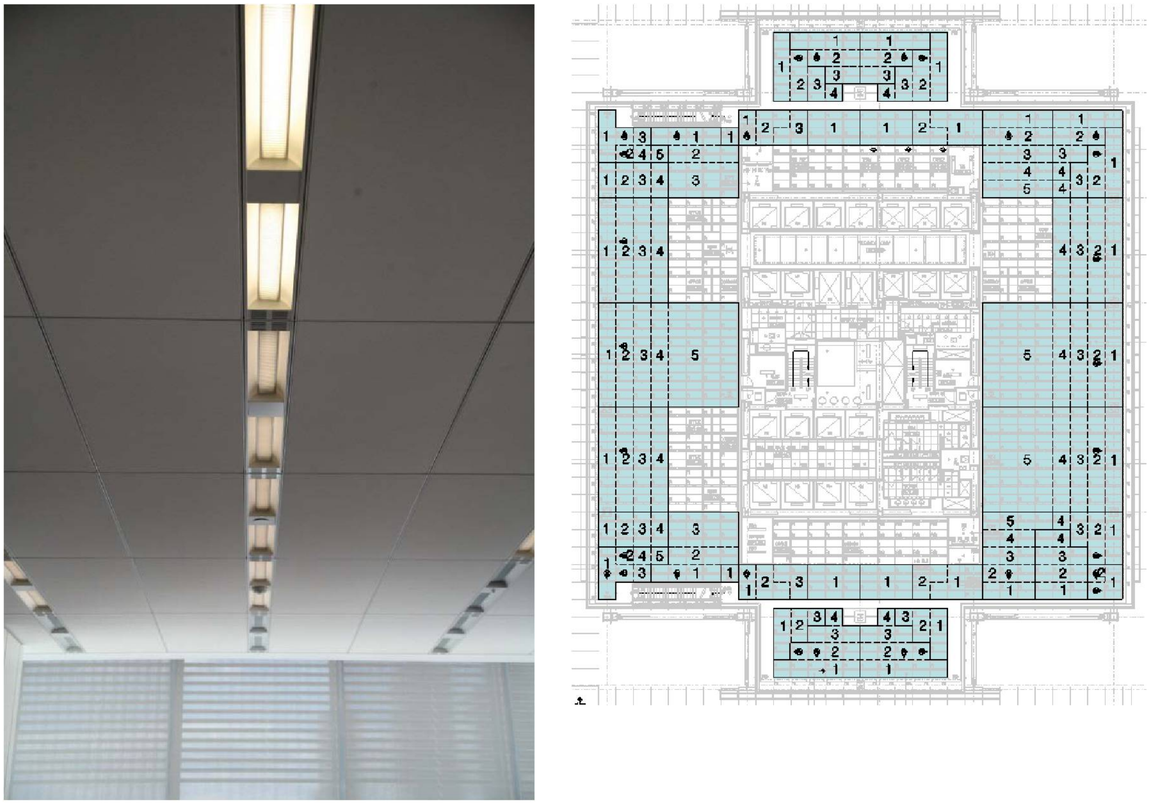


Figure 6. Left: Dimmable lighting fixtures in the open plan zone where the fixtures closest to the window are automatically dimmed or off and the ones farthest from the window are near or at full power output. Note that shades are lowered in this image. Right: Floor plan showing the daylight zones (shaded in blue) on the 20th floor that were evaluated in this analysis (ignore numbered labels on the zones). Layouts for the 6th and 11th were similar to the 20th floor. Data for the three floors were averaged. Copyright: LBNL (photo), The Times Company (diagram).

Energy savings for the daylit open plan zones of the 6th, 11th, and 20th floors of the tower were calculated relative to the ASHRAE 90.1-2001 prescriptive standard, which mandates a maximum of 1.3 W/ft^2 installed lighting power density and time-based, scheduled controls at minimum. All three floors had similar layouts and hours of occupancy. The Times Company indicated that if they had put in time-based controls, they would have set the weekday schedule to turn the lights off from 1:00 AM to 6:00 AM. The primary hours of occupancy were between 8:00 AM to 6:00 PM with the evening hours scheduled for the cleaning crew. On weekends and holidays, lighting was scheduled to be off. The 90.1-2001 baseline energy use was calculated based on this schedule but if occupancy did occur during non-scheduled hours (e.g., occupant or facility manager turns on the lights through the circuit panel or centralized control system), this lighting energy use was included in the total.

For this analysis, savings were calculated based on the assumption that most purchasing decisions are made based on the least cost option and shortest payback of energy cost. Since on-off ballasts are lower in cost than dimmable ballasts, the incremental savings of implementing occupancy sensor based controls using on-off ballasts over time-clock scheduling were determined first (Figure 7). Setpoint tuning and daylight dimming are best achieved using dimmable ballasts, so the incremental savings of implementing these two strategies compared to scheduling and occupancy based control were determined thereafter. Setpoint tuning can be achieved via bi-level switching or delamping but this type of control was inappropriate for the open plan office areas. Standby power use when the system was off was added to the total energy use for dimming controls, since dimming ballasts consume a small amount of energy when off, while on-off ballasts use zero energy when off.

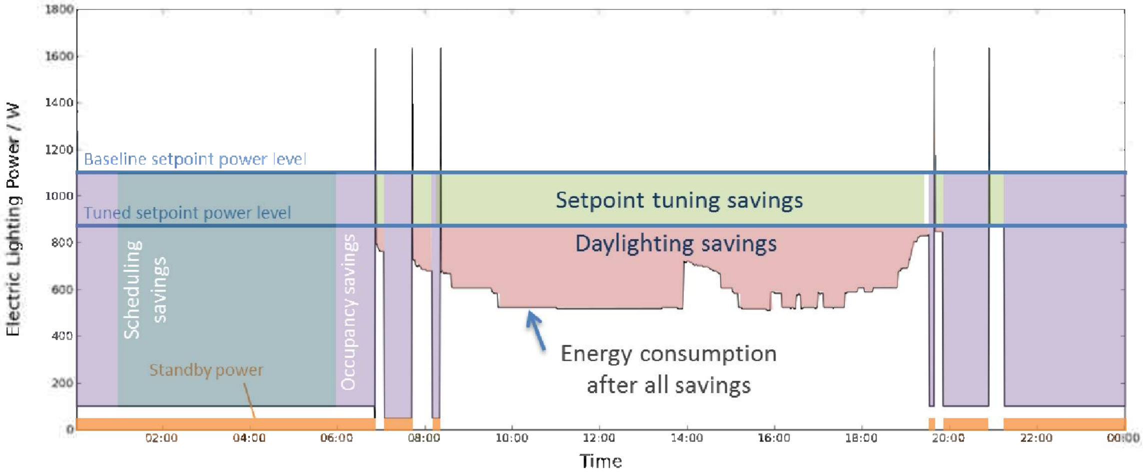


Figure 7. Example of how lighting energy use savings are attributed to each control strategy over a 24 h day. Control strategies include scheduling, occupancy, setpoint tuning, and daylighting. Copyright: LBNL.

With the installed base load of 1.3 W/ft^2, annual lighting energy use would be 11.4 kWh/ft^2-yr if there were no controls to turn off the lights year round (Table 3, Figure 8). With scheduling, lighting energy use was reduced to 7.09 kWh/ft^2-yr (38% savings). This is the energy use that would result when complying with the ASHRAE 90.1-2001 Standard. With scheduling and detailed occupancy sensing in the 30x40 ft open plan zones, lighting energy use was reduced to 5.11 kWh/ft^2-yr (55% savings compared to no controls). Lighting was further reduced to 3.15 kWh/ft^2-yr (72% savings) with setpoint tuning and daylight dimming. These values represent average savings computed for the daylit zones of the 6th, 11th and 20th floors of the tower for the period from June 21, 2010 to June 20, 2011. A more detailed explanation of this analysis is provided in [6].

To summarize monitored results for the perimeter zone open plan work areas with depths of up to 40 feet:

- Annual lighting energy savings due to occupancy, setpoint tuning, and daylighting was 3.94 kWh/ft^2-yr or 56% compared to the ASHRAE 90.1-2001 Standard which mandates scheduled lighting controls.

- Annual lighting energy savings due to dimming controls (setpoint tuning and daylighting) was 1.96 kWh/ft^2-yr or 38% compared to the ASHRAE 90.1-2001 Standard with scheduling and detailed occupancy sensing in the open plan work areas.

Table 3. Annual lighting energy use savings between ASHRAE 90.1-2001 and the Times Company lighting control system

	Energy use (kWh/ft^2-yr)	Incremental savings (kWh/ft^2-yr)	Cumulative savings (kWh/ft^2-yr)	Cumulative percent savings
No controls (a)	11.4			
Scheduling (b) – ASHRAE 90.1-2001	7.09	4.31	4.31	38%
Scheduling + occupancy (c)	5.11	1.98	6.29	55%
Setpoint tuning + daylighting dimming (d)	3.15	1.96	8.25	72%

Average annual lighting energy use and savings for all open plan perimeter zones on the 6th, 11th, and 20th floors. Perimeter zones extended up to 40 ft deep from the window.

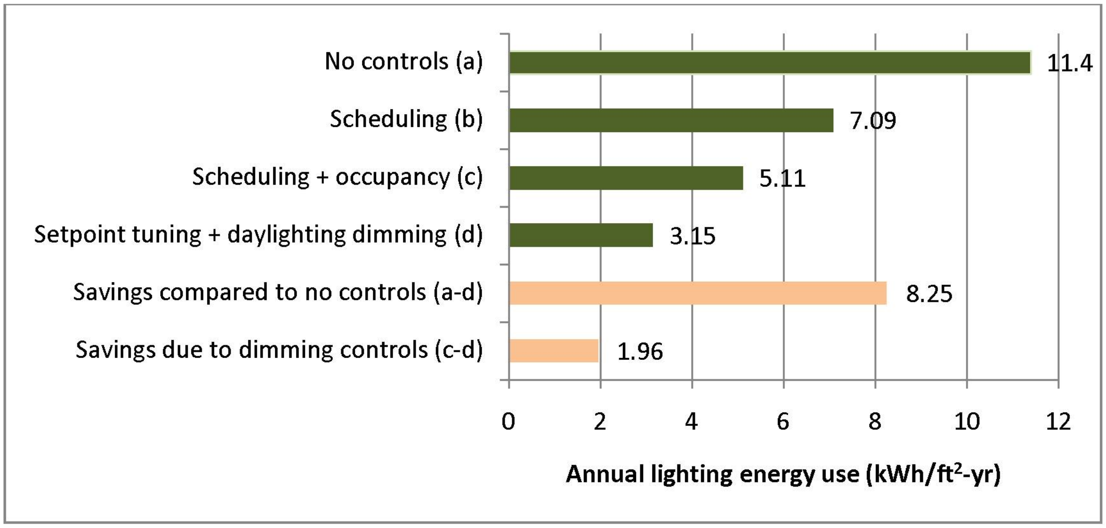


Figure 8. Diagram showing how energy use (green bars) and savings (orange bars) were attributed to the different control strategies.

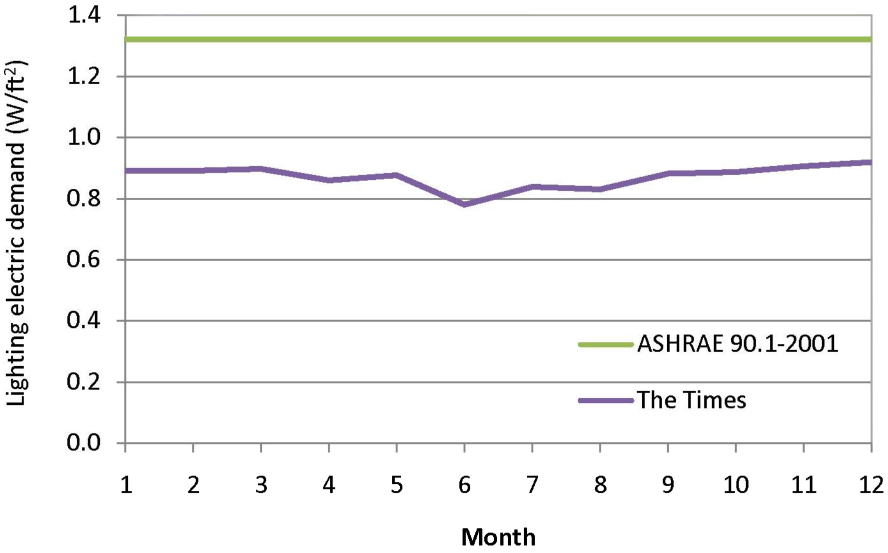


Figure 9. Peak lighting electric demand (W/ft^2) for the ASHRAE 90.1-2001 (scheduling) and the Times Building (scheduling, occupancy, setpoint tuning, and daylighting controls) cases.

Peak demand due to electric lighting was consistently lower due to the dimming controls. Demand was reduced by 30-41% throughout the year, with a maximum reduction of 0.54 W/ft^2 occurring in June (Figure 9). Peak demand was defined as the combined peak electricity demand in the daylit zones of the 6th, 11th and 20th floors of the tower between the hours of 8:00 AM and 6:00 PM. Because there was no control floor where the shades were manually operated, daylighting savings attributable to the automated roller shades could not be determined using monitored data. Savings did not vary significantly with window orientation or floor level. The automated shades caused daylight to be well managed irrespective of differences in daylight availability – for lower floors with greater urban obstructions, the shades were automatically raised more often and for upper floors with less urban obstructions, the shades were lowered more often to control sun and glare.

Adequate illuminance control has been a significant historical challenge with daylighting controls. With poorly commissioned systems, the lighting system would fail to reliably meet the setpoint illuminance level, resulting in occupant complaints. A monitored evaluation of this issue was addressed in the daylighting mockup prior to purchasing the system: the system was found to have achieved good reliability [1]. Evaluating this issue in the final building in the same manner was beyond the resources of the project. Instead, occupant surveys were used to assess lighting adequacy and quality (see Section 4.1.3 below).

The actual monitored electric lighting illuminance levels on the 20th floor were between 21 and 30 fc at night, with the specified setpoint level at 30 fc. About 25% of the workstations had a 9 W LED task lamp on their desk and when conducting a walk-through during daytime hours, we observed that 3% of the total workstations on the 20th floor had their task lamp turned on.

4.1.3. What did people think of the system?

A survey was developed and issued independent of this project by The Times and Sustainable Energy Partnerships (SEP), who was supported by NYSERDA, to determine the degree of occupant satisfaction with the energy-efficiency measures and indoor environmental quality of the new building [7]. The survey was issued in the summer of 2010 to 1911 full-time employees and 665 responses were received (35% of total). There were several questions related to the comfort and quality of the lighting and one question about the lighting control system itself (where 1 is "very dissatisfied", 4 is "neutral", and 7 is "very satisfied"). In addition, employees were invited to provide written comments. Later, LBNL was invited to conduct a detailed statistical analysis of this data to determine the potential causes of occupants' satisfaction or dissatisfaction with the systems and/or indoor environment [8].

- Satisfaction with overall lighting quality in the workspace and the belief that lighting quality enhances the occupants' ability to get their job done were significantly correlated to overall satisfaction with the building.
    - 78% of occupants were satisfied with the building overall (an average rating for all floors of 5.34).
    - 61% of occupants believed that the new building enhanced their ability to get their job done (average rating for all floors was 5.02).
- On a 7-point scale, 57% of the occupants responded with greater than neutral satisfaction with the automatic lighting controls (occupancy sensors, dimming in response to daylight conditions). The average rating was 4.77.
- 78% of the occupants were satisfied with the overall quality of the lighting in their workspace (average rating was 5.53, Figure 10).
- 66% were satisfied with the visual comfort of the lighting (average was 5.00, Figure 11).

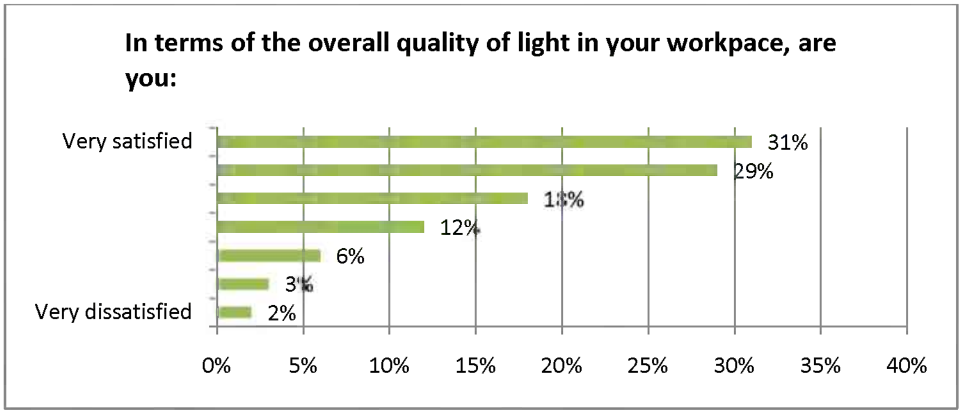


Figure 10. Subjective response to lighting quality

- When asked to identify the reasons why they were not satisfied with the overall quality of light, 285 occupants responded, where 45% indicated too much glare, 17% found the lighting too bright, and 13% found the lighting too dim. The survey did not allow the user to specify reasons based on the source of the lighting. "Lighting" could be from the overhead electric lighting and/or the window. The remaining occupants had other reasons for dissatisfaction, 2% of which were due to lighting control problems.

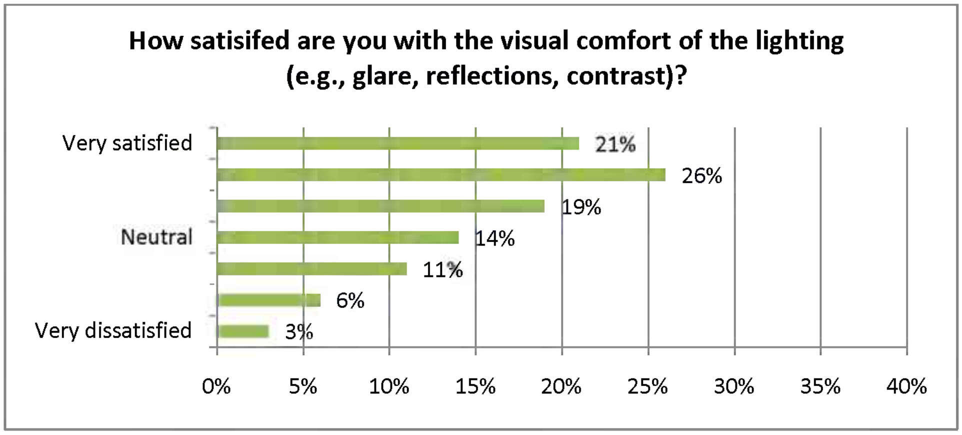


Figure 11. Subjective response to visual comfort.

- When asked to describe any issues related to visual comfort, 59 out of the total 318 specific complaints (19%) were due to electric lighting problems. The most common complaint with the electric lighting was with the occupancy controls (18 complaints), where the occupancy sensors failed to detect people or the lights were turned off too soon or not soon enough. Another cause of complaint was that the electric lighting did not respond well to changes in shade position (10 complaints), with 8 people complaining that it was too dim when the shades were down. Other complaints were on the quality of the electric lighting with the lighting being too bright or glaring (6), too dim (5), or poor (5). Five wanted tasks lights.

Survey results indicated that overall, a significant fraction of the occupants were satisfied with the automatic lighting controls and with the lighting quality and visual comfort resulting from the lighting system (as defined by both the electric lighting system and the window). There were relatively few complaints that could be directly attributed to the electric lighting system.

4.1.4. What were the cost savings?

An economic analysis was performed in order to determine how quickly the added cost of dimmable lighting controls could be offset by energy savings. Energy savings due to dimming were a result of setpoint tuning and daylighting and these savings were estimated to be 1.96 kWh/ft^2-yr on average for the daylit zones on the 6th, 11th and 20th floors of the tower. The following assumptions were made to estimate the incremental cost of dimmable lighting based on publicly available cost data for large-volume purchases [9]:

- dimmable, digitally addressable electronic ballasts at $25/unit more than an on-off ballast with 33 ballasts needed on average in a daylit zone on the 20th floor; there were a total of 468 ballasts for the 14 zones on the floor, where each 30x40 ft zone (without the private offices) was 836 ft^2;
- two photosensors at $50 each for each 836 ft^2 zone;
- installation, controls, networking, and commissioning at $1/ft^2.

The total incremental installed cost is therefore $2.12/ft^2 for a typical floor. Assuming average energy prices in the New York area [10] of $0.19/kWh, a life of 30 years for the dimmable lighting control system, and a discount rate of 6%, the energy savings of 1.96 kWh/ft^2-yr yielded a simple payback of 5.7 years, the net present value (NPV) was $3.01/ft^2 (or $5.13/ft^2 if the cost of the initial investment is included), and cost of conserved energy was $0.08/kWh. The internal rate of return was 17%. Results are summarized in Table 4.

In New York City, time-of-use rate schedules are imposed, charging significantly more for summer daytime on-peak demand than nighttime rates. The Times Company built an on-site co-generation plant, resulting in a negotiated rate schedule. For a more generalized payback, the Consolidated Edison rate schedule for large buildings (Category 9, Rate II) was used to determine energy costs for the period from June 21, 2010 to June 20, 2011. The simple payback was then 4.1years, the net present value was $5.04/ft^2 ($7.16/ft^2 including initial investment), cost of conserved energy was $0.06/kWh, and the IRR was 25%.

HVAC energy savings due to reduced heat gain from the lighting were not included in this analysis. These additional savings would further reduce the payback period. Dimming ballasts continue to improve minimum and standby power use. The dimming ballasts used at the Times Company had a minimum power of 35% and 3% of full power when the lights were "off" but since then, dimming ballasts have continued to improve on energy use performance, according to ballast manufacturers (the next generation ballast offered by the manufacturer had a minimum power of 17% with T5 lamps, as measured by LBNL). This economic analysis applies to the ambient lighting system in the open plan zones up to a depth of 40 ft from the windows.

Table 4. Economic analysis of the Times Company dimmable lighting controls

	Flat rate	Time-of-use rate
Expected savings (kWh/ft^2-yr)	1.96	1.96
Simple payback	5.7	4.1
Net present value (\$/ft^2)	\$3.01	\$5.04
Cost of conserved energy (\$/kWh)	\$0.08	\$0.06
Internal rate of return	17%	25%

Notes: Incremental installed cost \$2.12/ft^2 for a 30x40 ft perimeter zone, 30 year life, discount rate 6%. Flat rate: \$0.19/kWh; TOU: Category 9, Rate II. HVAC energy use reductions due to reduced heat gains from lighting and potential HVAC capacity reductions were not included in this analysis. The net present value is the net profit and does not include the cost of the initial investment.
*Cost of conserved energy should be less than or equal to the local utility rate (i.e., \$0.19/kWh).

For purchases made in today's context, the ASHRAE 90.1-2010 prescriptive code would define the baseline as follows: a maximum LPD of 0.98 W/ft^2 is permitted for open plan office zones, time-clock scheduling is required, and daylighting controls are also required for the zone immediately adjacent to the window (where zone depth is defined by the head height of the window) using at minimum a bi-level, automatically switched system.

Two questions arise: a) is dimmable lighting in the first 10 ft from the window economically viable?, and b) is dimmable lighting in the remainder of the space economically viable? Monitored energy use data were not available as a function of distance from window so we are unable to determine economic payback for the first scenario. However, we do know from detailed measurements at the daylighting mockup that about half of the savings over the 40 ft depth of the space occurred in the first 10-20 ft from the window [1]. Dimmable lighting in the first 10 ft would have an even shorter payback than the periods given in Table 4. The system itself would be preferable over switching systems, because bi-level switching results in abrupt changes in lighting level which can annoy occupants. Dimmable lighting in the remainder of the space could be cost justified with additional energy savings and increased amenity (ease of reconfiguration).

Daylighting availability is at its peak during mid-day hours which often coincide with peak demand periods in urban cities. In a separate simulation study quantifying the potential of automated control to reduce energy demand of the Times Building on the grid [2, 11], demand side dimming controls were able to curtail summer peak demand through demand responsive setpoint tuning strategies. The demand responsive modes of minimizing lighting energy use were found to yield small improvement over the energy-efficiency mode of operation and would cause degradation in visibility. Therefore, the Times Company selected other demand responsive measures when deciding to enroll in the demand response program.

Additional soft cost savings include the lower cost for reconfiguring the lighting system when spaces are reconfigured compared to hard-wired systems. With digitally addressable ballasts, fixtures can be reassigned to new zones via software, involving no changes in hardware. Over the past five years since initial occupancy, the Times Company lowered the setpoint lighting level once from 40 fc to 30 fc in most areas and reconfigured a very small percentage of the zones to accommodate changes in space use. These changes were implemented by the Times Company staff and took no more than 30 minutes per adjustment.

The Times Company put into place a service agreement with the vendor, where the vendor allocates two days per quarter to address any outstanding issues. The Facilities Director stated that the system has basically run on its own since installation with an "unbelievable" low level of maintenance required. The Times Company is able to make adjustments to the system on their own through the vendor's user interface either on site or remotely and run summary reports. The user interface shows the floor plan, fixtures on the floor, light output level, sensor readings, etc., enabling one to diagnose problems and fix problems in a timely manner.

4.2. Automated Shading System

4.2.1. Design and implementation

About one-third of commercial building HVAC energy use is due to heat gains and losses from windows with an annual impact of 1.39 Quads (1.39 x 10^{15} Btu) of primary source energy, while daylight represents a 1 Quad opportunity to reduce lighting energy use [12]. Properly designed, automatically-controlled, shading systems can offer a unique advantage over static solutions: the ability to respond to variable outdoor and indoor conditions over the course of a day in order to more optimally achieve performance objectives. The concept is not new: automated shading systems have been conceived of and in some cases have been commercially available for over 30 years. The digital revolution and growing interest in energy-efficiency has more recently made such systems cost competitive. The technical potential of optimized dynamic façade systems to reduce US building energy use has been estimated to be 1-2 Quads [12].

The majority of motorized shading systems sold in the US over the past 30 years has been controlled with simple time-clock scheduling or manually with a switch. In the mid-1970s during the Oil Embargo, an automated exterior roller shade system was installed as part of an energy-efficiency demonstration on the Gregory Bateson California State office building in Sacramento and controlled using sun sensors with solar calculations to lower exterior roller shades to block direct sun. A wide variety of intelligent, dynamic façade systems have been developed since then using interior shading, exterior shading, or between pane shading systems with sealed or ventilated air cavities to enable heat recovery, heat rejection, daylighting, and natural ventilation [13], but many of these solutions are targeted toward high-end niche applications. Automated interior roller shades are a simpler, potentially lower-cost solution that can be applied to new construction as well as tenant improvements and major renovations.

When the Times Company first investigated features and performance of automated roller shade systems in a full-scale daylighting mockup prior to purchase [1], most commercially-available systems they considered were designed simply to block direct sun from penetrating more than a defined distance horizontally from the window. As with the dimmable lighting system discussed above, a detailed monitored evaluation was conducted in a full-scale outdoor mockup, during which there were a number of additional features that were developed for the Times Company to improve performance. The Times Company then issued a competitive procurement specification for automated shading to be installed throughout The New York Times floors only (Figure 12). The final objectives listed in the specification are as follows (italic text is from the specification):

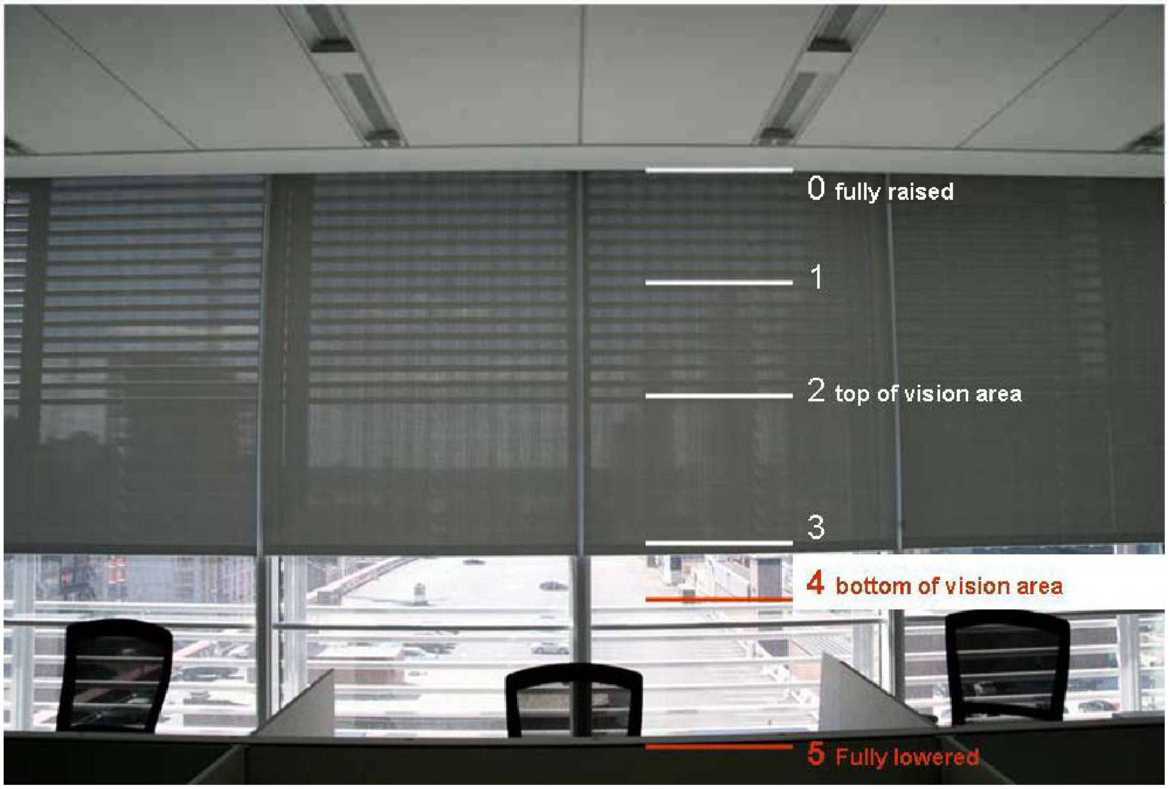


Figure 12. View of the automated roller shades showing the preset heights of the shade. Copyright: LBNL.

- *Maximize natural light* to maximize interior brightness so as to provide a potentially more healthy daylit environment for their employees (e.g., combat seasonal affective disorder, Circadian rhythm, etc.) and minimize lighting energy use, knowing that manually-operated shades tend to be lowered when discomfort occurs, but not often raised when the source of discomfort is no longer there;
- *Maximize occupant connectivity with the outdoors, i.e. external views* to the degree possible for all occupants working in the open plan areas near the perimeter and in the glass-fronted private offices near the core of the building;
- *Intercept sunlight penetration so as to avoid direct solar radiation on the occupants* which can cause both visual and thermal discomfort and increase HVAC energy use (Figure 13);
- *Maintain a glare free environment* so that occupants can conduct their work productively;
- *Provide occupant manual override capability*; and
- *On any given façade the shades are as a general rule expected to be controlled together to the same bottom-of-hem height* to maintain a uniform appearance across the façade.[1]

---

[1] This specification has to do with whether the shade motor is encoded and properly commissioned at the site. The Times Company did not want to see differences in height across a group of shades that were controlled as a single zone.

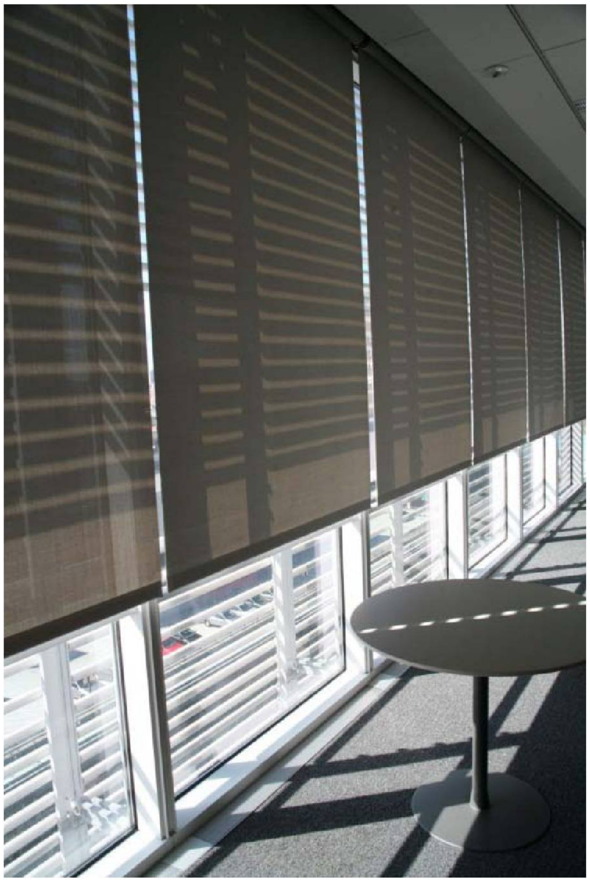


Figure 13. The automated shades controlled direct sun to within 3 ft from the window wall at floor level in most open plan work areas. Copyright: LBNL.

When selecting the final system, the Times Company had to make several critical decisions that affected performance:

Fabric choice. The color and openness of the roller shade fabric affects the view out, the amount of daylight that passes through the fabric when the shade is down, the directional quality of the light, the brightness of the backlit shade surface, and the effectiveness of the shade in reducing window heat gains. For example, a white, opaque fabric permits no view out, blocks sunlight entirely, reflects solar radiation (in the visible spectrum) back to the outdoors, and eliminates daylight and glare when fully lowered. The Times Company selected a twill weave fabric consisting of white and black yarns so that one face of the fabric was lighter than the other. The darker gray face was positioned to face the outdoors for aesthetic reasons. The lighter white face was positioned to face the indoors to brighten the interior when lowered. (Control of solar heat gains and glare may have been improved if the faces of the shade were reversed.)

The openness of the weave determines how well direct sun is controlled: a 1-2% openness factor lets very little beam sunlight through the densely woven fabric but also little daylight. An openness factor of 1.5%

was selected for all south-, east-, and west-facing elevations and a 3% openness factor was chosen for all north-facing elevations, which have less exposure to direct sunlight.

Type and number of shade motors and motor groupings. The higher the resolution of control one has on individual shades, the more likely one can tune the interior environment to the preferences of the occupants. However, to reduce capital costs and improve the uniformity of the façade, individual shades were grouped so that one motor controlled multiple shades (typically 20-30 ft wide per motor). In some instances, motors were also grouped; for example, adjacent shades at a glazed corner window were positioned to the same height. The shades were positioned to six different heights above the floor, two of which were aligned with the upper and lower edges of the unobstructed view portion of the exterior shading system (Figure 12). Encoded, line voltage (120 V AC) tubular motors were used to minimize noise and ensure accurate shade height positioning and bottom-of-hembar alignment between different motor groups. Built-in communication cards connected the motors to a common network, also promoting uniformity across individual motors.

Automated control. The manufacturer used indoor and outdoor roof top sensors combined with computational algorithms to determine the position of the shades. The location of the sensors was determined in consultation with the Times Company to meet aesthetic and maintenance requirements. The specified requirements were addressed as follows:

- Maximize natural light and maximize views to the outdoors. When direct sun and glare control were not in effect, the shades were raised after a 10-minute delay. The shades were raised incrementally, held at each intermediate height for 5 minutes before further retracting to its final position (as constrained by direct sun control) so as to minimize unnecessary shade movement and occupant disruption under variable sky conditions. The system was also designed to raise the shades if nearby buildings cast shadows across the windows, which in complex urban environments like Manhattan can be very challenging.
- Intercept sunlight penetration to avoid direct sun on occupants. If there was direct sunlight on the facade, the shade was lowered with minimal delay to a position which allowed sunlight to enter to a maximum predefined depth, typically 3 feet at floor level from the window for work areas and 10 feet in some circulation areas. The shades were lowered to the preset heights except for the fully lowered position so as to preserve daylight, unless defined otherwise for specific zone requirements.
- Maintain a glare free environment. Glare associated with the bright sky was addressed using local indoor sensors. If there was glare, then the shade was lowered with minimal delay to the pre-set position just covering the view portion of the window. Glare was originally defined by the average luminance of the view portion of the window exceeding a threshold value of 2000 cd/m^2 with further refinements implemented by the manufacturer.

- Provide occupant manual override capability. Occupants had the option of overriding automatic control at any time using a touch keypad placed on columns in the open plan area where it was readily accessible to all occupants. After selecting one of six reasons for overriding automated control, the shade could then be raised or lowered to the preferred height. Multiple recapture opportunities were defined for returning to automatic control, but ultimately at sunset the system returned to automatic control by moving the shades to the fully raised position in order to view the sunset.

After the bid phase, the final system was tested in the full-scale mockup for a period of six months to verify whether the system met the requirements of the procurement specification and to work out trade-offs between various aspects of control [2]. LBNL developed tools and guidelines for commissioning the system which were used by the Times Company to verify system performance of the final installation prior to occupancy (Figure 13).

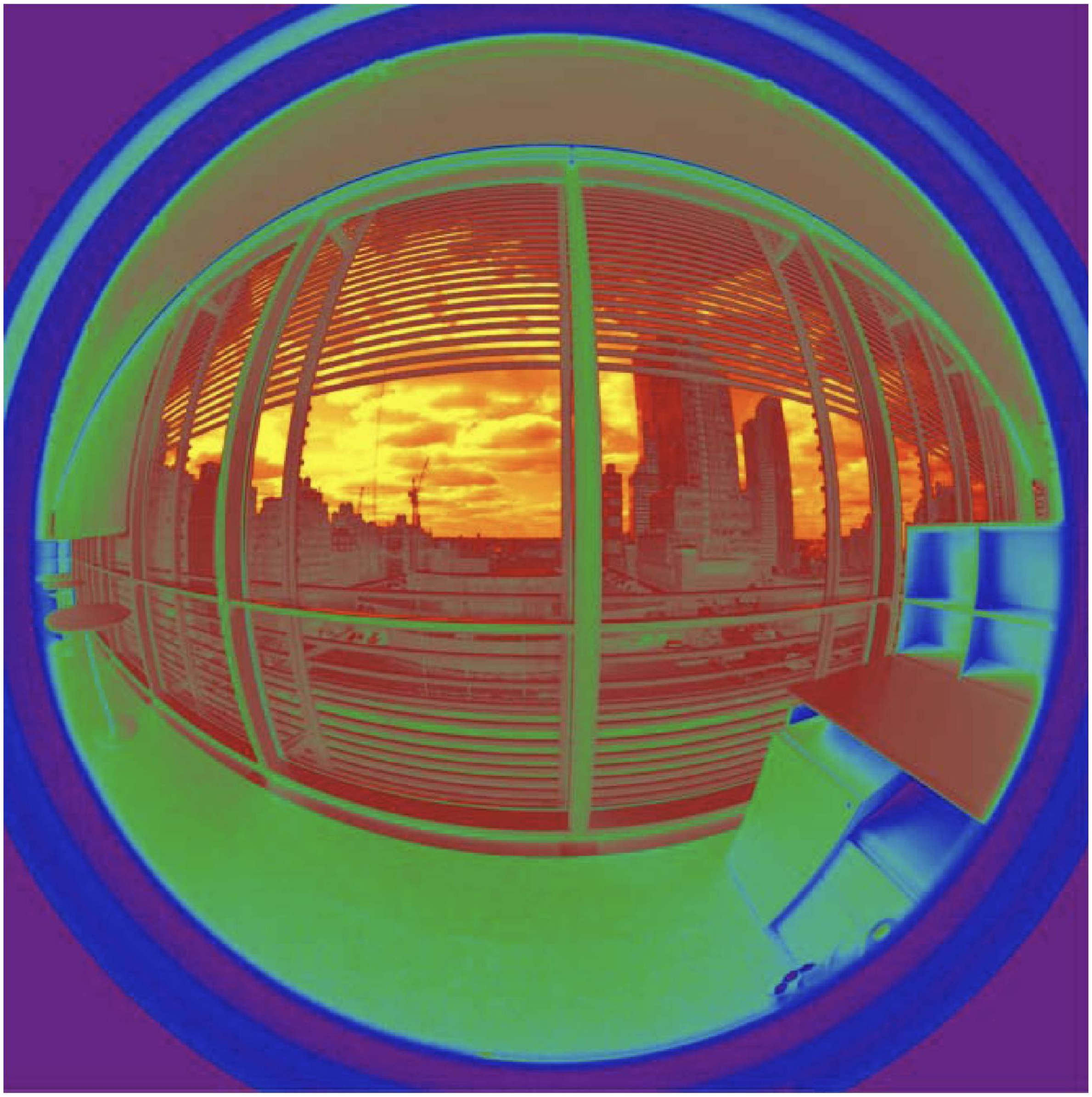


Figure 13. Luminance map produced by the commissioning tool to evaluate average window luminance (shades are in fully raised position in this image). The brighter yellow and red regions have the potential to cause discomfort glare. Notice how the architectural features of the building – the exterior shading system – mitigates glare from the upper, brighter regions of the sky. Copyright: LBNL.

4.2.2. What did people do with the system?

The post-occupancy evaluation of the automated roller shade system was made using two data sources: a) logged shade position, time duration, and selected reason for all manual overrides on all floors, and b) occupant responses from all floors to a survey questionnaire. The logged data were provided by the manufacturer for the period from July 1, 2010 to June 30, 2011 and were not independently verified by LBNL. In the month of February 2010, the shade control settings were modified to raise the shades to the fully raised position 10 min after sunset instead of 30 min before sunset. Occupant surveys were issued in the summer of 2010.

Upon initially occupying the building in July 2007, employees were given a small pamphlet (Figure 14) that explained the operation of the automatic shading system and how to use the touchscreen graphical user interface. The interface displayed the location of the shade motor groups along the window wall and text saying, "Please specify a reason for overriding the position of the shades by selecting one of the buttons below." The user could select one of six reasons for overriding the shades, then a second screen was displayed showing the current shade height and the various shade heights for selection. Occupants were able to override by "motor group", which was typically defined as one or more bands of 5-ft wide shades that were raised and lowered by a single motor.

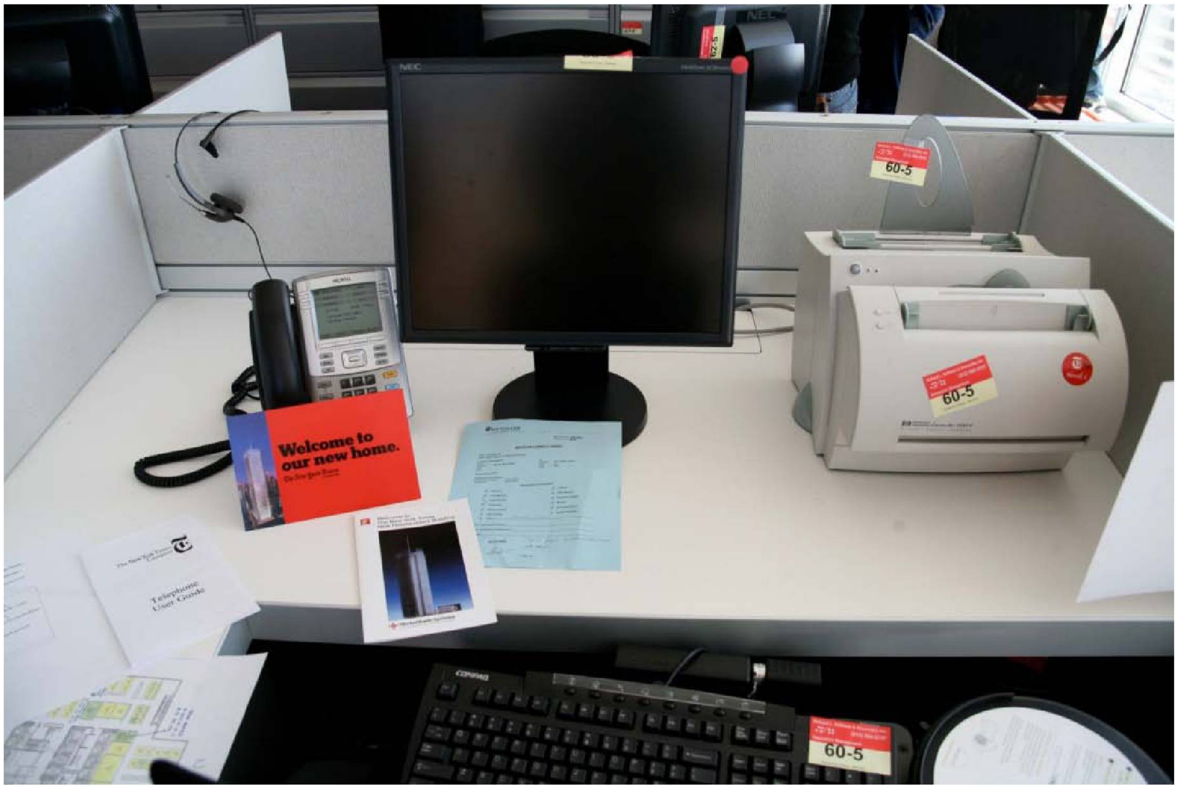


Figure 14. Information pamphlets explaining the energy-efficiency features in the building were put on every desk prior to move-in. Copyright: LBNL.

Six reasons were displayed on the touch screen. End users across all floors interpreted these given reasons, then moved the shade to one of six positions when overriding the automatic controls (0=fully raised; 5=fully lowered). Because end users interpreted the displayed reasons and then moved the shades in the *opposite* direction than anticipated, we used different terms to define the intended reason for overriding the shades (Table 5).

Table 5. User interpretation of the reasons for override listed on the touch screens for all floors

Displayed reason	Override action	% of all actions	Final position	% of all actions	Interpreted reason
Maximize view	raised	87%	0-2	92%	Maximize view
Privacy	raised	79%	0-2	89%	Decrease privacy
Too warm	lowered	91%	3-5	89%	Too warm
More sunlight	lowered	98%	3-5	90%	Reduce sunlight
Too bright	raised	53%	0-2	57%	Adjust brightness*
Other	lowered	89%	3-5	85%	Other - lower shade

*There was almost a 50/50 split between raising and lowering the shade for all floors.
For the 20th floor, shades were fully lowered to position 5, so the interpreted reason was "reduce brightness".

When selecting “more sunlight”, for example, end users *lowered* the shade for 98% of all occurrences when this reason was selected. For 90% of these occurrences or actions, the end user moved the shade to positions 3-5 (3=shade blocks the view portion of the window, 5= fully lowered). For this case, shade height selection was not consistent with the selected reason so the interpreted reason “reduce sunlight” was used instead in this analysis. On the 20th floor, shades were lowered fully (position 5), so the displayed reason of “too bright" was interpreted as “reduced brightness”. On a floor-by-floor basis, the interpretation of the reason might change, as was the case on the 20th floor, which is attributable to the actions of 2-3 individuals.

Results for all floors

Manual override of the automated system was, for the most part, very infrequent:

- If all motor groups in the building are evaluated, 80% of the motors in the building were overridden an average of 12 times per year for an average total time of 11 hours per year (0.4% of the year) during the primary work hours of 8:00 AM to 6:00 PM on weekdays (Figure 15).
- There were 17% of all motor groups that were never overridden. Automated shades were installed in conference rooms, the cafeteria, the data center, and near circulation areas.
- If we look at only the subset of motor groups that were overridden at least once (83% of all motors), then 80% of those motors were overridden an average of 18 times per year for an average total time of 38 hours per year (1.5% of the year).
- For the remaining 20% of this subset of motor groups, the motors were overridden an average of 199 times per year for an average total time of 757 hours per year (29% of the year).
- Of all actions taken, 70% were to lower the shade.

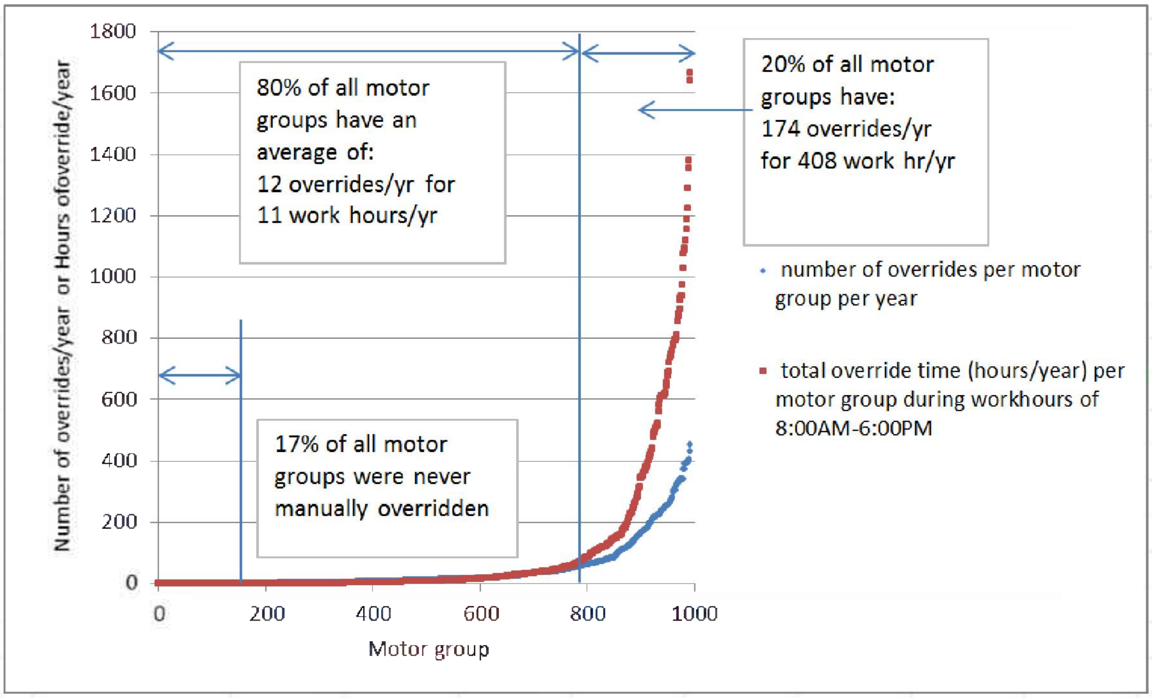


Figure 15. Distribution of the number of manual overrides per motor group for all motor groups on all floors during work hours (8:00 AM to 6:00 PM) on weekdays for one year.

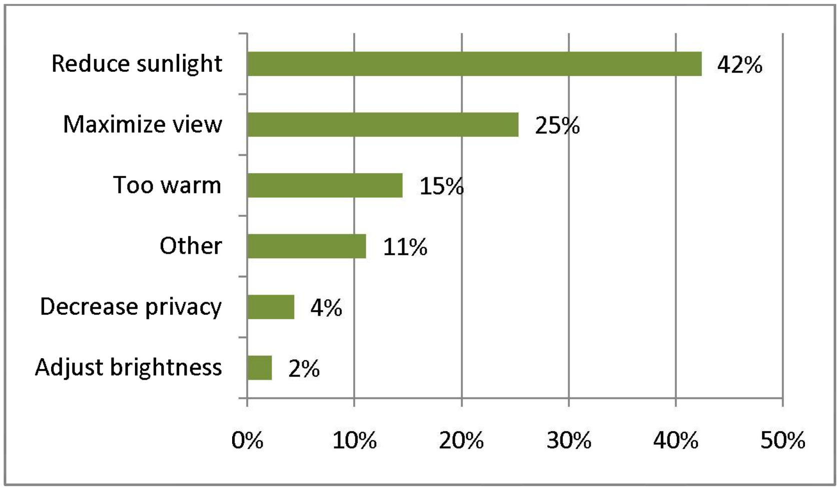


Figure 16. When the automatic controls were overridden, percentage of end users who selected the intepreted reason to adjust the shades.

When the shades were overridden, the primary reason was to reduce sunlight, where 42% of all manual overrides were for this reason. The second most common reason was to maximize view (25%). "Too warm" was the third reason at 15%, then "other – lower shades" at 11%. "Decrease privacy" and "adjust brightness" were selected at 4% and 2% of all actions, respectively. See Figure 16.

Results for the 20th Floor

Frequency of overrides was even less on the 20th floor compared to that of all floors and when overridden, the shades were lowered to reduce sunlight (64% of all actions) or raised to maximize view (20%), similar to the trends found for all floors. For 90% of all shade motor groups, automated control was overridden an average of 14 times per year per motor group and was in the manual override mode for an average of 8.4 hours per year. The number of manual overrides per orientation of the windows was almost equally distributed: north, east, south, and west percentages were 19%, 28%, 30%, and 23% of all actions, respectively.

For the remaining 10% of the shades (4 motor groups out of 36 total), the automated shades were overridden 80-235 times per year for an average of 170 daytime work hours or about 17 days in a year. Two shade motor groups on the east and west zones were overridden to reduce sunlight and maximize view (65% of the 170 total overrides), similar to the majority of total moves (positions 3-4 for sunlight, position 1 for view). Two adjacent motor groups on the south zone were overridden to maximize view or to decrease privacy (19%). Here, the shades were raised to position 0 (fully raised) for view and position 1 to decrease privacy. In this case, since the two motor groups were contiguous, the overrides were likely attributable to the actions of one person in that area.

4.2.3. What did people think of the automated shading system?

Sidebar: As discussed in Section 4.1.3, an on-line survey was issued to all Times employees. A sampling of 665 responses were received (35% out of the total number of occupants). There were several questions related to the comfort and quality of the lighting and one question about the automated shading system itself. Responses were on a 7-point scale, where 1 is "very dissatisfied", 4 is "neutral", and 7 is "very satisfied", in general.

Survey responses determined the degree of occupant satisfaction with the energy-efficiency measures and indoor environmental quality of the new building.

- 41% of the occupants responded with greater than neutral satisfaction with the automatic window shades, with an average rating on all 20 floors of 4.12 on a 7 point scale (Figure 17).
- 45% of the occupants were satisfied with the temperature in their workspace (average rating was 4.06). The indoor temperature was affected both by the operation of the UFAD system, lighting, and control of window heat gains by the automated shading system.
- 49% of the occupants felt that they were well informed about using the innovative lighting and comfort features in the building. The average rating was 4.37.
- The majority were satisfied with the overall quality of the light and visual comfort (see Section 4.1.3).

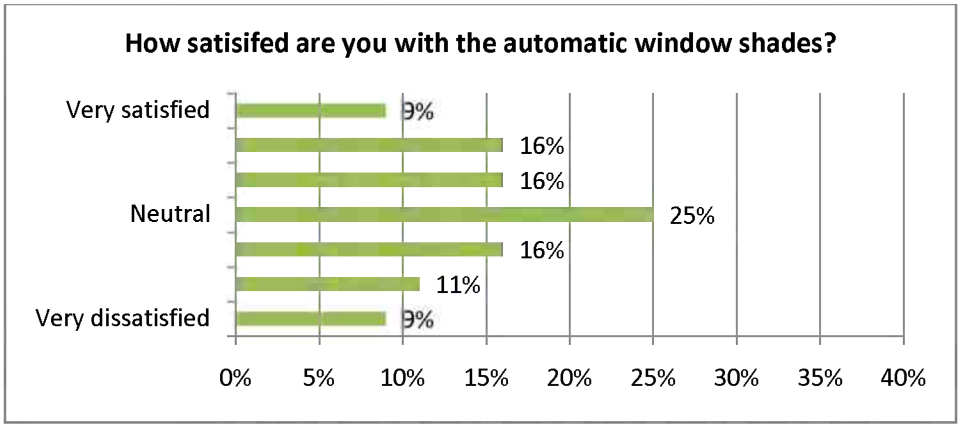


Figure 17. Subjective response to satisfaction with the automatic window shades.

To identify the potential *causes* of occupant satisfaction or dissatisfaction, several levels of statistical analysis were performed in this study. A statistical analysis was run, enabling analysis of how strongly dependent variables affected occupant satisfaction [8].

- Responses to "How satisfied are you to the building overall?" were most strongly correlated with lighting quality, with the source of light coming from both the overhead lighting and the windows.
- Responses to "Overall, does the new office building enhance or interfere with your ability to get your job done?" were also strongly correlated with lighting quality.
- Statistical analysis indicated that there was a significant positive correlation between lighting quality and visual comfort variables and how well informed the respondents were about the building features.
- There were weaker, but still significant positive correlations between lighting quality satisfaction and being adjacent to a window or having a private office.
- There was a plausible physical link between satisfaction with the window shades and satisfaction with the temperature and thermal comfort.

Written comments pertaining to the lighting portion of the survey were grouped, tallied and analyzed. These comments were more specific, enabling analysis of lighting quality and visual comfort pertaining to the automated shading system itself.

- When asked to comment on issues related to visual comfort, 206 out of the 318 comments (65% of the total comments, 31% of all survey participants) were related to visual comfort due to window shade problems. The most common concern with the window shades was that they failed to control glare. Many felt that the shades operated in a meaningless or inappropriate manner (n=50, 7.5% of total survey respondents) and were bothered by too much glare when the shade was up or too little light when the shade was down.
- Some mentioned specific problems with blocking reflected sunlight from nearby buildings (n=14). A new high-rise building was built directly across the street to the north of the Times Building

during the three year period after the Times Building was occupied and before the survey was issued. This and other new nearby buildings reflected sunlight onto the facade of the Times Building causing glare. Since the control system relied on both a combination of sensors and calculations, the shades were not always lowered to accommodate these changes in urban context. The Times Company is currently working with the manufacturer to modify the control system to address these changes.

- Others mentioned problems with the shade being raised 30 minutes before sunset (n=13). In February 2010, this setting was changed to raise the shades 30 minutes *after* sunset, but a clock error on the control computer occurred thereafter and may have contributed to these complaints seen in the survey issued in the summer of 2010.
- Occupants who reported any type of lighting problem were more likely to be in an open office than a private office and more prevalent for occupants next to the exterior windows than for those further away. 29% of the total unsatisfied who reported too much glare were adjacent to the window in the open plan office zones while 18% who were unsatisfied were not adjacent to the window but were located in the open plan zone. 51% of all respondents said that their workspace was next to an exterior window.

The type of manual overrides that occurred supported the survey data, although surprisingly infrequent. When the automatic system was overridden, 70% of all actions taken resulted in the shades being lowered, not raised, and 64% of the actions taken resulted in shade positions that covered part or all of the unobstructed vision portion of the window (positions 3-5). Sensitivity to discomfort glare varies widely depending on angle of view to the glare source, type of task being performed, age of the occupant, whether the occupant wears glasses, and other factors. This makes control of glare a very significant challenge, particularly if daylight and view are to be preserved.

4.2.4. What were the cost savings?

Although the outcome would have been more relevant, our analysis did not enable us to isolate the lighting and HVAC energy savings due to the automated shading compared to conventional post-occupancy performance with manually-operated shades for several reasons. First, the task would have involved reverting to manual control of the interior shades on an adjacent typical floor for at least a six-month monitored period in order to monitor then model baseline shade usage; this was beyond the scope of the project. Second, the modeling approach that was used in EnergyPlus involved source code modifications and other work-arounds that did not lend itself well to determining the incremental benefits of individual energy efficiency measures.

Instead, energy savings were determined by comparing simulated energy use on the 20th floor of the building with the automated shading to the same floor meeting the ASHRAE 90.1-2001 Standard which assumes unshaded windows. For lighting energy savings, no daylighting controls are assumed for the base case model so the difference in daylight availability between the reference case (whether there is no shade or a manually-operated shade) and an automated shade has no bearing on the calculated savings. For the HVAC energy savings, however, there is a significant difference in energy use between a 90.1-2001 unshaded window, a manually-operated shade (representing conventional post-occupancy performance), and the automated shade case, which as indicated above would be non-trivial to quantify.

The EnergyPlus simulation model of the as-built Times Building included all energy-efficiency measures, where the year-long monitored data for lighting energy use and shade positions were input as schedules into the model. For the HVAC system savings, the ASHRAE 90.1-2001 reference case was modeled with a VAV system and the test case was modeled with the UFAD system. The impact of the automated shades on HVAC energy use is confounded by both the difference in an unshaded and automatically shaded window and the difference between HVAC types. Indoor shades can reduce window heat gains since they can reflect solar heat gains in the visible spectrum to the outdoors. Prior field studies have measured reductions in window heat gain due to interior shades, e.g., [14]. The aggregate energy savings for all three energy-efficiency measures is given in Section 4.4.

In order to provide some sense of economic feasibility for this component measure, a simple economic analysis was conducted assuming partial credit for lighting energy savings only. A more robust calculation of economic payback is given in Section 4.4 for all three energy-efficiency measures combined (dimmable lighting, automated shading, and the UFAD system). The following assumptions were made to estimate the incremental cost of shading automation, based on discussions with the manufacturer and other experts in the field:

- 1 AC encoded tubular motor per 30 ft wide zone at \$300/unit more than a manually-operated shade;
- roof top mounted sensors (\$10/floor) plus 8 photosensors per floor at \$50/unit; and
- power, installation, daisy-chained controls at perimeter, networking, and commissioning at \$1/ft^2.

The total incremental installed cost is therefore \$1.39/ft^2 for a typical 30x40 ft zone. Setpoint tuning and daylighting reduced lighting energy use on the 20th floor by 1.96 kWh/ft^2-yr and if we assume that *half* of these savings can be attributed to the added daylighting from the automated shades, then at a flat rate of energy of \$0.19/kWh, the automated shades would have a simple payback of 7.5 years. The net present value (NPV) was \$1.16/ft^2 (net profit), cost of conserved energy was \$0.10/kWh, and internal rate of return was 13%. With time-of-use rates, the simple payback would be shorter (Table 6).

Table 6. Economic analysis of the Times Company automated roller shades

	Flat rate	Time-of-use rate
Expected savings (kWh/ft^2-yr)	0.98	0.98
Simple payback	7.5	5.4
Net present value (\$/ft^2)	\$1.16	\$2.18
Cost of conserved energy (\$/kWh)	\$0.10	\$0.07
Internal rate of return	13%	18%

Notes: Incremental installed cost \$1.39/ft^2 for a 30x40 ft perimeter zone, 30 year life, discount rate 6%. Flat rate: \$0.19/kWh; TOU: Category 9, Rate II. Neither HVAC energy use reductions nor potential HVAC capacity reductions were included. The net present value is the net profit and does not include the cost of the initial investment.
*Cost of conserved energy should be less than or equal to the local utility rate (i.e., \$0.19/kWh).

The allocation of half of the lighting energy savings to the automated shades is certainly arguable. Daylighting savings were about 0.80 kWh/ft^2-yr for both 1.3 and 1.1 W/ft^2, while tuning savings were 1.16 and 0.38 kWh/ft^2-yr, respectively (the 1.1 W/ft^2 is the maximum installed lighting power density prescribed by ASHRAE 90.1-2007; the higher 1.3 W/ft^2 value was the level permitted with 90.1-2001 when the building was built). Daylighting accounted for 41% and 68% of the total savings associated with a 1.3 and 1.1 W/ft^2 lighting power density, respectively, so if all the daylighting savings were attributed to the automated shades, then the life cycle economics are as given. Cost-effectiveness would be further improved if HVAC energy use reductions and possible downsizing of equipment capacity were included in the analysis. The challenge for the industry is having a robust predictive model on how people manually operate shades so that energy savings can be calculated as compared to a plausible base case. Automated shades do enable more access to daylight since occupants tend to lower the shades and neglect to raise them when discomfort is no longer present. However, there is still daylight in the space and some lighting energy use savings can be derived from dimming with manually-operated shades.

Maintenance and operations costs were modestly increased. After move-in, the Times Company facility management team worked with the manufacturer to further tune the control setpoints for the shades in response to occupant complaints and worked out minor problems over about 12 to 18 months. After this period, the Times Company has had to do very little maintenance on the system. Over the past five years since move-in, the Times Company has had to replace only six failed motors. Adjustments to the indoor sensors were also made.

4.3. Underfloor Air Distribution (UFAD) System

4.3.1. Potential benefits of UFAD systems

When the Times Company considered the use of underfloor air distribution (UFAD) in their new headquarters building, there were several key potential benefits over conventional overhead air distribution that were important to them. These, along with other more general UFAD benefits are described briefly below.

Reduced energy use. The main opportunities for reducing the energy use of UFAD systems are associated with three major factors: 1) cooling energy savings from economizer operation, which is highly dependent on climate (not available for the Times Building due to dedicated outside air system); 2) fan energy savings due to lower static pressure requirements and reduced room airflows, which is influenced by room air stratification, and offset by the amount of heat transferred from the room to the underfloor supply plenum; and 3) reduced reheat energy due to the beneficial impact of the plenum heat gain. In general, airflow requirements, economizer performance, and cooling energy are all interrelated resulting in tradeoffs; e.g., increasing supply air temperature (SAT) tends to decrease cooling energy due to better economizer performance, but increases fan energy due to increased airflow requirements. Recent energy simulation research has concluded that a UFAD system with optimized design and control may produce up to 10-20% HVAC energy savings compared to a normal practice overhead system conforming to ASHRAE 90.1-2010 [15].

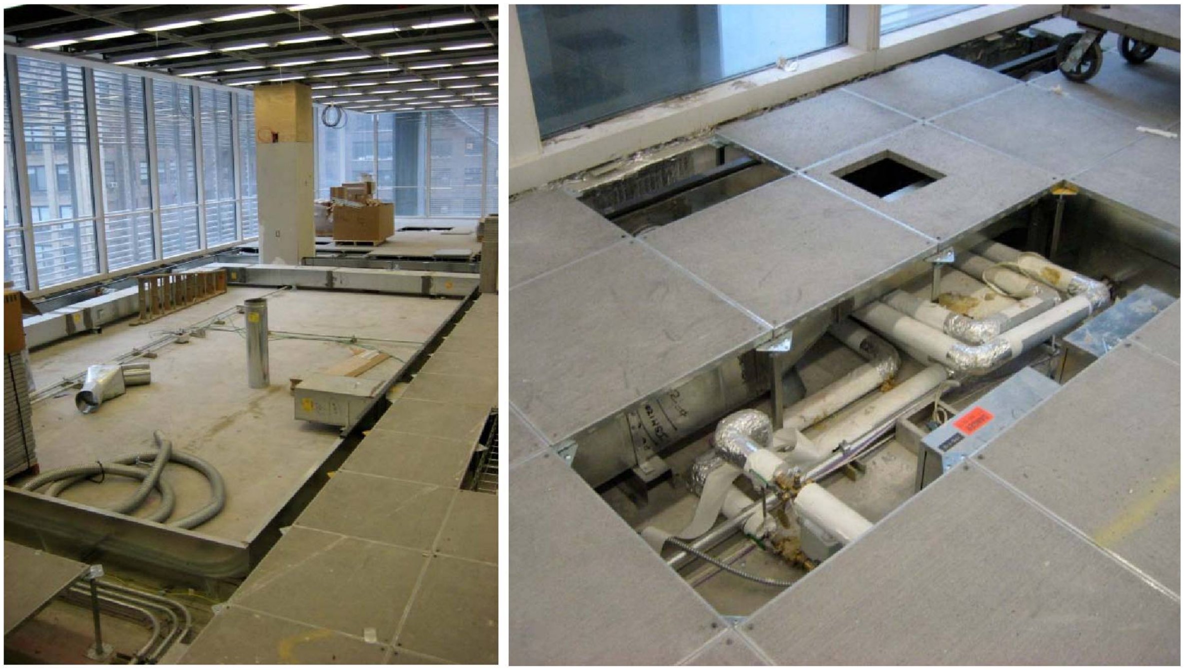


Figure 18. Images of the initial construction of the underfloor air distribution system. Copyright: LBNL.

Flexibility and reduced life-cycle building costs. In the open plan office space that was implemented in the Times Company occupied floors (2-21) of the building to enhance daylighting and outdoor views, as well as to foster communication between workers, the UFAD system provides a convenient and accessible integrated service plenum, allowing floor diffusers along with all required cabling and outlets to be placed almost anywhere on the raised floor grid. When departments or occupants needed to be reconfigured, the raised access floor system enables in-house maintenance personnel to carry out these changes at significantly reduced expense. Since the underfloor plenum provided both HVAC and cable management services across the floor plate, significant first cost savings were realized by installing non-powered modular furniture, thereby making the UFAD system cost neutral [16].

Improved occupant control and comfort. UFAD systems are typically configured to place one swirl floor diffuser near each workstation location, allowing individual occupants to adjust the amount of airflow supplied from the diffuser. Although swirl diffusers do not deliver a strong jet of airflow onto nearby occupants, even by being accessible, these diffusers can still be effective at influencing the perceived local comfort conditions. Research has shown that people who believe they have greater control over their thermal environment will tend to be more satisfied with their comfort [17]. Personal control helps to address individual comfort preferences since in today's work environment, there can be significant variations due to differences in clothing, activity level (metabolic rate), and other individual differences. Additional comfort benefits observed in The Times building include (1) ability to maintain a more consistent and uniform (horizontally) temperature throughout the space, and (2) elimination of cold downdrafts from overhead diffusers. It should also be noted that good humidity control, improving occupant comfort perception, is provided by the dedicated outside air system when needed by both steam humidification during the winter and dehumidification during the summer.

Improved air change effectiveness. Some improvement in ventilation and indoor air quality at the breathing level can be expected by delivering the fresh supply air at floor level near the occupants, and returning at the ceiling, resulting in an upward displacement of indoor air and pollutant flow pattern, similar to that achieved in displacement ventilation systems. Recent ASHRAE research has demonstrated that UFAD systems provide enhanced air change effectiveness when mixing (throw height) from floor diffusers is limited [18]. In addition, human subject laboratory studies have shown that whenever increased air motion is provided under occupant control, perceived air quality is significantly improved [19].

4.3.2. What was the operational quality of the UFAD system?

Field measurements were conducted on the 20th floor of the Times Building for about four months from August 25, 2011 – January 9, 2012, during which time an array of wireless sensors was deployed to measure room and underfloor plenum air temperatures, electrical power, and energy performance of all major HVAC equipment serving the floor (Figure 19). The purpose of these measurements was to characterize the operational quality of the UFAD system, and to provide energy use data to conduct a semi-validation of a specially developed energy simulation model of one tower floor of The Times Building using EnergyPlus. Full details of field measurements at the Times Building are reported in [20].

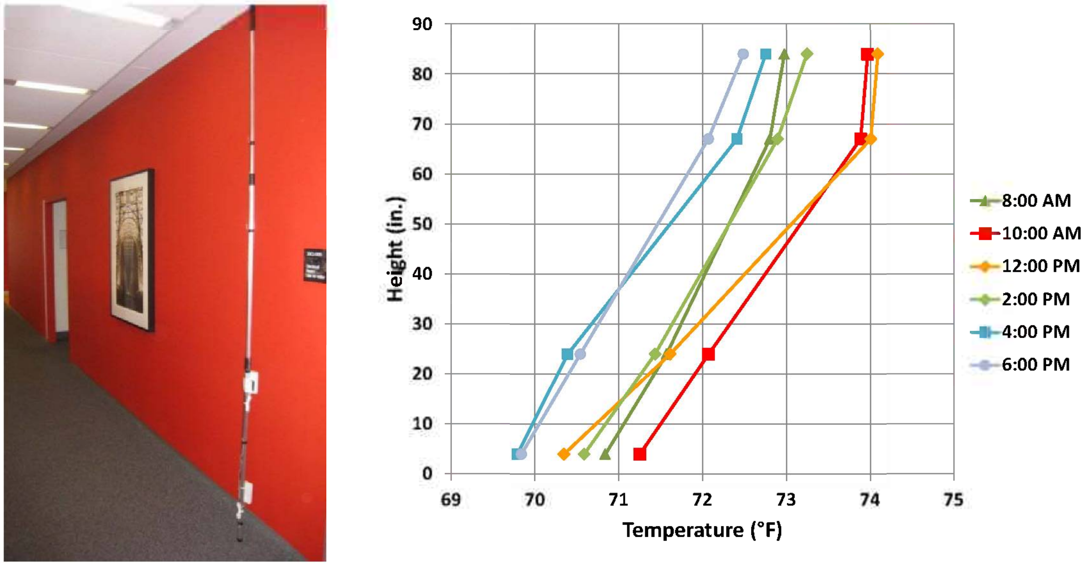
Figure 19. Map of wireless sensors deployed on 20th floor of the Times Building. Copyright: CBE.

Thermal Comfort Performance

Figures 20 and 21 present photos and representative measured hourly vertical temperature profiles from the stratification poles located in the east interior zone and east perimeter zone, respectively.
Data are shown for one day, 9/14/2011, during warm weather.

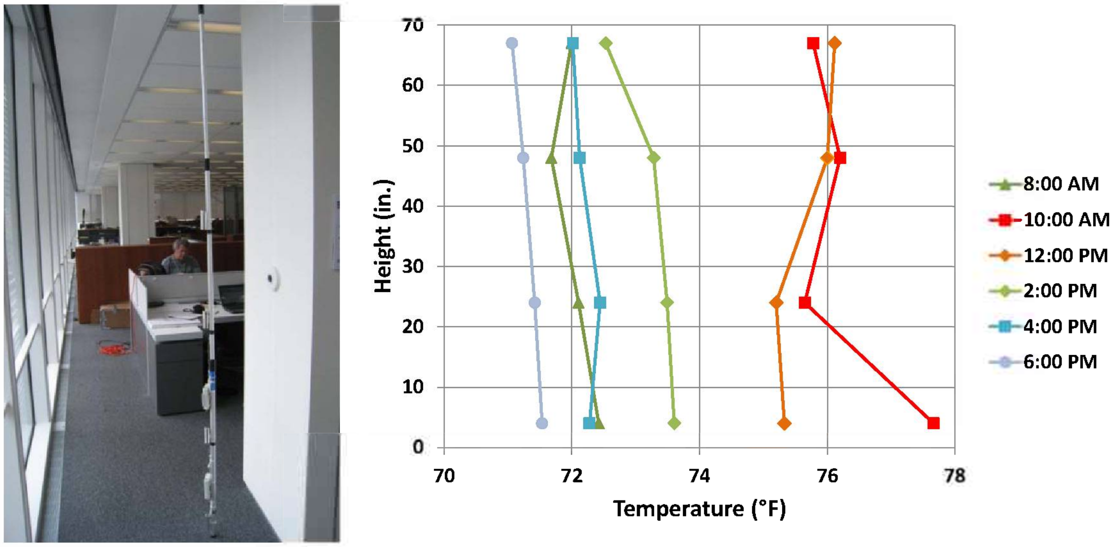
Results for the interior zone (Figure 20) indicate that a reasonable amount of stratification (2-3°F) is achieved in the occupied zone, as indicated by the difference in temperature between standing head height (67 in.) and ankle height (4 in.). Note that the warmest temperatures occurred at 10 AM and 12 PM noon, matching the expected peak solar load for this east-facing zone. Stratification is one indicator of good UFAD cooling performance because it demonstrates how comfortable conditions can be maintained in the lower occupied zone, while allowing warmer and less comfortable conditions to exist in the higher space elevations; in general, energy can be saved by increasing the setpoints (thus lowering the airflow and reducing cooling) while still allowing the average conditions in the occupied zone to remain comfortable. In the case of The Times building, the interior zone thermostats are all located at a height of 84 in. (for architectural reasons). The Times Company has implemented an interior zone setpoint temperature offset to ensure that the thermostat temperature is set high enough, accounting for stratification, so that the average temperatures down in the occupied zone are in a comfortable range.

To investigate comfort conditions in the interior zone, Figure 22a shows how the average hourly occupied zone temperature conditions compare with an estimated comfort zone based on ASHRAE Standard 55-2010 [21]. Each point represents the average of all temperatures measured within the occupied zone (4-67 in.) for the same hourly profiles in Figure 20. The width of the "comfort zone" shown on the x-axis can be determined from operational and occupant parameters. In this case, the comfort zone is determined by assuming a **Met**abolic value = 1.2, **Clo**thing value = 0.6, **R**elative **H**umidity = 50%, and **V**elocity near the occupant = 20 fpm. The amount of stratification in the occupied zone is shown on the y-axis; ASHRAE Standard 55 specifies the maximum acceptable stratification as 5°F. The comfort results shown in Figure 22b indicate that all average temperatures are very near or slightly below the lower (coolest) boundary of the comfort zone.



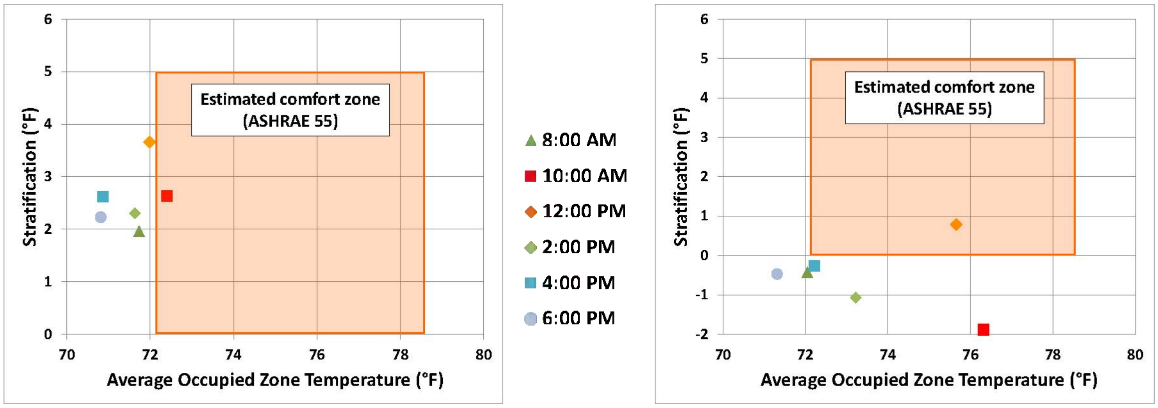
a) Photo of pole b) Temperature vs. height

Figure 20. East interior zone stratification pole and example hourly temperature profiles, 9/14/2011. Copyright: CBE.



a) Photo of pole b) Temperature vs. height

Figure 21. East perimeter zone stratification pole and example hourly temperature profiles, 9/14/2011. Copyright: CBE.



(a) (b)

Figure 22. Average occupied zone temperature and stratification, 9/14/2011. Comfort zone assumptions: 1.2 met, 0.6 clo, 50% relative humidity, air velocity of 20 fpm.

Figure 21 presents measured temperatures in the perimeter zone, which show a different temperature profile compared to the interior location. At this pole location, quite close to the exterior window with linear bar grilles in the floor along the base of the windows, virtually no stratification is observed, indicating a mixed room air distribution pattern. In all likelihood, higher supply airflow rates from the perimeter bar grilles are blowing cool air upwards into the space near the window, creating the mixing and in some cases negative stratification. This pattern of increased mixing with little stratification has been frequently observed in UFAD installations with open plan offices. Note that the higher measured temperature at the lowest (4-in.) height at 10 am is due to direct solar radiation, both incident on the shielded temperature sensor and creating a warmer carpet surface temperature. These perimeter grilles also provide heat during the winter (from the ducted underfloor variable speed fan-coil units) that serves as a warm air curtain next to the windows, thus preventing uncomfortable cold air downdrafts. When compared to the ASHRAE comfort zone in Figure 22b, higher average occupied zone temperatures (~76°F) are seen at 10 AM and 12 PM noon in this east perimeter zone, but at all other times during the day average temperatures are closer to the low end of the comfort zone.

Underfloor plenum performance

A key attribute of any UFAD system is the open underfloor plenum space than can be dedicated to services distribution. At the Times Building conditioned air from the air handler is delivered through an array of large distribution ducts (air highways) that circumnavigates the service core and then into the six major underfloor plenum zones for distribution across the floor plate to all floor diffusers and perimeter fan coil boxes. Pressurized underfloor plenums are able to deliver the required amount of supply air to anywhere on the floor plate for the vast majority of cases. However, research and field experience have shown that the temperature of air discharged into the space can vary substantially at different locations due to heat gain (thermal decay) from the building structure to the plenum air.

Measurements on the 20th floor found plenum pressures in the range of 0.01-0.06 iwc and thermal decay between 3-5°F (difference between air entering from the air highway and that delivered at the perimeter), both within acceptable ranges for good UFAD performance. The average temperature of the supply air entering the underfloor plenum from the air highways was 66-67°F, which results in typical supply air temperatures at the perimeter bar grilles of around 70°F.

4.3.3. What did people think?

As discussed in Section 4.1.3, an on-line survey was issued to all Times employees. A random sampling of 665 responses were received (35% out of the total number of occupants). There were several questions related to the comfort and quality of the thermal environment. Responses were on a 7-point scale, where 1 is "very dissatisfied", 4 is "neutral", and 7 is "very satisfied", in general.

Survey responses determined the degree of occupant satisfaction with the energy-efficiency measures and indoor environmental quality of the new building.

- 46% of the occupants responded with greater than neutral satisfaction with the temperature in their workspace, with an average rating on all 20 floors of 4.06 on a 7 point scale.
- 68% of the occupants responded with greater than neutral satisfaction with the humidity level in their workspace, with an average rating on all 20 floors of 5.26 on a 7 point scale.
- 39% of the occupants responded with greater than neutral satisfaction (enhances) in response to the question of "does thermal comfort in your workspace enhance or interfere with your ability to get your job done?", with an average rating on all 20 floors of 4.14.

Statistical analysis of the data indicated that:

- Responses to "How satisfied are you to the building overall?" were strongly correlated with satisfaction with humidity level and less strongly related to thermal comfort.
- Responses to "Overall, does the new office building enhance or interfere with your ability to get your job done?" were strongly correlated to thermal comfort and slightly less strongly correlated to humidity level.
- As mentioned in Section 4.2.3, there was a plausible physical link between satisfaction with the window shades and satisfaction with the temperature and thermal comfort.

Written comments from the survey were grouped and tallied, where the number of individuals' mentions related to the thermal environment being too cold were 206 ("too cold", " "sweater"). The number of mentions of the temperature being too warm were 31 ("too hot", "too warm"). Since occupancy, the Times Building Operations has been fine-tuning the system and making adjustments to temperature setpoints in response to occupant concerns.

4.3.4. Lessons learned and recommendations

Setpoint control to optimize thermal comfort and energy use

A review of measured space temperatures indicates that comfort conditions are being maintained close to the low (coolest) end of the comfort zone (72°F) specified by ASHRAE Standard 55-2010 for the large majority of time. This finding is consistent with results from the occupant survey conducted by the Times Company in which the large majority of people expressed satisfaction with thermal comfort, although among those expressing dissatisfaction, a slightly larger percentage of respondents indicated that conditions were too cool. Since the "comfort zone" represents a range of temperatures within which most people (80%) will be satisfied, these results suggest that cooling energy savings could be realized by raising the setpoint temperature while still maintaining similar or possibly more comfortable conditions. Previous research has demonstrated that increasing the space setpoint temperature by 2°F (1°C) can reduce cooling energy by 7-10%, depending on climate [22]. A similar increase in setpoint temperature is recommended for the Times Company, which would move the average comfort conditions closer to the middle of the ASHRAE comfort zone while achieving important energy savings. It is also recommended that the setpoint control logic, including the existence of a zone temperature deadband in the range of at least 2-3°F between cooling and heating setpoints for the perimeter fan-coil units (typically prescribed by building standards), within the building management system (BMS) be carefully reviewed to ensure that space setpoint control is operating to deliver efficient heating and cooling to the occupants.

Interior zone

Due to the 84-inch height of interior zone thermostats, setpoint temperatures should be at least 1-2°F higher than the desired temperature in the occupied zone to account for stratification. As described above and shown in Figure 20, the Times Company has already implemented a strategy of maintaining the setpoint temperature at the 84-inch height 1-2°F higher than the temperature at a typical (4-ft height) thermostat location. However, given the stratification that is maintained in the occupied zone for the majority of the time, it is recommended that the Times Company consider increasing the amount of this offset, so that average temperatures in the occupied zone can be increased above the low end of the thermal comfort zone.

Perimeter zone

The observed well-mixed conditions at the perimeter combined with the measured supply air temperature at the perimeter bar grilles of about 70°F suggest that relatively high airflow rates are being delivered to the space. The cooling setpoint temperature has been adjusted to be 73°F (typically, it would be 74°F), and the heating setpoint temperature has been increased to 74°F to offset the effects of the cold window frames in winter conditions (typically, it would be 70°F). These revised setpoint temperatures have been selected by the building operators to improve the overall comfort experience in the perimeter zones of the building. However, these adjustments will tend to increase both the cooling and heating energy use in the perimeter zones. It is recommended that these revised setpoint temperatures be carefully reviewed and changed, if possible, to reduce energy consumption while minimizing the impact on the employees. For example, it may be possible to reduce airflow rates (saving fan energy) by raising perimeter cooling setpoint temperatures, and thereby helping to promote more stratification while maintaining acceptable comfort conditions. Furthermore, it would be desirable to set the cooling setpoint equal or higher than the heating setpoint so that the system is not constantly trying to heat or cool when the operation switches between heating and cooling mode (sometimes several times per day).

Review of other control operations

The following additional control issues were observed during the review of monitored data from the Times Building. These lead to the following considerations for professionals designing, commissioning, and operating such systems, but would require deeper analysis to fully resolve.

1. Setpoint switching: Under some conditions in winter, setpoint switching occurs over short periods of time from 74°F heating to 73°F cooling. Operators have attempted to manage this by using supervisory commands for current setpoint in an attempt to lock the boxes into either heating or cooling mode, so the data may reflect isolated instances. This situation could be improved by implementing a deadband between heating and cooling setpoints in the fan-coil unit controllers instead of using a single setpoint imposed by the supervisory system.

2. Zone setpoint control issues: There were a number of instances observed in perimeter zones under cooling operation where the setpoints were not met (for example, see Figure 22), indicating inadequate airflow rates, too high of supply air temperatures, or both. Possible corrective actions that could be considered include: (1) check maximum airflow setting of fan-coil unit serving that zone (in some cases, settings were less than the specified design airflow capacity for the unit), (2) use a higher zone cooling setpoint temperature (see previous discussion) if acceptable comfort can still be maintained, and (3) reduce the supply air temperature at the air handler (see below).

3. AHU SAT: The AHU leaving temperature setpoint is relativity high at 66°F. This was established by Building Operations to provide optimal comfort, and in particular avoiding overcooling in the interior zone. Lowering this AHU setpoint temperature and/or using a reset strategy, may allow the perimeter fan-coil units to control to setpoint better (see above). However, if a lower AHU SAT is used, care must be taken to reduce airflow rates to the interior zone accordingly to avoid overcooling. One

approach to reduce airflow would be to review and possibly reduce the minimum volume setpoint for the zebra dampers controlling air delivery into the underfloor plenum. These strategies, along with raising the cooling setpoints (described above), and implementing a 1-3°F deadband in perimeter zones could improve overall control operation of the UFAD system.

4. Weekend and evening operation: The Times Building Operations has taken the wise approach of reviewing off-hour and weekend occupancy schedules for its various departments and implementing matching UFAD operating schedules. In the case of the Times Building, the underfloor plenum is divided into six separate low-pressure control zones per floor. This allows the UFAD system to be more efficiently operated to provide conditioning to one or more zones based on occupancy.

Overall, the operators have done an excellent job of navigating among these issues to provide an acceptable comfort level (see survey results). Without these constraints it appears that average comfort could be moved in a more positive direction.

Lessons learned drawing from the analysis of the Times Building, as well as experiences of the authors with other UFAD systems are as follows:

1. Cooling setpoints: As described above, cooling setpoints should be set higher than conventional practice with overhead systems to account for stratification and combat overcooling (a pervasive problem in the industry)
2. Heating setpoints may need to be set higher when large window to wall ratios are used (as in the Times Building).
3. It is recommended that a deadband of 2-3°F minimum be used between heating and cooling setpoints.
4. AHU supply air temperature settings (and reset) should be decided on the basis of the impact on interior zone comfort, minimum ventilation rates, and terminal unit sizing and potential cooling setpoints.
5. Linear bar grilles in the perimeter, while good for heating, provide challenges for desirable cooling (stratified) performance due to the increased mixing caused by the discharged air into the space.

4.4. *Total energy use and cost savings*

In addition to directly metered lighting energy use given in Section 4.1, total energy use savings were determined for the typical 20th tower floor of the Times Building. While desirable, we were unable to separate out energy savings that were attributable to *each* of the energy efficiency measures – the modeling challenges were very significant. Instead, whole floor energy use data are presented. Measured lighting energy use savings in just the open plan perimeter zones however are given in Section 4.1.2. HVAC energy savings due to reduced heat gains from the lights are included in this analysis.

Total energy savings were defined as the difference in energy use between the Times Building and an equivalent building with a conventional VAV system that conforms closely to the prescriptive standards of ASHRAE 90.1-2001, which was the version that the Times Company design team adhered to. A customized version of the EnergyPlus building energy simulation program (version 6.0 [23]) was used to determine energy performance, where measured data were used as either direct inputs or to calibrate the EnergyPlus model (see sidebar below). Table 5 provides a summary of the differences in assumptions between the two cases.

Modeling Assumptions for The New York Times Building

In order to provide an accurate estimate of energy savings for the three innovative energy efficiency measures, several critical modeling challenges were addressed, with particular attention paid to modeling all zone heat gains as accurately as possible:

- Accurate modeling of both the quantity and distribution of window heat gains was critically tied to UFAD system performance. Modified versions of the EnergyPlus and Radiance lighting simulation tools were developed by LBNL and used to determine the transmitted and absorbed solar radiation due to the facade system, where the facade was comprised of an exterior scrim of horizontal ceramic glazed rods, specular glazing, and the automated interior roller shade. The model allowed the assignment of transmitted radiation to both raised floor and furniture surfaces (Figure 23).
- Shade position was derived from monitored data provided by the manufacturer on a 15-minute time step and used in the calculation. Bidirectional scattering data were derived from goniophotometric measurements made from a sample of the shade fabric. The final computed values were input as schedules to the modified version of EnergyPlus.
- Lighting energy use was derived from LBNL monitored data for the year (Section 4.1), where the data were averaged for each 15-min increment and assigned to the modeled thermal zones.
- Equipment energy use and occupant loads and schedules were derived from CBE monitored data gathered from September through December 2011 (4 months) and these loads were assumed to be the same over the modeled 12-month period.
- A CBE-developed version of EnergyPlus was used to model the UFAD system. To obtain a more accurate simulation of HVAC energy use, CBE used the 4-month monitored data to set proper values in the input model (e.g., air temperatures, setpoints, energy use of fan powered boxes,

etc.) and to modify model parameters to minimize differences between modeling results and the measured data. The UFAD building model used some of the same assumptions (e.g., economizer) and settings (e.g., thermostat settings) as the baseline in an attempt to provide a fair comparison. Some elements departed from the letter of ASHRAE 90.1 to simplify modeling and create a more accurate portrayal of some factors (e.g., fan modeling).

- Local weather data were obtained and used to run the model. Weather for 2011 was found to be within the norm of TMY values. The period that was modeled was January 1, 2011 to December 31, 2011.

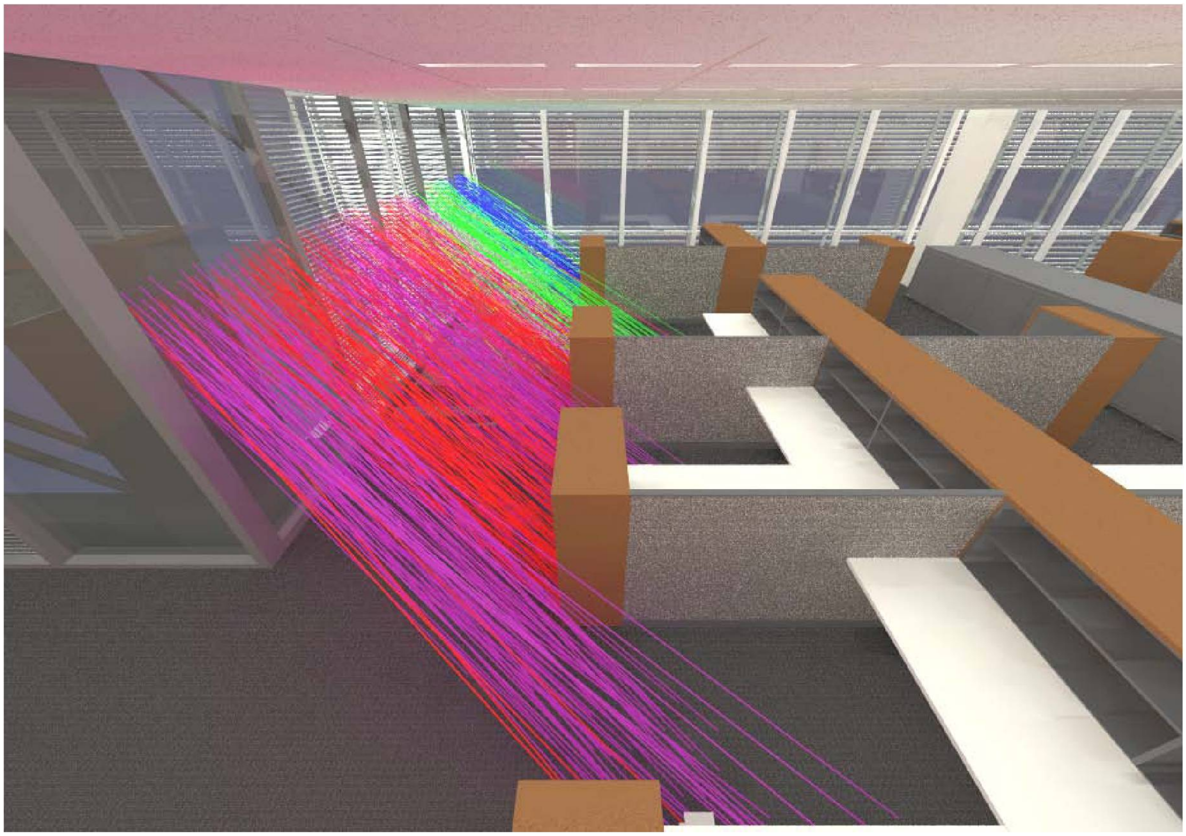


Figure 23. Using bidirectional scattering distribution function (BSDF) data, ray-tracing calculations, and computationally efficient matrix operations, absorbed solar radiation was determined for each time step at each layer of the window system and transmitted solar radiation was determined for each room surface in the furnished zones, including the UFAD floor plenum and furniture gains. The color of the rays indicate which surface (floor or furniture) and which zone (zone near window or core zone) the transmitted solar radiation was assigned to. Copyright: LBNL.

Table 5. Summary of modeling differences (major differences from baseline are highlighted in **bold**)

Description of modeling differences		
	ASHRAE 90.1-2001 Building	**The New York Times Building**
Glazing/solar gains	• WWR 40%, SHGC 0.25, U-value 2.61 • Standard EnergyPlus solar modeling	• WWR **76%**, SHGC **0.30**, U-value **2.43 W/m^2-°K** , Tvis=0.53 • **Solar gains derived from Radiance solar gain model**
Shading	• No indoor or outdoor shades • Neighboring buildings only	• **Outdoor scrim/ shade** • **Indoor automated roller shades** • Neighboring buildings
Plug loads	Same as the Times Co. model: 0.4 W/ft^2 at peak periods, 0.17 W/ft^2 nights and weekends	Calibrated model plug loads derived from 15-min field measurements
Lighting	Lighting power density (LPD): 1.3 W/ft^2; scheduled lighting controls: 6:00AM-1:00AM weekdays, off on weekends	LPD=1.3 W/ft^2; calibrated model lighting loads derived from 15-min field measurements
Controls settings	• Zone thermostats: Occupied hours; 70°F heating/75°F cooling • AHU supply air temp: 55°F, no reset • Min VAV box settings: 30% minimum and “dual max” heating • Schedules, system and thermostats: Weekdays, 7-7pm; Saturday, 8-5pm; Sunday/Holidays, off • Schedules, occupancy: Same as UFAD	• Zone thermostats: Same as baseline • AHU SAT: **63°F**, no reset • Min VAV box settings: **5%** minimum and “dual max” heating • Schedules, system and thermostats: Same as baseline • Schedules, occupancy: Derived from operators input and plug load monitoring
Air handlers (AHU) and Fan powered boxes (FPB)	• Central AHU: 70% efficient fan, part load curves reflect static pressure reset at 1 iwc duct pressure setpoint • FPB; none • Economizer, differential dry bulb, minimum outdoor air = 0.085 cfm/ft^2; a nominal reasonable value that meets various standards	• Same efficiency as baseline but with **reduced static pressure** and **part load curves** reflective of lower supply static pressure • FPB; **15% efficient fans with cubic part load curves derived from measured data** • Economizer, same as baseline
Cooling	Central chilled water system, single chiller with COP=5.5 (designed for single floor)	Same as baseline
Heating	• Heating from overhead limits discharge temperature to 100°F • The minimum VAV box fraction set a 30%; conforms to 90.1-2001. • Reheat boxes in interior zones	• Higher discharge temperatures **(110°F)** due to heating from floor • Minimum volume set at **5%** to account for better ventilation for UFAD • UFAD system has **no heating in interior** zones.
Sizing	• AHU and zone terminal units autosized	• AHU autosized, **terminal units and number of diffusers same as real building**

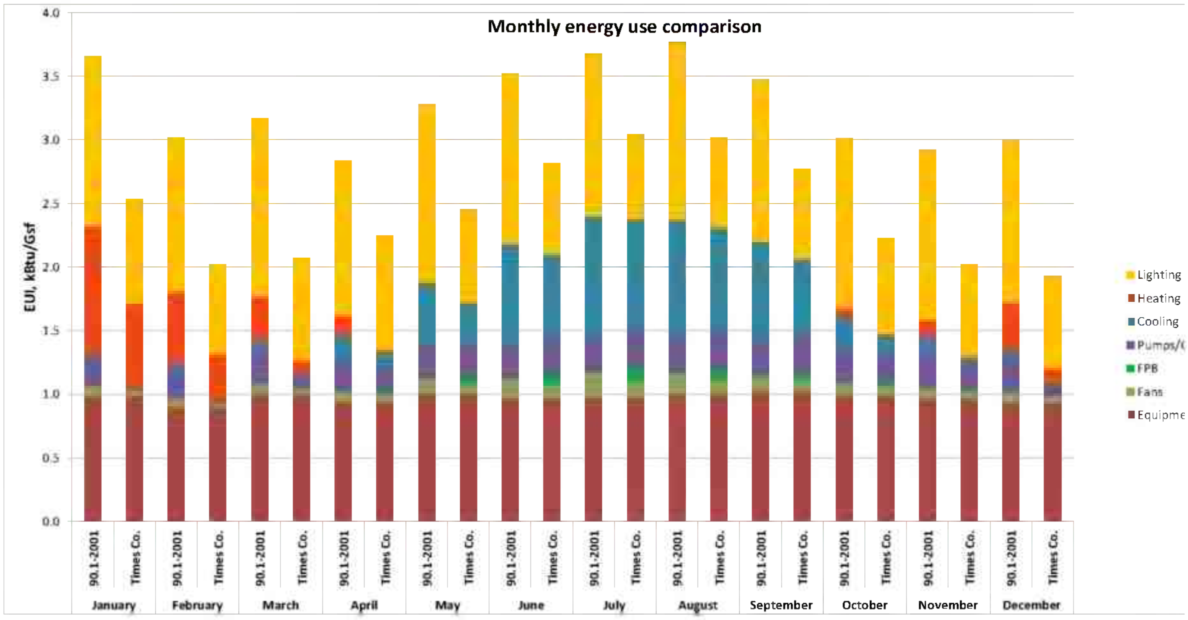


Figure 24. Monthly end use comparison between ASHRAE 90.1-2001 baseline and calibrated model of the Times Building.

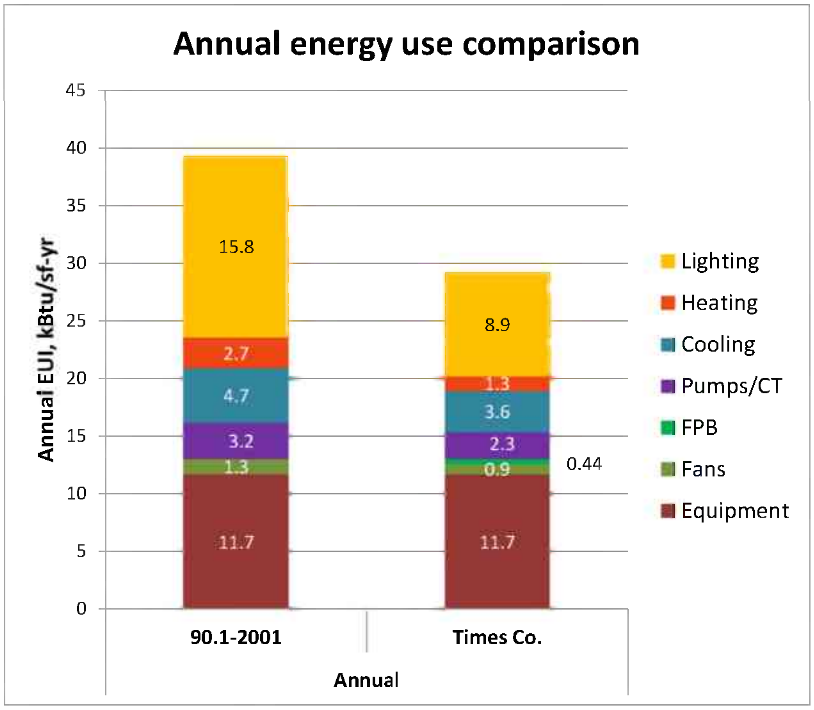


Figure 25. Annual end use energy comparison between ASHRAE 90.1-2001 baseline and calibrated model of the Times Building.

Table 6. Annual energy use intensity and savings (20th floor)

	ASHRAE 90.1-2001 (kWh/ft^2-yr)	Times Co. (kWh/ft^2-yr)	Savings (kWh/ft^2-yr)	Percent savings
Lighting	4.62	2.62	2.01	43%
Equipment (plug loads)	3.43	3.43	0.00	0%
Fans	0.39	0.26	0.13	33%
Pumps/Cooling tower	0.93	0.67	0.26	28%
Cooling	1.37	1.05	0.32	23%
Fan powered boxes	0.00	0.13	-0.13	NA
Total	10.74	8.16	2.58	24%

	(kBtu/ft^2-yr)	(kBtu/ft^2-yr)	(kBtu/ft^2-yr)	
Heating energy consumption	2.67	1.31	1.36	51%

Note: Energy use intensity calculated using gross floor area of the entire 20th floor. Note that lighting energy use in this table differs from the 3.15 W/ft^2 given in Table 3 because this analysis includes all lighting end uses over the total lit area of the floor.

Annual and monthly energy use values are given in Figures 24-25 and Table 6. Total site and source energy use intensity was 29 kBtu/ft^2-yr and 94 kBtu/ft^2-yr, respectively, assuming a site-to-source conversion factor of 3.34 for electricity and 1.05 for natural gas. Lighting energy use savings were the most significant: 2.0 kWh/ft^2-yr or 43% savings. Note that these values differ from that given in Section 4.1.2 because this analysis includes all lighting loads across the floor, not just the lighting in the open plan areas.

Cooling energy use was also decreased significantly by 0.32 kWh/ft^2-yr or 23%. While the window-to-wall area ratio (WWR) of the Times Building (WWR=0.76) was significantly greater than the ASHRAE 90.1 baseline (WWR=0.40), the combined effect of insulating glass (whole window SHGC=0.30, U-factor=2.43 W/m^2-°K, Tvis=0.53), exterior shading, automated interior shading, and dimmable lighting resulted in significant overall reductions in cooling demand.

Total peak electricity demand was reduced during daytime work hours (8:00 AM to 6:00 PM) from 3.73 to 2.65 W/ft^2 or 1.08 W/ft^2 (22%) on the peak day in July and by 21-25% during summer months from June through September. Average reductions during the summer were 0.80 W/ft^2. Lighting peak demand reductions of 0.42 W/ft^2 were consistent throughout the year with average monthly reductions of 0.49 W/ft^2 during these summer months. An example of the cooling demand profiles over a three week summer period are shown in Figure 26 where average demand reductions over this summer period during the day were about 0.18 W/ft^2. The sharp peaks in the figure are morning start-up periods when the HVAC system was working to cool down the zone after operating in the setback mode during the weekend or on particularly warm nights.

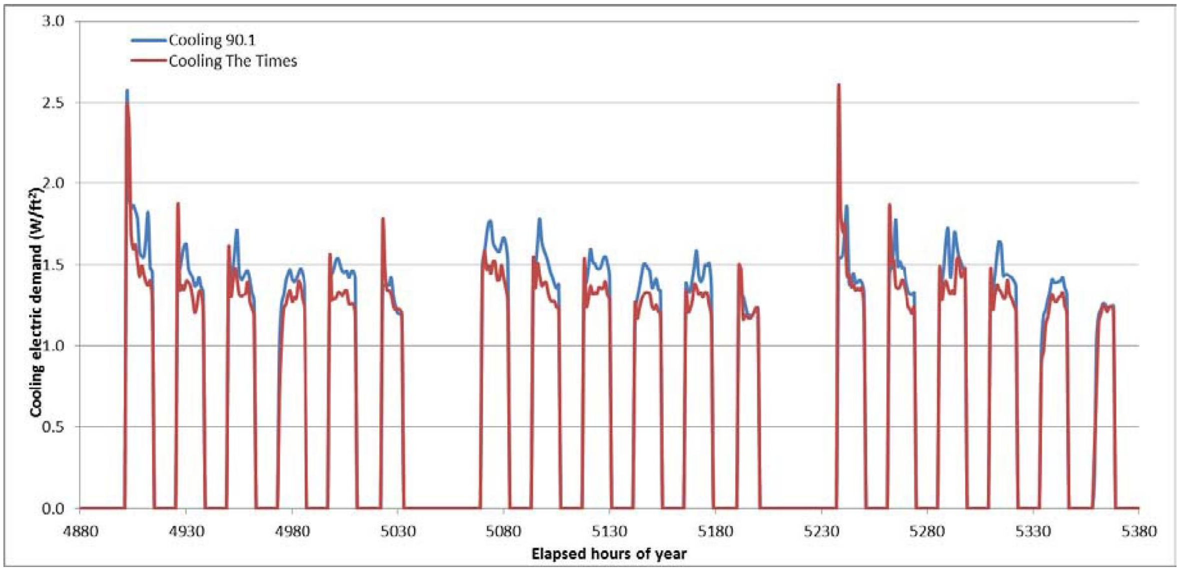


Figure 26. Peak cooling demand over the summer period from July 24 to August 12, 2011 for the ASHRAE 90.1-2001 and the Times Building model of the 20th floor. Data produced using the calibrated EnergyPlus models.

Generally, the effect of the energy efficient lighting and shading systems is to reduce loads on the HVAC system. The "efficiency" of the HVAC system has to do with characteristics associated with the type of system (e.g., see discussions about differences between UFAD and overhead systems in Section 4.3.2) and the sizing of components and their part load performance. However, these factors do not represent synergistic effects that would impact the performance of the HVAC system in a fundamental way. One potential synergistic effect is the impact of internal shading on UFAD performance. Some evidence (based on experimental work of the authors [24]) exists that lowering shades/blinds tends to increase stratification. However, this was not observed in the field measurements taken at the Times, largely due to the conventional linear diffusers at the base of the window wall which, in general, produced very little stratification. The remaining differences in energy use due to the HVAC systems are summarized in Table 7.

Based on this and other research conducted by the authors it appears, overall, that the contributions of lighting load reductions and thermal effects of the envelope system are the primary causes of the lowered HVAC energy use with secondary benefits from improved economizer performance and interior zone room air stratification for UFAD.

Table 7. Summary explanation of savings differences

End use	Description of differences
Plug loads	Same for both models, baseline uses calibrated model loads
Lighting	Lighting system differences reflect standard 90.1 loads versus the installed high performance lighting control system
HVAC: Fans	Fan energy use is a complex coupling of the following factors: • airflow required for cooling (lower for Times building), • AHU supply air temperature (SAT) settings that affect economizer performance (lower for UFAD), • static pressure requirements (lower for UFAD), • perimeter fan powered terminal units (higher for UFAD), • effect of higher zone supply air temperatures due to temperature rise in the supply plenum for UFAD (higher for UFAD), • effects of stratification for UFAD (lower for UFAD) • lower terminal unit minimum volumes (lower for UFAD) • and lowering of the zone load for UFAD due to heat transfer to the supply plenum (lower for UFAD)
HVAC: Cooling	UFAD cooling energy is less than baseline due to lower cooling load derived from lower lighting loads, an efficient building envelope (despite the large area windows), supply air temperature settings that allow economizer to lower cooling, and the effects on cooling load due to stratification.
HVAC: Heating	• Reheat energy is likely less for UFAD, thus reducing overall heating. Although zone heating loads may actually be larger for UFAD due to the cooling effect of the supply plenum, the savings in reheat dominate. • The minimum VAV box fraction for the baseline is 30% versus 5% for the real building, increase reheat for the baseline. • The UFAD system has no heating in the interior zones, whereas the overhead model does, this tends to further reduce reheat requirements for UFAD.

An economic analysis was performed for all energy efficiency measures combined. As assumed in prior sections, the incremental cost was \$2.12/ft^2 for lighting and \$1.39/ft^2 for shading. The incremental installed cost of the UFAD system with a raised floor compared to a standard slab floor with an overhead HVAC system was assumed to be \$3.50/ft^2 (cost based on prior research [25]). The total incremental cost for all materials and labor was \$5.58/ft^2 when normalized for the different floor areas in which the technologies were installed. The UFAD system was assumed to have been installed throughout the entire floor except for elevator shafts, mechanical shafts, and stairs.

In total, annual electricity energy use was reduced from 10.74 to 8.16 kWh/ft^2-yr and annual heating energy (modeled as a gas-fired boiler) was reduced from 2.67 to 1.31 kBtu/ft^2-yr. Assuming average energy prices in the New York area of \$0.19/kWh and \$1.20/therm, a life of 30 years for all measures, and a discount rate of 6%, the simple payback was 7.9 years, the net present value (NPV) was \$4.10/ft^2 (net profit), and cost of conserved energy was $0.11. The internal rate of return was 12%. Results using the time-of-use rate schedule were the same.

5. Ensuring success: Lessons learned for replication strategy

The time and care that the Times Company took to design, engineer, and follow-through on the design intent behind the energy efficiency measures and the actual performance of the technological measures themselves led to post-occupancy survey data indicating that a significant fraction of the building occupants were satisfied to very satisfied with the overall building and that, compared to other buildings, the overall level of satisfaction was greater than the norm of surveyed buildings [7]. There was also a high percentage of building occupants that felt that the new building enhanced the ability to do their job. While some particulars of the Times Building are unique (Figure 27), there are numerous lessons that can be learned from the Times Company experience and applied not only to other new buildings but also to the nation's existing building stock. The "lessons learned" by the Times Building staff and their collaborators, now reinforced with measured and simulated energy performance data and occupant surveys, should facilitate scalable replication of many of the systems evaluated in this study.

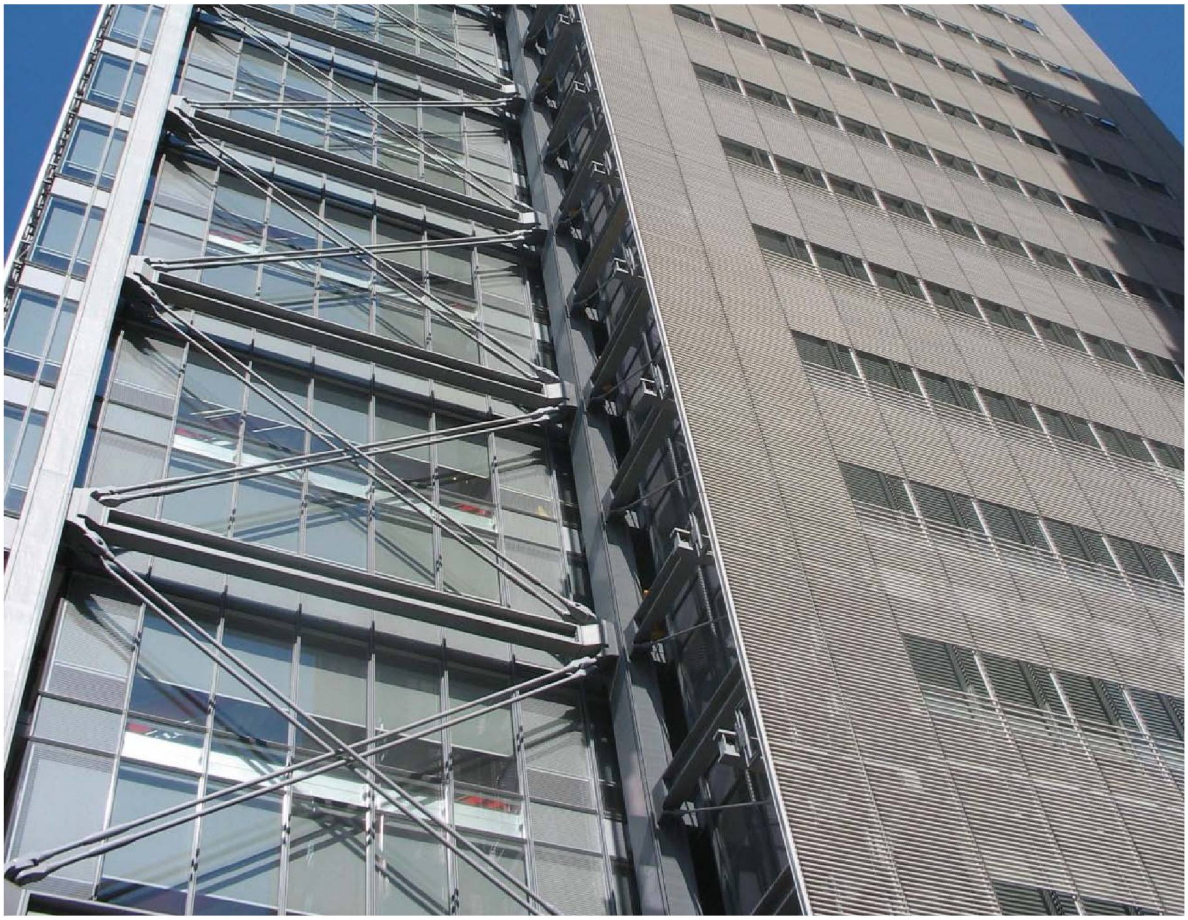


Figure 27. Exterior façade of the Times Company tower. Copyright: The Times Company.

5.1. Lessons learned: Lighting and the automated shading system

1. High performance can be attributed to the lighting control and daylighting technologies

First and foremost, the combination of the dimmable lighting system and automated roller shades led to significant lighting energy savings (1.96 kWh/ft^2-yr or 38% below ASHRAE 90.1-2001) for depths up to 40 ft from the window and even though these energy-efficiency gains were achieved through reduced electric light output, occupants were very satisfied with the overall quality and visual comfort of the resultant light in their workspace. The lighting quality is in part a product of the architectural design of the building envelope and the interior design and layout of the zone, furniture, and spaces within. But it is also a result of the successful implementation of dynamic shading and dimmable lighting in the same zone. A much poorer lighting quality and occupant satisfaction would have been achieved if the lighting system overdimmed or if the automated shades were rarely raised due to conservative setpoints on the control system or poorly calibrated sensors. The same could be said if the shades and lighting were not automated – electric lighting might have predominated if manually-operated shades remained lowered throughout the majority of the year, as has been documented in other field studies.

2. Details of specification and procurement matter

Details of specification and product selection can make the difference between a successful project and a project destined to fail. The shading and lighting control technologies are offered by multiple vendors but if specified and implemented incorrectly without the features needed to address the many complex facets of the control problem or the specific requirements of individuals, groups, or the facility management team, then it is likely that the ensuing quality of the indoor environment and the energy performance will be unsatisfactory.

Automated control systems are designed to respond to specific performance criteria that must be determined through calculation and/or measurements. The lighting system dims overhead lamps by sensing indoor work plane illuminance levels. The shading system raises or lowers shades by determining sky conditions using outdoor sensors, calculating solar position, and measuring window luminance with indoor sensors. Proper sensor placement and calibration, and adequate control algorithms are critical to achieving reliable performance in complex outdoor and indoor environments.

The Times Company was successful in their venture because they made the effort and investment to understand building performance, weighed the necessary trade-offs that needed to be made (e.g., roller shade fabric choice, pros/cons of different control algorithms), became familiar with product offerings, and understood the projected long-term benefits and outcomes. Developing the procurement specifications and then following through in the value engineering stage were then much more straightforward.

3. Ease of commissioning, troubleshooting, and finetuning also matter in the long run

Occupant satisfaction, ease of facility maintenance and operations, and ease of improving building performance would have been significantly less if software-based features for finetuning the control systems had not been put into place. Digitally-addressable, dimmable lighting enables finetuning of light levels to occur completely in software over the life of the installation. As lamps age, photosensing and dimming controls compensate for reduced light output. The ability to adjust photosensor sensitivity if under- or over-dimming or to change setpoint levels via simple software changes provides building managers with the essential tools to maintain high performance levels with very little effort compared to the preceding mechanical and analog systems of a decade ago.

For the automated shading system, similar capabilities for efficient tuning are built into their system. The Times Company has the option of rezoning shade motor groups if space reconfigurations are made or adjusting settings for depth of sun control all in software. The authors strongly advocate inclusion of manual override switches in the procurement package. Even though automated control of 80% of all motor groups installed in the building were infrequently overridden by occupants during daytime work hours (an average 0.4% of annual work hours), 20% of shade motor groups were overridden more frequently (an average of 29% of annual work hours for the subset of all motors that were overridden at least once). Given the challenge of achieving an optimum *trade-offs* or balance between competing performance criteria and the diversity of human response to glare in a shared open plan work environment where critical computer tasks were being performed, the level of overall acceptance of dynamic shading was probably increased by providing the option of manual override. Building occupants have diverse needs and desires which can be seen by examining the top two stated reasons why the shades were overridden: 42% of all overrides were to *lower* the shade to reduce sunlight, while 25% were to *raise* the shade to maximize view.

4. Active management and follow through is essential

The implementation of three complex building systems was also successful because the Times Company set up a process to track the systems after the bids were awarded and verified performance claims in the final building prior to sign-off of the systems. The Times Company and the selected manufacturer worked together to determine the likely outcomes of critical decisions involving placement of sensors, setting up zones, and determining the setpoints (when shades are retracted to view the sunset, what illuminance level the lights should be dimmed at, what temperature the thermostats should be set to). The final installed product was evaluated systematically for each and every zone using accurate measurement tools with a pre-defined set of objectives and protocols (e.g., [26]).

The final installation did require additional fine tuning for the first year of full occupancy. Afterwards, there was very little that needed to be done. In discussions with the Facilities lead, he noted that maintenance and operations were "surprisingly" minimal for all three systems, given that he initially thought that the innovative systems would result in problems from the start.

5. Diagnostic tools and effective communications with building occupants are essential for finetuning and troubleshooting automated systems

There were and will continue to be complaints or problems that need to be addressed after occupancy. Diagnostic tools that accompany control systems provide the critical data needed to enable informed troubleshooting in a timely manner. These dashboards can make building performance transparent, similar to that in cars or airplanes, providing feedback so that systems can be improved. Weekly reports from the lighting system informed the Facilities team of if, where, and how systems failed, minimizing the time needed to figure out and then fix the problem. Both the shading and lighting central control systems provided on-line, real-time diagnostic tools that could be used by the Facilities team for troubleshooting. The ability to respond quickly to occupant complaints no doubt contributed to increased occupant satisfaction.

The more challenging issues did take longer to address and required additional tools to detect. For example, occupant surveys provided anonymous information to the Facilities team on the degree of dissatisfaction, extent of the problem, and specifics on why occupants thought certain aspects of the building didn't work. Analysis of survey data showed a significant correlation between how well employees felt they were informed about the innovative lighting and comfort features in the building and a positive level of satisfaction with lighting quality and visual comfort variables. Taking the time to explain the hows and whys of automated control can make energy-efficient systems more acceptable to end users.

6. Automated controls need careful engineering and specification

It is important to conduct engineering studies prior to specification of the systems. The shade control algorithm used in the Times Building is applicable to internal load dominated commercial office buildings where the primary task involves use of computers. The controls minimized solar and lighting heat gains throughout the year for a building type that requires cooling in the perimeter zones during daytime hours even during the winter (note that there is minimal winter cooling energy use because free cooling is provided by the economizer so heating energy is needed to bring the outdoor air up to comfortable supply air temperatures to cool the zone!). Glare control was based on an average luminance of 2000 cd/m^2 as a starting point, the origin of which was a small but critical body of research on discomfort glare due to windows. Although the solution tested in this study is most likely applicable to the majority of US commercial office buildings, the control algorithm should be designed and optimized for a particular site and situation using building energy simulation tools.

7. Achieving a satisfactory balance between daylight admission and glare control is dependent on both the architectural design and innovative dynamic technologies

Achieving the right balance of daylight admission versus glare control is critical to achieving energy reductions and ensuring occupant comfort. If the automated shade control system is able to find the appropriate balance between maximizing natural light and interior brightness and minimizing glare, then the combined control of the shades and dimmable lighting will result in an acceptable and satisfactory indoor environment, minimize loads on the HVAC system, and enable significant reductions in lighting energy use.

The "enabling" critical component is the automated shades, aided and abetted by the design of the façade and the space. For this particular building, the façade system had already achieved the goal of admitting daylight (floor-to-ceiling, transparent window wall with a center-of-glass visible transmittance of 0.73), controlling window heat gains (low-e dual-pane glazing, fixed exterior shading), and to some degree controlling discomfort impacts of direct sun and glare (exterior shading mitigates bright sky luminance in the upper section of the window wall and blocks high angle sunlight from entering the building). The 4-ft high partitioned work stations enabled daylight to be admitted deeper into the 40-ft perimeter zones and view access through three sides of the building but also made control of discomfort glare significantly more critical.

The shades further mitigated the effects of the façade so that the average level of satisfaction with the automated system was greater than neutral (4.12 on a 7-point scale) and the overall satisfaction with lighting quality was closer to the upper range of very satisfied (5.53). Although the survey questionnaire did not distinguish between the source of light (daylight or electric light), lighting quality was also found to be significantly correlated to overall satisfaction with the building overall and whether the building enhanced an occupant's ability to get their job done.

However, 31% of the survey participants (665 people out of a total of 1900) did write in comments related to visual comfort due to window shade problems even though there was a low level of manual overrides to the automated system. The most common complaint was too much glare, which were correlated to the open plan workstations and employees adjacent to a window. It is generally well known in the industry that controlling discomfort glare remains a particularly challenging problem to solve. There has been very little basic research conducted to understand and quantify glare (a handful of studies compared to the hundreds on thermal discomfort). More work is needed in this critical area to better understand the origins of the problem and then to develop improved systems that address those problems.

8. Daylighting can be cost-effective, particularly for owner-occupied buildings

For office buildings with similar features (significant solar exposure and access to daylight, open plan work areas with low partition heights), the economics of an 8 year payback, 12% IRR for use of *all three* of these systems together in new construction may be compelling to building owners, given the large percentage (78%) of occupants that expressed satisfaction with the building overall.

The ASHRAE 90.1-2010 code and other newer building codes have, or are likely to, mandate daylighting in sidelit perimeter zones using automated bi-level switching controls, at minimum. Since the majority of lighting energy savings occurs in the first 10-20 ft from the window, dimmable lighting in this zone would have an even shorter payback than the 4-6 year payback calculated for the 15-40 ft deep perimeter zones. If reduced capital costs can be included in the economic analysis, such as reduced chiller capacity, smaller duct work, etc. due to reduced cooling loads from the envelope and lighting systems, the payback time will be reduced. If the reduction in costs for space reconfiguration or churn is included, payback time could be further reduced. If one includes occupant satisfaction, their ability to get the job done (productivity), and overall satisfaction with the building, this resultant high indoor environmental "quality" in the real estate market may override conventional bottom-line engineering-based economics.

For leased buildings, the trend toward individual metering for electrical energy will enable tenants to recover the cost of making energy-efficiency improvements to rented space. As reliable wireless communication systems for sensors, actuators, and supervisory control systems become more prevalent, applicability to retrofit buildings will also become more cost effective.

5.2. Lessons learned: Underfloor air distribution system

- Based on the high level of satisfaction reported in the survey responses, the thermal comfort and indoor environmental quality provided by the UFAD system in combination with the other energy efficiency measures were well received by both the Times Company facilities management team and the workforce.
- Beyond the careful selection of complementary advanced energy efficient technologies, the overriding reason behind the high quality environment achieved at the Times Company was the commitment and attention paid to installing and commissioning the various systems over time. In the case of the UFAD

system, operators were able to fine-tune control strategies and thermostat setpoints to provide a thermal environment that was stable and comfortable across the entire floor plate. Due to this consistent operation and reduced occupant complaints, the operators expressed strong support for the choice of a UFAD system.

- Specific lessons learned are as follows:
- Pay attention to the placement of floor diffusers in the vicinity of building occupants. Although most occupants will adjust their nearby floor diffuser very infrequently, the availability of having some amount of personal control is very important to occupant satisfaction and should always be provided if possible.
- Temperature stratification is an important characteristic of a well-operated and controlled UFAD system. At the Times Company, good stratification (2-4°F in the occupied zone) was maintained in interior zones. However, vertical mixing provided by the linear bar grilles at the perimeter tended to eliminate almost all stratification near the windows. Efforts to increase stratification in the perimeter could reduce energy consumption, but care must be paid to maintain acceptable comfort levels.
- In stratified environments, thermostat temperature setpoints (at 4-ft level) should be adjusted to account for the cooler temperatures near the floor. The goal is to maintain the average temperature in the occupied zone (up to 6-ft height) at the desired setpoint temperature. For example, in a stratified space, it may be necessary to raise the thermostat setpoint by 1-2°F. In fact, in the Times Building, temperature measurements demonstrated that most average occupied zone temperatures in the stratified interior zones were near the low end of the thermal comfort zone defined by ASHRAE Standard 55-2010. Raising the thermostat setpoints in these areas could provide an opportunity to reduce energy use (by reducing airflow quantities) without compromising comfort, and possibly improving comfort.
- A commonly observed operating condition in UFAD buildings is a tendency to “overair” the conditioned space. It is recommended to conduct a careful review of airflow quantities, including checking the minimum ventilation rates that are set in the underfloor VAV terminal units in the perimeter, as well as the primary VAV controls serving the underfloor plenum.
- Another option for control adjustment that can be considered in terms of improving comfort and/or energy performance is to change the supply air temperature leaving the air handler.

6. References

[1] Lee, E.S., S.E. Selkowitz, G.D. Hughes, R.D. Clear, G.J. Ward, J. Mardaljevic, J. Lai, M. Inanici, V. Inkarojrit. 2005. Daylighting the New York Times Headquarters Building: Final report. LBNL-57602.

[2] Lee, E.S., G.D. Hughes, R.D. Clear, L.L. Fernandes, S. Kiliccote, M.A. Piette, F.M. Rubinstein, S.E. Selkowitz. 2007. Daylighting the New York Times Headquarters Building: Final Report: Commissioning Daylighting Systems and Estimation of Demand Response.

[3] ASHRAE. 2001. *ANSI/ASHRAE/IESNA Standard 90.1-2001, Energy Standard for Buildings Except Low-Rise Residential Buildings.* Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

[4] US Department of Energy, Building Energy Databook, 2010, Table 3.1.5, p.3-3. http://buildingsdatabook.eren.doe.gov/docs/DataBooks/2010_BEDB.pdf

[5] US Department of Energy, Building Energy Databook 2010, Table 3.1.13, p.3-6.

[6] Fernandes, L.L., E.S. Lee, D.L. DiBartolomeo, A. McNeil. Monitored lighting energy savings from dimmable lighting controls in The New York Times Headquarters Building, Submitted to *Energy and Buildings*, January 2013.

[7] Sustainable Energy Partnerships. 2012. Final report: Post occupancy review for The New York Times Building. Sustainable Energy Partnerships, Tarrytown, New York.

[8] Clear, R.D. 2010. Technical Memo: Post-occupancy evaluation of The New York Times Headquarters Building: An examination of causes for occupant satisfaction and dissatisfaction with the energy-efficiency measures. Lawrence Berkeley National Laboratory, Berkeley, CA 94720. http://windows.lbl.gov/comm_perf/nyt_pubs.html

[9] US General Services Administration. GSA Advantage! https://www.gsaadvantage.gov/advantage/main/start_page.do

[10] U.S. Department of Labor, Bureau of Labor Statistics. News Release: Average energy prices in New York – Northern New Jersey – February 2012, April 13, 2012. http://www.bls.gov/ro2/avgengny.pdf

[11] Carrilho da Graça, G. and P.F. Linden. NaturalWorks Inc.: Energy Modeling for The new New York Times Headquarters Building, June 2006.

[12] Arasteh, D., S. Selkowitz, J. Apte, M. LaFrance, Zero Energy Windows, Proceedings of the 2006 ACEEE Summer Study on Energy Efficiency in Buildings, Pacific Grove, CA, 2006.

[13] Lee, E.S., S. Selkowitz, V. Bazjanac, V. Inkarojrit, C. Kohler. 2002. High-performance commercial building façades. LBNL-50502.

[14] Lee, E.S., S.E. Selkowitz, D.L. DiBartolomeo, J.H. Klems, R.D. Clear, K. Konis, R. Hitchcock, M. Yazdanian, R. Mitchell, M. Konstantoglou. 2009. *High Performance Building Façade Solutions.* California Energy Commission, PIER Publication. LBNL-4583E.

[15] Webster, T., T. Hoyt, E. Lee, A. Daly, D. Feng, F. Bauman, S. Schiavon, K.H. Lee, W. Pasut, and D. Fisher. 2012. Influence of design and operating conditions on underfloor air distribution (UFAD) system performance. Accepted for presentation at SimBuild 2012, Madison, WI, August 1-3.

[16] Hughes, G., and M. English. 2007. Underfloor air distribution in a commercial high rise: The New York Times Headquarters. *Proceedings, 15th National Conference on Building Commissioning*, Chicago, IL, May 2-4.

[17] Bauman, F.S., T.G. Carter, A.V. Baughman, and E.A. Arens. 1998. Field study of the impact of a desktop task/ambient conditioning system in office buildings. *ASHRAE Transactions* 104 (1).

[18] Lee, K., Z. Jiang, and Q. Chen. 2009. Air distribution effectiveness with stratified air distribution systems. *ASHRAE Transactions,* Vol. 115 (2).

[19] Zhang, H., E. Arens, D. Kim, E. Buchberger, F. Bauman, and C. Huizenga. 2010. Comfort, perceived air quality, and work performance in a low-power task-ambient conditioning system. *Building and Environment* 45 (1), pp. 29-39.

[20] Webster, T. et al. The New York Times Building Post-Occupancy Evaluation, Interim report. March 2012. Center for the Built Environment, University of California, Berkeley, CA.

[21] ASHRAE. 2010. *ANSI/ASHRAE Standard 55-2010, Thermal Environmental Conditions for Human Occupancy.* Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

[22] Hoyt, T., K.H. Lee, H. Zhang, E. Arens, and T. Webster. 2009. Energy savings from extended air temperature setpoints and reductions in room air mixing. *International Conference on Environmental* Ergonomics, Boston, August 2–7, 2009.

[23] EnergyPlus Engineering Reference, October 11, 2010. http://apps1.eere.energy.gov/buildings/energyplus/pdfs/engineeringreference.pdf

[24] Bauman, F., T. Webster, and C. Benedek. 2007. "Cooling Airflow Design Calculations for UFAD." *ASHRAE Journal*, Vol. 49, No. 10, October, pp. 36-44.

[25] Webster, T., C. Benedek, and F. Bauman. 2006. "Underfloor Air Distribution (UFAD) Cost Study: Analysis of First Cost Tradeoffs in UFAD Systems." Center for the Built Environment, University of California, Berkeley, CA, September.

[26] Lee, E.S., R.D. Clear, G.J. Ward, L. Fernandes. 2007. Commissioning and verification procedures for the automated roller shade system at The New York Times Headquarters, New York, New York. http://windows.lbl.gov/comm_perf/pdf/nyt-shade-cx-procedures.pdf