DAYLIGHTING THE NEW YORK TIMES HEADQUARTERS BUILDING
Final Report:
Commissioning Daylighting Systems
Estimation of Demand Response

Prepared for

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Washington D.C.

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7827
DRAFT: 8/30/07

NOTICE

ABSTRACT

The technical energy-savings potential for smart integrated window-daylighting systems is excellent and can yield significant reductions in US commercial building energy use if adopted by a significant percentage of the market. However, conventional automated shades and daylighting controls have been commercially available for over two decades with less than 1-2% market penetration in the US. As with many innovations, the problem with accelerating market adoption is one of demonstrating real performance and decreasing risk and cost. The New York Times considered use of such daylighting systems for their new 139,426 m^2 (1.5 Mft^2) headquarters building in downtown Manhattan.

In the initial phase of work, The New York Times employed a unique approach to create a competitive marketplace for daylighting systems and to address their concerns about risk by building a full-scale daylighting mockup and evaluating commercially-available products. This field test formed the strategic cornerstone for accelerating an industry response to the building owners' challenge to a sleepy market. A procurement specification was produced and bids were received that met The Times cost-effective criteria. The Times decided to proceed with using these innovative systems in their new building.

This next phase of work consisted of two distinct tasks: 1) to develop and use commissioning tools and procedures to insure that the automated shade and daylighting control systems operate as intended prior to occupancy; and 2) to estimate the peak demand savings resulting from different levels of demand response (DR) control strategies (from moderate to severe load curtailment) and then determine the financial implications given various DR programs offered by the local utility and New York Independent System Operator in the area.

Commissioning daylighting control systems is mandatory to insure that design intent is met, that the systems are tuned to optimal performance, and to eliminate problems and errors before occupants move in. Commissioning tools were developed and procedures were defined and then used to verify that the daylighting systems operated according to the technical specifications. For both lighting control and shading systems, the Times and the manufacturers were able to resolve most of the bugs and fine-tune the systems prior to occupancy.

The demand response (DR) strategies at the New York Times building involve unique state-of-the-art systems with dimmable ballasts, movable shades on the glass facade, and underfloor air HVAC. The process to develop the demand response strategies, the results of the EnergyPlus model, the activities to implement the DR strategies in the controls design at the New York Times Headquarters building and the evaluation of economics of participating in DR programs are presented and discussed. The DR simulation efforts for this building design are novel, with an innovative building owner evaluating DR and future DR program participation strategies during the design and construction phase using advanced simulation tools.

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

ACKNOWLEDGMENTS

This work was supported by the New York State Energy Research and Development Authority, with additional cost-shared support from the California Energy Commission through its Public Interest Energy Research Program, and by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, State and Community Programs, Office of Building Research and Standards of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

We are indebted to Glenn Hughes, Director of Construction/ Real Estate, David Thurm, Chief Information Officer, Hussain Ali-Khan, Vice President, and Larry Dumpert, Director of Facilities Technology, Real Estate Development, at The New York Times for their generous support and dedication to this collaborative effort. We are also indebted to our industry partners whose patience, hard work, and collaborative spirit proved their dedication to this project's objective of transforming the market. Industry partners in this phase of work included Lutron Electronics, Inc. and MechoShade Systems.

For the commissioning activity, we acknowledge Attila Uysal, SBLD Studio, Inc. and his graduate students Star Davis, Phan Dung, Meghan Smith-Campbell, and Travis Watson from Parsons The New School for Design, for their hard work assisting in verifying the daylighting control systems performance; and our LBNL colleagues Dennis DiBartolomeo, Daniel Fuller, Chad Howdy Goudey, Jim Galvin, and Mark Mensch, for their supportive work.

For the demand response activity, we thank the following people for their work in identifying opportunities with The Times building systems for demand response: Daniel H. Hall, Frank A. Cuomo and Garry Myers from Flack and Kurtz; Guilherme Carrilho Graca and Paul Linden from Natural Works; Chris Lesnik and Gary Marciniak from Siemens Building Technologies; Lem Mellusi, John-Paul Lalenne, and Michael English from Horizon Engineering; and Fred Bauman from University of California of Berkeley.

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EXECUTIVE SUMMARY

In 2004, The New York Times Company (The Times) approached the Lawrence Berkeley National Laboratory (LBNL) to discuss the use of daylighting technologies in their new headquarters building in New York, New York. As a result of that discussion, a collaboration was formed between The Times, LBNL, industry, The New York State Energy Research and Development Authority, the Department of Energy, and the California Energy Commission. The research was designed to demonstrate the energy savings potential of automated roller shades and dimmable daylighting controls in a building designed to maximize daylighting. Project activities included documenting and demonstrating that the technology worked and generated significant energy savings in real world applications, creating a market response so that these systems would become available at mainstream market prices and therefore be cost-effective, making third party performance data available to the public, and providing guidance to support widespread daylighting design and practice. Results from the pre-bid and post-bid phases are reported in [1].

This report summarizes research activities that were conducted during the commissioning phase of the building prior to occupancy. The work consisted of two distinct tasks:

1) develop and use verification tools and procedures to insure that the automated shade and daylighting control systems operate as intended prior to occupancy, and
2) estimate the electric demand savings resulting from different levels of demand response (DR) control strategies (from moderate to severe load curtailment) and then determine the financial implications given various DR programs offered by the local utility and New York Independent System Operator in the area.

Commissioning Daylighting Systems

Commissioning daylighting control systems is mandatory to insure that design intent is met, that the systems are tuned to optimal performance, and to eliminate problems and errors before buildings are occupied. LBNL and The Times developed verification tools and procedures to measure and verify control system performance after the manufacturer had commissioned their system.

The purpose of the automated shade system was to control direct sun, minimize window glare, and maximize daylight and view. Therefore, tools based on high dynamic range (HDR) digital photography were developed to verify that the average window luminance was maintained within specified levels – an entirely new glare control feature of the manufacturer’s automated shade system. The measurement system was coupled with simulation and spreadsheet-based tools that enabled the operator to determine the critical locations and times to evaluate the control system. Other tools and procedures were developed to verify that the control system accurately prevented direct sun penetration beyond a specified depth, given the complex urban obstructions and exterior ceramic tube shading system.

The system was not used by The Times to simply pass/fail the manufacturer as initially intended. Instead, it was used to enable a productive evidence-based discussion between the Times and the manufacturer so that the two parties could collaboratively diagnose and tune the system to manage window glare (which tended to keep the shades lowered) but also to maximize daylight and views out (which requires that the shades be raised). The verification tools and procedures were found to be very satisfactory by The Times, who directed and conducted the actual verification tasks at the headquarters (HQ) building. The verification procedure was facilitated by access to control status and sensor reading data from the manufacturer's central computer and by a diagnostic mode built into the touch screen user interface near each set of motorized shades on each floor.

First-year graduate students who had taken a daylighting course were able to learn how to operate the tool within two to three days and conduct the simple well-defined tests to identify problems with the shading controls. Conducting diagnostics with the cart to determine the source of the problems required more technical experience and active discussions with the manufacturer. The verification tools and procedures can be readily applied to other buildings with some tailoring to the specific design of the façade and building context. The HDR automated capture software is reliant on consumer-grade digital cameras, which makes them affordable ($3-5K for the computer and high-end camera to achieve ±10% accuracy within 0-5000 cd/m^2 range). The software will require upgrades each time the digital camera product line's proprietary interface to the camera changes or the computer's operating system is changed.

Verifying that the Digital Addressable Lighting Interface (DALI) dimmable fluorescent daylighting control system operated properly required a far simpler approach compared to the automated shading system. The goal of the dimmable lighting control system was to maintain work plane illuminance levels at the setpoint level. A 3x3 square grid of nine sensors was used to measure average work plane illuminance in randomly selected work stations. Measurements in the same location were taken over a 20-minute period during which the shades were manually overridden to determine whether the lights dimmed proportionately to available daylight. The setpoint levels of the entire control zone could also be changed (refresh rate of the entire system was required to be within a 30-second period) to produce a range in dimming response with which to judge performance. The location of the sensors and relative light output of the fixtures were documented with photographs. Like the shade cart, the lighting control measurements enabled The Times to push back on conservative dimming response settings that contributed to under-dimming (thus reducing potential savings) and identify conditions when over-dimming was occurring (potentially compromising user satisfaction).

The illuminance sensors and logging equipment are commonly available in the lighting industry and requires minimal expertise to use. The DALI feature posed no unique challenges to the verification process. The manufacturer provided real-time data and control status information per ballast to the owner's operator on the floor, which facilitated troubleshooting. The measurement tool was built by the manufacturer for the owner's verification task and was also used by the manufacturer to complete their commissioning activities.

For both systems, The Times and the manufacturers were able to work out most of the bugs and fine-tune the systems prior to building occupancy. After occupancy, the Times expects to make further adjustments to the control settings to tailor the controls to department preferences (e.g., lighting setpoint; daylight-view-glare balance, etc.) and to address occupants' complaints.

Estimation of Demand Response

For the demand response work scope, LBNL worked with The Times, Flack + Kurtz, Horizon Engineering, Siemens Building Automation Systems, and Natural Works to better understand the designed systems, to embed centralized controls into the design phase with integrated feedback mechanisms, to develop sequence of operations, and to predict the demand savings of the proposed demand response (DR) strategies.

An initial meeting where the building's systems were described to guide the EnergyPlus simulation development was followed by a demand response strategy development meeting. The EnergyPlus model for a typical floor in the building was refined through a set of assumptions and simplifications and used to simulate the developed DR strategies.

About 400 kW out of a typical estimated 4,300 kW for The Times portion of the building[1]is identified as the DR potential for The Times building. For the economic analysis of DR potential, the LBNL team developed scenarios around it using the various available DR program financials. The results were presented in a paper at the ACEEE 2006 Summer Study [8].

Key results are:

- **Evaluating DR potentials in the design and construction phase of a project is a novel approach.** Demand response is usually incorporated into building operations to "help out the grid" or to reap additional savings from utility bills. The owner's previous building management

[1] Estimated load for the entire building is 10 MW, 57% of which is expected to be The Times. The 1.4 MW co-gen unit covers approximately 14% of this demand, leaving about 43% for potential demand reduction during a DR event.

experience and awareness of the grid-related issues has provided unprecedented support for creating an evaluation framework for building operations.

- **Predicting the load savings impact of DR strategies during the design phase is a difficult but worthwhile exercise.** The lack of readily available simulation tools that accurately model building operations make it difficult to predict DR savings. However, engineering estimates of DR potential can help building owners curtail load at peak times, thus allowing them to increase return on their investment.
- **DR is typically done out of goodwill and not for economics.** The most lucrative program for The Times is the Independent Capacity Program (ICAP) which is predicted to deliver $17,600 annually. This is considered a small amount of savings by the owner (estimated at less than 1% of the annual utility bill) and the motivation to participate in DR programs continues to be sustaining grid conditions and operations. The second and third best available programs save $1,600 and $1,440 per year respectively, lagging in savings due to lack of monthly capacity payments. DR programs are relatively new and it is possible that in the future greater savings might become available by participating in the program.

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Section 1
COMMISSIONING DAYLIGHTING SYSTEMS

1.1. INTRODUCTION

The construction cycle of the building life cycle is the time when the design intent is translated into a physical reality. Given novel integrated systems with which contractors (vendors, installers, commissioning (Cx) agents, etc.) do not have much experience, there is a risk that carefully laid plans will go amiss. To insure that the automated shading and daylighting control systems were installed and operating as intended, the manufacturers, LBNL, and The Times developed procedures to commission and verify system performance. With verification data resulting from these procedures, The Times possessed the unique capability to measure and compare performance to design intent and then discuss and tune system performance with the manufacturer prior to closure of the work scope and occupancy of the building.

For the automated shading system, the critical aspect of the verification task was not simply to determine whether the various parts of the manufacturer's control were working; the system had to work per the performance specification and optimize competing performance tradeoffs. Direct sun and glare control has to be implemented to prevent occupant discomfort but causes the shades to be more closed (lowered). Maximizing daylight (to minimize lighting energy use), interior brightness, and view is less critical than ensuring occupant comfort and causes the shades to be opened (raised). If the manufacturer's setpoints, delays, and other factors used to dampen control system response and reduce occupant distraction are too conservative, the shades will be lowered for the majority of the year, eliminating much of the daylighting and energy saving benefits to the interior. Therefore, the verification task focused on tuning the setpoints and delays so that the control system achieved a satisfactory balance between the competing performance variables.

For the daylighting control system, the work did not focus on defining procedures for commissioning the photosensors (tuning the gains and offset) and other components of control. Rather, the work focused on verifying that the systems worked after the manufacturer completed commissioning the photoelectric control system. The installed system was an open-loop proportional control system where the ceiling-mounted photosensor signal near the window was used to determine the output level for each of the individual DALI ballasts or group of ballasts in the daylighting control zones. In prior simulation work (see [1]), LBNL provided the manufacturer with photosensor signal data (for their specific photosensor design and location) and work plane illuminance at every desk location for a typical floor plan layout on representative floors of The Times Headquarters. These data enabled the manufacturer to gauge the variability in photosensor response under various solar conditions, then predetermine how to set their photosensor gains and offsets. The focus of the verification task was to define procedures for determining whether the task illuminance setpoint was maintained under variable daylight and shading conditions, whether proportional dimming was occurring, and to ensure that underdimming did not occur. Similar to the balance in tradeoffs required by the shade control system, under-dimming (i.e., over-lighting) ensures that task illuminance levels are adequate but defeats the intent of installing daylighting controls to save energy. Given that dimmable daylighting control systems and commissioning guidelines have been available over the past two decades, the unique challenge was to develop new verification procedures given the capabilities of a DALI system.

In collaboration, the manufacturers, The Times, and LBNL developed two "commissioning" (Cx)[2] carts to measure system performance. Initial concepts were built, tested, and critiqued in The Times' daylighting mockup at College Point, New York in July 2005. After discussing the pros and cons of various practical approaches, the Cx carts were developed in detail then shipped to The New York Times Headquarters (HQ) in late 2006. Detailed procedures for verification were developed in parallel. Additional resource simulation tools were created to determine the control mode of the shading control system given urban obstructions, direct sun, and sky conditions. Lutron Electronics, Inc. designed and built the dimmable daylighting control systems Cx cart. LBNL designed and built the shading system Cx cart.

LBNL worked collaboratively with the manufacturer and The Times to commission the controls in the final HQ building on the first few floors that had been fit out with the two systems. The control systems were tested and the verification procedures were adjusted. The Times then proceeded to verify the two systems' performance as floors were completed between December 2006 and June 2007, discussing and resolving control problems with the manufacturer and LBNL as issues arose. Logs and data were transmitted to LBNL on a regular basis so that the data could be reviewed. Minor system tuning was anticipated to occur as occupants moved in and adjustments were requested.

This process of iterative refinement of installation and calibration techniques in large buildings based on collection and analysis of on-site performance data is a significant advance over common practice. This work should be valuable for other owners who are considering such projects.

[2] For simplicity, we use the term "commissioning" (Cx) interchangeably with "verification". The focus of this task was to develop tools and verification procedures for the owner to check manufacturer compliance with the specification, but the manufacturers were free to use the same tools and procedures to commission their control systems.

1.2. COMMISSIONING AUTOMATED ROLLER SHADE CONTROL SYSTEMS

The majority of this project's effort was focused on developing verification tools for the automated shading control system since there were aspects of its control system that have never been implemented or verified in any commercial building. In the procurement specification (http://windows.lbl.gov/comm_perf/nyt_shades-controls.html), the control requirements are as follows:

1. The shades shall block direct sun so that the depth of direct sun penetration is no greater than a specified horizontal depth from the face of the window wall at floor level. The specified maximum penetration distance may vary for different perimeter areas and on different floors. The shades shall not be deployed to block direct sun if the sun is blocked by nearby buildings within an entire shade control zone. The exterior ceramic rods provide direct sun shading. Automated shade control shall account for this shading. The profile angle and solar surface azimuth angle shall be determined by the Shade Controls System Supplier based upon the geometries of the curtain wall.
2. The shades shall control glare so that the window luminance viewed from any angle within the work space is no greater than a specified level during the day. This includes all periods throughout the day when there is or is not direct sun in the plane of the window.
    a. When there is no direct sun in the plane of the window wall, the average luminance of the unobstructed portion of the window wall (the glazing area not shielded by the exterior ceramic rods) shall not exceed 2000 cd/m^2 (candelas per square meter).[3]
    b. When there is direct sun in the plane of the window but the orb of the sun is not within the immediate field of view, the average luminance of the unobstructed portion of the window wall shall not exceed 2000 cd/m^2.
    c. When there is direct sun in the plane of the window and the orb of the sun is within the immediate field of view, the average luminance of any portion of the window wall shall not exceed 2000 cd/m^2 for more than 30 minutes.
3. Daylight admittance shall be maximized by raising the shades when sun control and glare control are not required.

Additional bullets 4 through 16 address the details of delays, retraction for view, etc.

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[3] The threshold value of 2000 cd/m^2 was based on the assumptions that the primary task involved an LCD computer monitor with an average luminance of 200 cd/m^2, the window was within the occupant's peripheral field of view so that a maximum luminance ratio of 10:1 between window and task was just acceptable, and that the average background luminance was 50-100 cd/m^2. It was also based on subjective survey results that found that there was a 50% probability that blinds would be lowered when the average window luminance was 2100 cd/m^2 [1, 2].

While it is relatively easy to determine whether the basic requirements of bullet 1 are satisfied[4], it is relatively difficult to verify whether bullets' 2 and 3 requirements are met. A new tool was built to measure average window luminance using high dynamic range (HDR) digital photography [3]. The tool uses a computer and a conventional full-frame digital camera with a fisheye lens. The verification software queries the user for information on the location of the measurement, sky condition, and a subjective rating of the window glare, then takes an HDR image of the scene. The user selects the window portion of the image, then the software computes the average luminance as well as detects potentially problematic glare sources that exceed 2000 cd/m^2 with solid angles that are greater than 0.1 steradians. The total time to take one measurement is 3-4 minutes. Measurements were not trended; if the system failed, the building owner requested that the manufacturer address the problem given these limited data.

The locations of the measurements were based on the furniture and space layout, likelihood of glare (considering urban and interior obstructions), and position of the occupants' primary task views. Because visual discomfort due to window glare is highly dependent on view direction, adaptation level and task, measurements in the open plan areas were taken at the worst case locations. The building owner had the option of raising the threshold value given occupant feedback. Approximately 10-20 measurements were taken per floor on one day. These were used to pass the floor. Additional measurements taken during a different season/ solar condition could be used to check the robustness of the system but were not required.

The schedule for the measurements (e.g., which control zone first? What time of day?) was determined using predictive tools so that the operator could determine when the shades were in the glare control mode and when the window luminance was likely to be within the critical range of 1500-2500 cd/m^2. Additional simulation tools were developed to help the operator determine what control mode the shades were likely to be in given the sky condition during the time of measurement. This enabled the operator to determine whether the shades were operating properly and if not, how to isolate the cause of the problem. A detailed description of the verification tool and procedures for its use are given in [4]. A quick how-to guide was also produced [5].

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[4] Verification of direct sun control involves a) checking that the manufacturer's solar geometry and penetration calculations are accurate, b) tuning the threshold and delays for determining whether it is sunny or cloudy, and c) checking that shades are retracted when urban obstructions shadow the façade. Items (a) and (b) were verified in the daylighting mockup — see [1]. Item (c) can be verified by observations in the field (in combination with the predictive tool developed in this phase of work.

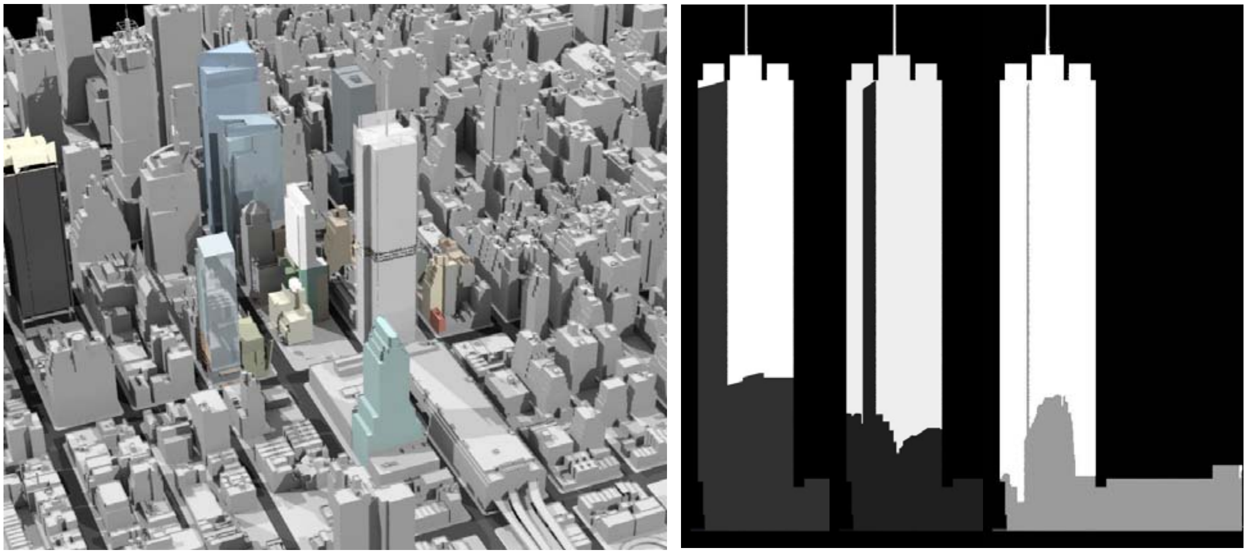

Figure 1-1. LBNL created a Radiance [6] model of the HQ building and urban context to produce time-lapsed visualizations of urban shadows cast on the facades. This enabled The Times to determine if the direct sun control mode was operating properly within a control zone.

1.2.1. Observations

The initial intended objective of the verification task was to ensure that the systems were working “properly” prior to occupancy and final payment for the system. While this objective did not change, the initial hard line stance changed over time as the building owner became more knowledgeable about the factors that affected control performance and the means to tune control system via owner-adjustable variables (e.g., setpoints, delays, sensitivity). The owner recognized that there were aspects of the shading control system that were entirely new. As such, the owner worked with the manufacturer to engineer and test hardware and software solutions. For example, the owner and manufacturer had to compromise on interior sensor locations in the final installation; some due to aesthetics and cost, others due to lack of adequate mounting surfaces to obtain the proper fields of view (e.g., near the stair). Other limitations were acknowledged. Perfect correlations between the control sensor values and the verification measurements taken at other locations within the control zone were improbable because the views of the exterior (sky and obstructions) differed, although the manufacturer did design and tune their sensors to accommodate these differences. Knowing that accurate shade control response relied on a variety of complex factors, the owner was more inclined to form a partnership with the manufacturer, collaborating to work out solutions.

At the same time, the verification data enabled the owner to hold firm, productive conversations with the manufacturer regarding inadequate control and to use the data to diagnose problems. As an example, the owner found that the shades were not raised on any of the four orientations despite the day being quite gloomy. This was true even for the façade orientations where the sun was in the plane of the window but the maximum allowable depth of solar penetration was not exceeded. Verification measurements indicated that the window luminance was below threshold levels when the shades were fully retracted on some facades. The owner had access to trend and event logs from the manufacturer for all control zones. After several detailed discussions, the owner discovered that the manufacturer had implemented conservative "release" thresholds (i.e., shade to be retracted only when the window luminance was less than 1000 cd/m^2) of which he was unaware. These thresholds were subsequently redefined as an owner-defined variable. In another example, The Times found sensors that inadequately measured/ predicted the glare conditions for the control zone due to improper location (not representative of typical glare conditions for the majority of the zone) or inaccurate calibration. On the mid-level floors (6-10), for example, urban obstructions which blocked the bright sky view varied across the width of some controls zones significantly. One sensor was found to have a clear shot down the street with a relatively unobstructed view of the sky whereas the majority of the occupants' views for the control zone were of a tall building across the street. Adjustments to sensor placement or sensitivity were required. The manufacturer provided time-of-day plotted data showing all sensor values, control sequences, and other relevant information, facilitating troubleshooting.

Verification activities in the HQ building were hindered by external factors typical in the construction phase of a high-rise building. Last minute changes to the furniture layout or space use prevented floors from being fully completed at one time, as previously intended. Hence, the shades were installed, commissioned, and verified in floor segments, complicating the sign-off of a floor. At any one time, the shade control system on the same floor was at different stages of completion, requiring good communication between the manufacturer and the owner prior to verification testing. The documentation features incorporated in the verification cart were essential for keeping track of progress, ensuring proper resolution of issues, and enabling historical checks over the verification and post-occupancy phases of the building.

Figure 1-2. Larry Dumpert, The New York Times, using the shade commissioning cart at the Headquarters building.

With construction delays, the time frame to conduct the verification task became compressed. Fortunately, as the verification procedures became more familiar and the initial problems with the control system were worked out, the required time to verify each floor decreased. On average, The Times spent one day per floor to verify control system's performance. In the first few months, much of the time was spent checking the installation and results of the manufacturer's pre-functional tests: motor assignments and groupings, electrical connections, motor operation, shade alignment and height calibration, operation of the touch pad user interface for each building wing, etc. Installation of the radiometers on the mast above the roof of the HQ building was delayed significantly, so solar data were not available when the owner began testing the shade control modes. Instead, the owner checked the direct sun mode of control incorporating the exterior ceramic tubes and urban shadows and the glare control mode for periods when the sun was out of the plane of the window (i.e., sensor assignments, setpoints, responsiveness, etc.). When the radiometers came on line, the owner was then able to check the glare control mode under cloudy conditions when the sun was in the plane of the window and spot check the direct sun control mode in its entirety. The controls functioned properly for the most part out of the box, despite it being a new product line. Tuning the system to achieve an acceptable daylight-glare balance was the main challenge as noted above in the Introduction. An example result from the verification activities is given in Figure 1-3.

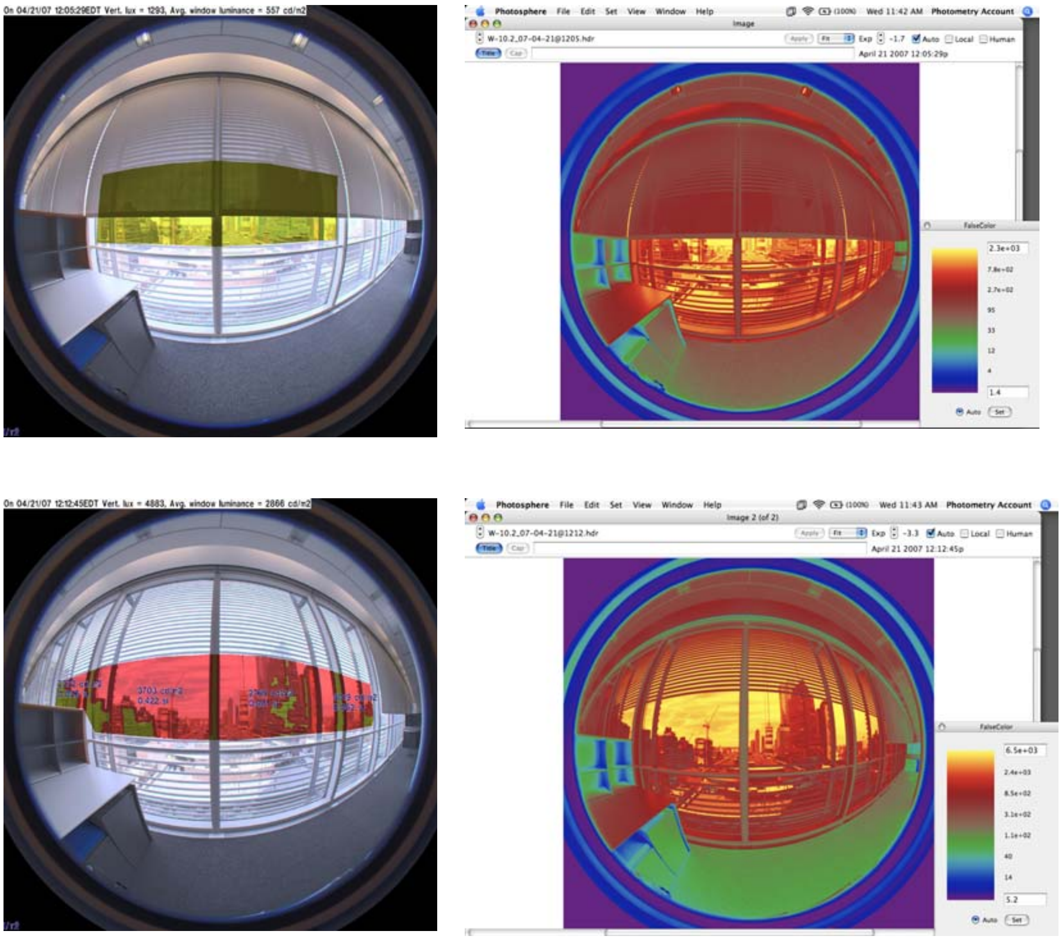

Figure 1-3. Example of results from shade commissioning cart. Top images shows shades in automatic mode where system passes because average window luminance is less than 2000 cd/m^2 (actual 557 cd/m^2). The shades are raised to determine if the shades should have been up because there was no need for glare control. Results of this second measurement (bottom images) show that the average window luminance exceeds 2000 cd/m^2 (actual is 2866 cd/m^2) so the shade again passes. Falsecolor luminance maps in right hand column images and pink area on left hand column images showing potential glare sources.

Clearly, the owner's level of determination to achieve acceptable and "optimal" control is a significant factor during the verification phase. The Times was committed to optimal control performance and dedicated the required time and resources to ensure that the performance targets were met. The project demonstrated that it is vitally important to include a performance verification test in the commissioning budget. If the owner representative or developer does not include a verification task in the commissioning budget, optimization of the controls may be left to the discretion of the manufacturer and not done at all. Further work is required to make the procedures generalizable for all types of building applications.

The high dynamic range (HDR) tool could be used to calibrate the window glare sensors but this was outside LBNL's scope of work. LBNL did measure the spatial and spectral response of the manufacturer's glare sensor and provided feedback to the manufacturer to improve the sensor design and calibration. In the HQ building, the Times allowed the manufacturer to use the verification shade cart to better understand how well their sensors accurately measured window luminance.

1.2.2. About the Verification Tool and Procedures

The verification tool itself was deemed by the owner to be excellent for its purpose, despite its simple command line user interface. With a rudimentary version of the tool in 2005, it took 10-20 minutes to measure and fully document a single point. The HDR tool must provide near instant feedback to the user so that the user's subjective impression of glare can be matched to the dataset and in-situ diagnostics can be performed in a timely manner. The final version of the tool provided data and diagnostic images within 1-2 minutes of image capture. Separately, the Radiance simulation tool showing urban shadows on each façade was used to sort out the control mode, while the scheduling tools predicting the direct sun control mode and sky luminance were not used regularly – after the first few weeks of verification activity, the operator learned and began to predict solar conditions and control status given field observations and working day to day with the tool. The tool and procedures can be modified for other buildings. Defining the location and timing of the measurements as well as which part of the window is to be measured is context dependent and requires a tailored solution.

To implement the verification procedures, the shade manufacturer must provide information on the status of the control mode and enable the operator to switch quickly between the automatic and manual control modes while out on the floor. For each point location, a measurement is taken with the shades in automatic mode, then the shades are raised and a second measurement is taken to determine whether the shades should have been raised. The owner was able to switch between modes via the touch screen user interface located in each building wing. Having easily accessible information about the control status and sensor readings on the floor in question would also facilitate diagnoses of control problems.

The manufacturer incorporates many types of time delays to dampen the control system's response to variable solar conditions. Evaluating a control system under unstable partly cloudy conditions can take significantly more time (20-30 minutes) and be exceedingly difficult to diagnose. To address this problem, the manufacturer should create a Cx mode where all time delays can be set so that the total response time is within minutes of the last control command. These additional features should be incorporated in the pre-bid procurement specifications.

The operator of the verification tool must have sufficient expert knowledge about the shade control system and generally about daylighting to be effective at diagnosing system performance. The operator must be able to work through the control algorithm, deduce the proper control mode, and diagnose possible problems in the field. The owner was able to train college students who had taken a class in daylighting on how to use the verification tool within 2-3 days, but diagnosing system failures required persistent discussions with the manufacturer to isolate the cause of the problems.

The verification tool itself relies on commercially-available digital cameras interfaced to a computer to automate image capture. Manufacturers of digital cameras develop a proprietary computer interface language to their cameras (API) and can change their suite of products and API at any time. Programming with the manufacturer's API is time-consuming and must be re-done and tested every time there is a change in the API or the computer's operating system. In addition, each camera and lens has its own unique response to light and therefore must be calibrated to a reference source. While the intention was to develop a publicly-available HDR tool for the industry, continued support will be needed to keep such a tool updated and widely useable.

1.3. COMMISSIONING DIMMABLE DAYLIGHTING CONTROL SYSTEMS

Verifying that the Digital Addressable Lighting Interface (DALI) dimmable fluorescent daylighting control system operated properly required a far simpler approach compared to the automated shading system. A 3x3 square grid of nine sensors (~ 2x2 ft area) was used to measure average work plane illuminance in randomly selected work stations. Measurements in the same location were taken over a 20-minute period during which the shades were manually overridden to determine whether the lights dimmed proportionately to available daylight. The setpoint levels of the entire control zone could also be changed (refresh rate of the entire system was required to be within a 30 second period) to produce a range in dimming response with which to judge performance. The location of the sensors and relative light output of the fixtures were documented with photographs. The procedure is documented in [7]. Like the shade verification cart, the lighting control measurements enabled The Times to push back on conservative dimming response settings that contributed to underdimming and identify conditions when overdimming was occurring.

Figure 1-4. Lighting commissioning cart (left) consisting of a 3x3 array of illuminance sensors placed on the work plane to monitor average illuminance over a 20 minute period. Ceiling pattern of dimmed fixtures (right) with window at the top of the photograph.

The illuminance sensors and logging equipment are commonly available in the lighting industry and requires minimal expertise to deploy in the field. The DALI feature posed no unique challenges to the verification process. The manufacturer provided real-time data and control status information per ballast to the Cx agent on the floor, which greatly facilitated troubleshooting. The Cx measurement tool was built by the manufacturer for the owner's verification activities and was also used by the manufacturer to complete their commissioning activities.

The Times and the manufacturers were able to work out the bugs and fine-tune the system prior to occupancy. The Times expected to make adjustments to the setpoint levels after each department moved in and had the opportunity to get used to the new building environment and the novelty of the lighting control system (3-6 months).

LBNL visited one of the occupied floors of the building on May 4, 2007, about two weeks after the roller shade and lighting control systems had been commissioned and verified by the Times using the procedures described in this report. Several observations were made. Lighting energy was demonstrably being saved while maintaining a very pleasant workplace environment. As shown in Figures 1-4 and 1-5, many of the rows of lights nearest the windows were off, while other fixtures nearby were visibly dimmed. This provided strong visual confirmation that the lighting system was not oversupplying electric lighting, thus satisfying design intent. Although LBNL did not perform light measurements, the Times had recently verified that illuminance targets were being maintained.

Several design decisions have led to this successful outcome.

- Automation of the shading insures that direct sun does not enter the space.
- During direct sun conditions, the roller shades are not lowered all the way to floor as originally intended. Instead, the shades are lowered only to the handrail height (30 inches above floor) to increase interior daylight levels and lighting energy savings. Sunlight is allowed penetrate greater than 3 ft from the window and to strike the occupant's feet.
- User exceptions are easily accommodated with the shade overrides via the touchpad.

Because of these design decisions, made possible by the use of the mockup, the final observed result is successful. The slowly changing patterns of dimmed electric lighting in the ceiling adds interest to the otherwise regular space.

Figure 1-5. View towards the south near noon on a sunny day (8^{th} floor, shading and lighting commissioned). Note the large number of fixtures that are off due to the large amount of daylight. Note also that many other fixtures are deeply dimmed as well confirming that the lighting system is performing as expected.

1.4. CONCLUSIONS

Instrumentation and procedures for verifying the installed performance of automated shade and dimmable daylighting control systems were successfully developed and applied in The New York Times Headquarters Building. With data gathered using two commissioning carts, The Times was able to have authoritative and productive conversations with the manufacturers on the control systems' performance.

The carts were used initially by the manufacturers to conduct system tuning and sensor calibrations if needed. The cart data were used for diagnostic purposes to troubleshoot control glitches. The Times maintained an open collaborative dialog with the manufacturers to insure that the systems performed to their satisfaction, which was important given the novelty and complexity of the control systems.

Whether or not the automated shade and daylighting control system succeeded in achieving a near-optimum balance between the competing trade-offs remains to be determined with post-occupancy evaluations and energy monitoring. At the conclusion of the installation and verification phase, both systems were operating generally as intended.

The verification tools and procedures could be readily applied to other commercial structures and other manufacturers' products with similar control intent. Building owners who are interested in using these systems in their building are advised to incorporate prior to building occupancy commissioning and verification activities in their work scope and schedule to ensure that the full benefits of these systems are realized.

Section 2
ESTIMATION OF DEMAND RESPONSE

2.1. GOALS AND OBJECTIVES

Commercial office buildings with dimmable lighting and high quality HVAC systems present significant opportunities for demand response (DR). The objectives of this project included:

- Development of DR control strategies and system integration concepts for different load management and demand response scenarios.
- Analysis of The Times building's energy savings and demand control potential by using a simplified model that considers the electric metering configurations, weather, and occupancy characteristics.
- Analysis of financial savings potential resulting from The Times' participation into DR programs offered by the utility company. This effort was coordinated with an energy services company in New York State to ensure that this task accurately predicts future DR program opportunities in New York City.

As a result of this work, the control of the daylighting systems and the under floor air distribution system in The Times' building design was supplemented with special control features to implement DR strategies.

2.2. METHODS

In order to achieve the above objectives, a set of working meetings were held. The first meeting was held at LBNL in June 2005. The owner brought together Flack and Kurtz (F&K), Horizon Engineering, Natural Works and researchers from UC Berkeley and Lawrence Berkeley National Laboratory. After this meeting, while Natural Works developed the building simulation model using Energy Plus (E+), the owner continued to work with F&K and Lutron to finalize the design of the systems. With the initial results from the simulations, LBNL conducted a financial analysis of the DR programs in which The Times would be eligible to participate. As the last part of the work, the owner continued to work with the commissioning agent to finalize the commissioning work.

2.2.1. Kick-off Meeting

A two-day meeting was held at LBNL on July 18th and 17th, 2005 to kick-off the project. Participants included F&K, Horizon Engineering, Siemens Building Automation, Natural Works, the owner, and researchers from both UC Berkeley and LBNL. The objectives for the meeting outlined by the owner on the first day of the meeting were to:

- Identify how much electricity the building will be using and how much it could give back to the grid as a reaction to price or reliability issues;
- Develop an energy model to understand energy consumption of the building; and
- Develop control strategies for DR that supports "no comfort", "partial comfort", and "typical comfort" conditions.

The initial roles and responsibilities of the teams involved in discussions were outlined by The Times at the beginning of the meeting. F&K was tasked with providing detailed information on the existing building systems and operations. Natural Works assisted with understanding the building and the under floor air distribution (UFAD) system. Developing the energy model required a set of assumptions that took shape in these meetings and presented after the development of the first Energy Plus model. The Times, with the assistance of F&K, promised to deliver the load profile and occupancy patterns of the floors. LBNL took on the task of carrying out a discussion with Consolidated Edison (ConEd) to learn about their DR programs and tariffs. The Times asked LBNL to develop financial scenarios of their possible DR program participation by considering the load shapes, developing DR strategies and evaluating economics.

2.2.2. EnergyPlus Model Development Process

With the information about the lighting and HVAC system designs acquired from the initial meeting and the follow up conversations with the project teams, Natural Works developed the E+ model for The Times in three phases. The first two phases were presented as slides and each were followed by a conference call to allow the team to ask questions. At the end of the third phase, a detailed report on the process and results of the DR simulations and control strategies were presented.

The first phase was delivered for review on November 28th, 2005. This effort concentrated on representing the building with realistic loads and occupancy patterns and deriving assumptions on the representations of the building systems based on the information available. The feedback from the first conference call was incorporated in the second phase of the development effort. In the second phase, delivered on February 24th, 2006, the building representation was completed and DR strategies were simulated. Second phase results were somewhat confusing with lower power densities and higher demand reductions than expected.

LBNL team decided to use a lower demand reduction amount to base the financial savings calculations. In addition, comfort indicators, such as predicted mean vote (PMV), from the final phase were believed to assist the owner to make a better decision about DR strategy selection. The final phase, including a report summarizing the three phases of development was submitted on June 15th, 2006. This report recommended applying DR strategies successively and progressively to achieve consistent demand reduction. The recommended DR strategy starts at 2 pm and is as follows:

2 pm:

- Cooling supply air temperature is set to 15.3ºC
- Thermostats: cooling set point increases to 24.7 ºC, various schedules
- Lights reduction: to 50% in Core, to 70% in PC interior zones and to OFF in PC perimeter zones.

4:30 pm:

- Thermostats: cooling set point increases to 25.8 ºC

5:30 pm:

- Lights reduction: to 50% in Core, to 70% in PC interior zones and to 70% in PC perimeter zones.

2.2.3. Economic Analysis of DR programs

The goal of the economic analysis of the DR programs for The Times was to find the most lucrative program the headquarters building could participate in after it is occupied. The details of each of the programs were summarized and the potential financial impact of participating in these programs with the estimated DR savings were calculated [8]. Historical information about the duration and the frequency of events was also collected and used for calculations. In addition, an energy services company was contacted to identify all the DR opportunities for The Times.

2.2.4. Commissioning

A final meeting was held on June 12th, 2006, to discuss the status of the DR strategies and make plans with the commissioning agent towards the completion of the DR strategy development and testing. The participants in this meeting were The Times, Horizon Engineering and LBNL. The agenda for the meeting included:

- Overview of the project
- Discussion on the preliminary DR simulation results.
- DR control strategies, sequences and graphical user interface (GUI) issues [9]
- Commissioning DR strategies
- Partnership issues

The Times presented an overview of the project and the timeline and finalized DR control strategies, sequences and discussed GUI issues with LBNL. Horizon Engineering was asked to include the DR control strategies into the commissioning scope

2.3. RESULTS

As a result of this work,

- DR strategies for lighting and HVAC systems were identified.
- The E+ model, originally developed to be used to evaluate UFAD technology, was used for the first time to estimate the DR potential of the building.
- The estimated DR potential was utilized to calculate the financial benefits under various DR programs offered by the utility.
- HVAC and Lighting specifications for DR operations were written.
- Specifications for commissioning DR operations were considered.

2.3.1. EnergyPlus Modeling

The EnergyPlus modeling report showed that the initial HVAC and lighting strategies were expected to yield 350 – 600 kW over 4 hours [10]. The comfort calculations show that pre-cooling of the inflow plenum slab during the morning of the DR event had a noticeable impact on comfort levels with little impact on energy consumption. The energy demand reduction resulted mostly from reductions in cooling demand and lighting energy use. The isolated impact of pre-cooling on energy demand was small. Still, the comfort analysis showed that pre-cooling should be pursued for its positive impact on occupant thermal comfort.

2.3.2. Economic Analysis of DR Strategies

The amount of financial savings depended on the financial structure of DR programs available from the local utility and the NY Independent System Operator (NYISO). LBNL completed the DR economic analysis for The Times and presented the findings in a paper presented at the ACEEE 2006 Summer Study. At the time LBNL was conducting this study, Consolidated Edison offered five DR programs to its customers. Table below summarizes DR programs offered at the time this study was conducted.
Two of these programs were NYISO programs and are exclusive of each other. The authorities were considering mandatory real-time pricing (RTP) in the region. Therefore, the final analysis and recommendations were done using with and without mandatory RTP scenario.

Program	Notification	Enrollment Period	Duration	Required Shed	Incentive
Independent Capacity Program (ICAP) - NYISO	Day ahead	Summer (5/1-10/31) Winter (11/1-4/30)	Min. 4 hrs.	Min. 100kW	$6.68/kW of Unforced Capacity + energy payment of no more than $0.5/kWh
Emergency DR Program (EDRP) - NYISO	Min. 2 hr.	1 year	Min. 4 hrs.	Min. 100kW	$0.45/ kWh or 90% of price of energy in the real-time wholesale market
Distribution Load Relief Program (DLRP) - Con Ed	Min. 30 minutes	1 year	Min. 4 hrs.	Min. 50kW for 4 hrs.	$0.45/ kWh or 90% of price of energy in the real-time wholesale market
Day-Ahead Demand Reduction Program (DADRP) NYISO	Day ahead	1 year	Variable	Variable	Customers are paid at least the forecasted price of electricity which will not be less than $.05 for each kilowatt-hour curtailed
Voluntary Real Time Pricing Program (VRTP) –Con Ed	Day ahead	1year	Not Applicable	No pre-required shed	Real time prices are the only incentive/disincentive for customers

RTP not Mandatory: If RTP were not mandatory, Independent Capacity Program (ICAP) and Day Ahead Demand Reduction Program (DADRP) participation might be beneficial to The Times. The goal of ICAP, which was to increase the reliability of the electric grid under constraints, was similar to the goals of The Times and yielded the most lucrative savings. In addition, The Times was advised to consider to participate in the DADRP program to experience with real-time prices at its own pace. DADRP was designed such that the next day's hourly prices were published a day ahead and the customers decide to participate or opt out of the program daily.

Under an RTP scenario, for example with the DADRP, a customer was paid at least the forecasted price of electricity or at least a minimum of $0.05 per kW that is bid and delivered as savings. Using 2005 NYISO's Day Ahead market location-based marginal pricing system and assuming a minimum increase of prices over a preset threshold of $0.25, the established threshold was exceeded five times over the summer in 2005. Since the limiting factor is the price of electricity, the duration of the shed depends on the duration of the price over the threshold. In 2005, the total duration of the price over the selected threshold was approximately 36 hours. This corresponds to 5 events each with seven to eight hours duration. Although the DR strategy that is simulated delivered 400kW over 4 hours, it is possible to sustain the savings with additional temperature adjustment of two to three degrees to extend the DR period up to four hours. If The Times participated in the DADRP in every hour with a 400 kW demand reduction, it would save a total of approximately $7,200.

Different penalties apply to different programs. Usually voluntary programs do not have any penalties associated with them. For example, in the DADRP, customers who fail to supply the load reduction that they committed are charged a penalty equal to 110% of the real-time or day-ahead wholesale price of electricity in effect during the time of the curtailment, which ever is higher. As a general rule, if the program requests a short response time and larger payments in return, the risks and penalties tend to be higher.

2.3.3. Final DR Strategies Developed for The Times

We do not have estimates of the electric peak reduction associated with each of these strategies. These strategies, however, have been evaluated for feasibility by the HVAC and lighting designers, commissioning agents, building owner, and LBNL. Field testing after the building is complete is needed to understand the performance of the individual strategies.

This section summarizes the DR strategies for the HVAC and Lighting System. For each component that is involved in DR, normal operation, DR strategy, end of DR mode and recovery modes as well as user interface issues are summarized.

HVAC Strategies

Duty Cycle ECMs (Electronically Commutated Motors)

Normal Operation: The ECM motors control the amount of air delivered to the perimeter by the Fan Powered Boxes. Under normal operating conditions, when the space temperature is below setpoint, the ECM motors are at minimum speed and the heating coil control valves are modulated. Upon a rise in space temperature, the heating coil control valve modulates closed, and when fully closed, the ECM motor speed increases to maximum speed as required to maintain space temperature at setpoint.

DR Strategy: There are six zones per floor on the tower portion of the building with approximately four (4) perimeter fan powered boxes (FPBs) per zone. During the DR mode, the motors in 2 non contiguous FPBs in the zones on the floor that are not experiencing a solar load (determined by the Mechoshade programming) shall be commanded to stop for a period of 5 minutes (adjustable). After the five minute time period, the selected FPB will be returned to normal control after the next two non-contiguous FPB motors are stopped. The zones that are on a solar zone will not shut off.

End of DR Mode: Demand recover mode for this strategy will occur when either the DR mode is concluded by the EMCS based upon the duration of the event planned, or when the normal un-occupied mode for this floor occurs, and that un-occupied mode has not been overridden.

DR Recovery Mode: The EMCS will examine the Time of Day schedule and determine if the space should be occupied or not, and based on that determination will recover.

If the floor is scheduled to be unoccupied at the same time as the DR period ends, the entire floor system will shut down and restart based upon the Time of Day Schedule.

If the floor is scheduled to be occupied, the zone motors that are off when the DR event concludes will have their speed increase limited to 10% speed increments over the next 15 minutes until the actual speed = required speed as determined by the space temperature sensor.space temperatures returned to normal occupied setpoints at the rate of 1 degree F per hour.

Graphical User Interface: The Screen will consist of a grid that has a row for each floor 2 through 28, and 14 columns. Column 1 would show the floor number, column 2 is for a check box (☒) where the operator can include the numbered floor in the strategy by checking the box, and the remaining columns (2 per zone) would have a status box to show which zones on a particular floor are currently oft, and the second column for the particular zone would be that zone's exterior temperature. (Solar zones on a particular floor would be blanked out.)

Perimeter Temperature Reset

Normal Operation: Under normal operating conditions, when the space temperature is below setpoint, the ECM motors are at minimum speed and the heating coil control valves are modulated. Upon a rise in space temperature, the heating coil control valve modulates closed, and when fully closed, the ECM motor speed increases to maximum speed as required to maintain space temperature at setpoint.

DR Strategy: There are six zones per floor. During the DR mode, the zone temperature setpoint is reset warmer by an adjustable amount.

End of DR Mode: Demand recovery mode for this strategy occurs when either the DR mode is concluded by the BMCS based upon the duration of the event planned, or when the normal un-occupied made for this floor occurs, and that un-occupied mode has not been overridden.

DR Recovery Mode: The EMCS examines the Time of Day schedule and determine if the space should be occupied or not, and based on that determination recovers.
If the floor is scheduled to be unoccupied at the same time as the DR period ends, the entire floor system shuts down and restarts based upon the Time of Day Schedule. Original temperature setpoints are restored (but floor remains off until next scheduled on).
If the floor is scheduled to be occupied, the zone temperature setpoints are restored in 2 degree increments, each 10 minute period.

Graphical User Interface: The Screen consists of a grid that has a row for each floor 2 through 28, and 14 columns. Column 1 would show the floor number, column 2 is for a check box (☒) where the operator can include the numbered floor in the strategy by checking the box, and the remaining columns (2 per zone) have a status box to show the zone temperature, and the second column would show the offset from setpoint (2 to 6 degrees).

Reset Interior Thermostat Setpoint

Normal Operation: The interior temperature sensors are mounted higher than the normal sensor height. They act as a watchdog to reset the static pressure setpoint of the underfloor static pressure based upon the temperature sensed. Normally this temperature is 78 degrees, resulting in a chest height temperature of 74 degrees. If the temperature sensed begins to drop, indicative that the floor load is less than design, the underfloor pressure is lowered slightly to cause less cooling to pass through the floor. Upon a rising temperature, the reverse occurs.

DR Strategy: When this strategy is implemented, the setpoint is raised to as high as 82 degrees.

End of DR Mode: Demand recovery mode for this strategy occurs when either the DR mode is concluded by the EMCS based upon the duration of the event planned, or when the normal un-occupied mode for this floor occurs, and that un-occupied mode has not been overridden.

DR Recovery Mode: The EMCS examines the Time of Day schedule and determine if the space should be occupied or not, and based on that determination recovers.

If the floor is scheduled to be unoccupied at the same time as the DR period ends, the entire floor system shuts down and restarts based upon the Time of Day Schedule.

If the floor is scheduled to be occupied, the setpoint is returned to normal occupancy setpoint gradually over the next 15 minutes.

Graphical User Interface : The Screen consists of a grid that has a row for each floor 2 through 28, and 14 columns. Column 1 shows the floor number, column 2 is for a check box (☒) where the operator can include the numbered floor in the strategy by checking the box, and the remaining columns (2 per zone) have a setpoint box where the operator fills in the DR upper limit temperature (any temperature between 78 and 282 based upon floor usage and experience), and the second column for the particular zone is that zone’s interior temperature.

Duty Cycle Toilet Exhaust Fans

Normal Operation: The toilets are served by fans TX-28-1 and TX-C-1. These fans start and stop with the outside air fans serving the NYT floors. When the NYT floors are placed in the occupied mode, the outside air supply fans start. The supply air volume is read by the system and the toilet and general exhaust fans speed are modulated to maintain system differentials.

DR Strategy: When this strategy is implemented, the toilet exhaust fans are turned off for 5 minutes out of each 15 minute period. The setpoint for the associated general exhaust fan (GX-28-1) is “locked’ to prevent it from ramping up in an attempt to achieve the CFM not exhausted by the TX fans.

End of DR Mode: Demand recovery mode for this strategy occurs when either the DR mode is concluded by the EMCS based upon the duration of the event planned, or when the normal un-occupied mode for the system occurs, and that un-occupied mode has not been overridden.

DR Recovery Mode: The EMCS examines the Time of Day schedule and determines if the space should be occupied or not, and based on that determination recovers from DR mode.
If the system is scheduled to be unoccupied at the same time as the DR period ends, the entire system shuts down and restarts based upon the Time of Day Schedule.
If the floor is scheduled to be occupied, the setpoint is returned to normal slowly over a two minute ramp up time period.

Graphical User Interface : The Screen consists of a grid that has four rows total for fans TX-C-1 and TX-28-12. Row 1 (Column 2) shows the fans descriptor (TX-C-1) and the second row is that fan's current status (On or Off). Rows three and four show the same data for TX-28-1. There are two columns. Columns 1 (Rows 1 and 3) are for check boxes (☒) where the operator includes the associated fan in the strategy by checking the box.

Raise Space Humidity to 55%
Normal Operation: The outside air handling units supplying conditioned fresh air to the floors presently delivers air at 47^0 degrees db (dry bulb)and 46.9^0 degrees wb (wet bulb)mresulting in a space humidity of 50%.

DR Strategy: When this strategy is implemented, the control loop setpoint is reset upward to cause the system to deliver supply air at 52^0 degrees db at 51^0 degrees wb resulting in a space humidity of 55%.

End of DR Mode: Demand recovery mode for this strategy occurs when either the DR mode is concluded by the BMCS based upon the duration of the event planned, or when the normal un-occupied made for the system occurs, and that un-occupied mode has not been overridden.

DR Recovery Mode: The setpoint for discharge air temperature is reset to $47^{0db}/46.9^0$ wb.

Graphical User Interface: The Screen depicts the outside air supply system (same graphic as used for normal operation) with the addition of a graphical "DR Mode" switch. When this "switch" is placed in the "DR" mode, the discharge temperature setpoint is raised to the DR Mode setpoint (adjustable).

Lighting Strategies:

There are two ways to implement demand shedding with lighting in commercial buildings: **absolute** reduction and **relative** reduction. Absolute reduction is achieved by programming preset scenes for lighting when demand response is dispatched. Relative reduction is reducing loads with respect to their settings at the time demand response is dispatched. Instead of dimming to a preset value, a certain percent reduction over its current value is achieved during a demand response event. This implementation requires that the light output from the lamp or power output from the ballast is communicated back to the lighting control system and centrally closed loop control is required.

The Times with its sophisticated lighting system was able to implement relative lighting reduction. Some of the key elements of DR with dimmable lighting controls in The Times were: 1) a number of preset strategies were created and saved; these include different strategies by floor depending upon the type of business activity, day of the week, occupancy etc.; 2) a master control that provided a relative power shave feature that reduced the output for every ballast selected by a percentage that can be selected at the main console; 3) a prediction model that simulated a selected DR strategy and determined what lighting energy savings would be achieved; and, 4) actual DR savings were tracked during DR events.

2.4. SUMMARY AND FUTURE WORK

This report has outlined and documented a series of tasks and research to evaluate the potential for savings from DR control strategies for The New York Times Headquarters building under construction in New York City. This research is novel for several reasons. First, it is rare for building owners and designers to consider demand response during the design and construction phases. Second, The Times building is the first known building where DR was incorporated in the building simulation model before the building was constructed. Finally, the entire process yielded a better understanding of the performance of the building's systems and should be completed with the final commissioning of the DR control strategies.

The future work includes: 1) commissioning the DR control strategies, 2) testing the strategies on DR event days and evaluating the results using the same methodologies with the utility, and 3) revising the economic analysis based on the actual DR sheds and the most current DR programs offered by the utility.

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