Office of the Future: Integrating DR and EE in Commercial Office Space Lighting

DR10SCE01

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ABBREVIATIONS AND ACRONYMS

ALS	Advanced Lighting Solution
Avg	Average
CASE	Codes and Standards Enhancement
CFL	Compact Fluorescent Lamp
GSM	Global System for Mobile Communication
K	Kelvin
kW	Kilowatt
kWh	Kilowatt Hour
LCD	Liquid Crystal Display
LED	Light-Emitting Diode
LPD	Lighting Power Density
M&V	Measurement and Verification
OTF	Office of the Future
RCP	Reflected Ceiling Plan
RFP	Reflected Floor Plan
SCE	Southern California Edison
SF	Square Feet
Title 24	California Building Energy Efficiency Standard
W	Watts
W/SF	Watts per Square Foot

FIGURES

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EXECUTIVE SUMMARY

Southern California Edison (SCE) in collaboration with Brookfield Properties Corporation conducted this project, as part of the Office of the Future effort at the Landmark Square building. The project demonstrates the demand response opportunities of introducing advanced lighting design and highly controllable lighting systems into office spaces.

This project has tree primary goals:

- Evaluate the demand response opportunities associated with advanced lighting design combined with innovative lighting controls and strategies to allow for easy and reliable control of the building lighting loads to foster greater customer participation in SCE's Demand Response (DR) programs.
- Quantify the demand reduction that can be achieved with advanced lighting design and innovative lighting controls.
- Provide measure and technical data that can be leverage for future utility program offerings.

Project renovated the lighting and lighting controls in a 1,577 square-foot office suite in the 24-story of the 443,000-square-foot Landmark Square building in downtown Long Beach, California. The office suite includes five private offices, a conference room, a kitchen, lobby, and corridor.

The testing performed indicated significant opportunities to implement DR strategies leveraging the advanced lighting design and innovative controls. However, the demand reduction was not proportional to the reduction being requested particularly for demand reduction requests of 20% or less. A part from the inherent dynamic nature of the lighting at the Landmark Square building, the lighting control used in the project does not measure power directly, which in turn may force the controls to over or under compensative given the nature of preset dimming scenes.

There were significant reductions in the lighting load when a DR strategy was invoked by the lighting controls. For a request of 50% power reduction, the control system delivered 0.254 W/SF (or 25% drop in power), while for a request of 30%, the reduction was 0.174 W/SF (or 30% drop in power). It is interesting to note that for requests for power reduction of 10, 15, 20, and even 25%, the lighting control system under performed significantly. This is most likely the result of the lighting control relying on preset dimming scenes to accomplish the demand reduction.

The project provided valuable data, insights, and lessons learned which should benefit not only future utility program offerings, but also the lighting controls industry as a whole.

The results of this project show the potential for leveraging advanced lighting design and innovative controls to promote effective DR strategies in office buildings. However, there are still several things that requires continue, if not greater, involvement with the lighting controls industry. Such as:

- Continue engagement of key lighting controls companies to demonstrate the need and value of having lighting control products measure directly power.
- Continue engagement of lighting controls companies to help them develop DR strategies that leverage power measurement instead of diming levels to further the incorporation of DR strategies into their product offerings.

- Continue engagement of lighting controls companies to help them develop DR strategies for leveraging their lighting control products to manage plug loads in commercial office spaces.
- Development of Codes and Standards Enhancement (CASE) studies to support requiring under California Building Energy Efficiency Standards that lighting controls must measure power.
- Evaluation of other markets segment that could benefit from incorporating aggressive lighting DR strategies.
- Renovation (or new construction) of an entire building lighting system to fully understand interaction of the various lighting systems and associated controls in delivering cost effective DR lighting strategies.

INTRODUCTION

Supported by the Office of the Future (OTF) Consortium, a collaboration of some of the nation's largest and most progressive utilities, including Southern California Edison (SCE), the OTF initiative is working to assemble technical guidelines for office renovation projects that specify performance requirements for different attributes of office spaces (e.g., lighting, plug loads, air conditioning, etc.) and whole building that result in at least a 25% and 50% savings over the building energy efficiency code.

As part of this initiative, the Landmark Square project was conducted by SCE in partnership with Brookfield Properties Corporation (the building owner) to demonstrate the demand response (DR) opportunities of introducing advanced lighting design and highly controllable lighting systems into office spaces.

PROJECT GOALS

The purpose of this project is to evaluate and quantify the demand response opportunities of advanced lighting design combined with innovated lighting controls and strategies to allow for easy and reliable control of the building lighting loads to foster greater customer participation in SCE's DR programs. Part of the project goals is to collect measured power usage, which allows for measurement and verification (M&V) of the demand reduction associated with the lighting systems and related controls to be used in support of future utility program offerings.

LIGHTING AND LIGHTING CONTROLS

Energy and demand can be reduced through a comprehensive lighting design, which incorporates advanced lighting technologies, proper luminaire selection, detailed lighting layout, and advanced controls and strategies. Proposed lighting solutions incorporate energy efficient and demand responsive technologies offering advanced control features to adjust to personal preferences, daylight availability, vacancy in workspace, and demand control. Advanced designs enhance lighting quality and provide options for personal control that are linked to increased visual comfort, satisfaction, health, and productivity.

LANDMARK SQUARE BUILDING

Landmark Square building is an all-electric, Energy Star-certified, multi-tenant office building owned and managed by Brookfield Properties. Located at 111 West Ocean Boulevard in Long Beach, California, the building has occupancy of 90% for at least the past 2 years. Built in 1991, the 24-story building has 443,000 square-feet (SF) of conditioned space (420,000 SF of office space and 23,000 SF of retail space) and over 1,300 covered parking spaces (212,000 SF). It has a steel frame and curtain wall exterior with granite façade.

The project involves 1,577 SF of space occupied by the owner, Brookfield Properties. The space is used by four full-time employees, but has five (5) private offices, one (1) conference room, one (1) lobby, one (1) break room/kitchen, and one (1) corridor. Figure 1 shows the general office layout.

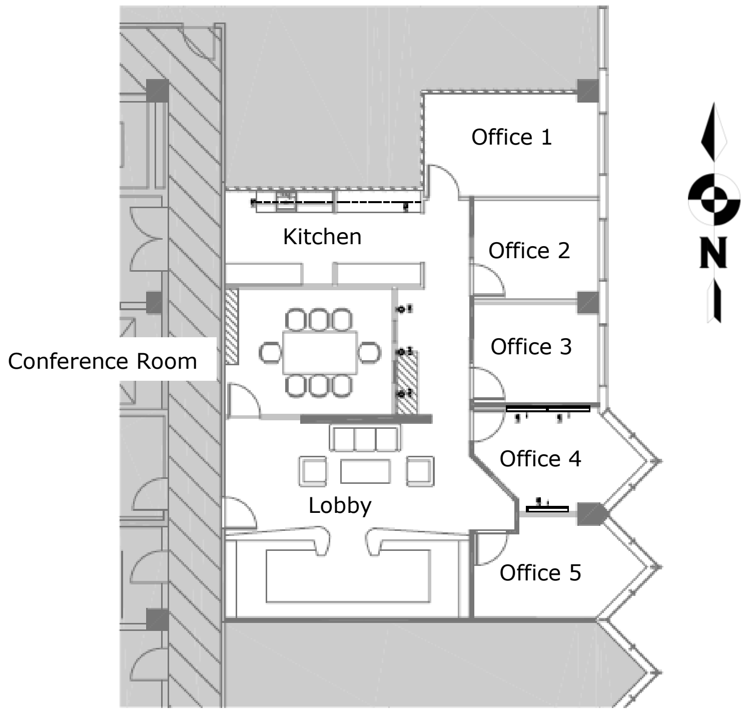

FIGURE 1. FLOOR PLAN OF THE LANDMARK SQUARE OFFICE SPACE

Lighting and plug load end-use monitoring equipment was installed in the office space to evaluate the potential energy savings and demand reduction associated with advanced lighting design and highly controllable lighting. The electrical service serving the space was metered in a way that both the lighting and plug load could be monitored separately.

EXISTING CONDITIONS

The existing lighting, before the energy efficiency measures were installed, is detailed below. The total connected load of the existing lighting was 1,564 Watts (W) and all fixtures were controlled entirely by manual switches. The private offices are east facing and receive ample daylight in the working hours though the lack of daylight dimming results in occupants choosing between maintaining lights entirely on or entirely off. Existing lighting power density (LPD) was assessed at 0.99 W/SF.

Most of the existing lighting system used conventional 2-foot by 4-foot recessed fixtures with two 4-foot T8 linear fluorescent lamps with one standard 2-lamp electronic ballast and on/off wall switches as the controls. Table 1 shows all the existing lighting fixtures by space type.

TABLE 1. EXISTING LIGHTING FIXTURE TYPES AND NUMBERS

SPACE TYPE	FIXTURE TYPE	NUMBER
Lobby	2 x 4 recessed fluorescent troffer with parabolic lens & two 4-foot T8 linear fluorescent lamps with one 2-lamp electronic ballast	3
	6-inch recessed fluorescent down light with spectral lens with integrated trim & one compact fluorescent lamp (CFL)	10
	Recessed halogen accent light with directional trim & one MR16 halogen lamp	3
	Edge lit decorative exit sign	2
Conference Room	2 x 4 recessed fluorescent troffer with parabolic lens & two 4-foot T8 linear fluorescent lamps with one 2-lamp electronic ballast	3
Hallway	2 x 4 recessed fluorescent troffer with parabolic lens & two 4- foot T8 linear fluorescent lamps with one 2-lamp electronic ballast	2
Kitchen	2 x 4 recessed fluorescent troffer with parabolic lens & two 4-foot T8 linear fluorescent lamps with one 2-lamp electronic ballast	1
	2 x 2 recessed fluorescent troffer with parabolic lens & two 2-foot T8 U-shap fluorescent lamps with one 2-lamp electronic ballast	2
Office 1	2 x 4 recessed fluorescent troffer with parabolic lens & two 4-foot T8 linear fluorescent lamps	2
Office 2	2 x 4 recessed fluorescent troffer with parabolic lens & two 4-foot T8 linear fluorescent lamps with one 2-lamp electronic ballast	2
Office 3	2 x 4 recessed fluorescent troffer with parabolic lens & two 4-foot inch T8 linear fluorescent lamps with one 2-lamp electronic ballast	2
Office 4	2 x 4 recessed fluorescent troffer with parabolic lens & two 4-foot T8 linear fluorescent lamps with one 2-lamp electronic ballast	2
Office 5	2 x 4 recessed fluorescent troffer with parabolic lens & two 4-foot T8 linear fluorescent lamps with one 2-lamp electronic ballast	2

An inventory of plug load devices in the various spaces is summarized in Table 2.

TABLE 2. EXISTING PLUG LOAD DEVICES AND NUMBERS

EQUIPMENT TYPE	NUMBER
Desktop Computer	6
LCD Computer Monitor	6
Desktop Printer	3
Fax Machine	1
Copier	2
Scanner	1
LCD Television	1
Coffee Maker	1
Refrigerator/Freezer	1
Toaster Oven	1
Microwave	1
Bagel Toaster	1

ADVANCED LIGHTING DESIGN AND CONTROLS

The lighting design goal was not only to provide energy efficient and demand responsive solutions but also to improve significantly the lighting quality and the overall look and feel of the space. To accomplish this goal a combination of modern fixtures with reflector technology, that maximized light output, and daylight sensors, occupancy/vacancy sensors, energy efficient lamps, and dimming ballasts was used creating a fully integrated and highly controllable lighting system.

As a leasing office space for Brookfield Properties, the project is used to show new and prospective tenants various lighting approaches that can be used given the building's physical characteristics. Therefore, each of the five private offices was equipped with a different lighting solution to present the many available alternatives to the standard 2 x 4 parabolic fixtures and to showcase the extensive improvements. High-performance, low-glare 2 x 2 recessed, wall washers, direct/indirect pendants, lensed light slots, and wall mount indirect fixtures were all represented. Calculations showed that the spaces performed similarly while meeting the Illuminating Engineering Society of North America recommended lighting standards. Separately controlled fixtures were dimmed based on available daylight from each office window in order to provide even illumination at the work surface while taking advantage of available daylight. When the office was not occupied, the lights were automatically dimmed and then shut off. Additionally, light emitting diode (LED) task lights were provided at each desk.

The most energy saving light fixture is the one that is turned off. At first glance, it appears that the design team added wattage to the design by providing dedicated lighting at major task areas and separately controlling decorative features. By designating 'task areas' within the project, lower ambient light levels were established for all other spaces. Separately controlled task lighting with automatic shutoff allowed the designers to put higher light levels specifically where they were required for the task, and through the use of controls, only when they were required by the users. In reality, by providing and separately controlling task and decorative fixtures that are usually turned off, the design helps to create a drastic reduction in energy consumed over the typical office layout without sacrificing design or the occupants' comfort for focused tasks.

The design specified under-cabinet task lights on a motion sensor for the kitchen and fax/prep area, and compact fluorescent downlights in the kitchen and corridor areas to be dimmed when these spaces were unoccupied. Decorative fixtures were also integrated into the public corridor in order to enhance perceived brightness of the walls and ceiling and create a high-end presentation of the office but were separately controlled and dimmable.

The conference room and entry lobby were examples of putting light only where it is needed. The new design used smaller square aperture low-glare dimmable compact fluorescent downlights to light task areas; wall washers were used to accent upgraded surfaces, art, and signage, while providing usable light for cabinet interiors. Lighting the walls created the perception of a much brighter space and saved energy by not over-lighting non-essential spaces.

Task lights were provided at the reception desk to supplement the overhead lighting as necessary. A decorative direct/indirect pendant with highly transmissive film in the conference room helped to create a visual anchor for the space, but also lit the work surface, ceiling, and walls without creating glare for the television in the room or the users. Compact fluorescent dimmable downlights lit the conference table workspace, and wall washers lit the presentation and pinup wall.

The installed design, referred to as the Advanced Lighting Solution (ALS), created a showcase of the many options now available for commercial office interiors, and underscores the importance of proper lighting controls and fixture selection for the optimized designs. The lighting fixtures and lamp descriptions are shown in Table 3.

TABLE 3. ALS LIGHTING FIXTURE TYPES AND NUMBERS

SPACE TYPE	FIXTURE TYPE	NO. OF FIXTURES	TOTAL WATTAGE
Lobby	Recessed 3500 Kelvin (K) CFL downlight with square aperture and Lutron Hi-Lume® 1% dimming ballast	2	144
	Recessed 3500 K CFL wall wash with square aperture, polished flange, and Lutron Hi-Lume 1% dimming ballast	3	78
	Ceiling suspended cable hung indirectly 4-foot linear T8 2-lamp fixture with remote Lutron EcoSystem® ballast	4	256
	Finelite 3500 K LED Personal Lighting System Desk Lamp	3	33
Conference Room	Decorative indirect/direct 2-lamp compact fluorescent cable hung pendant with cast aluminum shell	1	84
	Recessed 3500 K CFL downlight with square aperture and Lutron Hi-Lume 1% dimming ballast	4	104
	Recessed 3500 K CFL wall wash with square aperture and Lutron Hi-Lume 1% dimming ballast	3	72
Hallway	Recessed 3500 K CFL downlight with square aperture and Lutron Hi-Lume 1% dimming ballast	6	156
	Decorative indirect dimmable CFL sconce with stamped aluminum shell and Lutron EcoSystem dimming ballast	3	72
Kitchen	Recessed 3500 K CFL downlight with square aperture and Lutron Hi-Lume 1% dimming ballast	4	92
	Linear surface mount LED task lighting, 3300 K LEDs, and seamless continuous runs	6	42
Office 5	Narrow recessed 5-inch aperture 2-lamp T8 linear fluorescent 1 x 4 with perforated side basket and integral Lutron EcoSystem ballast	3	192
	Finelite 3500 K LED Personal Lighting System Desk Lamp	1	11
Office 4	Wall mount 4-foot 2-lamp T8 linear fluorescent fixture with steel housing and integral Lutron EcoSystem ballast.	3	192
	Finelite 3500 K LED Personal Lighting System Desk Lamp	1	11
Office 3	Recessed 2 x 2 indirect/direct high performance 2-lamp linear fluorescent fixture with perforated mesh lamp shield and integral Lutron EcoSystem ballast	4	136
	Finelite 3500 K LED Personal Lighting System Desk Lamp	1	11
Office 2	Recessed 1 x 4 asymmetric indirect 1-lamp linear fluorescent fixture with perforated side basket and integral Lutron EcoSystem ballast	4	256
	Finelite 3500 K LED Personal Lighting System Desk Lamp	1	11
Office 1	Ceiling suspended cable hung adjustable 4-foot 2-lamp linear T8 fixture with aluminum housing on 18-inch cables and integral Lutron EcoSystem ballast	3	192
	Finelite 3500 K LED Personal Lighting System Desk Lamp	1	11

Below is a summary of the installed ALS lighting by space type. Figure 2 shows a Reflected Ceiling Plan (RCP) and Reflected Floor Plan (RFP).

The specific controls implemented are described below:

- All fixtures are controlled by sweeps beginning at 10:00 p.m.
- All fixtures have dimming capability except the break room LEDs.
- Many fixtures are trimmed to allow the max power as a percentage of the rated Wattage (e.g. 60 or 70%).
- Office use area specific controls and maximum trim settings include:
  - Hallway: Occupancy dimming (70%/20%) – no wall controls
  - Kitchen: Occupancy dimming (70%/20%) – no wall controls
  - Private Offices: Daylight dimming (60%/20%) and vacancy on/off control – wall control, and occupant remote control
  - Conference Room: Occupancy on/off controls (70%/off) – Lutron GRAFIK Eye scene selector and wall control
  - Reception: Occupancy dimming (70%/50%) – wall control

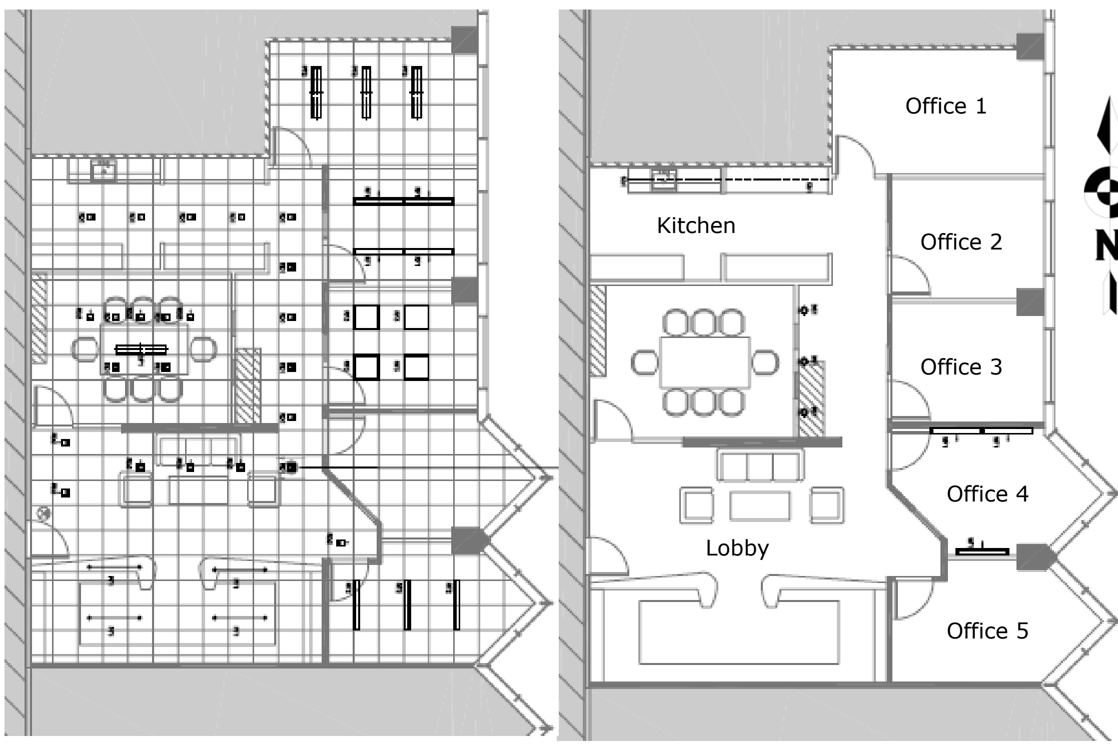

FIGURE 2. REFLECTED CEILING PLAN AND REFLECTED FLOOR PLAN FOR THE OFFICE SPACE

Table 4 shows the connected and calculated LPD of the existing and ALS system along with the 2008 Title 24 code requirements calculated with and without controls allowances. Controls allowances allow the connected load to be increased when the design requires sophisticated lighting controls.

TABLE 4. CONNECTED AND CALCULATED LIGHTING POWER DENSITIES

	EXISTING LIGHTING	2008 TITLE 24 W/O CONTROLS ALLOWANCE	2008 TITLE 24 W/ CONTROLS ALLOWANCE	ALS
Connected Load (W)	1,564	1,748	2,160	2,076
Calculated LPD (W/SF)	0.99	1.11	1.37	1.32

Greater detail in the energy savings and overall lighting performance of the ALS can be found in the SCE's Office of the Future Landmark Square report.[1]

[1] http://www.etcc-ca.com/images/stories/et_09.22_otf_landmark_square_final.pdf

TECHNICAL APPROACH/TEST METHODOLOGY

In order to characterize the savings resulting from the OTF projects, a formal M&V protocol was implemented that evaluates energy savings and demand reductions resulting from each type of measure and strategy implemented as well as the entire system. A formal protocol is important not only for assessing the project performance, but also for promoting consistency among all the various projects conducted by the OTF Consortium members. The protocol suggested that the construction schedule be tiered to allow distinct monitoring time periods after the installation of a measure type in order to establish a baseline from which to determine the impact of the subsequent measure type. The duration of each baseline is a minimum of 4 weeks except in the case of the plug loads where 2 weeks was deemed sufficient.

Metering installed at the whole building and office space level establishes the 'As-Is' baseline and represents the existing energy use before any energy efficient and demand response measures are installed. The performance review and feedback of whole building meter data are intend to establish an 'As-Restored' condition and it is intended to reflect how a code-level building will operate with the existing equipment and schedules being corrected for an optimal operating condition.

Next, the ALS lighting and controls are installed in the office space that includes a 100-hour "burn-in" period for the lighting. New lamps must stabilize (mercury distribution, phosphor/impurities settle, etc.) in order to operate optimally. This is especially important when dimming is to be utilized. The burn-in period also allows the monitoring of the total connected load of the newly installed lighting. After the lighting is burned in and fully commissioned, the 'post-lighting' baseline is established.

The project M&V was simplified to reflect the realities of the project, but it followed the general procedure developed for the OTF projects. The site already had an advanced metering installation with interval data and feedback to the operator that negated the need for a performance review. No plug-load energy efficiency or demand response measures were implemented in the project.

METERING EQUIPMENT AND DATA ACQUISITION

Metering equipment was installed in order to separate lighting from outlet loads. All metered data were uploaded via GSM cellular connection to a remote server for review and analysis. The following equipment was installed at Landmark Square building:

- Obvius AcquiSuite Server A8812-GSM with GSM cellular internet modem
- Wattnode® WNB-3Y-208-P meter with pulse output on the total office lighting service panel CTS-0750-100 Current Transformer
- Wattnode WNB-3Y-208-P meter with pulse output on the total office outlet service panel CTS-0750-100 Current Transformer

The metering provided the following data points for lighting and outlet loads at 15-minute intervals except during DR testing when data were gathered at 1-minute intervals:

- Energy use meter reading (kWh)
- Average Power in the Interval (kilowatt (kW))
- Instantaneous Power in the Interval (kW)
- Minimum Instantaneous Power in the Interval (kW)
- Maximum Instantaneous Power in the Interval (kW)

DEMAND RESPONSE TEST PROCEDURE

The DR tests occurred on three separate days in March of 2011: Friday, March 4; Tuesday, March 8; and Thursday, March 10, and they were performed at different times throughout the day. During the DR test period, the recoding intervals were reduced to 1 minute to better capture the DR events. During the DR tests, Lutron personnel initiated the test command from within the building.

The testing procedure included reducing the lighting power up to five different levels with each level lasting from 30 to 120 minutes, after which the lighting power was returned to the base level of zero reduction from 30 to 60 minutes. Tables 5 through Table 7 show the planned schedule for the lighting DR tests on March 3, 8, and, 10 respectively.

TABLE 5. LIGHTING DEMAND RESPONSE TEST SCHEDULE – FRIDAY, MARCH 4, 2011

DR POWER LEVEL REDUCTION	CONTROL SYSTEM TIMING
10%	9:30 a.m. – 10:30 a.m.
0%	10:30 a.m. – 11:00 a.m.
15%	11:00 a.m. – 12:00 p.m.
0%	12:00 p.m. – 1:00 p.m.
25%	1:00 p.m. – 3:00 p.m.
0%	3:00 p.m. – 4:00 p.m.
50%	4:00 p.m. – 5:00 p.m.
0%	5:00 p.m. normal operation

TABLE 6. LIGHTING DEMAND RESPONSE TEST SCHEDULE – TUESDAY, MARCH 8, 2011

DR POWER LEVEL REDUCTION	CONTROL SYSTEM TIMING
15%	1:00 p.m. – 2:00 p.m.
0%	2:00 p.m. – 2:30 p.m.
20%	2:30 p.m. – 3:30 p.m.
0%	3:30 p.m. – 4:30 p.m.
30%	4:30 p.m. – 5:30 p.m.
0%	5:30 p.m. normal operation

TABLE 7. LIGHTING DEMAND RESPONSE TEST SCHEDULE – THURSDAY, MARCH 10, 2011

DR POWER LEVEL REDUCTION	CONTROL SYSTEM TIMING
10%	10:00 a.m. – 10:30 a.m.
0%	10:30 a.m. – 11:00 a.m.
15%	11:00 a.m. – 12:00 p.m.
0%	12:00 p.m. – 12:30 p.m.
25%	12:30 p.m. – 1:30 p.m.
0%	1:30 p.m. – 2:00 p.m.
35%	2:00 p.m. – 3:00 p.m.
0%	3:00 p.m. – 3:30 p.m.
45%	3:30 p.m. – 5:00 p.m.
0%	5:00 p.m. normal operation

DATA ANALYSIS AND RESULTS

This section presents and discusses the data collected from monitoring of the controlled lighting. Analysis of the data included five DR tests on three different days. Graphs and tables displaying the data are presented in this section.

DEMAND RESPONSE TEST DAYS

DR testing was successfully conducted over three separate days in March of 2011: Friday, March 4; Tuesday, March 8; and Thursday, March 10. The tests were performed at different times throughout the day depending of the day of the week as shown in Table 5 through Table 7.

Figure 3 illustrates the lighting power profile during a non-test day (Thursday, February 24), which is somewhat representative of a typical lighting power usage for the entire office area. The shaded vertical portion of the graph indicates the periods where power would have been reduced if the DR tests had been performed. The expected percentage of power reduction during the DR test for each period is also shown in Figure 3.

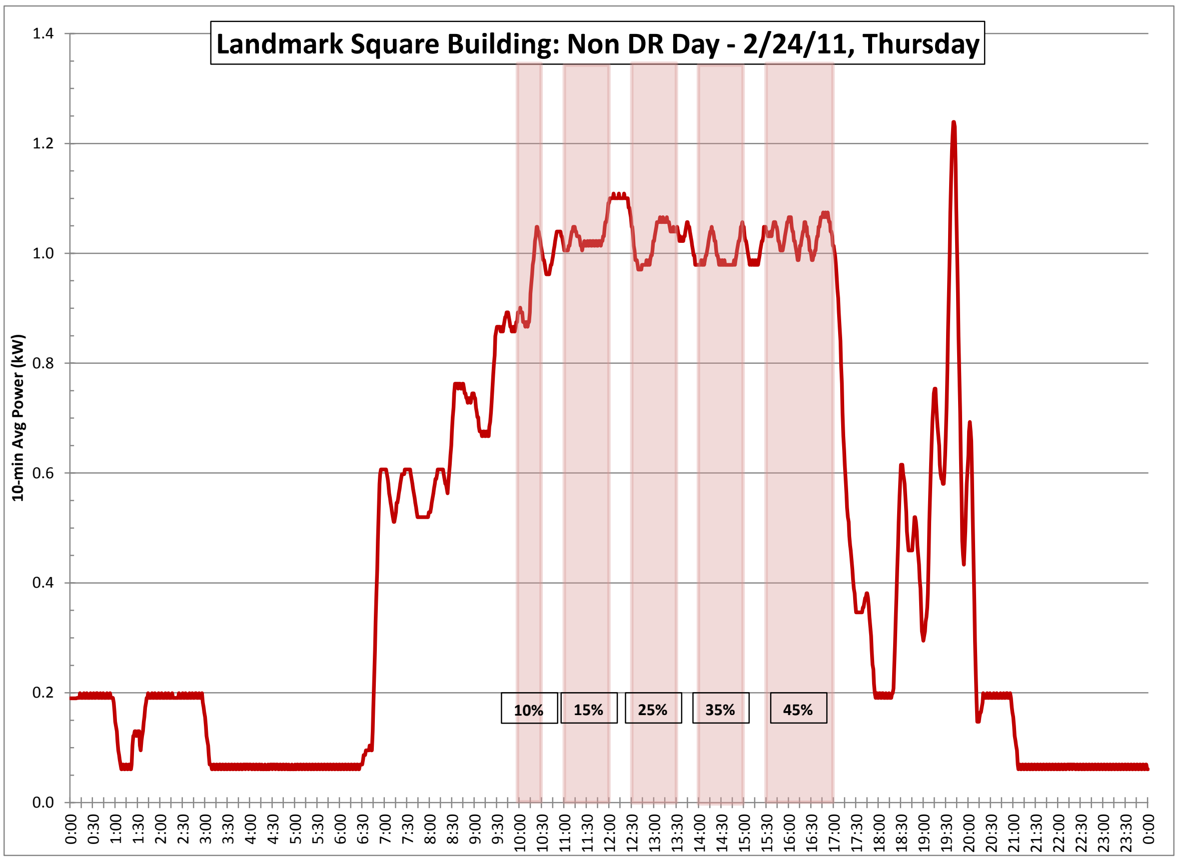

FIGURE 3. LIGHTING POWER WITH 10-MIN MOVING AVERAGE DURING A NON-TEST DAY: THURSDAY, FEBRUARY 24

The power fluctuations during the day are from occupancy sensors and daylighting controls. During the evening, it seems that the power fluctuation is due to the clean crew. A 10-minute moving average was used to smooth the fluctuations and show trends. The moving average plots data in terms of an average over a prior period of time. Each point of the moving average is an average of the prior 10 minutes of data calculated from the one-minute logged data.

Results for the DR tests conducted on March 4, 8, and 10 are shown in Figure 4 through Figure 6, respectively. The figures show drops in demand when power level settings were reduced based on the DR testing schedule.

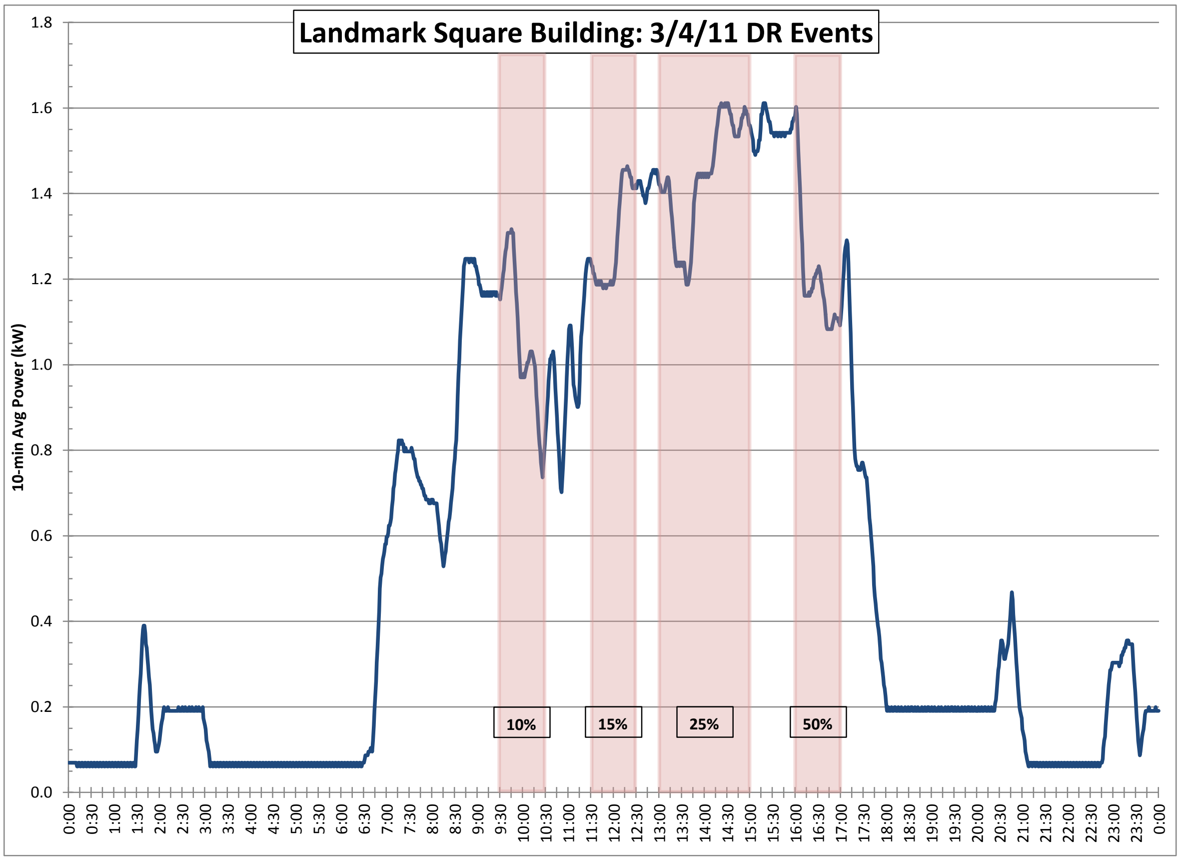

FIGURE 4. LIGHTING LOAD PROFILE DURING DEMAND RESPONSE TESTING: FRIDAY, MARCH 3

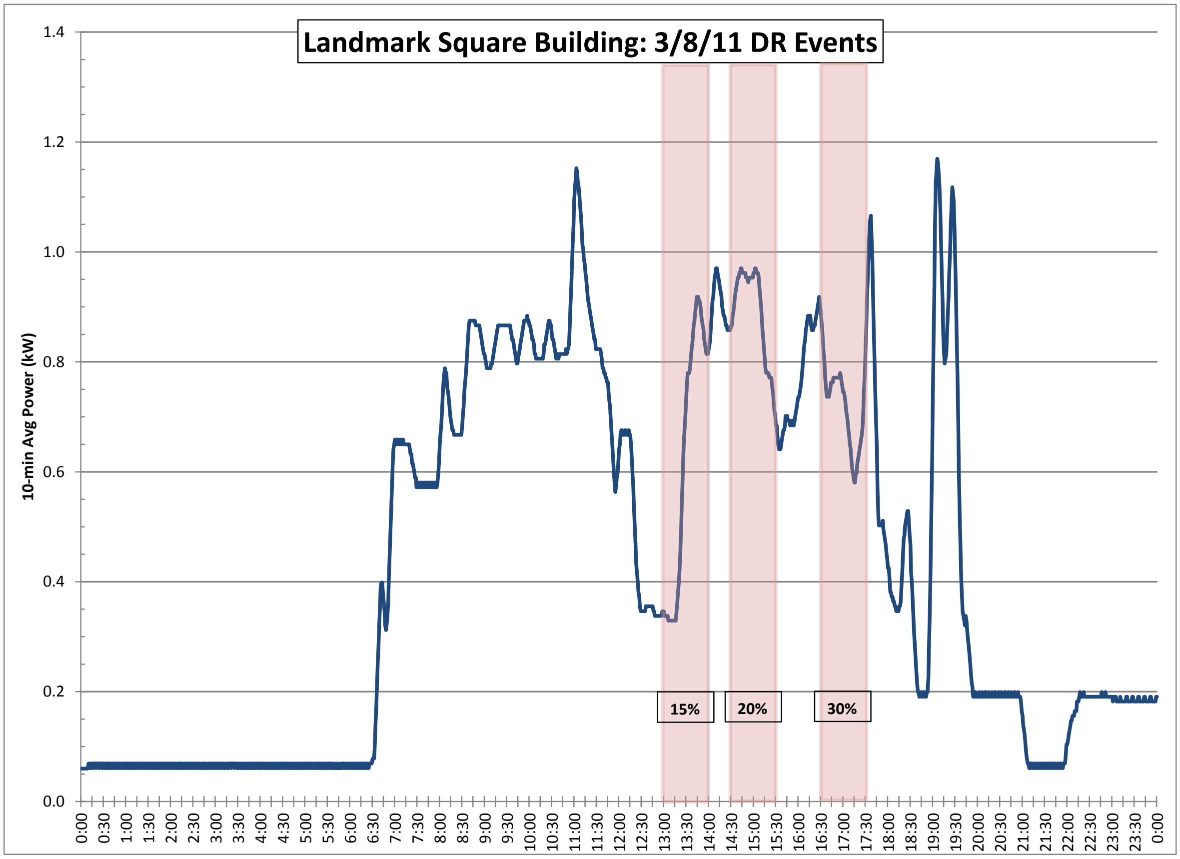

FIGURE 5. LIGHTING LOAD PROFILE DURING DEMAND RESPONSE TESTING: TUESDAY, MARCH 8

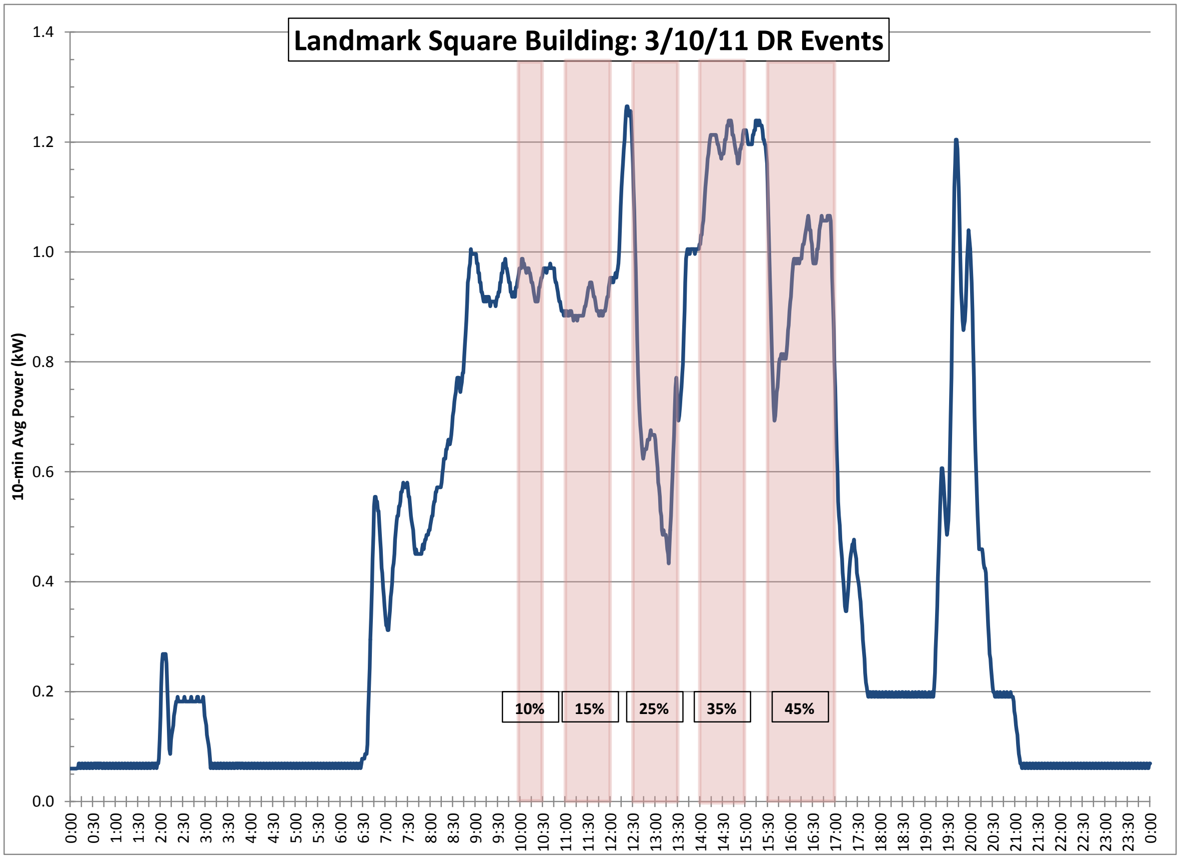

FIGURE 6. LIGHTING LOAD PROFILE DURING DEMAND RESPONSE TESTING: THURSDAY, MARCH 10

DEMAND RESPONSE TEST RESULTS

Power reduction, with the different DR level settings, is somewhat evident from inspecting Figures 4, 5, and 6 for each of the three days of testing. However, the power reduction does not always properly align with the DR event period throughout the day. At times, it seems the DR test was started earlier than scheduled (see Figure 5 at 12:15 p.m.) and at times it seems the DR event was terminated later than schedule (see Figure 4 at 11:00 a.m.).

Table 8 through Table 10 provides the demand reduction percentages for all three DR test days conducted in March of 2011. Table 8 shows the results for the Friday, March 4, Table 9 shows the results for Tuesday, March 8, and Table 10 shows the results for Thursday, March 10. The demand reduction was calculated by taking the demand at the start of the DR test period and subtracting from it the average demand over the DR test period. Using Figure 4 (Friday, March 3) as an example, and looking at the 50% power reduction level at 4:00 pm, result in a 25% power reduction as shown in Table 8.

TABLE 8. DEMAND REDUCTION PERCENTAGES FOR DR TESTING ON FRIDAY, MARCH 4

DR TEST LEVEL (%)	STARTING TEST DEMAND (KW)	AVG. DEMAND REDUCTION DURING THE TEST PERIOD (KW)	AVG. DEMAND REDUCTION (KW/SF)	AVG. DEMAND REDUCTION (%)
10	1.30	1.06	0.152	18.5
15	1.25	1.29	N/A	N/A
25	1.45	1.44	0.006	0.7
50	1.60	1.20	0.254	25.0

TABLE 9. DEMAND REDUCTION PERCENTAGES FOR DR TESTING ON TUESDAY, MARCH 8

DR TEST LEVEL (%)	STARTING TEST DEMAND (KW)	AVG. DEMAND REDUCTION DURING THE TEST PERIOD (KW)	AVG. DEMAND REDUCTION (KW/SF)	AVG. DEMAND REDUCTION (%)
15[1]	0.65[1]	0.63	0.013	3.1
20[2]	0.95[2]	0.89	0.038	6.3
30	0.93	0.65	0.174	29.7

Notes: 1. It appears that the 15% DR test started 45 minutes earlier than schedule.

2. It appears that the 20% DR test started 45 minutes later than schedule.

TABLE 10. DEMAND REDUCTION PERCENTAGES FOR DR TESTING ON THURSDAY, MARCH 10

DR TEST LEVEL (%)	STARTING TEST DEMAND (KW)	AVG. DEMAND REDUCTION DURING THE TEST PERIOD (KW)	AVG. DEMAND REDUCTION (KW/SF)	AVG. DEMAND REDUCTION (%)
10	1.00	0.95	0.032	5.0
15	0.90	0.90	0.00	0.0
25	1.25	0.66	0.374	47.2
35	1.00	1.18	N/A	N/A
45	1.20	0.95	0.159	20.8

DISCUSSION

The project results reveal that in general, advanced lighting design with innovative controls provided not only energy efficiency, but vast opportunities for implementing DR strategies. It is clear that while the DR test calls for an actual percentage reduction in power, the Lutron lighting controls used in this project could not directly measure power, only infer it. As a result, the control system would rely on preset dimming scenes to deliver the requested demand reduction. Combine this with occupancy sensing, daylighting controls, a dynamic office environment, and some missteps during the testing periods; it became difficult at times to properly isolate the impact of the lighting control system on demand reduction.

CONCLUSIONS

The three main goals of this project were to:

- Evaluate the demand response opportunities associated with advanced lighting design combined with innovative lighting controls and strategies to allow for easy and reliable control of the building lighting loads to foster greater customer participation in SCE's DR programs.
  - The testing performed indicated significant opportunities to implement DR strategies leveraging the advanced lighting design and innovative controls. However, the demand reduction was not proportional to the reduction being requested particularly for demand reduction requests of 20% or less. A part from the inherent dynamic nature of the lighting at the Landmark Square building, the lighting control used in the project does not measure power directly, which in turn may force the controls to over or under compensative given the nature of preset dimming scenes.
- Quantify the demand reduction that can be achieved with advanced lighting design and innovative lighting controls.
  - There were significant reductions in the lighting load when a DR strategy was invoked by the lighting controls. For a request of 50% power reduction, the control system delivered 0.254 W/SF (or 25% drop in power), while for a request of 30%, the reduction was 0.174 W/SF (or 30% drop in power). It is interesting to note that for requests for power reduction of 10, 15, 20, and even 25%, the lighting control system under performed significantly. This is most likely the result of the lighting control relying on preset dimming scenes to accomplish the demand reduction.
- Provide measure and technical data that can be leverage for future utility program offerings.
  - The project provided valuable data, insights, and lessons learned which should benefit not only future utility program offerings, but also the lighting controls industry as a whole.

RECOMMENDATIONS

The results of this project show the potential for leveraging advanced lighting design and innovative controls to promote effective DR strategies in office buildings. However, there are still several things that requires continue, if not greater, involvement with the lighting controls industry. Such as:

- Continue engagement of key lighting controls companies to demonstrate the need and value of having lighting control products measure directly power.
- Continue engagement of lighting controls companies to help them develop DR strategies that leverage power measurement instead of diming levels to further the incorporation of DR strategies into their product offerings.
- Continue engagement of lighting controls companies to help them develop DR strategies for leveraging their lighting control products to manage plug loads in commercial office spaces.
- Development of Codes and Standards Enhancement (CASE) studies to support requiring under Title 24 that lighting controls must measure power.
- Evaluation of other markets segment that could benefit from incorporating aggressive lighting DR strategies.
- Renovation (or new construction) of an entire building lighting system to fully understand interaction of the various lighting systems and associated controls in delivering cost effective DR lighting strategies.