DEMAND RESPONSE TESTS OF LIGHTING IN A CLASS A OFFICE CORRIDOR

DR11SCE1.05.01 Report

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Acknowledgements

Southern California Edison's (SCE's) Design & Engineering Services (DES) group is responsible for this project in collaboration with the Tariff Program & Services (TP&S) group. It was developed as part of SCE's Demand Response, Emerging Markets and Technology program under internal project number DR11SCE1.05.01. DES project manager Doug Avery conducted this project with overall guidance and management from Carlos Haiad of DES and Carl Besaw of TP&S. For more information on this project, contact doug.avery@sce.com.

ABBREVIATIONS AND ACRONYMS

ALCS	Advanced Lighting Controls Systems
FC	Footcandle
LPD	Lighting Power Density
M&V	Measurement and Verification
MW	Megawatt
OTF	Office of the Future
SCE	Southern California Edison
sf	Square Feet
W	Watt
W/sf	Watts per Square Foot

FIGURES

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EXECUTIVE SUMMARY

This report evaluates the lighting Demand Response (DR) technology installed at the Landmark Square office building in Long Beach, CA. The DR study is managed by Southern California Edison's (SCE) Design and Engineering Services group and is part of the Smart Corridor and Stairwell study. This study examined the energy savings potential in corridors and stairwell where the lighting was controlled by occupancy sensors.

The primary goals of this project are to:

1. determine whether the advanced lighting controls system allows for reliable control of corridor lighting loads from SCE or business management as part of a Demand Response Program,
2. examine demand reductions that can be achieved with a well-designed lighting system, and
3. provide measured and technical data in support of the Smart Corridor and Stairwell concept.

The project site consists of the 10^{th} floor corridor in the Landmark Square building. The corridor area represents 970 square feet (sf) of a multi-tenant high-rise office building.

A new lighting control system was installed as part of this DR pilot, consisting of 12 lighting fixtures. The existing corridor fixtures were retrofitted with Lutron H-Series, 2-lamp, T5 ballasts. The Lutron ballasts provide full dimming from 1% to 100% using Lutron's digital protocol. Occupancy sensors provide bi-level control of the lighting fixtures between high and low mode.

The bi-level control solution reduces demand on a regular basis based on occupancy. The ballasts use wired communication while the occupancy sensors use wireless communication to interact with the control system. The system optimizes both the reliability of wired ballasts and the convenience of wireless sensors while maintaining a low installation cost. It also allows users to place sensors in the most optimum location regardless of wiring capability.

Lighting fixtures were monitored to document the demand reduction of the new lighting and control systems.

Installation of the lighting system and control hardware was completed in September 2011. Commissioning reduced the ballast dimming settings to 65% of the lighting's rated electrical input (67.5 W/fixture down to 43.9 W/fixture), without any impact to building occupants. This new commissioned level is also designated as the baseline for the DR testing performed at the Landmark Square building.

Testing was successfully conducted during the same business hours over three separate days in October of 2011: Tuesday, October 18; Wednesday, October 19; and Friday, October 21. Part of the testing involved changing the DR level to five different settings: 10%, 15%, 20%, 25%, and 30% reductions with respect to the commissioned level. Each setting lasted for one hour after which it returned to the baseline DR level of 0%. Table 1 presents DR lighting average demand reduction in Watts per fixture and Watts per square foot (W/sf). The average DR reduction per fixture across the new commissioned ALCS is 7.4 Watts per fixture at the 30% DR level (43.9 W/fixture baseline to 36.5 W/fixture during the DR event). The average measured lighting density during the baseline period was (0.54 W/sf), and lighting density during the DR testing at the 30% level was (0.43 W/sf).

The demand reduction at DR level 30% is .092 W/sf. An average power savings of 17% was achieved for the lighting systems controlled during the DR test with control level at 30%.

Figure 1 shows the relationship between the DR levels and DR lighting demand reduction. The figure shows a general upward trend between DR level setting and measured lighting power reductions, with the greatest savings being 0.092 W/sf at the 30% DR level. This is for the typical occupancy observed in the corridor area. A second dotted line is added to the figure representing reduction potential if the lights were not dimmed via occupancy control.

TABLE 1. LIGHTING DEMAND REDUCTIONS

MEASUREMENT DESCRIPTION	DR LIGHTING VALUE	UNITS
Corridor Area	970	sf
Demand Response Savings at 30% DR	7.4	W/fixture
Baseline Lighting Power Density (0% DR Level)	0.54	W/sf
Lighting Power Density at 30% DR Level	0.43	W/sf
Demand Reduction at 30% DR	0.09	W/sf

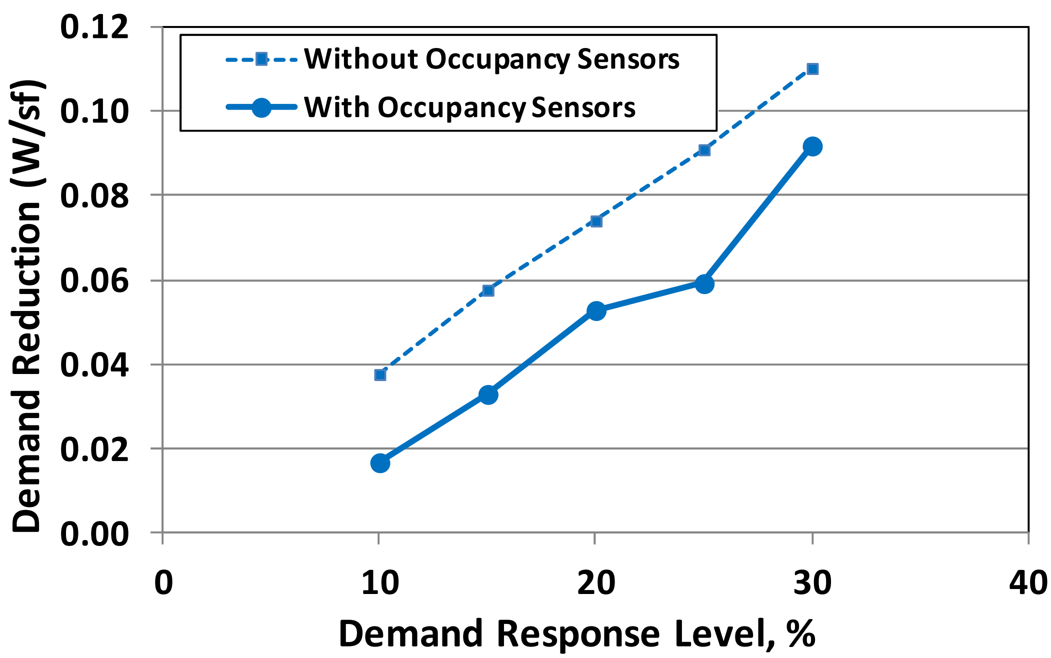

FIGURE 1. LIGHTING DEMAND REDUCTION PER SQUARE FEET AT VARIOUS LEVEL SETTINGS DURING DEMAND RESPONSE TESTING

The DR strategies tested in this study showed significant demand reduction with ALCS, and it is recommended that there are future studies to address:

- Evaluation of DR strategies and their interaction with other controls such as occupancy sensors
- Evaluation of DR reductions available at various peak hours based on various lighting profiles

INTRODUCTION

This study evaluates the Demand Response (DR) capability of Advanced Lighting Control System (ALCS) developed by Lutron Electronics. This ALCS was installed on the 10th floor of the Landmark Square building. This real-world setting allowed researchers to verify that the technology proposed by the participating manufacturer performed to the published specifications by delivering the predicted reductions through reliable DR capabilities.

BACKGROUND

The following is an explanation of the need for demand reduction based on stress to the electric grid. This stress occurs when demand for electricity nears the capacity of the available power generation, an event that is typically most prevalent during hot summer afternoons. Weather forecasts are used to predict the need for demand reduction tactics and to provide a degree of planning for electric load curtailment. However, malfunctions in power generation, or to the electric grid, may result in the immediate need to reduce electricity consumption.

Peak electricity load has been controlled by various program types, including very large customer participation in:

- Demand Bidding,
- Critical Peak Pricing and Interruptible Rate programs, and
- Time-Of-Use rates for large commercial customers.

Peak demand has also been controlled by residential customers participating in air conditioning cycling programs.

SCE is investigating the potential for DR technologies on several projects this year to reduce the peak electric system load. In 2005, SCE implemented testing of a Universal lighting ALCS as well as one manufactured by General Electric.

SCE will benefit from fast and flexible responding demand reduction systems. The larger the load that can be controlled, the more useful it will be. Large load reductions can be achieved either by substantially reducing loads at a few major facilities, or by performing smaller load reductions at a large number of facilities. New technologies are providing ways to coordinate the DR program participation of larger and more varied customer groups.

GOAL OF THE PILOT PROJECT

SCE is testing the implementation of ALCS on the 10th floor of the Landmark Square building, representing 970 square feet of corridor. The ALCS controls the level of dimming via dimmable ballasts installed as part of this project.

The primary goals of this project are the following:

1) determine whether the advanced lighting controls system allows for reliable control of corridor lighting loads from SCE or business management as part of a Demand Response Program,
2) examine demand reductions that can be achieved with a well-designed lighting system, and
3) provide measured and technical data in support of the Smart Corridor and Stairwell concept.

POTENTIAL MARKET IMPACT

According to the California Commercial Energy Use Survey (CEUS), offices are the single largest draw of commercial energy use in California. Offices represent 21% of the total commercial square footage and 25% of total commercial energy usage in California. In the SCE service territory, offices represent 18% of commercial square footage (385,110,000 sf), and have an interior lighting connected load of 1.16 Watts per square feet (W/sf).[1] It follows that the connected interior lighting load in offices is 447 Megawatts (MW). If 75% of the lighting was operating and DR could reduce 30% of the operating load, that would result in the shedding of 100 MW.

The market impact of lighting improvements in existing office spaces is a discrete analysis and not a part of this study.

[1] Itron, 2010, California End Use Survey Results March 2006 prepared for the California Energy Commission retrieved 3/5/10 at http://capabilities.itron.com/CeusWeb/Chart.aspx.

THE LANDMARK SQUARE DEMONSTRATION PROJECT DESCRIPTION

The advance lighting control system (ALCS) was installed in the corridor of the 10th floor of the Landmark Square building. The light fixtures have the capability to interface with an ALCS and dim the lights resulting in demand reduction. Lighting demand use was monitored to quantify the demand reductions. A series of tests was conducted on the system to show the feasibility of this type of installed DR system.

SITE DESCRIPTION

This project consists of the corridor lighting on the 10th floor of the Landmark Square office building in Long Beach, CA. The project area consists of an "L" shaped corridor and a freight elevator lobby directly connected to the corridor. The corridor is 850 square feet (sf), and the freight elevator lobby is 120 sf for 970 sf. Figure 2 shows the layout of the 10th floor corridor.

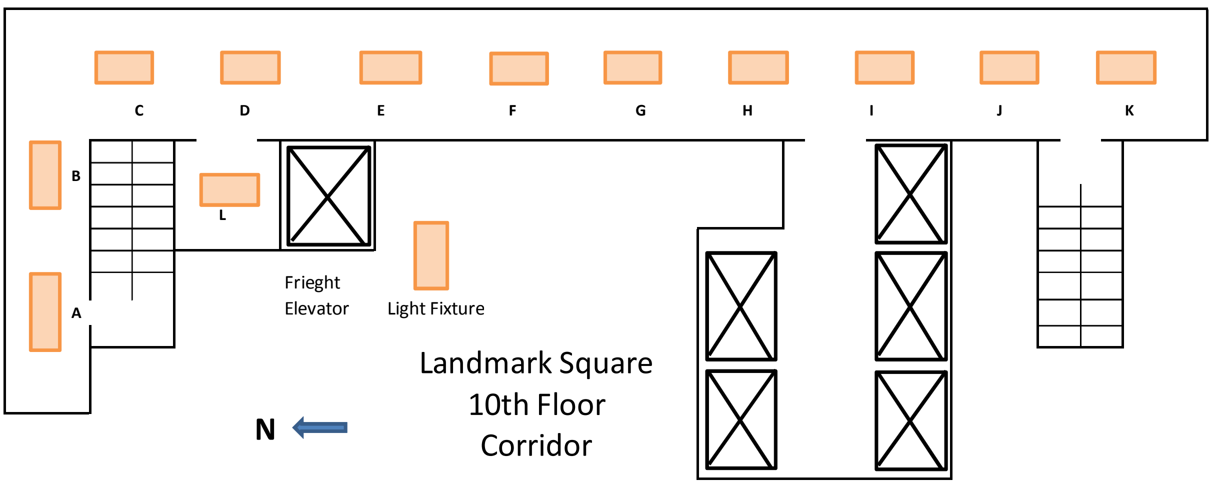

FIGURE 2. TENTH FLOOR CORRIDOR LIGHTING LAYOUT

The corridor lighting fixtures are recessed in a sheet rock ceiling with no access to the space between floors. There are 12 lighting fixtures involved in this project. The 11 lighting fixtures in the corridor have two T5 fluorescent lamps each. The light fixture in the freight elevator lobby has two T8 fluorescent lamps and is surface-mounted to the ceiling.

The new lighting system is capable of demand reduction and tuning. The project was highly representative of retrofit projects in typical Class A office buildings.

Data loggers were installed in the light fixtures to collect electric load profile data during DR testing, and to measure demand reductions attributable to the ALCS.

LIGHTING CONTROL SOLUTION

LIGHTING FIXTURES

The existing corridor fixtures were cleaned, re-lamped, and equipped with new ballasts. Eleven corridor fixtures were retrofitted with Lutron H-Series, 2-lamp, T5 ballasts. The Lutron ballasts provide full dimming from 1% to 100% using Lutron's digital protocol. This allows the user to fully personalize high and low levels in the space, achieving maximum savings while maintaining visual comfort.

LIGHTING CONTROLS

Installation of a new lighting control system occurred. The Lutron Electronics control system is compatible with fluorescent and light-emitting diode (LED) sources, and provides DR control that can dim lighting on a scale from 1% to 100%. The bi-level control solution is based on occupancy to reduce demand on a regular basis. The Lutron Wireless Control System uses Energi Savr Node, QS Sensor Module, and wireless occupancy sensors. The wired communication of the ballasts and the radio frequency (400 mega Hertz (MHz)) wireless communication of the sensors provide a system that optimizes both the reliability of wired ballasts and the convenience of wireless sensors. This is accomplished while maintaining a low installation cost. In addition, it allows users to place sensors in the optimum location, regardless of wiring capability.

The primary consideration is that this project is an excellent opportunity to demonstrate state-of-the-art DR practices in a normal, functional, office corridor. In many ways, this space is representative of large office buildings that are typically used by private businesses.

The system provides the following functions and strategies:

- Tuning to reduce overall lighting use by 35%. Commissioning reduced the ballast dimming settings to 65% of the lighting's rated electrical input, without an adverse impact on lighting levels. This new commissioned level is also designated as the baseline for the DR testing. This capability compensates for the normal overdesign of lighting. Overdesign is caused by the standard practice of rounding up to integers of luminaires and adding luminaires to make for aesthetically appealing installations.
- The installed lighting is capable of DR and can respond to a DR or real-time pricing signal. The lighting that is capable of DR can be dimmed to any level that is agreed upon by the owner and SCE. However, it should be noted that as the lighting is already dimmed down by 35%, this becomes the new 100% baseline level for all succeeding DR events.
- DR was measured for 12 lighting fixtures. A signal from SCE or building management can reduce the power setting of the fixtures by 10%, or more.

Lutron technical staff members commissioned the system during technical site visits involving upgrades, additions, or troubleshooting of the system.

TECHNICAL APPROACH/TEST METHODOLOGY

In order to characterize the demand reductions resulting from this pilot project, ADM Associates, Inc. devised a Measurement and Verification (M&V) protocol adapted to this facility.

Initially, lighting and controls are installed in the office space, including a 100-hour 'burn-in' period for the lighting. This period allows new lamps to stabilize (mercury distribution, settling of phosphor/impurities, etc.) and begin operating at optimal levels. This is especially important when using dimming features.

Metering was installed at individual lighting fixtures to measure current. This approach was chosen because measurements from the breaker panel would not exclusively measure the corridor lighting fixtures that were part of this pilot. In addition, one-time measurements were conducted during a test day, using a handheld meter to record the power factor of light fixtures at each of the DR levels. The one-time power measurements were taken from a corridor light and the freight elevator lobby light. The duration of each baseline is based on the lighting DR test schedule, shown in Table 2.

TABLE 2. LIGHTING DEMAND RESPONSE TEST SCHEDULE

DR LEVEL, %	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.
20%	1:00 p.m. - 2:00 p.m.
0%	2:00 p.m. – 2:30 p.m.
25%	2:30 p.m. - 3:30 p.m.
0%	3:30 p.m. - 4:00 p.m.
30%	4:00 p.m. - 5:00 p.m.

METERING EQUIPMENT AND DATA ACQUISITION

The current running to individual fixtures was measured using HOBO U12-006 data loggers with five Amp split-core current transformers. The wire powering the fixture was wrapped though the five Amp current transformers five times. This effectively made the current transformer one Amp full scale. The Hobo loggers were installed inside the light fixtures as shown in Figure 3. One-time power measurements were made using an AEMC 3910 true RMS power meter. To enhance the accuracy of the measurement, a loop of wire with 50 turns was placed in the conductor powering the lighting fixture.

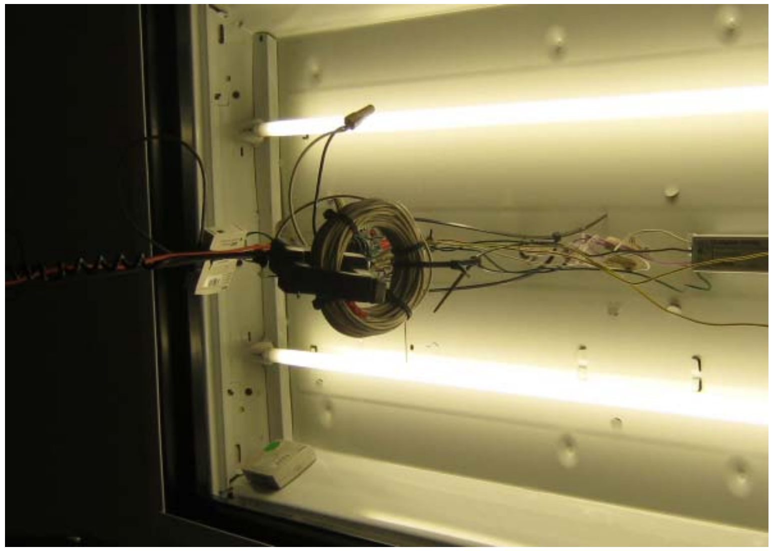

FIGURE 3. HOBO LOGGER IN A CORRIDOR LIGHT FIXTURE

Current data were recorded at 30-second intervals from October 17 to October 24. On October 18, when one-time power measurements were conducted, the loggers in those two fixtures were set to record data in 1-second intervals. This time resolution was used to confirm the high mode on time delay for occupancy. ADM's monitoring equipment was installed only a short period and manually downloaded data to a laptop at the end of the testing period.

TEST PROCEDURES

During DR testing, personnel from SCE initiated the test commands. Normally all computers, equipment, and loggers were intended to be synchronized to National Institute of Standards and Technology (NIST) clocks on Pacific Time, as obtained from the following web link: http://nist.time.gov/timezone.cgi?Pacific/d/-8/java. However, it was found that the controlling clock was running 2 minutes and 33 seconds ahead of NIST time.

DR testing was successfully conducted on the same business hours over three separate days in October of 2011: Tuesday, October 18; Wednesday, October 19; and Friday, October 21. During the test periods, recording intervals were 1-minute intervals. The testing procedure included changing the lighting level to five different settings: 10%, 15%, 20%, 25%, and 30% below the commissioned level. Each setting lasted for one hour, after which it returned to the baseline DR level of 0%.

Data loggers also recorded a non-test day, October 20, a comparison to demand during the three test days.

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. Charts and tables displaying the data are presented in this section.

DEMAND RESPONSE TEST DAYS

DR testing was successfully conducted during the same business hours over three separate days in October of 2011: Tuesday October 18, Wednesday October 19, and Friday October 21. The results of the representative test scenarios for the ALCS are shown below. During DR testing in the corridor, data logging occurred every 30 seconds. The DR levels were 10%, 15%, 20%, 25%, and 30% below the commissioned level. Each setting lasted for one hour after which the lighting level returned to the baseline DR level of 0% before the next interval setting.

The test for the DR system was conducted on the three October days mentioned above. Figure 4 illustrates power usage during a non-test day, which is representative of typical power use of the corridor space without ALCS DR reductions. The electrical use data series illustrates the minute-to-minute electrical usage from all 12 corridor lighting fixtures. The shaded vertical portions of the graph show the periods where power would have been reduced if the tests had been implemented. The load fluctuations during the day are from occupancy sensors.

Figure 5 through Figure 7 illustrate the three days of DR testing. The figures show drops in demand when power level settings were reduced as per the DR testing schedule. Signs of power reductions with the level settings for each of the three days of testing are very evident.

DATA ANALYSIS

Power was calculated from the recorded current measurements and multiplied by the average voltage and power factor for the current measurement. The one-time measurements were used to establish a relationship between percent full load current and power factor.

The DR power reductions were determined by using all available data for the testing periods over the three days. Therefore, each power level setting was activated three times and for each activation there was a similar deactivation back to the baseline DR level of 0%. Data were averaged over the three hours corresponding to the timing of each level setting. Averages include high and low mode operation of the fixtures during each of the DR levels.

Analysis was based on averaged power levels. A second analysis was based on reductions if no dimming from occupancy sensors had occurred.

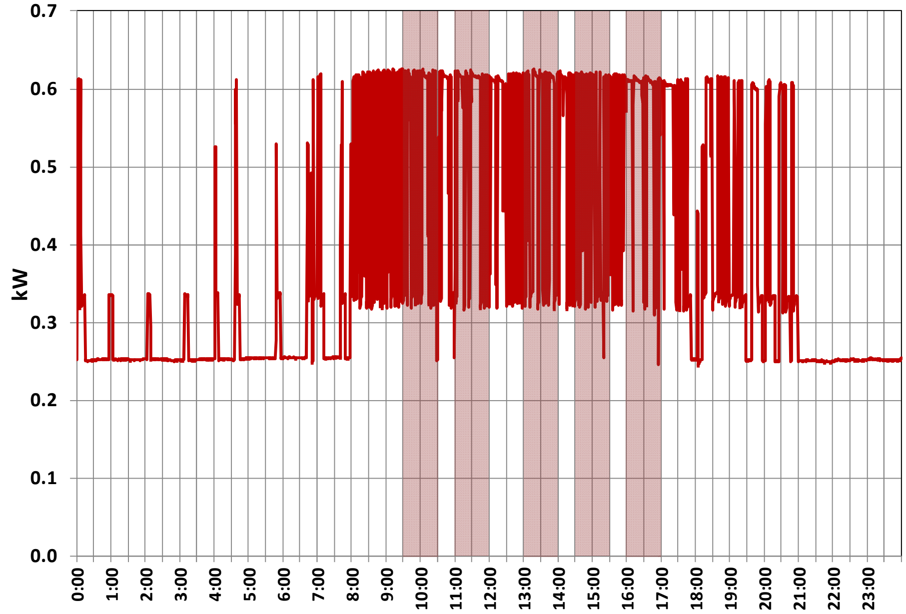

FIGURE 4. LIGHTING LOAD DURING A NON-TEST DAY THURSDAY OCTOBER 20

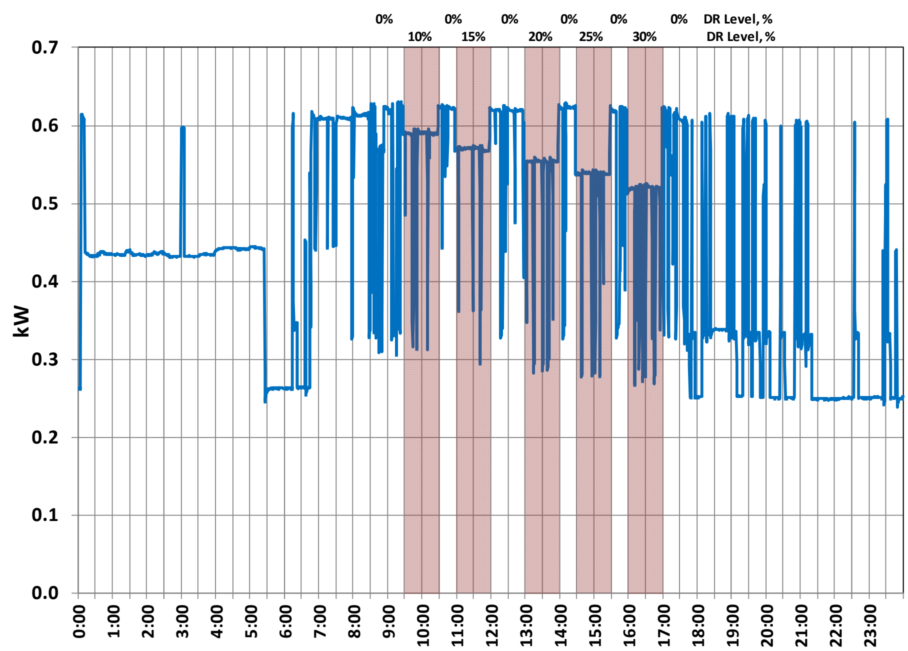

FIGURE 5. LIGHTING LOAD DURING DEMAND RESPONSE TESTING, TUESDAY OCTOBER 18

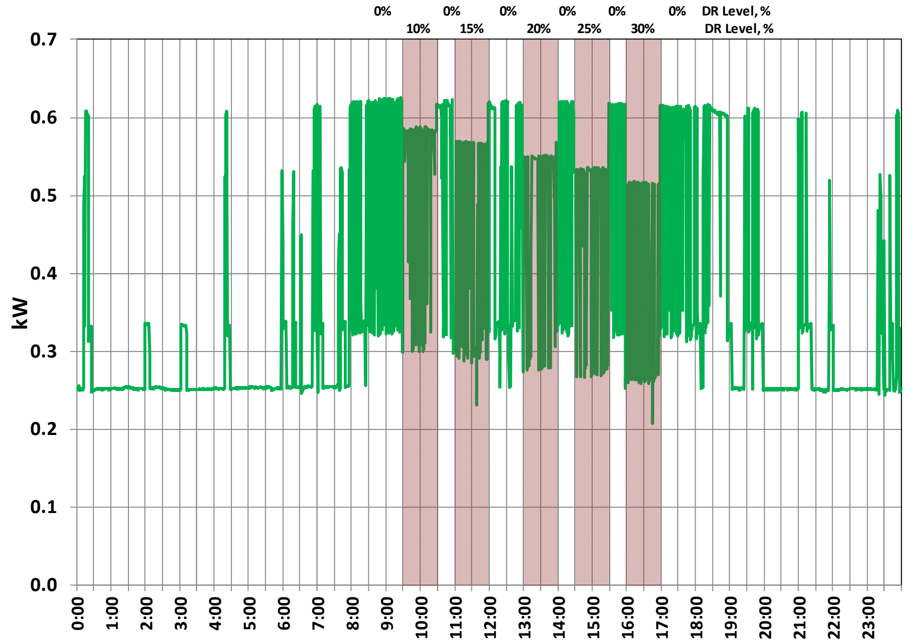

FIGURE 6. LIGHTING LOAD DURING DEMAND RESPONSE TESTING, WEDNESDAY OCTOBER 19

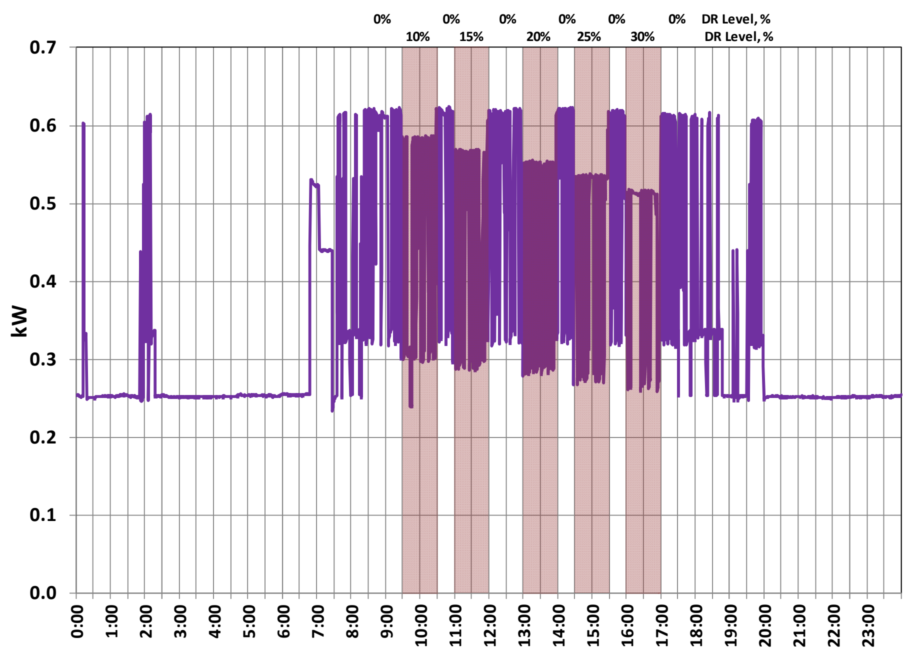

FIGURE 7. LIGHTING LOAD DURING DEMAND RESPONSE TESTING, FRIDAY OCTOBER 21

DEMAND RESPONSE RESULTS

One-time power measurements were taken in two different lighting fixtures. One fixture was located in the corridor (two T5 lamps), with the other located in the freight elevator lobby (two T8 lamps). Measurements were taken throughout one of the test days at each of the DR levels; results are presented in Figure 8. The measured DR percentage for the two fixture types versus the scheduled DR testing percent levels are presented in Figure 9.

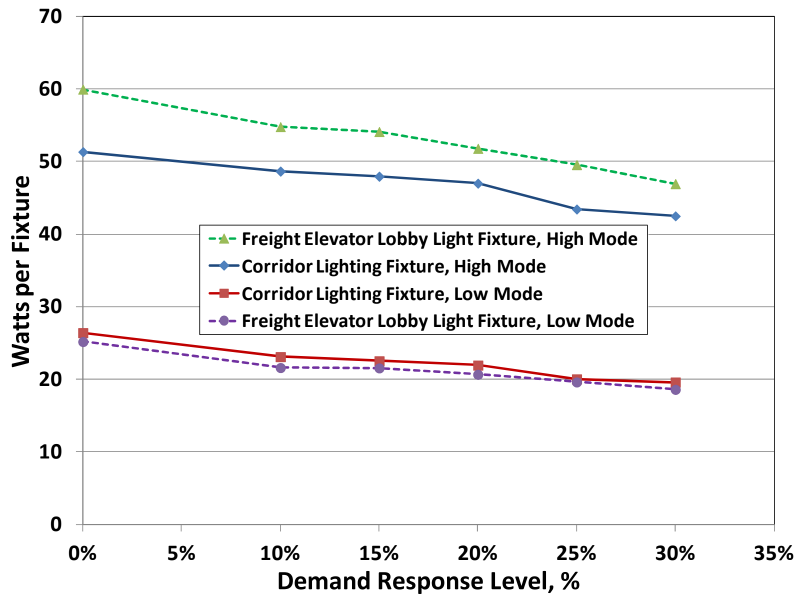

FIGURE 8. ONE TIME POWER MEASUREMENTS OF TWO FIXTURES AT VARIOUS DR LEVELS DURING TESTING

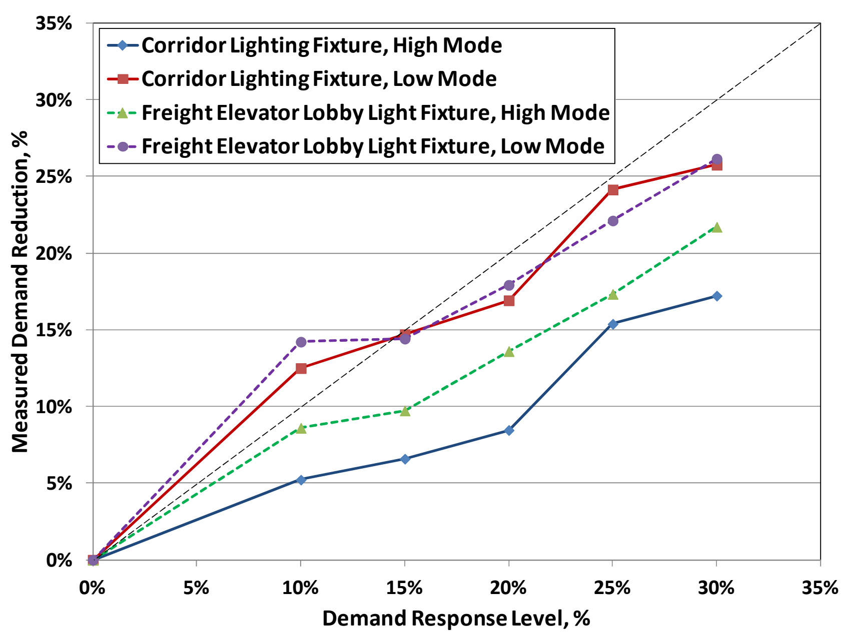

FIGURE 9. ONE TIME POWER MEASUREMENT PERCENT REDUCTION VERSUS DR LEVEL DURING TESTING

Data were averaged for the 12 fixtures over the three hours (all three test days) corresponding to the timing of each DR level. Averages include high and low mode operation of the fixtures during each of the DR levels and are presented in Figure 10.

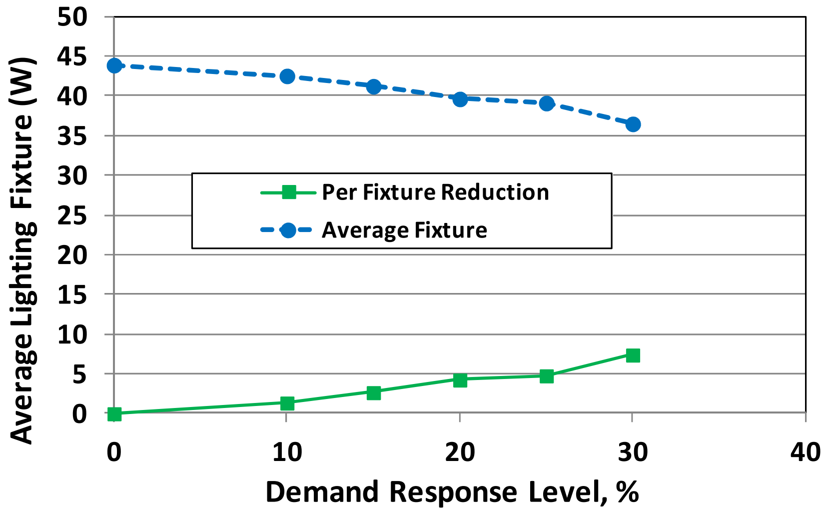

FIGURE 10. AVERAGE POWER MEASUREMENT FOR LIGHTING FIXTURES AT VARIOUS DR LEVELS DURING TESTING

Table 3 shows the average demand reductions per fixture, as well as lighting power density demand reductions for each level setting derived from data shown in Figure 5 through Figure 7. Averages include high and low mode operation of the fixtures during each of the DR levels. The maximum DR reduction was 7.4 Watts (W) per fixture (0.092 W/sf) from the fixtures at the 30% DR level setting. This is approximately 17% reduction of the average wattage.

TABLE 3. DEMAND REDUCTION LEVEL SETTING VERSUS MEASURED AVERAGE DEMAND REDUCTION

DR Level, %	Average Demand (W / Fixture)	Average Demand Reduction (W / Fixture)	Average Demand Reduction (W / sf)	Control System Timing
0%	43.9	0.0	0	9:00 a.m. – 9:30 a.m.
10%	42.5	1.4	0.017	9:30 a.m. – 10:30 a.m.
15%	41.2	2.7	0.033	11:00 a.m. - 12:00 p.m.
20%	39.6	4.3	0.053	1:00 p.m. - 2:00 p.m.
25%	39.1	4.8	0.059	2:30 p.m. - 3:30 p.m.
30%	36.5	7.4	0.092	4:00 p.m. - 5:00 p.m.

In an alternative analysis, the impact of dimming from the occupancy sensors was ignored. This resulted in a maximum DR reduction of 8.9 Watts per fixture (0.11 W/sf) or 17% of the commissioned wattage from the fixtures at the 30% DR level setting. The reduction of 0.11 (W/sf) is for the 970 square feet of corridor involved with the DR testing and is distributed over the 12 fixtures with DR capability.

Figure 11 displays the relationship between control system level settings and DR demand reduction of the ALCS. The figure shows a general upward trend between DR level setting and average measured lighting demand reduction with occupancy sensors. A second dotted line represents the demand reduction that would be achievable if the system did not have dimming, based on occupancy sensors.

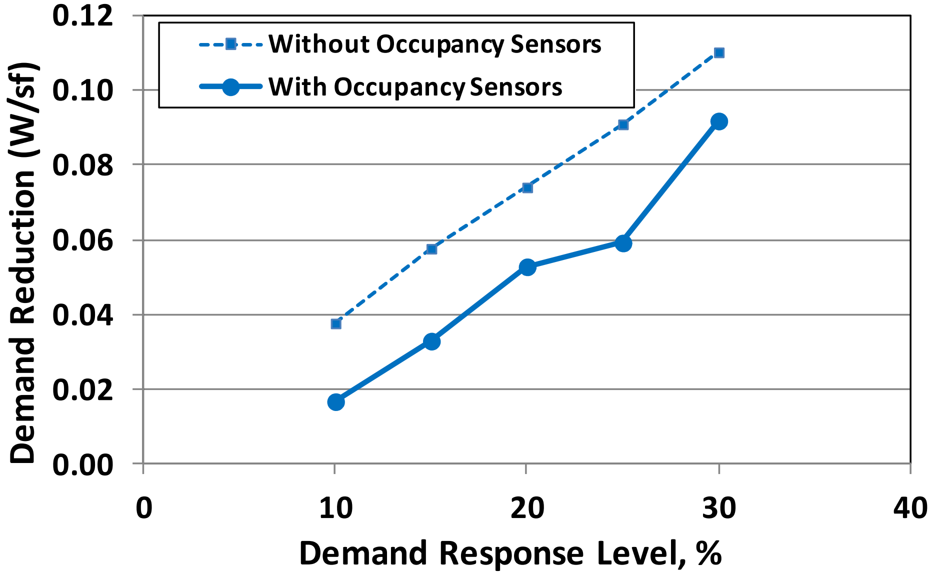

FIGURE 11. LIGHTING DEMAND REDUCTION PER SQUARE FEET AT VARIOUS DR LEVELS DURING TESTING

DISCUSSIONS

This project implemented new technology to provide demand reductions. Demand reduction is maximized when DR controls are the only method used to dim lighting. When dimming is available through other controls such as occupancy sensors, the DR impact is diminished.

The controls were originally designed to group fixtures into zones. It is noted that during the DR testing period all fixtures were grouped as one zone. Therefore, if someone were to activate an occupancy sensor, all of the lighting fixtures would change to high output mode. Although this strategy improves the average DR reduction, it reduces the energy savings capability of the system.

CONCLUSION

The main objectives of the project were to determine the following:

1. *Examine the advanced lighting controls system that allows for reliable control of corridor lighting loads from business management as part of a Demand Response Program:* DR testing for the ALCS confirmed that business management as part of a DR Program could reliably manage lighting loads.
2. *Examine demand reductions that can be achieved with a well-designed, smart lighting control system:* There was a reduction in overhead corridor lighting load demand after the installation of ALCS and new lighting fixtures, including occupancy sensors. The DR reduction for lighting averaged 7.4 W/fixture, or 0.092 W/sf at the 30% DR level. The percentage reduction is approximately 17%.

The controls were originally designed to group fixtures into zones. It is noted that during the DR testing period all fixtures were grouped as one zone. Therefore, if someone were to activate an occupancy sensor, all of the lighting fixtures would change to high light output mode. Although this strategy improves the average DR reduction, it reduces the energy savings capability of the system.

This was a case study of the impacts that automated lighting control systems can have on DR. The results provided may not be effectively extrapolated to other sites or to the general population.

This report can provide measured and technical data to the Smart Corridor concept process. The results of this study illustrate the power reductions under this ACLS.

RECOMMENDATIONS

The results of this pilot and other DR projects show evidence of demand reduction. The highly controlled lighting solutions demonstrated in the pilot quality for SCE's incentive program. In addition, the broader Smart Corridor concept that addresses demand feedback to occupants and overall building demand would experience further demand reduction under these methods.

The technical best practices and case studies resulting from this and other demonstration projects should also be clearly defined and promulgated for future purposes.

As new pilot programs are implemented, sites with the greatest potential for clear results and low measurement error should be chosen.

Further study of highly controlled lighting solutions may further clarify the results, which include the following:

- Measurement of power usage throughout the course of the year to better understand seasonal variations in various locations.
- Measurement of hourly profiles to study demand reduction impact potential for various time windows that are most likely to have a call for DR.

Additional recommended steps may support and expand upon the results of this pilot:

- This pilot only explored incremental DR settings up to 30%. Future studies that examine greater power reductions (for example, incremental DR settings up to 50%) could further the understanding of the power saving potential of this ALCS.
- Further study of the market impact of mass implementation of this ALCS would improve our understanding of factors related to easing the stress to the electric grid.

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APPENDIX A- DATA, EQUIPMENT CALIBRATION, AND POWER MEASUREMENTS

Raw and processed data collected for the evaluation of this project can be found in the embedded Excel file. In addition, information on equipment calibration is provided in one of the worksheets in the same file. A second file containing one-time power measurements is also included.

Landmark hall DR Data - Appendix.xlsx

Landmark DR OTM - Appendix.xlsx