Design & Engineering Services

SMART CORRIDORS: BI-LEVEL LIGHTING FOR OFFICE APPLICATIONS

ET10SCE1250 Report

Prepared by:

Design & Engineering Services
Customer Service Business Unit
Southern California Edison

October 11, 2011

SOUTHERN CALIFORNIA EDISON
An EDISON INTERNATIONAL® Company

Acknowledgements

Southern California Edison's Design & Engineering Services (DES) group is responsible for this project. It was developed as part of Southern California Edison's Emerging Technologies Program under internal project number ET10SCE1250. DES project manager Doug Avery conducted this technology evaluation with overall guidance and management from Paul Delaney, Emerging Technologies Program Manager. For more information on this project, contact *doug.avery*@sce.com.

ABBREVIATIONS AND ACRONYMS

AC	Alternating Current
BMS	Building Management System
CEUS	California Commercial End-Use Survey
CLTC	California Lighting Technology Center
DC	Direct Current
DLM	Digital Lighting Management
DR	Demand Response
ESN	Lutron Energi Savr Node
GWh	Gigawatt Hour
Hrs	Hours
IES	Illuminating Engineering Society
kW	Kilowatt
kWh	Kilowatt Hour
kSF	Kilo-Square Feet
LPD	Lighting Power Density
MHz	Megahertz
NFPA	National Fire Protection Association
RMS	Root Mean Square
W	Watt

FIGURES

TABLES

EQUATIONS

CONTENTS

EXECUTIVE SUMMARY

The objective of the Smart Corridor project is to quantify the potential energy savings in corridor lighting by implementing bi-level lighting technologies in commercial spaces such as office, hospitality, and educational buildings while also evaluating the market potential for the bi-level lighting strategy. The energy savings data gathered from this project is crucial to the large-scale implementation of bi-level strategies, as it will support the inclusion of bi-level lighting practices for secondary spaces in utility incentive programs and, eventually, building code language.

Bi-level lighting strategies for secondary spaces, such as corridors and stairwells, reduce light levels and power consumption during periods of vacancy. Two commercialized bi-level lighting systems are evaluated in this study. The Lutron Electronics, Inc. system was installed at the Landmark Square office building in Long Beach, California. This site represents 'Class A' office buildings. The Redwood Systems solution was installed in the Natural Sciences 1 building at the University of California, Irvine. This site represents educational office buildings. These sites have low occupancy rates in secondary spaces, making them ideally suited for bi-level lighting strategies.

Based on today's commercialized product offerings, the typical installation of bi-level lighting strategies is calculated to save 25-49% energy use. There is potential for even higher savings in areas with lower occupancy rates. To vet this estimation, field installations were conducted in Southern California Edison (SCE) service territory to demonstrate commercially available advanced control systems in retrofit applications. Data gathered by ADM Associates, Inc. demonstrates that the bi-level systems installed in office and educational building retrofit settings saved 46-65% annual energy use (kilowatts per hour (kWh)) per fixture. Survey results show 25% of the total commercial lighting energy use in the education sector is attributed to corridors.[1] By reducing lighting energy consumption in secondary spaces through bi-level lighting strategies, commercial buildings are estimated to reduce their lighting energy use by 12-16%.

In contrast to the demonstrated energy savings summarized in Table 1, long payback periods shown in the demonstrations implemented for this study confirm that the combination of material, installation, and commissioning costs for these systems must come down in price for these systems to be within an acceptable payback range for the typical end user. Calculated paybacks for installed systems range from 25 to 220 years, varying based on occupancy rate and installed fixture wattage compared to pre-existing fixture and control mode (i.e., on/off switches, time clock, etc.).

Paybacks for each demonstration were evaluated based on energy savings from bi-level control, energy savings from fixture retrofit, SCE available incentives for commercial buildings, material costs, and cost of installation labor. In larger, building-wide applications of the bi-level strategy, incurred installation costs are offset by broader energy savings. With contractor training programs supported by industry and often mandated by customers, it is anticipated that installation costs will come down as the number of contractors trained to install advanced lighting systems increases. Additionally, greater emphasis is now placed on proper commissioning for retrofits and new construction. With provisions for

[1] Siminovitch, Michael, and Christopher Cioni, UC Davis *Total Lighting Energy Survey*, 2009.

commissioning in place through CALGreen code and other statewide documents, more facilities are required to put these measures into action.

TABLE 1: SUMMARY OF DEMONSTRATION FINDINGS

	Landmark Square, Long Beach		University of California, Irvine, CA	
	Corridor Zone	Stairwell Zone	Corridor Zone	Stairwell Zone
Number of Fixtures	12	11	8	16
Materials ($)	$4,460	$2,795	$4,414	$0
Installation ($)	$9,168	$5,745	$10,110	$27
SCE Sensor Rebate - $35/sensor (Per Zone)	$210	$245	$280	$0
SCE Incentive - $0.05/kWh Reduction (Per Zone)	$107.64	$130.90	$24.88	$17.84
Kilowatt (kW) Reduction/Fixture (kW) - High Mode	0.0135	0.0069	0.0102	-
kW Reduction/Fixture (kW) - Low Mode	0.0398	0.0272	-	-
Occupancy Rate (Percent time in High Mode)	30.4%	0.17%	1.2% too low	7.2%
Weighted Load Reduction	0.0318	0.0272	-	-
SCE Incentive - $100/kW Reduction (Per Zone)	$38.17	$29.88	-	-
Energy Price/kWh ($)*	$0.13	$0.13	$0.13	$0.13
Annual Energy Savings/Fixture (kWh)	179	238	62	22
Annual Energy Savings/Fixture (%)	**46%**	**65%**	**55%**	**10%**
System Cost/Fixture ($)	$1,106	$740	$1,777	$0.55
Annual Savings/Fixture ($)	$23	$30	$8	$3
Simple Payback (Years)	**49**	**25**	**220**	-

*Based on SCE TOU-8-B rate schedule.

The next step for bi-level lighting systems is greater market adoption and widespread implementation in appropriate applications. This can be facilitated by inclusion of bi-level lighting strategies into building codes as well as by offering utility incentives to customers who install technologies that enable secondary spaces with bi-level lighting strategies. With increased market penetration, bi-level lighting strategies and training programs for installation will gain more traction and lead to a lower payback period for end-users. Revisiting the anticipated decrease in costs for material and installation as the demand for these systems increases will provide updated payback data.

Based on today's commercialized product offerings, the typical installation of bi-level lighting strategies was calculated to save 25-49% energy use. In addition, there is potential for even higher savings in areas with lower occupancy rates.

INTRODUCTION

The objective of the Smart Corridor project is to quantify the potential energy savings in corridor lighting for commercial spaces. These spaces include office, hospitality, and educational buildings. In addition, the project will evaluate the market potential for the bi-level lighting strategy. The energy savings data gathered from this project is crucial to the large-scale implementation of bi-level lighting strategies, as it will support the inclusion of bi-level practices for secondary spaces in utility incentive programs and building code language.

Simple bi-level lighting strategies for secondary spaces, such as corridors and stairwells, reduce light levels and power consumption during periods of vacancy. The market currently offers a number of adaptive, bi-level lighting systems.

The simplest versions of occupancy-based adaptive systems use stepped- or full-dimming ballasts paired with occupancy sensors and wired communications. More advanced systems offer additional control capabilities such as scheduling and tuning, which can be run independent of a building's management system (BMS), or tied in later at the discretion of the customer. This solution is often appropriate for retrofit installations, where tying into the BMS may not be easy or cost-effective. Systems available in the market today offer wired and wireless communication mediums between system components.

This project evaluated bi-level lighting strategies in corridors and stairwells through the development of system designs, a laboratory test plan, field demonstrations, and market and energy savings analysis. Market analysis includes estimated market penetration as well as the evaluation of current material, installation and commissioning costs, and anticipated cost trends based on projected product availability, new training programs, and California state building codes. The energy-savings analysis procedure is also outlined in detail for full disclosure of analysis methods.

The results of this evaluation provide data to quantify energy savings of bi-level corridor lighting compared to typical static lighting systems. Typical lighting systems in corridors are equipped with the building's standard, non-dimmable ballast and operate with wall switches or from the panel box. Smart Corridor technology products evaluated in this report are available in today's market for retrofit, or new construction applications.

MARKET ANALYSIS

Prior to field demonstrations, a statewide and SCE service territory market analysis was completed to estimate corridor lighting energy use. Significant energy use would justify an in-depth bi-level lighting, energy savings monitoring, and verification project.

Typical corridors found in commercial spaces such as office, hospitality, and educational buildings illuminate continuously, but are characterized by intermittent occupancy. Because of this, corridors and stairwells are appropriate spaces to implement bi-level lighting strategies to reduce energy consumption. Based on today's commercialized product offerings, the typical installation of bi-level lighting strategies was calculated to save 25-49% energy use. In addition, there is potential for even higher savings in areas with lower occupancy rates.

An independent survey conducted by UC Davis on the campus's lighting energy use indicates that corridors are one of the largest lighting energy users in college applications.[2] These results imply that corridor applications are a large opportunity for energy savings based on occupancy controls. Implementing bi-level lighting strategies in corridors and similar secondary spaces is an appropriate way to reduce campus-wide energy use.

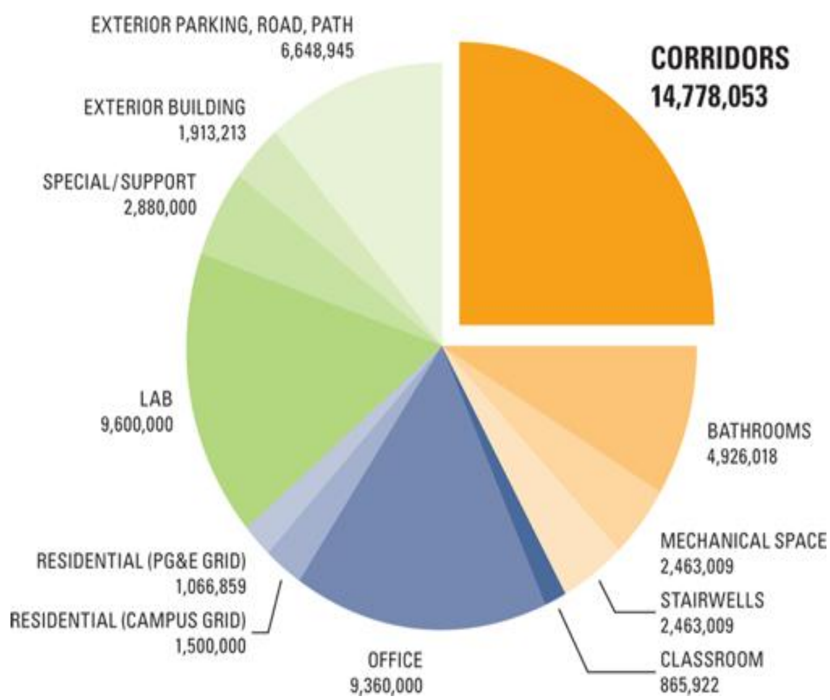

FIGURE 1. UC DAVIS – TOTAL LIGHTING ENERGY (KWH)

[2] Siminovitch, Michael, and Christopher Cioni, UC Davis *Total Lighting Energy Survey*, 2009.

The California Commercial End-Use Survey (CEUS) has compiled commercial floor stock for California by utility area, shown in Table 2.[3] Commercial applications appropriate for bi-level corridor lighting have been identified as office, school, college, health, and lodging. A cross-section of office and laboratory buildings at the University of California, Davis, attributes an estimated 23% of the floor stock to corridors.[4] Estimated energy use is based on typical operating hours of each commercial application and the lighting power density (LPD) for secondary spaces, defined by ASHRAE 90.1 as 0.6 Watts per square foot.[5] The amount of energy use attributed to corridor lighting statewide, and in SCE service territory is shown in Table 2, with estimated annual savings for these territories shown.

TABLE 2: FLOOR STOCK AND ENERGY USE

Space Type	Statewide (kSF)	Statewide Corridors (kSF)	Statewide Corridor Load (kW)	Assumed Hours of Use per Year (Hrs)	Statewide Annual Corridor Energy Use (kWh)	Estimated Annual Savings (Low) (GWh)	Estimated Annual Savings (High) (GWh)	SCE (kSF)	SCE Corridors (kSF)	SCE Corridor Load (kW)	SCE Annual Corridor Energy Use (kWh)	Estimated Annual Savings (Low) (GWh)	Estimated Annual Savings (High) (GWh)
Office	1,022,012	237,107	142,264	2600	369,886,583	92	181	385,110	89,346	53,607	139,379,011	35	68
School	445,106	103,265	61,959	2600	161,092,764	40	79	176,999	41,064	24,638	64,059,478	16	31
College	205,942	47,779	28,667	8760	251,124,027	63	123	64,809	15,036	9,021	79,027,576	20	39
Health	232,606	53,965	32,379	8760	283,637,896	71	139	106,471	24,701	14,821	129,829,886	32	64
Lodging	270,044	62,650	37,590	8760	329,289,493	82	161	112,405	26,078	15,647	137,065,758	34	67
TOTAL	2,175,710	504,766	302,859	31,490	1,395,030,763	348	683	845,794	196,225	117,735	549,361,709	137	269

[3] Itron, Inc. "California Commercial End-Use Survey (CEUS)." Prepared for California Energy Commission: CEC-400-2006-005. March 2006. http://www.energy.ca.gov/ 2006publications /CEC-400-2006-005/CEC-400-2006-005.PDF

[4] University of California, Davis. *Facilities Link.* California Lighting Technology Center, Nicole Graeber. 2011.

[5] American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. *Standard 90.1: Energy Standard for Buildings Except Low-Rise Residential Buildings.* 2010.

PRODUCT GUIDELINES

During the identification of commercial control systems to evaluate in this project, a number of guidelines were developed to ensure system compatibility. These have been compiled for future bi-level projects.

Bi-level lighting uses dimmable sources coupled with application-appropriate lighting controls. Dimmable light sources paired with controls allow the light level to vary based on a number of parameters. These include occupancy, daylighting, scheduling, tuning, and load shed.

Examples of dimmable sources appropriate for interior corridor and stairwell applications include fluorescent and LED technologies. Application-specific reflectors allow for the appropriate distribution of light to ensure the proper illumination of the space. Based on generic corridor geometry, appropriate distribution types for corridor lighting include wide-beam spreads as well as double wall washers.

The incorporation of the light source and controls can be accomplished through integrated, zoned, or networked controls. Each approach is appropriate for different scenarios and design strategies. A fixture-integrated approach results in minimal need for communication infrastructure as the sensor is wired directly to the ballast. Zoned controls offer a cost-effective way to control large spaces based on occupancy or daylighting with a minimal number of sensors. A networked approach is appropriate when additional functionality is desired from the system, such as tuning, scheduling, and load shed capabilities. By using a networked strategy, system components can communicate through wired or wireless approaches as well as offer a monitoring solution to record power usage among other parameters based on each manufacturer’s offerings.

PRODUCT IDENTIFICATION GUIDE

When identifying a new lighting system, component compatibility is the most important factor to consider:

1. Ensure the selected light source accommodates the dimming range desired for the application in which it will be used (e.g., step-dimming, full dimming, 10%-100% dimming range, 1%-100% dimming range, etc.).
2. Ensure the control components are compatible with the selected ballast communication protocol (e.g., 0-10 volt (V), DALI, etc.).
3. If using an integrated approach, either ensure the fixture is able to spatially accommodate the necessary additional components inside, or attached to the fixture.
4. If using a zoned or networked approach, ensure sensors have an appropriate communication platform to control the light source.
5. If using a networked approach, ensure that chosen platform can deliver desired functionality based on user’s data needs.
6. If using a networked approach, ensure the site has appropriate power sources and space to accommodate a permanent installation of the network system.

Various bi-level corridor and stairwell lighting systems offer users the ability to adapt their light based on the following parameters, according to users' needs:

- Occupancy/vacancy
- Available daylight in the space
- Time clock settings
- Utility Demand Response (DR) events

OCCUPANCY

Light levels in corridors and stairwells shall automatically vary based on occupancy of the space. Building space type defines the minimum light levels, as specified by the Recommended Practices of the Illuminating Engineering Society (IES) and National Fire Protection Association (NFPA), needed for comfort and safety of occupants.
When unoccupied, a space shall maintain a reduced light level as a safety feature. When occupied, a space shall illuminate to meet recommended light levels for that space type.

DAYLIGHT

When a space receives a daylight contribution, corridor and stairwell fixtures will reduce electric light contribution to use available daylight in order to maintain appropriate light level for the space.

TIME CLOCK SETTINGS

Corridor and stairwell lighting shall follow building time clock settings. This can be accomplished with a separate time clock, or incorporated into an existing BMS.

DEMAND RESPONSE (DR) EVENTS

Corridor and stairwell lights will be equipped to respond to demand response (DR) events issued by local utilities – this response can be manual or automatic.

LABORATORY EVALUATED TECHNOLOGIES

To qualify as a vetted 'Smart Corridor' system for this evaluation, the system adhered to the criteria listed in Table 3.

TABLE 3: SMART CORRIDOR TECHNOLOGY EVALUATION

Criteria	Yes/No
Provides automatic occupancy-based light levels	
- Low level provides enough light to act as a 'Safety Light'	
- High level provides enough light to meet minimum requirements for corridor/stairwell based on building type per IES recommended practice	
Capable of responding to DR events by reducing load a minimum of 10%	
Capable of reducing electric light contribution when daylight is available	
Capable of tying into the building time clock schedule	
System components available to general public (no prototypes)	

Lab evaluations were performed on the following commercialized bi-level systems:

LUTRON ELECTRONICS, INC.

The Lutron bi-level controls solution, based on occupancy, provides reliable operation in the laboratory installation at the California Lighting Technology Center (CLTC). This solution provides full dimming from 1% to 100% using Lutron's digital protocol, allowing the customer to personalize high and low levels in the space to achieve maximum savings while maintaining visual comfort.

Lutron technical staff commissions the system, with necessary site visits made for any upgrades, additions, or troubleshooting of the system.

The radio frequency (400 mega Hertz (MHz)) wireless communication of the sensors and the wired communication of the ballasts provide a system that optimizes both the reliability of the wired ballasts and the convenience of the wireless sensors. All this is accomplished while reducing the installation cost of the system. In addition, it allows users to place sensors in the optimum location, regardless of wiring needs.

The Lutron Electronics control system is compatible with fluorescent and LED sources, and can control Lutron window shades. The system uses Lutron sensors only.

REDWOOD SYSTEMS

The bi-level controls solution by Redwood Systems provides reliable operation in the laboratory installation at CLTC. The solution provides full dimming for LED fixtures that use 60W, or fewer. Full dimming allows for optimization of light levels to accommodate the user's comfort while maintaining maximum energy savings.

Redwood technical staff commissioned the system, with necessary site visits made for any upgrades, additions, or troubleshooting of the system. *Follow Me* mode achieves the greatest savings by offering a mode that "follows" the user through the corridor and initiates high mode directly in front of and behind the user, while leaving the remaining fixtures in low mode, creating a ripple of high-mode light level for users as they walk through the corridor.

The system uses the *Redwood Engine* that converts alternating current (AC) power to direct current (DC) power, powering up to a 1,580W load per engine. Power is delivered via Class 2 wiring from engine to LED fixture. The wire delivering power also acts as a communication line between the engine and the fixture.

The Redwood System is compatible with LED fixtures of 60W or fewer, and uses Redwood sensors.

FIELD DEMONSTRATION RESULTS

SCE and CLTC identified two sites as candidates to participate in the Smart Corridor project as demonstration sites. The two sites in SCE service territory were chosen to represent a cross-section of commercial space types appropriate for bi-level corridor implementation. The two sites monitored were:

1. Landmark Square, Long Beach, CA
2. Natural Science 1 and Steinhaus Hall, University of California – Irvine, Irvine, CA

SITE 1: BROOKFIELD'S LANDMARK SQUARE – 111 W. OCEAN STREET, LONG BEACH, CA

EXISTING CONDITIONS

Landmark Square is a 'Class A' office building, representing a large segment of the SCE customer base that is ideally suited to benefit from bi-level technologies. The chosen representative corridor is on the tenth floor, leading to the existing 'Office of the Future' site previously installed by SCE. The corridor area contains ten 2-lamp, T5 29W 2'x4' recessed fixtures and one 2-lamp T8 ceiling mount strip fixture in the freight elevator lobby.

The chosen representative stairwell area is located between the 10th and 15th floors, with two fixtures on each floor for a total of ten 2-lamp, T8 wall mount strip fixtures.

RETROFIT MEASURES

Existing corridor fixtures were cleaned, re-lamped, and equipped with new ballasts and controls as specified below:

- 11 corridor fixtures retrofitted with Lutron H-Series, 2-lamp, T5 ballasts
- Lutron Wireless Control System with Energi Savr Node, QS Sensor Module, and wireless occupancy sensors

Existing stairwell fixtures were replaced:

- Lutron Stairwell fixture with dimmable ballast and radio frequency (RF) receiver
- Lutron Wireless occupancy sensors, RF enabled

SITE 2: UNIVERSITY OF CALIFORNIA, NATURAL SCIENCES UNIT 1 AND STEINHAUS HALL – IRVINE, CA

EXISTING CONDITIONS

Natural Sciences Unit 1 is a four-story building that represents the educational market sector. The chosen corridor contains sixteen 6-inch downlights lamped with two Compact Fluorescent lamps (CFL) each, and mounted in a dropped ceiling. A wall switch operates the lights. Eight of the downlights must remain off the controls per the University's interpretation of the fire code. The doors are unlocked Monday through Friday, 7 am to 10 pm. The building contains professors' offices and classrooms.

Steinhaus Hall is a five-story building that contains the chosen stairwell, which was previously retrofitted with LaMar bi-level fixtures.

RETROFIT MEASURES

Existing corridor fixtures were retrofitted as follows:

- Eight were replaced with Lightolier Calculite LED downlights to provide a dimmable, efficacious source.

- The corridor was equipped with the Redwood Systems control solution, with fixture-integrated sensors commissioned to operate in 'follow me' mode to maximize savings.

- Existing bi-level stairwell fixtures were retrofitted as follows:
- The fixtures were evaluated to ensure proper settings would be used for the space and to calculate savings based on occupancy compared to stairwells equipped with fixtures operating at full power 24 hours a day, 7 days a week.

SUMMARY OF DEMONSTRATION RESULTS

The demonstrated networked utilizing bi-level technologies proved to be performing as designed by returning between 46-65% savings. However, the price points from the demonstration installations returned high paybacks due to the high first cost of the controls system.

The energy savings data from the Landmark Square, Long Beach site using the Lutron Electronics, Inc. control system displays in Table 4. Material costs are adjusted to account for the number of fixtures in demonstration compared to the number of fixtures the system could control at maximum capacity. Installation costs represent high-end customers you will find in the current market. Today, prices have been quoted to SCE for approximately half the installation costs used in this study. This significantly reduces the payback for the sites, reducing the payback from 49 to 32 years for the corridors, and from 25 to 16 years for stairwells.

Incentives are based on both prescriptive measures, as well as offering general kWh and kW reduction. Applicable rebates listed in the SCE Rebate Catalog for zoned occupancy sensor control solution offers $35/sensor. In addition, SCE offers $0.05/kWh reduction and $100/kW demand reduction over a 12-month period to customers installing custom lighting solutions. Customers are eligible to receive up to 50% of total project cost, not exceeding $6 million.

Calculated paybacks were based on 'System Cost/Fixture' and annual energy savings that the bi-level controls and fixture retrofit saved the customer. 'System Cost/Fixture' is based on material costs, installation costs and rebate incentives for each demonstration site. Annual energy savings is based on the SCE commercial rate schedule (TOU-8-B) and the monitored energy savings from the demonstration, extrapolated out for one year. For instance, in the Landmark Square, Long Beach, CA site the simple payback was calculated on a per fixture basis by dividing the 'System Cost/Fixture' by the annual energy savings, as shown in Equations 1-3.

EQUATION 1. SYSTEM COST PER FIXTURE

$$System\ Cost = Material\ Costs + Installation\ Costs - Rebates$$
$$System\ Costs = \$4{,}460 + \$9{,}168 - \$210 - \$108 - \$38$$

EQUATION 2: ANNUAL ENERGY SAVINGS

$$Annual\ Savings = Monitored\ Savings\ (kWh) * SCE\ Commercial\ Rate$$

$$Annual\ Savings = 179\ kWh * \frac{\$0.13}{kWh} = \$23$$

EQUATION 3: SIMPLE PAYBACK CALCULATION

$$Simple\ Payback = \frac{System\ Costs\ Per\ Fixture}{Annual\ Energy\ Savings\ Per\ Fixture} = \frac{\$1{,}106}{\$23} = 49\ \text{Years}$$

TABLE 4. SUMMARY OF DEMONSTRATION COSTS AND SAVINGS, LANDMARK SQUARE, LONG BEACH, CA SITE

	Corridor Zone	**Stairwell Zone**
Number of Fixtures	12	11
Materials ($)	$4,460	$2,795
Installation ($)	$9,168	$5,745
SCE Sensor Rebate - $35/sensor (Per Zone)	$210	$245
SCE Incentive - $0.05/kWh Reduction (Per Zone)	$107.64	$130.90
kW Reduction/Fixture (kW) - High Mode	0.0135	0.0069
kW Reduction/Fixture (kW) - Low Mode	0.0398	0.0272
Occupancy Rate (Percent time in High Mode)	30.4%	0.17%
Weighted Load Reduction	0.0318	0.0272
SCE Incentive - $100/kW Reduction (Per Zone)	$38.17	$29.88
Energy Price/kWh ($)*	$0.13	$0.13
Annual Energy Savings/Fixture (kWh)	179	238
Annual Energy Savings/Fixture (%)	**46%**	**65%**
System Cost/Fixture ($)	$1,106	$740
Annual Savings/Fixture ($)	$23	$30
Simple Payback (Years)	**49**	**25**

*Based on SCE TOU-8-B rate schedule.

Cost and energy savings data from the University of California, Irvine site using the Redwood System is shown in Table 5. Stairwell installation is for commissioning labor only.

Unique to this demonstration, bi-level stairwell lighting fixtures were already installed, allowing the effects of commissioning tuning to be analyzed. Low-level delay settings were reduced from 15 minutes to 5 minutes by changing dipswitch settings on each of the fixtures in the two stairwells. This is representative of the savings that can be obtained by correct commissioning of existing bi-level systems. This is calculated based on $10/hour labor rate, with an estimated 10 minutes needed per fixture to check dip switches for proper commissioning. In this demonstration area, there was a 10% energy savings by using the existing technologies as designed.

Installation costs represent the high-end customers you will find in the current market. Today, prices have been quoted for approximately half the installation costs used in this study. This significantly reduces the payback for the sites, reducing the payback from 220 years to 142 years for the corridors.

Incentives are based on both prescriptive measures, as well as offering general kWh and kW reduction. Applicable rebates listed in the SCE Rebate Catalog for zoned occupancy sensor control solutions offer $35/sensor. In addition, SCE offers $0.05/kWh reduction and $100/kW demand reduction over a 12-month period to customers installing custom lighting solutions. Customers are eligible to receive up to 50% of total project cost, not exceeding $6 million.

The exceptionally long payback attributed to the Redwood System is related to the pre-existing low wattage light source the controls are paired with, reducing the amount of savings that could be gained from tuning.

TABLE 5: SUMMARY OF DEMONSTRATION COSTS AND SAVINGS, UC IRVINE SITE

	Corridor Zone	Stairwell Zone
Number of Fixtures	8	16
Materials ($)	$4,414	$0
Installation ($)	$10,110	$27
SCE Sensor Rebate - $35/sensor (Per Zone)	$280	$0
Annual SCE Incentive - $0.05/kWh Reduction (Per Zone)	$25	$18
kW Reduction/Fixture (kW) - High Mode	0.0102	-
kW Reduction/Fixture (kW) - Low Mode	-	-
Occupancy Rate (Percent time in High Mode)	1.2%	7.2%
Weighted Load Reduction/Fixture (kW)	-	-
SCE Incentive - $100/kW Reduction (Per Zone)	-	-
Energy Price/kWh ($)*	$0.13	$0.13
Annual Energy Savings/Fixture (kWh)	62	22
Annual Energy Savings/Fixture (%)	**55%**	**10%**
System Cost/Fixture ($)	$1,777	$0.55
Annual Savings/Fixture ($)	$8	$3
Simple Payback (Years)	**220**	**0**

*Based on SCE TOU-8-B rate schedule.

FIELD DEMONSTRATION DATA

ADM Associates, Inc. monitored occupancy and energy use under pre- and post-retrofit conditions at these sites. That data is included below.

SITE 1: LANDMARK SQUARE CORRIDOR AND STAIRWELL LIGHTING MONITORING

Baseline and post-retrofit lighting monitoring was conducted at Landmark Square in Long Beach. A demonstration corridor and stairwell are included in this pilot project. Figure 2 shows a photo of the 10th floor corridor selected as part of the test area. A monitoring plan was developed to measure the energy savings for each area type. No unique electric circuits served the lighting selected for the test areas. The monitoring strategy for both area types was to monitor the mode of operation of the lighting fixtures and make one-time power measurements of the lighting fixtures. The lighting fixture mode of operation was monitored using Hobo lighting on/off loggers (model U9-002). Figure 3and Figure 4, respectively, show lighting loggers in a corridor ceiling fixture and on a stairwell lighting fixture. Note that although the stairwell lighting fixture is a 2-lamp fixture, only one lamp is used. A few occupancy loggers were also deployed to collect data on activity in the corridor and stairwell. The stairwell occupancy logger is shown in Figure 5.

FIGURE 2: 10TH FLOOR BASELINE CORRIDOR LIGHTING

FIGURE 3: CORRIDOR CEILING LIGHT FIXTURE WITH LIGHTING LOGGER

FIGURE 4: STAIRWELL LIGHT FIXTURE WITH LIGHTING LOGGER

FIGURE 5: OCCUPANCY LOGGER IN STAIRWELL

For the baseline period, on/off monitoring of the corridor lights was conducted on 12 ceiling fixtures (see Figure 6). Lighting loggers were installed in each fixture for the pre and post periods.

Baseline operation of the stairwell lighting was on 24 hours a day, 7 days a week, with no controls. Lighting loggers were deployed for the baseline stairwells to confirm the operation. An occupancy logger was installed in the south stairwell. Later, it was determined the north stairwell would be used as the demonstration area and the occupancy loggers was redeployed to the north stairwell. Lighting loggers were installed for the post-retrofit period in the 11 fixtures from the 10th to the 15th floor. One fixture is located by the door at each landing, and another halfway between floors (Figure 7).

One-time power measurements were made by opening up a sample of fixtures to gain access to the wiring. An AEMC model 3910 true root mean square (RMS) handheld power meter was used to make measurements. To increase the sensitivity of the measurement, a coil of wiring was temporarily added in line with the ballast. The coil provides a higher current flow for the meter to measure and is proportional to the number of windings in the coil. Table 6has the results of the average one-time power measurements for the pre- and post-retrofit lighting fixtures.

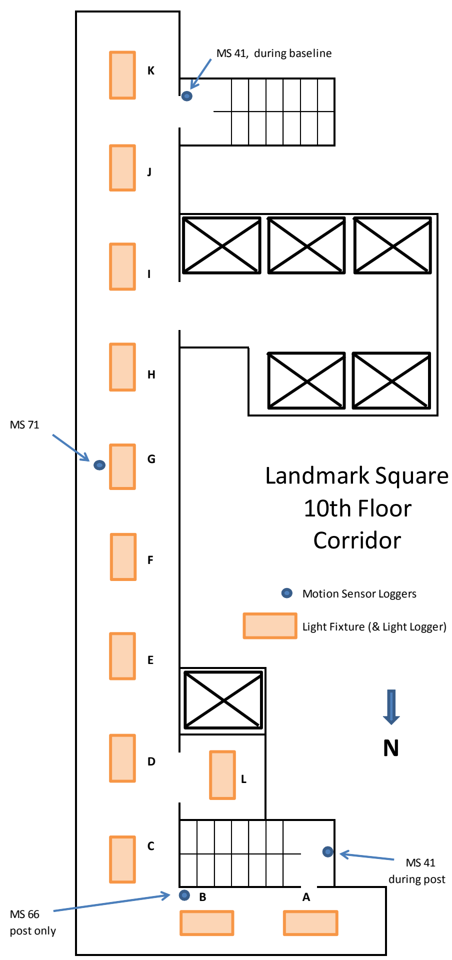

FIGURE 6: LAYOUT OF 10TH FLOOR CORRIDOR LIGHTING FIXTURES AND LOGGERS

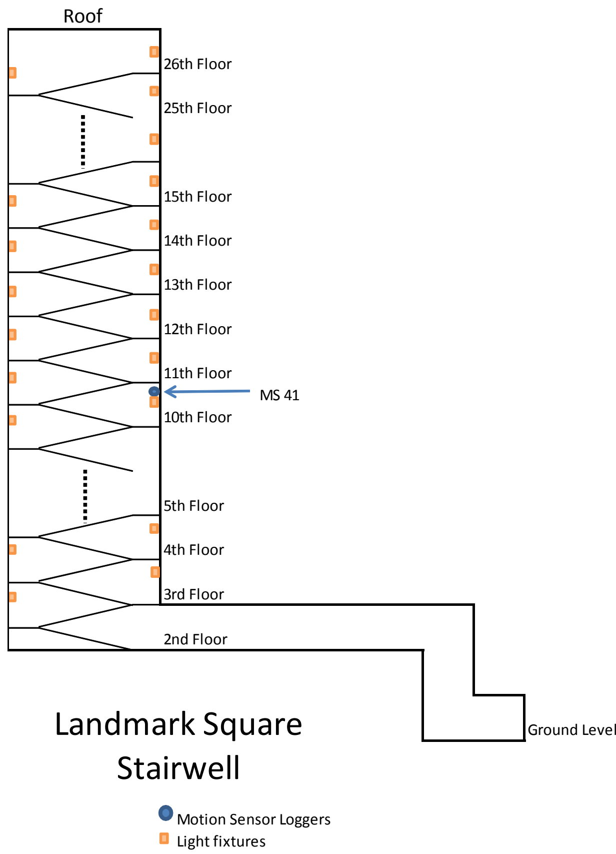

FIGURE 7: LAYOUT OF STAIRWELL LIGHTING FIXTURES AND LOGGERS.

TABLE 6: SUMMARY OF ONE-TIME POWER MEASUREMENTS FOR LIGHTING FIXTURES

	Pre-Retrofit (W/fixture)	Post-Retrofit (W/fixture)	Energy Savings (W/fixture)
Corridor Lighting			
High Mode	56.3	42.8	13.5
Low Mode	56.3	16.5	39.8
Stairwell Lighting			
High Mode	42.0	35.1	6.9
Low Mode	42.0	14.8	27.2

CORRIDOR LIGHTING

Data from May 4, 2011 to June 29, 2011 was used to develop the baseline corridor lighting typical operating profile across all 12 fixtures. Figure 8shows the average weekday and weekend-day percentage on time profiles. Note that although 8 of the 12 fixtures were on 24/7, the other 4 turned on and off according to the monitored data in a pattern normally associated with motion sensors. Data from August 7, 2011 to September 3, 2011 was used to develop the post-period corridor lighting typical operating profiles across all 12 fixtures. Figure 8shows the average weekday and weekend-day percentage of on time profiles. Note that for the post period the profiles are for operation of high mode with low mode making up the remainder of the time, shown in Figure 9.

FIGURE 8: AVERAGE BASELINE CORRIDOR LIGHTING PROFILES FOR WEEKDAYS AND WEEKENDS

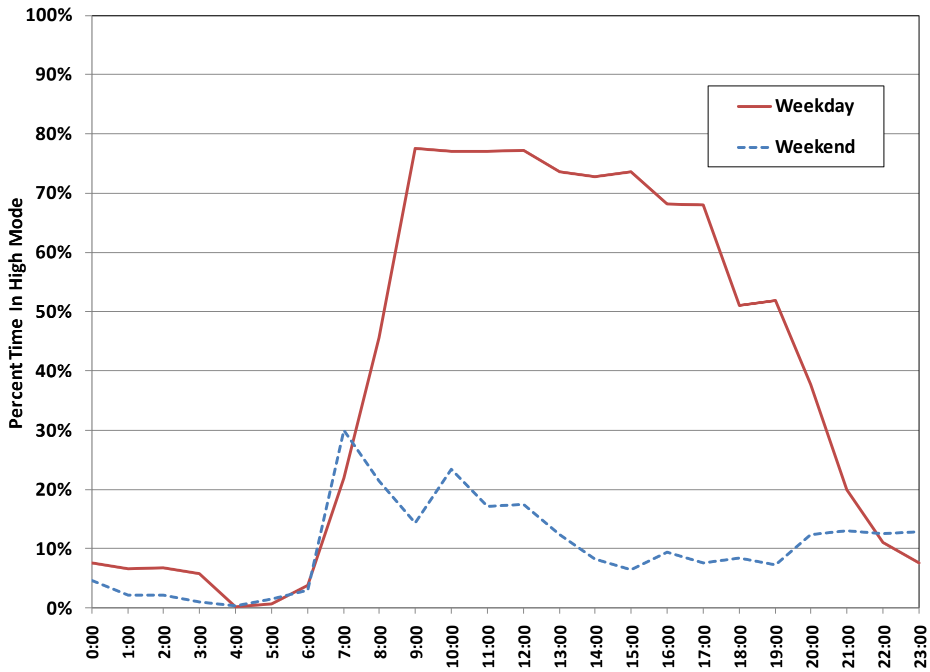

FIGURE 9: AVERAGE POST PERIOD CORRIDOR LIGHTING PROFILES FOR WEEKDAYS AND WEEKENDS

Analysis of the lighting energy use is presented on an average per-fixture basis. Weekday and weekend hourly profiles were used to generate daily energy use by day type. The analysis assumed eight holidays per year. The average baseline energy use per corridor lighting fixture was 394.0 kWh and the average post-retrofit energy use per fixture is 214.6 kWh (see Table 7). The average annual savings per fixture is 179 kWh, a 45.5% savings.

TABLE 7: SUMMARY OF CORRIDOR LIGHTING ENERGY USE PER FIXTURE

Period / Day Type	kWh/day/fixture	# of Days	Annual kWh/fixture
Pre			
Weekday	1.141	253	288.7
Weekend/Holiday	0.940	112	105.3
Total		365	394.0
Post			
Weekday	0.644	253	162.9
Weekend/Holiday	0.461	112	51.6
Total		365	214.5
Savings			
Weekday	0.497	253	125.8
Weekend/Holiday	0.479	112	53.6
Total		365	179.4

As additional information, an occupancy logger was located in the middle of the long corridor. Figure 10shows the average baseline occupancy profiles for weekdays and weekend days. The measurements were made using the motion sensor logger located on the 10th floor corridor, midway along the long hallway.

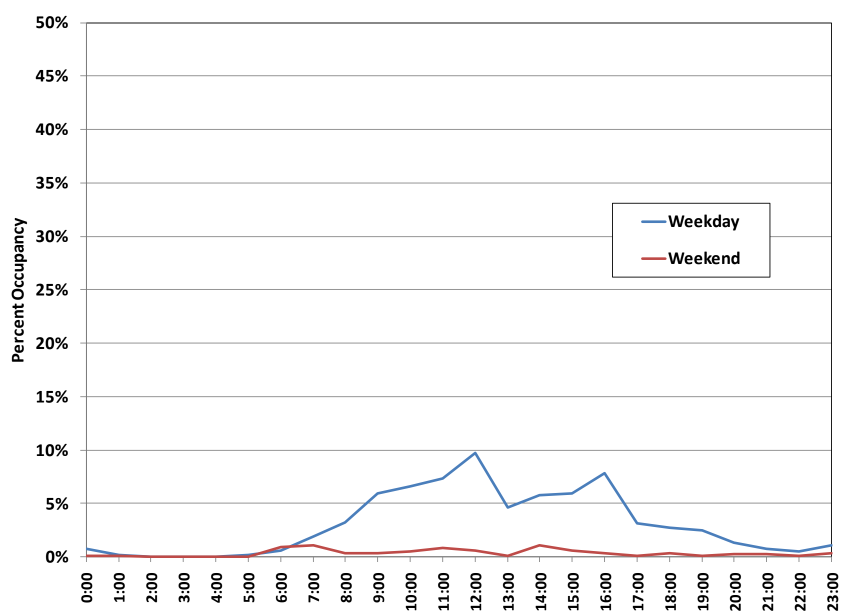

FIGURE 10: AVERAGE BASELINE OCCUPANCY PROFILES IN CORRIDOR FOR WEEKDAYS AND WEEKENDS

Data collected on a sample day during the post-retrofit period compares the occupancy logger with the lighting logger (Figure 11). The nearest fixture was the 7th fixture, or fixture "G" from Figure 6.

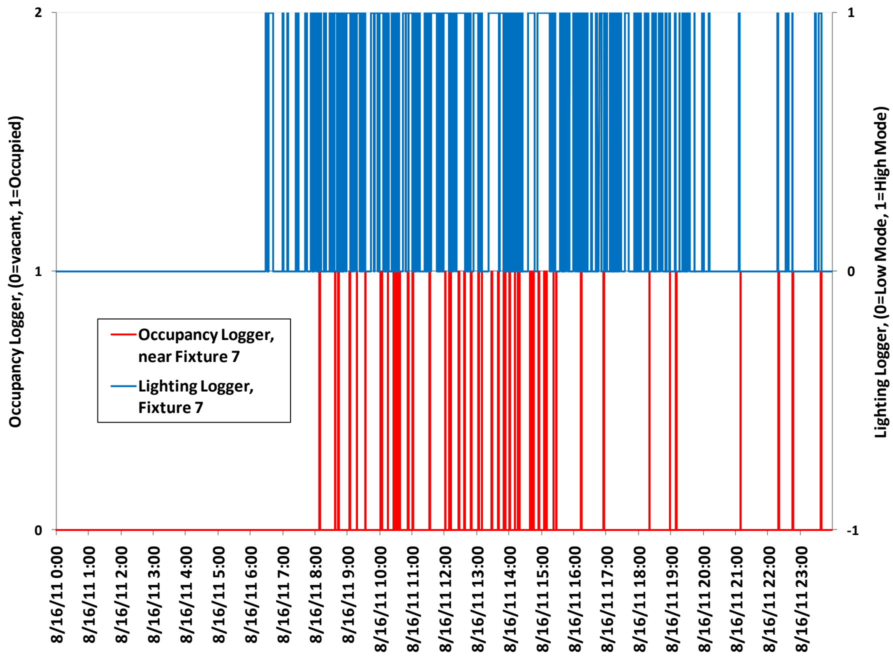

FIGURE 11: COMPARISON OF CORRIDOR OCCUPANCY LOGGER WITH LIGHTING LOGGER ON AUGUST 16, 2011

STAIRWELL LIGHTING

The baseline data showed that the stairwell lights were always on. No load profile chart was developed to display this result. Data from August 7, 2011 to September 3, 2011 was used to develop the post-period corridor lighting typical operating profiles across all 11 fixtures. Figure 12shows the average weekday and weekend-day percent on time profiles. Note that for the post-retrofit period the profiles are for operation of high mode, with low mode making up the remainder of the time.

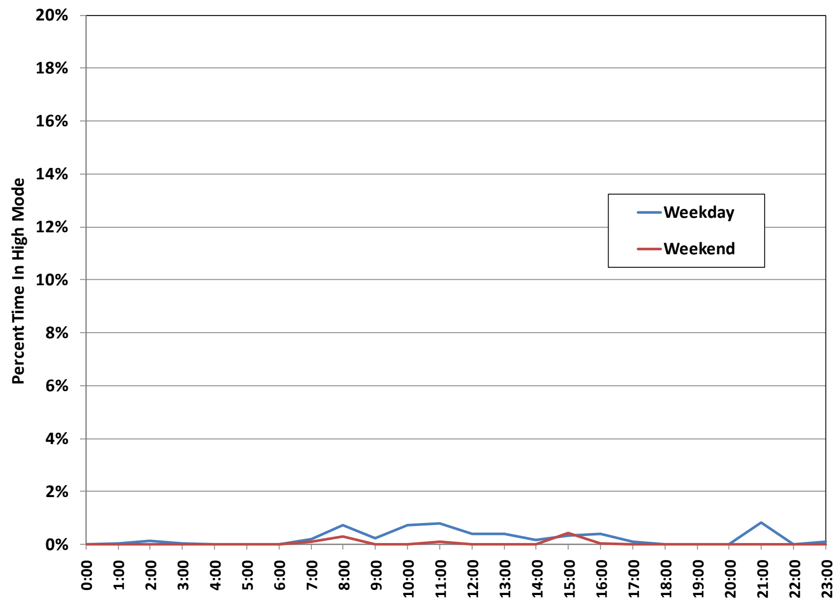

FIGURE 12: AVERAGE POST PERIOD STAIRWELL LIGHTING PROFILES FOR WEEKDAYS AND WEEKENDS

Analysis of the lighting energy use is presented on an average per-fixture basis. Weekday and weekend hourly profiles were used to generate daily energy use by day type. The average baseline energy use, per corridor lighting fixture, was 367.9 kWh and the average post-retrofit energy use per fixture is 130.0 kWh (see Table 8). The average annual savings per fixture is 237.9 kWh, a 64.7% savings.

TABLE 8: SUMMARY OF STAIRWELL LIGHTING ENERGY USE PER FIXTURE

Period / Day Type	kWh/day/fixture	# of Days	Annual kWh/fixture
Pre			
Weekday	1.008	253	255.0
Weekend/Holiday	1.008	112	112.9
Total		365	367.9
Post			
Weekday	0.356	253	90.1
Weekend/Holiday	0.355	112	39.8
Total		365	129.9
Savings			
Weekday	0.652	253	164.9
Weekend/Holiday	0.653	112	73.1
Total		365	238.0

As additional information, an occupancy logger was located in the north stairwell for the post-retrofit period. Figure 13shows the average post occupancy profiles for weekdays and weekend days. The measurements were made using the motion sensor logger located on the 10th floor landing in the stairwell.

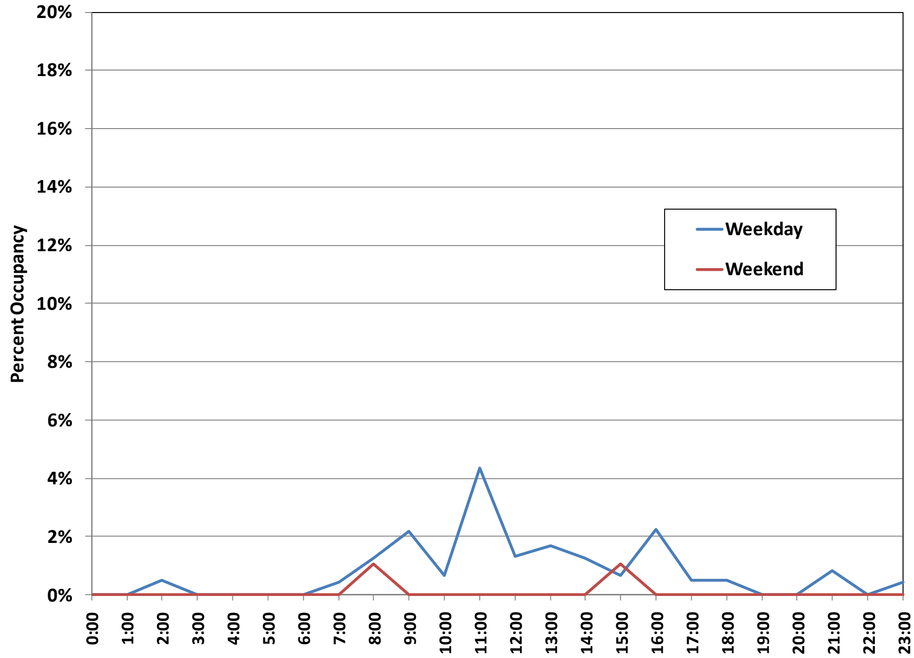

FIGURE 13: AVERAGE POST OCCUPANCY PROFILES IN STAIRWELL FOR WEEKDAYS AND WEEKENDS

Figure 14 compares data from the occupancy logger with data from the lighting logger, collected during a sample week within the post-retrofit period. The 10th-floor fixture was used for this sample comparison.

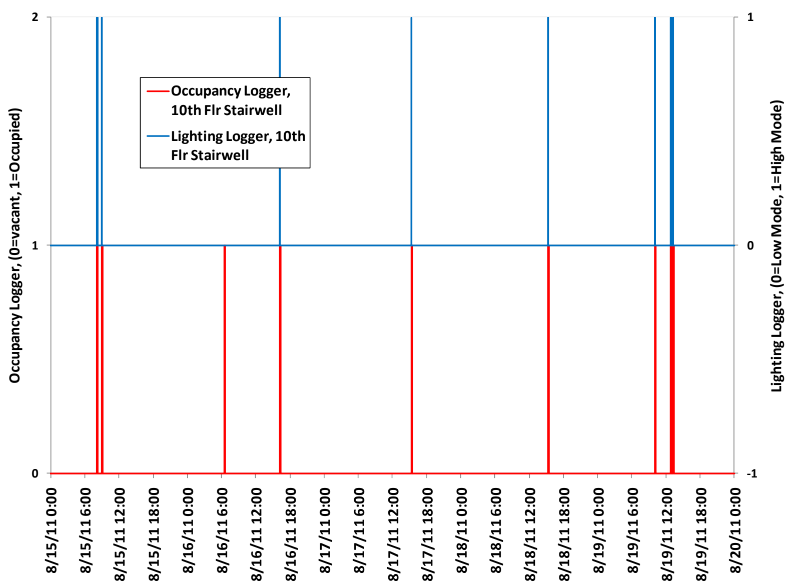

FIGURE 14. COMPARISON OF STAIRWELL OCCUPANCY LOGGER WITH LIGHTING LOGGER AUGUST 15-19, 2011

SITE 2: UC IRVINE CORRIDOR AND STAIRWELL LIGHTING MONITORING

Baseline and post-retrofit lighting monitoring was conducted at the University of California, Irvine campus. A demonstration corridor and stairwell are included in this pilot project. The corridor project was conducted in the Natural Sciences I building, and the stairwell lighting study was conducted in the Steinhaus Hall building. Figure 15 shows a photo of the Natural Sciences I building. The two photos in Figure 16 show the first floor corridor selected as part of the test area. Figure 17 shows a 2-lamp compact fluorescent baseline corridor ceiling fixture. Figure 18 shows a post-retrofit LED fixture with the occupancy sensor and a lighting logger in the fixture.

A monitoring plan was developed to measure the energy savings for each area type. The corridor lighting originally had occupancy controls that controlled all of the non-security lighting at the same time by turning them off when the area was not occupied. The baseline monitoring used Hobo external channel (model U12-006) loggers with 5-Amp current transformers to monitor the current at each fixture. To amplify the current signal, the lighting fixture wire was looped six times through the current transformer (see Figure 19). This data was primarily used to identify on and off operation of the lighting fixtures. The data collected during the pre-retrofit period for the corridor lighting identified that some of the selected fixtures were security lighting and that these fixtures were at full output continuously.

FIGURE 15. NATURAL SCIENCES I BUILDING

FIGURE 16. FIRST FLOOR BASELINE CORRIDOR LIGHTING

FIGURE 17. BASELINE CORRIDOR LIGHTING FIXTURE. FIGURE 18. CORRIDOR CEILING LED LIGHT FIXTURE WITH LIGHTING LOGGER AND OCCUPANCY SENSOR

FIGURE 19. CURRENT TRANSFORMER USED TO MONITOR THE BASELINE CORRIDOR LIGHTING

For the corridor lighting post monitoring period a two-pronged approach was used to monitor the lighting. The corridor lighting test area was modified to contain eight ceiling fixtures that were not security lights. These eight fixtures were identified as uniquely being powered by a circuit in an electrical panel. The power was monitored using a WattNode Watthour transducer, model WNB–3D-480-P, with a 5 Amp current transformer, see Figure 20. The eight fixtures were also monitored using Hobo lighting on/off loggers, model U9-002, see Figure 18.

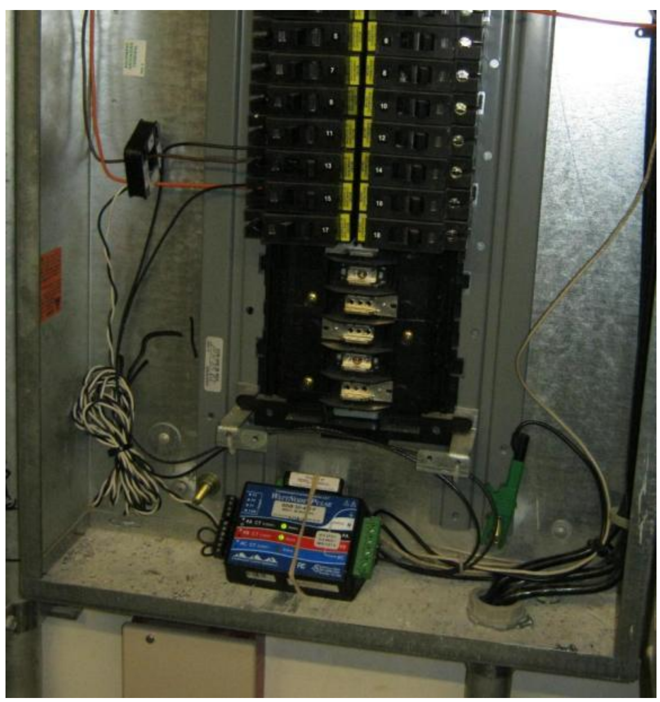

FIGURE 20. WATTNODE WATT-HOUR METER IN PANEL MONITORING THE CORRIDOR LIGHTING CIRCUIT

FIGURE 21. CORRIDOR OCCUPANCY SENSOR LOGGER MOUNTED ON CEILING TILE T-BEAMS. (TWO OCCUPANCY LOGGERS WERE USED TO MONITOR ACTIVITY IN THE CORRIDOR TEST AREA, PICTURED IN FIGURE 22.)

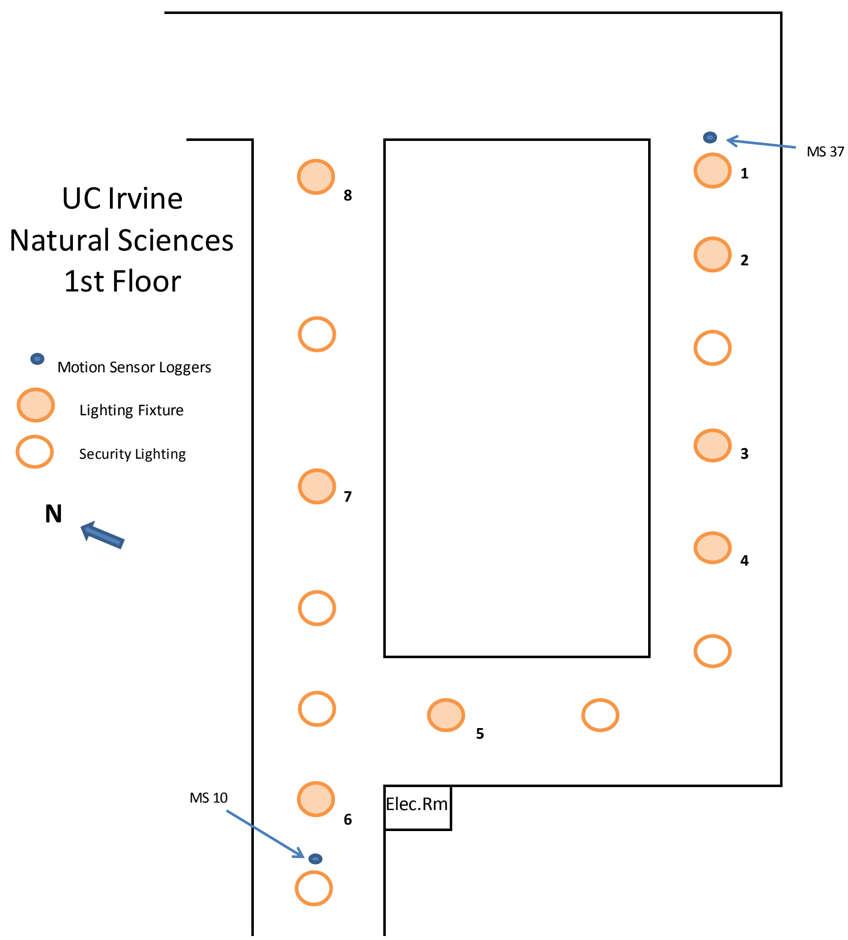

FIGURE 22. LAYOUT OF 1ST-FLOOR CORRIDOR LIGHTING FIXTURES AND LOGGERS

The lighting for both stairwells in the Steinhaus Hall building is supplied by one circuit breaker (Breaker #13, Panel 3EHB in the 3rd-floor electrical room). There were 16 fixtures included in the study: 9 in stairwell #1, and 7 in stairwell #2. One fixture was located by the door at each landing and another halfway between floors. At the top of both stairwells, there were two additional fixtures that remained on continuously (beyond the normal access points, the stairwell continues to the roof area through a doorway). One is a 2-lamp 6-Watt CFL, the other is a 1-lamp, T8, 4' fluorescent fixture. A WattNode was used to monitor the power use by the stairwell lighting circuit. The monitoring strategy for the stairwells remained the same for the pre- and post-retrofit periods. A few occupancy loggers were also deployed to collect data on activity in the stairwells. Stairwell occupancy loggers are shown in Figure 23and the layout of the stairwells is in Figure 24.

Error! Reference source not found.shows the results of the average one-time power measurements for the pre- and post-retrofit lighting fixtures. Pre-retrofit corridor lights were on/off. The measurements are from one-time measurements taken at the breaker. For the post-retrofit data, the 5.8W per fixture (Off) is from the monitored data. There is a draw of power while the LED lights are off that account for this load. One-time power measurements at the breaker with and without one LED "On" showed the difference was 9.3W, thus the 15.1W per fixture while turned on.

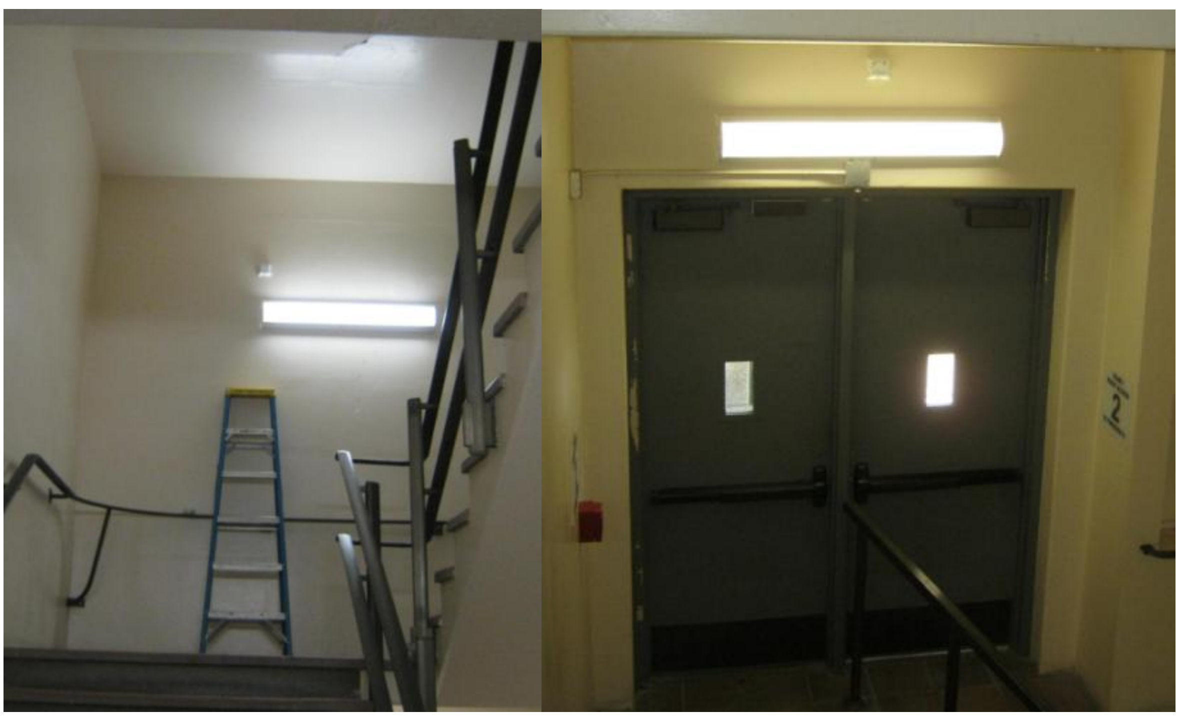

FIGURE 23. OCCUPANCY LOGGERS IN STAIRWELL

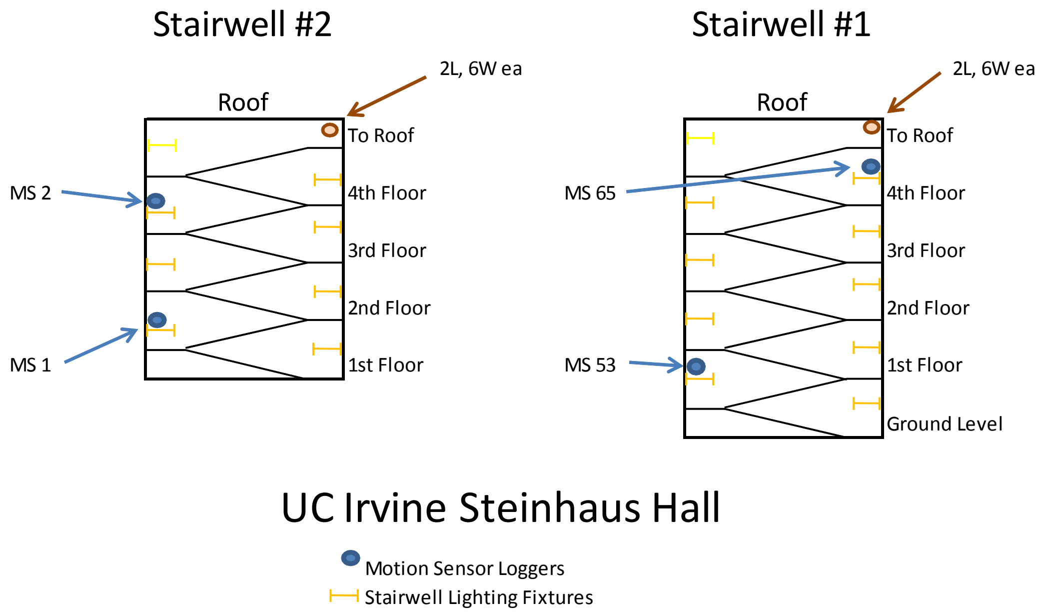

FIGURE 24. LAYOUT OF STAIRWELL LIGHTING FIXTURES AND LOGGERS

TABLE 9. SUMMARY OF ONE-TIME POWER MEASUREMENTS FOR LIGHTING FIXTURES

UCI	Pre-Retrofit (W/fixture)	Post-Retrofit (W/fixture)	Energy Savings (W/fixture)
Corridor Lighting			
ON Mode	25.3	15.1	10.2
OFF Mode	0	5.8	-5.8
Stairwell Lighting			
High Mode	35.2	35.2	0
Low Mode	13.1	13.1	0

CORRIDOR LIGHTING

Data from April 19, 2011 to July 7, 2011 was used to develop the baseline corridor lighting typical operating profile for the four fixtures that were part of the final demonstration project. One-time power measurements were made on a fixture by opening up a junction box above the ceiling tiles to gain access to the wiring. An AEMC model 3910 true root mean square (RMS) handheld power meter was used to take measurements. The baseline wattage per fixture was 25.3W. Figure 25shows the average baseline weekday and weekend-day percent on time profiles. Figure 26shows the average baseline load profile per fixture. Data from July 28, 2011 to September 7, 2011 was used to develop the post-period corridor lighting typical operating profiles across all eight test fixtures. Figure 27 shows the average weekday and weekend-day load profiles.

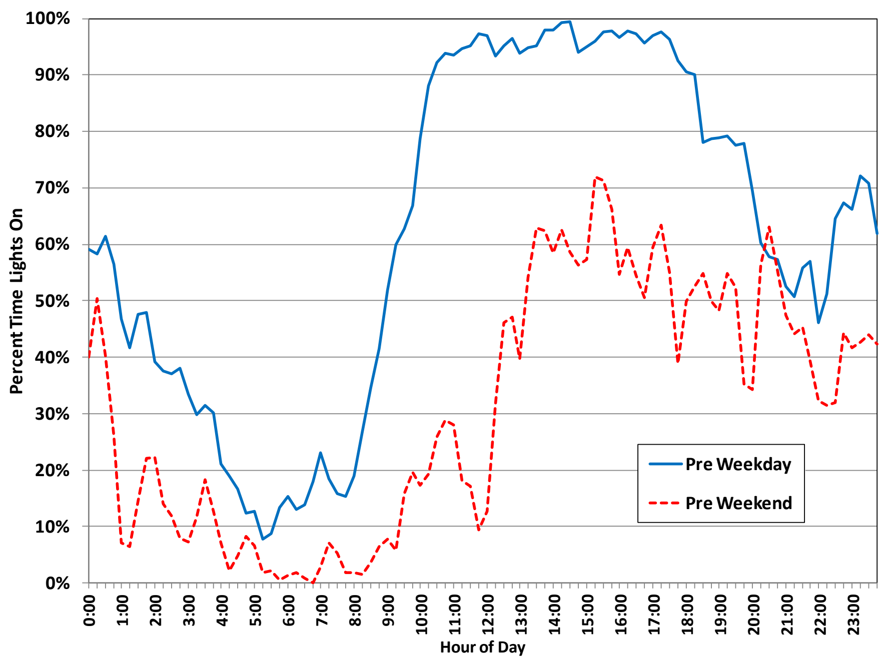

FIGURE 25. AVERAGE BASELINE CORRIDOR LIGHTING PROFILES FOR WEEKDAYS AND WEEKENDS

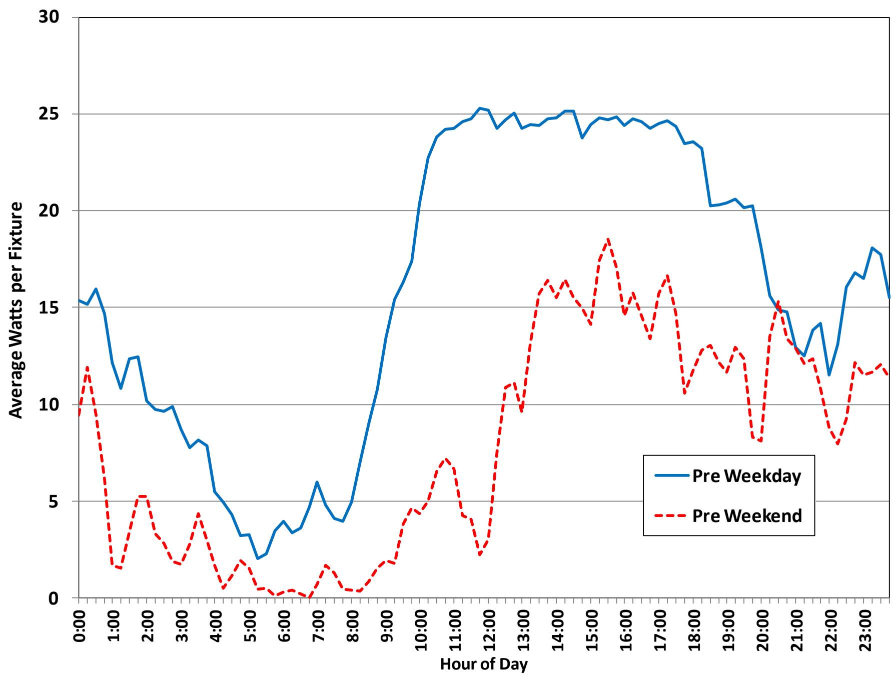

FIGURE 26. AVERAGE BASELINE CORRIDOR LIGHTING LOAD PROFILES PER FIXTURE

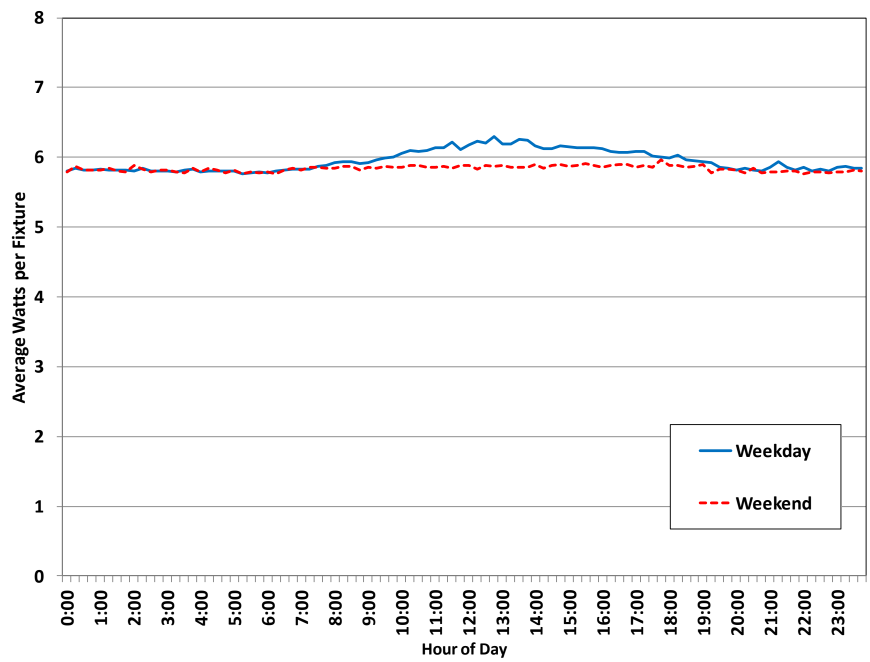

FIGURE 27:. AVERAGE POST-RETROFIT PERIOD CORRIDOR LIGHTING DEMAND PROFILES PER FIXTURE

Analysis of the lighting energy use is presented on an average per-fixture basis. Weekday and weekend hourly profiles were used to generate daily energy use by day type. The analysis used the online campus calendar to determine number of holidays per year. The average baseline energy use per corridor lighting fixture was 119.0 kWh and the average post-retrofit energy use per fixture is 51.8 kWh (see Table 10). The average annual savings per fixture is 62.2 kWh, a 54.6% savings.

TABLE 10. SUMMARY OF CORRIDOR LIGHTING ENERGY USE PER FIXTURE

Period / Day Type	kWh/day/fixture	# of Days	Annual kWh/fixture
Pre			
Weekday	0.382	233	89.1
Weekend/Holiday	0.188	132	24.9
Total		365	114
Post			
Weekday	0.143	233	33.3
Weekend/Holiday	0.140	132	18.5
Total		365	51.8
Savings			
Weekday	0.239	233	55.8
Weekend/Holiday	0.048	132	6.4
Total		365	62.2

As additional information, two occupancy loggers were located in the corridor. Figure 28 shows the average occupancy profiles for baseline and post retrofit weekdays. The measurements are an average of the two motion sensor loggers located on the 1st-floor corridor. The average occupancy of the pre- and post-retrofit periods is almost the same.

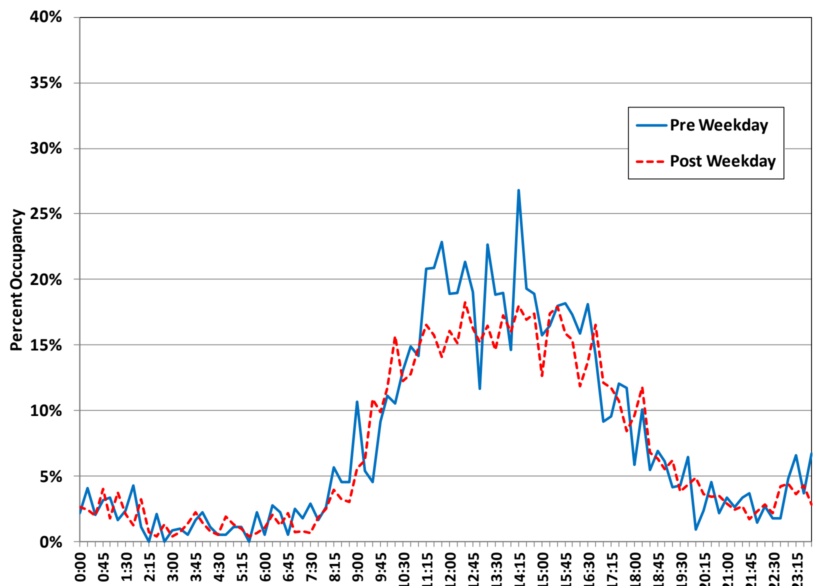

FIGURE 28. AVERAGE BASELINE AND POST RETROFIT OCCUPANCY PROFILES IN CORRIDOR FOR WEEKDAYS

Detailed data collected on a sample day during the post-retrofit period compares the occupancy logger with the lighting logger located in fixture 1 and shown in Figure 29. Fixture "1" is the upper right most fixture listed in Figure 22.

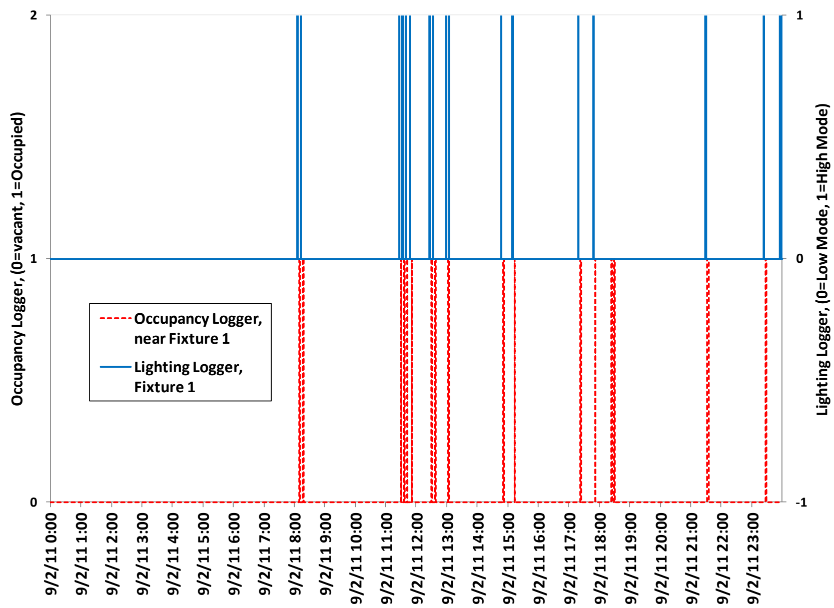

FIGURE 29. COMPARISON OF CORRIDOR OCCUPANCY LOGGER WITH LIGHTING LOGGER ON SEPTEMBER 2, 2011

STAIRWELL LIGHTING

The baseline stairwell lighting fixtures already had occupancy sensors to dim the lights when the area was unoccupied. Figure 30 shows the load profile chart for an average stairwell fixture during the baseline period of June 15, 2011 to July 18, 2011. The stairwell lighting fixture off delay settings were changed for the post period. The off delay was reduced from 15 minutes to 5 minutes by changing dip switch settings on each of the fixtures in the two stairwells. The post period average stairwell fixture profile chart in Figure 31 used data from July 30, 2011 to September 7, 2011. The analysis is for the 16 fixtures in the two stairwells that were part of the study.

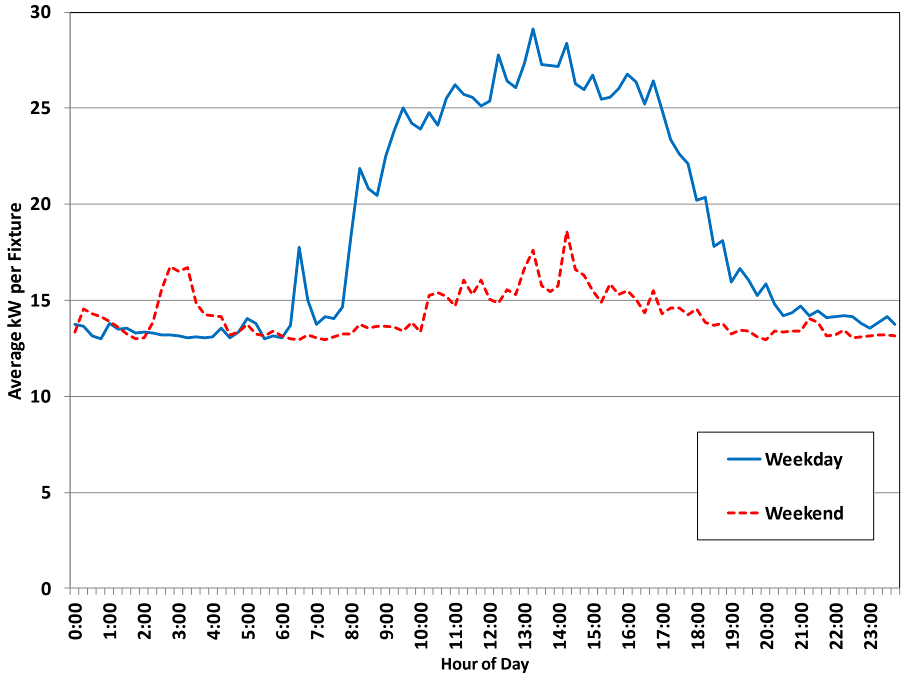

FIGURE 30. AVERAGE PRE-RETROFIT PERIOD STAIRWELL LIGHTING PROFILES FOR WEEKDAYS AND WEEKENDS

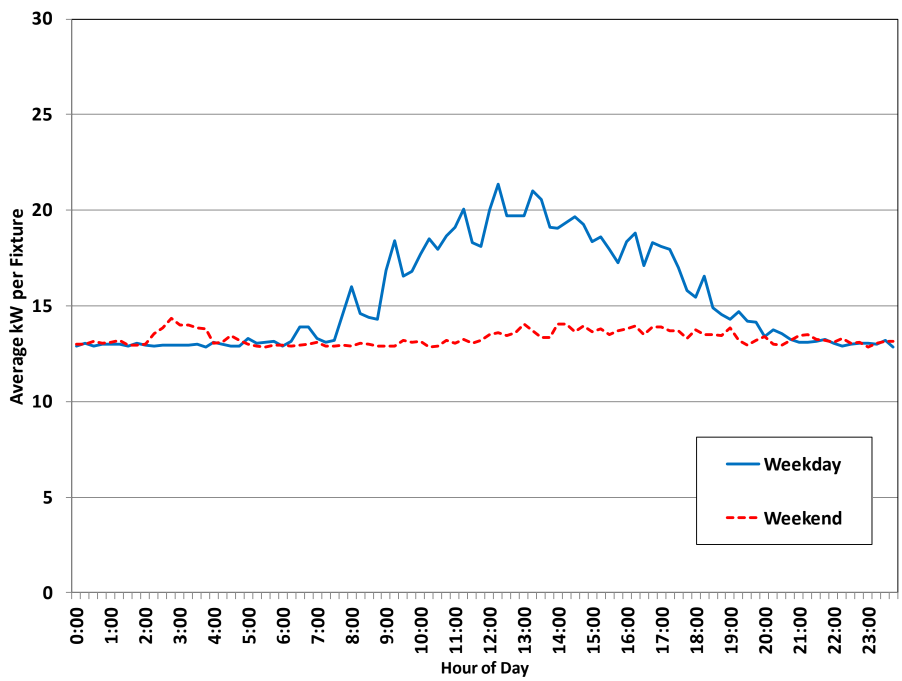

FIGURE 31. AVERAGE POST-RETROFIT PERIOD STAIRWELL LIGHTING PROFILES FOR WEEKDAYS AND WEEKENDS

Analysis of the lighting energy use is presented on an average per-fixture basis. Weekday and weekend hourly profiles were used to generate daily energy use by day type. The average baseline energy use per stairwell lighting fixture was 150.6 kWh and the average post-period energy use per fixture is 128.3 kWh (see Table 11). The average annual savings per fixture is 22.3 kWh, a 14.8% savings.

TABLE 11. SUMMARY OF STAIRWELL LIGHTING ENERGY USE PER FIXTURE

Period / Day Type	kWh/day/fixture	# of Days	Annual kWh/fixture
Pre			
Weekday	0.452	233	105.4
Weekend/Holiday	0.343	132	45.2
Total		365	150.6
Post			
Weekday	0.369	233	86.1
Weekend/Holiday	0.320	132	42.2
Total		365	128.3
Savings (Non-Adjusted)			
Weekday	0.083	233	19.3
Weekend/Holiday	0.023	132	3.0
Total		365	22.3

As additional information, four occupancy loggers were located in the two stairwells for the pre and post periods. Figure 32 shows the average pre- and post- occupancy profiles for weekdays while Figure 33 shows the same for weekend days. On Saturday mornings between 2 and 3 a.m. there is unusual activity shown in all four stairwell occupancy loggers.

The average stairwell occupancies are presented in Table 12. The occupancy data indicates the post period had less occupancy than the pre period with the average percent occupancy dropping from 2.9% to 1.9%.

TABLE 12. SUMMARY OF AVERAGE STAIRWELL OCCUPANCY

Period Type	Pre	Pre	Pre	Post	Post	Post
Day Type	Weekday	Weekend	Annual	Weekday	Weekend	Annual
Average % Occupancy	4.1%	0.7%	2.87%	2.9%	0.2%	1.92%

The stairwell lighting savings was adjusted to reflect the decrease in measured occupancy. The 22.3 kWh/fixture savings after adjustment for occupancy is reduced to 14.9 kWh/fixture.

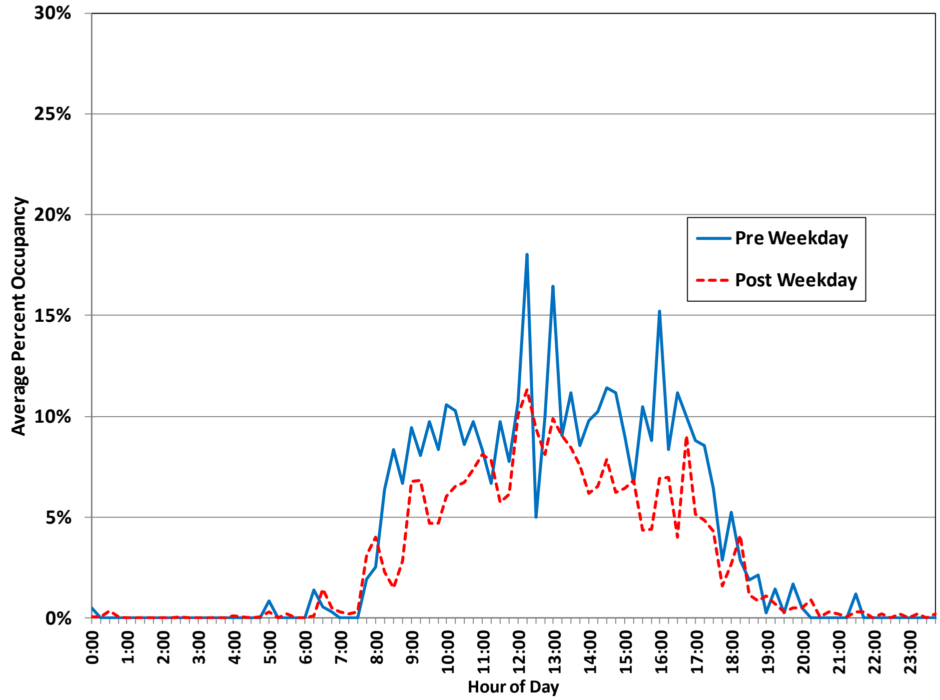

FIGURE 32. AVERAGE PRE -AND POST- OCCUPANCY PROFILES IN STAIRWELL FOR WEEKDAYS

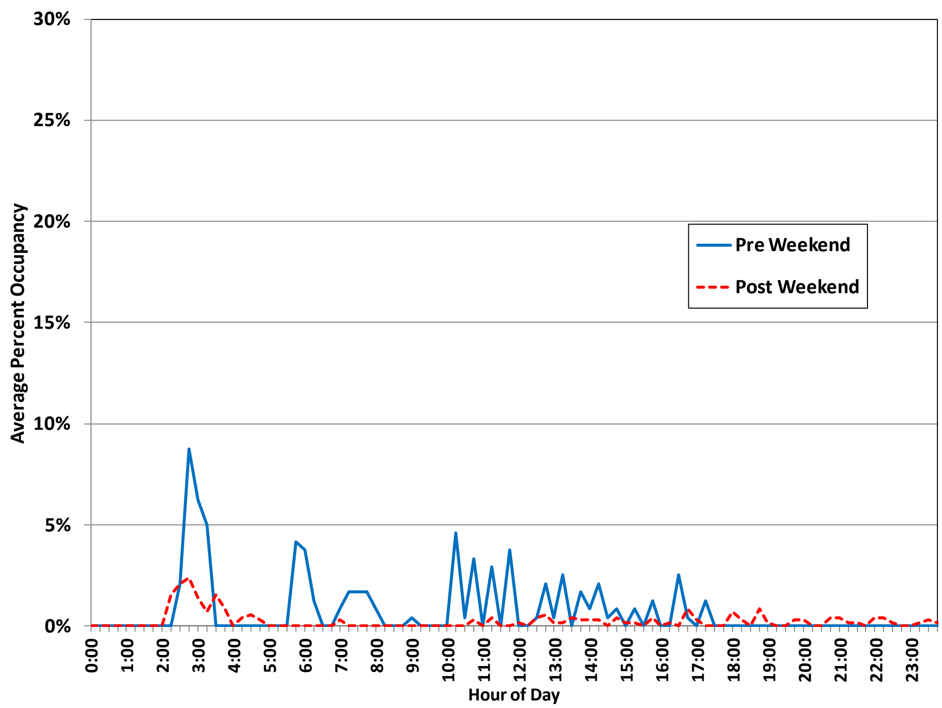

FIGURE 33. AVERAGE PRE- AND POST- OCCUPANCY PROFILES IN STAIRWELL FOR WEEKEND DAYS

CONCLUSIONS AND NEXT STEPS

The demonstrated commercial networked, bi-level lighting systems allow the end user to implement bi-level lighting strategies successfully by incorporating occupancy sensors and dimmable sources in secondary spaces. These are characterized by low occupancy. Commissioning of the system allows for low and high level trims to be set according to the users' preference based on visual comfort and energy-saving goals. Demonstration space users reported high satisfaction with this control aspect.

Energy savings for the installations sponsored by this project ranged from 46-65% per fixture. Survey results show 25% of the total commercial lighting energy use is attributed to corridors.[6] By reducing lighting energy consumption in secondary spaces through bi-level lighting strategies, commercial buildings are estimated to reduce their lighting energy use by 12-16%.

When identifying sites to implement bi-level lighting, it is critical to estimate project benefits based on energy, monetary, and design factors. Many corridors in commercial buildings have undergone systematic delamping or similar lighting reduction strategies designed to cut energy consumption, regardless of reductions to light levels or visual uniformity. Delamping or similar lighting reduction strategies often lengthen the payback period significantly, and do not take into account quality of light and user satisfaction. Starting from a baseline where delamping occurred prior to the new installation, bi-level project payback is exceptionally long.

The long payback periods in the demonstrations implemented for this study show that the combination of material, installation, and commissioning costs for these systems must come down in price for these systems to be within an acceptable payback range for the typical end user. Calculated paybacks for installed systems range from 25 to 220 years, varying based on occupancy rate and installed fixture wattage. Installation costs represent the high end customers you find in the current market. Today, prices have been quoted for approximately half the installation costs used in this study. This significantly reduces the payback for the sites, reducing the payback range 16 to 142 years.

Paybacks for each demonstration were evaluated based on energy savings from bi-level control, energy savings from fixture retrofit, SCE pricing for commercial buildings, material costs, and cost of installation labor. For instance, in larger, building-wide applications of the bi-level strategy, incurred installation costs are offset by broader energy savings. This results in a shorter payback period. Select technologies within this study, such as the Redwood Systems Engine supplying DC power to the fixtures in the Irvine location, are new and are currently produced in low volumes, which drive cost upward. With increased market penetration, higher volume production will lead to a lower price point and shortened payback period.

Based on the anticipated increase in market demand for the bi-level technologies, material costs are expected to decrease. This is dependent on the incorporation of the bi-level

[6] Siminovitch, Michael, and Christopher Cioni, UC Davis *Total Lighting Energy Survey*, 2009.

lighting strategy into building codes, as well as the continuing research and development of bi-level lighting products. A timely example of price decline is the new Lutron PowPak™. This unit is intended to replace the Energi Savr Node (ESN) as a cost effective room controller. The PowPak™ unit can control up to 32 ballasts/drivers, nine wireless switches, six occupancy sensors and one daylight sensor. Based on system pricing for identical applications, customers can expect a decrease of approximately 6% in total system costs.

With contractor training programs supported by industry and often mandated by customers, it is anticipated that installation costs will come down as the number of contractors trained to install advanced lighting systems increases. In addition, greater emphasis is placed on proper commissioning for retrofits and new construction. With provisions for commissioning in place through CALGreen code and other statewide documents, more facilities are required to put these measures into action.

The next step for bi-level lighting systems is greater market adoption and widespread implementation and use in appropriate applications. This can be facilitated by inclusion of bi-level lighting strategies into building codes as well as by offering utility incentives to customers who install technologies that enable secondary spaces with bi-level lighting strategies. With increased market penetration, bi-level strategies and training programs for installation will gain more traction and lead to a lower payback period for end-users. Using this study methodology and revisiting the anticipated decreasing costs for material and installation as the demand for these systems increases, will provide updated payback data.

REFERENCES

1. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. *Standard 90.1: Energy Standard for Buildings Except Low-Rise Residential Buildings.* 2010.

2. Energy Information Administration. "California Building Energy Consumption Survey (CBECS)." October 2006. < http://www.eia.doe.gov/emeu/cbecs/cbecs2003/ detailed_tables_2003/pdf2003/a1-a8.pdf>

3. Itron, Inc. "California Commercial End-Use Survey (CEUS)." Prepared for California Energy Commission: CEC-400-2006-005. March 2006. < http://www.energy.ca.gov/ 2006publications /CEC-400-2006-005/CEC-400-2006-005.PDF>

4. Siminovitch, Michael, and Christopher Cioni, UC Davis *Total Lighting Energy Survey*, 2009.

5. University of California, Davis. *Facilities Link.* California Lighting Technology Center, Nicole Graeber. 2011.