LIGHTING CALIFORNIA'S FUTURE: INTEGRATION OF LIGHTING CONTROLS WITH UTILITY DEMAND RESPONSE SIGNALS

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Preface

The PIER Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the Commission, annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings Energy Efficiency End Use
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Energy Systems Integration

This is the Final Report for the Integration of Lighting Controls with Utility DR Signals Project (Project 4) under the Lighting California's Future program, Contract 500-06-035, managed by Architectural Energy Corporation. Southern California Edison and the California Lighting Technology Center were the technical leads for this project, which contributes to the PIER Buildings End-Use Energy Efficiency Research Program.

For more information on the PIER Program, please visit the Commission's Web Site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at (916) 654-5200.

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Abstract

Lighting California's Future was the California Energy Commission's $3.7 million Public Interest Energy Research Program focused on lighting technologies for buildings. The project on Integration of Lighting Controls with Utility Demand Response Signals aimed to develop, test, and demonstrate lighting control systems that automatically respond to California utility demand response signals. This final report presents information about three lighting systems that were selected and tested in an office environment. It documents performance data for energy and demand savings, as well as light levels, for the three systems during simulated demand response events. Southern California Edison tested these three lighting systems (Convia, Lutron, and Universal) and concludes that all three of the installed systems were able to respond successfully to the requirements of demand response operation and to provide energy savings.

Keywords: Demand response, lighting controls, advanced lighting control systems, demand savings, DR, office lighting, energy efficiency.

Executive Summary

Introduction

Lighting California's Future was the California Energy Commission's $3.7 million Public Interest Energy Research Program focusing on lighting technologies for buildings. The program featured nine technical projects and a crosscutting market connection project. One of the technical projects was the Integration of Lighting Controls with Utility Demand Response Signals.

Purpose

The Integration of Lighting Controls with Utility Demand Response Signals project aimed to develop, test, and demonstrate lighting control systems that automatically respond to California utility demand response signals. The project team included Southern California Edison and the California Lighting Technology Center.

Objectives

Specific objectives were to:

- Identify and evaluate current and emerging technologies available to utilities for sending demand response signals through collaboration with California utilities.
- Identify and evaluate current and emerging technologies available for controlling electric lights in buildings through collaboration with lighting controls manufacturers and research institutions.
- Develop cost-effective solutions to achieve automatic lighting response to utility demand response signals through laboratory testing of existing and emerging technologies that are put together as complete automated lighting demand response systems.
- Demonstrate and validate complete automated lighting demand response solutions in the field through collaboration with California utilities.
- Develop guidelines to assist in widespread application of automated lighting demand response systems through collaboration with California utilities.

Project Outcomes

A preliminary examination of the available communications and lighting control technologies yielded the internet as one of the most promising technologies for communications between the utility and the building.

A review of the many different technologies that are available for the automation of light switching in buildings indicated three main categories: 1) Wired technologies requiring one or more dedicated control wires, 2) Powerline carrier, and 3) Wireless radio frequency signals transmitted through the air and building structures. Hybrid systems do exist that use combinations of these three communication technologies.

The research team at Southern California Edison selected and undertook a comparative evaluation between three advanced lighting control systems that were commercially available from Lutron Electronics, Inc., Universal Lighting Technologies, and Convia.

An office setting was chosen for the evaluation, since that office buildings represent a large proportion of demand from commercial buildings in California. The three systems were installed for evaluation, two with dedicated control wires (Lutron and Convia) and a third (Universal) that uses a power line carrier to communicate control signals to the luminaires.

Demand response testing was performed by Southern California Edison personnel, who initiated the test commands from an offsite office. Testing was conducted for four scenarios (immediate, hour of, later same day, and next business day). All three of the installed systems were able to respond successfully to the requirements of demand response operation. Relative to normal levels of operation, demand savings of up to approximately 35 percent were achieved during testing.

Although occupant reaction was not formally evaluated, anecdotal evidence indicates that occupants did not notice the reduction in light levels, even when informed that a test was being conducted.

The three systems, being more efficiently designed than the lighting system originally installed in the test space, also delivered significant energy savings when in normal operation. For overhead lighting, lighting power density was reduced from 1.13 to 1.39 Watts per square foot in the original system to 0.49 to 0.93 Watts per square foot for the new systems. The greatest savings for overhead lighting fixtures occurred in the Lutron building area where annualized energy use declined by 65 percent. This was because the spaces had the highest light density. The Convia and Universal systems had overhead lighting annualized energy savings of 40 percent and 8 percent respectively.

To determine the lighting performance of these systems both during normal operation and simulated demand-response tests, the California Lighting Technology Center staff performed horizontal illuminance measurements at several locations throughout the space. The lighting performance of the lighting system previously in operation in the space was determined using computer simulations.

All three systems operated adequately once installed and correctly commissioned. The installation and commissioning of several of these systems required unplanned repeat visits by the installers. This suggests that the level of complexity of advanced lighting control systems could pose significant barriers to market adoption. Also, the cost of the systems was higher than conventional lighting systems.

Southern California Edison has promoted the results of the demonstration portion of this project. The findings are published in the "Two-way Connectivity with a Lighting System as a Demand Response Resource" report that is posted on the Emerging Technologies Coordinating Council web site[1]. The Southern California Edison report also is provided as an attachment to

1 http://www.etcc-ca.com/component/content/article/48/2896-two-way-connectivity-with-a-lighting-system-as-a-demand-response-source

this document. Southern California Edison personnel also have provided numerous tours of the test site.

Conclusions

For communications between the utility and buildings, the internet stands out as the technology with the most promise. The widespread availability of personal computers with internet connections can enable the establishment of an automated demand response network in a faster and more cost-effective way than other technologies.

The picture is more complex for lighting control technologies. The main types of control – wired, wireless, powerline carrier – all have distinct advantages and disadvantages that can make each one the best for certain applications but not for others. To complicate matters, there are competing technologies within each category, again some having advantages for certain applications. Finally, lighting control is by no means a mature field, so there are several upcoming technologies that show promise. Therefore, it is unclear at this point whether a single solution will prove the best for a majority of situations.

The most prudent approach seems to be: 1) rely on the internet for communications between the utility and buildings, and 2) evaluate an array of controls technologies. Ideally, both an emerging and an established technology would be evaluated from each of the main types (wired, wireless, powerline carrier).

For commercial buildings, lighting demand response is achievable today with commercially-available advanced lighting control systems. These systems are available as off-the-shelf purchases.

Demand response testing for the three systems installed at the test site confirmed that lighting loads may be reliably managed by remote control as part of a demand response program. The demand response testing also confirmed the savings could be achieved for the four scenarios: *right now*, *next hour*, *later same day*, and *next day*.

For the three systems, demand was reduced by the design of the new overhead lighting system and the advanced lighting control systems tuning. The greatest savings for overhead lighting fixtures occurred in the Lutron zones, where annualized energy use declined by 65 percent. The Convia and Universal systems had overhead lighting annualized energy savings of 40 percent and 8 percent, respectively. Task lighting energy savings of 83 percent were measured for the Convia system where fluorescent under shelf lighting was replaced with light emitting diodes and controlled with motion sensors.

Significant issues, however, need to be addressed in order for these systems to become widespread. One issue is routinely achieving correct installation and commissioning. Also, the state's demand response infrastructure is not fully defined, so the question of how these systems are going to interface with statewide utility demand response infrastructures has not been fully answered. Finally, the initial cost of the advanced lighting control systems may be a barrier. As more manufacturers offer systems and market penetration increases, however, the initial cost should become more competitive for commercial building owners.

Recommendations

The ultimate success of demand-responsive lighting systems depends on how well the issues of cost, installation, and commissioning are addressed. Ongoing activity in California for training electrical contractors is occurring for installing advanced lighting control systems, which may significantly address the installation and commissioning issues.

Once the demand-response infrastructure's structure and technologies are defined, it will be important to demonstrate that advanced lighting control systems can satisfactorily interoperate with it. Also, expanding the incentives offered by California utilities for demand response technologies will help increase market penetration by financially motivating commercial building owners.

More demonstrations of the type exhibited in this project are recommended.

Benefits to California

The potential impact of advanced lighting control systems with demand-response capability on California's peak energy demand is 7.8 megawatts. The values for market penetration are conservatively estimated at one percent for selected markets such as large and small office buildings. The conservative approach is taken because of the cost, installation, and commissioning barriers.

1.0 Introduction

The goals of the Lighting California's Future (LCF) Program were to deliver advanced, energy-efficient lighting technologies, products, systems, and implementation tools and to bring them to market for the benefit of the citizens of California. The program, which was managed by Architectural Energy Corporation (AEC), featured nine technical projects and a crosscutting market connection project.

The Integration of Lighting Controls with Utility Demand Response Signals project aimed to develop, test, and demonstrate lighting control systems that automatically respond to California utility demand response (DR) signals. Funding for this project was received from multiple sources, including Public Interest Energy Research (PIER) and Southern California Edison (SCE). The project team included SCE and the California Lighting Technology Center (CLTC).

1.1. Background

In the past decade, California faced the prospect of its electricity supply and distribution system being overloaded at times of extremely high demand, such as afternoons of very hot days, during which there is unusually high demand for electricity for air conditioning. When the demand for electricity exceeds the capacity to deliver it, the critical response by electric utility companies is to shut down parts of the grid, a practice known as *rolling blackouts*.

Events of this nature took place in the summer of 2000 and spurred efforts to mitigate the need for such drastic measures by developing the means to modulate demand depending on the load level on the electricity grid. A body of research has been conducted on how to generate and transmit demand response signals. However, it remains to be fully defined how demand-responsive systems are practically implemented in buildings.

Lighting is a significant proportion of electrical energy use in California[2]. Part of that, especially in commercial buildings, occurs during the daytime and therefore coincides with the cooling season's periods of peak demand on the electricity grid. This coincidence makes lighting load a very suitable candidate for incorporation into the demand response infrastructure.

1.2. Project Objectives

The goals of this project were to develop, test, and demonstrate lighting control systems that automatically respond to DR signals sent by California utilities.

Specific objectives were:

- Identify and evaluate current and emerging technologies available to utilities for sending demand response signals through collaboration with California utilities.
- Identify and evaluate current and emerging technologies available for controlling electric lights in buildings through collaboration with lighting controls manufacturers and research institutions.

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2 According to the California Energy Commission (CEC, 2003), residential lighting represents 9% of California electricity end-use and commercial lighting represents 12%.

- Develop cost-effective solutions to achieve automatic lighting response to utility demand response signals through laboratory testing of existing and emerging technologies that are put together as complete automated lighting demand response systems.
- Demonstrate and validate complete automated lighting demand response solutions in the field through collaboration with California utilities.
- Develop guidelines to assist in widespread application of automated lighting demand response systems through collaboration with California utilities.

1.3. Benefits to California

The potential impact of advanced lighting control systems with demand-response capability on California's peak energy demand is shown in Table 1. The values for market penetration in Table 1 are conservatively shown at one percent. A conservative approach is estimated due to the high purchase and installation costs of these systems, which would negatively affect market uptake. Also, installation and commissioning issues are perceived as a barrier. The total peak demand reduction potential is estimated at 7.8 megawatts (MW) per year.

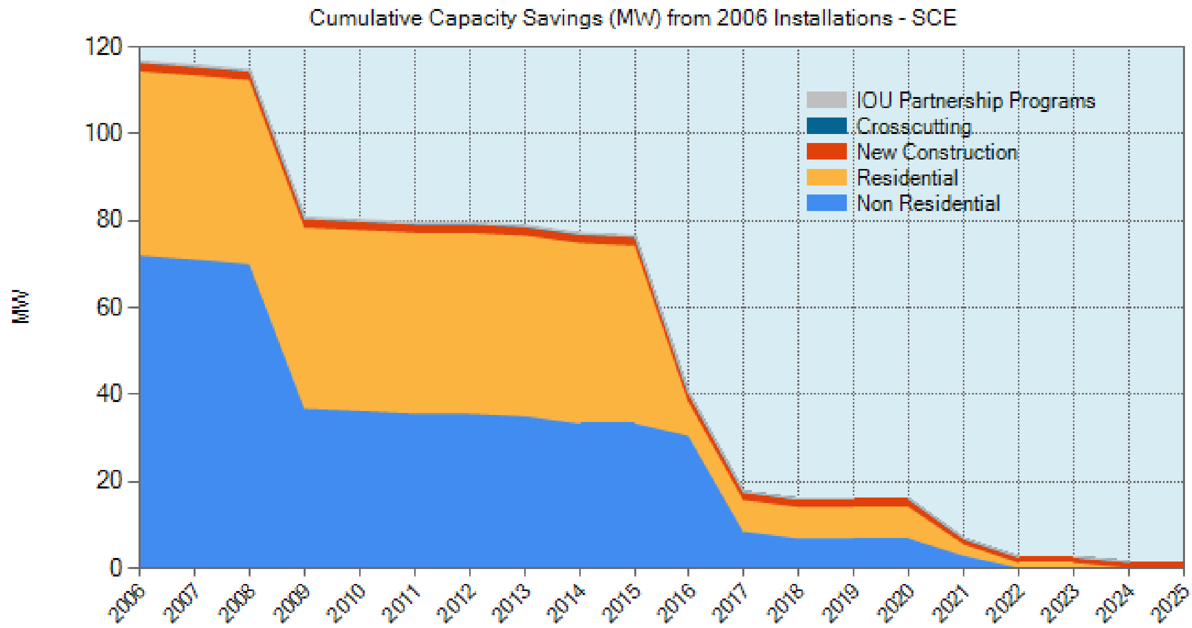
On the positive side, the results from this research project indicate the demand savings can be more than the 20% assumed in the Benefits to California calculation. However, given that the data in Table 1 is categorized by building type and not by space type within a building, it is difficult to make a reasonable estimate of percent savings from the technology, and therefore the original 20% parameter was kept.

Table 1. Potential Impact on California Peak Demand

Commercial Occupancy Types	Peak Demand Savings (MW)	CA peak demand for appropriate building segments and end uses (MW)	Savings in peak demand from proposed research product (%)	Expected penetration into building segment and end use markets (%)
Large Offices	4.4	2202	20%	1%
Small Offices	0.8	397	20%	1%
Retail	0.0	997	20%	0%
Food Stores	0.0	396	20%	0%
Warehouses	0.9	441	20%	1%
Schools	0.5	261	20%	1%
Colleges	0.3	130	20%	1%
Hospital/ Healthcare	0.0	571	20%	0%
Misc.	0.9	447	20%	1%
Total	**7.8**	**5842**		

Source: Southern California Edison

As a point of reference for the 7.8 MW savings calculation shown in Table 1, cumulative demand savings as reported by the California Public Utility Commission[3] for SCE in 2006 for new construction, residential, and non-residential buildings equaled 117 MW. For only the non-residential portion, the total was 72 MW. This indicates that up to 10 percent of demand savings in the SCE territory could be achieved through the use of advanced lighting control systems in non-residential buildings.



Source: CPUC website

Figure 1. Cumulative Demand Savings for SCE by Market for 2006

1.4. Commercialization Potential

At present, the commercialization potential that exists in commercial buildings for advanced lighting control systems that have demand-response capability is mainly as a secondary benefit to other capabilities of these systems that are more appealing to decision makers. While some of these capabilities are not directly related to energy, such as scene control or allowing control of lighting within work spaces to suite individual needs, others have direct energy savings benefits, such as control based on occupancy of a space or the ability to automatically modulate the power delivered to lamps.

With more widespread implementation of utility pricing schemes that increase the price of electricity at times of higher demand, the appeal of advanced lighting control systems that provide demand-response capability is likely to increase. The 2009-2011 goals for utility DR programs were to achieve approximately four to five percent DR penetration for the totality of DR programs [Chiu, 2009[4]], which includes residential as well as industrial customers. Given

3 CPUC Energy Efficiency (EE) program reports for the 2006-08 program cycle, http://eega2006.cpuc.ca.gov/Default.aspx

4 See notation in References.

that the preferred strategy for commercial customers to meet their DR load curtailment requirements is usually to use heating, ventilation, and air-conditioning (HVAC) rather than lighting [Chiu, 2009[5]], market penetration of lighting DR systems can be expected to have the potential to reach one to two percent of commercial building floor space. This could happen sooner if some of the components of these advanced lighting control systems, such as multi-level or dimmable addressable ballasts, start to be required by building codes.

1.5. Report Organization

This report is organized to present the goals, approach, outcomes, conclusions, and recommendations from this project. The demonstration portion of this project that involved the evaluation of three, off-the-shelf, advanced lighting control systems was conducted and co-funded by SCE. Their report, "Two-way Connectivity with a Lighting System as a Demand Response Resource", was published in March 2009 and is provided as an attachment to this California Energy Commission (Commission) report. The SCE report also is posted on the Emerging Technologies Coordinating Council web site[6]. Highlights from their report[7] are presented in several sections of this document. For full details including testing method, images, and data analysis from the three demonstrated systems, SCE's report should be referenced.

5 See notation in References.

6 http://www.etcc-ca.com/component/content/article/48/2896-two-way-connectivity-with-a-lighting-system-as-a-demand-response-source

7 Both PIER and SCE provided funding for the demonstration portion of this project.

2.0 Project Information

2.1. Project Approach

The goals of this project were to develop, test, and demonstrate lighting control systems that automatically respond to DR signals sent by California utilities. Key project members were SCE and the CLTC.

The CLTC staff researched promising technologies for communicating between the utility and an office building, and they prepared a preliminary review of lighting control systems for buildings. SCE personnel evaluated off-the-shelf products from various manufacturers and selected three systems to test. The three systems were installed, commissioned, and monitored at a SCE office facility in Irwindale, California. Due to the complexity of the systems and costs, it was determined that the Irwindale office facility would be the sole demonstration site. SCE worked closely with the three manufacturers to optimize each of the test systems. The CLTC provided support to this effort, taking light measurements and simulating baseline lighting conditions. SCE staff gathered feedback from the office workers on the quality of the new lighting and controllability aspects. The results have been publicized.

The project tasks are summarized in Table 2.

Table 2. Project Tasks

Identify and evaluate technologies for California utility DR signals
Identify and evaluate technologies for lighting controls in buildings
Develop complete systems using selected technologies
Test and refine complete automated DR lighting systems in the Laboratory
Identify field test sites
Deploy refined Lighting DR systems to field test sites
Test field reliability of experimental DR systems
Project-Level Market Connections Activities

Source: Southern California Edison

Outcomes associated with each task are described in the next section.

2.2. Project Outcomes

2.2.1. Identify and evaluate technologies for California utility DR signals

A preliminary examination of the available communications and lighting control technologies yielded the Internet as one of the most promising technologies for communications between the utility and the building. Given that a statewide or even utility-territory-wide infrastructure for demand response communications is yet to be fully defined and implemented, the Internet was selected as the best available communications technology to be used in this project.

Table 3 shows a summary of the evaluated communication technologies with respect to the performance criteria of cost, speed, reliability, and availability. Factors affecting cost are: cost of equipment that sends and receives messages, cost of setting up communications infrastructure, and cost of sending messages. The speed of communication between utility and the building is paramount in same-day DR events, during which the DR signal may be sent only a few hours before the demand reduction is to take place.

Several factors influence reliability, which is described as the likelihood that potential recipients will receive a DR signal and act on it. Most important are: transmission network coverage, transmission network reliability (i.e. frequency and duration of outages), ability to confirm reception of message, and reliance on a human operator.

Finally, availability addresses the availability of transmission network coverage and the availability of transmitting/receiving equipment.

Table 3. Comparative Matrix of DR Communication Technologies

'+' denotes an advantage and '-' denotes a disadvantage

	Criteria			
Technologies	Cost	Speed	Reliability	Availability
Internet	+	+	+	+
Land-line phone/fax	-	-	+	+
Text messaging	-	+		+
Radio (commercial)		+		+
Radio (dedicated)	-	+		-
Pager	-	+		
Power line		+	+	
TV cable		+	+	-
Satellite	-	+		

Source: Southern California Edison

Using the Internet for communicating DR signals has a great number of advantages. Personal computers and Internet connections are commonplace and easily obtainable. Both automation software and hardware specifically developed for DR are available (e.g. Client Logic Integrated Relay box or Internet-compatible building energy management systems). For software-based systems, personal computers are, again, commonplace in buildings and easily obtainable. Naturally, the reliability of the Internet as a DR communication technology depends on the reliability of the particular connection used. It will not work during a network outage, and it will work ideally with an always-on Internet connection, which precludes dialup connections.

After the power line (power-line carrier communications are discussed below), the telephone is the most likely communications infrastructure to be already available at any building site. Requiring someone to either pick it up or listen to a voice message, however, limits its reliability as a mass DR communications technology, unless dedicated automatic equipment is deployed on the receiving end. The cost of sending DR signals also may be a factor if the number of recipients is high enough, since there is a cost per call. Sending these signals may be automated, which is faster and less costly. Communication speed will be constrained by the fact that there is a limited number of originating telephone lines, since only a limited number of messages may be sent simultaneously. It is most likely that fax technology does not provide any advantages over telephony for this application.

Text messaging operates through the cellular phone network. It has the convenience of reaching the designated recipients regardless of their location, as long as they are within range of an antenna. However, in the interior of some buildings or underground, there may be limited or no reception. Also, delivery time of a message is not guaranteed. When sent, messages enter a queue for delivery. While delivery time is usually under an hour, it may take longer during periods of intense traffic. Like telephone calls, this type of communication also has a per-message cost, which may become an issue in a mass DR program. Finally, unless automated equipment that can receive and act on text messages is used, it also depends on a human operator reading the message and taking action.

Radio frequency (RF) communication has the advantage of being wireless and therefore much less costly to deploy than wired networks. It does require, however, a broadcasting infrastructure and appropriate receiving equipment. If based on commercial-band radio frequencies, such as traffic information radio frequencies, receiving equipment is widely available, and DR signals could possibly be broadcast from existing radio stations, although this would preclude two-way communication. A dedicated DR radio network probably requires investment in specific broadcasting and receiving equipment. Reliability of this technology may be limited in areas where radio reception is difficult, such as mountainous areas. Since the message is broadcast at once to all receivers, there is no additional cost for having more receivers, as is the case with some of the other technologies. Reliability is greatly increased if receiving equipment is available that can automatically operate the demand reduction.

Pager systems use redundant high-power terrestrial antennas and satellite networks and are used in many situations that require better coverage than provided by cellular phone. Pager system examples include emergency services and cell phone network repair personnel. Some of the issues mentioned above with reception in buildings or underground still apply. Most pagers only have the ability to receive messages; therefore, it is not possible to verify that the message was received. Furthermore, if a pager is turned off at the time of broadcast, it will never receive the message. However, two-way paging systems that may circumvent some of these issues are available.

The coverage of power line communications is the ideal one, since it coincides with the power network itself. It also has a high potential for automated load control (including plug loads), since power-line controlled equipment could be plugged into any outlet. Issues with radio interference and cost have been raised relative to this technology. There is also the issue of widespread availability of communications equipment.

TV cable is already in use to provide other communication services such as telephone or Internet, and is another possible route for transmitting DR signals. Coverage may not be as widespread as with some other technologies, and specific equipment also is required.

Satellite technology provides coverage even in very remote areas. Reliability of satellite telephony varies with service provider and the type of satellite network (low versus geosynchronous orbit) and this probably applies to other types of satellite communication as well. Two-way satellite communication is usually the most expensive technology, involving both costly equipment and service. One-way communication, such as used by global positioning systems (GPS), may be somewhat less costly, but will have similar limitations to one-way pager technology. Reception in the interior of built structures may be limited.

2.2.2. Identify and evaluate technologies for lighting controls in buildings

Many different technologies are available for the automation of light switching in buildings. They vary widely in complexity, availability of equipment, and capabilities, but they can be classified in three main categories, according to the medium used to control the lamps.

- Wired technologies require one or more dedicated control wires.
- Powerline carrier (PLC) uses higher-frequency signals superimposed on the 50/60 Hertz (Hz) Alternating Current (AC) power signal and thus requires no additional wiring.
- Wireless uses radiofrequency signals transmitted through the air and building structures.
- Hybrid systems use combinations of these three communication categories.

Table 4 provides a comparative matrix of several technologies of these types, according to relevant performance criteria such as market, cost, reliability, availability, lighting only capability, and openness.

For instance, some systems are aimed at, or more present in, the commercial buildings market, whereas others are mainly residential. For a lighting control system, costs can be substantial. Possible sources of cost: the equipment itself, labor for installation and commissioning, and labor for operation. In general, wired systems have an installation cost disadvantage in relation to wireless and powerline carrier systems, since they require the installation of extra wires along the building. More complex systems require more commissioning and operation labor. Reliability has several aspects. Has the system been successfully demonstrated in a variety of different settings? Does the system require frequent maintenance once installed and commissioned? Is the system vulnerable to interference from other equipment?

Lighting control systems evaluated within this research project range from research prototypes with limited field trials to commercially available systems with proven installations. It is important to understand the stage of development for a particular technology. Some systems are solely for lighting control, whereas others can be used for controlling other building systems. The latter can be used to take advantage of more complete demand response operation. Openness describes whether the system, or parts of it, is proprietary to a single manufacturer or components of different manufacturers that can be integrated into one system.

Table 4. Comparative Matrix of Lighting Controls Technologies

		Criteria					
Technologies		Market	Cost	Reliability	Development	Lighting only	Openness
Wired	DALI	Comm			Comm. Avail.	Y	Y
	BACnet	Comm			Comm. Avail.	N	Y

	IBECS	Comm			Prototype	N	?
	Lutron Ecosystem	Comm			Comm. Avail.	Y	N
	Convia	Comm			Comm. Avail.	N	N
Wireless	Zigbee	Comm?			Comm. Avail.	N	Y
	Z-wave	Res?			Comm. Avail.	N	Y
	WiLight				Prototype	Y	?
	Bluetooth				Comm. Avail.	n/a	Y
	WiFi				Comm. Avail.	n/a	Y
	Convergence				Prototype	?	N
	Adura	Comm			Comm. Avail.	Y	N
Power line	CEDR				Prototype	N	?
	Insteon	Res			Comm. Avail.	N	Y
	UPB	Res			Comm. Avail.	N	Y
	DCL	Comm			Comm. Avail.	Y	?
Hybrid	Insteon	Res			Comm. Avail.	N	Y
	LonWorks				Comm. Avail.	N	N
	X-10	Res			Comm. Avail.	N	Y

Note: Columns in gray indicate insufficient information available for cost and reliability. Also, not all criteria are known for evolving technologies. Res denotes Residential; Comm denotes Commercial

Source: Southern California Edison

2.2.3. Develop complete systems using selected technologies; test and refine complete automated DR lighting systems

The research team at SCE decided to undertake a comparative evaluation between three Advanced Lighting Control Systems (ALCS) that were commercially available from Lutron Electronics, Inc., Universal Lighting Technologies, and Convia.

Lutron ALCS

The Lutron ALCS allows a remote operator, in this case SCE, to dim lighting and reduce electric demand. This system can be used for demand response programs where the utility wants direct control of customer load. Internet access software was installed so SCE staff had the security clearance to change settings on the test building's ALCS. The system components are shown in Table 5.

Table 5. Lutron ALCS Components

Quantity	Equipment
1	Scsi Server with Microsoft Windows 2003 Server Operating System Installed (QM-A-CMP-S-0-CCP0036)
1	Quantum Lighting Hub Panel (LSP-1P-4C-1Q)
4	EcoSystem Daylight Sensor with IR Receiver (C-SR-M1-WH)
57	EcoSystem Infrared Receiver for Personal Control (C-R-M1-WH)
66	Personal IR Remote for On/Off, Raise/Lower, and Single Favorite Scene Control of EcoSystem Ballasts (C-FLRC-WH)
5	EcoSystem 1-button with Raise/Lower Wall Control (CC-1BRL-WH)
2	EcoSystem 4-button with Raise/Lower Wall Control (CC-4BRL-WH)

Quantity	Equipment
37	500 sq ft. Occupancy Sensor (37 LOS-CDT-500-WH)
14	277V EcoSystem Digital Dimming Ballast (EC5 T832 J UNV 1)
80	(120V - 277V) EcoSystem Digital Dimming Ballast (EC5 T832 J UNV 2)
13	T8 Fixtures (GE94B-132T8-277-DIM-4'-C(4')-OP/PBB-Paint)
6	T8 Fixtures (GE94B-132/17T8-277-DIM-6'-C(4')-OP/PBB-Paint)
13	T8 Fixtures (GE94B-132T8-277-DIM-8'-C(4')-OP/PBB-Paint)
1	T8 Fixtures (GE94B-132/17T8-277-DIM-10'-C(4')-OP/PBB-Paint)
2	T8 Fixtures (GE94B-132T8-277-DIM-12'-C(4')-OP/PBB-Paint)
1	T8 Fixtures (GE94B-132/17T8-277-DIM-14'-C(4')-OP/PBB-Paint)
6	T8 Fixtures (GE94B-132/17T8-277-DIM-18'-C(4')-OP/PBB-Paint)
1	Scsi Server with Microsoft Windows 2003 Server Operating System Installed (QM-A-CMP-S-0-CCP0036)
1	Quantum Lighting Hub Panel (LSP-1P-4C-1Q)
4	EcoSystem Daylight Sensor with IR Receiver (C-SR-M1-WH)

Source: Southern California Edison

Operation of the system occurs through user-issued commands using Lutron's Internet software. The commands can be issued through any computer connected to the Internet by operators with the proper security codes. The software allows the user to set the level for any fixture or shed load across all fixtures. The commands are received by the computer interface installed at the site, which is connected to the Internet via a network router. Then, the controller slowly adjusts the lighting level from the initial setting to the requested setting over a period of time. The duration of the transition period can be set for the system. The ballasts receiving the signal adjust their dimming level according to the instructions issued by the controller. A command is issued to change the dimming level and change the power use of the lighting fixtures.

The dimming ballasts have built-in transition periods of 42 seconds. This is a constant time fade rate independent of the starting and ending level setting. Occupants generally don't notice the transition with this long of a fade.

The EcoSystem ballasts provide continuous flicker free dimming from 100% to 10% power settings. A handheld remote programmer with wireless infrared communication is used to configure ballasts and fixture groups. Lighting fixtures can be grouped so they are dimmed together. Individual fixtures can be setup to have independent dimming from surrounding fixtures. A personal handheld remote Infrared (IR) control can adjust the dimming level to suit immediate local lighting needs. Ceiling mounted IR receivers relay the signal to dim the lighting ballasts. For DR purposes, all of the dimmable lighting fixtures are also grouped to be controlled by one command.

Universal Lighting Technologies ALCS

The Universal ALCS may be controlled locally or networked for control over the Internet. The installations included 88 Universal Demand Responsive Ballasts. The system uses the existing power line to communicate commands to the ballasts. Each circuit has its own controller, allowing different lighting levels to be simultaneously set.

In addition to the Universal ALCS, 46 Corelite Suspended Indirect-Direct Ambient Lighting 32W T8 luminaires and 44 Lightolier desktop Dome Light Emitting Diode (LED) task lights were installed. The under shelf task lighting was not changed for the Universal zone of the test site. The LED task lights were installed with 44 Isole Occupancy Sensors and Power Strips in order to turn the task lights on and off based on work area occupancy. The system components are shown in Table 6.

Table 6. Universal ALCS Components

Quantity	Equipment
1	Universal System Controller
2	Universal Circuit Controllers (LP12ALCUNV-nm)
44	Lightolier LED Task Lights (SU-L-L-S-T-BL)
44	Isole Task Lighting Occupancy Sensors and Power Strips (IDP-3050)
46	Corelite Suspended Indirect Direct Ambient Lighting 32W T8 Luminaires (Navigator II)
88	Universal Demand Responsive Ballasts (B232PULV50-A)
184	Site Standard High CRI (Color Rendering Index), 24,000 Hours, 3,100 Lumen T8 Lamps

Source: Southern California Edison

Convia ALCS

The Convia ALCS allows a building space to be networked as a group of programmable zones allowing individual system users to implement their lighting level preferences. The wireless switches are not hardwired to the lighting equipment they control; rather, they may be programmed to control any or all zones controlled by the ALCS. The wireless controller may be used to program associations between the network zones and switches, motion detectors, or infrared sensors on the network. Convia Scene Controllers allow various dimming levels to be preset.

The Convia Gateway controls the system and may be run locally or on any computer with an Internet connection. The system also allows the creation of an individualized web portal for each employee in the work space. This allows the employee to set lighting preferences and view the direct impact of energy savings decisions. The system components are shown in Table 7.

Table 7. Convia ALCS Components

Quantity	Equipment
1	Convia Gateway Controller
1	Wireless Controller
2	Power Distribution Modules for Plug Loads at Work Stations and Task Lights
48	Smart Connectors – 277 Volt Relay Dimming Type for Lighting Fixtures
12	Smart Connectors – 120 Volt Relay Type for Plug Loads – Task Lights
48	Infrared Sensors for Smart Connectors
2	Scene Controllers for Conference Rooms and Open Area Control
3	Wireless Switches for Offices and One Conference Room
9	Sensor Interface Modules for Sensor Control at Each Work Pod and for Offices

Source: Southern California Edison

SCE staff worked with the three manufacturers to refine and customize the systems to meet the needs of the field site.

2.2.4. Identify field site and deploy refined DR lighting systems

An office setting was chosen for the evaluation, given that office buildings represent a large proportion of demand from commercial buildings in California. The three systems were installed for evaluation, two with dedicated control wires (Lutron and Convia) and a third (Universal) that uses a power line carrier to communicate control signals to the luminaires.

The test site is a SCE office building located in Irwindale, California. The selected space occupies the southwest corner of the facility. All ceiling lighting fixtures of this office space were selected for replacement on this project, with the exception of those in the entry area. The retrofit included lighting fixtures on 277 Volt circuits.

The three systems were installed in separate zones of the large office space and their energy and lighting performance monitored during normal operation as well as during the simulated demand-response events. The following table compares the three installations.

Table 8. Comparison of ALCS Systems at Test Site

	Convia Zone	Universal Zone	Lutron Zone
Area (square feet)	5,268	9,715	5,150
Number of Cubicles	23	43	59
Number of Private Offices	6	None	6
Other Rooms	Conference Room and Lunch Room		Lobby
Overhead Lighting Control Strategy	Cubicle-level control using motion sensor in cubicle	Zone-level control using area motion sensors	Zone-level control using area motion sensors
Tuning Strategy	Reduce maximum dimming ballast setting to 80% level, with further 15% dimming when cubicle unoccupied, EMS turns lights off at specified hour	Reduce maximum dimming ballast setting to 80% level, turn lights off when area unoccupied, EMS turns lights off at specified hour	Reduce maximum dimming ballast setting to 80% level, turn lights off when area unoccupied, EMS turns lights off at specified hour
Additional Lighting	14 wall-mounted fixtures added to space perimeter, Fixtures turn off when area is unoccupied	None	None
Task/Undershelf Lighting	Both	Task	None

Source: Southern California Edison

Each system adheres to the California Energy Commission *2005 Nonresidential Compliance Manual* requirement that lighting power density in office spaces not exceed 1.2 Watts per square foot. The three overhead lighting systems installed at the test site are shown in the following images provided by the SCE project team.

Figure 2. Lutron Suspended Lighting System at Test Site
Source: Southern California Edison

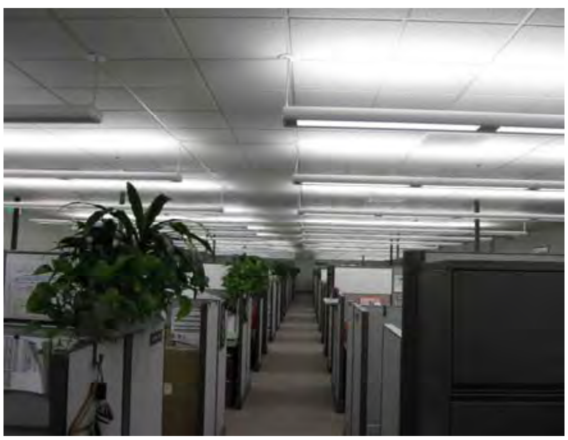


Figure 3. Universal Suspended Lighting System at Test Site
Source: Southern California Edison

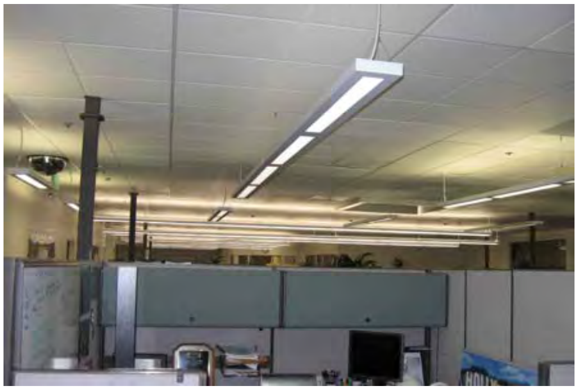


Figure 4. Convia Suspended Lighting System at Test Site
Source: Southern California Edison

2.2.5. Test field reliability of experimental DR systems

Demand response testing was performed by SCE personnel, whom initiated the test commands from an offsite office. Testing was conducted for four scenarios (right now, hour of, later same day, and next business day). During the test periods, recording intervals were reduced to one-minute intervals. Part of the testing involved changing the lighting level to five different settings, while a field engineer witnessed each change and made measurements. The settings were 10%, 25%, and 50% below maximum tuned power settings (90%, 75%, and 50%). After each drop in lighting power, the next step was to raise the lighting power setting back to 100% before the next reduction. Each setting lasted for five minutes.

All three of the installed systems were able to respond successfully to the requirements of demand response operation. Relative to normal levels of operation, demand savings of up to approximately 35% were achieved during testing. Figure 5 shows the testing results for four zones of the Lutron ALCS during the testing. Figure 6 shows testing results for two zones of the Universal ALCS during the five minute intervals. Figure 7 shows the results for two zones of the Convia ALCS. The graphs show the drop in lighting power and the corresponding demand savings captured during the testing period for all three systems.

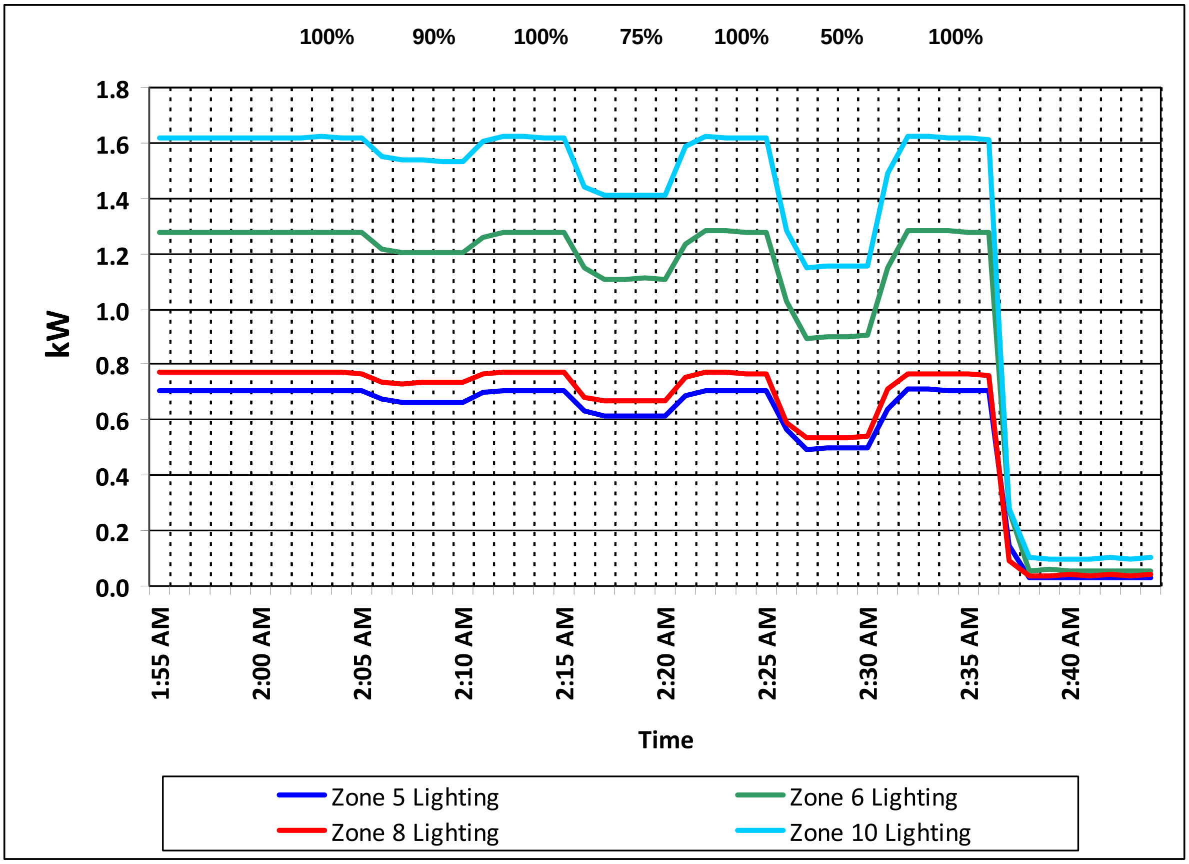


Figure 5. DR Testing Results for Lutron ALCS

Source: Southern California Edison

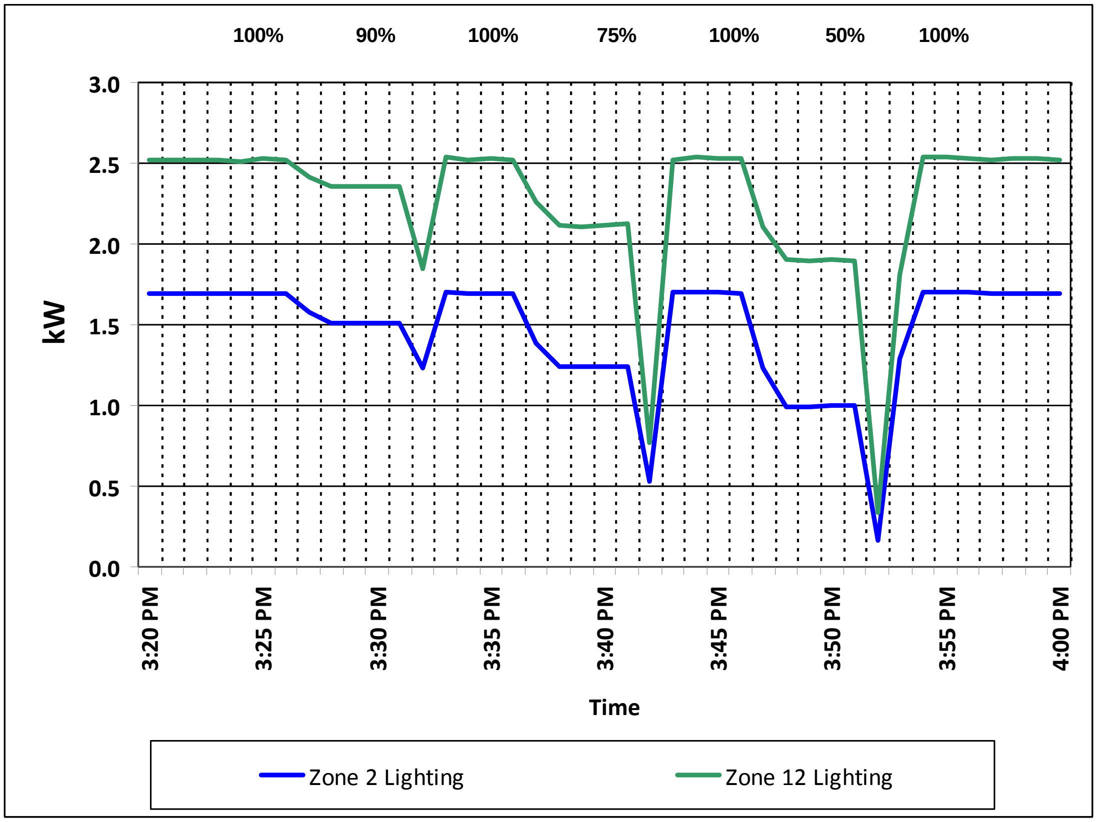


Figure 6. DR Testing Results for Universal ALCS

Source: Southern California Edison

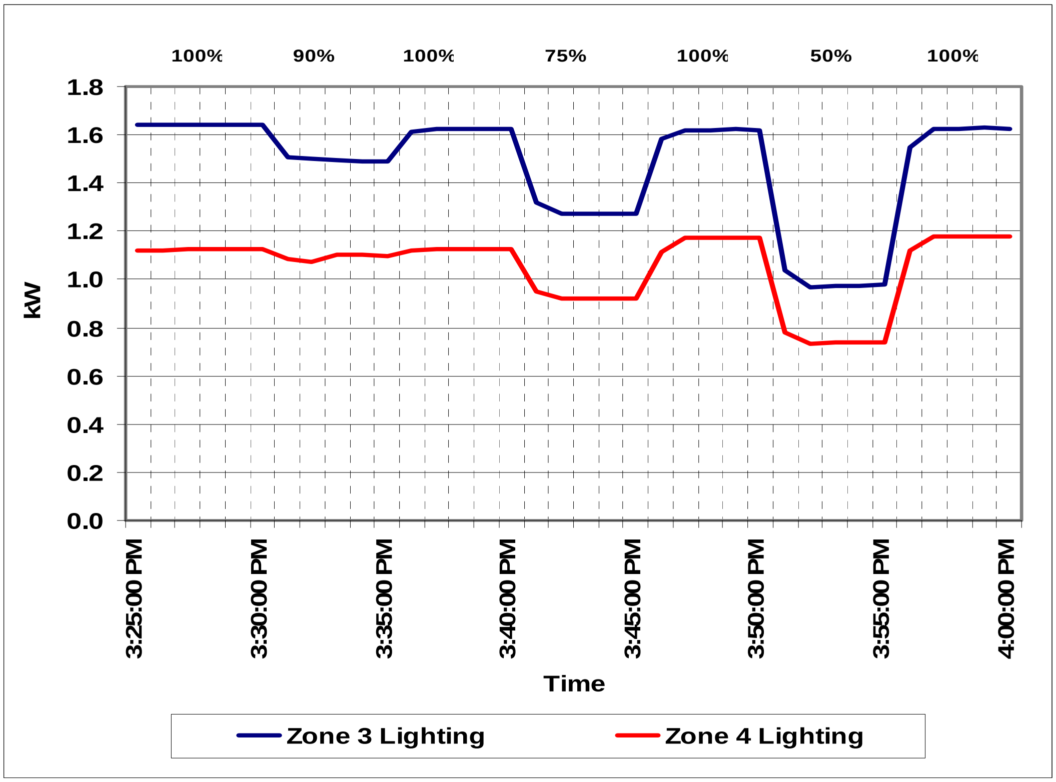


Figure 7. DR Testing Results for Convia ALCS

Source: Southern California Edison

Although occupant reaction was not formally evaluated, anecdotal evidence indicates that occupants did not notice the reduction in light levels, even when informed that a test was in progress. This most likely happened because light levels changed smoothly over the course of approximately a minute. This feedback indicates that further demand savings may be achieved without significantly affecting occupant tasks.

The three systems, being more efficiently designed than the lighting system originally installed in the test space, also delivered significant energy savings when in normal operation. For overhead lighting, lighting power density went from 1.13 to 1.39 W/ft^2 in the original system to 0.49 to 0.93 W/ft^2 for the new systems.

Table 9. Lighting Power Density Data and Demand Savings by ALCS for Overhead Lighting

	Convia Overhead Lighting	Universal Overhead Lighting	Lutron Overhead Lighting
Baseline Measured Lighting Power Density – W/ft^2	1.13	1.25	1.39
Post-Retrofit Measured Lighting Power Density – W/ft^2	0.52	0.93	0.49
Post-Retrofit Measured Lighting Power Density Savings – W/ft^2	0.62	0.32	0.90
Square Footage of Area	5,516	4,896	8,945

Demand Savings – kW	3.40	1.57	8.05

Note: Task lighting for Convia and Universal is not included.

Source: Southern California Edison

The Lutron zones had the highest lighting density (1.39 W/sq ft) during the baseline period and included the entrance area in which there was a relatively high density of lighting fixtures in the baseline period. The Convia building area, which had the lowest lighting density (1.13 W/sq ft) during the baseline period, includes a conference room and lunch room with a relatively low density of lighting fixtures in the baseline period. The Lutron building area had the lowest lighting density (0.49 W/sq ft) during the post-retrofit period. No emergency lighting fixtures were installed in the Lutron building area. Fourteen-wall mounted fixtures were installed in the perimeter of the Convia building area. A high density of overhead lighting fixtures was installed in the Universal lighting area. The total demand savings across all three building areas are 13.02 kilowatts (kW).

ALCS tuning in the Universal Lighting building areas did not generate task lighting energy savings. In fact, task light energy use increased by 8.6%. For the Convia zones, task lighting energy use declined by 82.9% after the installation of LED task lights and ALCS tuning occurred.

A reduction in energy demand was expected from both the retrofit of overhead lighting fixtures and the tuning of the three systems. The greatest savings for overhead lighting fixtures occurred in the Lutron zones where annualized energy use declined by 65%. The Convia and Universal systems had overhead lighting annualized energy savings of 40% and 8% respectively.

All three systems operated adequately once correctly installed and commissioned. It should be noted, however, that the installation and commissioning of these systems required unplanned repeat visits by the installers. This suggests that the level of complexity of advanced lighting control systems could pose significant barriers to market adoption. Also, the cost of the systems was higher than conventional lighting systems.

In order to determine the lighting performance of these systems both during normal operation and simulated demand-response tests, CLTC performed horizontal illuminance measurements at several locations throughout the space. The lighting performance of the lighting system previously in operation in that space was determined using computer simulations. Table 10 shows the results.

Table 10. Measurement of Actual Post-Retrofit and Simulated Values of Original Lighting Levels

		Measured Illuminance After ALCS Install (all values in footcandles)				Original Values
	Cubicle no.	**Full w/task light**	**Full w/out task light**	**60% no task light**	**50% no task light**	
Convia	1	27.8	24.7	21.4	18.05	54.2
	2	26.8	24.6	18.4	16.1	51.9
	3	36.6	28.4	24.1	20.7	42.4

	Cubicle no.	Measured Illuminance After ALCS Install (all values in footcandles) Full w/task light	Full w/out task light	60% no task light	50% no task light	Original Values
	average:	30.4	25.9	21.3	18.3	49.5
Lutron	1	24	21.6	14.8	13.2	59.5
	2	27.3	20.2	13.7	11.06	65.7
	3	21.4	19.4	12.5	10.6	70.5
	4	22.8	20.7	14.08	11.6	61.2
	5	23.1	19.5	12.1	11.1	38.6
	6	21.6	21.2	13.1	10.9	44.2
	average:	23.4	20.4	13.4	11.4	56.6
Universal	1	47.2	47.2	37.2	34.2	61.7
	2	28.4	23.8	17.2	13.5	31.0
	3	40.8	33.5	23.6	18.2	27.7
	4	47.8	29.3	24.7	17.2	39.2
	average:	41.1	33.5	25.7	20.8	39.9
Lutron	1	25.6	25.6	16.4	14.8	51.2
	2	24.4	23.7	13.6	11.3	58.2
	3	27.7	26.2	16.5	14.2	66.9
	average:	25.9	25.2	15.5	13.4	58.8
	overall average:	29.6	25.6	18.3	15.4	51.5

Source: Southern California Edison

As expected, horizontal illuminance levels were lower during demand response operation than at full power and averaged as low as 15 footcandles, a level still sufficient for general orientation and object recognition tasks. The availability of task lighting and also the computer-based nature of many, if not most, office activity suggests that these light levels may be sustainable for short periods of time in office environments.

As can be seen, the values obtained by simulation for the original lighting system are generally much higher than the light levels provided by the new systems, with the exception of the Universal system, for which the levels provided where much closer to the simulation results. This is consistent with the fact that, of the three new systems, this was the one with the highest lighting power density at 0.93 W/ft^2 as compared to 0.49 for Lutron and 0.52 for Convia.

It should be noted, however, that simulation results should be taken as indicative only of general lighting levels (an average of approximately 50 footcandles) and should not generally be individually compared to measurements. Although geometry and surface properties used for simulation were based as closely as possible on the available information about the test site, errors are undoubtedly accentuated by the variability, from one measurement point to the other, in the actual arrangement of cubicle artifacts (furniture, images, whiteboards, personal items), and the actual point where measurements were taken.

Another noticeable feature is that the task component of horizontal illuminance (the difference between the "full with task" and the "full without task" levels) is highly variable, and this again reflects the high variability of cubicle disposition and in the type of task lighting system that was provided.

2.2.6. Project-Level Market Connections Activities

SCE has promoted the results of the demonstration portion of this project. The findings are published in the “Two-way Connectivity with a Lighting System as a Demand Response Resource” report that is posted on the Emerging Technologies Coordinating Council web site[8]. SCE personnel also have provided numerous tours of the test site.

The three lighting companies – Lutron, Universal, and Convia – also have leveraged the project demonstration to advance and promote their systems.

The PIER LCF market connection team has promoted the results of this project as part of the program-wide market connection activities including highlighting project results on the program web site[9].

2.3. Conclusions and Recommendations

2.3.1. Conclusions

For communications between the utility and buildings, the Internet stands out as the technology with the most promise. The widespread availability of personal computers with Internet connections can enable the establishment of an automated demand response network in a faster and more cost-effective way than other technologies, notwithstanding some limitations with network availability for certain remote areas and also – for the applications that require it – the current price of specific communications hardware. For a mass DR program, it is likely that this last issue could be easily circumvented using a software-centric approach.

The picture is more complex for lighting control technologies. The main types of control – wired, wireless, powerline carrier – all have distinct advantages and disadvantages that can make each one the best for certain applications but not for others. To complicate matters, there are competing technologies within each category, again some having advantages for certain applications. Finally, lighting control is by no means a mature field, so there are several upcoming technologies that show promise. Therefore, it is unclear at this point whether a single solution will prove the best for a majority of situations.

The most prudent approach seems to be: 1) rely on the Internet for communications between the utility and buildings, and 2) evaluate an array of controls technologies. Ideally, both an

8 http://www.etcc-ca.com/component/content/article/48/2896-two-way-connectivity-with-a-lighting-system-as-a-demand-response-source

9 http://www.archenergy.com/lcf/integrated-projects/utility-dr.html

emerging and an established technology would be evaluated from each of the main types (wired, wireless, powerline carrier).

For commercial buildings, lighting demand response is achievable today with commercially available advanced lighting control systems. These systems are available as off-the-shelf purchases.

Demand response testing for the three systems installed at the test site confirmed that lighting loads may be reliably managed by remote control as part of a DR program, although the load reduction was not proportionate to the reduction in setting level. The demand response testing also confirmed the savings could be achieved for the four scenarios: right now, next hour, later same day, and next day.

For the three systems, demand was reduced by the design of the new overhead lighting system and the ALCS tuning. The greatest savings for overhead lighting fixtures occurred in the Lutron zones where annualized energy use declined by 65%. The Convia and Universal systems had overhead lighting annualized energy savings of 40% and 8% respectively. Task lighting energy savings of 83% were measured for the Convia system where fluorescent under shelf lighting was replaced with LEDs and controlled with motion sensors.

Significant issues, however, need to be addressed in order for these systems to become widespread. One issue is achieving routine correct installation and commissioning. Secondly, the state's DR infrastructure is not fully defined, so the question of how these systems are going to interface with the DR infrastructure has not been fully answered. Finally, the initial cost of the advanced lighting control systems may be a barrier. However, as more manufacturers offer systems and market penetration increases, the initial cost should become more competitive for commercial building owners.

2.3.2. Recommendations

The ultimate success of demand-responsive lighting systems depends on how well the issues of cost, installation, and commissioning are addressed. Ongoing activity in California for training electrical contractors is occurring for installing advanced lighting control systems, which could significantly address the installation/commissioning issue.

As for the demand-response infrastructure, once its structure and technologies are defined, it will be important to demonstrate that advanced lighting control systems can interoperate satisfactorily with it. Also, expanding the incentives offered by California utilities for DR technologies would help increase market penetration by financially motivating commercial building owners. Finally, more demonstrations of the type exhibited in this project are recommended.

Glossary

Specific terms and acronyms used throughout this work statement are defined as follows:

Acronym	Definition
AC	Alternating Current
ADM	ADM Associates. Inc.
AEC	Architectural Energy Corporation
ALCS	Advanced Lighting Controls Systems
CFL	Compact Fluorescent Lamp
CLIR	Client Logic Integrated Relay
CLTC	California Lighting Technology Center
Commission	California Energy Commission
DR	Demand Response
FC	Footcandles
GPS	Global Positioning System
HVAC	Heating, Venting, and Air-Conditioning
Hz	Hertz
IES	Illuminating Engineering Society
IOU	Investor-Owned Utility
IR	Infrared
kW	Kilowatt
kWh	Kilowatt-hour
LCF	Lighting California's Future
LED	Light Emitting Diode
LPD	Lighting Power Density
M&V	Measurement & Verification
MW	Megawatt
MWh	Megawatt Hour
N/A	Not Available
PIER	Public Interest Energy Research
PLC	Powerline Carrier
RF	Radio Frequency
Rms	Root Mean Squared
SCE	Southern California Edison
Title 24	California Non-Residential Energy Efficiency Building Standards
TOU	Time of Use (electricity rate)
UCC.1	Uniform Commercial Code
Vdc	Volts Direct Current
W	Watts
W/ft^2	Watts per Square Foot

Attachments

I. “Two-way Connectivity with a Lighting System as a Demand Response Resource”, Design and Engineering Services, Customer Service Business Unit, SCE, published March 2009.

References

California Energy Commission, 2003, *California Energy Demand 2003-2013 Forecast*, Staff report 100-03-002.

Chiu, Albert, manager for demand response programs at Pacific Gas and Electric Company, personal communication with Luis Fernandes, California Lighting Technology Center, Jul 31 2009.