

**PREFACE**

**PROJECT TEAM**

This project is sponsored by San Diego Gas & Electric’s (SDG&E®) Emerging Technologies Program (ETP) with A.Y. Ahmed (aahmed1@semprautilities.com) as the project manager. Jon Coger, Energy Manager, was the contact and project manager for Veterans Administration Medical Center San Diego. Daryl DeJean (daryl.eta@gmail.com) from Emerging Technologies Associates, Inc. provided technical consulting, data analysis, overall coordination of all parties involved, and finalized the report.

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**ACKNOWLEDGEMENTS**

We would like to acknowledge Veterans Administration Medical Center San Diego and SDG&E® for their cooperation in the project. Without their participation, this assessment project would not have been possible. Furthermore, we would like to acknowledge the work of PG&E’s Emerging Technologies Program in their assessment project entitled “Advanced Lighting Controls for Demand Side Management (ETCC reports 0806, 0813, 0814) completed in 2009 that provided collaboration of results included in this report.
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Abbreviations and Acronyms

ALCS Advanced Lighting Control System
CALCTP California Advanced Lighting Controls Training Program
CT Current Transformer
DALI Digital Addressable Lighting Interface
DSL Digital Subscriber Line
ETCC Emerging Technologies Coordinating Council
ETP Emerging Technologies Program
GWh Gigawatt Hour
HID High Intensity Discharge
IES Illuminating Engineering Society
IT Information Technologies
kW Kilowatt
kWh Kilowatt Hour
LED Light Emitting Diode
LPD Lighting Power Density
PG&E Pacific Gas & Electric
PLS Personal Lighting System
SDG&E San Diego Gas & Electric
VA Veterans Administration
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EXECUTIVE SUMMARY

Emerging Technologies Associates, Inc. evaluated the functional performance and energy efficiency potential of advanced lighting control system (ALCS) technology under contract to the Emerging Technologies Program of San Diego Gas & Electric Company (SDG&E®). This report summarizes the results of monitoring and evaluation of the ALCS system in an office environment. The system assessed is a microprocessor-based lighting control system utilizing a combination of simultaneous wired (DALI) and wireless (Zigbee) communication. This assessment project will form the basis of subsequent projects for the performance evaluation of the Office of the Future 25% Solution as provided by the New Buildings Institute in collaboration with various utility companies.

During the technology evaluation, the lighting control system was used to decrease lighting energy use on a daily basis for a period of approximately two weeks. Power measurements were taken using Dent Instruments Elite Pro Data Loggers (Line Powered, Extended Memory) with 20 amp current transformers (CTs) before and during the test.

The following control strategies were evaluated in a phased approach:

1. Tuning light levels
2. Occupancy sensors
3. Daylight harvesting
4. 1&3 combined

For control strategy 2, the open office area was zoned and light levels were reduced based upon occupancy. This control strategy proved to be insignificant because the entire office space was almost permanently occupied during business hours.

Onsite verification and monitoring showed that the controls performed as expected during the evaluation period, and have good potential to deliver energy efficiency savings of up to 50% in applications and lighting layouts similar to those in this project.

Statewide interior lighting energy use for the large and small office sectors is 4,331 GWh/year and commercial interior lighting energy use is responsible for roughly 29% of total statewide energy use.¹ However, lighting controls are not widely installed due to a lack of understanding of how the controls work and the perception that it is expensive to retrofit a building with advanced lighting controls. The type of advanced lighting controls evaluated in this report better enables customers to realize the potential of advanced lighting controls due to ease of installation and decreased costs. This project could prove beneficial as a driver to increasing market penetration of lighting controls from less than 1% to 5% or more in the next three to five years. Furthermore, the results and assumptions of this project are supported by earlier assessments conducted by Pacific Gas and Electric’s (PG&E) Emerging Technologies Program.²

Electric power measurements were taken for the project. Figure 1 illustrates the electric energy reduction results for the tuning of light levels and daylight harvesting.

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¹ California Commercial End Use Survey data, Itron, 2006
² PG&E Report, Advanced Lighting Controls for Demand Side Management (reports 0806, 0813, 0814), Energy Solutions, 2009
Figure 1: Energy Reduction for One Day

Table 1: Project Electric Energy and Demand Savings with Lighting Power Density Reductions

<table>
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<tr>
<th>Lamp</th>
<th>Power (watts)</th>
<th>Annual Operating Hours</th>
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This assessment project will assist numerous facility managers and building owners across the country when considering advanced lighting control systems as an option for new lighting installations in office buildings to meet their energy efficiency goals as well as employee comfort and productivity. Local site requirements, lighting design, as well as economic considerations may directly impact the outcome of similar assessment projects. Therefore, readers are advised that each installation is unique. It is recommended the reader exercise due diligence in selecting the advanced lighting control system to properly address their needs.

Based upon the findings of this project, it is recommended that future projects consider the following:
- develop a matrix comparing the various advanced lighting control systems currently available in the market
- data logging of illuminance levels during daylight and dimming
- development of educational outreach programs to trades, professionals, designers and engineers
- development of higher level incentives for ALCS installed by a certified control professional as per California Advanced Lighting Controls Training Program (CALCTP)
INTRODUCTION

In response to the whole building approach to achieve energy efficiency, San Diego Gas & Electric’s Emerging Technologies Program’s (ETP) objective with this assessment was to:

- assess the energy efficiency potential of an advanced lighting control system
- determine the difficulty of properly installing an ALCS
- understand occupant acceptance of light levels

Despite the significant potential benefit to energy utilities and their customers, several barriers to the widespread promotion and adoption of advanced lighting control system technologies exist:

1) Added cost (dimming ballasts, complex installation, commissioning, ongoing operations, IT overhead).
2) Feasibility (wiring not possible without major retrofits, lack of staff who can operate the system, integration with existing building controls).
3) Lack of knowledge that such a system exists.
4) Lack of acceptance (perceptions of light levels being too low, maintenance being too complicated or of poor cost/benefit).

This project will provide:

1) better understanding of advanced lighting control systems and the proper installation and commissioning
2) true energy reduction and operational cost benefits

By doing so, this project will help address cost and feasibility barriers and increase implementation.
PROJECT BACKGROUND

Project Overview

The Advanced Lighting Control System Technology Assessment project was conducted as part of the Emerging Technologies Program of San Diego Gas & Electric Company (SDG&E®). The Emerging Technologies Program “is an information-only program that seeks to accelerate the introduction of innovative energy efficient technologies, applications and analytical tools that are not widely adopted in California. The information includes verified energy savings and demand reductions, market potential and market barriers, incremental cost, and the technology’s life expectancy.” Emerging Technologies Associates, Inc. was retained by SDG&E® to manage the Assessment project, develop project methodology, coordinate the participants and stakeholders and conduct the data collection and analysis for the project.

The Advanced Lighting Control System Assessment project studied the energy and demand reduction potential and the economics of lighting energy costs when controlled by an advanced lighting control system. The ease of installation and the simplicity for the end user to adjust and administer the ALCS were important factors considered.

Technological Overview

The performance of advanced lighting control systems is linked directly to reduced electrical consumption without negatively impacting employee comfort or productivity. It is believed that a well-designed lighting control system would reduce lighting related energy costs by an average of 30% or more (according to the New Building Institute) throughout the life of the facility, manage peak energy usage through load shedding and demand response, empower users to select appropriate light levels when and where needed, and streamline installation to reduce labor and material costs. Additionally, depending upon the office space lighting layout, ALCS may allow for personal lighting systems (PLS) in spaces allowing for individual occupant control over the lighting affecting their work space.

The ALCS used in this project is a microprocessor-based lighting control system providing a full-range dimming and individual addressability of incandescent, low-voltage, fluorescent, LED, and HID lighting sources. Through a combination of simultaneous wired (DALI) and wireless (Zigbee) communication, the digital lighting control system provides enhanced functionality through intuitive user interfaces, daylight harvesting and occupancy monitoring while reducing energy consumption by as much as 50% (according to the New Buildings Institute). The system’s Administrative Software provides real-time access, monitoring and control of lighting systems; employing such features as built-in Demand Response, Peak Load Shedding, and Power Monitoring.

While the system capabilities are robust, design and installation are simple and intuitive. The project was conducted in phases based upon a specific control strategy. The first phase, tuning light levels, required reducing light levels to a specific point. Since light loss factors such as aging lamps, dust, etc. can force designers to engineer more light into spaces than is initially required, light levels were set to the IES recommended light level for open office to achieve uniformity and eliminate energy wastage.

The second phase of the project, occupancy monitoring, involved installing “smart” dual-technology sensors which turn off lights when spaces are empty and instantly return them to an entry light level when occupants return. This phase, however, did not significantly reduce energy consumption during working hours in the open office area and thus the sensors were only activated during non-working hours.
Additional savings were achieved from the last phase of the project, daylight harvesting. Since the open office area was conveniently located next to windows allowing plenty of daylight to illuminate the office area, daylight harvesting sensors were installed to identify available sunlight and adjust lighting system performance accordingly.

**Market Overview**
Advanced lighting control systems represent a significant energy efficiency, demand reduction and demand response opportunity in the commercial sector for retrofit as well as new construction applications. Statewide interior lighting energy use for the large and small office sectors is 4,331 GWh/year and commercial lighting energy use in general is responsible for roughly 29% of total statewide energy use.\(^3\) Despite their energy saving potential, lighting controls are not widely installed because of the perception that it is expensive and difficult to retrofit a building with such controls.

The type of advanced lighting control systems evaluated in this report better enable customers to install lighting controls due to ease of installation, commissioning and decreased costs. These benefits may contribute to an increased market penetration of lighting controls from less than 1% to something on the order of 5% or more within the next three to five years.\(^4\)

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\(^3\) PG&E Report, Advanced Lighting Controls for Demand Side Management (reports 0806, 0813, 0814), Energy Solutions, 2009

\(^4\) Ibid.
**PROJECT OBJECTIVES**

The primary purpose of the evaluation was to provide functional testing of the advanced lighting control systems, within the context of energy efficiency. The approach was two-fold, including functional testing of the system (i.e., did the control technology work as intended) and quantification of energy savings resulting from use of the controls.

A phased approach was used to determine the effectiveness of each measure separately: tuning light levels, occupancy sensors and daylight harvesting. The final phase had all measures implemented for the overall effectiveness of the ALCS to be assessed.

The control strategies were also evaluated for ease of installation, reliability, and customer acceptance.
**METHODOLOGY**

**Host Site Information**

The host site was chosen based on its willingness to allow for the installation and assessment of emerging or state-of-the-art technologies and participation in SDG&E® energy efficiency programs. The Advanced Lighting Control System Assessment was hosted by the Veterans Administration Medical Center located in La Jolla, CA.

The office area chosen for the evaluation of the ALCS is approximately 3040 square feet in the Engineering Department. This area is located in a six-story building dominated by an open floor plan with cubicles. The office operates 251 days/year. The working lighting hours are 11.5 hours/day. The annual working lighting hours are 2886 hours.

There were 52 fixtures in the study, 44 of which were 2’ x 4’ recessed, lensed troffers. The other eight fixtures were 2’ x 2’ recessed, lensed troffers. Eight of the fixtures served as emergency lighting and were part of the two circuits for all lighting in the area. Eight of the 44 2’ x 4’ fixtures in the study were in three private offices (four in one office and two in each of the other two offices); the rest were in an open floor plan area of 2640 square feet with work station cubicles. It is the open floor plan area that will be the focus of this report.

The site initially had a four-lamp ballast controlling three lamps in one fixture and one lamp in another fixture. All fixtures in the evaluation were retrofitted with addressable four-lamp ballast and appropriate sockets to enable dimming and daylight harvesting prior to the energy efficiency testing.

The Veterans Administration Medical Center has a cogeneration plant and is on a rate structure in which it is charged an average rate of $0.43/kWh.

**Measurement Plan**

The technology was installed, commissioned and operated, and functionality was observed. To estimate energy efficiency resulting from the use of the various advanced lighting controls, monitoring included collection of power data before, during, and after the energy efficiency test. CTs, voltage probes, and a data logger were installed on the proper electrical circuits to record power and energy readings at a given interval for the designated time period. Power measurements were taken using the Dent Instruments Elite Pro Data Logger (Line Powered, Extended Memory) with 20 amp CTs.

The energy efficiency test aimed to determine whether the advanced lighting control system functioned properly and to measure the associated energy efficiency savings. Two months of baseline power data was collected prior to the beginning of the energy efficiency testing, after which the manufacturer commissioned the ALCS. A consistent daily usage was found with the lights being on at 3.5 kW for 11.5 hours/day on average.

In addition to the capability to tune the light levels, ALCS allowed for occupancy and daylight sensors for the open office area, occupancy sensors for all the private offices, daylight sensors for one of the private offices, and scene control wall switches to allow for manual scene selection. The open office area scenes provided were from 0 – 100% in 25% increments.

Once the light levels were tuned to the recommended 35 foot candles as per IES recommended light level guidelines\(^5\), two weeks of energy efficiency monitoring was conducted. After this monitoring period, the

\(^5\) IES Lighting Handbook - 9th Edition
occupancy sensors were activated in the open office area to determine the energy efficiency of the devices. After a few days of monitoring, it was noted that the occupancy sensors in the open area had no impact on the energy efficiency of the open office area during normal working hours. Therefore, the system cost may be able to be reduced by the cost of the occupancy sensors.

To properly establish the algorithm for the daylight sensors, numerous sensors were placed throughout the open office area to collect daylight data for a period of 4 days. The daylight sensors were programmed according to the daylight levels recorded and activated for a period of two weeks to monitor the energy efficiency potential of daylight harvesting.

The final phase of this assessment had both the occupancy and daylight sensors activated in the open office area and monitoring was conducted. As previously stated, the occupancy sensors demonstrated no impact on energy savings so the results achieved by activating all the sensors remained the same during working hours as those of the daylight sensor monitoring period.

Evaluation of the functional testing of the advanced lighting control system included a survey of the Energy Manager, as well as our own observations of the installation and commissioning process. The Energy Manager was asked to characterize:

- ease of understanding how the lighting control system would interface with the existing lighting system
- ease of installation of the lighting control system
- design of the lighting control system, including its ability to integrate well with the existing lighting system

**Equipment**

The following equipment was used to collect the light and power characteristic data. All meters were calibrated in accordance to manufacturer specifications.

**Illuminance and Correlated Color Temperature Meter:**
Konica Minolta Chroma Meter, Model CL-500
Accuracy: ± 2.0%

**Power reading:**
Dent Instruments ElitePro Power Meter
Accuracy: ± 0.5-1.0%

http://www.konicaminolta.com/sensingusa/products/Light-Measurement

http://www.dentinstruments.com
**PROJECT RESULTS AND DISCUSSION**

Currently, market penetration of lighting controls technologies is low. Wherever controls are installed, it is not uncommon to find them disabled, possibly without the knowledge of the facility managers. The results of this project demonstrate that advanced lighting control system technologies are available to capture savings potential for commercial lighting applications in the new or retrofit sector. Robust lighting controls systems exist that include two-way communication for better management of lighting systems, flexibility in design and commissioning, and combined demand response and energy efficiency opportunities. Moreover, an ALCS may be installed and commissioned at a price that is more cost-effective than most are aware.

Manufacturers’ technologies achieve similar results through different means in regards to communication, switching, dimming and controls options. The types of energy efficiency controls strategies used in this project included using controls to tune light levels, wired photocells for daylight harvesting and wired occupancy sensors and wall switches with scene control capabilities.

**Electrical Demand and Energy Savings**

To estimate energy efficiency savings resulting from the use of the advanced lighting control system, monitoring included the collection of power data before, during, and after the energy efficiency test period. CTs, voltage probes, and a data logger were installed on the proper electrical circuits to record power and energy readings at a given interval for the designated time period. Comparison of the data collected to that provided by the manufacturer showed that the technology generally performed as expected during the evaluation period, and has good potential to save energy, as shown in the figures below. Figure 2 provides the base case energy. Figure 3 shows the potential energy reduction when the light levels are tuned. Figure 4 shows the effect of daylight harvesting on energy. Figure 5 provides the overall composite results of the various phases of this project.

**Figure 2: Baseline Daily Energy Consumption**

*System at 100% On*
*Main Office Space with 44 total fixtures*
*Mid October Day*

100% On - 39.75 kWh used
Figure 3: Daily Energy Reduction Results from Tuning Light Levels

Figure 4: Daily Energy Reduction Results from Daylight Harvesting
The measured savings are a function of this project’s assessment design and do not necessarily represent the maximum energy efficiency potential of all advanced lighting control system technologies. Savings potential is not necessarily represented by a technology selection or proper installation and commissioning of a single energy control measure. The characteristics of the building space play a crucial role in the results of implementing an ALCS. Some of the building characteristics which may impact results include: circuit and luminaire layouts, windows, shading, hours of operation, occupancy patterns, light level requirements, task lighting availability, etc. A controlled comparison would require evaluation within identical spaces and characteristics.

The open office area lighting consists of 44 fluorescent troffers. Since daylight is available, daylight sensors were included in the control strategy. Tuning the light level resulted in a 29% reduction in power and energy. Daylight harvesting accounted for an additional 21% reduction in power and energy. The total power and energy reduction potential of the ALCS assessed in this project is 50%. The reduction in the lighting power density (LPD) due to each measure was calculated as well. The results are shown in Table 2.

**Table 2: Project Electric Energy and Demand Savings with Lighting Power Density Reductions**

<table>
<thead>
<tr>
<th>Lamp</th>
<th>Power (watts)</th>
<th>Annual Operating Hours</th>
<th>Annual Energy (kWh)</th>
<th>Demand (kW)</th>
<th>Savings (%)</th>
<th>Lighting Power Density (LPD) watts/sq ft</th>
<th>LPD Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case - 44 fixtures open office area</td>
<td>3454</td>
<td>2886</td>
<td>9,968</td>
<td>3.5</td>
<td>-</td>
<td>1.3</td>
<td>-</td>
</tr>
<tr>
<td>Light levels tuned</td>
<td>2452</td>
<td>2886</td>
<td>7,076</td>
<td>2.5</td>
<td>29%</td>
<td>0.9</td>
<td>29%</td>
</tr>
<tr>
<td>Daylight harvesting</td>
<td>2729</td>
<td>2886</td>
<td>7,867</td>
<td>2.7</td>
<td>21%</td>
<td>1.0</td>
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<tr>
<td>Total Potential - Tuning and daylight harvesting</td>
<td>1727</td>
<td>2886</td>
<td>4,984</td>
<td>1.7</td>
<td>50%</td>
<td>0.7</td>
<td>50%</td>
</tr>
</tbody>
</table>
Economic Performance

It is important to note that the cost and equipment assumptions made in this section apply only to VA. Readers should consider their specific variables such as maintenance, energy, ballast costs and type of advanced lighting control system before drawing any conclusions about the cost effectiveness of an ALCS. For this project, material costs including system hardware (includes addressable ballast, sensors, high efficiency lamps), software, wiring and commissioning is approximately $5.00 per square foot.

1. Energy Cost Estimates

The energy cost is based upon the VA blended rate of $0.43 per kWh. VA Engineering office lighting operates 2886 hours annually. Table 3 provides the energy cost and savings results of this project.

<table>
<thead>
<tr>
<th>Lamp</th>
<th>Cost/sq ft ($)</th>
<th>Square Feet</th>
<th>Total Product Cost ($)</th>
<th>Energy (kWh)</th>
<th>Energy Cost (per kWh)</th>
<th>Annual Energy Cost ($)</th>
<th>Percent Cost Savings</th>
<th>Payback (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case - 44 fixtures open office area</td>
<td></td>
<td>2640</td>
<td></td>
<td>9,968</td>
<td>0.43</td>
<td>4,286</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Potential - Tuning and daylight harvesting</td>
<td>5</td>
<td>2640</td>
<td>13,200</td>
<td>4,984</td>
<td>0.43</td>
<td>2,143</td>
<td>50%</td>
<td>6.2</td>
</tr>
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The simple payback calculations were calculated for the existing building scenario. It should be noted that the assessment did not include an area large enough to result in maximizing the capacity of the system’s digital controller.

2. Life Cycle Cost Analysis

Even though life cycle cost analysis was not part of the scope of this project, a full life cycle cost analysis is recommended. There are many variables and considerations which are specific to each reader’s situation. It is recommended that variables such as labor, cost of materials, maintenance practices, cost of financing, inflation, energy rates, material cost, product life, etc. be determined for the specific project under evaluation.

The VA Energy manager was asked about ease of use of the technology as well as perceived energy efficiency benefits. In general, the Energy Manager recognized the potential energy efficiency benefits of all control strategies.

The Energy Manager indicated that the system’s interface with the existing lighting system was relatively easy to understand.

The Energy Manager provided these comments about the installation of the ALCS:

It allows great flexibility. The system was relatively easy to install. The only area requiring specific clarification was the requirement of properly wiring the new sockets. As for IT, a separate DSL line had to be installed to conduct this project. A brief survey of the occupants indicated they preferred the lighting levels after the tuning took place. The Energy Manager is moving forward with recommending the inclusion of ALCS on future projects and expects to get IT collaboration as he moves forward with this strategy.
CONCLUSION

Currently, market penetration of lighting controls technologies such as those evaluated here is low, particularly in the existing buildings market. The results of this assessment project show that effective technologies are available to capture savings potential in commercial lighting.

Advanced lighting control systems represent a significant energy efficiency opportunity in the commercial sector. Technologies such as the one evaluated in this report present an excellent opportunity to penetrate the existing building market due to their ease of installation and commissioning. The ability to meet organizational IT requirements due to offering both a wired or wireless solution proved beneficial at this host site.

At 19,265 GWh/year, commercial lighting energy use represents roughly 29% of total statewide energy use. Lighting in the large and small office sector represents 4,331 GWh/year statewide. The types of advanced lighting controls similar to one evaluated in this report will better enable customers to install lighting controls due to ease of installation and robust capability. These benefits could increase market penetration of lighting controls from less than 1% to 5% or more within the next three to five years with the proper educational outreach programs.

For the evaluated digital technology, system cost estimates included materials to provide user scene selection, occupancy sensing and automatic daylight harvesting for all fixtures in each space. In addition, software is available allowing system monitoring and remote user control for all networked spaces. Material costs including system hardware (includes addressable ballast, sensors, high efficiency lamps), software, wiring and commissioning is approximately $5.00 per square foot. The DALI digital dimmable ballasts used by this system are available from all major manufacturers. Costs will vary based on building type, use, office configurations, and the robustness (degree of control) required for the particular office.

The ALCS was quickly and easily installed at the host site. Because the ALCS controls the lighting system on a ballast-by-ballast basis, it is robust and very flexible, allowing customizable energy efficiency strategies based on user input, even as cubicles and other workspaces are altered over time.

The ALCS installed for this assessment allowed the Energy Manager to easily modify the various settings via a drop down menu. The ALCS compatibility with a dimmable ballast allowed for a very robust range of tuning light levels and various settings based upon occupant feedback. This increases the ALCS energy efficiency and demand response potential.

Due to the phased approach of implementing each measure or control, the effectiveness and contribution of each measure to power and energy reduction was determined. In this project, it was determined that tuning and daylight harvesting contributed on a fairly significant basis to the reductions realized. The zonal occupancy sensor strategy proved ineffective in this project due to limited periods of no occupancy.

Based upon the findings of this project and others, it is important to note that each situation is different. It is highly recommended that prior to committing to a technology, readers should conduct their own pilot or mini assessment of the available options to determine the economic feasibility of their particular project.

Moreover, it is also recommended that future projects consider the following:

- develop a matrix comparing the various advanced lighting control systems currently available in the market
- data logging of illuminance levels during daylight and dimming
- development of educational outreach programs to trades, professionals, designers and engineers
- development of higher level incentives for ALCS installed by a certified control professional as per California Advanced Lighting Controls Training Program (CALCTP)