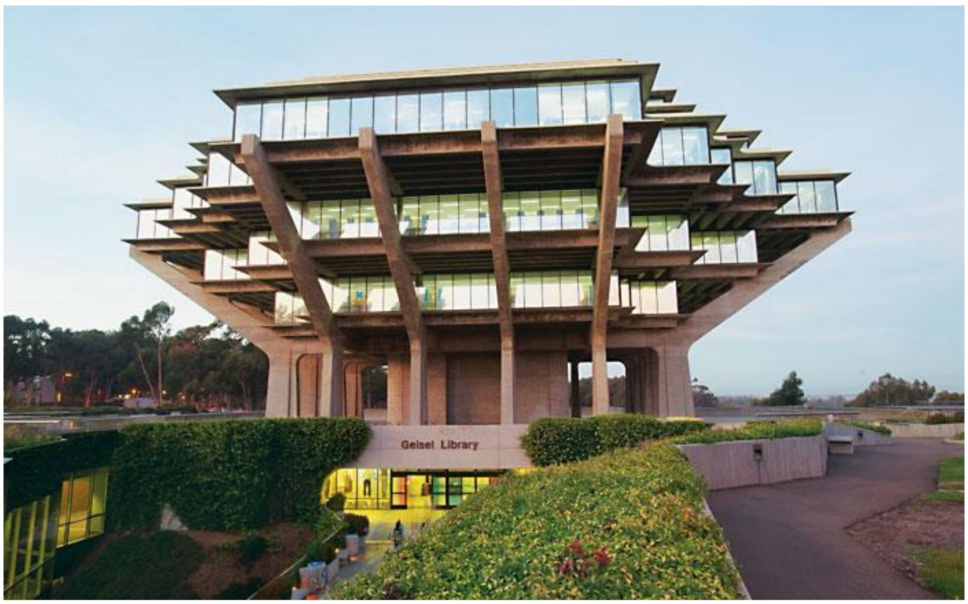
Wireless Lighting Controls

Automated Demand Response

DR15SDGE0001 Report



Prepared by:

Emerging Technologies Program
San Diego Gas & Electric

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UCSD

SDGE
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This technology assessment project is sponsored by San Diego Gas & Electric's (SDG&E) Emerging Technologies Program (ETP) Demand Response (DR) under the guidance and management of Christopher Roman, CRoman@semprautilities.com. Anna Levitt, Assistant Energy Manager, the University of California San Diego (UCSD) Facilities Management, and Gary Oshima, Project Manager, UCSD Facilities Management, were the contacts and project managers for UCSD. Daryl DeJean of Emerging Technologies Associates, Inc. (ETA) provided technical consulting, coordination of all parties involved, with EFM Solutions who provided the data collection and analysis, and the Project Report.

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Executive Summary

SDG&E's ETP saw the opportunity of a scaled field placement of connected lighting points with advanced controls providing demand response (DR) capabilities. This allows the leveraging of open automated demand response (OpenADR) as a way to help various markets recognize the benefits of selecting connected lighting solutions as part of their strategic energy plan. Being able to participate in DR programs benefits the customer not only financially due to the incentives, but helps them achieve their energy and greenhouse reduction goals. Additionally, having ADR capable lighting systems positions them for the smart grid and price signals to better manage their peak load.

Funding for scaled field placements is provided to influence adoption of specific energy efficiency and demand reduction measures. The complexity of ADR technologies, the advanced lighting controls connectivity to the energy management system (EMS), proper validation of load reduction, and concern regarding the customer maintaining control over their reduction levels were key reasons to provide a first hand opportunity to key influencers like the UCSD.

The goals of the project were to:

- Determine reliability of the lighting points to receive the DR signal without customer intervention.
- Determine whether the stated customer established demand reduction in the lighting systems DR event schedule was achieved.
- Determine the actual demand reduction achieved for each time period tested.
- Validate that DR strategies implemented using ADR can be trusted to respond and are controlled based upon established customer preferences.

The solution selected is a connected LED lighting systems with embedded sensors and wireless controls integrated into the luminaire. The luminaires can connect wirelessly to wireless access controls (WACs) that are connected to the EMS. This smart luminaire with wireless controls provides a dynamic approach to controlling and monitoring lighting points on the network. As a prototype, the version of the solution used for this project allowed for grouping of fixtures by functional area. Newer versions allow for fixture by fixture control. To accommodate the normal changes in a building's space utilization, the easy to use interface allows for fast reconfiguration of the lighting points without any wiring changes or need to relocate fixtures. The solution is scalable for any job size, from small to large. Integration into EMS or building management systems (BMS) can be achieved through the network gateways.

The technology will provide the building manager the ability to shave peak demand and participate in utility incentive programs. The building manager will have the ability for dynamic demand management for certain time periods of the day. This enables the building manager to manage their load curves by establishing load profiles for various time periods throughout the day, not only during a DR event. For example, a maximum peak load can be established and the technology can monitor the peak demand triggering load reduction if that peak is approached at any time of the day. By continuously controlling peak demand, significant demand charge and energy consumption cost savings may be realized.

The findings of the project shown in Table 1 indicate connected lighting points that leverage OpenADR protocols can deliver significant demand reduction during DR events. Table 2 represents expected results of a building-wide implementation of connected lighting points. The results shown in Table 2 were extrapolated from the results shown in Table 1 that were actual results of our pilot project. Although the stated reduction was not achieved, the project results will assist manufacturers in insuring acceptable tolerances in measured results are available to the utility programs teams for proper DR participation incentive payouts.

The manufacturer's claimed reduction of 80% reduction in demand was not achieved because the provided solution was a development prototype that did not include disabling of the occupancy and daylight harvesting sensors during a DR event. In this project it was determined that the daylight harvesting sensors on 14 luminaires took control to maintain a certain light level even though a DR event signal was received thereby unfavorably impacting the results. Additionally, restoration to pre-event levels did not occur since lighting load was manipulated manually prior to the commencement of the event. Both of these findings were already addressed and corrected by the manufacturer for the market launch of the solution. It is anticipated that the market launch version will deliver the within acceptable levels of the stated results.

Table 1: Test Area Project Financials

Pilot Test Area Project Financials with Rebates and Incentives											
Total Luminaires	Total Installed Cost $175/ea ($)	Fluorescent T8 28W Baseline Energy (kWh)	LED 38W Energy (kWh)	kWh Reduction	kWh Savings ($)	EEBR* ($25/ea)	Permanent kW offset	TI Incentive $300/kW ($)	CBP Incentive 7 events** ($)	Net Installed Cost ($)	Simple Payback*** ($)
30	5,250	10,140	7,410	2,730	328	750	0.4	0	0	4,500	14

*EEBR code 462707
** Annual participation assumed same day 30 minute notification: 2 events in July, 4 events in August and 1 event in September 50/50 share with aggregator
*** Combined kWh savings and annual incentive for participation in CBP

Table 2: Extrapolated Whole Building Project Financials

Whole Building Scaled Project Financials with Rebates and Incentives											
Total Luminaires	Total Installed Cost $175/ea ($)	Fluorescent T8 28W Baseline Energy (kWh)	LED 38W Energy (kWh)	kWh Reduction	kWh Savings ($)	EEBR* ($25/ea)	Permanent kW offset	TI Incentive $300/kW ($)	CBP Incentive 7 events** ($)	Net Installed Cost ($)	Simple Payback*** ($)
2,767	484,225	935,246	683,150	252,096	30,252	69,175	39	11,610	5,494	397,947	11

*EEBR code 462707
* *Annual participation assumed same day 30 minute notification: 2 events in July, 4 events in August and 1 event in September 50/50 share with aggregator
*** Combined kWh savings and annual incentive for participation in CBP

Based upon the above stated project findings in Tables 1 and 2, there is significant potential for connected lighting points to increase market participation in DR Programs for buildings that have a reasonable lighting load consisting of several thousand lighting points or fixtures. The ability for these lighting points to report the reduction within an acceptable level of tolerance (i.e. 3%) may eliminate the need for the aggregation of customers to participate in DR Programs. This would in turn allow the customer to feel more in control of their systems not requiring a third party to be involved in their strategic energy and load management.

If a customer has an electric demand of at least 20kW and is equipped with a meter that records data in 15-minute intervals and is remotely read by SDG&E, they may want to consider the opportunity to participate in SDG&E's Critical Peak Pricing (CPP) DR rate, referred to as CPP-D rate. The essence of the CPP-D rate is that you will pay a lower rate during non-peak critical times while the rate during critical peak times is much higher. CPP-D is designed to provide you with more accurate information on energy cost, a customer can better manage their electric use. When a customer has connected lighting points, the ease of control over all lighting would afford the customer an opportunity to weight the risk/reward of participating in the CPP-D rate. SDG&E's Program at the time of this report allowed for a customer to try the CPP-D rate for one year under its bill protection program. If the CPP-D rate results in a higher annual electric bill as compared to the normal rate structure of the customer, the customer would be credited the difference. For more information on CPP-D and other demand response programs, please visit http://www.sdge.com/business/demand-response-overview.

The technology is rapidly evolving to allow for behind-the-meter distributed energy storage. Based upon the results of this assessment project, it is recommended that a similar scaled field placement be conducted on the newer version being released in late 2016. The system is stated to provide for lithium ion based energy storage in the connected lighting system. The goal is to work off the grid for up to ten hours for an individual luminaire and three to five hours of autonomous smart luminaire operation. The recommended test would have the connected lighting points operate off grid measuring lighting performance throughout that period of time.

Abbreviations and Acronyms

DR	Demand response
Open ADR	Open automated demand response
EMS	Energy management system
WAC	Wireless access controller
BMS	Building management system
EEBR	Energy efficiency business rebate
TI	Technology incentive
CBP	Capacity bidding program
CPP-D	Critical peak pricing demand response
CEC	California Energy Commission
M&V	Measurement and verification

CONTENTS

FIGURES

TABLES

GRAPHS

Introduction

A recent McKinsey report estimates that the ability for lighting to be connected via the internet can help manage office spaces with an economic impact of $70 - $150 billion per year in 2025. The impact due to enhanced energy monitoring and other energy related services is estimated to be between $12 - $ 21 billion dollars. The report states that offices can achieve approximately an additional 20% savings in their energy related expenses. Figure 1 below is the chart illustrating all the ways that connected lighting points can have an impact on business. These categories depicted are the foundation of the business case of customers for selecting and implementing such lighting solutions.

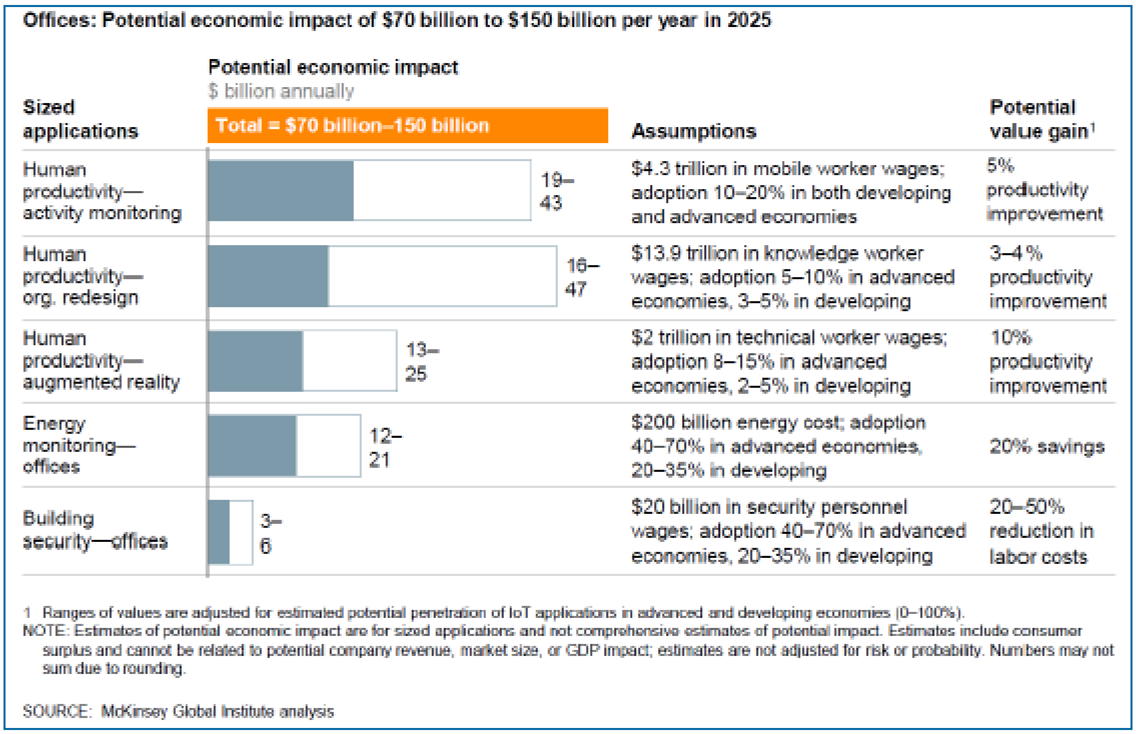


Figure 1: Potential Impacts of Connected Lighting Points on Business

SDG&E ETP's interest in this technology was based upon the information provided by McKinsey Global Institute in Figure 1, connected lighting offers tremendous potential benefits from demand side management that are far reaching beyond energy issues.

SDG&E's ETP was interested in conducting a scaled field placement project to evaluate, monitor and validate the DR capabilities of connected lighting points to leverage Open ADR in the substantial lighting retrofit market. The reason for interest in this solution is due to the numerous buildings that do not have proper metering for participating in DR programs requiring an aggregator for participation in DR programs. A solution for such buildings is desirable and can provide more opportunities for DR program participation.

This project specifically relates to connected LED lighting systems with embedded sensors and wireless controls integrated into the luminaire. The luminaires connect wirelessly to wireless access controls (WACs) that can be connected to the EMS. This type of lighting system was selected due to the perceived low-cost entry for various market segments and buildings without metering for participation in DR programs to explore the potential demand savings as well as to increase participation in ADR programs.

The UCSD Geisel Library was selected as the host site for this project. UCSD Library has 2,767 fixtures with two 28 watt T8 fluorescent tubes that operate approximately 6,500 hours per year. All major campus buildings are networked to an EMS that centrally controls building mechanical systems based on occupancy. The EMS is programmed to reduce energy use in buildings during nights, weekends and holidays. The lighting systems are manually controlled driving UCSD to identify the appropriate dynamic lighting control system solution that can easily integrate into their EMS. Table 3 illustrates the fluorescent lighting baseline for the UCSD Library. Based upon the results of the pilot, Table 4 illustrates the potential for the entire UCSD Library if all lighting was converted to LED technology.

Table 3: UCSD Library Pilot Baseline Metrics

Energy and Demand Reduction Pilot Area				
Total Luminaires 30	Baseline Energy (kWh)	kWh Reduction	Baseline Demand kW	Permanent kW offset
Fluorescent T8 28W	10,140		1.56	
LED 38W	7,410	2,730	1	0.4

Table 4: UCSD Library Potential Energy and Demand Reduction

Potential Energy and Demand Reduction Whole Building				
Total Luminaires 30	Baseline Energy (kWh)	kWh Reduction	Baseline Demand kW	Permanent kW offset
Fluorescent T8 28W	935,246		143.9	
LED 38W	683,150	252,096	105	38.8

Figure 2 below shows the current load profile of the UCSD Library. The demand was broken into major end-use categories, approximated based on the California Commercial End-Use and adjusted from experience with other municipal libraries in San Diego County. Lighting is estimated to account for 24% of the current load.

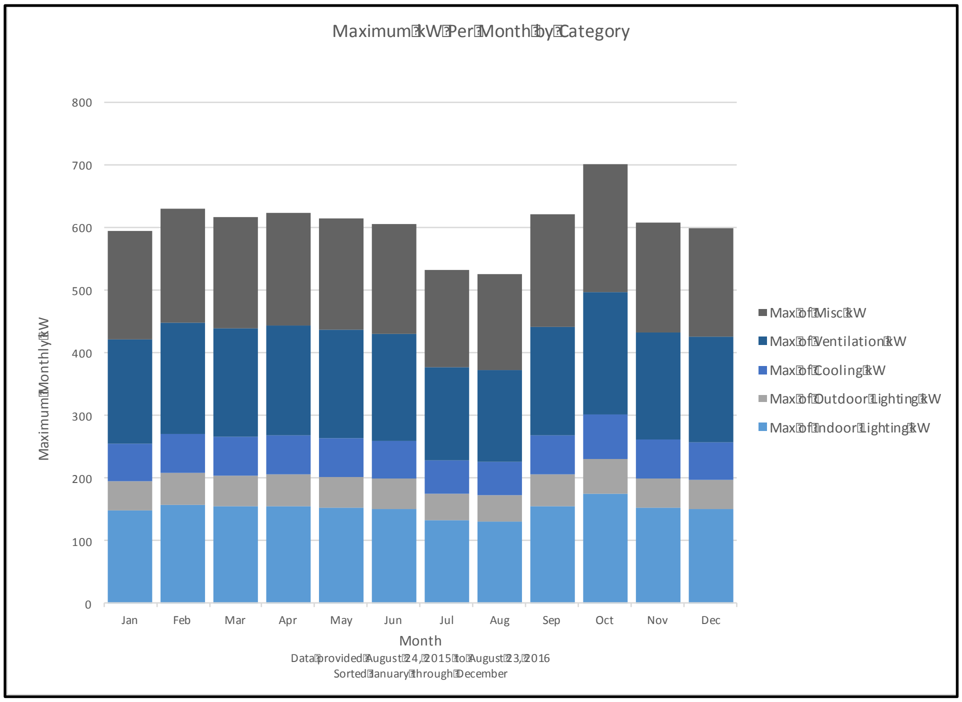


Figure 2: UCSD Library Load Profile by Category

UCSD has been interested in incorporating LED lighting systems into the EMS allowing them to increase their ability to participate in DR programs, specifically ADR, to improve their energy efficiency as well as be able to initiate campus-wide peak demand reduction. The University expressed an interest in the additional benefits of DR: reduced greenhouse gases and integration of renewable generation to contribute to their desire for a micro grid.

Background

Emerging Technology/Product

The ability for lighting to be connected via the internet can help manage office spaces. Technology for connected lighting points utilizing LED technology is evolving rapidly. "An issue that's of huge concern to lighting designers and specifiers–how to deal with the fact LED technology has been improving at a pace so rapid that it can outstrip long lead times for new construction." (article in LD+A April 2015 by James Brodrick, Lighting Program Manager, US Department of Energy Building Technologies Office.)

Connected lighting points system architecture as shown in Figure 3 includes:

1) Luminaires that are seamlessly integrated into an IT network
2) Luminaires with integrated sensors become a point of intelligence sharing information on occupancy, activity patterns, temperature, humidity and daylight
3) Potential to deliver location-based services and in-context information via mobile apps
4) Software capable of storing, visualizing and analyzing information about luminaire performance and overall lighting performance
5) Integration with other systems, i.e. EMS, to create synergies, making lighting a part of the broader system of digital nodes with user defined boundaries.

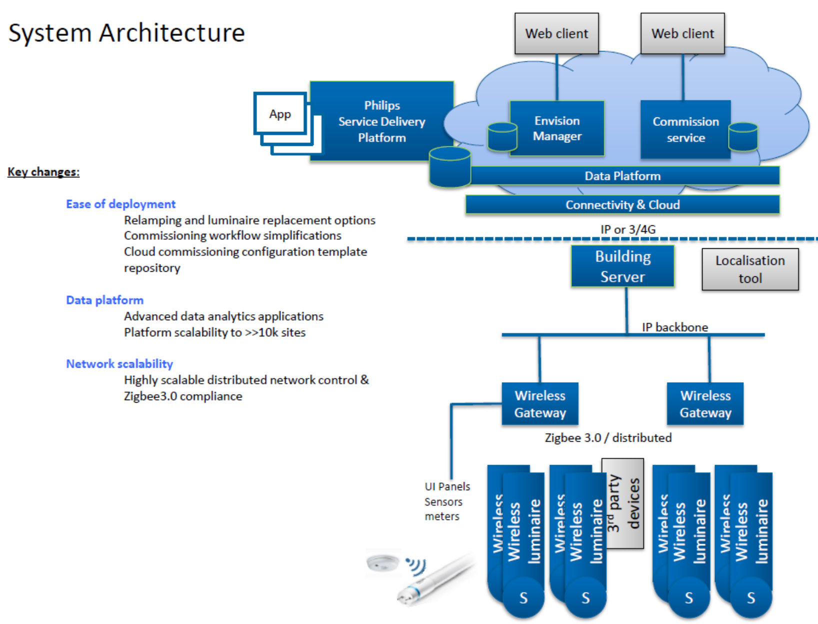


Figure 3: Typical Connected Lighting Points System

The prototype of a near market ready solution was selected for this assessment project. The technology has preset demand reduction levels that can be selected by the end user or adjusted to desired levels responsive to OpenADR 2.0a protocol. The preset reductions levels are "low" 15%, "medium" 40% and "high" 80% DR event reduction levels. The technology allows for ongoing demand and energy management. Customers can set internal DR events to manage their peak load. The version to be released to the market will be ADR 2.0b compatible and have "fault detection" capabilities to alert when potential system issues are possible.

It is the ability to have the lighting system integrate with other systems as specified by the end user that is of interest to the end user. The previously perceived lack of "control" if they opened their network to others is now being addressed in such a manner that should help increase participation in DR Programs. However, these systems must prove to be secure and provide reliable data to make the DR Program management streamlined and easier for even smaller loads to participate.

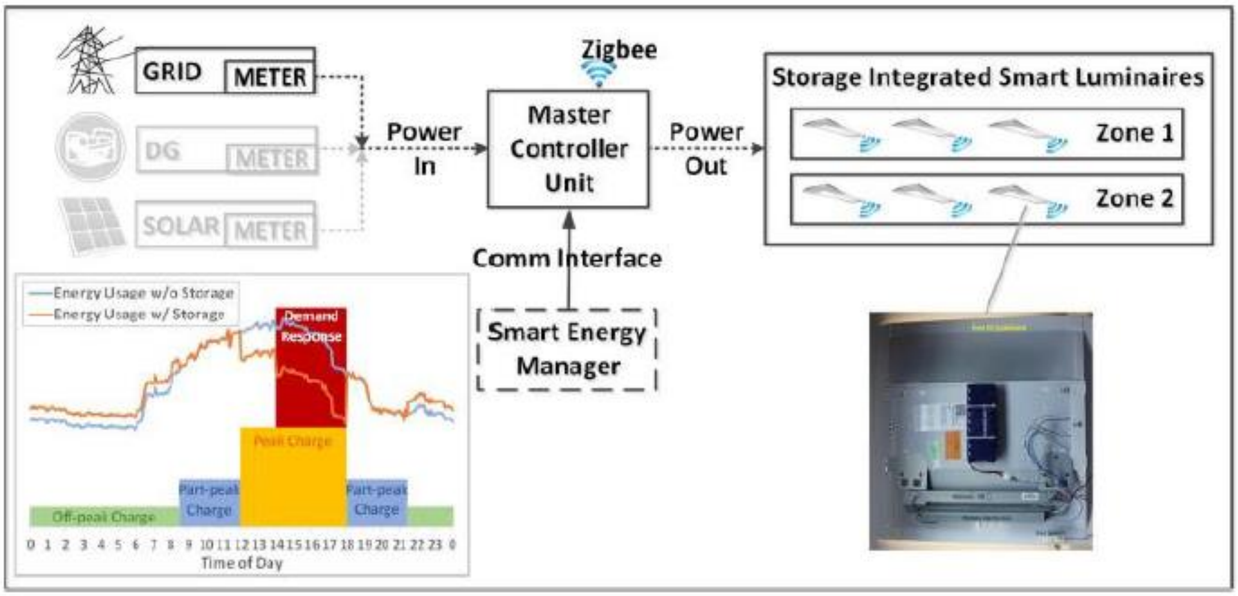


Figure 4: Connected Lighting Points for DR and Energy Storage

The California Energy Commission (CEC) has been incorporating more stringent lighting control requirements in Title 24, stating that lighting system must be DR capable. The CEC Lighting Certification and Controls Fact Sheet addressing this requirement can be found at:

http://www.energy.ca.gov/2014publications/CEC-400-2014-023/CEC-400-2014-023-FS.pdf

Assessment Objectives

The goals of the project were to:

- Determine reliability of the lighting points to receive the DR signal without customer intervention.
- Determine whether the stated customer established demand reduction in the lighting systems DR event schedule was achieved.
- Determine the actual demand reduction achieved for each time period tested.
- Validate that DR strategies implemented using ADR can be trusted to respond and are controlled based upon established customer preferences.

To accomplish these goals, the project team from UCSD, SDG&E ETP and ETA worked closely with the manufacturer to create a scaled field placement project to gain a better understanding of how the technology can be included in future programs and possibly simplify the current process for the validation of actual demand reductions. The testing plan was developed to evaluate performance in situ to validate manufacturer's stated performance claims.

Technical Approach/Test Methodology

Thirty fluorescent fixtures were replaced with a “smart” LED troffer with integrated sensors and wireless connectivity in a section of the UCSD Library. The section of the library was selected by UCSD personnel due to the availability of daylight as the University wanted to optimize energy consumption as well as study the potential impact of DR, specifically ADR, responsive luminaires. Energy and demand was reduced by 27% over the fluorescent fixtures when retrofitted to LED technology.

Two DR events were to be simulated: one two-hour event and one four-hour event. The LED luminaires were to be monitored using data loggers to insure the preset demand reduction levels were achieved and held for the duration of the even and returned to original lighting levels upon the completion of the event.

“For DR to be successful, a collection of technologies, strategies, and software components in addition to customers’ commitment is crucial. Challenges are systems architecture and integration, reliable control technology and strategies, consumer technology, fragile cyber security, fostering customer interest and engagement, measurement and validation, and policy lag and confusion.” (O’Connell et al. 2014; Spam, Jin, and Earle 2013

ADR load reduction is based on pre-programmed demand response reduction levels and targeted facility systems, i.e. mechanical, lighting. Typically, no customer intervention is required since they establish the reduction levels and systems for the event and level. A customer can “opt out” or override DR events in their EMS if participation is not deemed desirable for a facility during that event.

SDG&E was looking to learn more about “simple” connected lighting point systems and the ability to provide accurate DR event data eliminating the need for extensive on-site metering. The system selected allowed for integration into the EMS, pre selected event levels established by the customer, and reporting of event results. The system had to be Open ADR 2.0a compatible with plans to be OpenADR2.0b when launched in the market spring of 2017.

Field Testing of Technology

Test Plan

The open areas of the UCSD Library 6th floor is currently illuminated by 1'x4' recessed troffers with two T8 28 watt lamps per fixture. The fixtures are manually switched ON/OFF by library staff.

The plan is to replace a section of the 1'x4' fixtures with thirty (30) SpaceWise controlled 2'x4' LED troffers to save energy and be able to lower demand during a power alert. ETA had been asked to develop and implement the plan to measure and verify the energy and demand savings for this project.

The nature of this project requires the use of International Performance Measurement and Verification Protocol (IPMVP) M&V Option B. The IPMVP describes Option B as:

- Savings are determined by field measurement of the energy use of the systems to which the ECM was applied, separate from the energy use of the rest of the facility. Short-term or continuous measurements are taken throughout the post-retrofit period.

The lighting system/fixtures that are to be replaced can be easily isolated for measurement purposes.

The baseline energy usage can be established by a using a data logger on one fixture for 2 weeks. It is assumed each fixture uses the same amount of energy since no controls or daylight harvesting controls are installed on the fixtures. The final baseline energy use will be calculated by multiplying the energy use of the measured fixture by the total number of fixtures removed to make room for the new SpaceWise controlled fixtures. If the removed fixtures are on more than one circuit, one fixture per circuit will be data logged.

Holidays and Non School Schedules – Depending on the timeframe of the data logging, the final energy savings may need to be adjusted for the difference in occupancy hours for when school is in session and when it is not. ETA will make the appropriate adjustments once the data logging phase of the project is complete.

Each individual fixture has built in daylight harvesting and demand response capabilities, making it difficult to calculate the total energy use of the new lighting system. ETA proposes monitoring the energy use of each fixture separately using one data logger per fixture.

Data gathered during the M&V period will be compared to the DR event schedule provided by SDG&E. Savings will be calculated for 3 types of savings:

- Fixture Efficiency – Energy use of the new fixtures will be compared to the baseline energy use
- Demand Response Savings –Demand (kW) savings will be calculated over the course of the DR events in this filed demonstration
- Daylight harvesting – Any savings generated during the daylight hours that do not occur with and DR event will be calculated.

ONSET Corporation HOBO Data Loggers, Figure 5, will be used to capture the energy use of each new SpaceWise controlled fixture.

Figure 5: Hobo Data Logger Equipment

Instrumentation Plan

In an effort to validate the system performance, two separate DR test events were conducted; a 2-hour and 4-hour event were conducted on consecutive days. The goal was to validate the systems ability to hold the event and capture the reduced levels in accordance with the customer prescribed participation level.

LED fixtures draw very low amperage compared to fluorescent fixtures. This resulted in the project team trying different methods to collect the data to evaluate the outcome of the solution. The integrity of the project required accurate data collection. The team selected various loggers and was careful in defining the installation of each. The following three methods were used to collect accurate and appropriate data.

1. The first attempt to collect energy data from the LED fixtures was done using HOBO U12 external input data loggers with 2-20-amp split-core AC current sensors. This resulted in inaccurate data due to the very low amperage draw of the LED fixtures on the 277 volt lighting circuit. The recorded amperage was less than the accuracy level of the AC current sensor.

2. The second attempt to record energy usage of the LEDs at each fixture was done using a HOBO H22 Energy Data Logger system with 20 Amp Accu-CT Split-Core Current Transformer 333mV Sensors. This combination of equipment is recommended by Onset for recording lower amperage levels and has a much higher accuracy level at low current (±0.75% from 1% to 120% of rated primary current). Although the calculated fixture amperage was near the accuracy level of these sensors the data proved to be unreliable with this equipment.

3. The final method to collect individual luminaire data was made with the HOBO H22 Energy Data Logger and 20 Amp sensors by wrapping the power wire to each fixture around the current sensor body three times. The sensors measure the inductive field around the wire to record AC current. By wrapping the wires through the sensors multiple times the induction field is multiplied by the number of times the wire passes through the sensor. Three wraps were the limit based on available wire length in the LED fixtures. This method also proved to be unreliable as the measured current was still too close to the bottom of the accuracy range.

The strategy of data logging at each individual fixture was finally abandoned after the three methods resulted in inaccurate data. The decision was made to record the amps of the total lighting circuits where the test fixtures were located with the assistance of building maintenance personnel and lighting power plans made available by library staff. Four different lighting circuits were identified in the electrical panel room as providing power to 26 fixtures. The HOBO U12 loggers and 2-20 amp current sensors were used to record AC current at each circuit. The total current included the test LED fixtures as well as original fluorescent fixtures. The success of the DR test was measured by recording the total decrease in AC amps measured in all four circuits divided by the number of fixtures that were included in the DR test.

Figures 6 – 10 show the equipment used in the various methods for the data collection.

Figure 6: HOBO Temperature/Relative Humidity/Light/External Data Logger

Figure 7: 2-20 Amp split-core AC current Sensor

A Hobo H22 Energy multi-channel data logger was used with 20-amp Accu-CT Split Core Current Transformer 333mV sensors to record individual luminaire data.

Figure 8: HOBO H22 Energy Data Logger – Multi Channel

Part # H22-001

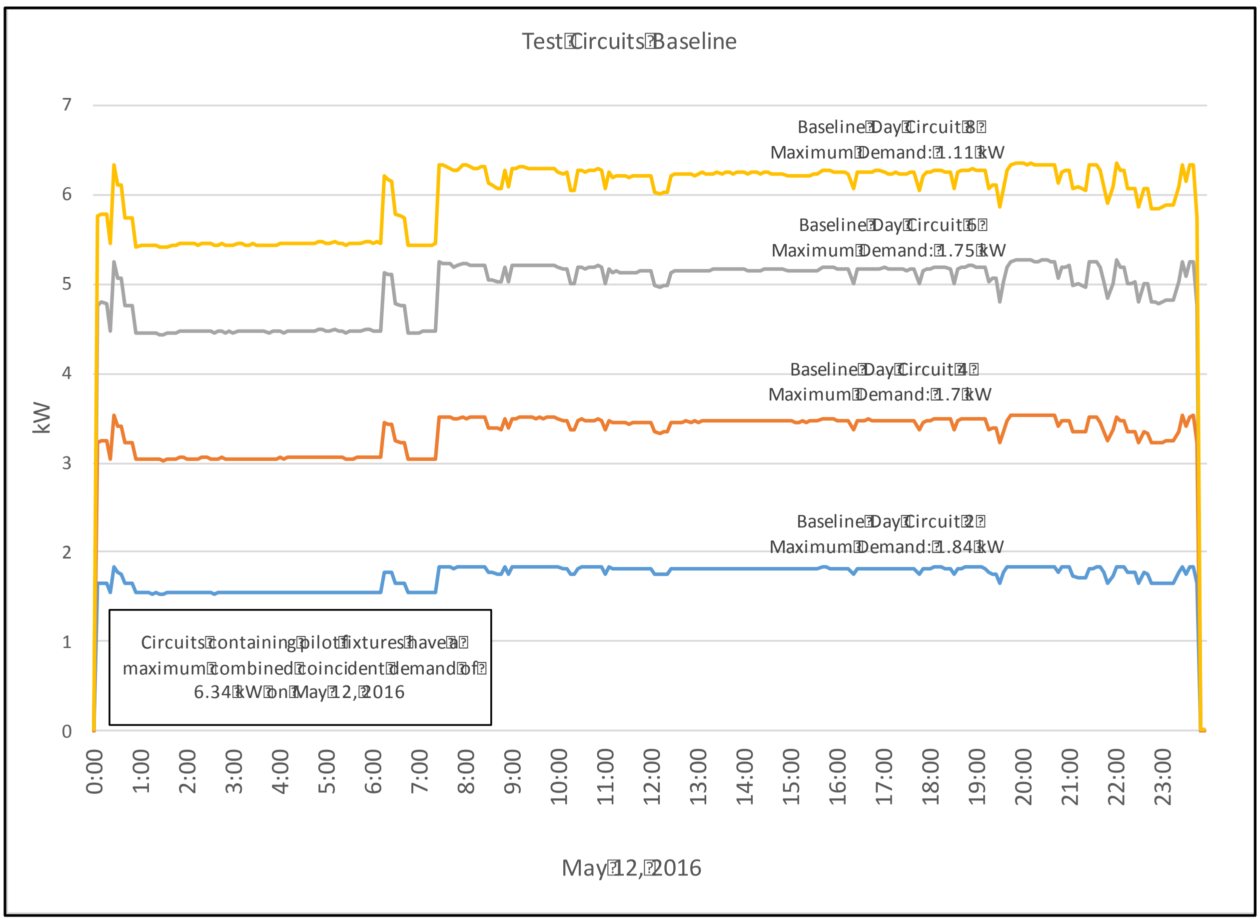
Figure 9: 20 Amp Accu-CT Split-Core Current Transformer 333mV Sensor

Part # T-ACT-0750-020

Results

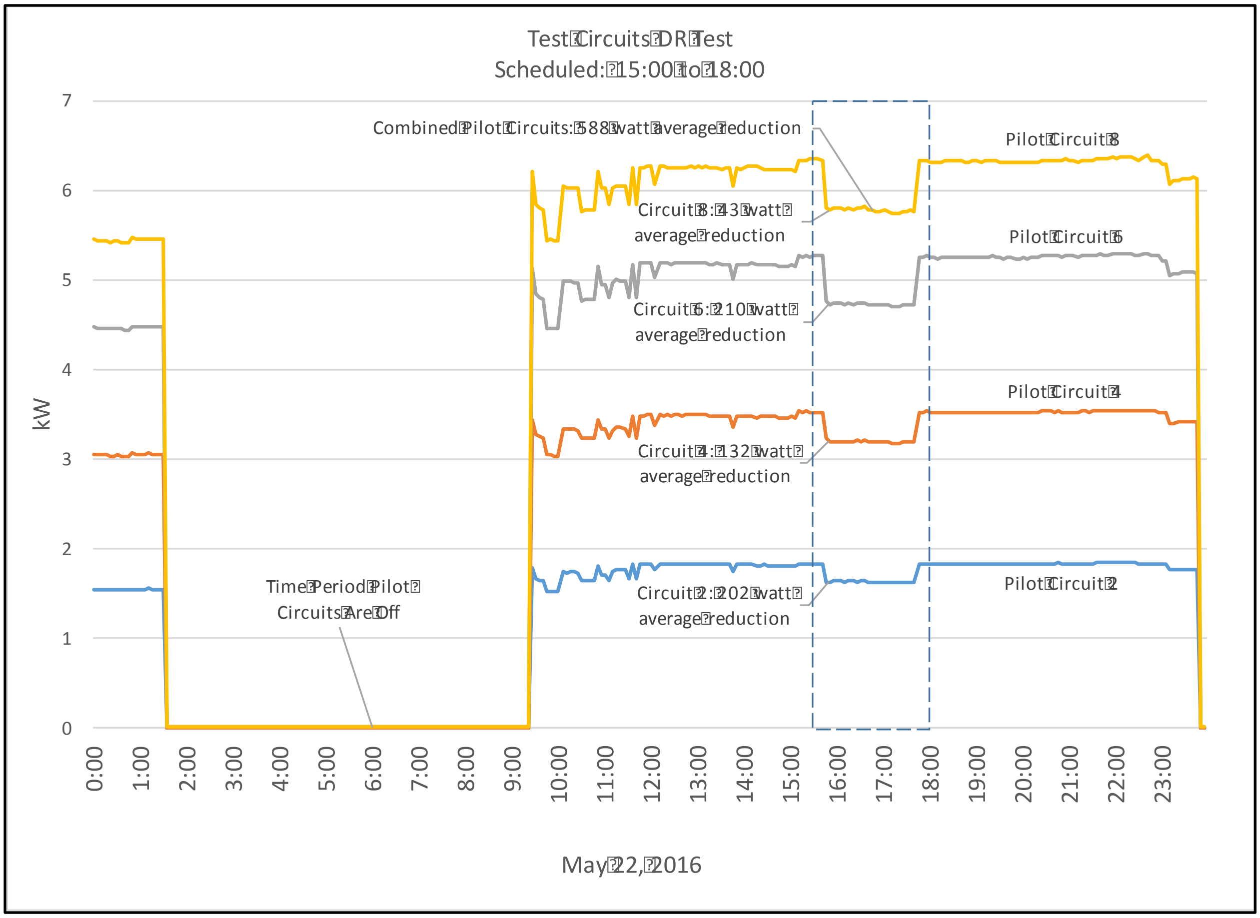
Circuit based data logging was used to capture the baseline demand of the four circuits supplying the LED fixtures and the results of the DR tests conducted on May 22nd and May 23rd. Electricity was supplied to the 30 LED test fixtures via four different circuits on the lighting panel on the 6th floor of the library. The data set is not able to isolate the demand of the LED fixtures, but we can capture the total demand reduction by measuring the delta in each of the four circuits at the time of the test start.

Graph 1 shows the demand profile for a typical day (May 12th) for the four circuits that supply electricity to the LED fixtures. Please keep in mind that four different lighting circuits supply power to the 30 LED fixtures in addition to an unknown amount of fluorescent fixtures and other unknown loads. It should be noted that 4 of the LED luminaires provided by the manufacturer for this pilot project were not capable of ADR since they were an earlier release that did not have the prototype controller capable of receiving and responding to ADR signals. As a result all DR events reference only 26 luminaires.



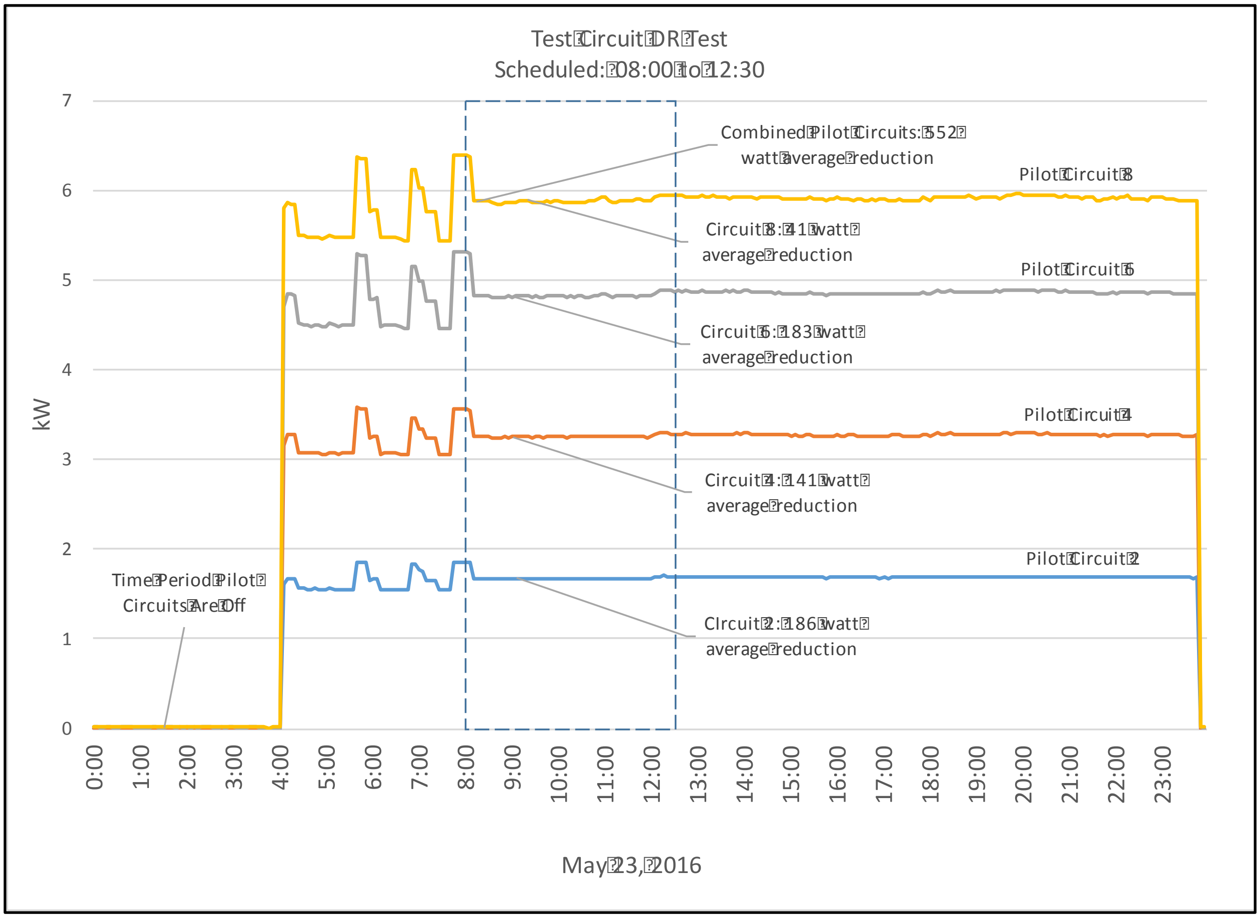
Graph 1: Typical Demand Profile for UCSD Library Lighting Circuits

Graph 2 clearly shows a reduction in overall demand during the testing period on May 22nd.



Graph 2: May 22 Two Hour DR Event Results by Circuit

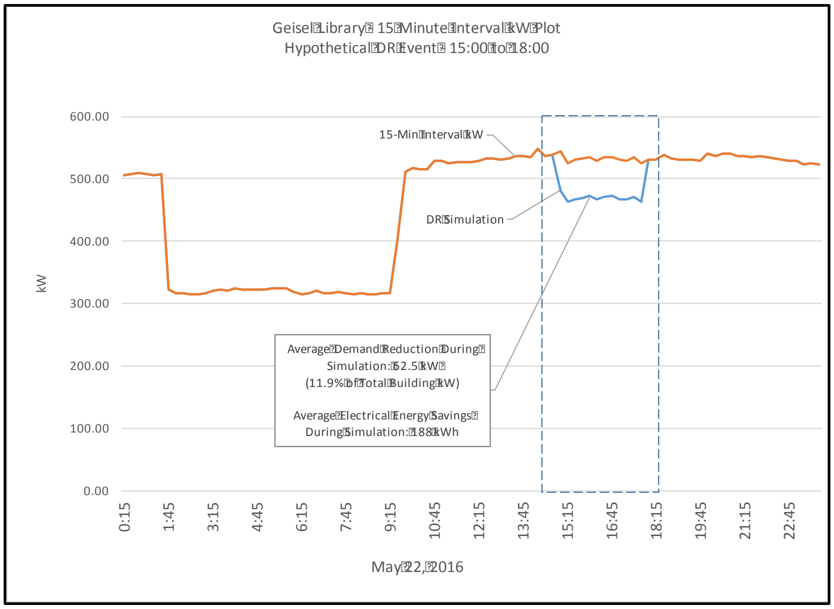
Graph 3 clearly shows a reduction in overall demand during the testing period on May 23rd.



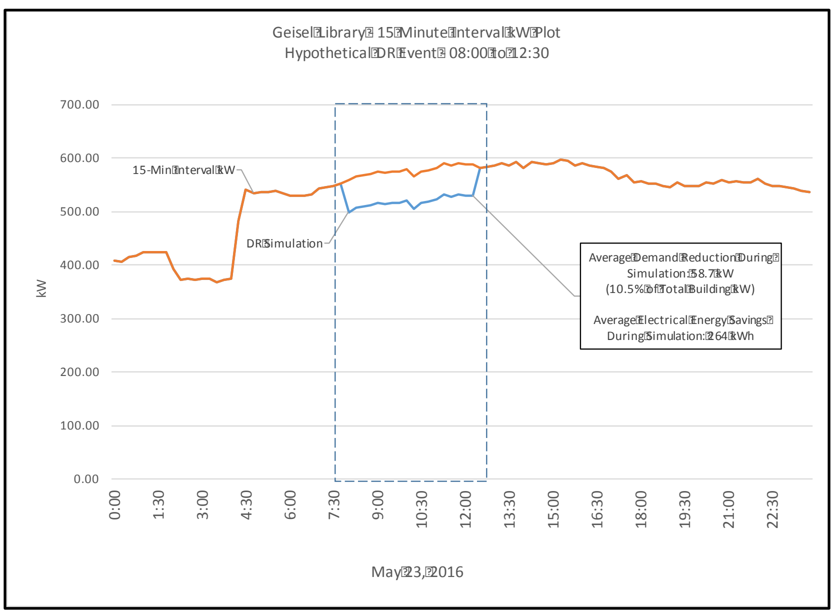
Graph 3: May 23 Four Hour DR Event Results by Circuit

Please note that the DR test for May 23rd started at approximately 8:30 AM. The software used to conduct the DR test left the 26 LED fixtures in DR reduction mode for the remainder of the day. The data clearly shows a measureable reduction in demand at 8:30 AM.

There are 2,767 fixtures in the UCSD Library that are considered eligible for DR reductions. If we extrapolate the results of the DR tests of the 26 fixtures to all 2,767 fixtures and overlay that data onto the interval data for the entire facility for each of the DR test days the new demand curves would look like the following graphs, Graph 4 and 5:



Graph 4: May 22 Two Hour DR Event Results Extrapolated for Entire UCSD Library



Graph 5: May 23 Four Hour DR Event Results Extrapolated for Entire UCSD Library

The two DR test periods, two and four hours, proved that the system being evaluated provided for between a 58.7 – 62.5 kW reduction (60.6 kW average). This is based on extrapolating results for 26 pilot fixtures to 2,767 troffer fixtures throughout the library.

$$kW\ Reduction = \left(\frac{2{,}767}{26}\right) x \left(\frac{Watts\ Reduced\ per\ Fixture}{1{,}000}\right)$$

15

Data Analysis

Five-minute interval amperage data was recorded on four test circuits between May 10th and May 24th, 2016. Demand response (DR) simulations were performed on May 22nd and May 23rd, 2016. Analysis and extrapolation of collected data shows a reduction of 62.5 kW (11.9% of total building kW) and 58.7 kW (10.5% of total building kW) respectively.

Data was collected on four lighting circuits (circuit 2, 4, 6 and 8 on panel L6A) on the 6th floor. These circuits have 26 pilot fixtures installed on them along with incumbent lighting technology. The data was sorted to isolate a baseline day on May 12th and the two DR tests on May 22nd and May 23rd, 2016. Maximum circuit wattage was found immediately before and after the DR test on both days. Data collected during the DR tests were averaged. The average wattage during the DR test was subtracted from the maximum circuit wattage to find the average wattage reduction per circuit. The wattage reduction of each circuit was summed and divided by the total number of pilot fixtures in the data logging to calculate an average wattage reduction per fixture. The average wattage reduction per fixture was then used to extrapolate an average wattage reduction for the entire library if every qualifying incumbent light fixture was replaced with the pilot fixture. This resulted in the calculated demand savings of 62.5kW on May 22nd and 58.7 kW on May 23rd.

Amp readings were taken in 5-minute intervals. The lighting circuits are 277-volt. Amps are converted to watts.

$$Watts = Volts\ x\ Amps$$

Final useful data logging occurred on the four test circuits between May 10, 2016 at midnight through May 24, 2016 at noon. The DR testing occurred on May 22, 2016 between 3:30pm and 6:00pm and again on May 23, 2016 between 8:00am and 12:30pm. The May 23rd DR test appears to have been left on through the end of the day, data collected after 12:30pm is excluded from the analysis of May 23, 2016. May 12, 2016 was chosen from the collected data as a 'baseline' day. May 12th is used to demonstrate typical lighting use on the logged circuits for comparison against the two scheduled DR tests. The remaining data collected between May 10th and May 24th is excluded from the analysis.

To reduce the recorded data to useful results the DR test time period was isolated from the rest of the collected data for analysis using data point time-stamps. For the May 22nd DR test the time window between 3:00pm and 5:55pm was used. To determine the high wattage for each circuit during this time the maximum circuit watts was found using a Max() function on data for circuits 2, 4, 6 and 8 for the specified time interval.

$$= max(N16: N51)$$

To determine the wattage for each test circuit during the DR simulation the average circuit watts was calculated between 3:30pm and 5:40pm using the Average() function on data for circuits 2, 4, 6 and 8 for the specified time interval. This interval contained 24 measurements of the circuit amperage. Standard deviations are shown in the tables below.

$$= average(N25: N48)$$

By subtracting the two results on each circuit the DR test wattage reduction was calculated for each circuit.

$$= max(N16: N51) - average(N25: N4)$$

The sensors used to record amperage have a range of 2 amps to 20 amps with an accuracy of ± 4.5% of the maximum rated amps. The calculated maximum error is 0.9 amps, when used with the U12 logger. The average amperage recorded on all four circuits was 5.36 amps on May 22nd and 5.26 amps on May 23rd. The potential error introduced from data logging is ± 0.9 amps or 17.1% on May 22nd and 16.8% on May 23rd.

The results of the data analysis for the two DR events are shown in Tables 5 and 6.

Table 5: May 22 Two Hour DR Event Results by Circuit and Extrapolated for Entire UCSD Library

May 22 DR - Scheduled: 15:00 to 18:00

Test Results	Circuit 2	Circuit 4	Circuit 6	Circuit 8
Circuit Watt Average During DR Test	1,635 W	1,563 W	1,528 W	1,049 W
Standard Deviation	3.95 W	7.03 W	4.22 W	11.13 W
Maximum Circuit Watts Before and After Test	1,837 W	1,695 W	1,738 W	1,092 W
Demand Response Test Wattage Reduction	202 W	132 W	210 W	43 W

Total Power Reduction	588 W
LED Full Load Power From Installation Test	1,114 W
Demand Reduction	0.53 kW
Percent Reduction in Power	53%

Fixture Test Results Extrapolation	
Test Fixtures	26
Avg Watt Reduction per Fixture	22.6 W
Entire Library Fixtures	2,767
Total Watt Reduction	62,545 W
Reduction as Percentage of Total kW	11.9%

Table 6: May 23 Four Hour DR Event Results by Circuit and Extrapolated for Entire UCSD Library

May 23 DR - Schedule 08:00 to 12:30

Test Restuls	Circuit 2	Circuit 4	Circuit 6	Circuit 8
Average Circuit Power During DR Test	1,677 W	1,580 W	1,569 W	1,058 W
Standard Deviation	7.30 W	5.43 W	8.46 W	10.93 W
Maximum Circuit Power Before and After Test	1,863 W	1,721 W	1,752 W	1,099 W
Demand Response Test Power Reduction	186 W	141 W	183 W	41 W

Total Power Reduction	552 W
LED Full Load Power From Installation Test	1,114 W
Demand Reduction	0.56 kW
Percent Reduction in Power	50%

Fixture Test Results Extrapolation	
No. of Test Fixtures	26
Avg Power Reduction per Fixture	21.2 W
No. of Entire Library Fixtures	2,767
Total Power Reduction	58,698 W
Reduction as Percentage of Total Building kW	10.5%

The Philips Day-Brite pilot fixture LEDs with SpaceWise have a minimum 100,000 hour rated life. If the fixtures are operated approximately 6,500 hours per year the fixtures will have a service life of fifteen years, in the USCD Library. For a comparable lighting control system to be used with fluorescent fixtures, the incremental cost is negligible if not favorable for the LED solution.

Discussion

The assessment project proved to be very enlightening in regards to the ability for the developing controlled lighting points technology. Enabling individual lighting points to be able to leverage OpenADR protocols and be integrated with EMS or BMS allows for strategic control to reduce not only demand during an event but at any time when the customer is trying to limit an increase in demand.

As a result of the conversion to a connected LED lighting system with integrated sensors in each luminaire, UCSD Library achieved, on average, 27% permanent load reduction in demand as compared to the baseline fluorescent fixtures. The additional temporary load reduction achieved during DR events were 60% over the LED baseline. Table 7 below illustrates the potential permanent and temporary demand reduction for UCSD Library.

Table 7: Results Demand Reduction Extrapolated for Entire UCSD Library

Project Demand Savings and DR Summary	
Current Library Max Demand for Fluorescent Stack Lighitng	143.9 kW
Max Demand for Stack Lighting Using LED (38 watt fixtures)	105.1 kW
Permanent Demand Savings From LED Retrofit	38.7 kW
Average DR kW Reduction During Two Tests	60.6 kW

The project results provided valuable insight as to key areas that must be addressed by the developing solutions. The prototype assessed in this project did not deliver the expected results. The manufacturers' stated reductions and system functionality were not achieved.

Onset Hobo Loggers were used to record circuit level data. Two DR events were simulated with the stated reduction of 80%. One two-hour and one four-hour event were conducted. The assessed solution held the reduction for the entire period of time for each event. At the end of the event the lighting circuits remained at the reduced load. This was a result of manually forcing the load to the max level prior to the commencement of each event. Therefore, the system was looking for manual intervention to restore to pre event status.

The load reduction achieved was approximately 20% less than manufacturers' claim of 80%. After careful review of all the algorithms and functionality of the prototype, it was discovered that the integrated sensors where not disabled at the time of the DR event. As a result, the manufacturers claimed reduction amount was overstated.

During the assessment period, the manufacturer had already identified these two issues. Corrections were made to the algorithm and functionality to insure the solution properly responded and delivered stated results of the event. Additionally, the manufacturer added a 1'X4" luminaire capable of being a connected lighting point capable of ADR. This would eliminate the need to reconfigure the ceiling grid to accommodate a different size luminaire.

A quick calculation to determine the impact of the sensors not being deactivated for the 26 luminaires was done. The ceiling layout in the pilot area had 14 luminaires that could be impacted by daylight. It was assumed an average daylighting reduction is 50% during the time both DR events were conducted. This would result in 14 luminaires being at 20.5 watts in lieu of the 7.6 watts during the event calling for an 80% reduction. This means an additional 180.6 watt reduction may have been achieved during the event. As a result it would bring the results closer to the manufacturer's claimed 80%.

The ease of installation, integrated sensors, embedded wireless network and the ability for the solution to integrate into EMS makes this technology better than the incumbent technology. This technology allows for continuous demand management of the lighting points. The facility can establish preset internal events to manage their load throughout the day. This offers the customer a much more robust solution allowing them to take advantage of the systems full functionality to further manage their demand and energy and report results from lighting system DR Program participation without the need for extensive metering equipment.

The perceived market barriers are the cost of the solution. To address this, manufacturers have/or are developing low cost retrofit solutions that incorporate this same functionality as the full luminaire product. To assist customers in adopting such technology, in addition to the incentives provided in the Capacity Bidding Program (https://www.sdge.com/sites/default/files/documents/762666168/Capacity%20Bidding%20Program%20Tariff%2007032014.pdf), SDG&E has a rebate program for the luminaire. Currently the rebate is $25 per luminaire when all requirements are met. Please refer to the EEBR Lighting Rebate Handbook: http://www.sdge.com/documents/business-rebates-lighting-product-catalog.

Conclusions

The assessment project was a success regardless of a few areas of improvement identified during the project. The manufacturer had already identified the "gaps" in the technology requiring correction and stated that this assessment validated their initial lab results and improvement opportunities.

With the improvements made to the technology to be released to the market, customers will have a dynamic approach to controlling and monitoring lighting points on the network. Not only will they be able to strategically manage energy and demand, but have predictive maintenance built-in to their lighting systems. The increase in workplace productivity and better space utilization and management are added business benefits of the technology.

Another key point to consider is how manufacturers are developing or have developed retrofit technologies that are based upon identical features of the assessed technology. These retrofit solutions will be introduced at significantly lower entry costs and may help drive market adoption since installation would be similar to the previous T12 to T8 retrofit in lieu of entire luminaire replacement.

The potential for energy storage at each luminaire is of interest. Future projects could include a reassessment of the version being launched in the market to:

1) validate the ADR functionality to meet stated claims simultaneously.

2) assess the potential impact and validation of the manufacturer claims of the energy storage capability.

Recommendations

As manufacturers continue to improve upon their lighting control systems in an effort to provide granular data and control per lighting point, the ease of installation and commissioning open the potential for significant market adoption.

Developing appropriate program incentives and educational outreach promoting the business case for such technology is key. Perhaps, once the technology has “matured” into a viable retrofit option, consideration should be given to the technology becoming a direct install initiative. The benefits to both the utility industry and end users are significant due to the impact on the national grid, especially when the energy storage feature has been validated.