Easily Commissioned Lighting Controls Review

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A Report of BPA Energy Efficiency's Emerging Technologies Initiative

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Abstract

Several new lighting control systems are marketed as “plug and play” lighting controls which claim to be easier to install, commission, and operate. LRC conducted an online survey to query specifiers’ opinions on these types of lighting controls and to determine which types of products were being considered. LRC conducted a market assessment of almost 100 lighting control product lines and selected 6 lighting control systems for review in this report.

An Emerging Technologies for Energy Efficiency Report

The following report was funded by the Bonneville Power Administration (BPA) as an assessment of the state of technology development and the potential for emerging technologies to increase the efficiency of electricity use. BPA is undertaking a multi-year effort to identify, assess and develop emerging technologies with significant potential for contributing to efficient use of electric power resources in the Northwest.

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The Lighting Research Center (LRC) at Rensselaer Polytechnic Institute is the world's leading center for lighting research and education. Established in 1988 by the New York State Energy Research and Development Authority (NYSERDA), the LRC has been pioneering research in energy and the environment, light and health, transportation lighting and safety, and solid-state lighting for more than 25 years. Internationally recognized as the preeminent source for objective information on all aspects of lighting technology and application, LRC researchers conduct independent, third-party testing of lighting products in the LRC's state of the art photometric laboratories, the only university lighting laboratories accredited by the National Voluntary Laboratory Accreditation Program (NVLAP Lab Code: 200480-0). LRC researchers are continuously working to develop new and better ways to measure the value of light and lighting systems, such as the effects of light on human health. The LRC believes that by accurately matching the lighting technology and application to the needs of the end user, it is possible to design lighting that benefits both society and the environment.

Acknowledgments

Leora Radetsky and Russ Leslie were co-principal investigators for this project. Leora Radetsky and Russ Leslie co-authored the report. LRC thanks Levin Nock, John Wilson and Karen Janowitz for their input and review.

Project Background

In July 2014, Washington State University Energy Program (WSU) / Bonneville Power Administration (BPA) requested that the LRC create a buying guide for end-users who want to purchase "easily commissioned lighting controls" which reviews and compares currently available products.

The LRC proposed that the project be broken into two phases. In the first phase LRC would cover five or six easily deployed lighting control systems currently in the market, based on product literature and interviews with manufacturer representatives. This phase is the subject of this report. The second phase, would pilot test several of the reviewed products included in Phase 1 in an open office space at the LRC.

Five tasks were completed in Phase 1. This report describes Phase 1 results for tasks 2 through 5.
Task 1: Project management
Task 2: Conduct specifier survey
Task 3: Conduct market assessment
Task 4: Conduct product analysis and review
Task 5: Write product reports and buying guide

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Executive Summary

Task 2: Specifier Survey

An online specifier survey conducted from August - September, 2014 sought specifiers' opinions on easily commissioned ("plug and play") lighting controls. This information was also used to help determine which products the LRC would review for this report.

- Over 200 respondents participated in the survey; 145 of these were non-manufacturers (specifiers). 36 of these specifiers had evaluated, installed or specified "plug and play" lighting control systems in the past 12 months and answered additional questions about lighting controls.
- 69% of the specifiers had evaluated wired controls, 44% had evaluated wireless controls, and 22% had evaluated hybrid controls (with wired sensors and wireless monitoring and reporting).
- 50% of the 36 specifiers had evaluated luminaire-integrated controls, while 63% had evaluated "plug and play" control systems with separate sensors.
- Most "plug and play" control systems did not provide energy monitoring reports.
- Most "plug and play" control systems provided a means for adding controls to existing fixtures.
- Many lighting control features were important to the respondents, including dimming capability, reliability, control grouping, ease of installation and configuration, and third-party product integration. Respondents also indicated that capital cost, reduction of energy costs, warranty and increased lighting product lifespan were import.
- Philips, Lutron and Wattstopper lighting control systems were most frequently mentioned.

Task 3: Market Assessment

During September – October 2014, the LRC used internet search engines, lighting control websites and lighting trade journals to identify lighting control products.

- 96 interior and exterior lighting control product lines were identified for review. These included product lines for commercial, residential and theatrical applications.
- Among the 80 interior lighting control product lines reviewed, 28 claimed that they were easily installed and commissioned.

Task 4: Product Analysis and Review

- Six lighting control systems were selected for product reviews in this report: Cooper Room Controller, CREE SmartCast, Hubbell wiHUBB, Leviton LevNet RF, Lutron Energi TriPak and the Wattstopper DLM system.
- The products included both wired, wireless and hybrid systems.
- Four of the six systems use sensors that are separated from the luminaires they control, two brands offered luminaire-level sensors (CREE and Lutron).
- Five of the six systems can integrate input/output information from third-party devices (all except CREE).
- Three of the systems reviewed include remote energy monitoring and system management capabilities.

- All of the reviewed systems offered some level of advanced system adjustment in addition to the default system setup.
- Case studies have been published for all of the reviewed systems except for Cooper's Room Controller system. Third-party case study information was available for the Lutron and Wattstopper systems.
- The report concludes with a page of recommended questions for specifiers to ask.

Task 2: Specifier Survey

Background

This chapter provides information regarding Task 2, an online specifiers' survey that was conducted from August to September, 2014. The survey sought specifier opinions on easily commissioned lighting controls. This information was used to inform the project team as to which products the LRC would review in Task 4 and to identify specifiers who had field experience with these products and would be willing to share those experiences with the project team.

Method

LRC used Survey Monkey to create an online survey that was sent to approximately 3500 email addresses obtained from people who had previously downloaded National Lighting Product Information Program (NLPIP)[1] reports from the LRC website. The survey included 12 questions and an additional comment box. The survey was designed to take less than 10 minutes for a respondent to complete. Personal information was not collected unless it was voluntarily provided. The introductory text at the beginning of the survey was as follows:

> *This survey is conducted by the Lighting Research Center (LRC) and concerns easily commissioned lighting control systems. These "plug and play" (i.e. automatic setup) lighting control systems may be 1) integrated into individual light fixtures by the fixture manufacturers, 2) offered as stand-alone systems or 3) added to individual light fixtures already in place. The claims include ease of installation, control by wireless remote control, smartphone, or tablet, and setup or commissioning without additional equipment such as light meters.*
>
> *The survey remains open until September 25, 2014. Thank you for your participation.*
>
> *The LRC, part of Rensselaer Polytechnic Institute, is the leading university-based center devoted to lighting research and education. Established in 1988, the LRC has an international reputation as a reliable source for objective information about lighting technologies, applications, and products.*
>
> *Your participation in this survey is voluntary. You may choose not to participate. If you decide to participate in this research survey, you may withdraw at any time.*
>
> *This online survey includes twelve questions that will take approximately ten minutes to complete. LRC does not collect identifying information such as your name, email address or IP address. Your information will be confidential. The results of this study will be aggregated for scholarly purposes and may be published. Comments or "Other" responses that are provided may be quoted anonymously in a future publication.*

[1] National Lighting Product Information Program. http://www.lrc.rpi.edu/NLPIP/

Most of the questions included multiple-choice responses as well as an "other" comment box allowing user-input. Multiple choice responses were randomized using Survey Monkey to minimize order effects. Specifiers were required to answer most questions, and could answer "prefer not to respond" to any question.

Results

Question 1: Do you consent to having your answers included anonymously in a future publication?

In total there were 225 respondents (about 6% of the survey list). 215 of these consented to have their answered included in the survey and answered follow-up questions. The survey ended at this point for specifiers who did not consent to have their answered included.

Question 2: Please specify your affiliation.

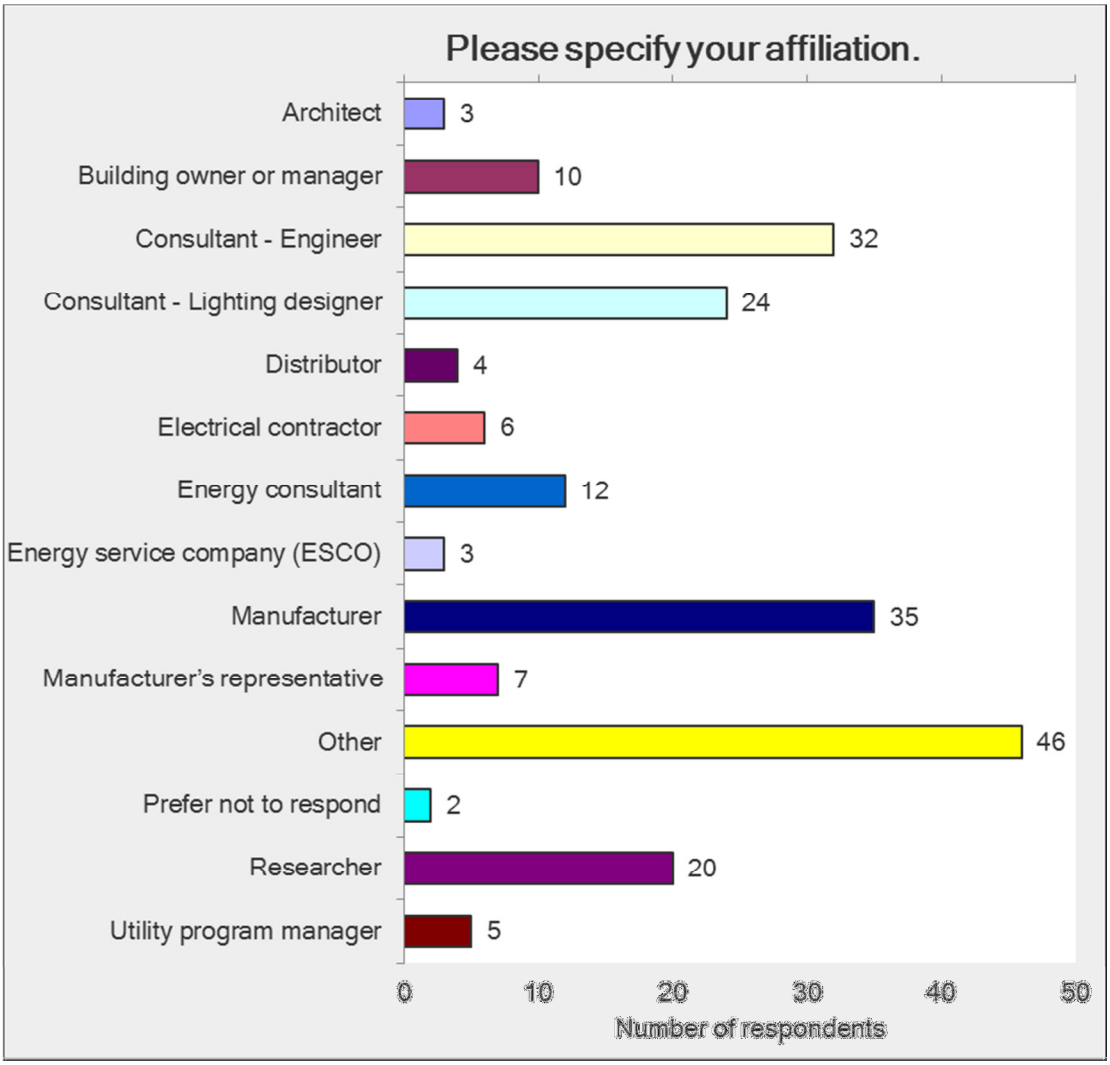

Figure 1: Specifier survey details regarding affiliation

209 respondents answered this question. Those that indicated they were manufacturers, manufacturers' representatives and researchers continued with the survey, but their answers are not included in this report. In total, 145 respondents are included in this report, as shown in Figure 1 and Table 1.

Table 1: Details for "Other" response with regard to respondent affiliation

- Marketing
- I am a licensed architect working as a building energy specialist in a utility supported energy efficiency program affiliated with a major public university.
- LED Manufacturer
- Paralegal.
- a salesperson who works in the electrical department of a home improvement center
- Distribution Standards Technical Authority for a utility.
- Landscape Architect
- Retired electrical engineer
- Photographer
- I am basically working in ISRO (Indian space Research Organisation) Ahmedabad, India. as SCI/Engineer since last 25 yrs in electrical field which includes lighting system, external electrification, sub-stations etc.
- engineer
- Mechanical Design Engineer
- Owner/Builder
- Member of the public
- former retail lighting, former wholesale electrical supply sales
- I am a retired facilities manager who maintains an interest in cost effective and functional lighting.
- Project manager for the NZ Energy Efficiency and Conservation Authority responsible for energy efficiency subsidies including lighting upgrades.
- Zoning, Housing and Property Maintenance Code Enforcement
- Planner
- Neighbor of a sports stadium
- Electric Utility
- Homeowner
- Cemig is one of the most solid and important groups in the electric energy segment in Brazil, as it owns or has stakes in 103 companies and 15 consortia. CEMIG - An open capital company controlled by the Government of the State of Minas Gerais and has 114,000 shareholders in 44 countries. Its shares are traded on the São Paulo, New York and Madrid stock exchanges
- Student
- I am City Traffic Engineer and manage the City's street light system.
- Sea turtle Biologist
- volunteer
- Trade Supervisor - University
- Local Agency (City)
- lector
- Safety specialist
- Color Scientist

- Researcher in power electronics apply to Street lighting systems area.
- Homeowner
- Citizen who cares about the quality, quantity, and color of light and is concerned re light trespass, especially as it affects sleep.
- State Agency Employee
- Light Therapist
- Homeowner interested in advanced lighting systems
- I am from India qualified electrical engineer from IIT Mumbai with Electrical and Electronics with nearly experience of 30years in Lighting in India,Oman,Abu Dhabi with Equipment of European and Indian Origin. As a result I am an Lighting Engineer with Energy Conservation and aesthetics experience. I also taught Illumination Engg in Univ of Pune.,India
- Attorney
- Trade association
- Home owner

Question 3: Have you evaluated, installed or specified "plug and play" lighting control systems in the past 12 months?

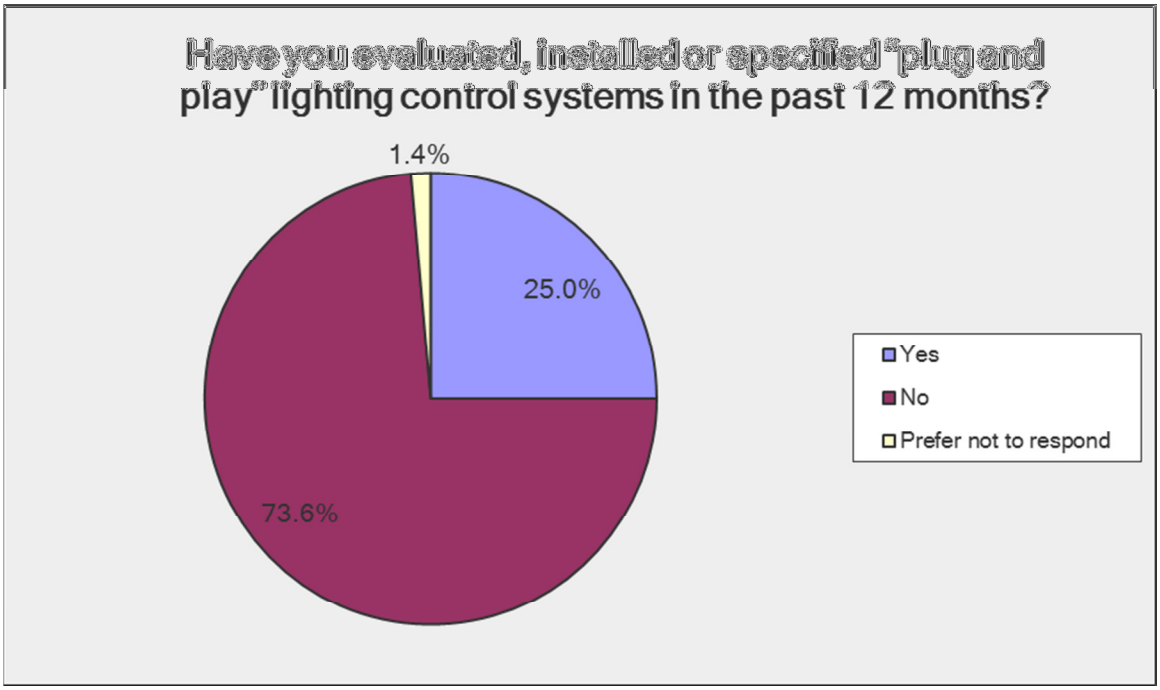

Figure 2: Responses to Question 3. Respondents experience with plug and play lighting control systems.

144 of the 145 non-manufacturer respondents answered this question. Of these, 25% had evaluated, installed or specified "plug and play" lighting control systems in the past 12 months (Figure 2). These 36 respondents continued with the survey. The survey ended for the other 108 respondents.

Question 4: Are the "plug and play" lighting control systems wired or wireless? Select as many as applicable.

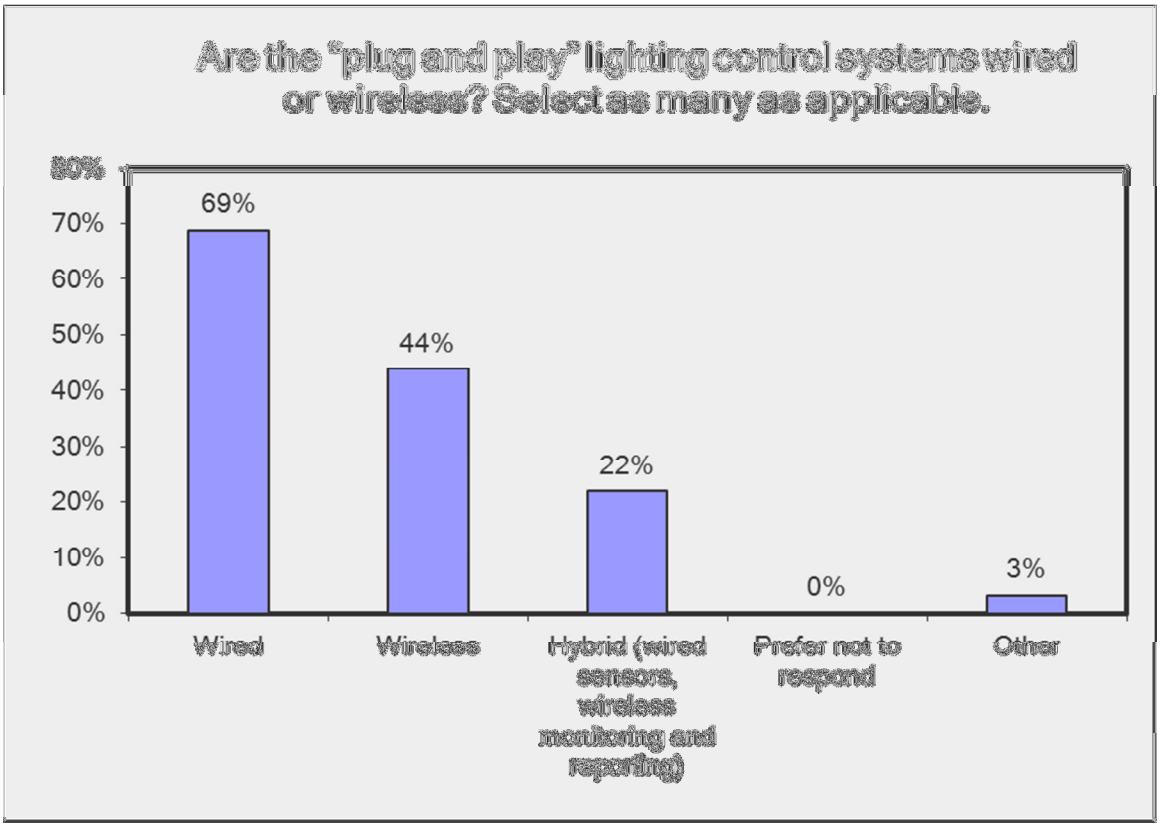

Figure 3: Responses to Question 4. Respondents' selection of wired or wireless plug and play lighting control systems.

32 of the 36 respondents who had experience with plug and play lighting control systems answered this question. As shown in Figure 3, 69% indicated they had evaluated wired controls 44% had evaluated wireless controls, and 22% had evaluated hybrid controls (with wired sensors and wireless monitoring and reporting).

Question 5: Are the sensors integrated in each fixture or separate? Select as many as applicable.

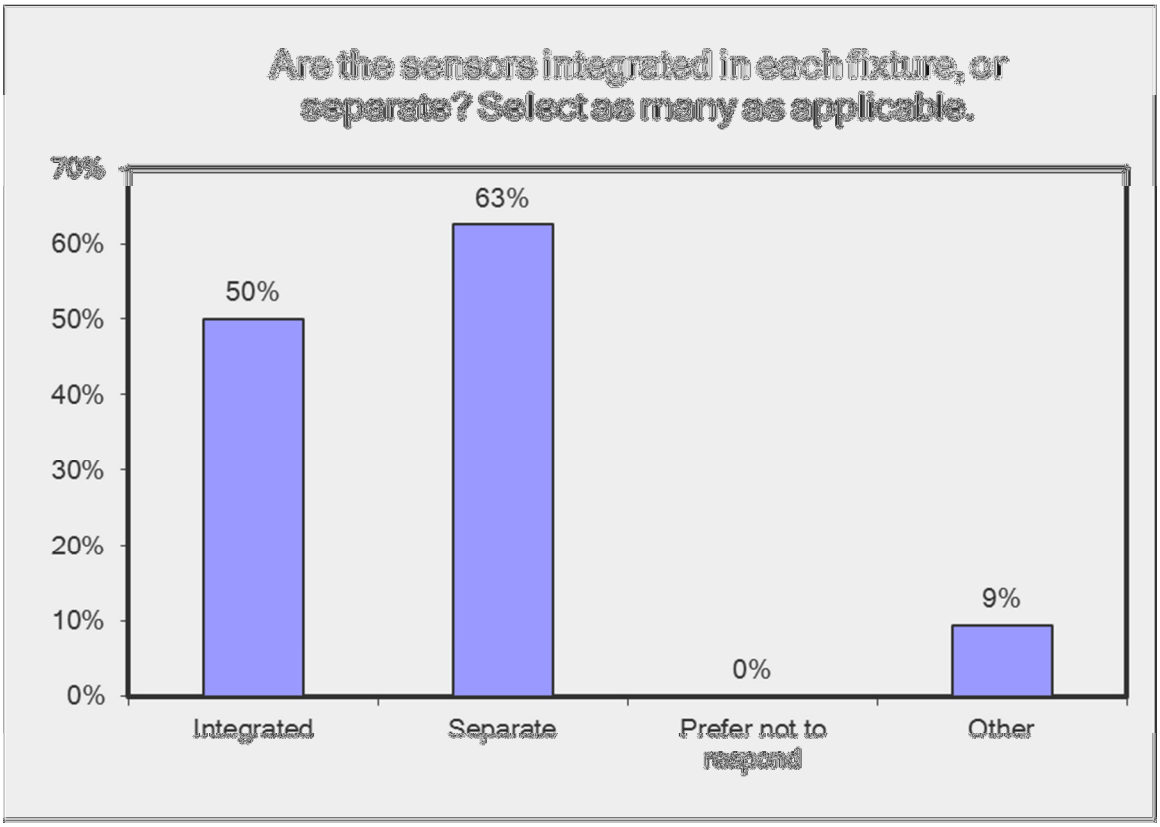

Figure 4: Responses to Question 5. Respondents' selection of plug and play lighting control systems with integrated or separate sensors.

32 respondents answered this question. Respondents indicated that the plug and play lighting control systems they had evaluated had either integrated or separate sensors (shown in Figure 4). The respondents who chose the "Other" option gave the following responses:

- In Estonia our customer prefers cheaper solution - it means mostly separate sensor
- Typically don't use sensors with plug and play fixtures. more of a Lutron control system

Question 6: Do the "plug and play" lighting control systems provide any reports about energy use, such as an energy dashboard? Select as many as applicable.

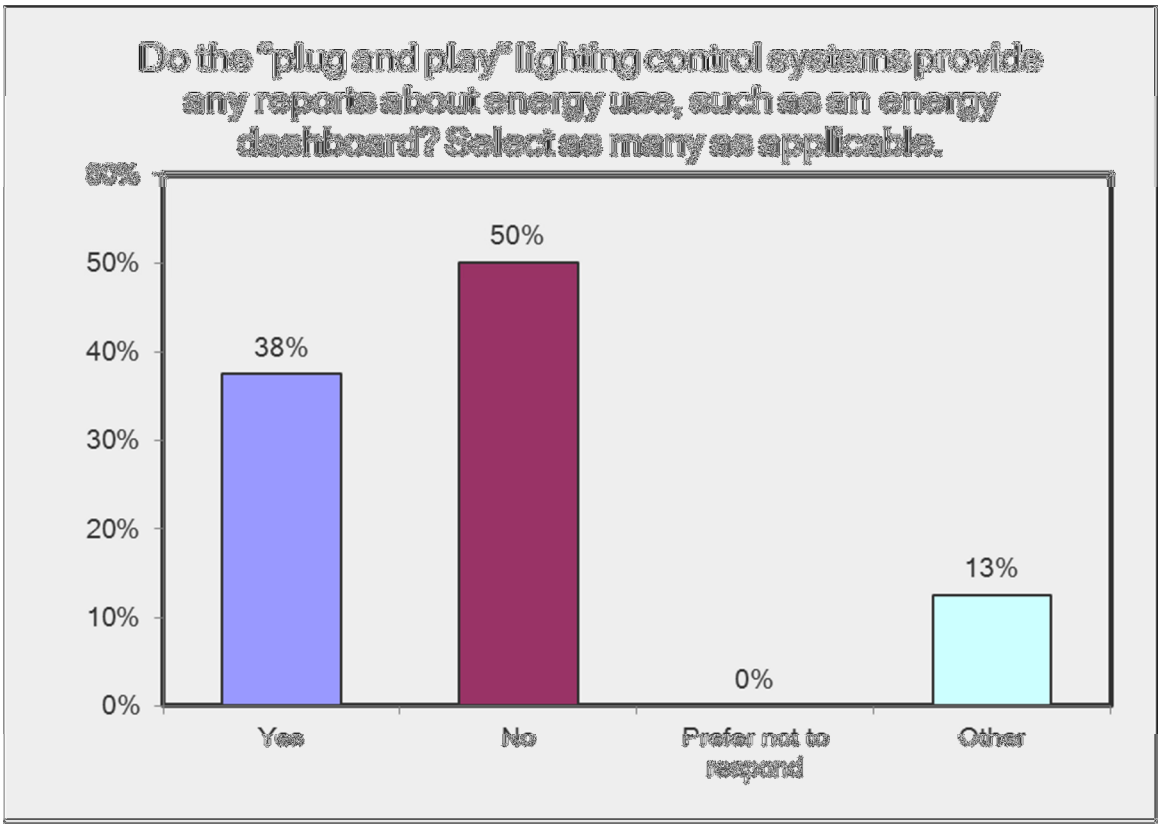

Figure 5: Responses to Question 6. Responses regarding plug and play lighting control systems reporting of energy usage.

32 respondents answered this question, indicating that most plug and play lighting control systems did not report energy usage, as shown in Figure 5. Respondents who selected "Other" provided the following comments:

- Yes as an additional option
- unfortunately these do not report about energy use
- does not apply
- some do, some don't

Question 7: Do the "plug and play" lighting control systems allow adding individual controls to existing fixtures in a retrofit? Select as many as applicable.

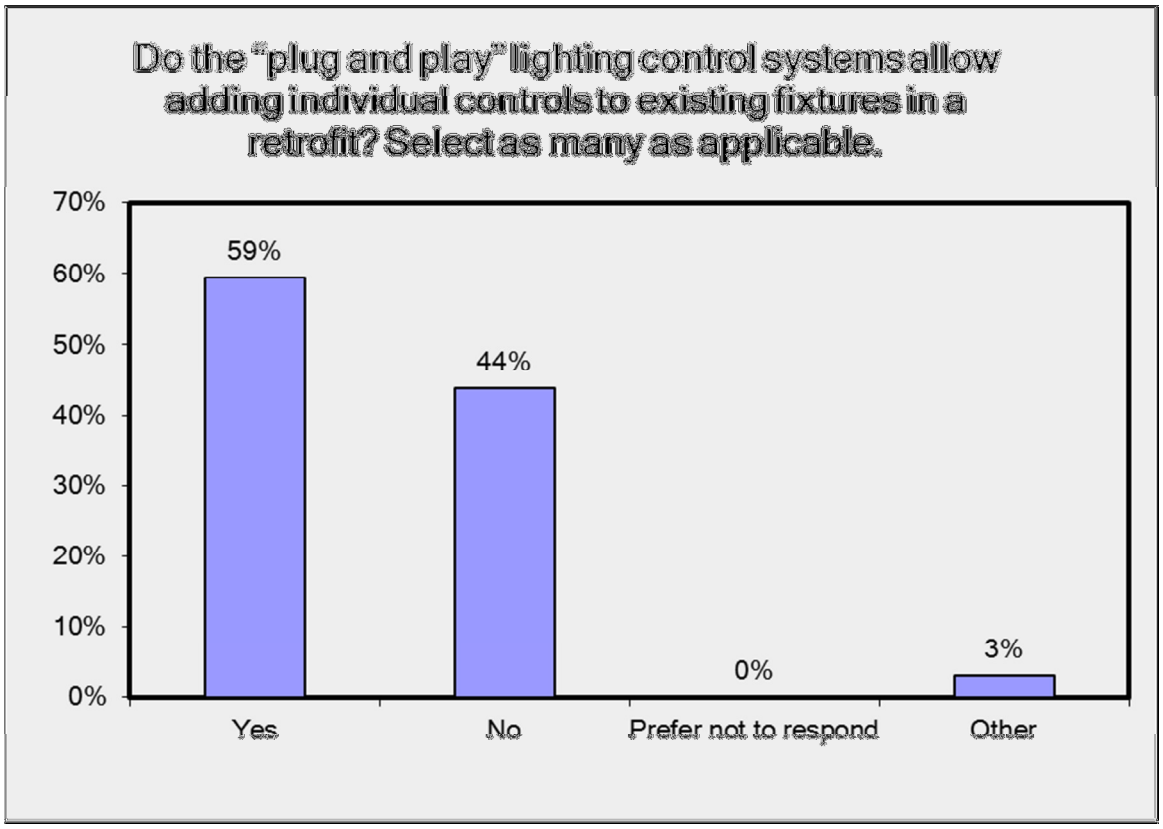

Figure 6: Responses to Question 7. Responses regarding plug and play lighting control systems allowing individual luminaire control in a retrofit application.

32 respondents answered this question, indicating that most plug and play lighting control systems did controls to be added to individual luminaires in a retrofit application. See Figure 6.

Question 8: Specify the importance of the following lighting control systems characteristics (very important, important, somewhat important, not important)

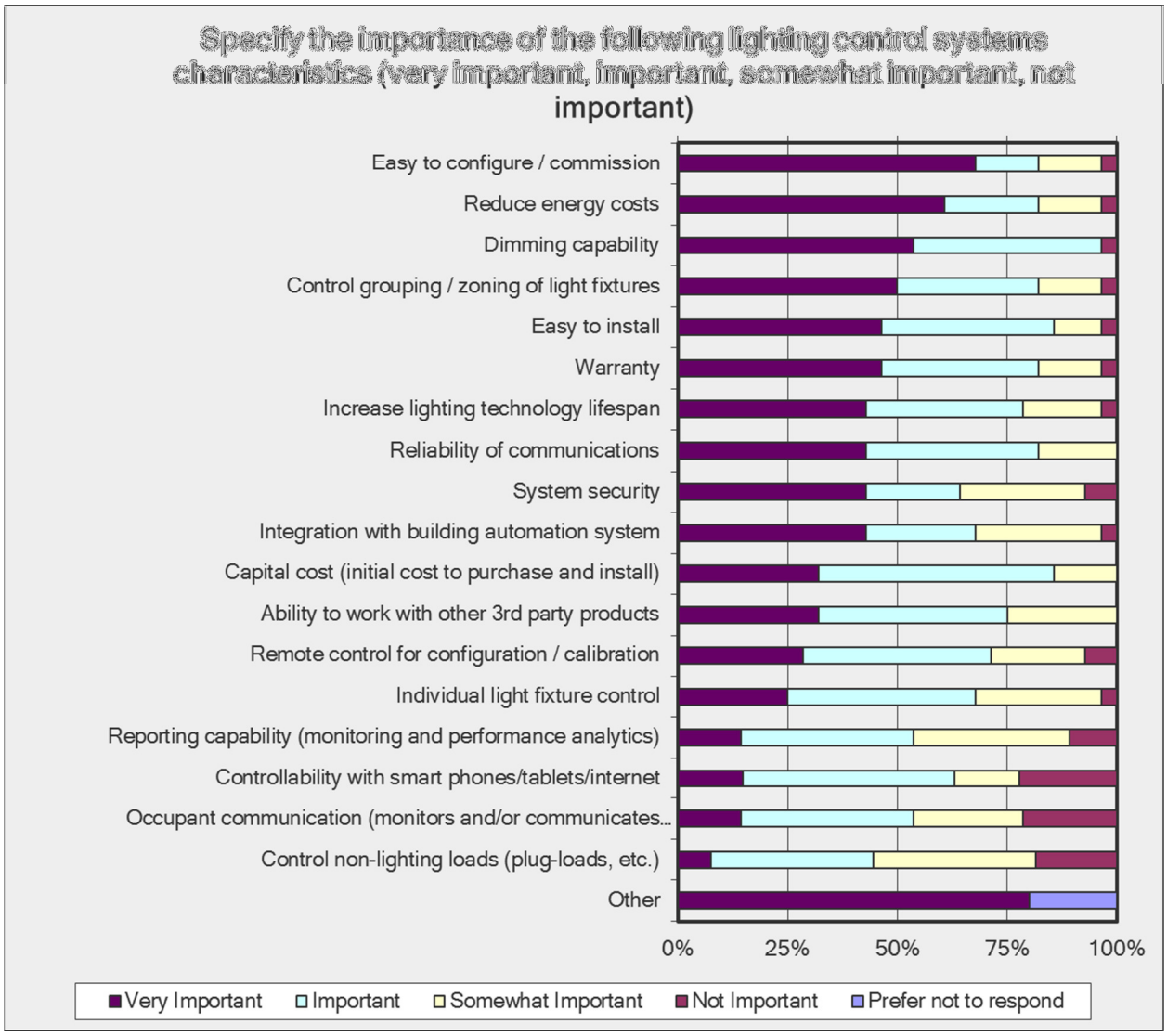

Figure 7: Responses to Question 8. Respondents' rank ordering of lighting control system characteristics in terms of importance.

28 respondents answered this question. Their responses are shown in Figure 7, and indicate that most of the listed characteristics were considered to be very important or important, except for control of non-lighting loads. Respondents who selected the "Other" option gave the following information:

- Easy availability of the fixture
- Being able to expand in the future without overhauling the entire system
- Track record of product support and established reputation, not just flash in the pan new thing for unknown company

Question 9: Please list up to three brands and models of "plug and play" lighting control systems that you have evaluated or specified in the last 12 months.

23 respondents provided brand information for plug and play lighting control systems. Philips lighting control systems were mentioned 5 times, followed by Lutron (4 mentions) and Wattstopper (3 mentions). CREE, Crestron, Esylux, Hubbell and OSRAM lighting control systems were each mentioned twice. The following brands were each mentioned once: American Electric, BEG luxomat, Cooper Lighting, Crompton Greaves, Douglas, Ecosense, Encelium, Helvar, Holophane, i2 systems, KANEPI, Klemko, Leviton, Lighting Science, Redwood Systems, Roam, Schneider, Sensor Switch, Steinel, Telematic, VitaLED and Zumtobel.

Question 10: If you have direct installation experience with "plug and play" lighting control systems and would like to share information about this installation, please provide comments here and, optionally, your contact information.

6 respondents provided additional information about direct installation experience with plug and play lighting control systems, as shown in Table 2

Table 2: Responses to Question 10. Details of respondents' experience with plug and play lighting control systems.

Response Text
Don't use cheap Chinese systems, dangerous wiring and falsely labelled wattage/current
Irritated that the Leviton wireless systems available to end users are not compatible with CFL/LED ballasted loads.
I am not an installer, I am a specifier of products. However the feedback we've gotten from most building owners is generally positive.
lumen output/watts dictated by ballast factor- high ballast factor = not much energy savings i.e. F32T8 29.5 watts, Bf 0.88
I do not install, I help to make choices depending of aptness and demands of the customer. If needed, show on my schemes, how to attune etc. My destination is to put my customers to understand, that lighting control is very easy, even easier than some computer programm. I am woman, 61 years - if I can, then it have to be easy to men too. I started earlier 2000-s with Tridonic classical Dali systems, Touchboxes etc. Usually systems were installed before manuals were done due to new models - I could manage and can say - don´t be afraid - it is easy and playful. Enjoy! Same message is to my students, when they excercise the schemes and attune these afterwards.
Still trying to buy one, favor the CREE SmartCast

Question 11: Where are you located?

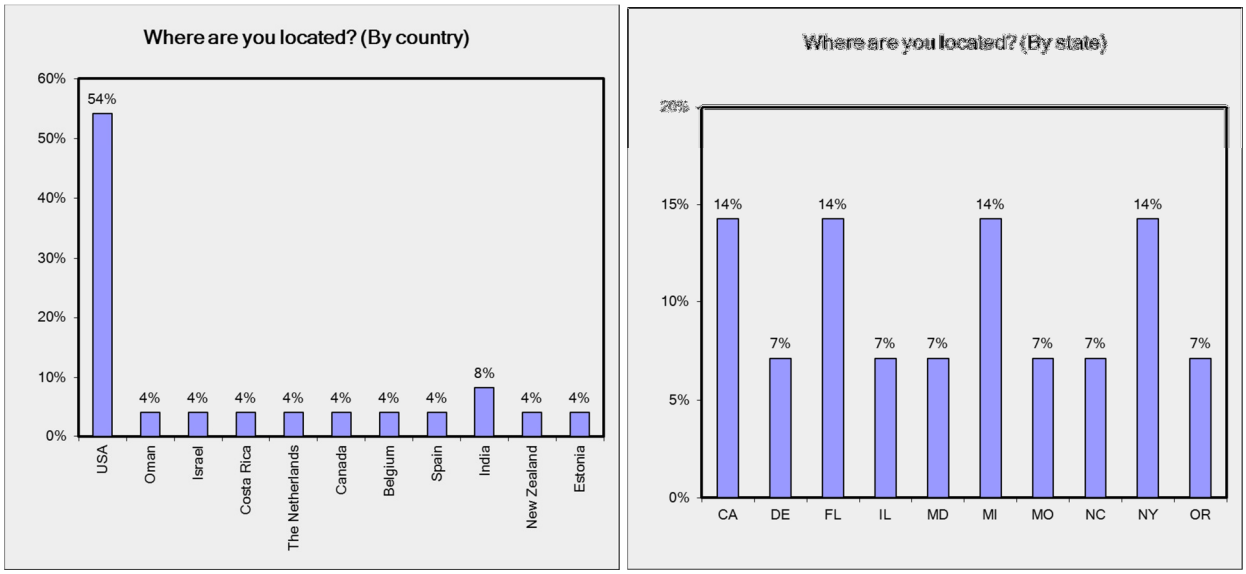

Figure 8: Responses to Question 9. Respondents' location by country and by US state.

25 respondents answered this question. As shown in Figure 8, 54% (n=13) of the respondents are located in 10 states across the US. No single state was overrepresented in the survey.

Question 12: Thank you for your time and attention. If you have additional comments, please let us know in the comment box below.

6 respondents provided information in the comment box as shown in Table 14.

Table 3: Responses to Question 9. Additional comments from respondents regarding plug and play lighting control systems.

Response Text
I enjoyed this survey please do more
I hope to be helpful. Sorry my bad English - it is easier to read than talk or write.
Keep up the good work. Stop researching T8s and premises based wiring controls, they are obsolete technology.

Task 3: Market Assessment

Background

Using information gained from the specifier survey and knowledge of the lighting controls market, the LRC gathered information about these new lighting control products that report to be easier to install, configure, and commission, focusing on products that are currently available to the Pacific North West market.

Method

During September and October 2014, the LRC used internet search engines, lighting control information portals[2] and lighting trade journals to identify lighting control manufacturers and product lines. Each product line was organized into a spreadsheet application and the data is summarized below.

Results

Table 4 shows an overview of the quantities of interior and exterior lighting control product lines offered by each manufacturer in each application category (residential, commercial and theatrical). Ninety six lighting control product lines were identified for review.

Table 4: Number of exterior and interior lighting control product lines available by manufacturer and application.

Manufacturer	Commercial Controls	Residential Controls	Theatrical Controls
Acuity Brands	9		1
AT&T		1	
B.E.G. Luxomat	1		
BRUMBERG	1		
CLAY PAKY	1		1
Commscope	1		
Cooper Lighting	5		1
CREE	1		
Crestron	1	1	
Douglas Lighting Controls	1		
Ecosense Lighting	1		
Enlighted	1		
EsyLux	1		
GE		1	
Helvar	2		
Holophane	1		
Hubbell	6		

[2] http://lightingcontrolsassociation.org/

i2 systems	2	1	
Kanepi Innovations	1		
Klemko	1		
Leviton	6	2	
Lutron	6	3	
NicoLaudie	2	1	1
Organic Response	1		
OSRAM	3		1
Philips	12	2	1
Schneider Electric	1		
Shreder	1		
Steinel	1		
Telematics Wireless	1		
Universal Lighting Systems		1	
Wattstopper	4		
Zumtobel	2		
Grand Total	**77**	**13**	**6**

Table 5 lists interior control system product lines offered by each manufacturer for commercial, residential and theatrical applications. Rows shaded in gray indicate the total number of interior control product lines offered by a particular manufacturer. Their control system product lines are shown in the subsequent rows in white. Eighty interior lighting control product lines are listed in Table 5.

Table 5: Interior Lighting control product lines and applications. Manufacturers are indicated by shaded gray rows; their control product lines are indicated by unshaded rows.

Manufacturer and brand name	Commercial Controls	Residential Controls	Theatrical Controls
Acuity Brands	**7**		**1**
Architectural Lighting Controls	x		x
Lighting Controls and Design	x		
NLight	x		
Sensor Switch	x		
Synergy Lighting Controls	x		
Wireless systems	x		
XPoint Wireless	x		
AT&T		**1**	
Digital Life Home Security and Automation		x	
B.E.G. Luxomat	**1**		
BRUMBERG	**1**		
VitaLED	x		

Manufacturer and brand name	Commercial Controls	Residential Controls	Theatrical Controls
Commscope	**1**		
Redwood intelligent lighting network solution	x		
Cooper Lighting	**4**		
Fifth Light	x		
iLumin	x		
Room Controller System	x		
Venergy Advanced Metering System	x		
CREE	**1**		
SmartCast Technology	x		
Crestron	**1**	**1**	
Douglas Lighting Controls	**1**		
Ecosense Lighting	**1**		
Enlighted	**1**		
EsyLux	**1**		
GE		**1**	
Z-Wave		x	
Helvar	**2**		
iDim	x		
Holophane	**1**		
ISHB (individually sensored high bays)	x		
Hubbell	**5**		
CX Commerical Lighting Control	x		
LX Networked Lighting Controls	x		
WiHUBB	x		
wiSTAR	x		
Zone5 Daylight Harvesting System	x		
i2 systems	**2**	**1**	
i2Link	x	x	
i2Wave	x		
Kanepi Innovations	**1**		
Kanepi Wireless Controls	x		
Klemko	**1**		
Leviton	**6**	**2**	
Architectural Controls	x		
Integrated Room Control (IRC)	x		
Intelligent Distributed Controls	x		
LevNet RF™	x		
Lighting Automation	x	x	
Lumina Energy Management System	x	x	

Manufacturer and brand name	Commercial Controls	Residential Controls	Theatrical Controls
Lutron	**6**	**3**	
Caseta Wireless		x	
Energi Savr Node	x		
Energi TriPak	x		
GRAFIC Eye 4000	x		
HomeWorks QS		x	
LCP 128	x		
Quantum	x		
RadioRA2		x	
XPS	x		
NicoLaudie	**1**	**1**	
STICK / Easy Stand Alone (SLESA)	x	x	
Organic Response	**1**		
OSRAM	**3**		**1**
ENCELIUM	x		
Light management systems (LMS)	x		
Traxon e:cue	x		x
Philips	**8**	**2**	**1**
(Micro)LuxSense	x		
ActiLume	x		
Color Kinetics	x		x
DuaLED Recessed LED with SpaceWise Technology	x		
DynaLite	x	x	
Hue		x	
LightMaster KNX	x		
LightMaster Lon	x		
OccuSwitch	x		
Schneider Electric	**1**		
C-BUS	x		
Steinel	**1**		
Wattstopper	**4**		
Digital Lighting Management (DLM)	x		
HBP-100 Series High/Low Bay PIR Occupancy Sensors	x		
Neutral Sense™ Wall Switch Sensors	x		
Wireless Occupancy Sensors	x		
Zumtobel	**2**		
CircleKit	x		
LUXMATE lighting management systems	x		

Manufacturer and brand name	Commercial Controls	Residential Controls	Theatrical Controls
Grand Total	**65**	**12**	**3**

Among the 80 interior lighting control product lines identified above, 28 made claims that they were easily installed and commissioned. Table 6 lists the brand names of these systems and repeats their marketing claims.

Table 6: Interior lighting control product lines that are marketed by manufacturers as having easy installation and commissioning procedures.

Manufacturer and brand name	Commercial Controls	Residential Controls	Marketing claim
Acuity Brands			
nLight	x		"nLIGHT is an easy-to-use, easy-to-install system"
Cooper Lighting			
Room Controller System	x		"Minimize installation and set-up time with smart devices that perform immediately without programming"
CREE			
SmartCast Technology	x		"Cree luminaires and dimmers enabled with Cree SmartCast™ Technology deliver essential lighting control without the complex design, installation, and setup of today's lighting control systems"
Enlighted	**x**		"Smart Sensors and the sensor grid are simple to install."
Helvar			
iDim	x		"Imagine the easiest lighting control solution ever. It is easy to install, use and integrate."
Hubbell			
LX Networked Lighting Controls	x		"SAVE TIME - LX control panels are simple to install and use. The LX series utilizes LonMark® certified architecture so sensors and switches can be installed plug-and-play by connecting to any point on the topology-free, polarity-insensitive 2-wire communication network."
WiHUBB	x		"Wireless Networking Made Easy – It's a SNAP!"
wiSTAR	x		"From retrofitting older structures to designing new buildings, wiSTAR is a simple way to ensure flexibility, energy savings, and cost reductions to almost any space."
Kanepi Innovations			
Kanepi Wireless Controls	x		"Just a few Kanepi components put facility control right at your fingertips, quickly and easily."
Leviton			

Manufacturer and brand name	Commercial Controls	Residential Controls	Marketing claim
Integrated Room Control (IRC)	x		"The Leviton Integrated Room Control (IRC) combines single room occupancy sensing, daylight harvesting, 0-10V dimming, Partial ON, Partial OFF and demand response capabilities into a single, easily installed package."
Intelligent Distributed Controls	x		"Easy to Install - All SectorFlex components – including occupancy sensors, photocells, relays, switches, dimmers, and controllers – are interconnected using the same wiring throughout the entire system using a topology-free technique."
LevNet RF	x		"With no additional wiring required, installation is quick and easy and takes only minutes to configure. LevNet RF™ offers simple lighting control and configurability for occupancy sensing, ON/OFF switching, 3-way switching, bi-level switching, hotel HVAC control, and much more for design flexibility."
Lutron			
Energi Savr Node	x		"Installs easily - The Energi Savr Node solution offers the QS sensor module which provides wireless communication with wireless sensors and controls via Lutron reliable Clear Connect™ Radio Frequency (RF) technology. Wireless occupancy/vacancy sensors, daylight sensors, and Pico® wireless controls allow for easy retrofit with no need for rewiring."
Energi TriPak	x		"Energi TriPak installs 70% faster than wired systems."
LCP 128	x		"LCP 128 is easy to design, install, and program"
NicoLaudie			
STICK / Easy Stand Alone (SLESA)	x	x	"Every single interface is made for a specific installation. Once integrated with one of the compatible software packages, it is possible to easily control the lighting within a variety of places such as homes, hotels, restaurants, fountains, gardens, commercial and many more."
Organic Response	**x**		"Plug & Play installation is as simple as that of a standard luminaire. No additional design or commissioning required once luminaires installed"
OSRAM			

Manufacturer and brand name	Commercial Controls	Residential Controls	Marketing claim
ENCELIUM	x		"Encelium's EMS™ is ideal for retrofit projects as it works with standard lighting components – you don't have to deal with costly proprietary ballasts, sensors or fixtures. As well, thanks to click and go cabling, EMS is incredibly easy to install."
Philips			
ActiLume	x		"Philips ActiLume is a new simple method of installing and using lighting control systems in offices."
DuaLED Recessed LED with SpaceWise Technology	x		"The benefits of lighting controls, without the hassle."
DynaLite	x	x	"Ease of installation and configuration"
OccuSwitch	x		"OccuSwitch Wireless - The perfect solution for retrofit; a wireless sensor that can be placed anywhere you need it, easy and fast."
Wattstopper			
Digital Lighting Management (DLM)	x		"Out-of-the-box code compliance with patented Plug n' GoTM automatic configuration"
Neutral Sense™ Wall Switch Sensors	x		"Optional neutral occupancy sensors turn complex retrofits into easy projects."
Wireless Occupancy Sensors	x		"Enjoy faster, simpler installation with preconfigured wireless occupancy sensor kits, resulting in significant savings on labor and materials."
Zumtobel			
CircleKit	x		"Installation and commissioning - As simple as can be for an electrician: the control point fits into a standard deep back box, and wiring involves just a few simple steps that can be performed even by an untrained person. Similarly, commissioning is too complex a word to describe the simple set up required, which is quick and easy."
Grand Total	**26**	**2**	

The research team and sponsors reviewed the 28 interior lighting control product lines that report to be easy to install, configure, and commission and narrowed down the list to 7 manufacturers as shown in Table 7. Product lines were selected based on the specifier survey results plusfeatures of particular interest to the research team and sponsors. All of the manufacturers listed in Table 7 are included in this report except for the OSRAM Encelium product which was not included because a manufacturer's demonstration could not be arranged in time for the report.

Table 7: Lighting control systems selected for further review and inclusion in report

Manufacturer	Product	Survey %	Wireless?	Energy Monitoring Reports?
CREE	SmartCast	9	Wireless	No
Cooper	Room Controller	4	Wired	No
Hubbell	wiHUBB	9	Both	Yes
Leviton	LevNet RF	4	Both	Yes
Lutron	Energi TriPak	17	Both	No
OSRAM	Encelium	9	Wired	Yes
Wattstopper	DLM	13	Wired with some wireless devices	Yes

Task 4: Lighting Control System Product Reviews

Method

The LRC team used published information from the manufacturers to complete the product line reviews, including product specifications, installation instructions and brochures. In addition, LRC requested product demonstrations from local manufacturers' representatives. A product matrix identifying the features of each system was developed including information about the commissioning process and energy monitoring reports. The LRC also reviewed published case studies and third-party evaluations of these control products.

Manufacturer representative meetings

Members of the research team met with local manufacturers' representatives to review the product literature and see a lighting control demonstration. When the manufacturer offered more than one lighting control line, the lighting team asked for a demonstration of all products shown in Table 7, and particularly of products that were comparable to the CREE Smartcast system.

The representatives were asked which of these lines was the most "easily deployable" and this system was selected for further review. The six systems selected for product reviews were Cooper Room Controller, CREE SmartCast, Hubbell wiHUBB, Leviton LevNet RF, Lutron Energi TriPak and the Wattstopper DLM system.

The local manufacturers' representatives were unwilling to share local case studies with the team members, citing privacy concerns. The representatives mentioned schools most often as the types of applications that were implementing lighting control systems, particularly easily deployable systems. They mentioned that buy-in from the teachers was critical for proper product performance and subsequent energy savings.

Lighting Control System Performance Comparison

The summary table below provides an overview of the performance characteristics of the six lighting control systems reviewed in this report. Each system is reviewed in more detail on the following pages.

Table 8: Lighting control system performance characteristics

Performance characteristics	Cooper Room Controller	CREE SmartCast	Hubbell wiHUBB	Leviton Levnet RF	Lutron Energi TriPak	Wattstopper DLM
Wired control	✓	✗	✗	✗	✗	✓
Wireless control	✗	✓	✗	✓	✓	✗
Hybrid (wired sensors, wireless monitoring and reporting)	✗	✗	✓	✗	✗	✗
Dimming capability	✓	✓	✓	✓	✓	✓
Dimmers and switches	✓	✓	✓	✓	✓	✓
Control grouping / zoning of light fixtures	✓	✓	✓	✓	✓	✓
Remote control for configuration / calibration	✓	✓	✓	✓	✓	✓
Sensor sensitivity adjustments	✓	✓	✓	✓	✓	✓
Separate sensors	✓	✗	✓	✓	✓	✓
Interoperability with other 3rd party products	✓	✗	✓	✓	✓	✓
Control non-lighting loads (plug-loads, etc.)	✓	✗	✓	✓	✓	✓
Customizable time delay	✓	✓	✗	✓	✓	✓
Customizable bi-level lighting control	✓	✓	✓	✗	✓	✓
Add luminaire level controls to existing fixtures (retrofit application)	✗	✓	✓	✓	✓	✗
Integration with building automation system	✓	✗	✓	✗	✓	✓
High-end trim	✓	✓	✗	✗	✓	✓
Low-end trim	✓	✓	✗	✗	✓	✓
Reporting capability (monitoring and performance analytics)	✗	✗	✓	✓	✗	✓
Controllability with smart phones/tablets/internet	✗	✗	✓	✓	✗	✓
Luminaire integrated sensors (Individual light fixture control)	✗	✓	✗	✗	✓	✗
Occupant communication (monitors and/or communicates with occupants via smartphones/tablets)	✗	✗	✗	✗	✗	✗

Cooper Controls Room Controller Product Report

Performance characteristics	Cooper Room Controller
Wired	✓
Wireless	×
Hybrid (wired sensors, wireless monitoring and reporting)	×
Luminaire integrated sensors (Individual light fixture control)	×
Separate sensors	✓
Add luminaire level controls to existing fixtures (retrofit application)	×
Dimming capability	✓
Remote control for configuration / calibration	✓
Interoperability with other 3rd party products	✓
Reporting capability (monitoring and performance analytics)	×
Control grouping / zoning of light fixtures	✓
Control non-lighting loads (plug-loads, etc.)	✓
Integration with building automation system	✓
Controllability with smart phones/tablets/internet	×
Occupant communication (monitors and/or communicates with occupants via smartphones/tablets)	×
Customizable bi-level lighting control	✓
High-end trim	✓
Low-end trim	✓
Customizable time delay	✓
Sensor sensitivity adjustments	✓
Dimmers and switches	✓
Standby power demand	Not stated
Battery life	Not applicable
Reliability of communications	Guaranteed compatibility with Cooper Lighting LED and 0-10V fluorescent fixtures
Warranty	5 years
System security	Not stated

Retrofit and new construction applications

The Cooper Controls Room Controller lighting control system is a preprogrammed wired lighting control system that uses RJ-45 connections with "Click & Go QuickConnect cables" to connect control devices (e.g., wallstations, occupancy/vacancy sensors, daylight sensors and receptacle control devices). The Room Controller is located in each room above the entrance door. Each Room Controller is connected to a 120 VAC or 277 VAC 20 Amp circuit in order to provide power to the unit and power to the individual relays in the controller. Slider Station Zone wallstations are pre-engraved, and control Room Controller outputs using factory defaults. Scene wallstations use a preset light configuration that can be adjusted using the HHPR-RC personal remote. The connected daylight sensor will immediately adjust the lighting levels based on natural light.

The system claims to "reduce installation and setup time with smart devices that perform immediately without programming." Energy codes are able to be met without the installer having to use interfaces or auxiliary devices. The installer selects a pre-packaged room system that "guarantees design integrity 100% of the time".

Cooper Controls provides an online best practices configuration tool for selecting the Room Controller Quick Kit.[3] The following sequence is used to specify a Room Controller Quick Kit:

1. Select the room type, which defines the room controller (e.g. office switching, classroom 2 zone dimming, etc.)
2. Select wall stations (up to 4)
3. Select required occupancy sensors (up to 2, depending on room controller)
4. Select daylight sensor option
5. Select plug-in load control or BMS/Egress option

Sensors

Up to two occupancy sensors and one daylight sensor are included in each quick kit. The Room Controller connects to standard Greengate occupancy sensors, through the OCC-RJ45 Input/ Output device. The daylight sensor is specified with or without a remote control.

Sensor adjustments

The Room Controller provides dipswitches for Manual-On (vacancy mode) or Automatic-On (occupancy mode) control selection. The default mode is Vacancy mode. In Occupancy mode, the dipswitches can be set to bi-level control (all relays on 50%) or to use daylight levels. Tri-level control is also claimed, but installation instructions do not provide details on this dimming option.

The Room Controller connects to one open loop daylight sensor for three-zone dimming control and has three available light levels (low, high and direct sun). By default, the daylight sensor uses the high light level to automatically control three zones and targets an illuminance level of about 45 fc at the work plane throughout the space . The default light levels can be adjusted using the Daylight Sensor Programming Remote HHPRG-RC. The remote control contains Zone

[3] http://cooperroomcontroller.sumoc.com/

Level buttons, 1, 2 and 3, which correspond to dimmers 1, 2 and 3 on the Room Controller. Zone 1 should be the zone closest to the window, while zone 3 should be farthest from the windows (control lighting circuits with luminaires that are oriented parallel to glazing).

High-end and low-end trim adjustments are available using trim adjustment dials on the room controller. Trim levels are preset to approximately 90% of maximum.

Time delay settings depend on the selected Greengate occupancy sensor.

Dimming

Up to 6 lighting zones, including 3 Relays and 3 0-10V dimming outputs, are available to control compatible dimming ballasts and drivers. Switched and dimmed zones do not need to overlap, as each relay and dimming output has separate control. The maximum combined load of the relay outputs should not exceed 20A.

Each dimming output allows 100mA per output for control of up to 50 compatible ballasts/drivers.

Commissioning and remote control

The room controller is preprogrammed and requires no adjustments to operate. However, Cooper does recommend that installers follow a verification checklist to ensure energy savings and occupant satisfaction.[4] Cooper Controls also provides online videos showing the specification, setup and commissioning steps for installers to follow.[5]

The daylight sensor behaves as an IR receiver in the space. A Room Controller Personal remote allows manual override of the multizone lighting system allowing control of the three relay outputs (toggle) and dimmers outputs (raise /lower). The personal remote can also be used for scene control and to program scenes.

Interoperability

The Room Controller Input/Output Device (OCC-RJ45) provides connection of any Greengate low voltage occupancy sensor, to define the occupancy state of the space. The OCC-RJ45 also can be used as an input to an HVAC system, third party systems or switchpacks using room occupancy status.

Control of non-lighting loads

The Receptacle/BMS output port supports the use of a Receptacle Switchpack or BMS Output. The BMS output will close when the occupancy sensor senses motion (even when in Vacancy

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4 http://www.cooperindustries.com/content/dam/public/lighting/controls/products/documents/greengate/instruction_sheets/room_controller_install_guide.pdf

5 http://www.cooperindustries.com/content/public/en/lighting/controls/resources/library/vid_gal.html

Mode) or when any switch button is pressed to turn lighting loads ON. The BMS output will open when the occupancy sensor no longer senses motion or, in applications where there is no occupancy sensor, when commanded into After-Hours Mode from an external contact.
The Room Controller also allows for advanced input functionality from integration control inputs on the room controller including: External Time Clock, Alert Mode, Demand Response system and A/V system. The Room Controller will provide inputs for an external dry contact closure. (Advanced Integration connections are not available on all models.)

Reliability of communications

The Cooper Room Controller system guarantees “design integrity 100% of the time with pre-packaged systems.” Wiring errors and installation time are claimed to be reduced with “Click & Go” technology. The Cooper Room Controller system also has “guaranteed compatibility with Cooper Lighting LED and 0-10V fluorescent fixtures”.

Case studies

No published case studies were found on the Cooper Room Controller system.

CREE SmartCast Product Report

Performance characteristics	CREE SmartCast
Wired	✗
Wireless	✓
Hybrid (wired sensors, wireless monitoring and reporting)	✗
Luminaire integrated sensors (Individual light fixture control)	✓
Separate sensors	✗
Add luminaire level controls to existing fixtures (retrofit application)	✓
Dimming capability	✓
Remote control for configuration / calibration	✓
Interoperability with other 3rd party products	✗
Reporting capability (monitoring and performance analytics)	✗
Control grouping / zoning of light fixtures	✓
Control non-lighting loads (plug-loads, etc.)	✗
Integration with building automation system	✗
Controllability with smart phones/tablets/internet	✗
Occupant communication (monitors and/or communicates with occupants via smartphones/tablets)	✗
Customizable bi-level lighting control	✓
High-end trim	✓
Low-end trim	✓
Customizable time delay	✓
Sensor sensitivity adjustments	✓
Dimmers and switches	✓
Standby power demand	Not stated
Battery life	Not applicable; 10 year non-volatile memory settings
Reliability of communications	2.4 GHz wireless mesh technology. Finds quietest channel during OneButton setup
Warranty	5 years
System security	128-bit AES encryption

Retrofit and new construction applications

The CREE SmartCast system is incorporated into select CREE integral LED luminaires and consists of a wireless combination occupancy sensor and daylight sensor, and a wireless interface, all integrated into each luminaire. CREE luminaires operate at 100% light output until the OneButton commissioning setup is initialized using the CREE Configuration Tool (remote control).

Two types of groups are created as part of commissioning process, switched groups that are controlled by a dimmer/switch, and occupancy groups. Luminaires in separate rooms are grouped by room by default. Groups can be modified by the end-user.

The SmartCast devices require line voltages of 120V – 277V.

The SmartCast technology is claimed to be half the cost of "traditional lighting control systems", with an incremental cost as low as $0.40/SF. [6]

Sensors

PIR occupancy sensing technology is used; the coverage area of each sensor "roughly matches the illumination coverage".[7] Motion detected by one sensor is signaled to other luminaires in the group and the group responds as a whole.

In a retrofit application, the CREE SmartCast control can also be added as a separate wired sensor device to any third-party luminaire that has a 0-10V dimming driver. This device is connected to each luminaire and includes a wired sensor with a connected wireless dimming/switching interface device.

Sensor adjustments

Sensor adjustments are available via the configuration tool.
If a wall dimmer/switch is grouped with the luminaires, the luminaire groups are operated in vacancy mode by default (manual-on). If no wall dimmers are grouped with the luminaires, the luminaire groups are operated in occupancy mode (automatic-on).

The occupied light level is 100% by default. It can be adjusted down to 50% if the space is controlled with occupancy mode (automatic-on). The PIR sensor sensitivity can also be adjusted with the remote control.

During vacancy mode, fixtures are switched off (0% light level) by default; customizable minimum light level for bi-level dimming can be selected with remote control (0 – 50% light level available in vacancy mode).

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[6] CREE SMARTCAST TECHNOLOGY: OPERATION, APPLICATION, SELLING TOOLS. February 14, 2014

[7] CREE SMARTCAST TECHNOLOGY: OPERATION, APPLICATION, SELLING TOOLS. February 14, 2014

The default time delay is 20 minutes. It can be adjusted to a range of 5-30 minutes using the remote control.

Each individual daylight sensor is calibrated to the space during the OneButton Setup. If dimming is over- or under-aggressive after commissioning, the daylight sensors can be recalibrated, all at once, via the remote control.

Dimming

A wireless dimmer or switch is available; a neutral wire is required for the wall controller to communicate with the network. One wall controller can be associated with up to 99 luminaires. Each group of luminaires controlled by the wall control is called a "Switch" group in the configuration tool, and zones that are controlled by a dimmer are created using the configuration tool. The dimming zones cannot overlap, and one wall controller cannot control multiple zones.

Commissioning and remote control

The CREE configuration tool is a remote control used to commission the SmartCast system and to change the default setup.

A maximum of 250 luminaires can be located on each network, with up to 100 luminaires per group. Default grouping is created during the OneButton Setup commissioning process. Groups can be recreated by selecting devices individually. Groups can also be merged, individual devices can be added to an existing group and groups can be ungrouped so each luminaire is its own group. Nested groups are not allowed in switched groups (where one luminaire is in multiple groups), however occupancy groups can overlap switched groups. Multiple dimming zones are allowed in one space, but each space has only one occupancy zone controlling all luminaires.

Interoperability

The SmartCast system uses the ZigBee protocol, however only Cree SmartCast enabled devices and Cree wall controls are supported.

Reliability of communications

The range of reception between RF devices is 30 – 300 feet depending on site conditions (30 ft. in typical commercial applications). The system communicates using 2.4 GHz bandwidth and uses a Zigbee mesh communication protocol. 128-bit AES encryption is used, and CREE claims the luminaires "self-assign to the quietest channel during OneButton™ Setup".

Case studies

Two case studies have been published by CREE, however energy savings and cost information is not provided in either case study.

The LORD Corporation in Cary, NC replaced fluorescent luminaires in their corporate headquarters with CREE CR22 LED luminaires with integrated SmartCast lighting controls.[8]

[8] https://www.creelink.com/exLink.asp?8967276OA83E97I33798186

The end-users were relamping their fluorescent lamps every 3500 hours, although no reason was given for such frequent relamping. LED luminaires were selected to reduce the maintenance interval, and the end-users were especially interested in the ease of commissioning this lighting control system and implementing daylight harvesting because the building has an optimal daylight orientation (building is oriented on an east-west axis). No energy savings information is provided.

North Carolina State University installed CREE CR22 LED luminaires with integrated SmartCast lighting controls on the first floor of one campus building.[9] The incumbent technology, presumably fluorescent, is not stated. This floor includes a lobby, recreation area and computer lab with 24/7 intermittent occupancy. The lighting controls were commissioned to switch the lights off when the spaces are vacant, and additional energy savings are gained from daylight harvesting in some spaces. Installation simplicity and maintenance savings were determined to be major benefits of this retrofit.

[9] https://www.creelink.com/exLink.asp?8975317OJ72M28I33803229

Hubbell WiHUBB Product Report

Performance characteristics	Hubbell wiHUBB
Wired	✗
Wireless	✗
Hybrid (wired sensors, wireless monitoring and reporting)	✓
Luminaire integrated sensors (Individual light fixture control)	✗
Separate sensors	✓
Add luminaire level controls to existing fixtures (retrofit application)	✓
Dimming capability	✓
Remote control for configuration / calibration	✓
Interoperability with other 3rd party products	✓
Reporting capability (monitoring and performance analytics)	✓
Control grouping / zoning of light fixtures	✓
Control non-lighting loads (plug-loads, etc.)	✓
Integration with building automation system	✓
Controllability with smart phones/tablets/internet	✓
Occupant communication (monitors and/or communicates with occupants via smartphones/tablets)	✗
Customizable bi-level lighting control	✓
High-end trim	✗
Low-end trim	✗
Customizable time delay	✗
Sensor sensitivity adjustments	✓
Dimmers and switches	✓
Standby power demand	Not stated
Battery life	Not applicable
Reliability of communications	902-928 MHz RF frequency
Warranty	5 year limited
System security	AES 128 Security

Retrofit and new construction applications

Hubbell wiHUBB controls can control interior or exterior luminaires. The In-Fixture Module (IFM) can control one interior or exterior luminaire individually or control multiple luminaires

on one or more circuits. The on-fixture module is located in the standard NEMA photocell receptacle controlling an individual exterior luminaire.

In interior applications, IFMs can be installed in each luminaire, which are controlled by a Smart Pack or luminaire circuits can be connected to the Smart Pack directly for circuit control. The Smart Pack is connected to wiHUBB sensors and switches using category 5 twisted pair (CAT5) cable. An Access Point device in each space is used for scheduling and commissioning.

Sensors

Individual wiHUBB daylight and occupancy sensors are connected to a wiHUBB Smart Pack with a CAT5 cable. Each Smart Pack includes four SmartPORTs which power the sensors.

The ceiling-mounted wiHUBB occupancy sensor can be specified with multiple detector options: PIR, Ultrasonic, dual technology (PIR + Ultrasonic or PIR +Acoustic), each with a variety of coverage areas. A wall-mounted version provides similar options.

The wiHUBB daylight sensor is an open loop sensor available in interior and exterior models. The exterior model is IP54 rated and has a wider operating temperature range. Both models appear to have the same illuminance range. The manufacturer recommends locating the daylight sensor 45 degrees back from viewing the window. The daylight sensor lens should be pointed towards the window.

Sensor adjustments

The wiHUBB occupancy sensor includes "IntelliDAPT® self-adaptive technology" which claims that no manual adjustment is required. This technology claims to provide a self-adjusting timer (timeout setting), self-adjusting PIR and ultrasonic detection thresholds and automatic false-on, false-off corrections. In automatic mode, the occupancy sensor has a timeout range of 8-30 minutes, which is self-adjusting based on occupancy. A test mode provides an 8 second timeout for use during setup.

The occupancy sensor settings can be manually adjusted by accessing switches inside the sensor.[10]

The wiHUBB daylight sensor has 4 jumper settings which provide 4 selectable light level ranges ranging from 0.3 - 30 fc to 60 - 6,000 fc. The default setting is 3 – 300 fc. The sensor works with the network devices to switch or dim the luminaires based on the amount of daylight, but no information about the control algorithm is provided on the specification sheet.

Dimming

[10] http://www.hubbell-automation.com/content/products/instructions/instructions_files/wihubb_occupancy_sensors_installation_instructions_72_00467_mdc_rev_0_04_02_11.pdf

The wiHUBB system allows individual dimming control or circuit dimming control. The wiHUBB Smart Pack can be specified with one or two outputs; the latter is intended to allow bi-level control for one circuit or to control two circuits. In addition, the Smart Pack can be specified with a 0-10V output to control dimmable ballast and drivers. The Smart Pack contains four plug and play SmartPORTs which connect to wiHUBB occupancy sensors, daylight sensors and switches via CAT5 cable. Multiple dimming and switch options are available.

Alternately, the in-fixture module (IFM) devices can be specified with a 0-10V 30mA output option to individually control two-wire, low-voltage dimming ballasts and drivers.

Several Hubbell luminaire brands offer luminaires with optional factory installed wiHUBB devices within.

Commissioning and remote control

Two Access Point devices allow web-based commissioning and control of wiHUBB system. The Access Point device supports up to 100 wiHUBB devices over a wiHUBB network, whereas the Access Point 2.0 device supports “hundreds of devices” (no limit on the number of devices is stated in the specification sheet). Commissioning and management of the supported devices is conducted through an integrated web browser providing a graphical user interface (GUI) allowing Area, Group and Zone configuration options (up to 64 areas per network, 64 zones per area, 16 groups per zone). Each IFM can control one fixture and be grouped with other IFMs to create these configuration options.

Energy monitoring

The web-based GUI provided by the Access Point device allows end-users to see the real-time power demand of each device.

Interoperability

The occupancy sensors can be specified with an optional three-wire, isolated Form C relay that allows interoperability with other devices. The relay has a normally-open (NO) and normally-closed (NC) contacts with a single terminal [Single Pole Double Throw (SPDT)], and a 500 mA @ 24 VDC rating.

Control of non-lighting loads

The wiHUBB system can be accessed from a building automation system (BAS) using a wiHUBB BAS Gateway Interface device. Supported protocols include BACnet, LONworks, Metasys N2 and Modbus. A separate power supply is required, in addition to an Access Point 2.0 device. The Access Point web-based GUI is used to program the device.

Reliability of communications

This lighting control system uses Spread Spectrum Frequency Hopping which minimizes narrowband interference and a peer-to-peer, self-organizing, self-healing mesh network. The maximum distance between wireless sensors is 100 meters (328 ft).

Case studies

Hubbell has published three case studies involving the wiHubb lighting control system. [11]

One case study reports energy savings for a new construction project involving an automobile dealership in Wernersville, PA. In this project, the client wanted automatic control of the lighting and wanted to use LED luminaires to save energy and create an inviting environment. In-fixture modules were factory-installed into Hubbell LED exterior area (shoebox) luminaires, and additional in-fixture modules were added to exterior signage luminaires and wall packs. The wireless control system was controlled by the astronomical clock in the wiHUBB Access Point, and the luminaires were programmed to turn on before sunset, turn off after sunrise and dim down throughout the night. The case study cites that the coverage range provided by the 900 MHz system was particularly important in this application because of the large parking lot area and spacing of the luminaires. Installation cost of the control system was reduced because the in-fixture modules were factory installed and tested with the LED luminaires by the manufacturer. The case study reports 47% energy savings compared to normal operation, but does not define normal operation (i.e., if the energy savings are based on controls implementation alone or from both LED and controls implementation above incumbent performance).

Another automobile dealership case study in Salt Lake City, UT reports energy savings for a retrofit application. In this retrofit project, the client wanted individual luminaire control as well as preset lighting schedules. The dealership had an existing lighting control system that switched the lights on and off at sunset and sunrise, respectively. On-fixture modules were added to the photocell receptacle of the existing exterior area (shoebox) HID luminaires. The wireless control system was controlled by the astronomical clock in the wiHUBB Access Point, to switch the luminaires on and off before and after sunset and sunrise. The Access Point was also used to create programmed scenes where certain luminaire were switched off or on at preset times. One competitive advantage given in the case study is that the wiHUBB system operates using a 900 MHz frequency which results in a larger coverage range than that provided by other lighting control systems that operate using a 2.4 GHz frequency. Installation cost of the control system was reported as lower because the on-fixture module easily plugged into the photocell receptacle and no rewiring or retrenching of electrical circuits was needed. The case study reports 40% energy savings compared to normal operation, but does not define normal operation (i.e., if the incremental energy savings come from the programmed scenes).

The third case study reports energy savings for a retrofit project for a university ice rink in Cortland, NY. The university wanted individual bi-level control of existing T8 luminaires to create individual scenes for varying events in the facility. Manual control of certain lighting

[11] http://www.hubbell-automation.com/content/products/literature/literature_files/wihubb_case_studies.pdf

circuits was also desired, and the client did not want to rewire their existing lighting circuits. The existing luminaires each had 12 lamps and two ballasts, with the ballast driving 6 lamps. In-fixture modules with 2-relay control were mounted externally to each luminaire allowing bi-level control for each luminaire. A wiHUBB Smart Pack controlled the lighting circuits over the bleachers and indoor track. Preset switch stations were configured to provide 11 lighting control options. The case study reports 43% energy savings compared to normal operation.

Leviton LevNet RF Product Report

Performance characteristics	Leviton LevNet RF System
Wired	✗
Wireless	✓
Hybrid (wired sensors, wireless monitoring and reporting)	✗
Luminaire integrated sensors (Individual light fixture control)	✗
Separate sensors	✓
Add luminaire level controls to existing fixtures (retrofit application)	✓
Dimming capability	✓
Remote control for configuration / calibration	✓
Interoperability with other 3rd party products	✓
Reporting capability (monitoring and performance analytics)	✓
Control grouping / zoning of light fixtures	✓
Control non-lighting loads (plug-loads, etc.)	✓
Integration with building automation system	✗
Controllability with smart phones/tablets/internet	✓
Occupant communication (monitors and/or communicates with occupants via smartphones/tablets)	✗
Customizable bi-level lighting control	✗
High-end trim	✗
Low-end trim	✗
Customizable time delay	✓
Sensor sensitivity adjustments	✓
Dimmers and switches	✓
Standby power demand	Less than 1 Watt per device
Battery life	Photovoltaic panels (up to 48 hours of stored power at full charge); optional battery life: 10 years
Reliability of communications	315 Mhz currently, 902 Mhz will be used in future products
Warranty	Limited 5 year
System security	not stated

Retrofit and new construction applications

The LevNet RF lighting control system is a wireless lighting control system that is based on EnOcean technology. Leviton claims that installation time per device is only 10-15 minutes, compared to 45-50 minutes for wired devices.[12] The devices in the LevNet RF system include occupancy sensors, multi-location (3-way and 4-way) switches, and HVAC control. Bi-level and zoning control is possible by adding relays to individual luminaires or existing circuits. To add lighting controls in a retrofit application, wireless relay receivers or dimmer modules are wired to existing luminaires, wireless sensors are located in environment and wired or wireless switches are used to communicate with the wireless sensors and luminaire-wired wireless relay receivers.

Leviton recommends that a 4 step system is used to specify and install the lighting control system:

1. Determine the loads (lighting, HVAC, fans, TVs, etc.) to be controlled.
2. Select the appropriate wired RF Receiver and/or Transceiver to control the load
3. Select the appropriate Self Powered RF Transmitter (Sensor or switch)
4. Install the Receiver's, then pair the Transmitters, and install the Transmitters at the desired location.

EnOcean technology

LevNet RF incorporates EnOcean Technology in its devices. According to the Leviton website. "EnOcean's technology consists of miniaturized energy harvesting modules and ultra-low power radio technology. By harvesting the minute energy changes that are created by ordinary events (pressing a button, changes in temperature), EnOcean technology-based products generate enough energy to not only process the sensory data but also to communicate with other devices by generating and wirelessly transmitting signals. Such energy harvesting precludes the need for a battery or other additional power supply source."

EnOcean-based products, such as LevNet RF devices, are self-powered, use wireless (RF) communication protocols and are interoperable within an RF-based network.

Sensors

Rather than using integrated luminaire control, the LevNet RF system uses separate sensors and devices. There are three main types of devices in this system: transmitters, receivers, and transceivers (transmitter-receiver in one).

Transmitters send a wireless control signal to receivers and transceivers. They are self-powered devices which can be located anywhere. The devices include occupancy sensor transmitters, light sensor transmitter, switch leg transmitters, Vizia remote switch transmitters, Decora rocker switches, remote transmitters, handheld remote transmitters, and hotel key card remote transmitters.

[12] Leviton Energy Management Catalog (G-8047C/E14-ak), REV MAY 2014

Receivers are wired-in devices that control a connected load; they receive a control signal from transmitters and transceivers. These devices include basic and advanced wall switch receivers, 3- and 5-wire relay receivers, plug-in receivers, and thermostat receivers.

Transceivers act are transmitters and receivers in one device; they can also act as a repeater to retransmit the control signal in large spaces or where there is possible interference. These devices include room controllers, shade controller, dimmer controllers, and 4- and 8-channel relay controllers.

Accessories used to expand the system or assist in commissioning include RS-232 serial boxes, signal strength meters, power packs, and industrial wireless relays.

Sensor adjustments

Occupancy and daylight sensors are not hard-wired into a particular location, so the sensor can be placed in an optimal location to improve performance. Some of the sensors have photocells that allow them to use available ambient light to power the devices instead of batteries or low voltage wiring. These self-powered devices require that the ambient light level is at least 20 foot candles at the sensor for 3 hours every 24 hours. If these light levels cannot be met in certain spaces, a backup battery should be used or power should be provided to the two pin 24 vdc connection located inside the sensor.

Occupancy sensors (PIR) have a customizable time delay, from 2 - 30 minutes, which is commissioned through the switch receiver. The default setup is: manual on/automatic off, walk thru = disabled, time delay = 10min, PIR sensitivity = 75%. The sensors send a wireless control signal once per minute, so a 2 minute time delay is not recommended for normal operation, only for testing. A walk-through time delay feature determines if the room is only occupied momentarily by using a walk-through time-out interval of 2.5 minutes. If the space is occupied for less than 2.5 minutes, the connected loads will be switched off if no occupancy is detected during this time period. Otherwise, the specified time-out delay interval is used. When an occupancy sensor is associated with a receiver, its load will turn on each time the sensor's field of view senses occupancy. The time delay resets every minute if the space is occupied.

The daylight sensor sensitivity is 0-1020 lux at the sensor. The sensor will switch or dim lighting depending on the associated type of receiver.

Dimming

The LevNet RF system has several devices that can be used to enable dimming control including constant voltage dimmers, RF LED dimmers, and 0-10V RF dimmers. Dimmers respond to signals from occupancy sensors or daylight sensors. One sensor can wirelessly control an unlimited number of RF dimmers in range.

Commissioning and remote control

Commissioning instructions are provided on each device allowing installers to set up the control system by going through a specified sequence of steps using the transmitters, receivers, and transceivers. As an option, a LevNet RF USB computer link can also be used for trouble

shooting and commissioning; this device requires LevNet RF View Software which supports the EnOcean Serial Protocol V3 (ESP3) protocol.

A Leviton signal strength (field intensity) meter, or other third party signal meters, can be used to determine the ideal mounting positions for sensors and receivers and to check the strength of the RF signals in already-installed devices.

Programming videos are shown on the Leviton website.[13]

Energy monitoring

This system allows energy monitoring and performance analytics, via the TCP/IP LevNet RF Gateway and Leviton V Energy UI software[14].

Interoperability

Leviton claims that products are interoperable within an RF network because of the incorporation of the EnOcean technology. No details on compatibility with other EnOcean (non-LevNet RF) devices are provided.

Control of non-lighting loads

Several different types of receivers and transmitters are available to control non-lighting loads such as motor loads, HVAC, plug-loads and thermostats. Switch leg transmitters communicate the power state of connected loads or input/output signals from connected building management systems or HVAC systems and communicate that state to an RF receiver to control another load. A RS-232 serial box data interface also allows the LevNet RF system to interface with other systems.

Reliability of communications

The range of reception between RF devices is 50 – 150 feet depending on site conditions. Currently the system communicates using 315 Mhz currently, 902 Mhz will be used instead in future RF devices. Leviton indicates that they are moving to the 902 Mhz bandwidth so that "our new LevNet RF and upcoming Lumina RF line will offer more flexibility and enhanced reliability. LevNet RF 315Mhz products will be phased out with a replacement 902Mhz line to follow. Existing 315 Mhz LevNet RF products will remain under their Leviton warranties with support through 2018. The complete line of new LevNet RF 902Mhz products will be available shortly. Please visit Leviton.com for updates on releases."

[13] http://www.leviton.com/OA_HTML/SectionDisplay.jsp?section=37824&minisite=10251
[14] http://www.leviton.com/OA_HTML/SectionDisplay.jsp?section=56355&minisite=10251

Case studies

Leviton has published several case studies demonstrating energy savings and controls solutionswith LevNet RF systems.

A VA hospital in Dayton Ohio used self-powered wireless light switches and plug-in dimmer receivers to provide patients with easy to reach lighting controls.[15] The hospital was very concerned with wireless interference with other incumbent wireless devices. The client also wanted easy installation and zero-maintenance requirements, and didn't want to have to change batteries in the wireless devices. Energy consumption and installation costs were reduced by 30% according to the case study.

The Science and Engineering Library at UC Santa Cruz retrofitted its lighting from T12 luminaires to T8 luminaires and installed LevNet RF daylight sensors, occupancy sensors and relay receivers.[16] Luminaires adjacent to the windows are switched by the daylight sensor, all general lighting has bi-level switching controlled by the occupancy sensor. Rebate incentives were given for the lighting upgrade and lighting control system. With both energy saving measures, the energy consumption has decreased by 50% ($48,000 annual energy cost reduction).

A Workers Compensation Fund building in Sandy, Utah needed to replace false tripping wired-in ultrasonic sensors.[17] They replaced the ultrasonic sensors with wired PIR sensors, however the PIR sensors had a smaller coverage area, so additional LevNet RF wireless PIR sensors were installed to eliminate dead spots. Relay receivers were attached to the existing wired occupancy sensors and luminaires and paired with the new wireless sensors. The lighting control solution was completed in one weekend and no new wiring was required.

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https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0CB4QFjAA&url=http%3A%2F%2Fwww.leviton.com%2FOA_HTML%2FibcGetAttachment.jsp%3FcItemId%3Dg5tB3rnsFbzqpH2MBT740w%26label%3DIBE%26appName%3DIBE%26minisite%3D10251&ei=FjuPVK_oAfTGsQTvnoC4DQ&usg=AFQjCNHRxT98cs70T_rVdHSMi9e3ksPrqA&sig2=u8MhdoG1VBh5jSolHgL95A

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https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0CB4QFjAA&url=http%3A%2F%2Fwww.leviton.com%2FOA_HTML%2FibcGetAttachment.jsp%3FcItemId%3DZGpU1j8KXg0LEuRL7YPCmg%26label%3DIBE%26appName%3DIBE%26minisite%3D10251&ei=WD2PVJ_9DviSsQS1ioGgBw&usg=AFQjCNEcsYnmYIcodZtesAt4pVd5qzouSg&sig2=o4_bo2yJcG8xHytDP39XXA&bvm=bv.81828268,d.cWc

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https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=5&cad=rja&uact=8&ved=0CDcQFjAE&url=https%3A%2F%2Fwww.enocean.com%2Ffileadmin%2Fredaktion%2Fpdf%2Freferences%2FWorkers_Compensation_Building.pdf&ei=_0KPVKXGC-O1sQS_6ID4BQ&usg=AFQjCNGsXLIe6kAf5r0Euy9NnDsvZNLvhg&sig2=W2zC2_S_f_sO1lBOvKMG9A&bvm=bv.81828268,d.cWc

Lenox Hill Hospital, in Manhattan, NY used LevNet RF wireless remote switches and relay receivers to activate a yellow LED TAXI sign, which is used to call taxis for outgoing patients and visitors on a busy street.[18]

Wayne County Airport Authority installed wired occupancy sensors in private and open offices and wireless LevNet RF sensors and switches in rest rooms and locker rooms in two maintenance facilities in Detroit MI.[19] These spaces had cinder block construction and asymmetrical layouts that prevented wired controls. Wireless occupancy sensors and wall switch receivers were used in this installation. Energy savings are claimed but not quantified.

Lava Beds National Monument in Tulelake, CA upgraded the lighting in its administrative facilities to T8 lighting and newer lighting controls.[20] LevNet RF wireless occupancy sensors, transmitters and receivers were installed in common areas, rest rooms and offices. 40% energy savings ($6400 annual energy cost reduction) are reported from the lighting and controls upgrade.

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18 http://www.leviton.com/OA_HTML/ibcGetAttachment.jsp?cItemId=nTCK29pIIhqnsCys8Wiwiw&label=IBE&appName=IBE&minisite=10025

19 http://www.leviton.com/OA_HTML/ibcGetAttachment.jsp?cItemId=ucVIELc0mrVd0QghLy3VqA&label=IBE&appName=IBE&minisite=10251

20 http://www.leviton.com/OA_HTML/SectionDisplay.jsp?section=55125&minisite=10251

Lutron Energi TriPak Product Report

Performance characteristics	Lutron Energi TriPak
Wired	✗
Wireless	✓
Hybrid (wired sensors, wireless monitoring and reporting)	✗
Luminaire integrated sensors (Individual light fixture control)	✓
Separate sensors	✓
Add luminaire level controls to existing fixtures (retrofit application)	✓
Dimming capability	✓
Remote control for configuration / calibration	✓
Interoperability with other 3rd party products	✓
Reporting capability (monitoring and performance analytics)	✗
Control grouping / zoning of light fixtures	✓
Control non-lighting loads (plug-loads, etc.)	✓
Integration with building automation system	✓
Controllability with smart phones/tablets/internet	✗
Occupant communication (monitors and/or communicates with occupants via smartphones/tablets)	✗
Customizable bi-level lighting control	✓
High-end trim	✓
Low-end trim	✓
Customizable time delay	✓
Sensor sensitivity adjustments	✓
Dimmers and switches	✓
Standby power demand	Less than 1-1.25 Watts per device (depends on device)
Battery life	10 years; non-volatile memory settings
Reliability of communications	Clear Connect RF technology
Warranty	1 – 5 years depending on device. Extended coverage is available.
System security	Not stated

Retrofit and new construction applications

The Lutron Energi TriPak control system with separate sensors is marketed for small and medium sized interior applications such as private offices, conference rooms, stairwells, classrooms and restrooms. Depending on the specified system, each module controls one or more zones within a room. Wireless sensors and switches simplify installation and commissioning. The luminaire-level PowPak Fixture Control system extends the system capability to larger spaces such as open office areas, because they increase the control granularity around each luminaire. Lutron claims that the Energi Tripak system "installs 70% faster than wired systems" and that switches and sensors can be installed in 15 minutes without disrupting occupants in the space.[21]

The basic Energi TriPak includes a two-wire switch that wirelessly communicates with a ceiling-mounted or wall-mounted occupancy/vacancy sensor. More devices are available which allow dimming, daylight harvesting and third-party device control.

Sensors

The Energi TriPak control system includes a fixture connected sensor and dimming module and/or separate battery-operated, wireless occupancy/vacancy sensors as well as battery-operated, wireless daylight sensors.

Recently, Lutron has introduced a PowPak Fixture Control system which controls an individual luminaire. Each Fixture Control system is specified with one PowPak dimming module (for 0-10V or Ecosystem dimmers/ballasts) and one PowPak occupancy/vacancy/daylight sensor per luminaire. The sensor is mounted to the ceiling adjacent to the luminaire it controls. Each PowPak dimming module can control up to 3 ballasts or drivers (controlled as one lighting zone). The daylight sensor has a closed-loop proportional control response and an automatic calibration. The Radio Powr Savr wireless occupancy vacancy sensor uses a PIR detector to detect occupancy in its coverage area. Occupancy groups and presets are available.

The Radio Powr Savr wireless daylight sensor is an open loop sensor with a linear dimming response to available light. The sensor has a range of response from 0 – 1600 lx. One daylight sensor can interface with up to 10 PowPak modules (dimming and switching) allowing the daylight system to control lighting with a switching, step dimming or continuous dimming response. This device operates using a lithium battery and claims to have a 10-year battery life. Calibration is required.

Sensor adjustments

The PowPak occupancy/vacancy/daylight sensor provided in the PowPak Fixture Control system does not have an adjustable timeout (15 minute setting only) but does have adjustable high-end and low-end trim settings. Light levels are adjustable via the PowPak dimming module. The high-end trim can also be changed via a separate RadioPowr Savr occupancy sensor.

[21] http://www.lutron.com/en-US/Products/Pages/SingleRoomControls/Energi_TriPak/Overview.aspx

The Radio Powr Savr wireless occupancy vacancy sensor has available adjustments for timeout, activity and automatic -on settings. Timeout settings range from 1 minute to 30 minutes; 15 minutes is the default setting. The occupancy detection model has three automatic-on settings: enabled – which switches lights on and off automatically based on occupancy detection (default setting); low light – which turns on lights if the ambient light detector detects less than 10 lx at sensor (switches lights off automatically); and disabled – which is a manual-on, automatic-off setup (vacancy sensor). Three activity levels can be selected: low (default), medium and high. This device operates using a lithium battery and claims to have a 10-year battery life.

The daylight sensor has available tuning options that allows the setpoint to be changed for different lighting zones.

Dimming

Dimming is accomplished by wiring a dimming PowPak module to an individual luminaire or circuit. Three types of dimming PowPak modules are available.

The 0-10V PowPak dimming module controls 1-10V dimming ballasts/drivers (60mA total load) in one zone and receives input from up to 9 Pico wireless controls, 6 wireless occupancy/vacancy sensors and 1 wireless daylight sensor.

The EcoSystem PowPak dimming module controls up to 32 EcoSystem dimming ballasts/drivers in multiple zones, and receives input from up to 9 Pico wireless controls/switches, 6 wireless occupancy/vacancy sensors and 2 wireless daylight sensors. Luminaires are grouped together for daylight harvesting or scene control using Pico wireless switches or the PowPak module and the daylight sensor.

High-end and low-end trim are adjustable via the PowPak dimming module. For the 0-10V module, the low-end trim can be adjusted from 0-45%. High-end trim is adjustable from 100%-55%. For the Ecosystem module, the low-end trim can be set to 0% (off) or 10%; the high-end trim can be adjusted from 100% - 50%. Light levels during occupancy and vacancy events can also be adjusted.

Pico wireless controls allow individual wireless control, adjustments to favorite light levels and control grouping for the Ecosystem PowPak modules.

Commissioning and remote control

The PowPak Fixture Control system does not require calibration, as daylight calibration is an automatic feature.

However, the separate wireless occupancy/vacancy sensors and daylight sensors which are part of the Energi TriPak system have to be paired with the PowPak dimming modules and Pico wireless switches as part of the setup process. In addition, daylight calibration is required for each separate daylight sensor (location dependent).

The PowPak Fixture module controls one luminaire (with up to 3 ballasts or drivers). The 0-10V PowPak dimming module can control one zone per daylight sensor; the Ecosystem PowPak module can control two daylighting zones for each daylight sensor.

Luminaires can be grouped by Pico control, and nested grouping is allowed (luminaires can be located in different groups). Occupancy/vacancy sensors provide input to all connected ballasts/drivers, however, grouped Pico controls can adjust occupancy/vacancy light levels and/or override occupancy inputs (manual control).

Energy monitoring

The Energi TriPak system does not appear to have energy monitoring capabilities.

Interoperability

Some relay modules are available with a dry contact closure output (CCO) that allows integration with building automation systems, VAV, HVAC, and other third- party systems.

Control of non-lighting loads

PowPak Relay modules can control non-lighting loads (such as receptacles, monitors, fans, humidifiers and printers) and 120V – 277V lighting loads based on wireless input from up to ten controls (Pico wireless controls, wireless occupancy/vacancy sensors and daylight sensors). The standby power demand of these devices is less than 1.25 W. Plug-in appliance modules are also available.

Reliability of communications

Lutron's Clear Connect™ RF technology[22] operates at 434 MHz. Lutron claims that operating its devices at this frequency minimizes in-band interference. Lutron uses a fixed network rather than a mesh network and grouped commands as part of this protocol to provide fast, synchronized responses. Lutron lighting control systems can co-exist and be integrated with other 3rd party systems, via devices such as the CCO relay module.

In general, Lutron wireless devices must be installed within 30 feet of the PowPak modules. Some devices have a shorter RF range. Lutron recommends that the PowPak modules be mounted in the center of the room to maximize RF range.

Lutron offers additional services where sensor layout and tuning can be specified as well as system setup.

Case studies

Lutron has published four case studies demonstrating the Energi TriPak lighting control system. In addition, three independent case studies have been published by the California Lighting

22 http://www.lutron.com/TechnicalDocumentLibrary/Clear%20Connect%20Technology%20white paper.pdf

Technology Center (CLTC) showing energy savings compared to a non-controlled T8 lighting system in corridors.[23,24,25]

One Lutron case study involved refurbished hotel rooms at a Marriott Hotel in Frankfurt, Germany.[26] 588 guest rooms were refurbished with Lutron PowPak modules and wireless Pico switches to increase lighting control, providing full control from the bedside as well as the entry area. Three Lutron PowPaks were added to each room; one in the bathroom ceiling, one in the AC box in the entry way and a third underneath the bed. Wireless switches replaced existing switches. The existing room wiring was difficult to access which made rewiring challenging and the client wanted to complete the retrofit with minimal noise and disruption. The retrofit was completed 15% faster than with standard switching and no redecorating costs or booking losses were incurred. Compared to a wired switch installation, the client saved 1.1 million euros, due to avoided loss in revenue and redecoration costs. No energy savings are reported in this case study.

Another case study published by Lutron involves a K-12 school in Bexley, England.[27] The Business Academy is housed in a predominantly glazed structure with three glass atriums. Daylight is available periodically throughout each day, and the management wanted to implement daylight harvesting. The management were also interested in "promoting sustainability", minimizing disruption during the installation period, reducing lighting costs, and eliminating capital costs. The retrofit project included new custom LED luminaires including 1800 Lutron 5 Series LED drivers, 150 PowPak dimming devices, 280 wireless occupancy sensors and daylight sensors and more than 100 wireless switches. The school set up a 7 year loan with a European bank that required no capital investment. The loan was repaid by the resulting energy savings. The overall project, including LED lighting, saves the school £25,000 per year on its lighting energy costs.

Lutron has published a third case study demonstrating the Energi TriPak system at Pepperdine University. [28] This retrofit project included luminaire retrofits (details not provided), wireless occupancy sensors to switch lighting off in unoccupied classrooms and offices, and reduction of HVAC in unoccupied classrooms. Energi TriPak devices included PowPak relay modules, wireless occupancy sensors and switches and wireless closed contact modules (CCO) on the regulated air supplies in each classroom. Lighting energy use was reduced by 20-30% and HVAC energy use was reduced by 14%. The case study does not specify the impact on energy

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[23] http://cltc.ucdavis.edu/sites/default/files/files/publication/pier-lutron-latham-square-adaptive-corridors.pdf

[24] http://cltc.ucdavis.edu/sites/default/files/files/publication/20130600-speed-business-case-adaptive-corridors.pdf

[25] http://cltc.ucdavis.edu/sites/default/files/files/publication/CASE_STUDY_UCSF_Adaptive_Corridors_140602.pdf

[26] http://www.lutron.com/TechnicalDocumentLibrary/368-3320_The_Marriott%20Hotel_Frankfurt_case_study_EA.pdf

[27] http://www.lutron.com/TechnicalDocumentLibrary/368-3498_EA_Bexley_Case_Study.pdf

[28] http://www.lutron.com/en-US/CaseStudyPDF/Pepperdine_%20University_case_study.pdf

use from the luminaire retrofits (these are presumably included in the lighting energy savings). The retrofit project costs were 100% paid for by Southern California Edison (SCE) Private Schools and College Audit and Retrofit Program.

A fourth case study describes the performance of wireless controls in a small pilot retrofit application at the Gurdon Institute at the University of Cambridge in Cambridge, England.[29] The pilot project installed wireless occupancy sensors and a wireless switch in an intermittently occupied storage room that previously used manual switching. Included in the retrofit project was a fluorescent T8 to T5 lamp and ballast replacement. Lighting energy use was reduced by 60% as a result of the upgrade (which includes lamp and ballast replacements). As a result of this pilot study, the Energi Tripak control system has been installed in 97 additional zones, including research and storage areas, restrooms and some small office areas. The capital cost was £20,000 and the projected payback is 2 years.

CLTC conducted an independent case study of bi-level lighting in several office corridors in a multi-story office building in Oakland, CA. The corridors have lighting switched on 24/7 to meet egress regulations. Existing 86W 3-lamp fluorescent T8 luminaires were replaced with 64W 2-lamp fluorescent luminaires outfitted with Lutron Ecosystem H-series ballasts. The Lutron Energi Tripak with wireless occupancy sensors, PowPak dimming modules and wireless controls were also specified. The high end trim was set to 100% of full light output when occupied, and the low end trim was set to minimum required light levels when the space was vacant (dimming percentage is not specified). The average occupancy rate was 8%. The replacement system reduced the lighting energy use by 86%. The total retrofit cost of the project was $57,000 but incentives and rebates reduced the project cost to $7,200. The simple payback of the project, after incentives, was 6 months. Without the incentives, the payback would have been 3.3 years. The case study notes that the wireless controls reduced the installation costs, were easily commissioned, and were compatible with new and existing luminaires.

A California State Partnership for Energy Efficient Demonstrations (SPEED) case study evaluated the Lutron Energy TriPak and the Wattstopper DLM control systems in retrofit corridor applications at several University of California (UC) campuses. An Enlighted networked lighting control system was also evaluated in this case study but is not described in this report. In this case study, 2-lamp 2x4 T8 recessed troffers were retrofitted with Lutron DALI ballasts and connected to a Lutron Energi PowPak dimming module. Wireless Lutron occupancy sensors were also specified. The dimming module was commissioned to provide a bi-level adaptive lighting schedule; the high end trim was set to 85% of full light output when occupied, and the low end trim was set to 10% of full light output when the space was vacant. The average occupancy rate was 20%. The lighting control system reduced the pre-retrofit lighting energy use by 70%. The per-fixture projected costs were $186, including installation costs. The total energy and maintenance cost savings per fixture were $27. Simple payback for this demo, including incentives, was 4.1 years (and without incentives would have been 6.9 years).

Another SPEED case study evaluated the Lutron Energy TriPak and a Wattstopper control system in a retrofit corridor application at the Mount Zion Medical Center at the University of

[29] http://www.lutron.com/TechnicalDocumentLibrary/368-3313_The_Gurdon_Institute_EA.pdf

California, San Francisco campus (UCSF). An Enlighted networked lighting control system was also evaluated in this case study but is not described in this report. In this case study, 17 fluorescent T8 luminaires located in one corridor were connected to a Lutron Energi TriPak PowPak dimming module. A wireless occupancy sensor was also installed. The dimming module was commissioned to provide a bi-level adaptive lighting schedule; the high end trim was set to 70% of full light output when occupied, and the low end trim was set to 20% of full light output when the space was vacant. The occupancy rate was found to be 12%. The lighting control system reduced the pre-retrofit lighting energy use by 62%. The project included a 50% cost incentive (net cost per luminaire: $45) reducing the payback period to 1.2 years.

Wattstopper DLM Product Report

Performance characteristics	Wattstopper DLM
Wired	✓
Wireless	×
Hybrid (wired sensors, wireless monitoring and reporting)	×
Luminaire integrated sensors (Individual light fixture control)	×
Separate sensors	✓
Add luminaire level controls to existing fixtures (retrofit application)	×
Dimming capability	✓
Remote control for configuration / calibration	✓
Interoperability with other 3rd party products	✓
Reporting capability (monitoring and performance analytics)	✓
Control grouping / zoning of light fixtures	✓
Control non-lighting loads (plug-loads, etc.)	✓
Integration with building automation system	✓
Controllability with smart phones/tablets/internet	✓
Occupant communication (monitors and/or communicates with occupants via smartphones/tablets)	×
Customizable bi-level lighting control	✓
High-end trim	✓
Low-end trim	✓
Customizable time delay	✓
Sensor sensitivity adjustments	✓
Dimmers and switches	✓
Standby power demand	Not stated
Battery life	Not applicable
Reliability of communications	Linear topology RS485 (MS/TP) wire terminated with industry standard RJ45 connectors.
Warranty	1-5 years depending on component
System security	128-bit AES encryption on wireless network bridge

Retrofit and new construction applications

The Wattstopper Digital Lighting Management (DLM) system is a wired lighting control system that uses Cat 5e cables to connect all system devices. The DLM system can be used to control lighting in individual spaces (local network) or in a centralized system with individual rooms connected via network bridge devices. On power up, devices are automatically recognized and

operated using the default configuration ["Plug n' Go" (PnG) operation] but load configuration can be modified using "Push n' Learn" (PnL) buttons and individual device functionality can be adjusted. For example, a single-relay DLM room controller with an occupancy sensor attached defaults to automatic-on/automatic-off switching. Adding a switch to this local network changes the default operation to manual-on/automatic-off. Using a two-relay DLM room controller to control two circuits with an occupancy sensor and switch, results in the following default bi-level functionality: Load 1 has automatic-on/automatic-off operation; Load 2 has manual-on/automatic-off operation.

Room controllers provide communication protocols and low-voltage power (24 VDC) to connected DLM control devices. Each DLM Local network supports up to 24 devices (including up to 4 room controllers and/or 4 plug load controllers). Switching or dimming room controllers with single-, double-, or triple-relays are available.

Sensors

Various separate occupancy/vacancy, daylighting, plug load sensors and relays are available, all connected through RS485 cables (LMRJ cables) with RJ45 connectors. Devices can be connected in a daisy chain or star pattern. LMRJ cables are sold separately.

Occupancy sensors are available with PIR, ultrasonic or dual technology (PIR + ultrasonic) detectors. Some sensors are available in wall-mounted and ceiling-mounted versions and with a variety of coverage areas.

Daylight sensors dim or switch the lighting loads based on the connected room controller.

Sensor adjustments

Occupancy sensor parameters that can be adjusted include time delay, walk-through, sensitivity, test mode and detection triggers (for dual technology sensors only). The default time delay is 20 minutes, and can be modified to a range of 1 to 30 minutes. An override option which bypasses the occupancy control to manual control is available. PIR and ultrasonic sensitivity ranges from 0 – 100% and can be specified in 10% increments. The default PIR sensitivity is 90%; the default ultrasonic sensitivity is 70%. Test mode changes the time delay to 5 seconds for setup purposes. Configuration settings may be saved.

Single-zone and multiple-zone daylight sensors must be calibrated using the LMCT-100 Digital Configuration Tool or by pressing the USER button on the daylight sensor. By default, multi-zone sensors control load 1; zone setup is modified using the LMCT-100 Digital Configuration Tool. Manual calibration allows setpoints, time delays and ramp rates to be modified. Advanced setting options include override options, hold options (daylight sensor behavior when switch or occupancy sensor switches connected loads on), scene adjustments and after-hours behavior. A test mode to assist in manual calibration setup is available.

Dimming

The DLM system works with any 0-10V dimming ballasts / drivers, as long as a dimming room controller is also specified.

The remote configuration tool has a dimming configuration that allows each load to have the following options modified: high-end trim: 1-100% (default 100%); low-end trim: 0-99% (default 0%); preset: last used level or 1-100%; burn-in: 0, 12 or 100 hours. I-100 Burn-in is typically applied for fluorescent lighting to stabilize lamp operation.[30,31]

For switched loads, the trip point option determines the level at which a load is to be switched off after ramp up or ramp down (presumably during daylight harvesting). The options are 1%, 25%, 75%, 51% or 100% (default is 51%).

Commissioning and remote control

To assist in the setup process, each room controller has a Load ON/OFF button to toggle override connected devices and toggle the connected load on and off.
LMSW wall switches have blue indicator LEDs that indicate when a load is switched on or off and a red indicator LED for PnL.

Scenes may be assigned to LMSW switches by using the remote configuration tool, with the handheld IR personal scene control device or by using the switch directly (with some types of LMSW switches).

The configuration button is used to change load configurations (PnL) and sensor settings. Although all DLM devices (sensors, switches, remote digital configuration tool and room controllers) have configuration buttons that can be used for PnL adjustments, the sensors and remote configuration tool have LCD displays that are used to configure the control options. When multiple room controllers are used on one local network, the load numbers are reassigned based on ascending serial numbers on the room controllers (room controller with the lowest serial number is the master controller).

In addition, a LMCI-100 Digital Computer to DLM interface device can be connected via a USB port to a PC running Wattstopper's freely available DLM software to program and monitor the DLM system. The LMRJ cable from a connected DLM device is connected to the LMCI-100 device. The LMCS-100 software can also be connected to DLM networks via the BACnet/IP for centralized management.

A handheld IR personal dimming remote is available to dim and switch connected lighting loads. The remote control is pointed at an IR-enabled DLM device within range to send the signal. A handheld IR personal scene control remote is also available.

Energy monitoring

Dimming room controllers monitor load current. To communicate the current data from the room controllers, a network bridge device is used to send this data to the building automation system or Wattstopper's BACnet-compatible DLM Digital Network Segment Manager.

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[30] http://www.osram.com/media/resource/hires/335135/manufacturers-declaration--burning-in-of-fluorescent-lamps.pdf

[31] http://www.nema.org/Standards/Pages/Recommended-Practice-Lamp-Seasoning-for-Fluorescent-Dimming-Systems.aspx

The LMCI-100 Digital Computer to DLM device can be connected to a PC running Wattstopper's DLM software to program and monitor lighting control panels. The LMCS device can also be connected to DLM networks via the BACnet/IP for centralized management.

Interoperability

The Wattstopper DLM system provides a local lighting network that can be extended to multiple rooms by connecting wired network bridge devices to room controllers. These devices communicate power demand to the building automation system or to Wattstopper's DLM Digital Network Segment Manager. The Segment Manager allows global control of all the networked DLM systems as well as monitoring, adjustment and scheduling functionality. The Segment Manager uses a web-based interface.

A wireless network bridge device is also available to extend BAS network capabilities without the need for additional data lines. Applications for these devices include multi-building applications and retrofit applications.

Control of non-lighting loads

Wattstopper has several devices that can control non-lighting loads, including plug-load room controllers that can interface with occupancy sensors, input/output interface devices that interface with occupancy sensors and third-party equipment and isolated relay devices. One of these devices, the Digital low-voltage Input/Output Interface (isolated relay) device allows for integrating third- party equipment into the DLM system. These devices respond to a DLM occupancy sensor and provide input/output information from/to connected devices (such as time clocks, key switches, HVAC systems, exhaust fans and building automation systems). Input commands include load shedding (load-off), after-hours (load off or on), clean (load on or off) and Force-on.

Reliability of communications

Wattstopper only "assures proper performance of the DLM system" if its LMRJ cables are used to connect devices. Pre-terminated cables are available in lengths up to 100 feet and in plenum-rated, non-plenum rated and direct-burial versions. The maximum LMRJ cable length per device is 150 feet.

Case studies

Wattstopper has published four case studies demonstrating DLM performance. In addition, one independent case study involving the DLM system has been published by the California Lighting Technology Center (CLTC).[32]

One case study describes the DLM performance in a football stadium at the University of Alabama.[33] The DLM system was used to control lighting in several types of spaces including

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32 http://cltc.ucdavis.edu/sites/default/files/files/publication/CASE_STUDY_UCSF_Adaptive_Corridors_140602.pdf

33 http://www.wattstopper.com/~/media/92D3E30F2F3B4818A1B970AD8A792894.ashx

offices, skyboxes and boardrooms. Another type of Wattstopper control system was used to control lighting in common areas; the DLM Network Segment Manager was used to monitor, and manage all of the connected systems. A DLM "Game Day Switch" was used to temporarily override all time delays for all spaces in "Game Day Mode." Some of the advantages of the DLM system noted in the case study were easily-substitutable switches and the easy-to-learn web-based monitoring and management system provided by the Segment Manager.

Another case study describes energy savings using DLM systems across multiple buildings at the Weber State University (WSU) campus in Ogden, UT.[34] DLM controls and new lighting fixtures and lamps were installed in five buildings including a library, classrooms, administrative offices, warehouse spaces and a maintenance shop. The advantages of the DLM system cited in the study are: the ability to quickly fine-tune the lighting system using a hand-held remote; Wattstopper's reputation for dependability; flexibility in space configuration due to control options; ease of installation, including minimal disruption and low labor costs; and favorable responses from occupants. The net investment for the DLM controls was $300,000. Estimated annual energy savings due to controls alone were $130,000 (59% of total energy savings) and the simple payback period was 2.3 years. The campus is planning on upgrading additional facilities using this new energy efficiency standard.

A third published case study involves newly redesigned multi-story spaces covering 170,000 SF for an investment firm in Boston, MA. [35] The DLM system was installed in a variety of spaces including private and open offices, meeting rooms, reception areas, bathrooms, kitchens, stairwells and hallways. The construction management team noted that the installation was fast and easy ("like plugging in a phone") and saved time and labor. The flexibility of changing control options and the simplicity of using a hand-held remote control was also noted. No cost or energy information was provided in this case study.

The final case study describing DLM performance is for a fast-track, three-month long remodeling project involving a 10,000 SF magnet public high school in Miami, FL.[36] Cree LR24 LED fixtures were installed prior to the control specification, and the control installation was operational two weeks after specification. Dimming room controllers, wall-mounted switches and dual-technology occupancy sensors were installed in classrooms, a lounge and an open classroom. Personal scene controllers are also provided for classroom use. In the restrooms, switching room controllers were used with ultrasonic occupancy sensors providing automatic on/off control. No wall switches were located in the restrooms. Other Miami-Dade County public schools have specified DLM controls for their school buildings. No energy or cost information was provided in this case study.

As previously described in the Lutron Case Studies section, a SPEED case study evaluated the Lutron Energy TriPak and the Wattstopper DLM control systems in retrofit corridor applications at several University of California (UC) campuses. 14 2-lamp 2x4 T8 recessed troffers were retrofitted with 0-10V dimming ballasts and connected to a DLM system (components not

[34] http://www.wattstopper.com/~/media/44791E48095D45E3B9E2E0059B511148.ashx
[35] http://www.wattstopper.com/~/media/BD89E1B4D227486F82083A8649F8E045.ashx
[36] http://www.wattstopper.com/~/media/394A37241E574D4EAEE1AA3CCE8B228C.ashx

specified). The DLM system used three relays to lower the light levels to 20% of full light output when the space was vacant. The average occupancy rate in this corridor was 16%. The lighting control system reduced the pre-retrofit lighting energy use by 53%, and the energy cost savings per fixture were $31. The project included a 41% cost incentive (net cost per luminaire: $76) reducing the payback period to 2.5 years.

Guidance for selecting lighting controls

All of the lighting controls reviewed in this report offer some method of automatic setup that apply default settings for calibration purposes. Specifiers should determine if these default settings will allow their target light levels and lighting schedules to be maintained. It is recommended that specifiers conduct a mock-up of the lighting control system and selected fixtures to determine how well the system works in a given space. If the same lighting control system is to be specified in a variety of spaces, additional control options may ensure better performance to account for different spatial geometries, light level requirements and user needs.

Recommended questions for specifiers to ask

- What is the spatial response of the sensors (coverage area)?[37] At a given mounting height, will the sensor cover the entire space or are multiple sensors required? This question typically requires that a sensor layout is completed to ensure that there are no "dead spots" in coverage.
- What is the spectral response of the daylight sensor?[38] Daylight sensors that block IR radiation and have a similar response to the standard photopic human eye response will have improved performance.
- What control algorithm does the daylight sensor use? This determines the type of 0-10 V control voltage sent to the dimming driver/ballast.[39] Ideally, a daylight sensor will use a closed-loop proportional control to account for the difference in spatial distribution and spectrum of daylight and electric light and allow the user to specify a target electric light level (setpoint) for each space.
- Are manual calibration options available? For the system as a whole, can light levels be tuned (dimmed) for each space when the system is setup? For bi-level control, what options are available to set the light level when the space is vacant? For occupancy sensors, these may include customizable time delay, detector sensitivity, test setting, temporary override, and switch/zone selection. For daylight sensors, these may include electric lighting on setpoint, an off setpoint for switching systems, dimming/gain setting, and ramp rate (how quickly the electric lighting dims up or down in response to daylight).
- What override options are available using wall switches or personal lighting controls? Can light levels be increased and decreased? Some systems only allow the user to decrease light levels from those initially calibrated, and increases in light level are not allowed.
- Will the lighting control system turn lights off completely when daylight is abundant?
- What is the power demand of the electric lighting when the electric lighting is fully dimmed? This will depend on the lighting control system and connected dimming driver/ballast, and may require a mock up to determine.
- What is the standby power demand of the lighting control system? Systems with wireless control require some amount of additional power in order to listen for and respond to lighting control signals.

[37] http://www.lrc.rpi.edu/programs/NLPIP/tutorials/photosensors/spatial.asp
[38] http://www.lrc.rpi.edu/programs/NLPIP/tutorials/photosensors/spectral.asp
[39] http://www.lrc.rpi.edu/programs/NLPIP/tutorials/photosensors/control.asp