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LIGHTING CALIFORNIA'S FUTURE: RESEARCH PROGRAM SUMMARY

PIER FINAL PROGRAM REPORT

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Preface

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

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

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

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

Lighting California's Future: Research Program Summary is the final report for the Lighting California's Future project (Contract number 500-06-035 conducted by Architectural Energy Corporation. The information from this project contributes to PIER's Building End-Use Energy Efficiency Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

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Abstract

Lighting California's Future was a $3.7 million contract in the California Energy Commission's Public Interest Energy Research Program that focused on lighting technologies for buildings. The lighting research program's goals were to deliver advanced, energy-efficient technologies, products, systems, and implementation tools and to bring them to the market to benefit California residents. Research organizations teamed with manufacturing partners and utilities to develop, demonstrate, and commercialize products and systems for both commercial and residential applications. Key research areas included daylighting, demand response systems, integrated lighting and control systems, and solid-state lighting products. Prototypes were developed and demonstrated for several of the projects. Three products also reached the marketplace during this contract. Future demonstrations are recommended to support further marketing efforts. This report presents information about the approach, outcomes, conclusions, and recommendations for the nine technical projects and one market connection project within the Lighting California's Future research program. In California, this project can produce technologies capable of delivering electrical load savings and peak load reductions each year.

Keywords: Tubular daylighting devices, demand response, DR, advanced lighting control systems, retrofit integrated classroom lighting system, R-ICLS, wireless integrated photosensor and motion sensor, WIPAM, indirect LED downlight, novel LED downlight, LED ceiling fan light kit, LED exhaust fan, scattered photon extraction

Executive Summary

Introduction

The lighting research program, which began in May 2007 and concluded in December 2010, featured nine technical projects and a crosscutting market connection project.

Purpose

The Lighting California's Future research program goals were to develop advanced, energy-efficient lighting technologies, products, systems, and implementation tools and to bring them to the market to benefit the California residents. Subsequent sections of this report provide more information about the specific purpose of the individual projects.

Objectives

The Lighting California's Future program goals met the Public Interest Energy Research Program goals of improving the reliability and quality of California's electricity system by developing advanced lighting technologies, products, systems, and implementation tools that are energy-efficient, cost-effective, and reliable, and reduce pollution. The technical projects focused on taking advantage of natural light and daylighting controls to offset energy use, demand response systems that can reduce peak demand during critical periods, integrated lighting systems that contribute to affordability and ease of use, and solid state lighting. One secondary goal was to improve the energy cost and value of California's electricity by working with manufacturers to develop cost-effective lighting technologies and to understand market dynamics.

Project Outcomes

A summary of the outcomes for the individual projects follows:

- Improved Daylight Performance of Tubular Daylighting Devices sought to develop, demonstrate, and commercialize new diffuser elements that redirect a significant portion of emitted daylight towards the ceiling and precisely filter and spread the rest, producing a direct/indirect luminaire effect. The goal was to increase the acceptance of tubular daylighting devices by introducing systems with luminance ratios that are closer to the accepted norms for interior spaces. The team included Solatube International, Inc., the California Lighting Technology Center, and Southern California Edison. As a result, Solatube developed several indirect/direct tubular daylighting device prototypes. The performance of the units, however, did not meet the research team expectations.
- Cost-Effective Demand Response sought to develop, demonstrate, and commercialize a new demand response lighting control technology capable of receiving a utility's demand reduction signal and transmitting a load-shed signal to multiple receiver devices, using an existing building's power lines. Cost-Effective Demand Response takes a low-technology approach, doing only one simple task inexpensively—reducing loads during direct lighting conditions. The team included NEV Electronics, the California Lighting Technology Center, and Southern California Edison. As a result, NEV Electronics produced a prototype system for testing. Based on feedback from the Underwriters Laboratories®, the Cost-Effective Demand Response system had to be

further modified at the component level. NEV Electronics plans to continue development and testing of the system with private funding.

- Integration of Electric Lighting Controls with a utility's direct response signals sought to identify and demonstrate the most cost-effective and reliable combinations of utility direct response signals and electric lighting controls to implement automated direct response capabilities with bidirectional communication capabilities. Resulting systems will allow utilities to get feedback on achieved lighting load reductions during direct response conditions and is applicable to all buildings. The team included Southern California Edison and the California Lighting Technology Center. Because of this project, Southern California Edison tested three Advanced Lighting Control Systems (Convia, Lutron, and Universal). All three of the installed systems were able to respond successfully to the requirements of demand response operation and to save energy. Cost barriers exist for these systems.
- Retrofit Integrated Classroom Lighting System sought to develop and demonstrate retrofit lighting solutions for classrooms to integrate luminaires, sensors, and controls, providing quality lighting for general and audio/visual settings together with white-board lighting. This gives schools a "good", "better" or "best" way to combine state-of-the-art luminaires, lamps, ballasts, sensors, and controls into cost-effective, retrofit system solutions. The team included Finelite, Inc. and the California Lighing Technology Center. The outcome is four levels of Retrofit Integrated Classroom Lighting Systems that were developed and demonstrated in 13 classrooms in three schools in California. Results have shown a range of equipment and installation costs and energy use effects. Finelite has commercialized some components of the Retrofit Integrated Classroom Lighting Systems.
- Wireless Integrated Photosensor and Motion Sensor Lighting Control System sought to develop and commercialize an easy-to-install lighting control system that combines photosensors and motion sensors with low-power wireless communication, and eliminates the need to be wired into the switchbox or ceiling-mounted near the luminaire. This reduces the installed cost and improves the reliability of lighting controls by placing sensors in convenient and accessible locations. The team included Adura Technologies and the California Lighting Technology Center. Adura developed a prototype system for private offices, corridors, and parking garages. The California Lighting Technology Center installed and monitored demonstrations. Adura has commercialized the system.
- Advanced Light-Emitting Diode Downlighting Systems sought to develop and commercialize a component-based system specifically tailored to the unique characteristics of light-emitting diodes' indirect light sources, optimizing light-emitting diode components while maintaining the features and functionality that have made downlights so popular. This provides more energy-efficient and cost-effective product than light-emitting diode downlights based on components intended for compact fluorescent lamps light sources. The California Lighting Technology Center was the primary team member, with support from Samsung and Phillips Capri Lighting. California Lighting Technology Center worked with various manufacturers to develop several versions of an integrated prototype with an indirect light-emitting diode source.

The prototype has been demonstrated at the California Lighting Technology Center facility and at trade shows, generating high interest from potential users.

- Novel Light-Emitting Diode Downlights sought to develop and commercialize a new recessed downlight fixture using light-emitting diodes that are dimmable. This achieves a cost-effective system that has a high overall lumen output while providing continuous dimming control at low output levels. The team included the California Lighting Technology Center and Cooper Lighting. Working with the California Lighting Technology Center, Cooper Lighting developed, tested, and commercialized the HALO® Recessed Light-Emitting Diode Downlight. The product is the first ENERGY STAR®-approved solid state downlight product.
- Smart Light-Emitting Diode Lighting in Residential Fans sought to develop and commercialize light-emitting-diode-based lighting kits for ceiling and exhaust fans for use in the home and explore the integration of controls. This helps to determine the amount of energy savings that can be achieved in a cost-effective manner, providing an option to incandescent-based ceiling-fan light kits for consumers. The team included the California Lighting Technology Center and Hunter Fan Company. The California Lighting Technology Center worked with Hunter Fan Company to design and develop prototypes for a retrofit light-emitting diode lighting fan kit. Also, a prototype exhaust fan with light-emitting diode lighting was developed. Hunter Fan Company has shown interest in commercializing a kit based on the prototype versions.
- Advanced, Energy-Efficient Light Emitting Diode Lighting for Residential and Commercial Applications sought to develop a light emitting diode-based downlighting system for use in homes and commercial buildings based on the patented Scattered Photon Extraction technology. The technology, developed by the Lighting Research Center, has been shown to improve significantly the efficacy and light output of current generation light-emitting diode technology. The Lighting Research Center directed this project. The Lighting Research Center developed and tested recessed downlight prototypes using the SPE technology. It is exploring commercialization opportunities.
- Programwide Market Connections sought to provide project-specific information to various national and California stakeholders and evaluate codes and standards implications. This accelerates broad market adoption by various groups involved in lighting commercialization and energy-efficient strategies, and commercial and residential consumers. The team included the New Buildings Institute, the California Lighting Technology Center, and Architectural Energy Corporation. The market connection efforts have included presentations and attendance at various conferences and industry trade shows, along with electronic posting of information on the Lighting California's Future participant websites. Marketing material for commercialized products also has been developed.

Conclusions

Lighting California's Future was a cohesive program of integrated programmatic lighting research designed to meet the ever-evolving needs in California for energy efficiency, demand response, and alternative energy use by commercializing technologies. Throughout this program, the research organizations and manufacturing partners have focused on not only

producing energy-efficient products and systems, but also providing environmental benefits, non-energy benefits, which help the environment like air quality, and connecting to the marketplace.

Recommendations

The main recommendations are to continue with demonstrations of the Lighting California's Future technologies to drive market connection efforts and commercialization. Support from the California utilities is crucial.

Benefits to California

The goal of the program was to produce technologies capable of delivering electrical load savings and peak load reductions each year. Based on individual project estimates, the total energy consumption savings is estimated to be 253 gigawatt-hours with an estimated peak load reduction of 39 megawatts[1].

Reducing the requirements for electrical power that is produced primarily with fossil fuels creates a series of resource reductions that cascade into a multitude of public benefits. Most obvious is that saving energy saves fuel and creates less pollution.

The reduction in energy use will have a commensurate reduction in power plant emissions in California, as shown below[2]:

- Carbon dioxide (CO_2) emission reductions 140,654 metric tons
- Sulfur dioxide (SO_2) emission reductions 103 metric tons
- Nitrogen oxides (NO_x) emission reductions 120 metric tons

Personal benefits not related to energy include improved lighting and daylighting in commercial and residential spaces with more personal control in some installations, which improves occupant comfort and productivity, and may positively affectoccupant's health and focus. Also, property values may increase with the installation of these emerging technologies as part of building certification programs, such as the Leadership in Energy and Environmental Design™.

For more information about these individual reports please visit the Energy Commission's website at http://www.energy.ca.gov/research/.

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1 Data based on California Energy Commission Commercial and Residential lighting usage by building type and floor area. The estimates are calculated using 1 percent market penetration and 20 percent energy efficiency gain.

2 Calculations based on EPA egrid, http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html, using WECC subregion.

1.0 Introduction

1.1. Background and Approach

Lighting California's Future Research Program (LCF) was a $3.7 million project under the California Energy Commission Public Interest Energy Research (PIER) Program that focused on lighting technologies for buildings. The program featured nine technical projects and a crosscutting market connection project. The goals of the program were to deliver advanced, energy-efficient lighting technologies, products, systems, and implementation tools and to bring them to the market for the benefit of the citizens of California.

Architectural Energy Corporation (AEC) managed the program and coordinated with the individual project teams, communicated with the Energy Commission and the Program Advisory Committee, and participated in the Market Connection and Codes activities.

Research organizations included the California Lighting Technology Center (CLTC) and the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute. Many manufacturers participated in the LCF, including Solatube International, Inc., NEV Electronics, Inc., Finelite, Inc., Adura Technologies, Samsung, Capri Lighting, Cooper Lighting, and Hunter Fan Company. These manufacturers provided match funding in the form of technical and marketing expertise, prototype development, and demonstration support for individual projects. Several other manufacturers participated indirectly, including Lutron, Universal Lighting, and Convia.

The New Buildings Institute (NBI) led the market connections activities with extensive involvement from the CLTC marketing staff.

In addition, Southern California Edison (SCE) and Sacramento Municipal Utility District (SMUD) provided match funding support for this program. The support involved developing and testing new demand response (DR) technologies, providing technical input to the project teams, and supporting demonstrations in their service territories.

Program advisors that provided input included representatives from Pacific Gas andElectric, SCE, Sempra, SMUD, Integrated Design Associates, Inc., Heschong Mahone Group, and the National Renewable Defense Council. Representatives from Roseville Electric, New York State Energy Research and Development Authority (NYSERDA), the Collaborative for High Performance Schools, the California Institute for Energy and Environment (CIEE), and the Consortium for Energy Efficiency also were kept updated on the technical product development.

The program integrated lighting research designed to meet the ever evolving needs in California for energy efficiency, DR, and alternative energy utilization by commercializing more energy-efficient technologies. Throughout this program, the research organizations and manufacturing partners have focused on not only producing energy-efficient products and systems, but also providing environmental benefits and non-energy benefits and connecting to the marketplace.

Specific objectives of this Program were:

- Carry out nine energy-efficient lighting research projects with the potential collectively to deliver electrical load and demand savings.
- Create lighting products and systems that have evolved through the key stages of concept development, design, prototype development, demonstration, and documentation of results with input from stakeholders.
- Demonstrate that non-energy goals have been addressed, such as improved occupant comfort, better quality of illumination, and reduced operation and maintenance.
- Provide linkages to California markets through documented cost-effectiveness for the Title 24 Building Energy Efficiency Standards process, through specific strategies appealing to the California marketplace, and through communication of results to California lighting industry groups, end users, codes and standards groups, and utilities.

1.2. Benefits to California

Reducing the requirements for electrical power that is produced primarily with fossil fuels creates a series of resource reductions that cascade into a multitude of public benefits. Most obvious are the facts that saving energy saves fuel and creates less pollution. Less obvious are that saving energy decreases water consumption and saves transportation fuels, such as for trains that carry coal to power plants. Noise is reduced when the number of trains is reduced, as is the pollution and other consumables associated with transportation. Light sources that have long useful lives reduce the material that goes into landfills.

For individuals, less risk of interrupted power from overburdened electrical grid systems provides increased security. Less money will be spent on buying power that has the potential to strengthen California's economy. The PIER research investments have far reaching impacts today and for future generations.

Personal benefits include improved lighting and daylighting in commercial and residential spaces with more personal control in some installations, which improves occupant comfort and productivity, and may positively impact occupant's health and focus. Also, property valuation may be increased with these emerging technologies.

1.3. Report Organization

The program is designed around the areas of daylighting, DR, integrated lighting systems, and solid-state lighting. This report is organized to present the approach and goals, outcomes, conclusions, and recommendations for each of the technical projects and the one crosscutting market connection project within this program.

Subsequent sections are as follows:

- Improved Performance of Tubular Daylighting Devices (TDD) (Section 2)
- Cost-Effective Demand Response (Section 3)
- Integration of Lighting Controls With Utility Demand Response Signals (Section 4)
- Retrofit Integrated Classroom Lighting System (Section 5)

- Wireless Integrated Photosensor and Motion Sensor Lighting Control System (Section 6)
- Advanced Light-Emitting Diode Downlighting Systems (Section 7)
- Novel Light-Emitting Diode Downlights (Section 8)
- Smart Light-Emitting Diode Lighting in Residential Fans (Section 9)
- Advanced Energy-Efficient Light-Emitting Diode Lighting for Residential and Commercial (Section 10)
- Programwide Market Connections (Section 11)

2.0 Improved Daylight Performance of Tubular Daylighting Devices

The purpose of this project was to develop commercially available direct/indirect tubular daylighting devices (TDD) diffuser options that significantly reduce discomfort glare from the diffuser surface. Reducing glare would allow this potentially cost-effective daylighting solution to offer the visual comfort desired by both building occupants and lighting professionals to meet the requirements of many lighting applications. In combination with turning off electric lights when sufficient daylight is available, more widespread adoption of TDDs would help to reduce lighting energy consumption and the contribution of lighting energy consumption to peak electricity demand.

For this project, researchers at the CLTC partnered with TDD manufacturer Solatube International, Inc., who also provide match funding.

2.1. Approach and Goals

TDDs capture light through a dome on a building's rooftop and channel the light to interior spaces through a tube with an interior reflective system. These devices are effective in bringing daylight into a building's interior spaces. The latest reflective tubing technologies are so effective that, with today's commercially available products, the amount of daylight reaching the diffuser (the surface that building occupants see in the ceiling) is so great that it can create visual discomfort, also termed "discomfort glare" or simply "glare."

For this project, researchers developed reduced-glare direct/indirect diffuser options for Solatube International TDDs. The CTLC measured and analyzed the performance of current Solatube International TDDs that use direct diffusers, participated in discussions of desired performance characteristics and criteria for improved diffuser options, developed and tested a procedure for simulating proposed diffuser designs using high dynamic range (HDR) imaging processes, measured and evaluated prototypes that Solatube International designed and built, and made recommendations for further development and testing of the most promising new diffuser design.

Specific objectives were to:

- Develop conceptual, commercially viable direct/indirect diffuser options for detailed photometric analysis.
- Produce 2-3 commercially viable diffuser options for prototyping, physical testing, and evaluation relative to performance criteria established by the project team and advisory committee during a project kick-off meeting, which photometric analysis indicates will produce a minimum of a 40% uplight component.
- Develop one commercially viable product solution and perform detailed photometric testing and analysis to develop the required photometric data required to support and launch the diffuser option to the general public.
- Produce design guidelines to support the application and use of the new commercially available diffuser options by architectural and lighting design practitioners.

Specific activities included:

- Measuring the current daylight distribution of Solatube International skylights.
- Designing optical element(s) that will improve distribution.
- Simulating daylight distribution using ray-tracing software.
- Evaluating simulation results.
- Refining and evaluate the improved design.
- Developing prototype of final design.
- Demonstrating performance of prototype.
- Conducting discussions with utility staff.

2.2. Project 2 Outcomes

The primary TDD outcomes of this project are as follows:

- Development of design goals for a new TDD direct/indirect diffuser.
- Discovery of the challenges of using ray-tracing software for reproducing results obtained under real sky to determine the optical performance of skylights.
- Development of several prototypes, one of which showed promise to meet the design goals.
- Refinement of the promising prototype and installation in test spaces at the manufacturer's headquarters.
- Identification of additional issues to be resolved with the prototype.
- Recommendations to undertake field testing and perform rigorous comparison testing of the old and new diffuser designs.

In July 2007, CTLC researchers performed initial measurements of Solatube International TDDs using the first-generation daylight engine (dome and tubing assembly) under sunny skies at Solatube International headquarters in Vista, California. The maximum luminance of this existing product with a direct diffuser was 86 kilocandelas per square meter (kcd/m2). This is significantly brighter than the luminance of a typical T8 fluorescent lamp, which is in the range of 15 kcd/m2.

Based on these initial measurements, the Solatube International design team, with input from CLTC, selected 20 – 30 kcd/ m^2 as the target maximum luminance for an improved TDD with indirect diffuser. At this luminance, the product would still create glare, but it would create much less than the existing direct diffuser and still elicit the occupants' perception that the space is daylighted. Table 1 shows the initial product specifications.

Table 1. Initial product specifications for new prototype direct/indirect TDD diffuser

Performance Goals
Desired Spread of Light Cast light evenly on ceiling plane up to 7-feet from fixture center Support fixture spacing of 10' – 12' on center

Performance Goals
Acceptable Suspension/Pendant Length Ideal: 6” – 12”
Ceiling Contrast Uniformity Benchmark Criteria: Range of 15:1 to 20:1 for daylight source
Max Luminance of Fixture Benchmark Criteria: Range of 20,000 to 30,000 cd/m² for daylight source
Visual Comfort Probability (VCP) and/or Universal Glare Rating (UGR) UGR ≤ 19 (CIE max recommendation for office space) VCP ≥ 70
Light Distribution (Up to Four Options) Not to Limit “View of Sky” Direct/Indirect: 80% Downlight / 20% Uplight and 60% Downlight / 40% Uplight Indirect/Direct: 40% Downlight/ 60% Uplight and 20% Downlight / 80% Uplight

Source: Architectural Energy Corporation

To accelerate the design process, CLTC researchers used lighting-simulation software to determine the performance of a sample Solatube International TDD installed at the Western Cooling Efficiency Center (WCEC) at the University of California, Davis. Simulations would have allowed the design team to evaluate more configurations more rapidly than would be possible by building and measuring prototypes. However, the simulation results did not correspond to the measured data for the TDD. Although the order of magnitude was correct, the shape of the intensity distribution was very different.

Solatube International developed and refined the direct/indirect prototype and installed it at its headquarters in two settings: 1) open-plan office, side by side with TDDs using the original diffuser and 2) a private office. In addition to the new diffuser, the new prototype also used a new dome and tube design (future-generation daylight engine) that improved light distribution. The CLTC staff performed luminance measurements of both diffusers in October 2009.

Although the new prototype direct/indirect diffuser does not display the extremely bright hot spots that are characteristic of the original diffuser, very bright areas are still visible. Additionally, because the new diffuser protrudes into the interior space below the surface of the ceiling, it is a larger object in the building occupants’ field of view than the old diffuser, which was flush with the ceiling surface, and it can still cause significant glare. In the installation in an individual office setting, the new TDD appears more visually comfortable than the original TDD, at least for the first few minutes an occupant is in the room.

The measurements indicate that the new system's maximum luminance, which is 26 kcd/m^2, is about half of the maximum luminance of the original system (57 kcd/m^2). The absolute values of these measurements are not strictly comparable to the original system because of the significant difference in sun position and intensity between October (when researchers measured the new prototype) and July (when researchers measured the original system, the maximum luminance exceeded 80 kcd/m^2). Furthermore, the fact that the new prototype was fitted with the future generation Daylight Engine in addition to the new diffuser introduces the possibility that at least some of the reduction in luminance is not due completely to the new diffuser.

Figure 1 shows the new prototype diffuser with new tube and dome, installed at the Solatube International headquarters. Figure 2 shows the luminance measurement results for the new prototype.

Figure 1. New prototype TDD with new dome, tube, and diffuser

Photo Credit: Architectural Energy Corporation

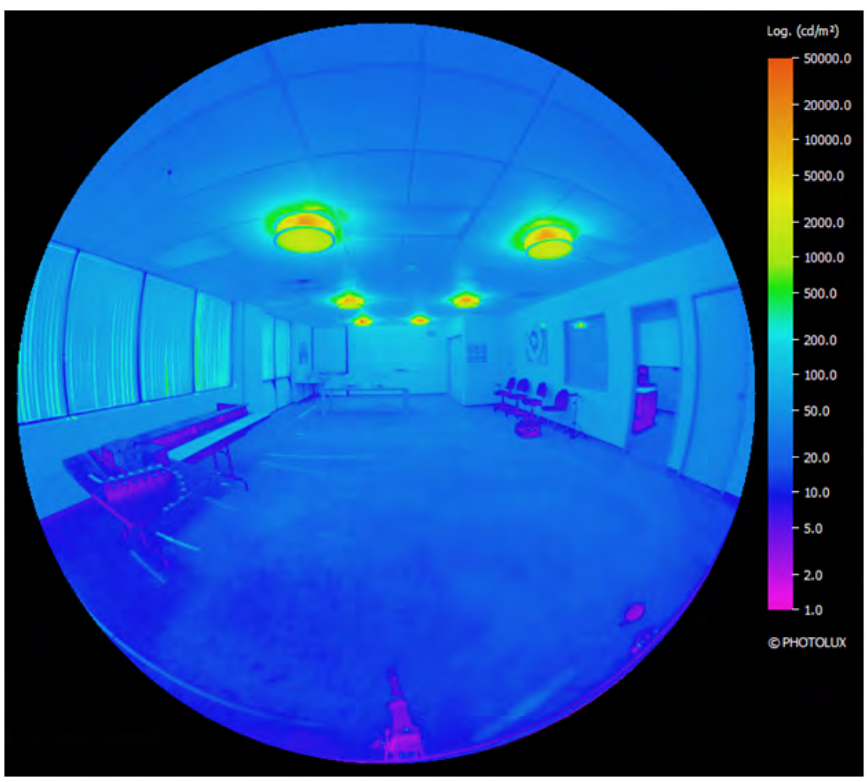

Figure 2. Luminance image and measurements for new prototype with new dome, tube, and diffuser

Source: Architectural Energy Corporation

The average luminance for the area of the field-of-view subtended by the diffuser is lower for the new system, which significantly lowers the ratio of average fixture luminance to the darkest parts of the ceiling in between fixtures (approx. 216:1 for the original TDD, 76:1 for the new prototype). However, computed glare indices (Unified Glare Rating) are similar for both systems—in the range of 23-24—which is well above the maximum recommended value of 19 for offices.

For some applications such as individual offices, the new product with indirect diffuser utilizing a future generation daylight engine may improve visual comfort. However, it still falls short of the quantitative goals set at the beginning of the project. A natural next step would be to demonstrate the new product in the field, both with building occupants familiar with the current TDD product and with occupants not familiar with TDDs, in order to determine whether the developed direct/indirect diffuser results in increased acceptance.

At present, producing more prototypes for a field demonstration is not part of Solatube International's plans. Although the ultimate goal and desire of this project were to apply the technologies developed to a demonstration project, it was determined that the viability of retrofitting an existing installation would be problematic because of the extent of changes to the daylight engine. As an alternate demonstration, it was proposed to apply the components that were released in 2008 during this program to an existing space and conduct detailed building analysis and occupant surveys to assess the improvements and their acceptance by building occupants as well as study the energy savings related to applying this enhanced daylighting solution. Unfortunately, the selected site was unable to make the necessary modifications to their existing lighting system necessary to complete the study in the allotted time.

2.3. Project 2 Conclusions and Recommendations

2.3.1. Conclusions

Although the new prototype produced for a TDD product represents a step toward meeting the design specification for the project, it still produces glare. Moreover, the incorporation of a future generation daylight engine with the new diffuser in the prototypes produced for this project made it difficult to isolate the impact of the new diffuser in reducing glare.

Photometric simulations using lighting-simulation software would have enabled a more rapid design process for this project. With the available resources, however, the simulation process did not produce accurate results when compared with measured data, using the simulation software tools that were available at the time. Since the start of this project and the time when the initial photometric studies were initiated, significant advancements have been made in the ability to perform photometric modeling of advanced TDD systems, incorporating new, more exacting processes for inclusion of actual sky maps. To use photometric simulations to develop optical components for skylights requires more in-depth validation than was possible for this project, in addition to more precise data about product materials.

The significant evolution of the TDD daylight engine that occurred simultaneously during the direct/indirect diffuser development process provides new and critical optical control of the constantly variable daylight resource that is necessary to provide the necessary controlled optical input to the diffuser's daylight delivery system. With the optical control afforded by the future-generation daylight engine, it was shown that the potential for shifting patterns of

redirected light across the ceiling plane was substantially reduced. This greater optical control also allows for improved optical design of the direct/indirect diffuser's optical elements, since the variability of daylighting input angles to the diffuser's optical system was greatly reduced.

In all, more than 20 variations of direct/indirect and indirect/direct diffuser design were designed, constructed, and field-observed/tested by Solatube International at its Vista, California-based Product Development facility. The field measurement of the various direct/indirect diffuser prototypes clearly indicate the viability of direct/indirect diffuser options and their ability to reduce potential glare to acceptable levels in visually critical environments, when paired with the future generation of TDD daylight engines. Unfortunately, the concurrent and significant evolution of the daylight engine system forced delays in Solatube International's diffuser design and testing schedule, which impacted the ability to produce final, acceptable diffuser products in the project's time frame.

The development of these direct/indirect diffuser prototypes was done by Solatube International's researchers independently from the CLTC researchers, with the latter involved only in performance evaluation. While this kind of arrangement minimizes intellectual property concerns for the manufacturer, in this case, it probably negatively impacted the likelihood of achieving solutions that met the design goals, especially because the difficulties with the computer simulations significantly reduced the number of design-evaluation cycles.

2.3.2. Recommendations

The results obtained in this project indicate that the use of lighting simulation programs to determine the lighting performance of TDDs needs further validation to ensure its accuracy for product design purposes.

Since the luminance measurements of the direct/indirect diffuser prototype were conducted on a TDD that also had an improved dome and tube, it would be valuable to repeat these measurements side by side with a direct diffuser mounted on the same type of dome and tube, so that the performance of the two diffusers can be directly compared.

It would be very valuable if the prototype developed in this project were tested in a field setting. This would be best done with both occupants who have worked under existing TDD products and occupants new to TDDs. The first can provide a sense of whether the prototype represents an improvement over existing TDD diffusers, whereas with the latter it may be possible to understand the level of acceptability of this kind of product to the general public.

In future product development research and development of products, a more collaborative industry-university design process will probably be more likely to achieve solutions that meet the design goals.

2.3.3. Commercialization Potential

As of the conclusion of this project, Solatube International has developed product designs that have commercialization potential, but further refinement will be needed in order to develop products suitable for widespread application. At this time, further refinements to the daylight engine assembly are also under development, which will further change the design requirements for a commercialized direct/indirect diffuser design.

Solatube International recognizes the value and potential of the new technologies explored, developed, and evaluated during this project; and portions of the technologies developed have already been deployed, and additional features are currently being incorporated into future product design. While true direct/indirect diffusers have not been commercially produced, other significant glare reduction advancements developed during this project by Solatube International were successfully launched and commercialized in 2008 as the future generation daylight engine and have been widely accepted around the world in visually sensitive environments.

The market need for these advanced technologies has been demonstrated through the fact that 45% of Solatube International's commercial product installations incorporate portions of these new product offerings. The deployment of additional features in future product designs from Solatube International is expected to even further enhance the adoption of these unique optical-daylighting technologies.

2.3.4. Benefits to California

Tubular daylighting device systems have potential to light the building core, which is not reachable by conventional skylights or windows. When TDDs are coupled with control systems that regulate lights in response to daylight levels, the resulting lighting energy savings are greatest at times of peak grid demand. A reduced-glare TDD will likely be more widely accepted by building occupants than current products because of increased visual comfort and therefore would result in greater lighting energy savings than are possible with today's commercially available products.

Based on 1 percent market penetration and energy savings potential of 20%, when TDDs are combined with electric lighting controls, electric consumption savings of 66 gigawatt-hours (GWh) and demand savings of megawatts (MW) could be achieved for large office building and residential applications.

3.0 Cost-Effective Demand Response (Project 3)

The Cost-Effective Demand Response (CEDR) project sought to introduce a novel DR lighting control technology that can be easily retrofit to existing buildings. The new system would be capable of receiving a utility DR signal and transmitting, over the building power lines, a load-shed signal to multiple receiver devices. The project team included NEV Electronics, who also provided match funding, and the CLTC.

3.1. Project 3 Approach and Goals

The principal feature of the CEDR system is the ability to retrofit into existing buildings of all types, from residences to hotels, office buildings, and even industrial sites. No major rewiring is required; transmitting devices are installed at the electrical panel, and receiving devices are installed at loads, in the ceiling above wall switches or outlets. Loads are shed upon command. A safety feature prevents shedding unless both switches in a bilevel system are on, so the user can override which half is shed. Unlike competing and foregoing concepts, CEDR uses low-cost, robust devices that are easy to install in existing or new buildings. CEDR is capable of plug-and-play operation and does not require complicated setup or programming. It solves the problem of how to control many lights with just a few receivers.

While the most attractive case is shedding nonessential lighting, CEDR technology can also shed appliance, air conditioning, and almost any other electrical load during power emergencies. The CEDR system can be used as a communication channel by future products that address energy conservation, allowing personal dimming control and dimming in response to daylight. The reuse of already installed and paid for CEDR technology will make those future products economically viable and provide an opportunity to sell more devices to existing customers.

The goal was to develop, refine, and demonstrate a commercially viable, low-cost control system for achieving DR control over bilevel lighting loads in commercial buildings.

Specific objectives were to:

- Develop and demonstrate a control device that is capable of receiving a utility demand reduction signal and transmit, over building power lines, a load-shed signal to multiple receiver devices.
- Develop and demonstrate receiver devices that are capable of receiving a load-shed signal from a control device and respond by turning off one of the connected loads on a bilevel switching lighting system.
- Demonstrate that the method of transmitting the load-shed signal is robust enough to reach 75% or more of the connected receiver devices in field test applications.
- Demonstrate that the method of transmitting the load-shed signal does not alter building power quality to the point that it leads to the failure of any connected electrical devices.

Specific activities included:

- Performing market analysis and development of product specification.
- Developing and refining CEDR System.

- Conducting detailed laboratory evaluation of CEDR system.
- Producing prototypes for field test.
- Conducting field tests.
- Identifying and connecting with manufacturing partner(s).
- Providing technical assistance to manufacturing partner(s)

3.2. Project 3 Outcomes

Proof of concept prototypes were built and tested. NEV Electronics developed the various components and built the CEDR prototypes. The CLTC tested the prototypes at its facility in Davis, California. Modifications to the prototypes were identified and made. This development process was iterative in nature until all of the components seemed suitable for more robust field tests. Figure 3 shows the system.

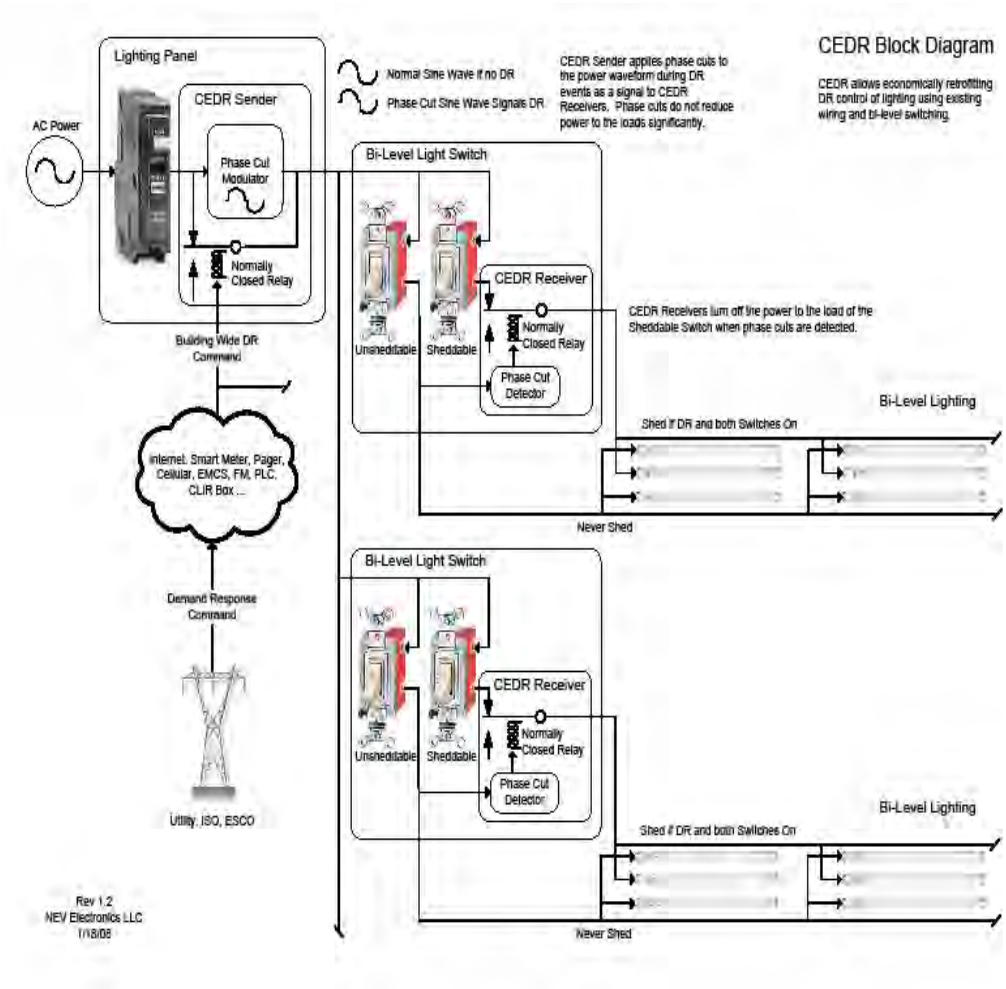

Figure 3. Block diagram of the CEDR System

Source: Architectural Energy Corporation

Two demonstration sites were identified where the CEDR system could be placed in the spring of 2008. The plan was to install the system, monitor the summer DR events as alerted by the investor-owned utility (IOU), and measure the corresponding performance. Demand savings would then be calculated along with occupant feedback at the two sites. However, the facility

managers for the test sites requested Underwriter Laboratories® (UL) approved products due to the connectivity to the building's electrical system. Given the request, the focus shifted to obtaining UL approval of the CEDR components prior to proceeding with field tests. The process of gaining approval proved to be lengthy but highly valuable.

Based on UL recommendations received in late spring 2009, NEV Electronics had to reassess and further modify the system at the component level. Consequently, the demonstration phase was delayed, and it was determined that the system could not achieve robust site testing during the term of the LCF program. NEV Electronics plans to continue development and testing of the CEDR system and strive for UL certification with private funding. The timetable for a full product release has not been specified.

The CLTC, under direction of AEC, searched for DR systems that were already commercially available. One system, which appeared to be promising, contained a component that used a powerline communication protocol. However, the system proved unable to broadcast DR commands to the lighting control devices in a small commercial application. This component was not available in a more robust communication protocol.

3.3. Project 3 Conclusions and Recommendations

3.3.1. Conclusions

Within this research project, the initial functionality of CEDR was demonstrated in a test office. The CLTC demo office installation had all the elements of CEDR, reliably shedding the lighting load when commanded and not interfering with the lighting that it controlled. The research project also paved the way towards a promising UL-certified DR product.

This research showed the DR load with the greatest potential for CEDR is bilevel switched lighting. Bilevel lighting was deemed of high potential because:

- No economically viable lighting retrofit DR solutions exist for bilevel switched lighting served by a single circuit breaker, according to the market industry survey.
- Only non-critical lighting loads will be placed under CEDR's control, and safety features are built in to avoid turning off all the lights.
- Unlike with thermostat setback DR, the effects of shedding lighting load do not decay over the course of the load shed.
- Many programs exist to set back thermostats for DR. The approach is thus sufficiently well-served and is not a prime candidate for CEDR.
- Plug load studies to date have not shown sufficient economically suitable DR candidates.
- Large single-device loads like large water pumps are more economically shed with dedicated load-shed receivers that actuate existing controls to shut down the devices.

The CEDR technology provides a viable business opportunity because it targets a poorly served market and offers a potentially high profit margin with little investment. Because CEDR is a low-cost method of delivering the utility DR signal to commercial buildings, it has strong potential to be selected by utilities considering various DR alternatives.

The key risk factor is that DR is an incentive-driven business. Variations in utility rebate programs can dramatically affect the CEDR business model. Success of DR products like CEDR hinges on successful field trials, regulatory approvals of DR incentive programs, acceptability of load shedding by office occupants, and high volume sales that hold price points low.

Electric utility DR incentive programs have been endorsed and institutionalized by the California Public Utilities Commission. Although not necessarily mature, the DR market is fairly established with a number of growing, solvent companies actively promoting and participating in utility DR incentive programs.

DR programs typically have large minimum load-shed requirements that may exceed the load-shed potential of lighting in an individual building. DR aggregators exist to allow smaller customers to participate. Smart meters are being deployed throughout California and have the potential to make participation in DR programs easier.

UL certification is essential to the success of this product because field demonstrations are essential to convince the DR community that CEDR is effective, to confirm occupant acceptance, and to show that productivity is not negatively affected.

One key technical risk for CEDR is that power quality regulations are under discussion and may cause changes to the size of the phase cuts presently used in signaling.

3.3.2. Recommendations

The main focus is to find a manufacturing partner to license the CEDR patents from the University of California. Another option is to work with an energy service company (ESCo) to participate in product commercialization with a startup manufacturing business. ESCos are an especially suitable partner or sales channel because they have a base of customers that typically do not have a lighting DR solution and should be receptive to expanding their DR participation.

Other recommendations are to:

- Continue with product development based on UL recommendations. Develop a set of hardware that demonstrates the principles and functionality with an installed price that is economical for at least the best cases.
- Find, install, and monitor several field test sites. Record the installation times, and refine the estimates for calculating payback periods. Create case studies based on the test site results.
- Focus on the bilevel switching receiver and delay development of the wall plug and power supply receivers that may not be economically viable at this time.
- Focus on large commercial office buildings as the best economic fit. Large open offices have a favorable ratio of ballasts per bilevel switch, which minimizes the number of CEDR receivers required. A 277 volts (V) lighting is common, which more than doubles the payback compared to 120V. Large office buildings typically have multiple lighting circuits in the same panel, minimizing the wiring required between the device that receives the shed signal from the utilities and multiple CEDR senders.
- Work with a manufacturer of wall switches to integrate the CEDR receiver with dual switches as a drop-in replacement for bilevel switches. Work with a manufacturer of circuit breakers to integrate the CEDR sender into a snap-in 16 A circuit breaker. The

signaling element of the CEDR sender would have to be redesigned to dissipate less heat. Together, these changes would make installing CEDR in retrofit or new applications very fast, easy, and inexpensive.

Once CEDR is a commercially available product, it would be a viable DR candidate for the California Investor-Owned Utilities' Emerging Technologies Programs.

3.3.3. Commercialization Potential

Installing CEDR in retrofit applications is fast, easy, and inexpensive. The system is composed of senders installed at the circuit breakers on lighting circuits and receivers installed at the bilevel switches. Installation and maintenance costs are minimized because the existing electrical wiring in the building is used for transmitting signals between the components.

The CEDR product targets the huge commercial building retrofit market, specifically buildings that have bilevel light switching. The technology is not designed for the new construction market primarily because there are other technology solutions that are more likely to dominate this sector. The CEDR technology also could be considered for the residential market, but residential lighting adds a relatively small amount to summer peak load and has fewer lights per switch than commercial buildings.

It is anticipated that CEDR will be structured around the successful DR and ESCo model. ESCos and DR companies provide free consulting services; a building lighting inventory is produced to identify the potential lighting load reduction of the commercial building, and historical energy usage and cost data are used to triangulate and to assess peak load characteristics. The ESCo performs the analysis and then presents a proposal to the customer that features no upfront costs; periodic payments are made through a combination of savings, utility incentives, and sometimes federal and state tax credits.

3.3.4. Benefits to California

As a DR device, CEDR significantly reduces peak demand. Initial estimates indicate that 20 to 30 percent of the building's lighting demand, or 7 to 10 percent of total demand, can be shed and maintained off during the DR event. This means a potential demand savings of 289 MW from bilevel switched lighting in all California office buildings. Because 100% market penetration is not reasonable, a more realistic estimate of benefit to California is 3 MW demand savings in office buildings and another 4.8 MW savings in other building types that have bilevel switched lighting.

4.0 Integration of Lighting Controls With Utility Demand Response Signals (Project 4)

The Integration of Lighting Controls With Utility DR Signals project aimed to develop, test, and demonstrate lighting control systems that automatically respond to California utility DR signals. The project team included SCE, who also provided match funding, and the CLTC.

4.1. Project 4 Approach and Goals

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

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

Lighting is a significant proportion of electrical energy use[3] in California. Part of that, especially in commercial buildings, occurs during the daytime and therefore coincides with the cooling season's periods of peak demand on the electricity grid. This coincidence makes lighting load a very suitable candidate for incorporation into the DR infrastructure.

The goal was to develop, test, and demonstrate lighting control systems that automatically respond to DR signals sent by California utilities.

Specific objectives were to:

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

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3 According to the California Energy Commission (Energy Commission, 2003), residential lighting represents 9% of California electricity endues, and commercial lighting represents 12%.

- Develop guidelines to assist in widespread application of complete, automated lighting DR systems through collaboration with California utilities.

Specific activities were to:

- Identify and evaluate technologies for California utility DR signals.
- Identify and evaluate technologies for lighting controls in buildings.
- Develop complete systems using selected technologies.
- Test and refine complete automated DR lighting systems in the laboratory.
- Identify field test sites in the SCE and SMUD territories.
- Deploy refined lighting DR systems to field test sites.
- Test field reliability of experimental DR systems.

4.2. Project 4 Outcomes

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

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

The research team at SCE selected and undertook a comparative evaluation between three advanced lighting control systems (ALCS) that were commercially available from Lutron Electronics, Inc., Universal Lighting Technologies, and Convia. The following figures show the pendant lighting from the three manufacturers.

Figure 4. Lutron suspended lighting system at test site

Photo Credit: Architectural Energy Corporation

Figure 5. Universal suspended lighting system at test site

Photo Credit: Architectural Energy Corporation

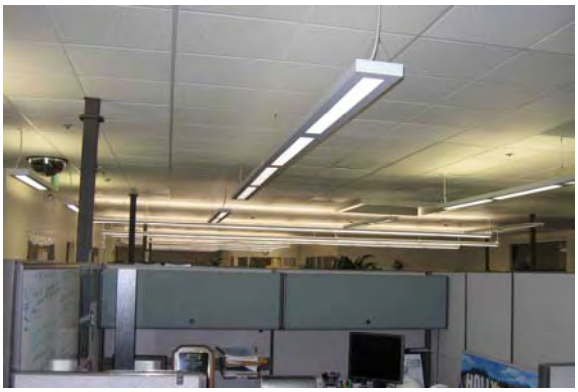

Figure 6. Convia suspended lighting system at test site

Photo Credit: Architectural Energy Corporation

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

DR testing was performed by SCE personnel, who initiated the test commands from an offsite office. Testing was conducted for four scenarios (right now, hour of, later same day, and next business day). During the test periods, recording intervals were reduced to one-minute intervals. Part of the testing involved changing the lighting level to five different settings, while a field engineer witnessed each change and made measurements. The settings were 10%, 25%, and 50% below maximum tuned power settings (90%, 75%, and 50%). After each drop in lighting power, the next step was to raise the lighting power setting back to 100% before the next reduction. Each setting lasted for five minutes. Figure 7 shows the DR test results for the Lutron ALCS.

All three of the installed systems were able to respond successfully to the requirements of DR operation. Relative to normal levels of operation, demand savings of up to approximately 35% were achieved during testing. Although occupant reaction was not formally evaluated, anecdotal evidence indicates that occupants did not notice the reduction in light levels, even when informed that a test was being conducted.

The three systems, being more efficiently designed than the lighting system originally installed in the test space, also delivered significant energy savings when in normal operation. For overhead lighting, lighting power density was reduced from 1.13 to 1.39 watts square foot (W/sq.ft.) in the original system to 0.49 to 0.93 W/sq.ft. for the new systems. The greatest savings for overhead lighting fixtures occurred in the Lutron building area where annualized energy use declined by 65%. The Convia and Universal systems had overhead lighting annualized energy savings of 40% and 8% respectively.

In order to determine the lighting performance of these systems both during normal operation and simulated DR tests, the CLTC staff performed horizontal illuminance measurements at several locations throughout the space. The lighting performance of the lighting system previously in operation in the space was determined using computer simulations.

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

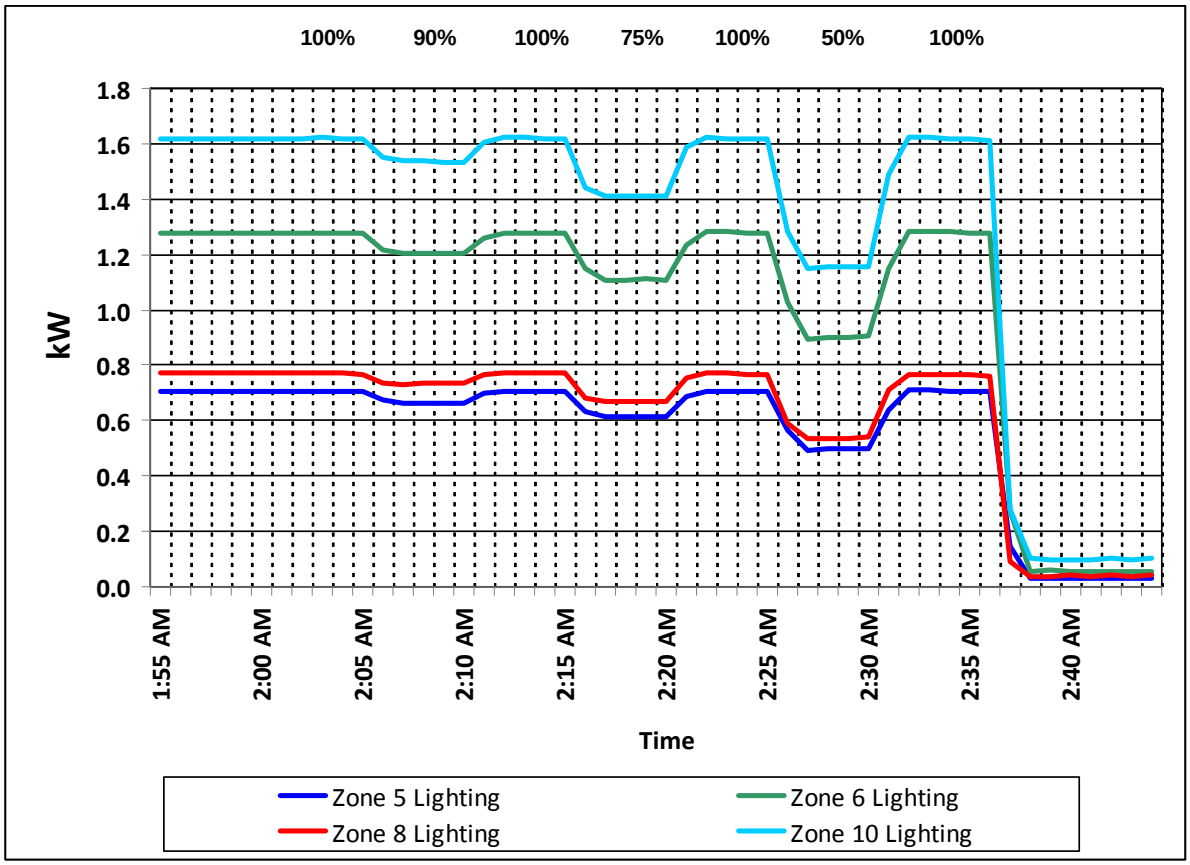

Figure 7. DR testing results for the Lutron Advanced Lighting Control System

Source: Architectural Energy Corporation

SCE has promoted the results of the demonstration portion of this project. The findings are published in the *Two-Way Connectivity With a Lighting System as a Demand Response Resource* report that is posted on the Emerging Technologies Coordinating Council website[4]. The SCE report also is provided as an attachment to this document. SCE personnel have provided numerous tours of the test site.

4.3. Project 4 Conclusions and Recommendations

4.3.1. Conclusions

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

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

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

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

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

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

Significant issues, however, need to be addressed in order for these systems to become widespread. One issue is routinely achieving correct installation and commissioning. Also, the

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

state's DR infrastructure is not fully defined, so the question of how these systems are going to interface with statewide utility DR infrastructures has not been fully answered. Finally, the initial cost of the advanced lighting control systems may be a barrier. However, as more manufacturers offer systems and market penetration increases, the initial cost should become more competitive for commercial building owners.

4.3.2. Recommendations

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

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

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

4.3.3. Commercialization Potential

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

With more widespread implementation of utility pricing schemes that increase the price of electricity at times of higher demand, the appeal of advanced lighting control systems that provide DR capability is likely to increase. The 2009-2011 goals for utility DR programs were to achieve approximately 4 to 5 percent DR penetration for the totality of DR programs (Chiu, 2009[5]), which includes residential as well as industrial customers. Given that the preferred strategy for commercial customers to meet their DR load curtailment requirements is usually to use heating, ventilation, and air conditioning (HVAC) rather than lighting, market penetration of lighting DR systems can be expected to have the potential to reach 1 to 2 percent of commercial building floor space. This could happen sooner if some of the components of these advanced lighting control systems, such as multilevel or dimmable addressable ballasts, start to be required by building codes.

4.3.4. Benefits to California

The potential impact of advanced lighting control systems with DR capability on California's peak energy demand is 7.8 MW. The values for market penetration are conservatively estimated

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

at 1 percent for selected markets such as large and small office buildings. The conservative approach is taken because of the cost, installation, and commissioning barriers.

5.0 Retrofit Integrated Classroom Lighting System (Project 5)

The Retrofit-Integrated Classroom Lighting System (R-ICLS) project sought to commercialize a cost-effective, retrofit-specific version of the Integrated Classroom Lighting System (ICLS), which is also a PIER-supported technology and has been demonstrated through many University of California (UC) and California State University (CSU) campuses. Through the UC/CSU demonstrations of the ICLS, it has been learned that installation labor contributed heavily to long payback periods that are unacceptable in retrofit applications. The research team included Finelite, Inc., who also provided match funding, and the CLTC.

5.1. Project 5 Approach and Goals

As shown in Figure 8, lighting typically represents 30% of the total electricity used in educational facilities. Accordingly, many schools are exploring cost-effective ways to retrofit the electric lighting in their classrooms. Equipment and high labor costs are viewed by school decision makers and designers as prohibitive in achieving wider campus specification in retrofit applications.

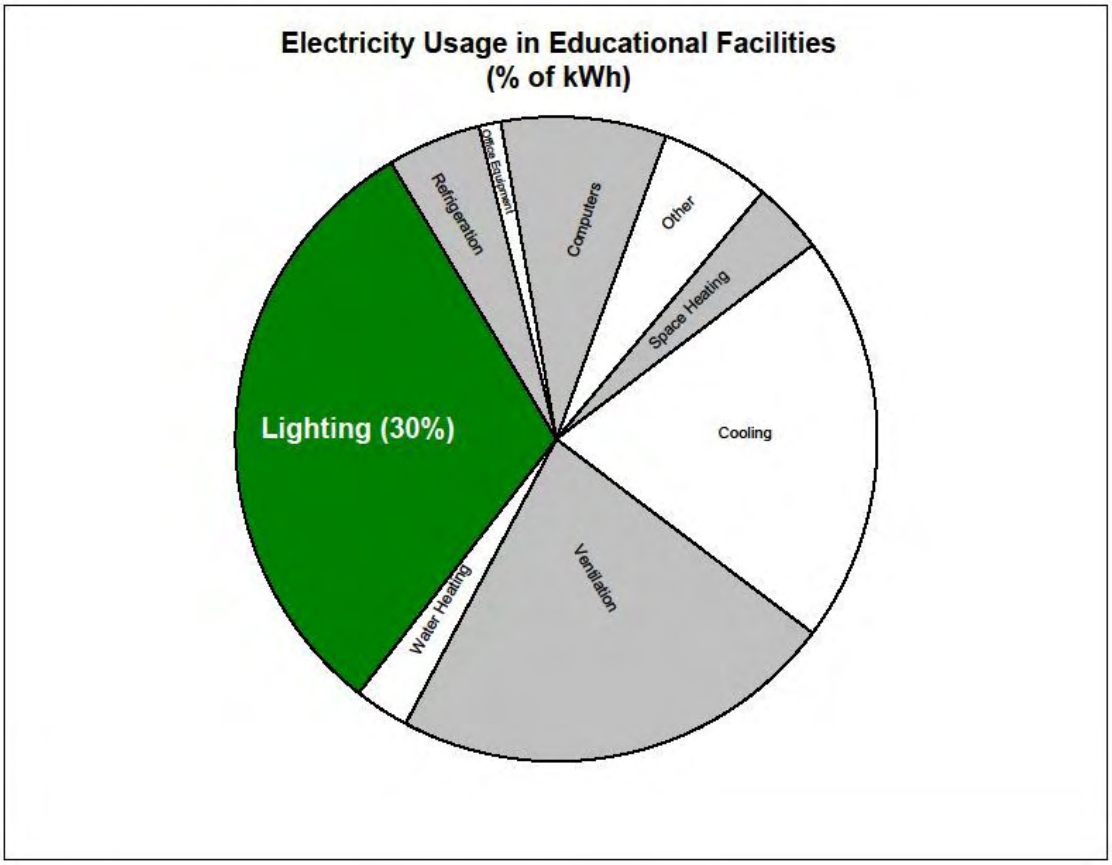

Figure 8. Electricity Usage in Schools

Source: Energy Information Admin. 2003 Commercial Buildings Energy Consumption Survey

The goal was to develop cost-effective, retrofit systems that bring the benefits of the ICLS to the retrofit market segment. Key aspects of this project were to develop a classroom lighting system that improves lighting quality, simplifies instructor scene control, and reduces energy demand

and consumption. Another part of this project was to demonstrate the systems in actual classrooms, monitoring and gathering feedback from teachers and students about the quality and functionality of the systems. Finally, the project team hoped to increase the cost-effectiveness of the R-ICLS, by optimizing the designs based on lessons learned from the field demonstrations.

Specific objectives were to:

1) Document the major opportunities and differences between new construction and retrofit with respect to lighting and control systems for classrooms and the different cost and payback requirements required for each project type. Use this understanding to develop "Good," "Better," and "Best" levels of R-ICLS to reflect different payback levels and different goals.
2) Research, design, build, and install 13 R-ICLS demonstration systems as follows:
    a) Three "Good" R-ICLS systems targeted at retrofits that need a three year or better payback based entirely on projected energy savings.
    b) Three "Better" R-ICLS systems targeted at retrofits that need a six year or better payback based entirely on projected energy savings.
    c) Three "Best-Recessed" R-ICLS systems targeted at retrofits that can have up to a 10-year payback on energy savings. This payback period would reflect a school district's interest in the many benefits associated with more control of better quality lighting in addition to energy savings.
    d) Four "Best-Pendant" R-ICLS systems targeted at retrofits that can have up to a 10-year payback on energy savings. This payback period would reflect a school district's interest in the many benefits associated with more control of better quality lighting in addition to energy savings.
3) Use independent researchers to document R-ICLS lighting performance including light-levels, energy savings, teacher preferences, installed costs, and payback periods.
4) Create a Classroom Retrofit Guide that will help school districts find out what level of retrofit approach is most appropriate given the nature of their existing classrooms and their payback criteria.

Specific activities were to:

- Survey the retrofit market.
- Survey luminaries, sensors, controls, and interconnection technologies.
- Develop different levels of R-ICLS systems.
- Deploy and monitor R-ICLS systems in classrooms.
- Develop a classroom retrofit guide.

This research effort built on two earlier studies focused on new construction and major remodels: PIER Lighting Research Program (LRP) Project 4.5 and NYSERDA Program Opportunity Notice 953[6].

5.2. Project 5 Outcomes

The standard lamp/ballast retrofit system yields energy savings. However, it offers no improvement to the performance of the classroom. The project team used the development process to identify issues and solutions associated with retrofitting typical classroom lighting. The product development effort also was guided by the standards for classroom lighting established by the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED®) and the Collaborative for High Performance Schools (CHPS).

Finelite and the CLTC surveyed the available technologies to achieve luminaire control with the following requirements: 1) eliminate the need to penetrate the ceiling; 2) eliminate the need to run excess electrical conduit or low voltage dimming lines; 3) controls could not be battery-powered or remotes (not physically mounted to the wall); 4) the system will achieve an audiovisual (A/V) mode; 5) the system must be robust in order to accommodate the long life of educational facilities; and 6) the system developed must not cause interference between classrooms.

This project developed the following categories of systems to deliver energy savings, improve the lighting quality, address the needs of today's classrooms, and meet varying payback timelines. Each category builds upon the previous list of components.

- R-ICLS "Good" was developed to bring an A/V mode into the classroom environment to meet today's new teaching methodology without the need for additional wiring or ceiling supports.
    - Replace lamps and ballasts
    - Install teacher control center
    - Install dual technology occupancy sensors
    - Use existing master on/off controls
    - Install wireless control center
- R-ICLS "Better" was developed to do more than deliver an A/V mode. In previous studies focused on new construction and major remodels, adding whiteboard illumination yielded higher user preference and reduced energy consumption.
    - Add whiteboard luminaire
- R-ICLS "Best" was provided the highest quality option. In addition to adding A/V mode to the classroom, the R-ICLS "Best" replaced the luminaires with higher performing luminaires to deliver even greater quality and energy savings to the classroom.

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6 PIER Lighting Research Program Project 4.5 and NYSERDA Final Reports are located at www.finelite.com/products/icls-overview.

- Replace luminaires with high performance recessed luminaires or high performing pendant luminaires

Existing lighting systems were retrofitted in 13 classrooms in three schools in California. Three classrooms were "Good", three were "Better", three were "Best" using recessed luminaires, and four were "Best" using pendant luminaires. Initial conditions were recorded at each site. Installation costs were recorded to capture material and labor costs for each site. A data monitoring system recorded actual usage every minute of every day for a complete teaching year (3.2 million data points). The data recorded how the teachers used the system and the energy consumed over that school year. Figure 9 shows an example of the lighting usage data gained during the monitoring period.

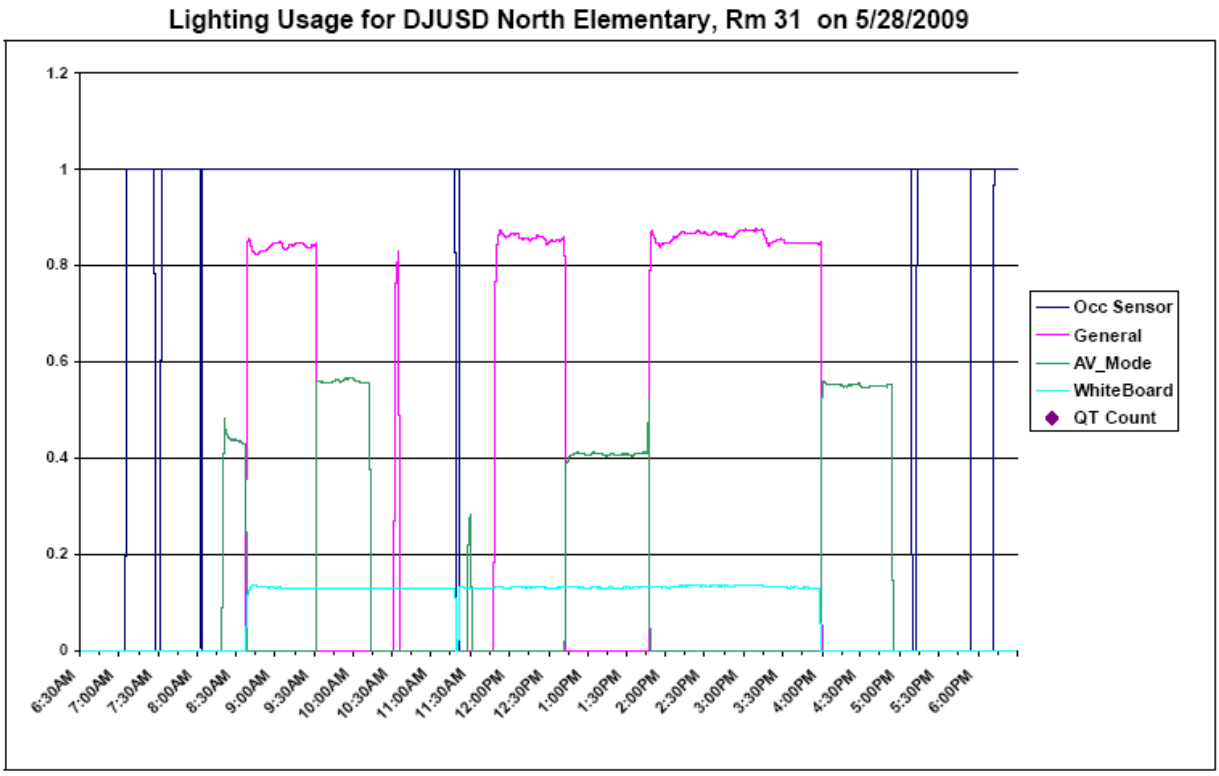

Figure 9. Lighting usage chart for Davis North Elementary

Source: Architectural Energy Corporation

Table 2 contains the pre-retrofit and post-retrofit power usage and power densities for each system. In Title 24 2008, the power density for classrooms is 1.1 W/sq.ft. for the Complete Building method and 1.2 W/sq.ft. for the Area Category method. In American National Standards Institute (ANSI)/American Society of Heating, Refrigerating, & Air Conditioning (ASHRAE)/Illuminating Engineering Society of North America (IESNA)[7] Standard 90.1-2007, the lighting power density for classrooms is 1.2 W/sq.ft. for the Building Area method and 1.4 W/sq.ft. for the Space-by-Space method.

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7 Acronyms for American National Standards Institute, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, and Illuminating Engineering Society of North America.

The Good-Recessed, Best-Recessed, and Best-Pendant systems had power density reductions of 53%, 54%, and 79%, respectively. The pre-retrofit lighting power densities were higher than code at 1.55, 1.92, and 4.26, and the post-retrofit lighting power densities were lower than code at 0.73, 0.89, and 0.88.

The Better-Recessed system had a power density increase of 14%. The pre-retrofit lighting power density, 1.18, was close to the most strict code level while the post-retrofit lighting power density, 1.35, was close to the least strict code level. The power density increase results from the addition of the whiteboard luminaire, the fact that not all of the pre-retrofit lamps and ballasts were working, and the fact that the dimmable ballasts installed consume slightly more wattage than the electronic T8 ballasts they replaced.

Table 2. Actual lighting power and lighting power densities

School	Davis Senior High	Davis Senior High	North Davis Elementary	Franklin Elementary
System Type	**Good-Recessed**	**Better-Recessed**	**Best-Recessed**	**Best-Pendant**
Pre-Retrofit Power (W)	1,488	1,062	1,728	3,544
Pre-Retrofit Power Density (W/sq.ft.)	1.55	1.18	1.92	4.26
Post-Retrofit Connected Power (W)	696	1,212	796	735
Post-Retrofit Power Density (W/sq.ft)	0.73	1.35	0.89	0.88
Retrofit Power Savings (%)	53%	-14%	54%	79%

Source: Architectural Energy Corporation

Simple paybacks for the R-ICLS options were calculated but found not to meet the original goals of the research project. The research team identified two key cost criteria required to make lighting retrofits viable for school districts: 1) $2,500 cost per classroom for R-ICLS and 2) $500 energy cost savings.

Teachers were interviewed by researchers and completed questionnaires with respect to qualitative aspects of the retrofit alternatives. Teachers readily accept R-ICLS with an A/V mode. Eight out of 10 teachers surveyed felt the R-ICLS system was better than previous systems used. No teachers reported the previous lighting was better than R-ICLS. Teachers surveyed found the lighting comfortable even with lighting levels being reduced and found location and usage of the teacher controls to be convenient. Figure 10 shows the teacher survey results for this project.

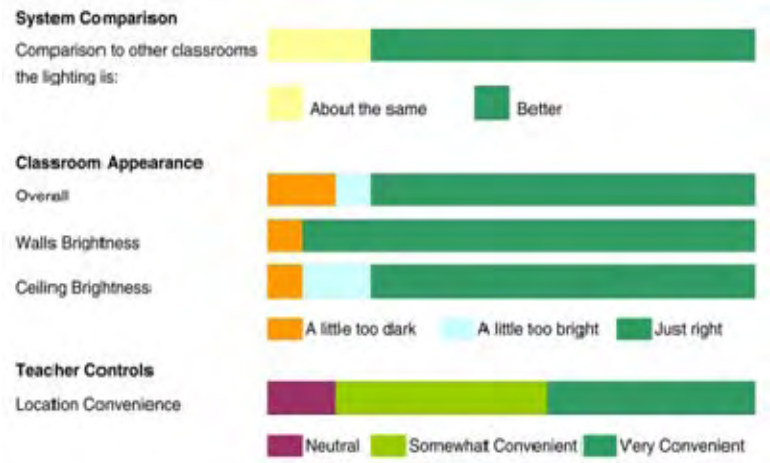

Figure 10. Teacher survey results

Source: Architectural Energy Corporation

A Classroom Retrofit Guide was developed by Finelite as part of this project. The brochure covers the reasons why a high-performance retrofit is important for today's classroom environment, the costs associated with different strategies, and the templates necessary to achieve the results described in this project. The guide references project data including installation costs, energy savings, and teacher preferences.

5.3. Project 5 Conclusions and Recommendations

5.3.1. Conclusions

Existing luminaires in the classroom drive the retrofit decision. Retrofit projects minimize costs by reducing construction labor and materials. The budget does not accommodate rebuilding space, rewiring, or adding additional ceiling supports. Replacing existing luminaires with those of similar form factor ensures the existing supports and electrical feeds can be used, drastically reducing installation costs. The R-ICLS options address the two most common fixture types used in classrooms: recessed 2x4 and suspended linear fluorescent luminaires.

The research evaluated three categories of retrofit solutions (Good, Better, and Best). However, factoring in utility incentives would make these solutions more viable for a wider range of school districts throughout California.

- R-ICLS "Good" is viable for recessed luminaire projects. The project evaluated and found the "Good" level was not viable for pendant luminaires as the unique configurations of pendant luminaires would lead to higher than acceptable labor costs to rewire.
- R-ICLS "Better" was not found to be viable for either recessed or pendant classrooms. The inability to change luminaire layouts in the recessed application leads to higher light levels, which decreases the importance of the whiteboard luminaire. The added cost and added power of the whiteboard luminaire also increases the payback timelines beyond acceptable limits. "Better" pendant range is not viable for the same reasons as the "Good".

- R-ICLS "Best" is viable for both recessed and pendant applications. Lighting quality is improved by replacing existing recessed luminaires one-for-one with high-performance luminaires, or changing the pendant luminaires and layout. This is a great solution for schools that want to improve lighting quality and energy efficiency at costs significantly below major remodels.

Retrofitting pendant luminaires requires a different strategy than recessed luminaires due to the unique construction and layout of pendant systems. Older design philosophy and luminaire efficiency led to using more luminaires than necessary. Today's luminaires are much more efficient, and two rows of luminaires can now provide what previously took three rows. The wiring of pendant luminaires impacts luminaire design making, "Good" and "Better" options not viable. The pendant retrofit decision is either simply replace the lamps with lower wattage T8 lamps or change out the luminaires. Changing luminaire layouts dramatically improves the lighting quality and yields the greatest energy savings. R-ICLS "Best-Pendant" replaced three rows of T12 direct/indirect luminaires with two rows of efficient direct/indirect luminaires.

Figure 11. Pre-retrofit classroom with three rows of T12 pendant luminaires

Photo Credit: Architectural Energy Corporation

Figure 12. Post-retrofit with two rows of T8 indirect/direct luminaires with a whiteboard luminaire

Photo Credit: Architectural Energy Corporation

High-performance retrofit classrooms emphasize an A/V mode and teacher controls at the front of the classroom. It is critical for classroom lighting retrofits to give instructors a lighting mode that improves the contrast and effectiveness of A/V presentations used to instruct and engage students. The placement of teacher controls is equally important. Controls placed at the front of the classroom provide more teacher control and opportunities to save energy. Missing the opportunity to update the classroom during a retrofit project reduces the overall effectiveness of the classroom for years.

Other conclusions drawn from this project are strong teacher preference for classroom lighting with A/V mode and controls for A/V mode located at the front of the classroom. Also, energy savings can be achieved with excellent user acceptance.

Despite significant power and energy savings, the R-ICLS system cost remains prohibitive, with simple paybacks exceeding the typical windows that many school districts need. Labor and materials costs are the two factors that must be impacted. For material costs, the driving factor in making R-ICLS viable for more districts is reducing the cost of dimming ballasts and wireless controls. When compared to a traditional lamp/ballast retrofit, significant incremental expenses for R-ICLS are for the dimming ballasts and wireless controls.

It also is important to factor in the economy of scale as efficiency gains can be realized in larger projects. If an entire building, school, or district were to be retrofitted, the install cost would be less because of the contractor's learning curve.

5.3.2. Recommendations

The research team has identified two key cost criteria that must be met to achieve viable paybacks for school districts: 1) $2,500 labor and material cost per classroom for R-ICLS and 2) $500 annual energy cost savings. School retrofits eliminating high LPDs or T12 classroom lighting, volume pricing for R-ICLS options, and efficiency labor gains are critical to meeting these cost parameters. Scheduling is an important part of installation cost containment, taking place when schools are not in session.

Retrofitting lighting in additional areas such as corridors and gymnasiums could increase energy savings and allow schools to take advantage of economy of scale and gains in labor efficiency, resulting in more tenable payback periods.

The manufacturing partner will continue to evaluate the design and system configuration to develop cost-effective classroom retrofit solutions. The R-ICLS options provide a great visual environment and user flexibility in a system that is environment friendly and LEED/CHPS friendly.

More demonstrations of the R-ICLS with the above recommended changes would better define viable retrofits.

5.3.3. Commercialization Potential

This project demonstrates that the R-ICLS yields energy savings, has the potential to improve the learning environment, and is preferred by teachers. The wireless technology used to achieve results is easily implemented without the need to run additional ceiling supports or electrical conduit. The labor required to install the system is greater than the traditional lamp/ballast retrofit, and the material costs for the wireless controls and dimming ballasts are still too high to meet the payback requirements for many retrofit applications.

Retrofit projects should focus on one of two directions. Either delamp luminaires and change to more efficient T8 systems or, if the budget can accommodate a major renovation project, then the "Best" solution, which emphasizes use of either high-performance recessed or pendant luminaires, becomes the viable solution with much better lighting quality, teacher controls, and energy savings potential.

5.3.4. Benefits to California

An estimated 305,000 public K-12 classrooms exist in California with 210,000 rooms that are more than 25 years old. Each school district has the opportunity to drastically reduce the amount of energy consumed in these classrooms while updating these classrooms to accommodate new technology and teaching methodology making them better learning environments. Missing the opportunity to update classroom lighting to high-performance systems today means the learning environment is not improved for another 20 to 30 years.

Based on 1 percent market penetration and energy savings potential of 20% for lighting, electric consumption savings of 4 GWh and demand savings of .8 MW could be achieved. Demand savings are dependent on use of the school buildings and classrooms during peak demand periods.

6.0 Wireless Integrated Photosensor and Motion Sensor Lighting Control System (Project 6)

The Wireless Integrated Photosensor and Motion Sensor (WIPAM) Lighting Control System project sought to design, develop, demonstrate, and commercialize an easy-to-install lighting control system that adds low-power wireless communications capability to photo and motion sensors. The WIPAM project team comprised the CLTC and Adura Technologies, who also provided match funding.

6.1. Project 6 Approach and Goals

Lighting systems account for about 35% of the total average electrical use in California commercial buildings. Lighting control systems are broadly acknowledged as offering large, near-term opportunities to reduce this energy use. Traditional lighting control systems turn lights off when spaces are unoccupied or when sufficient daylight is available. The control systems involve wiring, which can be an expensive proposition in existing buildings. A wireless lighting control system would simplify and reduce the cost of adding lighting controls to many buildings and, thus, greatly expand the number of buildings that could cost-effectively reduce their lighting energy use.

From the conceptual stages of this project, it was believed that occupancy sensing and light level sensing were critical pieces of energy-conserving lighting controls. However, neither type of device was integrated into wireless lighting control networks in commercially available product offerings. This project was targeted to demonstrate how these vital components could be integrated into a wireless control network.

A retrofit project utilizing this kind of control technology could reduce office lighting as much as 25% by turning off lights either when a space is unoccupied or is lit sufficiently by daylight, facilitate the potential for automated DR, and reduce installation and commissioning time by as much as 50% over standard industry practice for competing technologies.

Specific objectives were to:

- Develop photo sensors powered with low-power radios that are interoperable with wireless luminaire specific relays.
- Develop motion sensors powered with low-power radios that are interoperable with wireless luminaire-specific relays.
- Develop a form factor and package size for photo sensors that would be noninvasive to building occupants.
- Develop a form factor and package size for motion sensors that would be noninvasive to building occupants.
- Develop algorithms that coordinate the control signals between occupant awareness, light level awareness, and automated DR.
- Establish application guidelines that foster best practice, reduce systemic error, and reduce installation time.
- Develop public specifications aimed at commercialization of wireless integrated photo sensors and wireless integrated motion sensors and installation/operation guides for

lighting control systems based on 1) wireless integrated photo sensors, 2) wireless integrated motion sensors and 3) wireless integrated photo sensors together with wireless integrated motion sensors

Specific activities were to:

- Conduct market analysis and develop WIPAM product specification.
- Develop photosensor motherboard prototype.
- Evaluate photosensor prototype housing and mounting.
- Develop motion sensor motherboard prototype.
- Evaluate motion sensor housing and prototype mounting.
- Develop control algorithms for heterogeneous system.
- Construct and evaluate preproduction prototype.
- Conduct WIPAM field test.

6.2. Project 6 Outcomes

In December 2008, Adura Technologies completed a comparative analysis of existing wireless occupancy sensors and photocells. For photocells, a number of innovative devices were found both for devices that were designed to provide coverage for a small area and for self-powered devices. Among the occupancy sensors studied, there was less standardization in describing the occupancy sensing coverage areas than is typical of more traditional U.S. occupancy sensors. The project team found that the most viable technology for a low-powered occupancy sensor device was passive infrared sensing technology.

Adura developed a printed circuit board that utilized a processor, ZigBee[8] radio, a light sensing chip that communicated digitally with the processor, and a battery. This device transmitted light level values to the Adura wireless network. Lab testing showed reliable performance. The results of this test showed the concept was viable.

In evaluating photocell housing and mounting, Adura investigated key areas and identified or created strong solutions to each area. However, the researchers were unable to identify a solution that satisfied all of the objectives that did not require designing a new plastic enclosure.

Adura set its focus on creating a device that would integrate existing occupancy sensors and photocells into the wireless network. This device was named the Sensor Interface (reference Figure 13). In addition to creating the physical device, much of the algorithm development involved this device. The Sensor Interface is designed to mount above a ceiling and be powered by the same power pack that supplies the occupancy sensors. The Sensor Interface is designed to mount onto an electrical junction box. The Sensor Interface is plenum-rated, and the low voltage wiring connections do not have to be enclosed within an enclosure. The method of installation and wiring is intended to match common electrical installation methods.

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8 ZigBee is a low-cost, low-power, wireless mesh networking standard.

Figure 13. Sensor Interface

Source: Architectural Energy Corporation

Adura evaluated the Sensor Interface product with a variety of commercially available occupancy sensors and photocells for signal compatibility and control response. Lab test results showed compatibility with the standard devices manufactured by all of the major U.S. lighting controls manufacturers.

The project team continues to field test of Adura's wireless control system, known as the Adura LightPoint System (ALPS), at the CLTC facility in Davis, California. A WIPAM system demonstration also took place in a parking garage at the University of California, Santa Barbara.

Field testing at the CLTC facility has demonstrated 64% energy savings compared to energy used by the same fluorescent light fixtures without lighting controls under normal work conditions. The project team installed the WIPAM system in two corridors at the CLTC facility: the classroom corridor (new construction) and the restroom corridor (retrofit). The demonstration system was commissioned for bilevel lighting (i.e., fixtures are commissioned to operate at two power levels and corresponding light levels to address both high and low occupancies). The ballasts in the demonstration have dimming capability, allowing the system to take advantage of daylight. Table 3 and Table 4 show the saving calculations in kilowatt hours (kWh) for the CLTC field test based on fixture wattage in kilowatts (kW).

Table 3. Lighting energy use calculation

Baseline	Fixture Wattage (kW)	Number of Fixtures	Hours Per Day	Days Evaluated	kWh
New Construction	0.0325	7	10	3	6.83
Retrofit	0.0318	3	10	3	2.86
				Total:	9.69
W/Controls	**Fixture Wattage (kW)**	**Number of Fixtures**	**Hours Per Day**	**Days Evaluated**	**kWh**
New Construction	0.0325	7	10	3	2.36
Retrofit	0.0318	3	10	3	1.17
				Total:	3.53

Source: Architectural Energy Corporation

Table 4. Field test savings calculation

Savings Calculations	(for the 10 demo fixtures)
2.05	kWh saved for demo area/day
492.70	Annual kWh savings (Based on 240 workdays/year)
$0.13	Average kWh rate
$61.59	Annual savings
$1,387.22	System Cost
63.58%	System Savings (Energy)

Source: Architectural Energy Corporation

The project team demonstrated the WIPAM system at the 2009 University of California/California State University/California Community College Sustainability Conference at the University of California, Santa Barbara, on the second level of a parking structure. All luminaires operated 24 hours a day, 365 days a year. The goal of this retrofit project was to demonstrate cost-effective perimeter daylighting. Because of the existing circuit configurations at the site, a traditional wired photosensor controlling all circuits serving the daylighting zone would extinguish too many interior garage luminaries, resulting in scenario dark interior conditions with light levels below standards. To avoid costly rewiring and demonstrate a cost-effective solution that achieved project goals, the demonstration team replaced 10 perimeter high-pressure sodium luminaires with deck-mounted bilevel induction fixtures equipped with Adura wireless daylighting systems. The new fixtures used were 70-watt (W) Everlast® induction step-dimming garage luminaires.

The Adura system consists of a light controller installed inside of each of the 10 fixtures. It also includes a Sensor Interface connected to an industry standard photocell. The control system consisted of individual occupancy control and daylighting control across a zone. When adequate daylight is sensed, the fixtures turn off. When there is not adequate daylight and no occupancy, then the fixtures are on at 50%. If occupancy is sensed, then the fixtures go to 100%.

The initial annual energy use prior to the retrofit was 14,893 kWh. The annual energy use after the retrofit was 2102 kWh or an energy consumption reduction of 86%. This translates to annual energy savings of about $1,600 and a simple payback period of six years.

6.3. Project 6 Conclusions and Recommendations

6.3.1. Conclusions

The WIPAM system is expected to reduce installation and commissioning time by as much as 50% over standard industry practice for competing lighting control technologies and could reduce open office lighting energy use by as much as 40%. The field test at the CLTC corridors demonstrated 64% energy savings in new construction and retrofit applications. The field test at the University of California, Santa Barbara, showed energy savings up to 86% for wireless lighting controls combined with more efficient lighting technologies.

Innovative occupancy-based and daylight- responsive lighting control can provide significant energy savings. Utilizing a wireless control system can reduce the barriers to installation in existing buildings.

The field tests demonstrated innovative lighting control approaches that are highly applicable to existing buildings where retrofitting wired lighting controls can be cost-prohibitive. The field tests demonstrated that the product offering is ready for commercial sales.

6.3.2. Recommendations

The field test identified some technological refinements to improve the setting up and energy reporting of the Adura system:

- It would be useful to be able to analyze the lamp-ballast system to which a light controller is connected, which would allow for individualized responses to the voltage input signal. This would entail automated mapping of direct current (DC) voltage output to power wattage.
- It would be useful to be able to specify system settings based on power usage in addition to light output.
- For system scheduling, transitioning between normal work time and energy saver settings needs to be refined to address situations such as ensuring that the system makes the scheduled transition even when a space is unoccupied at the scheduled transition time.

Adura Technologies should continue to look at opportunities to create a wireless occupancy sensor and a wireless photocell either through partnering with another manufacturer or creating these products themselves. The wireless products, while not applicable to all spaces, would further open opportunities for installing lighting controls in spaces that are challenging to install with wired devices.

Adura Technologies should continue to identify enabling technologies that can extend the cost-effective reach of advanced lighting controls. With specific regard to this project, new technologies will allow the creation of wireless occupancy sensors and photocells. For both devices, these advancing technologies include lower power radio transmission standards, new battery technologies, and lower cost of energy harvesting components. For occupancy sensors, the advancing technologies include lower power technologies that sense small motion. For photocell, the advancing technologies include new light sensing chips.

6.3.3. Commercialization Potential

Researchers found that presence detection could impact as much as 41.5% of California's floor space representing approximately 2.04 billion square feet (sq. ft.). Daylighting controls are only good for about 355 million sq. ft., or about 7.2% of California floor space. The total size of the WIPAM market is about 540 million sq. ft. but overlaps with both light level switching and presence detection. Based on this analysis, the payback estimate for WIPAM, when fully commercialized, given a $0.14/kWh electricity price and $0.75/sq. ft. installed cost, would be 2-5 years for most applications. Higher electricity rates, utility installation rebates, federal tax credits and other incentives could impact this payback.

For this project, the research team realized paybacks ranging from 22 years for the CLTC corridor demonstration down to 6 years for the UC Santa Barbara garage demonstration. The corridor demonstration was a proof-of-concept system with a minimal number of prototyped components and not representative of an off-the-shelf product with more competitive pricing.

Adura Technologies has productized and commercially launched the Sensor Interface module. The product has been installed in 15 sites.

6.3.4. Benefits to California

Benefits to California from commercialization of the WIPAM system include reduced start-up cost and improved reliability of commercial lighting controls, which would lead to their wider adoption and more reliable use. This would substantially reduce lighting energy use in new and existing buildings.

Applications for the system include small offices, corridors, and parking garages. Based on one percent market penetration and energy savings potential of 20%, electric consumption savings of 26 GWh could be achieved. Demand savings are more difficult to assess since this technology is used to lower light levels during low or zero occupancy and return the lights to higher levels when presence is detected.

7.0 Advanced Light Emitting Diode Downlighting Systems (Project 7)

The Advanced Lighting Emitting Diode (LED) Downlighting System Project sought to design, develop, demonstrate, and commercialize an advanced downlight system, retooling the traditional downlight and optimizing it for LED sources while maintaining the features and functionality that made downlights popular. The CLTC was the primary technical leader on this project. Two manufacturers also involved in this project were Samsung Electronics and Philips Capri Lighting.

7.1. Project 7 Approach and Goals

LEDs are dimmable, have long life spans, minimal recycling requirements and reduced radiated heat, and are highly directional. All of these characteristics make the LED an optimal technology for energy-efficient luminaire research and development.

Performance goals included compliance with ENERGY STAR® requirements for downlights, maximization of system efficacy and optical efficiency using an indirect optical design, and optimization of controllability through creation of a plug-and-play, dimmable system with multiple downlights serviced by a single power supply.

Specific objectives were to:

- Develop or specify, then demonstrate, an easy-to-install central power supply system that is capable of powering at least six LED downlights.
- Develop an indirect LED optical head that has:
    - Fixture efficiency of at least 70%.
    - Light output of at least 400 lumens (lm).
    - Maximum surface brightness of no more than 12,000 candela per square meter (cd/m^2) at all angles between nadir[9] and 45 degrees off-nadir.
- Develop a thermal management mechanism that maintains LED junction temperatures within manufacturers' recommended guidelines and verify the objective by comparing the LED manufacturers' specifications for junction temperatures to laboratory measurements with thermal probes.
- Establish a simplified installation technique that results in a reduction of labor costs, material costs, or both, and then verify the technique by observing installations of an LED downlight system in the field and interviewing field installers.
- Provide an LED downlight system that matches the lighting quality (i.e., light levels, color, and dim ability) of incandescent downlighting systems while using a significantly lower amount of energy.

Specific activities were to:

- Provide market analysis and develop LED downlighting product specification.

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9 Nadir refers to the direction pointing directly below a particular point.

- Design and develop power supply.
- Design and develop optical and thermal subsystem.
- Design and develop system integration.
- Construct and evaluate preproduction LED downlighting system prototype.
- Conduct LED downlighting system field test.

7.2. Project 7 Outcomes

The project team completed a comparison of traditional downlight systems to develop the energy and cost characteristics necessary for a competitive LED system. Table 5 provides a comparison of technologies for a standard residential kitchen, an application appropriate for the type of LED downlight system developed. This analysis showed that a competitive LED downlight system should deliver approximately 650 lm and have an installed cost of $120. Calculations are based on initial lamp lumens, $0.12 per kWh electricity cost, and 3.5 hours of operation per day.

Table 5. Downlight product comparison

	Standard incandescent (BR30)	4-pin CFL* downlight system	LED downlight system
Total # of downlights	10	8	10
Delivered lumens per downlight	620	850**	650
Power per downlight (Watts)	65	28	12
Materials cost per downlight	$20	$38	$90
Installation cost per downlight	$30	$30	$30
Total kitchen lamp lumens	6,200	6,800	6,500
Total kitchen power (Watts)	650	224	120
Total initial installed cost	$500	$544	$1,200
Operating cost per year	$99.65	$34.34	$18.40
Additional initial cost vs. incandescent	NA	$44	$700
Annual savings vs. incandescent	NA	$65.31	$81.25
Simple payback	NA	0.67	8.62
Color rendering index (CRI)	100	~82	~92

Source: CLTC staff calculations

Based on the characterizations of existing downlight products on the market, the project team identified performance criteria for a new, advanced LED downlight that would meet ENERGY STAR downlight requirements, provide appropriate visual comfort, and reduce glare for residential use. The following are the ENERGY STAR photometric requirements for recessed downlights.

Minimum Light Output

- Aperture ≤ 4.5″ : 345 lm (initial)
- Aperture > 4.5″ : 575 lm (initial)

Zonal Lumen Density Requirement

- Luminaire shall deliver a minimum of 75% of total lm (initial) within the 0-60° zone (bilaterally symmetrical).

Minimum Luminaire Efficacy

- 35 lumens/watt (lm/W)

Allowable Correlated Color Temperatures (CCTs)

- 2,700 Kelvin (K), 3,000 K and 3,500 K for residential products
- No restrictions for commercial products

Building from the ENERGY STAR foundation, the team identified a set of initial performance criteria for the LED downlight system. Initial specifications sought to achieve the maximum level of energy efficiency, optical efficiency, and controllability. In particular, the power supply was conceptualized to include multiple control channels capable of accepting control signals for various types of controllers such as occupancy sensor, photosensors, and scene controllers. These optional features would be coupled with a dimming driver to achieve the multiple light levels anticipated to result from these control scenarios.

Optical System

- Utilize an indirect design to reduce brightness and increase visual comfort
- Meet ENERGY STAR criteria for total lumen output and efficacy

Power Supply

- Utilize switch mode power supply (SMPS) technology (see the section on Task 7.2, Power Supply Design and Development, for details on this technology)
- Electrical efficiency > 87%
- Operate up to 10 downlights
- Meet Underwriters Laboratory safety standard 1598 for luminaires
- Meet Federal Communications Commission Class B (residential use) electromagnetic compatibility standard for radio frequency
- Total harmonic distortion < 10%
- Power factor > 90
- Optional low-voltage control inputs
- Optional digitally addressable control inputs
- Optional occupancy sensor input
- Optional manual dimmer input
- Optional scene controller input
- Optional timer input
- Optional photosensor input
- Withstand insulation contact at 55° Centigrade (C) ambient temperature

Driver

- Electrical efficiency > 94%
- Operate up to two downlights
- Accept maximum input of 48 V
- Produce maximum output of 700 milliampere (mA)
- Drive 14 LEDs @ 700 mA maximum
- Have current follow voltage from 48V-32V
- Off state if voltage < 32V

The CLTC then focused on design optimization and development for each of the three key components of an LED downlight: optical system, power supply, and driver. All potential designs utilized an indirect approach, whereby LED emitters were shielded from direct view and their light was directed into the downlight housing where it was reflected back out of the aperture. Figure 14 is a rendering of the indirect cross design that was selected by the project team for prototype fabrication and testing.

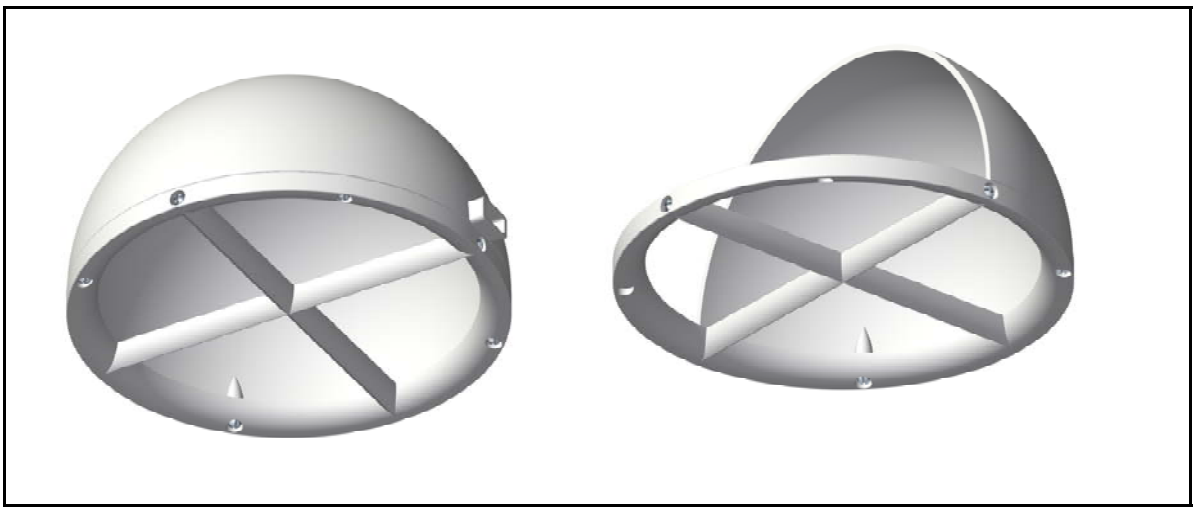

Figure 14. Indirect cross design

Source: CLTC

Based on a survey of available LED providers, the project team determined that a Cree product would be the best choice for the LED. Prototypes were fabricated. The project team verified the thermal performance of the prototypes and refined the power supply and driver design several times in order to achieve optimal operating conditions. Additional design work was conducted at the end of the project to update the indirect downlight concept light engine.

The following figures show the initial and final indirect downlights, and the final performance test results are provided in Table 6.

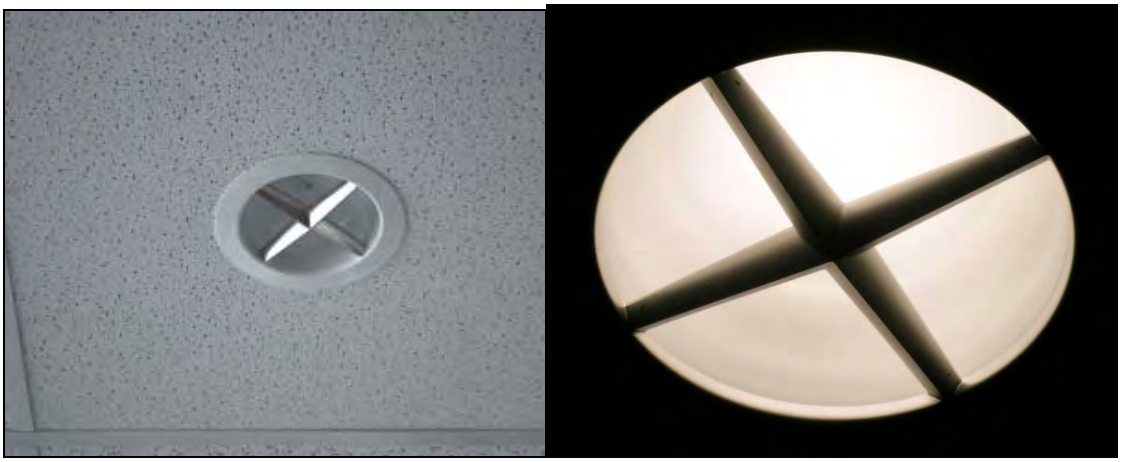

Figure 15. First prototype produced by Philips Capri Lighting, based on CLTC design (left) and final indirect downlight (right)

Source: CLTC

Table 6. Final indirect cross downlight performance test results

Source Lumen Output	825.0 lm
Luminaire Lumen Output	486.8 lm
Fixture Efficiency	59%
CRI	85.1
CCT	3,060 K
Power	16.2 W
Luminaire Efficacy	30.0 lm/W

Source: Architectural Energy Corporation

The CLTC fabricated several prototypes using the final design and installed these units in local area displays. Four units are currently on display at the CLTC facility. These units are part of a kitchen vignette, which is used to demonstrate the lighting quality and energy savings of next-generation downlights. Visitors to the facility can compare the indirect downlights to other LED and fluorescent products, also installed in the display. The units have drawn interest from manufacturers, lighting designers, and homeowners regarding their availability.

7.3. Project 7 Conclusions and Recommendations

7.3.1. Conclusions

The CLTC and Phillips Capri Lighting worked together to determine the feasibility of manufacturing the indirect downlight concept. After exhausting all viable options, it was determined that manufacturing and cost constraints would result in a downlight system that would not meet the performance specification. Because of this, Capri decided it would be best to commercialize a more traditional LED downlight system utilizing lessons learned during the design process of the indirect downlight project. The net result of this project was Philips Capri

Lighting offering a reliable, efficacious LED downlight module (CRL6K-14) that provides significant energy savings over equivalent incandescent technology.

7.3.2. Recommendations

The CLTC continues product development and research on indirect downlight concepts and other light distribution designs. These designs have the ability to mitigate the visual discomfort commonly associated with LED luminaires. In particular, the CLTC recommends that manufacturers pursue emerging next-generation optical coating and films to improve optical efficiency, which allow indirect designs to achieve the system efficacies necessary to compete with traditional downlights.

7.3.3. Commercialization Potential

The energy savings potential of LEDs is very high, and many market sectors have experienced increased penetration of white-light LED luminaires into applications dominated by incandescent, fluorescent, and high-intensity discharge (HID) sources. The residential and commercial downlight market is one niche application that is expected to see exceptional growth of LED products. One study estimates the energy savings potential of LEDs for these applications to be more than 80 billion kilowatt hours per year, assuming 100% market saturation, and the benefits go beyond energy savings[10]. Other benefits are LEDs have long life spans, minimal recycling requirements, and reduced radiated heat.

7.3.4. Benefits to California

Estimates show that an average California home contains approximately three recessed downlights and that these luminaires account for 15% of all lighting energy use in the residential sector. This amount is expected to grow by 0.5% annually[11]. Energy-efficiency improvements to this important market sector will create significant energy savings for California. While similar statistics are not available for California's commercial sector, nationwide estimates show more than 800 million installed units, accounting for approximately 103 billion kWh of energy use. Energy-efficient LED downlights are estimated to deliver 80% energy savings over these baselines.

Calculating the potential savings for the California residential market, 47 GWh and 4 MW could be reduced each year based on 1 percent market penetration and 20% energy efficiency improvement. This estimate is conservative for two reasons: LED recessed downlights have quickly gained market share and, if replacing incandescent bulbs rather than CFLs, the energy efficiency improvement is greater than 20%.

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10 Navigant Consulting. *Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications*. September 2008.

11 California Energy Commission. *Lighting Efficiency Technology Report – Volume 1 California Baseline*. September 1999.

8.0 Novel LED Downlights (Project 8)

The Novel LED Downlight project, originally named the Hybrid Downlight project, initially sought to design, develop, demonstrate, and commercialize a hybrid LED and CFL downlight that takes advantage of the CFL source's strengths (high lumen packages, high efficacy, low cost, and availability), and the LED technology's strengths (dimmability, optical control, small size, low power options, and long lamp life). However, early in this project, the industry partner, Cooper Lighting, determined that advancements in LED technology indicated that an all-LED downlight would be a superior product to the hybrid LED/CFL downlight concept. Therefore, with California Energy Commission approval, the project refocused on development of an all-LED downlight.

The CLTC and Cooper Lighting collaborated on this project. Cooper Lighting did not receive any PIER funding, generously providing its technical and marketing expertise as a match fund partner.

8.1. Project 8 Approach and Goals

The goal was to design, develop, demonstrate, and commercialize a novel LED downlight. This project team wanted to develop a uniquely new downlight that takes advantage of the strengths of the LED technology. LEDs, which emit light from the movement of electrons through semiconductor material, produce less heat and last longer than many other types of light sources.

Specific objectives were to:

- Develop an LED optical head that has a fixture efficiency of at least 65%.
- Develop and demonstrate a downlighting control system capable of controlling LED sources.
- Develop a LED system that offers smooth, continuous dimming in the range between 1% and 20% of the luminaire's total light output.
- Develop and verify a thermal management system that maintains LED junction temperatures within the manufacturer's recommended guidelines.

Specific activities were to:

- Provide market analysis and develop LED downlight product specification.
- Design and develop initial optical.
- Construct initial LED downlight prototypes.
- Evaluate optical and thermal and refine initial LED downlight prototype.
- Develop, refine, and evaluate control system.
- Construct and evaluate preproduction prototype LED downlight.
- Conduct LED downlight field test.

8.2. Project 8 Outcomes

After researching the existing downlight market, Cooper Lighting chose to target the residential market for the new LED downlight, in the price range equivalent to a top-of-the-line CFL downlight product.

The CLTC and Cooper Lighting collaborated to develop initial product specifications, shown in Table 7, for a competitive LED downlight product. Cooper Lighting's goal was to have a variety of trim kits to address lighting designers' demand. In general, the target was a 50-degree beam angle, which is standard in the downlight market.

Table 7. Initial LED downlight product specification

Delivered lumens: 650 (based on white and specular reflectors)
Light output comparable to: 65 W BR30, 18 W CFL
Luminaire Efficacy: 46 lumens/W
Luminaire power: ~14W
CRI: 83
CCT: 3,000 (K) +/-125
Lifetime: 50,000 hours at 70% lumen maintenance
Dimmable down to ~5% total light output
compatible with multiple standard analog DC dimmers
no color shift when dimming
>90% efficient, 0.9 power factor
Distribution: 50° cutoff
LED Module fits standard H 7 - 7.5- inch housings
Underwriters Laboratories (UL)-approved connector and Edison base accessory
Meets Solid State Lighting (SSL) 2008 ENERGY STAR requirements
IC/Air tight new construction housing (no Edison base) - T24 applications
Multiple reflector options:
1. Matte white trim and matte white reflector
trim at 0.160" at outside diameter (OD), 0.180" at inside diameter (ID)
2. Matte white trim and specular reflector
trim at 0.160" at OD, 0.180" at ID
3. Matte white trim and haze reflector
trim at 0.160" at OD, 0.180" at ID
4. Matte white regressed shower lens and trim
thinner trim options: matte white trim ring
0.120" at OD, 0.180 at ID

Source: Architectural Energy Corporation

Cooper Lighting determined it would be beneficial for the module to fit in as many existing downlight housings as possible to maximize its retrofit market potential. Cooper Lighting requested the CLTC's assistance in surveying the downlight housing market and making recommendations for a maximum physical envelope and hanger design that would allow for the most cross-brand compatibility.

Cooper Lighting created the optical design for the new downlight; the design drawings and information are proprietary. Cooper Lighting had an existing relationship with the LED manufacturer Citizen and chose to use Citizen LEDs for the new downlight.

Cooper Lighting constructed the initial LED downlight prototypes. CLTC staff tested the prototypes in the CLTC integrating sphere and compared the prototypes' optical performance to the initial product specification. Initially, the product did not meet the specification because the vendor had supplied an LED with incorrect output and color temperature. Once the vendor corrected this error, the product met specifications. Thermal measurements were conducted with the product in its intended vertical orientation at thermal steady-state.

The CLTC advised Cooper Lighting regarding modeling of the downlight modules for IC (insulation contact) housings and airtight cans. Cooper Lighting used a thermal design tool to prepare the fixture heat sink design. The CLTC and Cooper Lighting then collaborated to measure prototype thermal performance in both open air, thermally stabilized environments, and a confined, insulated environment.

The main focus of the control system development was ensuring the product's compatibility with existing dimmer technology. CLTC engineers researched other products on the market and worked with the LED driver vendor to specify the electrical components necessary for the LED driver to dim properly. The design consensus was to adapt the product to work with traditional incandescent dimmers. The dimming feature is offered on two HALO models. CLTC staff also tested the LED driver provided with modules to ensure the unit met project performance specifications.

The HALO LED downlight is designed for retrofit and new construction applications and can be retrofitted into any existing HALO or ALL-PRO™ housing. For new construction, the LED module can be installed with a dedicated housing designed specifically for the unit, which is the HALO H750ICAT housing. The H750ICAT is designed for insulated ceilings and can be in direct contact with ceiling insulation.

The HALO LED module has 99% fixture efficiency and is low glare due to its optical design and efficient trim. The module has acceptable color rendering (80 CRI typical) and a warm white color temperature (3500K). The LED module lifespan is 50,000 hours.

Figure 16. HALO LED module, housing and trim commercialized by Cooper Lighting

Source: Architectural Energy Corporation

The PIER LCF and the PIER Demonstration Programs partnered with the Bidwell Mansion State Historic Park, a California State Park in Chico, to demonstrate the HALO LED downlight at the Bidwell Mansion Visitor Center (BMVC). The retrofit illustrated the energy and maintenance savings that can be realized through the use of highly efficient light sources with a long life span. The demonstration also showed the high quality of illumination that new technologies provide due to their advanced light engines and efficient optical controls.

The LED downlight retrofits at BMVC reduced electricity consumption and improved the lighting environment. Overall project energy savings were 49% or approximately 770 kWh of energy saved each year. Life-cycle costs were compared and are shown in Table 8 for the HALO product versus CFLs for both new and retrofit installations.

Table 8. Life-cycle cost analysis for retrofit and new construction projects

Technology	Retrofit Life Cycle Cost	New construction Life Cycle Cost
HALO LED downlight	$100.28	$150.28
Double CFL downlight	$159.83	$159.83
Incremental cost	$59.54	$9.54

Source: Architectural Energy Corporation

Figure 17. Renovated lobby at BMVC

Source: Architectural Energy Corporation

8.3. Project 8 Conclusions and Recommendations

8.3.1. Conclusions

This project designed, developed, demonstrated, and commercialized the HALO LED downlight, which is the first recessed LED downlight that is both ENERGY STAR-rated and exceeds efficacy requirements set by California's Title 24 energy regulations. The unit consumes approximately 15 watts of power. The product was successfully testing in both the laboratory and field demonstrations, which showcased the energy savings potential and light quality delivered by the unit.

The commercialization potential for LED recessed downlights is very high. Recessed downlights have become the most common fixture used for general ambient lighting in both residential and commercial sectors[12]. Since the start of this project, multiple manufacturers have brought LED products to the marketplace including CREE LED Lighting Solutions, Lightolier, Focal Point, Juno Lighting, Capri Lighting, and Progress Lighting. As LED technology develops, simple paybacks likely will become comparable to those for current technologies.

Cooper Lighting has already commercialized the design developed during this project. The product is known as the HALO LED recessed downlight and is widely available in the marketplace. The unit comes with multiple trim options; some are rated for damp locations. Work is currently underway by Cooper Lighting to develop additional diameter modules beyond the 6.5" module developed under this project. Cooper Lighting continues to expand the HALO LED product line, based in part on the following recommendations.

8.3.2. Recommendations

Recommendations include pursuing additional optical designs to reduce glare from the LED. In addition, the CLTC recommends Cooper Lighting pursue a modified mechanical design that will increase the number of compatible competitor housings for the LED module. This will increase the product's market share in retrofit applications.

The CLTC also recommends that Cooper Lighting expand the product line to address additional downlight market places and include integrated lighting controls strategies that incorporate network functionality.

8.3.3. Commercialization Potential

The commercialization potential for LED recessed downlights is exceptional. Recessed downlights have become the most common fixture used for general ambient lighting in both residential and commercial sectors[13]. It is estimated that recessed downlights account for 15% of all lighting energy use in the United States[14]. Since the start of this project, multiple

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12 Navigant Consulting, Inc. *Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications*. September 2008, page 31.

13 Navigant Consulting, Inc. *Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications*. September 2008, page 31.

14 Gordon, Kelly and Jeffery McCullough. Recessed Downlights: A New Take on an Old Standby," *Builder News Magazine*. January 2004.

manufacturers have brought LED products to the marketplace including CREE LED Lighting Solutions, Lightolier, Focal Point, Juno Lighting, Capri Lighting, and Progress Lighting.

Cooper Lighting has already commercialized the design developed during this project, and the HALO LED recessed downlight product is widely available on the marketplace.

8.3.4. Benefits to California

An estimated 684 million recessed incandescent downlights and 144 million recessed CFL downlights currently are in operation in the United States[15]. Replacement of these downlights with an appropriate LED alternative could save 81.2 TWh (TeraWatt-hour) per year. At a standard energy cost of $0.13 per kWh, energy cost savings annually could reach $10.5 billion[15]. Additional operating and maintenance savings, a result of the long life and reduced recycling requirements of LEDs, would further increase these cost savings.

Estimates show that an average California home contains approximately three recessed downlights. These luminaires account for 15% of all lighting energy use in the residential sector and this amount is expected to grow by 0.5% each year[16]. While similar statistics are not available for California's commercial sector, nationwide estimates show more than 800 million installed units, accounting for approximately 103 billion kWh of energy use. Energy-efficient LED downlights are estimated to deliver 80% energy savings over these baselines[17].

Calculating the potential savings for the California residential market, 47 GWh and 4 MW could be reduced each year based on one percent market penetration and 20% energy efficiency improvement. This estimate is conservative for two reasons: LED recessed downlights have quickly gained market share, and, if replacing incandescents bulbs rather than CFLs, the energy efficiency improvement is greater than 20%.

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15 Navigant Consulting, *Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications*, prepared for the U.S. Department of Energy, September 2008, page 32-34.

16 California Energy Commission. *Lighting Efficiency Technology Report – Volume 1 California Baseline*. September 1999.

17 The benefits to California for this project are identical to the potential benefit of the LED downlight technology developed in LCF Project 7 – Advanced LED Downlighting System.

9.0 Smart LED Lighting in Residential Fans (Project 9)

The LED smart fan project sought to design, develop, and demonstrate a novel LED lighting and controls system that optimizes emerging LED technology and commercially available lighting controls and can be implemented in residential ceiling, exhaust, and other fans. The goal of this research is to save energy and reduce peak demand compared to existing fan lighting options. The project team included the CLTC and Hunter Fan Company, who also provided match funding.

9.1. Project 9 Approach and Goals

In California, 90% of ceiling fans sold include light kits that have incandescent sources with an average connected load of 120 W. Although changes in California's Title 24 2008 Building Energy Efficiency Standards marginally increased energy savings in these applications through the use of dimmers for ceiling fan lighting and occupancy sensors for bathroom lighting, these new requirements have also complicated code compliance for builders. LEDs use less energy, give off less heat, and last longer than other types of lighting. Replacing traditional incandescent fan lights with LED fan lights would save significant energy.

The goal was to optimize a combination of emerging LED technology and commercially available lighting controls to create a cost-effective LED lighting kit. The project also would investigate integrating smart LED lighting controls into both the ceiling fan and exhaust fan markets for energy and peak demand savings.

Specific objectives were to:

- Develop an LED lighting system for residential ceiling fans, exploring the potential for integration of lighting controls into LED ceiling fans for added energy savings and user amenity.
- Develop a hybrid LED/integrated lighting controls system for residential exhaust fans (i.e., both retrofit and new construction).
- Develop public specifications for an LED optical system that achieves:
    - A source efficacy of at least 40 lm/W.
    - A fixture efficiency of at least 75%.
    - A light output of at least 1000 lm for ceiling fans.
    - A light output of at least 150 lm for exhaust fans.
- Develop and verify a thermal management system that maintains LED junction temperatures within manufacturers recommended guidelines.

Specific activities included:

- Provide market analysis and develop system product specification.
- Develop initial concepts for LED fan light kits.
- Develop initial prototype for LED fan light kits.
- Design and develop thermal management.
- Determine ceiling and exhaust fan controls options.

- Produce LED fan lighting and control system prototypes.
- Plan and conduct LED fan lighting and control system field test.

9.2. Project 9 Outcomes

Three product concepts were the focus on this project – LED light kit for existing ceiling fans, ceiling fan with native LED light source, and LED light kit for exhaust fans. Market research was conducted primarily by utilizing the industry partner's knowledge of the residential ceiling fan market place combined with surveying big box retailers. This information combined with Internet product searches resulted in the research team estimating equivalent light output values and control features for the LED lighting systems.

The CLTC developed a set of residential fan LED light kit specifications and the prototypes to meet those specifications as well as designs for a decorative dedicated or native LED residential ceiling fan. The specification for the LED optical system had a system efficacy of 40 lm per watt (lm/W). This system consists of 16 Cree XR-E LEDs driven at a drive current of 500 – 700 mA. This array also met the target 1000 lm output for the ceiling fan. It should be properly mounted to a quality circuit board and attached to an appropriately designed heat sink. The fixture efficiency for the LED fan light kit is dependent on the transitivity of the decorative glass placed in front of it.

The initial product specification included designs for pull-chain dimming controls. The concept was to emulate existing ceiling fan light kits dimming functionality by providing three levels of light – high, low, and off. During the course of the project, it was determined that a continuous dimming light kit would provide added functionality, energy savings, and value to the customer.

Hunter Fan Company and the CLTC worked on design concepts for a LEED exhaust fan with a night light mode. The exhaust fan bezel that houses the main LED light, the night light, and the power supply was designed such that it would be mountable to an existing exhaust fan or easily installed in new construction. The CLTC also developed a specification for an LED exhaust fan. This system consisted of 10 Osram Opto Golden Dragon Plus warm white LEDs driven at a drive current of 500 mA. The light output of the initial prototype met the target of a 150 lm for the exhaust fan light kit. Prototypes of a LED exhaust fan were fabricated.

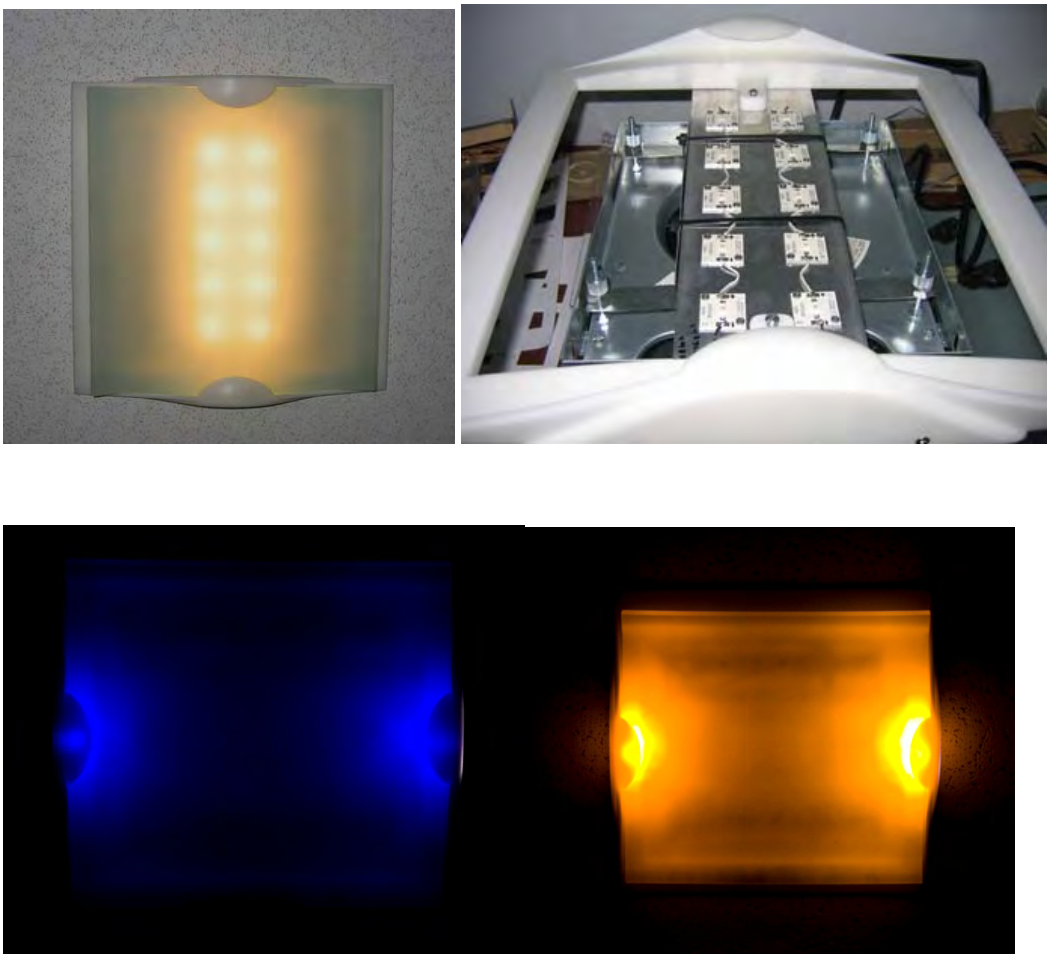

Figure 18. Exhaust fan concept design – High mode, LED module, blue night light, amber night light

Photo Credit: Architectural Energy Corporation

The efficacy and light output for these systems were characterized using an integrating sphere and a Xitron power analyzer. The light output and efficacy of the LED ceiling fan light kit met the 40 lm/W target while exceeding the 1000 lm output target by achieving ~1600 lm. The initial exhaust fan light kit exceeded the light output target of 150 lm by achieving ~ 300 lm. The initial exhaust fan light kit did not meet the target efficacy of 40 lm/W. The second exhaust fan light kit concept design is anticipated to exceed the efficacy target but was not measured.

Thermal management systems were designed based on specified wattages. A conservative heat sink design was developed and prototyped for both the ceiling fan light kit and the exhaust fan light kit. Both of these thermal systems were validated by measure solder point temperatures on the circuit board and comparing to LED manufacturers recommended. The solder point temperatures were found to be within the manufacturer's recommendations.

Hunter Fan Company developed three successive iterations of a residential ceiling fan light kit during this project and continues to work toward commercialization. Each successive prototype attempted to improve performance. The last iteration of the Hunter Fan light kit tested at the CLTC for this project achieved the performance results show in Table 9.

Table 9. Hunter ceiling fan LED light kit – iteration 3 test results

Hunter Fan Kit #3	
Lumens	877
CCT	3351 K
CRI	68
AC wattage	10
Efficacy	88 lm /W

Source: Architectural Energy Corporation

The CLTC also developed a prototype LED light kit that achieved the following performance results.

Table 10. The CLTC ceiling fan LED light kit test results

The CLTC Fan Kit	
Lumens	~1,619
CCT	2928 K
CRI	~82.7
AC wattage	39.8 W
Efficacy	40.6 lm/W

Source: Architectural Energy Corporation

Because the concepts were not commercialized at the time of this report, formal field testing was not completed. A CLTC LED light kit was installed in SMUD's E-House to raise the public's awareness about LED products. This prototype installation has received positive feedback and is scheduled to remain installed indefinitely. Figure 19shows the installation at SMUD.

Figure 19. The CLTC prototype light kit installed in SMUD E-House

Source: Architectural Energy Corporation

9.3. Project 9 Conclusions and Recommendations

9.3.1. Conclusions

The CLTC and the manufacturing partner worked to design and commercialize LED lighting for both a ceiling fan and an exhaust fan targeted at the residential marketplace. During the course of this project, it was determined that the residential marketplace is extremely cost sensitive. This was observed in relation to the LED bill of materials, the heat sink design, and the light controls.

While the performance targets were technically feasible, the cost constraints made achieving them in a commercial grade version extremely challenging at the time this project was complete. As the cost of LEDs and electronics continues to decrease, residential ceiling fan and exhaust fan LED light kits will become more affordable and improve in quality.

9.3.2. Recommendations

Recommendations stemming from this project include pursuing the development of a light kit for replacing candelabra style light kits, investigating the potential for wireless controls for both the ceiling fan light kit and the exhaust fan, and an in-depth market analysis of existing Triac dimmer switches and their associated performance.

9.3.3. Commercialization Potential

As of this writing, Hunter Fan Company has not commercialized LED light kits for residential ceiling fans. The company also has not pursued the conceptual designs for a ceiling fan with dedicated LED lighting or a LED exhaust fan.

9.3.4. Benefits to California

The benefits to California of cost-effective LED lighting in residential fans would be increased energy and peak demand savings. LED lights can provide high-efficacy, controllable light in an economic long-lasting package. The widespread use of dedicated LED lighting systems in residential fan applications would reduce waste and generate energy savings while potentially guaranteeing code compliance.

Once commercialized, LED light kits for residential ceiling fans have the opportunity to annually provide 47 GWh in energy savings and 4 MW in demand savings. This assumes 1 percent market penetration with a conservative estimate of 20 percent savings converting from incandescent to LED light sources.

10.0 Advanced Energy-Efficient LED Lighting for Residential and Commercial Applications (Project 10)

This project sought to develop an LED-based luminaire for use in residential and commercial buildings. The LED lighting module is based on the LRC's patent-pending SPE™ (Scattered Photon Extraction) technology, a remote-phosphor technique that has been shown to significantly improve the efficacy and light output of current generation LED technology. The project team included the LRC, which is part of Rensselaer Polytechnic Institute.

10.1. Project 10 Approach and Goals

Commercial white LEDs combine a short-wavelength light-emitting semiconductor with a phosphor to produce white light. The scattering nature of most phosphors, however, causes more than half of the light, or photons, generated by the phosphor to divert back toward the semiconductor die, where much of it is absorbed and lost. This scattering reduces the LED's overall light output, luminous efficacy, and life.

The LRC researchers developed a SPE method to improve the light output and efficacy of white LEDs. The method combines optimally shaped optics and placement of the phosphor away from the die. This configuration allows light traveling back toward the die to escape through the sides of the optics, generating 30 to 60 percent more light output (lumens) and luminous efficacy (lumens per electrical watt) than typical white LEDs.

The new SPE-based LEDs are able to achieve an efficacy of more than 100 lm/W. Moreover, moving the phosphor layer away from the die improves LED life. Figure 20 below illustrates the concept.

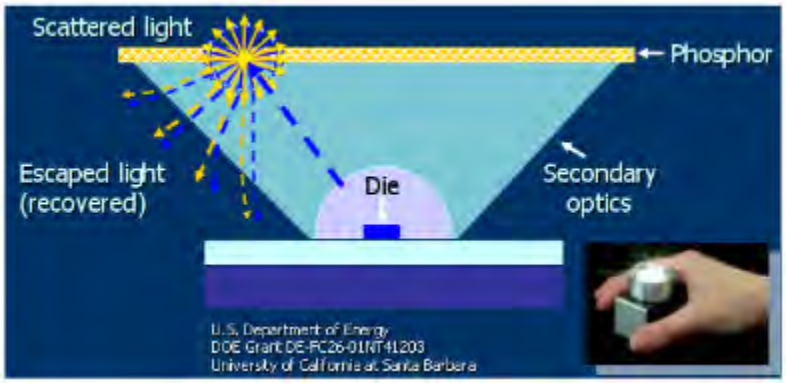

Figure 20. SPE technology recovers most of the backscattered light before it reaches the semiconductor die.

Source: Lighting Research Center

This PIER project was needed to move this technology to the product development stage and closer toward commercialization, where it can provide significant energy benefits. Typically, luminaire developers and manufacturers were unlikely to undertake the research and development necessary on their own due to the high cost of LED components, their lack of knowledge concerning LED operation, and the relatively small market penetration of LED systems for general illumination.

The goal was to develop an advanced, energy-efficient LED lighting system for wall wash and other accent lighting applications in homes and commercial buildings.

Specific objectives were to:

- Reduce lighting energy use in the selected application by 50% to 70% over current state-of-the-art lighting technologies.
- Be cost-effective to purchase, install, use, and maintain.
- Allow for easy and cost-effective control in response to occupancy and daylight.
- Respond easily to the need for reduced power requirements during times of peak electric demand.

Specific activities included:

- Conduct in-depth market analysis.
- Further develop SPE technology.
- Develop and prototype LED luminaire.
- Evaluate LED luminaire evaluation and develop final prototype.

10.2. Project 10 Outcomes

An analysis of both the residential and commercial downlighting markets indicated that one of the fastest growing luminaire types in each category is the recessed downlight. In the United States, the current residential downlight market exceeds $400 million per year, and the commercial downlight market exceeds $537 million per year. About $250 million of this market is for specification-grade fixtures with an initial cost greater than $65 per unit. Products sold in the specification-grade market segment are selected primarily based upon the product's performance[18].

This market is an attractive segment for a light source that can show performance improvements over currently available light source technologies. The most common lamp type used in commercial downlights is the CFL. However, recent testing of CFL downlights showed that these downlights are, on average, only 44% efficient[19]. Also, a growing trend in commercial and residential downlights is consumer preference for downlights with smaller apertures, generally four inches, which typically cannot accommodate CFLs[20].

The LRC determined that the development of highly efficient, small aperture, specification-grade, recessed downlight fixtures geared toward the commercial lighting market would be the best course of action for this project. This would allow for the highest impact on energy savings in the shortest amount of time, especially in California, where lighting and energy conservation trends tend to push the market toward more efficient, environment friendly products. Based on the market analysis and knowledge of competing products, the LRC project team focused on

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18 Market analysis information provided by Lithonia, 2008.

19 National Lighting Product Information Program, 2008.

20 Lightolier, 2007.

the commercial downlight market, currently served primarily by 32 W CFL downlight products. The LED lighting system would have a target efficacy of 100 lm/W, exceeding current incandescent, LED, ceramic metal halide, and CFL technologies.

The LRC intended and initially started to work with a major manufacturer, Lightolier, throughout this project. During the early stages of the project, however, the manufacturing partner was not able to continue as part of the team due to a change in the company's ownership. In response to this change in logistics, the goal of the project shifted to producing a sufficient prototype to conduct a field demonstration to survey end users' opinions on the SPE-based LED downlights. In parallel, the LRC continuously sought partnerships with other companies, an effort that eventually did not materialize.

In order to carry out a field demonstration, the target specifications of the SPE-based LED downlight were adjusted to reflect the most likely retrofit scenario in a commercial application, while being consistent with the overarching energy-efficiency goals of the project. The final specification for the SPE-based LED downlight were selected so that it could be installed to replace either a 75W incandescent or a 26-32 W CFL 6-inch downlight, and included:

- Photometric
    - 600-1000 lm
    - CRI of 85 at 3000 K to 3500 K
    - Beam distribution: general downlight
- Electrical
    - Preferably dimmable
- Mechanical/thermal
    - 5-inch to 6-inch diameter
- Non-IC (insulation contact) rated

It is worth emphasizing that the economics of the design were always considered but not optimized during this project. The experience and capabilities that a manufacturing partner can offer are needed to achieve specific manufacturing costs and sales prices.

The development process of this project included working iteratively on the following activities:

- Characterization of several commercial phosphors, types of lenses, and types of blue LEDs.
- Optical modeling to determine the phosphor density needed to achieve a target chromaticity between 3000 K and 4000 K with optimum luminous efficacy and color rendering properties.
- Experimental verification of optical models.

With the components available toward the end of the project, the LRC team achieved SPE-based LEDs with luminous efficacies of up to 106 lm/W, 118 lm at 350 mA (milliamps) and 4793 K, and up to 114 lm/W, 69 lm at 200 mA and 4020 K. These SPE-based LEDs had an average efficacy of 96 lm/W when operated at 350 mA and produced an average of 109 lm, average CRI = 74 at an average CCT of 4100 K. During the final iteration, the LRC team created over 100 SPE lenses for use in seven prototype downlights intended for a field evaluation. The final set of lenses was

created at a CCT of 4100 K to account for the changes in color temperature resulting from the integration of the lenses inside the downlight. With these lenses, the resulting CCT of the downlights was 3500 K on average, as intended.

During the luminaire development and evaluation stage, the LRC carefully evaluated the performance of the prototype luminaires built and modified the luminaire design as needed, conducted further testing, and developed a final design for the SPE-based LED downlight system. The final prototype minimized the use of metal to reduce weight and the cost of the design without compromising the thermal performance. The design performed well enough to keep the LED junction temperatures as low as 44° Celsius when the LEDs are operated at a current of 175 mA (~8 W LED power, ~700 lm) inside an IC environment. Such junction temperature can be translated into an estimated life of 50,000 hours, according to the LED manufacturer.

The final system had a nominal aperture of 6 inches and produced similar light output to a 75W BR40 (bulged reflector) or a 26W CFL downlight, but with only 9.5W of input power. The SPE downlight features an efficient driver with three additional settings if a higher light output is desired (up to 1036 lm). The driver is dimmable and has power factor correction (>0.95 at full load). The CCT is nominally 3500 K, a neutral white suitable for many commercial and hospitality applications. The design of the SPE LED downlight affords a sufficiently low LED operating temperature to achieve a target life of 50,000 hours. The one-part reflector and trim is housed in a traditional 6-inch housing that can be installed from below the ceiling (suitable for remodeling jobs and requires a ceiling opening of 7 1/8-inch). The average performance characteristics of the seven prototypes (shown in Figure 21) produced are:

- Lumen output 720 lm at 9.5W.
- System efficacy 76 lm/W.
- CRI of 75 at 3500 K CCT
- Life (L_{70}) rating 50,000 hrs (junction temperature = 44 °C).
- Light distribution general diffuse.
- Installation labor costs are the same as comparable CFL or incandescent luminaires.

Figure 21. The seven SPE-based LED downlight prototypes on a table (left), and six of them installed in an open area lab at the Lighting Research Center (right).

Photo Credit: Architectural Energy Corporation

10.3. Project 10 Conclusions and Recommendations

10.3.1. Conclusions

Overall, this project demonstrated the potential of the SPE technology in terms of energy efficiency, light output, and life at the luminaire level. In general, the remote-phosphor approach to creating white LED-based luminaires seems very promising and a viable option for luminaire manufacturers looking for a different product with high energy efficiency performance.

Appropriate applications include commercial lobbies, offices, conference rooms, open areas and hospitality lobbies, reception areas, corridors, and general open areas. Based on the performance measured by the LRC team, it is expected that a production version of the SPE-based downlight would be ENERGY STAR-rated.

10.3.2. Recommendations

In order to further this project work, it is recommended that product development be continued, a manufacturing partner should be found to participate in product commercialization, and several field test sites should be selected for installation and monitoring of the SPE downlight.

Once the LED lighting system is fully developed, the LRC intends to work through the ENERGY STAR® program to ensure that the product meets ENERGY STAR specifications. Having the ENERGY STAR designation will assist with the product's market penetration.

The LRC research team also has identified a need to develop a specification-grade, highly efficient small-aperture downlight (4") producing at least 1000 lumens to compete with compact fluorescent-based luminaires in size and light output, and with ceramic metal halide-based luminaire in life, cost, and dimming features. The primary market for the new LED lighting system is ambient and accent lighting applications in retail and hospitality (i.e., hotel, restaurant) industries and institutional (i.e., assisted living, dormitory) applications. For example, large retailers such as Macy's, Kohl's, Nordstrom, and Sears are continuously

evaluating new lighting technologies that improve the sales floor environment while reducing maintenance and energy costs in their retail stores. These companies are such large purchasers of lighting equipment that they often work directly with manufacturers and have great influence over the new product development process. Downlights, wall-washers, and accent lighting are a substantial part of this market. A specification-grade LED product, which competes in price and performance with the incumbent technologies (ceramic metal halide, CFL, and incandescent), reduces required ceiling aperture, is dimmable and controllable by occupancy sensors, and has great potential to be preferentially specified in retail building design.

10.3.3. Commercialization Potential

The LRC hopes to develop a partnership with a major manufacturer that will license the SPE technology and move the system design to commercialization. Originally, the LRC intended to collaborate with Lightolier, a company that has a highly effective marketing strategy and distribution chain in California, excellent name recognition, and a reputation among lighting specifiers and end users of producing high-quality products that provide excellent long-term value. Lightolier has the expertise and experience needed to engineer, produce, and bring a luminaire to market in the most cost-effective manner possible. However, Lightolier was purchased by Phillips, and during the course of this project, the Lightolier/LRC collaboration did not materialize.

There are two main market barriers to be overcome before this LED lighting system will reach commercialization and any significant market penetration. The first market barrier is the luminaire's projected initial cost. This issue was to be addressed as part of the project development efforts. The SPE technology to be incorporated into the product allows for the production of a luminaire that will use 50% to 70% less energy than the most efficient luminaires available. The LED engine within the luminaire lasts 2 to 10 times longer than competing state-of-the-art technologies. The SPE technology is likely to be more cost-effective to produce than current white LED products, thus bringing down the overall product cost. These production cost reductions, coupled with reduced maintenance and energy costs provided by the product, allow for a reasonable rate of return for end users who purchase the LED lighting system. The payback period could be further enhanced if electric utilities in California offer financial incentives for end users to purchase and install the product.

The second market barrier to be overcome is a general reluctance of the lighting specification and end-use communities to accept new and unproven technologies. One of the recommendations is for the LRC to seek further funding, once this project is completed, for a full-scale demonstration and evaluation of the product in a "real world" application.

10.3.4. Benefits to California

The primary market for the new LED lighting system is ambient and accent lighting applications in retail and hospitality buildings. Based on 1 percent market penetration and energy savings potential of 20%, electric consumption savings of 15 GWh and demand savings of 2.6 MW could be achieved. This estimate is conservative for two reasons: LED recessed downlights have quickly gained market share and, if replacing incandescents bulbs rather than CFLs, the energy efficiency improvement is greater than 20%.

11.0 Programwide Market Connections (Project 11)

The market connections project sought to encourage and broaden market adoption of products developed as part of the LCF program to ensure that the energy savings potential is realized. Team members include the New Buildings Institute, who guided this effort, the CLTC, and AEC.

11.1. Project 11 Approach and Goals

The goal was to shape and support technology development and early deployment efforts in order to accelerate the technology diffusion process. The ultimate outcome of this market connections element is broadening market adoption of the lighting products developed in the overall program, including codes and standards covering qualified products.

Specific objectives were to:

- Work with manufacturers and product developers to enhance their product business case and market appeal, and to resolve key market barriers.
- Build alliances with key institutions to support market adoption and expand market opportunities.
- Build relationships with the California utility efforts that are aimed at energy efficiency and DR.
- Support the development of pilot efforts for LCF technologies to demonstrate reliability and energy savings.
- Facilitate technology transfer and market adoption to disseminate information about LCF products, energy savings, and other benefits.
- Inform code and standards processes of products developed under this Program.
- Develop market support strategies for the post-contract period.

Specific activities included:

- Conduct program-level technology transfer activities.
- Develop partnerships.
- Develop pilot efforts and innovator markets.
- Accelerate market adoption.
- Support codes and standards processes.

11.2. Project 11 Outcomes

The market connections team developed a program-level technology transfer plan based on product-specific technology transfer plans developed for each LCF project. For each project, the team collected information on the product, its market, and key barriers and opportunities, to enable each project team to anticipate major opportunities and impediments to successful transfer of the technology into the market. These documents were used an internal tools for each project team.

The market connections team formed partnerships with Solatube, Finelite, Adura Technologies, Cooper Lighting, Philips Day-Brite, NEV Electronics, Lighting Research Center, and Hunter Fan to support expansion of market opportunities for the LCF products. In support of this activity, the team developed specification sheets and technology briefs for each of the viable products that emerged from the nine LCF projects, including specialized briefs for utilities.

The market connections team made numerous presentations to potential project partners, including the following utilities: the Sacramento Municipal Utility District (SMUD), Pacific Gas and Electric Company, and Southern California Edison in California, as well as Duke Energy (NC and region) and the New York State Energy Research and Development Authority. Also, a presentation was made at the E Source Forum, where utility representatives from across the United States were in attendance. LCF projects were included in CLTC overview presentations given to visitors to the facility on a weekly basis.

The market connections team established a brand and identity for LCF, including the development of a website[21], which will remain active after the close of the program. The team produced signage and publications to promote awareness of the LCF technologies and pitched stories about LCF products to the media. The team focused on promoting the LCF program as a whole and prepared project-specific marketing materials as individual products neared commercialization. For some products, the industry partners conducted their own marketing campaigns, and the CLTC provided support as needed.

Publications developed for this program include several technical briefs and case studies. Also, the Title 24 2008 *Residential Lighting Guide,* Classroom Retrofit Guide, HALO rack card, and the Advanced Lighting Guidelines new ALG Online Edition (ALG) were all part of the LCF market connection efforts. These publications or links to these publications can be found on the PIER LCF website[22].

Highlights of pilot efforts are:

- The Finelite High-Performance Recessed Troffer entered the marketplace in part as a result of the collaborative work done on the R-ICLS project. The PIER sponsored State Partnership for Energy Efficient Demonstrations (SPEED) program is currently seeking demonstration sites for this recently released product.
- The ALPS is the proprietary name for the LCF WIPAM system. Adura Technologies, the commercial partner on this effort, partnered with the PIER Demonstrations program to test the system in several environments: at the CLTC facility in Davis, California; at a UC Santa Barbara (UCSB) parking garage; and, in the near future, at the University Communications Office, Mrak Hall, on the UC Davis campus.
- The Advanced LED Downlighting System prototypes were installed in both CLTC's 1554 Drew Avenue location and in the 633 Peña Drive facility in demonstration kitchen areas in Davis, California. The downlights were consistently popular with visitors for their sleek presentation, unique indirect LED cross-bar design, low can height, and

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21 www.archenergy.com/lcf

22 Ibid. footnote 20.

centrally located power supply. An average of 20–30 guests visit the CLTC on a weekly basis. With the addition of the 2010 Open House guests, roundtable events, and tours, it is estimated that over 2000 CLTC guests will have seen the prototypes by the close of 2010.

- The HALO LED downlight, the commercialized product developed under the LCF project originally conceived as a hybrid CFL/LED downlight, has been included in several PIER Demonstration projects: the California State Parks BMVC, the California Department of Public Health in Richmond, the SMUD E-house, and at CLTC.
- The LED ceiling fan prototype is currently installed in a living room demonstration at the CLTC. The light board is the CLTC proposed version, rather than the Hunter version. The fan is installed with a dimmer, which appeals to visitors who have switched to non-dimmable CFLs for ceiling fan light kits but prefer dimming capabilities. The ceiling fan is a popular display, and most visitors are disappointed to hear that it is not currently available for sale.

For several of the research efforts, products were either ready for commercialization late in the life of the program or were not ready for commercialization by the time the program ended. Therefore, the products that made the most rapid progress toward commercialization received the most marketing attention: the HALO® downlight, the smart LED fan light kit, and the WIPAM. The team worked in partnership with PIER Demonstrations Program to offer information on LCF technologies to energy managers, design professionals, and building occupants.

Market connections for products developed in the LCF Program also support California's Title 24 standards as all LCF researchers aim to meet Title 24 requirements. The *Title 24 2008 Residential Lighting Guide* developed by the CLTC staff also serves as a quick-reference tool to make the code more accessible to a wider audience. Funded in part by the LCF Market Connection project, this guide is available on the CLTC and LCF websites.

Of the nine LCF projects, three are commercially available products in the marketplace at the conclusion of this program – Cooper HALO LED downlight, the Adura LightPoint Wireless Control System developed under WIPAM project, and the Finelite HPR/High Performance Recessed troffer, which was produced through their R-ICLS project. These products were assessed to be capable of meeting California's Title 24 and other pertinent codes and standards.

11.3. Project 11 Conclusions and Recommendations

11.3.1. Conclusions

Overall, the market connections team focused primarily on promoting the LCF program as a whole rather than on promoting individual products. Presentations, demonstrations, and media work all aimed at reducing the key market barrier of lack of information among designers and the public about new energy-efficient lighting products. Because the LCF project included, for example, three LED downlight projects, the market connections team approached the downlight market and the physics of downlights overall and promoted all three efforts.

There were some limitations to the collaboration between the LCF market connections team and industry partners. For some LCF products, the manufacturer chose to handle marketing using

its in-house team; this proved particularly true once a project neared commercialization. As a result, it was challenging for the market connections team to ensure that publicity for the product conveyed the message that development of the new technology had been supported by public funding. In other cases, assistance with market research would have been helpful. In addition, because team members and project participants were not all at a single location, for future projects, a robust online central file repository that allows multiple contributors would enhance communications.

The technologies that reached viable or near-viable market status did so near the end of project—too late for the team to be of much assistance in publicizing these products. As noted above, the team focused primarily on publicizing the program as a whole, promoting awareness and education about energy-efficient lighting among professionals and the public.

In addition to the three commercialized products, the market connections team feels that there are two additional products developed under the PIER LCF Program that remain viable if a manufacturing partner is found. The LCF team and potential market adopters were both in support of the commercialization of the CLTC-developed LED Ceiling Fan Light Kit prototype and the Advanced LED Downlight prototype. The overall enthusiasm from specifiers and users at conferences and the CLTC display presentations indicates real promise for each product.

Demonstration projects were key to the overall LCF Program effort. The market connections team observed that side-by-side installations of LCF technologies were especially effective, allowing consumers and designers to see how the new technology compared to familiar products. Side-by-side displays enabled the public to correct misconceptions about efficient technologies, e.g., the perception that LEDs cannot product a warm color temperature similar to incandescent bulbs.

Another key to the team's marketing efforts was Internet-based publicity. The investment in Web infrastructure and programming for this project was minimal, and the website was completed in house using team members' existing knowledge; the team concludes that this is a cost-effective alternative to expensive print publicity and that information technology support is important to consider in the plans and budgets of future efforts.

With regard to trade shows as a venue to promote research efforts, the team concluded that the value of attending a trade show can be maximized if there are multiple points of contact with attendees (e.g., exhibit booth, speaker, poster session), which aids in overcoming the difficulty of communicating information about research concepts and products that are not yet available to an audience that is expecting to learn about commercially available products.

In general, the market connections team found that California utilities are already well versed in energy-efficient products and technologies, so very little effort was needed in this area. Additionally, most utility representatives were eager to support the LCF demonstrations in their service territories.

11.3.2. Recommendations

Future projects could benefit from a central online file system, a robust online central file repository that allows multiple contributors would enhance communications.

At the time this project was established, the CLTC brand was not fully developed, and PIER has its own style manual and suggestions. With efforts such as LCF, there can be confusion between an "overall" brand (e.g., for PIER projects), a specific project or "sub" brand (e.g., for LCF), and an individual research participant (e.g., CLTC). Future branding campaigns should fully examine the need for a hierarchy within all brands being represented and consider how to differentiate individual projects from umbrella organizations in an effective manner. The team recommends that, despite these complexities, a brand be developed for future projects intended to reach a wide audience and especially those intended to appeal to residential products manufacturers or customers.

Marketing efforts can leverage presence at trade shows by ensuring multiple points of contact with event attendees so there is ample opportunity to communicate information about research projects in a forum otherwise geared toward products that are already commercially available. For example, a booth in the exhibit hall can be effectively complemented by a speaker and/or presentation (such as a poster session) at the event. This arrangement provide more opportunity to explain the research concepts to attendees.

The team recommends that Internet-based methods of communicating information about efficiency research projects be explored, including the use of social networking tools. In addition, the team recommends that budgets include subcontractor funding for Web development and information technology support, and that project websites be easy to update with only basic knowledge of html required.

Future projects could benefit from advance market research and advance planning of both the objectives of the marketing efforts and for working relationships with marketing departments of industry partners. For advance market research, programs could take advantage of opportunities to enlist graduate students in research activities.

The market connections team recommends that finalized case studies be sent to the marketing departments of PIER partners to encourage their use in the broader marketplace.

11.3.3. Commercialization Potential

The commercialization potential of each the LCF projects has been addressed by the individual project sections of this report.

11.3.4. Benefits to California

The benefits to California from the LCF market connections activities are increased energy savings from expanded awareness and adoption of the new energy-efficient products developed through this program. This extends beyond the lifetime of the products developed during the contract period as other manufacturers imitate LCF products, further broadening the market of efficient technologies. Market connections activities also educate consumers about efficient products and evaluating the efficacy promises of products they consider for purchase.

Glossary

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

Acronym	Term
ACEE	American Council for an Energy-Efficient Economy
AEC	Architectural Energy Corporation
AIA	American Institute of Architects
ALCS	Advanced Lighting Control Systems
ALG	Advanced Lighting Guidelines
ALPS	Adura LightPoint System
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
A/V	Audio / visual
BMVC	Bidwell Mansion Visitor Center
BOMA	Building Owners and Managers Association
C	Centigrade
CCT	Correlated Color Temperature
cd/m2	Candelas per square meter
CEDR	Cost-effective demand response
CEE	Consortium for Energy Efficiency
CFL	Compact fluorescent lamp
CHPS	Collaboration for High Performance Schools
CIEE	California Institute for Energy and Environment
CLTC	California Lighting Technology Center
CRI	Color Rendering Index
DOE	Department of Energy
DR	Demand response
EPA	U.S. Environmental Protection Agency
ESCo	Energy service company
ETCC	Emerging Technology Coordinating Council
fc	Footcandles
GW	Gigawatt
GWh	Gigawatt-hour
HDR	High dynamic range
HID	High intensity discharge
HMG	Heschong Mahone Group
HVAC	Heating, ventilating and air conditioning
IC	Insulation contact
ICLS	Integrated Classroom Lighting System
IECC	International Energy Conservation Code
IESNA	Illuminating Engineering Society of North America
IOU	Investor-owned utility
K	Kelvin
kcd/m^2	kilocandelas per square meter
kW	Kilowatt

Acronym	Term
kWh	Kilowatt-hour
LCF	Lighting California's Future
LED	Light-emitting diode
lm	lumens
lm/W	Lumens per watt
LPD	Lighting power density
LRC	Lighting Research Center
mA	Milliamps
MDL	MicroDataLogger
MW	Megawatt
MWh	Megawatt-hour
NBI	New Buildings Institute
NEC	National Electric Code
NEMA	National Electrical Manufacturers Association
NYSERDA	New York State Energy Research and Development Authority
O&M	Operations and maintenance
PAC	Program Advisory Committee
PCC	Phase cut carrier
PG&E	Pacific Gas and Electric Company
PIER	Public Interest Energy Research
PLC	Power Line Carrier
PWL	Portable workstation luminaire
R&D	Research and Development
R-ICLS	Retrofit Integrated Classroom Lighting System
SCE	Southern California Edison
Sq. Ft.	Square foot
SMUD	Sacramento Municipal Utility District
SPETM	Scattered Photon Extraction
TDD	Tubular Daylighting Device
THD	Total Harmonic Distortion
TWh	Tetrawatt-hour
UCSB	University of California Santa Barbara
UL	Underwriters Laboratory
UPB	Universal Powerline Bus
Vdc	Volts direct current
V	Volts
W	Watts
WIPAM	Wireless Integrated Photosensor and Motion Sensor