Emerging Lighting Technologies and Applications: Combining the New with the Tried and True

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ABSTRACT

With lighting consuming roughly 30 percent of commercial sector electricity use, this technology area continues to be a key energy savings target, which recent research is demonstrating. Advanced lighting technologies such as LEDs and 96 percent reflectivity plastic material are being combined with established products such as occupancy controls and direct-indirect luminaires to deliver increased control and user satisfaction, flexible lighting levels, reduced peak demand, and lower energy bills. Research funded by the California Energy Commission's Public Interest Energy Research Program is developing innovative technologies to better meet commercial and residential lighting needs. This paper highlights five projects that use unique combinations of both new and tried and true technologies:

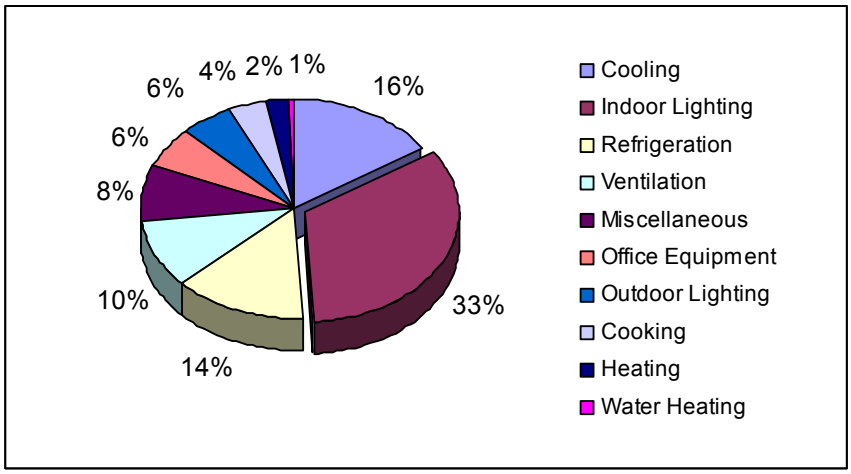
- Integrating direct-indirect fluorescent lighting with occupancy sensors, photosensors, and controls into easy-to-install systems for classrooms – cutting costs while improving lighting quality.
- Using compact fluorescent lamps in a unique plug-and-play system for retrofit downlight applications – cutting installation costs while delivering higher-quality lighting.
- Combining a bi-level step down ballast with energy efficient lamps and motion sensors – reducing wasted energy in stairwells.
- Coupling LED technology with occupancy sensors for entryways – providing low-cost lighting and higher illumination when needed.
- Evaluating the effectiveness of combining LEDs with occupancy sensors in hotel bathrooms – offering low-cost night lighting while cutting electricity use.

The authors will describe how these projects have combined the strengths of various organizations and manufacturers, leveraged public and private funds, provided valuable performance results, and focused on rapid market introduction of these lighting products.

Introduction

In California, electricity used for lighting represents 28 percent of the total electricity used in the residential sector and 33 percent of the total electricity used in the commercial sector, and over 23 percent of total electricity used in the state. Figure 1 shows the breakdown of commercial energy use by end use (Commission 2001). The direct electricity use of lighting systems represents only part of the impact on energy consumption, the state's electric system reliability, and the environment. For example, in commercial space, about five percent of the electricity used for air conditioning is directed at eliminating heat generated from lighting equipment.

Figure 1. California Commercial Energy Use



Source: California Energy Commission

Improving lighting efficiency has both direct and indirect benefits. Studies have shown that the potential exists to reduce typical lighting energy consumption and peak demand by up to 50 percent by the year 2020, while improving the quality of lighting to the end user (Interlaboratory Working Group 1997). Reductions in lighting system use during peak demand periods can clearly help avoid or reduce electric system reliability problems. Improvements in lighting efficiency and controls can provide a substantial reduction in the need for new electric generation and distribution systems. Also, improved energy-efficient lighting products and controls will help reduce the environmental impacts of lighting, and represent a significant step towards improving the societal value of electricity use.

The Lighting Research Program (LRP), funded by the California Energy Commission Public Interest Energy Research (PIER) program, is designed to focus on both short-term and longer-term lighting technology research (PIER LRP 2002). The program combines the unique strengths of various organizations and manufacturers, leverages public and private funds, provides valuable research activities, emphasizes involvement from lighting designers and consultants, and focuses on rapid market introduction. The LRP also strives to ensure that identified lighting research gaps are addressed and information is shared with lighting designers and manufacturers. The ultimate goal of the LRP is to optimize lighting systems that end users will employ to reduce electricity use, peak electric demand, and environmental impacts in California. This program encompasses both residential and commercial sectors, as well as outdoor lighting associated with buildings.

PIER Lighting Research Program

The $5.2 million LRP, which runs from October 2002 through October 2004, is focused on effectively introducing new energy efficient lighting products and systems into the California marketplace using a programmatic approach to research and development (R&D). The need to concentrate much of the LRP work on short-term projects is necessitated by the enormous energy savings potential identified in specific residential and commercial uses of electric lighting. Several longer-term projects are also part of the LRP portfolio.

Additionally, the LRP activities are partnered with both researchers and lighting product manufacturers. These include researchers from Lawrence Berkeley National Laboratory (LBNL) and the Lighting Research Center (LRC), as well as manufacturing partners like The Watt Stopper and Finelite Inc., who are willing to cost-share in product development and provide open access to project results so others may choose to produce competitive products. In some instances, the manufacturers are leading the research and, in other areas, manufacturers are involved only in prototype development and commercialization efforts. The manufacturers are great assets because of the knowledge they provide about market pathways and their willingness to share in research costs. The LRP also integrated the market connection funding and activities into one cross cutting effort for the entire portfolio. This strategy fosters synergy in the program and effectively leverages market connection activities with research and manufacturing expertise, providing a cohesive effort.

With the researcher and manufacturer partnerships combined with PIER funding and the programmatic approach, the various aspects involved in bringing energy efficient lighting products and systems to the marketplace – R&D, value engineering, manufacturing, distribution, and marketing – are packaged into a unique blend. The LRP combines traditional R&D with manufacturer partnerships and market connection activities to provide California with the best opportunity to lower statewide energy consumption and peak demand in the short-term through the accelerated introduction of energy efficient lighting products into the marketplace.

Integrated Classroom Lighting Systems

Integrating direct-indirect fluorescent lighting with occupancy sensors, photosensors, and dimming controls into easy-to-install one-source systems has shown significant opportunities for cutting costs for design, specification, operation, and installation while improving lighting quality for K-12 classrooms. The systems, developed by Finelite Inc. with technical support from The Watt Stopper, offer school administrators and designers flexibility in selecting the level of lighting quality, control, energy savings, and cost that best meets their needs.

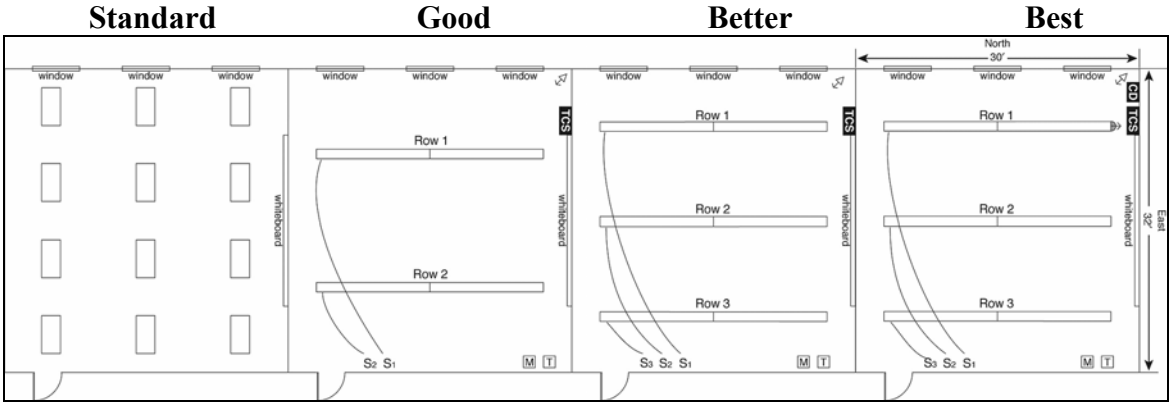
The Product

As an alternative to the standard classroom design with two-foot by four-foot lay-in troffer two-lamp light fixtures, the integrated classroom lighting system uses direct-indirect lighting and is comprised of three primary template systems: good, better, and best. The “good” system is equipped with two rows of light fixtures, three high performance T-8 lamps per fixture, an occupancy sensor, manually switched rows for daylighting control, a specially selected ballast factor depending on room size, and one source for layout, pricing, and warranty. The “better” system includes the above features and adds a third row of light fixtures to provide more uniform illumination, and uses a lower ballast factor to drive the lamps. The “best” system enhances either the “good” or “better” systems with dimming features, using a manual teacher control switch and/or automatic daylighting sensing and controls. The teacher control switch allows instructors to manually change the light levels quickly in the room during audio/visual (A/V) presentations. The systems are highlighted in Figure 2 (Finelite 2003).

All systems feature light fixtures that use a new 96 percent reflective white plastic material, tested as a part of this project. The new material provides a more efficient diffuse reflector system that can still meet the cost constraints imposed by the educational market. By

using more efficient reflectors, classroom lighting fixtures deliver the same level of desk-level illumination in the classroom with less electrical power, as compared with the standard lay-in troffer system. All system options meet the IESNA (Illuminating Engineering Society of North American) and CHPS (Collaborative for High Performance Schools) guidelines for illumination and uniformity.

Figure 2. Integrated Classroom Lighting Systems



Source: Finelite, Inc.

Performance Results

One of the three optional systems was installed in each of 19 classrooms in six California school districts. The test classrooms along with base case classrooms were monitored for energy use, system performance, and teacher satisfaction during the 2003/2004 school year. Preliminary results indicate a 50 percent reduction in energy use with 0.85 Watts/square foot (sf) for the classroom with the good system as compared to 1.75 Watts/sf for the base case classroom that did not receive a retrofit. The better system, which added a third row of fixtures, showed a 57 percent reduction with 1.0 Watts/sf. Dimming features added with the best system provided minimal additional savings. Desk-level lighting in the retrofit classrooms ranged from ~30 footcandles (fc) in the far corners to ~80 fc directly under the light fixtures. Teacher surveys were also taken. The majority of teachers indicated they liked the "calming feeling" of the direct-indirect lighting and they used the A/V mode (downlight only) at some point during each day. Specific information on the installed lighting system components, room dimensions, surface reflectivity, and measured light levels and energy savings for each test classroom is available in the PIER LRP final report.

Overall, the system provides the proper amount of light on the student's desk and the teaching walls, gives teachers more lighting control, provides a plug-and-play system for easier contractor installation, and offers a single source for support. Typical classroom lighting systems that use 15 parabolic fixtures cost approximately $2.86/sf or $2,745 to install. The good system featured in this project is $2.71/sf or $2,600, actually costing less than the standard lighting system found in most classrooms. Adding a third row of fixtures and dimming and daylighting control increases the overall lighting system cost but, if integrated properly with the overall building and air conditioning design, may payback to the school district within seven to 10 years for new installations.

Market Introduction

Finelite Inc. has introduced this product line and has been working with the CHPS Program and the California State Architect to meet their guidelines for acceptance and adoption of the integrated systems. Also, all three optional systems meet the Title 24 2005 code, which requires a maximum of 1.2 Watts/sf of classroom lighting in new schools, down from 1.6 Watts/sf in the 2001 code version. Applications for the systems include both the new construction and retrofit school market and training or conference facilities in office buildings using A/V equipment. Future product variations are expected to have widespread use in general office applications. The new integrated classroom lighting systems have the potential to reduce energy use in California classrooms by 50 percent over the next 10 years. If adopted by twenty percent of the schools, the integrated classroom lighting system could save over $20 million a year in electricity costs and conserve 176,000 megawatt hours (MWh) of electricity per year, equivalent to the power used annually by 26,000 average California homes.

Retrofit Downlight Systems

Using compact fluorescent lamps in a unique plug-and-play installation system for retrofit downlight applications has demonstrated huge benefits in the residential sector and offers promise of similar impact in commercial markets. The system will reduce installation costs while delivering a higher quality energy efficient product that benefits both contractors and owners. LBNL is leading the research to design, manufacture, and test the product in new and retrofit applications with the involvement of a major lighting manufacturer and municipal utility.

The Product

Building on an earlier project to develop a downlight system for residential kitchens in new homes, LBNL researchers are developing a similar system for residential and commercial retrofit applications. The retrofit downlight system utilizes recessed optical heads with two-lamp electronic ballasts, 26-Watt CFLs, and plug-and-play wiring. By integrating the various components into a single package, numerous performance and installation benefits are realized: one two-lamp ballast instead of one ballast per fixture cuts the ballast costs in half, optical heads replacing individual fixtures simplifies material and mounting, and plug-and-play wiring helps installers avoid costly wire-nut connections. Researchers refined the reflector in the new heads to produce high efficiency, low glare optics. The electronic ballast used in the system is thermally isolated to minimize lamp and ballast overheating, and the CFL is high output, producing quality light in the designated space. The system approach optimizes the performance of the product, while minimizing the initial cost and installation time.

For retrofit applications either with attic or no attic access, the system consists of a master-slave fixture system in which the ballasts for the entire system are all present at a central location. This central location is thermally optimized to maintain the ballasts within acceptable ranges throughout their operation, in order to prevent premature failures. The ballasts are accessible and replaceable from the room side by the simple removal of the reflector. The plug-and-play downlight whips can be strung to the desired downlight locations. Figure 3 shows the final prototype system for new construction residential applications. The final prototype system

for retrofit residential and commercial applications is under development. Units can be daisy-chained by the installer in even quantities (2,4,6).

Figure 3. Retrofit Downlight System

Source: LBNL

Performance Results

Currently, the prototype retrofit downlight system is under final development. Field-testing is planned and performance results should be available in early 2005. The system should provide increased light levels over standard 75-Watt incandescent fixtures with ten times the amount of lamp life and approximately one-third the energy use. The systems will offer existing residential customers the opportunity to realize 50 to 70 percent energy savings over incandescent recessed lighting fixtures. Also, increased light output enables owners to reduce the number of fixtures required in the retrofitted area compared to typical downlighting systems, lowering initial costs and subsequent maintenance costs. Payback of the systems is dependent on retail price and installation costs. For new construction, payback is expected to be less than one year compared to standard incandescent systems. Pricing for new construction and retrofit versions was not available at the time this paper was written.

Market Introduction

The systems are envisioned as "out of the box" lighting systems that can go into residential or commercial office areas that currently have incandescent downlighting as well as areas with no downlighting at all. This system has the potential to greatly reduce the wiring requirements for installation of a downlight system, which can be significant given the difficulties often encountered when working in confined attic spaces and the number of fixtures required to provide the same light output in the designated space.

Working with LBNL, Lithonia is expected in late 2004 to introduce the system, which is Title 24 compliant, UL listed, and IC rated, into the new construction residential market (Lithonia 2004). The product lines for the retrofit residential market are expected in 2005. Based on preliminary market assessment data from LBNL, kitchen remodels are the most common household renovations and downlights are highly popular retrofits in kitchen remodels. Once the retrofit downlight systems are introduced, they have the potential to greatly impact the remodel market and save a significant amount of energy for California.

Bi-level Stairwell Fixture

Combining a bi-level step down ballast with energy efficient lamps and an ultra-sonic motion sensor reduces wasted energy in enclosed exit stairwells by offering standby lighting levels when the space is unoccupied, and full light output when the space is occupied. The International Facility Management Association (IFMA) teamed with LBNL and LaMar Lighting (LaMar) to evaluate the performance, California code issues, and potential energy savings of bi-level ballast technology when coupled with occupancy sensors and fluorescent T-8 lamps in several California sites.

The technology has also been evaluated at two New York sites by the LRC with funding from the NYSERDA (New York State Energy Research and Development Authority) with technical support from LaMar (NYSERDA 2003). Both research programs are providing important data that can be used by building managers, fire marshals, and code officials to expand the use of bi-level technology nationwide.

The Product

Due to reasons of safety and code compliance, stairwells need to be lit 24 hours per day regardless of whether they are occupied. For enclosed stairwells that have high wattage light fixtures, such as two-lamp four-foot fluorescent T12s or T8s, 24-hour usage can result in a significant and unnecessary waste of electricity. The bi-level fixture installs just like any ordinary fluorescent fixture and utilizes standby wattage consumption as low as 8 Watts using a one-light 25-Watt T8 fixture. Both full and standby light levels from the fixture are designed to provide the proper amount of light required by local and national code officials.

Figure 4. Bi-Level Fixtures

Source: LaMar Lighting

Facility managers can select from a variety of fixture styles, one or two-lamp configurations, and choose either 120 or 277 volts. Step-down ballast options include 5, 10, or 33 percent of full light output depending on fixture configuration. For example, two 4-ft T8s with step down to 10 percent reduce power from 62 Watts at full output to 13 Watts at standby. The occupancy sensor is a high frequency and extremely sensitive ultra-sonic motion sensor mounted internally to the fixture. The UL-listed product, shown in Figure 4, recommends 100-hour lamp conditioning to assure long lamp life, and has an adjustable setting that ensures full light levels for a specified period of time ranging from 15 seconds to 30 minutes when the stairwell is unoccupied (LaMar 2003).

Performance Results

Since March 2004, LRP researchers have been monitoring occupancy use patterns, energy savings, and installation and operational factors in four California sites installed with the bi-level technology, and they have been investigating code issues that may affect California applications. The sites include a 10-story university building, a four-story corporate office building, a 10-story government building, and a 12-story corporate office building. Occupancy patterns vary widely at the four sites with the university building demonstrating an average stairwell usage of 25 percent, the four-story corporate building showing a ten percent average usage, and the 10-story government and 12-story corporate office buildings yielding a three percent average usage. In all sites, the bi-level fixture provides at least 1 fc during all hours of the day and night, which is required by state and local codes, in both the full on and standby positions.

Overall, the results indicate energy savings ranging from 50 to 80 percent over standard stairwell lighting fixtures. The technology is applicable to new construction and retrofit projects. Paybacks to building owners are dependent on the type of fixture that was displaced and whether the project is new construction or retrofit. Based on the economic calculations prepared as part of this project, using the technology in new construction projects in California yield paybacks in the three to five year range, while retrofit projects have paybacks closer to five to seven years because of the added labor component. Additionally, code and building officials have been receptive to the bi-level technology.

Market Introduction

The bi-level technology is available currently from LaMar Lighting for both new construction and retrofit applications. The current product line is focused on building managers looking to maintain proper levels of lighting when stairwells are occupied, but wanting to save electricity when stairwells are not in use.

The products have the potential to save 40 to 50 MWs in enclosed stairwells in commercial buildings in California. Applications such as institutional stairwells or other low use areas offer even greater statewide opportunities. It is important to note that the International Code Council® has recommended an increase in the light level of occupied egress stairwells from 1 fc to 10 fc (ICC 2003). Based on the future adoption by state and local code officials of the ANSI recommendation, bi-level fixture technology could prove to be even more valuable to building owners.

LED Exterior Fixtures

Coupling LED technology with occupancy sensors for use in entryways and porches, researchers are working with manufacturers to develop low-cost, all-night lighting products that operate at lower illumination levels most of the time, yet deliver higher illumination when needed. Current prototypes combine the LED technology and occupancy sensors with incandescent or compact fluorescent lamps (CFL) creating hybrid fixtures. LBNL is leading the research and teaming with three separate manufacturers (LBNL 2003).

The Products

LBNL researchers designed, built, and photometrically tested new designs of exterior luminaires that incorporate LEDs to supplement existing inefficient fixtures containing only incandescent lamps. Combining a low-cost incandescent lamp with an occupancy sensor and an optimized LED package creates a fixture that provides adequate ambient light levels when necessary, and energy saving light levels when the area around the fixture is unoccupied. In most applications, the low-efficiency incandescent lamps are expected to have little usage, so their relatively high wattage as compared to CFLs should have a minimum impact on annual energy use, and the fixture cost should be competitive with standard incandescent units.

Three hybrid product concepts have been developed and are shown in Figure 5. The first concept enhances the standard PAR security fixture that already utilizes occupancy sensing technology. LEDs are added to the fixture and provide minimum light levels all night long, with PAR lamps operating during occupied periods. While the LEDs increase energy usage compared with standard occupancy sensor PAR security fixtures, the new units offset usage of standard continuously operating incandescent fixtures in applications where continuous illumination is desired.

The second product concept mimics the traditional residential or commercial entry light using a standard fixture design with the addition of an occupancy sensor and LED package. In one variation, the LEDs are connected with a low voltage wire, which may be located anywhere within the general area of the porch fixture. Similar to the first concept, the LEDs operate continuously while the incandescent lamp or CFL operates only during occupied periods. The third product concept is an LED-only wall pack fixture, which will provide adequate ambient light to illuminate the surrounding area.

Figure 5. Exterior LED Fixtures

Source: LBNL

Performance Results

The three product concepts are under development and information on performance testing on the prototypes currently is not available. However, LEDs have specific, directional light output qualities that can be used to place light where it is needed. LED technology also exhibits high lifetimes, low failure rates, and robust physical designs that can withstand considerable shock and vibration. These qualities have been a major driving force for LED usage in applications where lamp replacement and maintenance is difficult or expensive. The low lumen (lm) output per white LED, currently around 20 to 30 lm/LED as compared to ~1000

lumens from a 60-Watt incandescent lamp, does require many LED products to use multiple LEDs.

The wall pack LED-only fixture described above uses an LED package with eight 1-Watt white LEDs. The output is 101 lumens, and the fixture efficiency is 90 percent. Compared to a 60-Watt incandescent bulb, the product yields 85 percent energy savings while providing comparable illumination near the entry. Customers benefit from lower energy consumption, less light trespass, and longer fixture life. Working with the Sacramento Municipal Utility District (SMUD), several demonstration sites are planned with the LED products and LBNL researchers will collect performance data.

Market Introduction

Three manufacturers are planning to introduce exterior LED product lines based on results from this project, one for each of the three product concepts. For the state of California, projected energy savings from the use of the new products are dependent on the overall acceptance of LED technology over the next 10 years. Operating cost factors are likely to be the major driving force behind commercial viability of LED-based fixtures. In the residential sector, off-the-shelf product pricing is of prime importance, with cost of ownership a distant second.

Product performance features also play a significant role. The unique properties of LEDs enable applications and outputs not currently obtainable with other sources. Proper utilization and exploitation of these properties are key to developing viable applications. Dimming, switching, motion sensing, color mixing, and other considerations regarding LED sources may yield significant and novel features that accelerate market acceptance and help justify or lower the cost of LED technology.

LED Bathroom Nightlights

By evaluating the effectiveness of combining LEDs with occupancy sensors in hotel bathrooms, researchers have been able to document how offering low-cost night lighting provides benefits to travelers while cutting electricity use during unoccupied periods for hotel owners. The bathroom nightlight was installed and monitored in a hotel for a period of four months - two months pre-retrofit to establish a baseline and two months post-retrofit to measure the energy use and practical advantages and disadvantages of the product. LBNL directed the project work and leveraged support from SMUD, Doubletree Hotel, The Watt Stopper, and the PIER LRP.

The Product

The LED bathroom nightlight serves the dual purpose of night lighting and occupancy-based lighting control for hotel bathrooms. As shown in Figure 6, the product integrates an occupancy sensor and LED light into a wall switch, and is designed specifically to save energy while providing users a higher level of lighting amenity. The nightlight uses a super bright, energy efficient white LED and passive infrared (PIR) technology to detect occupancy. Other features include a manual-ON or automatic-ON operation, adjustable time delay from 15 minutes to two hours, and contractor-friendly terminal wiring, which eliminates the need for twist

connectors. The 120-volt product is UL-listed and compatible with 0 to 500-Watt incandescent or fluorescent loads. Average install time is 15 minutes.

Figure 6. LED Bathroom Nightlight

Source: The Watt Stopper

Performance Results

The project team replaced the standard wall switches with the devices in 448 guest bathrooms at the Doubletree Hotel in Sacramento, California. The hotel, which caters mostly to business travelers, was built in several phases during the 1970s. Consequently, the bathroom layouts and fixtures vary widely throughout the guestrooms. Of the rooms, 25 percent are rented on a long-term basis by a major airline providing spaces for flight crews. LBNL selected rooms with varying conditions (different bathroom layouts, and flight crew/no flight crew occupancy), so the study results could be applied widely. They monitored the devices using light status loggers.

The data for the baseline and post-LCS conditions were tabulated separately, and indicated most savings occur during the day when bathroom lights are left on when the guestroom is unoccupied. It should also be noted that the LCS yields additional savings during the night when the LED nightlight feature is used instead of the hotel patron leaving on the bathroom light. The average energy savings from the LED bathroom nightlight measured from this study were found to be 46.5 percent with a 2.5-year simple payback.

Market Introduction

The product is currently manufactured and sold by The Watt Stopper. The product will benefit hotel and institutional owners looking to reap the benefits from energy savings and provide guests with a friendly nightlight product. Other market influencers include designers and architects involved in new or major redesign projects for hotels.

The LRP team has been working through industry groups, making presentations at hotel supplier conventions and directly to individual hotels, and working through influencers, especially those who have an interest in environmentally friendly technologies. Utility incentives may also be available to building owners for this product. The nightlight product provides the opportunity to save significant energy for California over the next 10 years. Retrofitting all of California's 350,000 hotel rooms would realize savings of more than 20,000 MWh per year, or enough energy to power 3,000 average California homes.

LBNL developed two product concepts for the LRP – one for retrofit applications as described above and a second one, a smart fixture, for new construction and major renovations. The second concept is currently under development.

Conclusion

This paper describes five PIER LRP projects that successfully combined new lighting technologies and methods with tried and true devices producing viable energy efficient products for the residential and commercial markets. These examples also illustrate the effectiveness of the Lighting Research Program, which integrates traditional R&D with manufacture partnerships and program-wide market connection activities. With 15 research projects in the program, other diverse lighting products and systems are either under development, involved in field-testing, or scheduled for upcoming market release.

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