Saving Energy with LEDs, Wireless Controls

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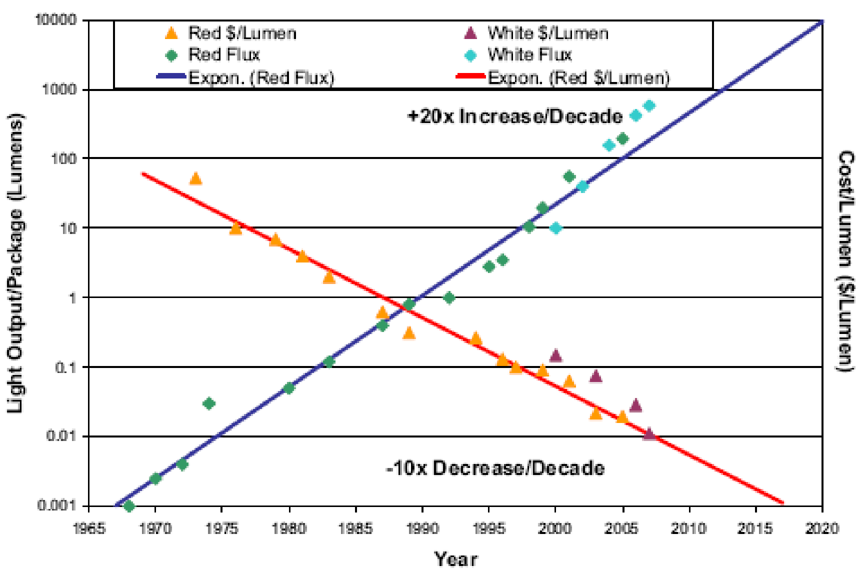
ABSTRACT

Lighting energy use can be reduced through two general means—the use of efficient light sources and effective controls. The most promising new light source—the light emitting diode (LED)—has come a long way, even in the year since we made our last AESP presentation. Three of the most promising applications feature LEDs in refrigerated display cases, recessed downlights, and street and area lighting. In the realm of lighting controls—there are billions of square feet of commercial building space with no controls beyond the simple on/off switch. Retrofitting with conventional controls is expensive and disruptive to ongoing activities. Wireless controls promise to be a low-cost way to provide scheduling, occupancy sensing, daylight dimming, personal control, and demand-response capabilities to a large range of facilities.

Introduction

There are two general ways to reduce energy use in a lighting system—use more efficient light sources, and use controls that ensure that the lights are on only when and where they're needed. Among light sources, LEDs are not yet the most efficient for all applications, but the technology has made great strides in the last few years, improving in efficiency and decreasing in cost (**Figure 1**). Those trends, along with efforts by the U.S. Department of Energy to provide objective test data and offer Energy Star specifications for LED products, have opened up a number of areas for cost-effective use of LEDs. Leading applications include refrigerated display cases, recessed downlights, and street and area lighting.

Figure 1 LEDs come down in cost, up in performance



Source: DOE, Roland Haitz, Lumileds

LED output has been increasing and cost decreasing according to Haitz's Law.

Wireless controls are an emerging technology that has the potential to be a cost-effective way to bring capabilities such as scheduling, occupancy sensing, daylight dimming, personal control, and demand-response to both existing and new facilities. The most promising architecture for wireless controls uses a concept known as a mesh network, which has been embodied in several ways in new products and standards.

Here Come LEDs

The best LED products now provide efficacies as high as 70 lumens/watt, a figure that accounts for losses in both the fixture and the driver (a component that is essentially equivalent to a ballast). That means that in some applications they can outperform CFL and HID products. The problem is that there are also a lot of products on the market that do not perform well, yet their manufacturers are making exaggerated claims about their performance. As a result, many lighting experts are concerned about repeating the mistakes made with CFLs, where CFLs, due to poor product performance, exaggerated claims, and high prices, developed a bad reputation early-on that has been hard to overcome (for more details, see a report for the U.S. Department of Energy's Office of Building Technologies, Emerging Technologies Program (Sandahl et al. 2006)). Two efforts led by the U.S. Department of Energy (DOE) are helping users to sort out the good products from the bad. In September of 2008, the DOE's The Energy Star standard for LEDs took effect and should begin to help users and utilities identify effective LED products. The second effort is DOE's Commercially Available LED Product Evaluation and Reporting Program (CALiPER) program, which provides objective test results for selected, commercially available products.

Energy Star Specifications

The Energy Star specifications establish performance criteria that will help both end users and utilities that want to provide incentives, identify worthy products. A key factor in setting up the criteria is the definition of efficacy for LEDs. A conventional light source is rated in terms of its efficacy, defined as the lumens of light output divided by the input power in watts. For light sources that require ballasts (fluorescent and HID sources) a system efficacy is defined that accounts for the power used by the ballast. For LEDs, the Energy Star specification is defined in terms of luminaire efficacy, or lumens delivered out of the fixture divided by the power input. That metric helps to account for the directional behavior of LED light (it's easier to get the directional light of an LED out of a fixture than it is to get diffuse fluorescent light out); and also for the real world impacts of the fixture design. LED output is very sensitive to temperature and if the fixture does not have a well-designed heat sink, the LED will lose both output and longevity.

Using that definition, the DOE ENERGY STAR strategy for LEDs for general illumination products establishes a transitional two-category approach. Category A addresses near-term applications, where LED technology can be appropriately applied (**Table 1**). Since the specifications were issued, DOE has identified several more near-term applications and issued draft specifications (**Table 2**). Category B establishes efficacy targets for a wider range of future applications, which will take effect once LED technology is more mature. As the technology improves over time, Category A will be dropped.

Table 1. Energy Star LED Application Categories

Undercabinet Kitchen
Undercabinet Shelf-mounted Task
Portable Desk/Task
Recessed Downlights (Res./Com.)
Outdoor Wall-mounted Porch
Outdoor Step
Outdoor Pathway

Table 2. Proposed Expanded LED Energy Star Application Categories

Surface and pendant-mounted downlights
Area and roadway luminaires
Outdoor decorative luminaires
Wall packs
Asymmetric cove lighting
Parking garage luminaires
Bollards
Wall-wash luminaires
Ceiling-mounted with diffusers; Directional

General requirements in category A include a color rendering index (CRI) of at least 75 and a thermal management system that follows the LED maker's specifications so that the LEDs don't overheat. LED power supplies will be required to have a power factor of at least 0.7 for residential applications and at least 0.9 for commercial installations. The lamps will also be required to maintain at least 70 percent of their initial lumen output for at least 35,000 hours for most applications. Efficacy requirements are set by requiring the LED fixtures to match typical CFL fixture performance for the specific applications listed in Table 1. So, for example, a CFL downlight is assumed to have a system (lamp and ballast) efficacy of 58.8 lumens per watt (LPW) and a fixture efficiency of 60 percent. Based on those numbers, an Energy Star LED luminaire would be required to have an efficacy of at least 58.8 × 0.60, or 35 LPW. Details on the Energy Star criteria are available on the web at http://www.netl.doe.gov/ssl/energy_star.html. For category B, the required efficacy will be at least 70 LPW.

[Note: The EPA, which co-manages the Energy Star program with DOE, has issued a different Energy Star specification for LEDs as part of version 4.2 of the Energy Star requirements for Residential Light Fixtures. As of this writing, the DOE spec seems to have gathered more support from utilities and is the one described here.]

DOE testing

To track progress in LED technology and to share reliable product performance data, the US Department of Energy established the CALiPER program. Through six rounds of testing, the program has tested about 120 commercially available products (see http://www.netl.doe.gov/ssl/comm_testing.htm). Products tested have exhibited a wide range of efficacies with products tested in the latest round ranging from 4 lm/W to 62 lm/W. DOE also reports that the average efficacy of products tested has improved, but in most cases, manufacturer performance claims for energy use, light output, or comparable wattage continue to be highly overstated and misleading (U.S. Department of Energy, September 2008.)

LEDs for Refrigerated Display Cases

One of the most promising of the new applications for LEDs is refrigerated display cases. LEDs offer several attributes that given them an edge over the fluorescent tubes that have been the mainstay in that category:

Good performance at cold temperatures. Fluorescent lamps lose a considerable portion of their light output at cold temperatures—they provide about 25 percent less light at display case temperatures than they do at room temperature. LEDs actually perform better when the temperatures are cold, and they last longer as well.

Directional light output. Fluorescent lamps emit light in all directions and are typically located near the display case door hinge and use reflectors to direct light onto the case contents. That process results in only about 60 percent of the light getting to where it is needed. LED light output can be aimed just where it is needed. In practice, that can mean the elimination of light-source glare on store floors and provision of even illumination of all products in the case. Tests at the Lighting Research Center have shown that customers like the illumination that LEDs provide.

No IR. Fluorescent lamps, like most light sources, emit a lot of heat into the area they illuminate, in the form of infrared radiation. LEDs produce waste heat also, but that heat can be conducted out the back of the LED; and the LEDs can be arranged so that much of the heat can be conducted away from the display case, which reduces the cooling load on the display case refrigeration compressor.

Controllability. Frequent cycling on and off shortens the life of a fluorescent lamp, but has little impact on an LED. Therefore LEDs can be used with occupancy sensors that turn off the lights when no one is near. The more time the LEDs spend turned off, the lower the load on the compressors as well; and the longer the lamps will last.

The technology has been deployed by a number of companies and field measurements have shown significant savings. For example, field testing sponsored by the Pacific Gas & Electric Company and conducted by the California Lighting Technology Center, was carried out at a grocery store in Northern California. In this demonstration project, LEDs were installed in place of T8 fluorescent lighting in a row of freezer cases. A total of 36 five-foot F58T8 high-output fluorescent lamps and associated ballasts were replaced with 60 LED bars, each 4-feet in length. Lighting demand was cut by about 0.96 kW, and refrigeration load by another 0.46 kW. Lighting energy savings of 43 percent were measured; and the consistency of the lighting between cases was found to be more uniform with the LEDs than with the fluorescent lighting. In addition, the researchers estimated that more than three cycles of fluorescent lamp replacement will be avoided during the expected 50,000 hour life of the LED system, leading to a reduction in maintenance costs as well. LED technology is improving rapidly, so even greater savings can be expected over time. In addition, the fluorescent system that served as the baseline was a fairly modern one—retrofitting older display cases with LED technology would result in even greater savings.

In a field trial, Wal-Mart found that refrigerated display cases illuminated by LEDs, with illumination controlled by occupancy sensors, used 92 percent less energy than conventional models. That display case reduction amounted to an overall reduction in store energy consumption of 3 percent.

The company is now retrofitting more than 500 stores with the technology, and will outfit new stores in the same way (Case Study, July 2007).

A number of utilities are now offering incentives for this application, including, PG&E, SMUD, and Progress Energy.

Recessed Downlights

Another promising application, covered in the initial release of the Energy Star spec, is residential downlights (also commonly called can lights). These lights represent one of the fastest growing categories in residential lighting, with DOE estimating that there are at least 500 million recessed downlights installed in US homes, with more than 20 million sold each year (DOE LED Application Series, January 2008). The most commonly used light source is a 65-watt incandescent reflector lamp with a standard Edison base. Both CFLs and LEDs offer the potential to cut energy use by 75% or more.

In this application, one of the chief benefits of the LED is the directionality of the light output. Reflector-style incandescent lamps are shaped and coated to emit light in a defined cone, but "A" style incandescent lamps and CFLs emit light in all directions, leading to significant light loss unless the luminaire is designed with internal reflectors. Therefore the downlights that use CFLs typically offer a fixture efficiency of only about 50% to 60%. Reflector lamps lead to better fixture efficiency but the lamps themselves are less efficient than bare spiral lamps. Enter the LED boasting very directional light output that enables the production of very efficient fixtures that emit almost all the light produced.

Table 3 shows a comparison of various types of recessed downlights. Notable is the fact that there is a very high-efficiency LED product available—more efficient than the best CFL alternatives, but the table also shows a low-efficiency LED product, less than half the efficacy of a CFL, that is also on the market, highlighting the need to chose carefully. Lamp life for the incandescent option is roughly 1,000 hours, for the CFLs 6,000 to 12,000 hours, and for the LEDs, if the fixtures are designed properly, 25,000 to 50,000 hours.

Table 3 Recessed Downlight Options

	Incandescent	CFL		LED	
	65 W BR-30 Flood	13 W 4-pin spiral	15W R-30	A	B
Rated lamp output (lumens)	725	860	750	NA	NA
Lamp power (W)	65	13	15	NA	NA
Luminaire output (lumens)	652	514	675	300	730
Luminaire power (W)	65	12	15	15	12
Luminaire efficacy (lm/W)	10	42	45	20	60

Source: E Source, data from US DOE

The high performance LED downlight product listed in the table performed well when it was installed and monitored in two homes in Eugene, OR, as part of a DOE demonstration program (DOE

Gateway Demonstrations, October 2008). The product cut energy use by more than 80 percent compared to incandescent alternatives; and also increased light levels at counter height and on the walls and floor. Builders who toured the homes gave the LEDs high marks for appearance.

However the demonstration also illustrates two remaining challenges for the technology—dimming and cost. Many recessed downlights are installed on dimming circuits, which can be problematic for CFLs—few if any CFLs dim smoothly to low levels of light output. LEDs have greater potential for dimming, but so far only with specific dimming products. At the homes in Oregon, it was difficult to find the brands of dimmers that were identified by the LED downlight manufacturer as compatible with its product. The lamp was tested with a non-compatible dimmer and was found to be difficult to set below 50%. The lamps either didn't dim enough or turned off and they did not operate in unison. According to the builder, a compatible dimmer was finally found after the testing, and it appears to be working satisfactorily (DOE Gateway Demonstrations, October 2008).

Although LED costs are coming down, the payback period calculated for the Eugene application was about 13.5 years based on local electric rates of $0.05/kWh and assuming three hours per day of operation and a product cost of $95. For a national average of $0.11/kWh, the payback period was estimated at about 7.6 years. With increased demand, and as more competing products enter the market costs should come done and the payback will be more rapid.

As of late 2008, there is only one entity offering a prescriptive rebate for the downlight technology, although that is expected to change now that the Energy Star rating is available, in fact the California IOUs (PG&E, SCE, and SDG&E) are planning to offer incentives for Energy Star rated LED recessed downlights in 2009 (Eaton, August 2008). Efficiency Vermont has been providing a $30 rebate LED Downlight Instant Lighting Coupon for qualified products since April 1, 2008. Initially the rebates were provided for the 6-inch downlight from LLF (now Cree), which was selected based on good performance in the DOE's CALiPER tests. Cooper Lighting's Halo LED downlights were also recently added to the list.

Street and Area Lighting

LEDs have several potential advantages for streetlighting applications, and several cities have announced that they are using them or intending to use them—but it doesn't appear that LEDs are currently a cost-effective option. However, the technology is improving rapidly so that conclusion could soon change.

Some factors make streetlighting a tough challenge for LEDs—the high pressure sodium (HPS) and metal halide (MH) lamps that they must compete against are very efficient and have a long life. This wasn't the case in other applications where LEDs have already displaced the incumbent technology, like exit signs and traffic signals. In those applications, the competition was incandescent lighting, made even less efficient than usual by filtering to obtain a desired color.

However, other factors can make streetlighting a good application for LEDs. The first involves the way LEDs reject heat. Conventional light sources feel hot to the touch because they dissipate heat as infrared radiation. LEDs are cool to the touch but must dissipate their waste heat through a solid heat sink, which can be difficult to do indoors where space is at a premium and temperatures can get pretty high. Streetlighting fixtures have an advantage in that they can provide very large heat sinks that wouldn't be possible on indoor or wall-mount outdoor fixtures; they also operate only at night, when the air is cooler. Because heat dissipation is vital to good LED performance, LEDs can operate at higher efficiencies and last longer in a streetlighting application than they can indoors.

Another factor is that LED output is very directional, making it easier to reduce light pollution and put the light where it's needed. And LED proponents tout the ability to vary the color of the LED output to provide the best quality of light for a given time of night.

That's the theory. How have streetlighting LEDs performed in practice? The most comprehensive study to date was completed in January 2008 by Pacific Gas and Electric (PG&E). Field testing of 15 LED luminaires in Oakland, California, found that LED fixtures reduced energy use by about 30 percent compared to new HPS fixtures. Total illumination from the LEDs was less, but the light distribution was better than with the HPS fixtures and met minimum requirements.

However, the study did find long payback periods for the LED fixtures depending on the assumptions made. Assuming group replacement for the HPS lamps every six years and each LED luminaire costs $487 more than an HPS luminaire in new applications, the LEDs in this installation would pay for themselves in energy and maintenance cost savings in about 15 years. The LED cost increment was based on an assumed high-volume purchase price. In a retrofit—where there's no installation cost for sticking with the HPS option—the payback period almost doubles. The study also provides a range of payback calculations to account for uncertainties in LED lifetimes and the potential need for periodic cleaning. Follow-up testing is underway with new models of the fixtures that provide similar performance but cost less.

PG&E also surveyed nearby residents to see how they felt about the new lights. Overall, 17 out of the 20 respondents reported that the new streetlights were as good as or better than the old lights (DOE Gateway Demonstrations, January 2008).

Other cities that have installed or are planning to install LED streetlights include Ann Arbor, Michigan; Raleigh, North Carolina; Austin, Texas; Anchorage, Alaska; Toronto, Canada; Yakima, Washington; and London, UK. However, at least one city, Grand Rapids, MI, decided not to proceed with a full installation because they were dissatisfied with light output in a trial installation (The Light of the Future? Not so Fast, November 2008).

One conclusion from all this is that there are some good products out there and some bad ones. Anyone considering installing LED streetlights should insist on a pilot test first, and when evaluating products, make sure the right comparison is being made. For example, compare the LED fixture to a new HPS or MH fixture, not to a lumen-degraded, dirty, old fixture with poor light distribution.

Wireless Controls

Lighting accounts for almost 40 percent of the electricity used in commercial buildings—4.7 million buildings covering about 75 Billion sq ft of floor space—yet few existing buildings have any type of automated control. Instead those spaces are often overlit; illuminated when no one is present, and rarely make effective use of daylight. For example, although automatic shut-off for lighting systems is common in new construction, it’s used in only 1 to 2 percent of the floor space in existing buildings. Adding controls in a conventional manner is expensive and disruptive, but new advances in wireless technology may soon make it feasible to retrofit controls. The potential for energy savings would be large thanks to the ability to add some or all of the following capabilities:

- Scheduling: making sure that lights are only on during scheduled hours can cut energy use by 35 to 70%
- Daylight dimming: dimming electric lights when daylight is available can cut energy use by 20 to 80%, although the upper end is generally only achievable when a building is designed from the beginning to use daylight.
- Occupancy sensing: savings from occupancy sensors vary widely depending on the space and the diligence of occupants in turning off lights, but 30% is a typical average value.

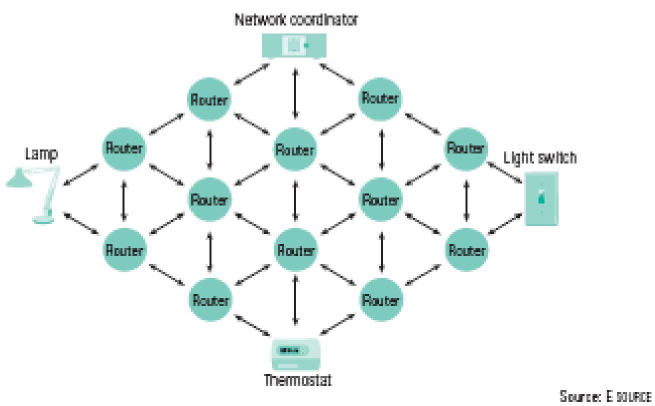
- Personal control: giving occupants control of their own lighting can cut energy use by 15% to 40% and increase occupant satisfaction as well.
- Demand response: controls also provide the ability to strategically turn lights off when the local utility asks.

The benefits of wireless controls include:

- Ease of installation—because there are fewer wires to run, installation takes less time, costs less, is less disruptive to ongoing activities, and results in fewer wiring errors
- Reduced maintenance—in a conventional installation wires can crack/fail over time, and failures at connectors can occur
- Flexibility—because there are no wires to move around, it's easy to regroup fixtures and relocate sensors/switches as spaces are reconfigured.
- Synergy with HVAC—the same sensor can feed both HVAC and lighting systems.

The leading approach to wireless building controls is a concept known as a mesh network (**Figure 2**). In a mesh network, control is split up among the different points in the network (which may be sensors, switches, or other addressable devices) so that you have multiple, redundant paths through the network. This makes it possible to communicate between two nodes that might temporarily have no direct link to each other because of some transient problem. It also makes it possible to cover large distances with limited transmitting power because the nodes can hand off data to each other. Mesh networks are also scalable to larger sizes.

Figure 2 Mesh Network Configuration



In a mesh network, control is split up among the different nodes so that there are multiple, redundant paths through the network.

You can establish a mesh network in many ways, but the leading approach today comes from the ZigBee Alliance (www.zigbee.org). Formed in 2002 as an independent nonprofit organization, ZigBee consists of more than 200 companies working together to develop an open global communication standard for low-power, wireless networks. Members include leading controls companies like Honeywell, Samsung, Eaton, DSCI, Leviton, Siemens, Philips, and Texas Instruments. Utility members include CenterPoint Energy, Southern California Edison, and Sempra Utilities. ZigBee's ultimate goal is to build wireless intelligence into a variety of devices such as flexible and automated lighting controls. Although the group is growing rapidly and products are already on the market, the ZigBee approach still needs to prove itself in terms of reliability, scalability, and cost.

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Wireless devices may currently cost more than their conventional counterparts, but manufacturers claim that the overall cost of installing a ZigBee control network is actually less than that for installing a conventional system with similar capabilities because of the labor savings from reduction or elimination of wiring. How that actually works out in practice depends on a number of variables, including labor rates, the level of complexity, and the level of control (for example, a system that controls individual ballasts would cost more than one that controls groups of ballasts through one wireless device). The cost analysis will also be different for different applications. **Table 4** shows an example for Light Corporation's lighting control network, Intu!. Here the extra costs for ZigBee-enabled controls lead to a longer—although still attractive—payback in a lighting retrofit, but the ZigBee solution provides added capabilities that could pay for the system over time. For example, the ZigBee system would cost less to rezone. A ZigBee network can also interact with compatible equipment for other functions such as thermostats, fire alarms, and security systems.

Table 4 Cost effectiveness of wireless controls

This table compares the cost-effectiveness of upgrading the lighting system in a warehouse with 1036 metal halide fixtures. Two alternatives are considered: a fluorescent system with occupancy sensors; and that same fluorescent system with wireless communications capabilities. The wireless system is assumed to save more energy because of the ability to use scheduling protocols, to control the ballasts for step dimming, and to make more effective use of occupancy sensors. The payback period is longer for the wireless approach, but the analysis doesn't account for some of the benefits of the system, such as the ability to participate in demand response programs, and the ease of reconfiguring when conditions change.

	Baseline (metal halide)	Fluorescent fixtures w/occ sensors	Wireless Intu
Power/fixture, lamp+ballast (W)	460	205	205
Annual energy use (kWh)	2453331	1081724	655999
Annual energy cost ($)	196266	86538	52480
Annual energy savings ($)	NA	109729	143787
Fixture cost ($)	Na	155400	155400
occupancy sensor cost	Na	2772	252
Zigbee node	Na	na	124320
gateway	Na	na	1560
control panel	Na	na	1246
Commissioning cost ($)	Na	na	7140
total cost ($)	Na	158172	289918
payback period (years)		1.4	2.0

Notes:
1036 fixtures
System B uses 44 strategically-placed occupancy sensors

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System C uses 4 occupancy sensors to communicate wirelessly with all fixtures
Commissioning costs include setting up and mapping fixtures and monthly server fee
Electricity costs $0.08/kWh
Lamps operate 5148 hours/yr

Source: E Source, data from Light Corporation

The Intu! system is one of the few ZigBee compatible systems for lighting control that is available today. It features wireless nodes mounted in lighting fixtures with standard ballasts along with web-based software. The software enables scheduling and the flexible zoning of fixtures to respond to on/off and dimming signals based on occupancy sensing, photosensing, and demand-response signals. The mesh configuration allows you to place daylight and occupancy sensors anywhere and move them around—so you can find the optimum locations. You also don't need a sensor for every fixture, which helps keep costs low. The system could include a demand-response application that can be automated, but the company anticipates most users will prefer the manual mode: A call from the utility prompts an energy manager to use the software to activate preset dimming levels. Light Corporation says it will host the system off-site to eliminate the need for IT involvement. A cellular or local area network would transmit commands from the off-site server to the local site.

Another product entering the market uses a proprietary version of the mesh concept. LightPoint wireless relay transceiver/microprocessor units are mounted inside a fluorescent fixture to control ballasts individually or in zones. No electricians are needed for installation, which takes less than five minutes per ballast. Originally developed at the Center for the Built Environment at the University of California, Berkeley (UCB), the technology is now being commercialized by Adura with funding from the California Energy Commission's Public Interest Energy Research (PIER) Program. The Adura system is being used at two UCB libraries. The two projects, installed for $28,000, are expected to cut annual electricity use by a combined 170 megawatt-hours (MWh) and will pay for themselves in less than a year. At one site, the system allows the lighting to be scheduled according to the nuances of an academic schedule—allowing different hours for exam periods, holidays, and recess—through a web interface. At the other library, the system turns off the fluorescent lights during the day when daylight is provided by a series of skylights. Previously, the lights were on 24/7 in both facilities.

What about batteries

Many facility managers are skeptical of wireless systems because of the maintenance requirements associated with the batteries needed to power the sensors and switches that make up a wireless network. One approach that may help overcome this obstacle is battery-free technology. The leading supplier is a company called EnOcean, whose products eliminate the need for batteries by using energy from the environment: The kinetic energy of pushing on a switch, the energy in ambient light, and the energy in a temperature difference as small as 7° Fahrenheit can all be converted to electrical energy to power the network devices.

The EnOcean technology has been commercially available for several years but has been used mostly in Europe so far. Its sensors, switches, and radio frequency communication devices are used in a variety of applications including building and home automation, lighting, and automated meter reading. In addition, EnOcean has announced the formation of the EnOcean Alliance—a group of companies that will incorporate EnOcean technologies into their products. Alliance members include Leviton, Osram Sylvania, Texas Instruments, and Masco Corp. Masco, a leading manufacturer and installer of home-improvement and building products, announced a new battery-free product line called Verve—aimed at reducing wiring complexity while enabling whole-house lighting control. Other Alliance members will be introducing products aimed at the commercial market.

Conclusions

Two technologies, LEDs and wireless lighting controls, stand poised to help users cut their lighting energy use. LED technology is already cutting energy use in a number of niche applications, and as LED performance continues to improve, and as costs come down, LEDs will become an energy-efficient choice for a growing variety of uses. However, along with the good products, there also continue to be many poorly performing products on the market, so potential users need to investigate thoroughly to make sure that what they select will meet their lighting needs. Tools like the Energy Star ratings and the DOE's CALiPER program should help keep LEDs on the growth path.

Wireless lighting controls are still an emerging technology. Careful examination of products in development or newly available, together with pilot installations, will help this technology become a viable means of reducing energy use in the vast number of existing buildings with no lighting controls capability.

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