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TECHNOLOGY AND APPLICATIONS OF LIGHT EMITTING DIODES

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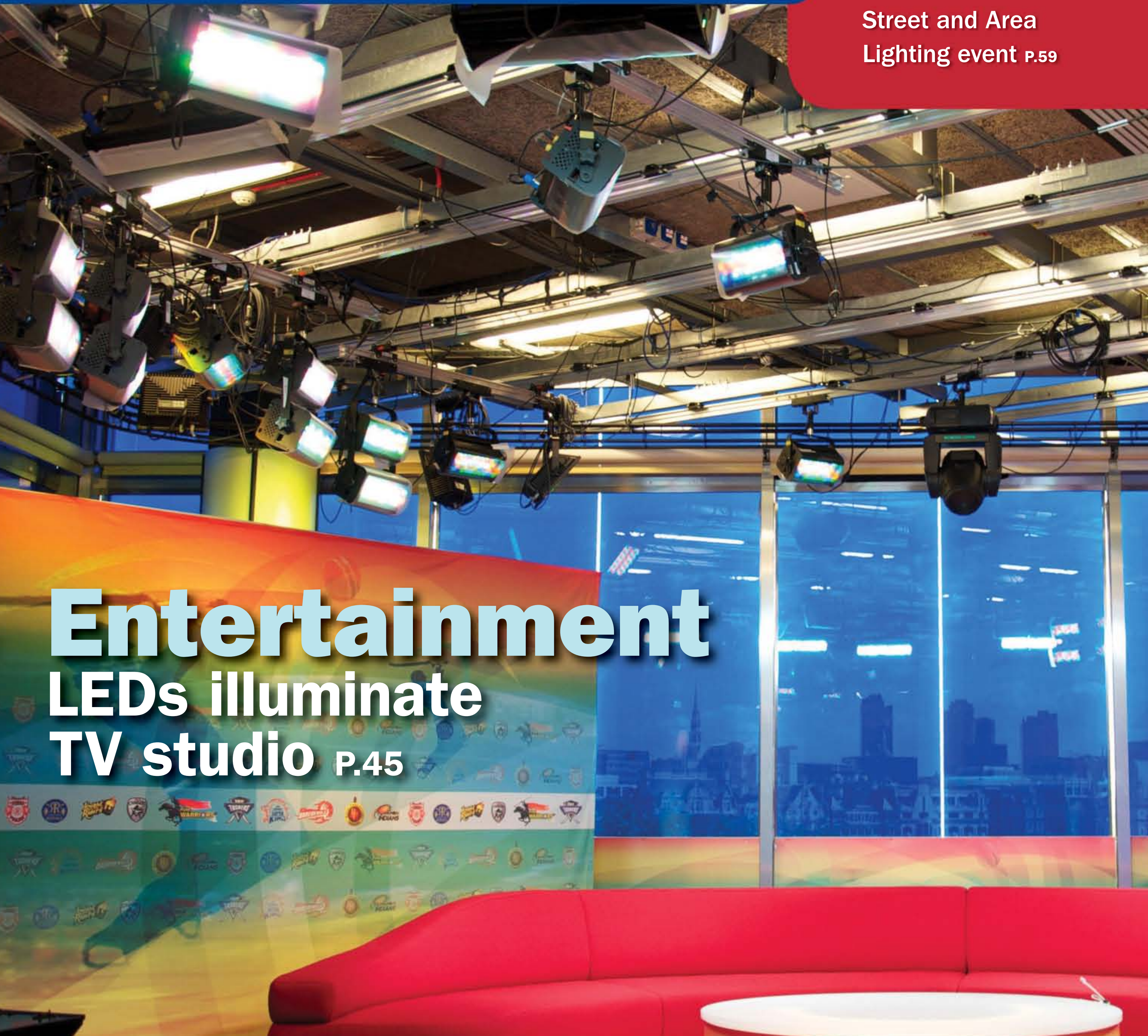

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LEDs MAGAZINE® ISSUE 46

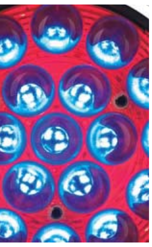
october 2011

Cover Story

The Daybreak TV studio in London is lit almost entirely with LED-based fixtures from ETC, and was the focus of a case study presentation at the annual PLASA tradeshow - *see page 45.*

features



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commentary

Lighting market reflects economic uncertainty

In our last magazine issue, we commented on the busy summer that had just passed, but September turned out to be equally lively. The start of the month saw the phase-out of 60W incandescent lamps in Europe, as part of the region's ongoing program to eliminate the most inefficient lamps from the marketplace (page 19). LED lamps are still not fully ready, in terms of price/performance ratio, to fill the void that will be created when stocks of the undesirable incandescents are sold off.

Also, Siemens confirmed what most observers already realized i.e. that the industrial giant's planned IPO for its Osram lighting division will be delayed until the market stabilizes (page 10). This is one of the strongest indicators that the general economic slowdown is having a strong effect on the lighting market, via factors such as weakness in the construction market, and sluggishness in consumer markets in Western Europe. Even so, it's important to note that the lighting market appears to be growing less rapidly than predicted, rather than contracting.

Slower rates of growth in demand are also being felt by LED makers, and this in turn has caused suppliers such as Aixtron to revise their sales estimates for 2011 (page 10). MOCVD-equipment-supplier Aixtron cited the short-term fragility of the economic recovery, as well as rapidly-dropping end-market prices for LEDs, as reasons why customers have delayed deliveries and purchase-order placements. One example is the joint-venture company being established by Epistar in China, which is not expanding as rapidly as planned due to weak market conditions and lack of demand growth.

Even so, it's not all doom and gloom. At the end of September, Taiwan-based Lextar, a subsidiary of LCD-panel maker AU Optronics, went public on the Taiwan stock exchange (www.ledsmagazine.com/news/8/9). Lextar is vertically integrated, from MOCVD growth through to LED modules, lamps and fixtures, and its 2010 revenue was $255 million.

The LED Show

As many LED readers will be aware, LEDs Magazine is a sister publication of the Strategies in Light (SIL) family of conferences, which cover LEDs and lighting, and take place in several locations around the globe. Pennwell, which owns this publication and the SIL events, recently added a new event to its stable with the acquisition of The LED Show.

This annual tradeshow was launched in 2009 and takes place in Las Vegas, attracting 87 exhibitors and more than 3000 attendees in 2011. The focus is on lighting design and lighting-product technology, and The LED Show will provide an excellent complement to our existing SIL events. The next event takes place on July 30-August 1, 2012 in Las Vegas, when hopefully market conditions will have stabilized somewhat.

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Webcasts:

LED Lighting Made Easy – A Modular System Approach to Designing Fixtures

PHILIPS

FUTURE Lighting Solutions – Making LED Lighting Solutions Simple

DATE: October 19, 2011
PRESENTERS: Costa Politakis, Future Lighting Solutions; Dan Sullivan, Philips Lighting

Light and Color - Methods of Achieving High CRI with LEDs

OSRAM Opto Semiconductors

DATE: October 26, 2011
PRESENTER: Marc Dyble, OSRAM Opto Semiconductors

More Webcasts for Fall 2011

DATES: Oct 31, Nov 7, Nov 28, Dec 1, Dec 15
PRESENTER: ON Semiconductor

DATE: November 2, 2011
TITLE: Three Basic Functions of LED Power Supplies
PRESENTER: Arrow and Fairchild

DATE: November 15, 2011
TITLE: Diagnose and Solve Thermal Challenges in Next Generation LEDs
PRESENTER: Mentor Graphics

View www.ledsmagazine.com/webcasts to access upcoming and archived presentations.

FEATURED *events*

Professional Lighting Design Convention
October 19-22, 2011
Madrid, Spain

LEDs 2011
October 24-26, 2011
San Diego, CA, United States

IES Annual Conference
October 30-November 01, 2011
Austin, TX, United States

China SSL
November 08-10, 2011
Guangzhou, China

4th International LED Forum Moscow
November 09-10, 2011
Moscow, Russia

LuxLive
November 09-10, 2011
Earl's Court, United Kingdom

LED EXPO 2011
December 1-3, 2011
Delhi, India

Forum LED Europe
December 7-8, 2011
Lyon, France

LED/OLED Lighting Technology Expo 2012
January 18-20, 2012
Tokyo Big Sight, Japan

Strategies in Light 2012
February 7-9, 2012
Santa Clara, CA, United States

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news views

OLEDS

Osram, Panasonic accelerate production of OLED lighting

Two major lighting companies, one in Germany and one in Japan, have made significant announcements that will help to bring more OLED lighting products to market.

In Germany, Osram AG has celebrated the opening of a pilot manufacturing plant for OLEDs. The facility in Regensburg West, which currently employs 220 people, is the result of an investment of EUR20 million ($28.9 million) over the course of one year. Osram described the opening as "an important milestone on the road toward volume manufacturing."

Testing of OLED panels in Osram's facility in Regensburg, Germany.

Osram is the only company with production sites for both (inorganic) LEDs and OLEDs in Europe, and currently dedicates two-thirds of its R&D expenditures to LEDs and OLEDs. In the past five years, the company has invested approximately EUR50 million ($72.25 million) in R&D for OLEDs. Osram's product portfolio includes OLED panels and modules as well as complete luminaires.

Osram has received considerable support from Germany's Federal Ministry of Education and Research (BMBF) through the organization's OLED 2015 initiative and the TOPAS 2012 project (www.ledsmagazine.com/news/8/8/36).

Panasonic Idemitsu OLED Lighting

Panasonic Idemitsu OLED Lighting Co., Ltd. (PIOL), a joint venture established this year between Japanese companies Panasonic Electric Works Co., Ltd. (PEW) and Idemitsu Kosan Co., Ltd., began shipping OLED lighting panels to the international markets in September. The OLED panels have a minimum color rendering of Ra=90, a panel section as thin as 2 mm and a luminance of 3000 cd/m^2. The panel's luminous efficiency is 30 lm/W (60 lm at 2W), the lifetime is 10,000 hours (to 70% lumen maintenance) and the color temperature is 3000K.

In addition, PEW will ship OLED lighting modules (the OLED panel plus driver circuitry, embedded in a frame) later this year. The luminous efficiency of the modules is 21 lm/W, with a dimming control range of 10% to 100% (www.ledsmagazine.com/news/8/9/8). ◄

STANDARDS

IES approves TM-21 for projecting LED lumen maintenance

The Illuminating Engineering Society (IES) of North America has approved technical memorandum TM-21 entitled "Projecting Long-Term Lumen Maintenance of LED Light Sources." The starting point for the projections is the data obtained by the procedures found in IES document LM-80-08, the "Approved Method for Measuring Lumen Maintenance of LED Light Sources."

TM-21 provides a method for determining when the useful lifetime of an LED is reached, a point when the light emitted from an LED depreciates to a level where it is no longer considered adequate for a specific application. Lumen maintenance of LEDs can vary from manufacturer to manufacturer and between different LED package types produced by a single manufacturer.

TM-21 is designed to work with the data produced by LM-80 testing of 20 samples over 6000 hours at three specified temperatures. TM-21 provides a method to determine the light source's expected depreciation over time. It should therefore provide an idea of the light-output level of a luminaire at a point in time, or indicate the time when a certain output level is reached.

Importantly, the document is limited to lumen maintenance; it does not contain procedures for determining the time-to-failure or reliability of other LED luminaire components such as the driver or lenses. This point is discussed further in our Standards article on page 51.

LEDs Magazine plans to provide expanded coverage on the TM-21 technical memorandum in our next issue. The TM-21 document can be purchased for $40 from the IES store – see http://bit.ly/pwRSvK ◄

news+views

BUSINESS

Lighting market slowdown affects Osram IPO, MOCVD sales

The general market slowdown in lighting is affecting companies in all parts of the supply chain, having delayed Siemens' intended initial public offering (IPO) of Osram, as well as affecting shipments of MOCVD systems to LED makers.

As we predicted in the September issue of LEDs Magazine, Siemens AG has decided to delay the IPO of its Osram lighting unit, which had been planned for the fall of 2011. Demand for LED and SSL products is less robust than many expected this year, as is the overall economy. An oversupply situation for LED-backlit TVs has reduced the market price for LEDs. There is also increasing price pressure on LED components and SSL luminaires caused by new players in Asia. These factors are all influencing the timing of the Osram IPO.

However, Siemens stated in a press release that it is "firmly holding to its plans" for the sale. "Preparations are on track and will be continued," Siemens said, adding that the timing of a listing depends on "the stabilization of market conditions."

Meanwhile, Osram's rival Philips said that its growth was being affected by "sluggish consumer markets in Western Europe, and the continuing weakness of the construction market." Even so, Philips' Lighting division reported comparable sales growth of 5% in the first half of 2011 relative to the same period last year. Growth was driven by all business units except Consumer Luminaires and Lumileds, Philips' LED division. Philips said that the decline at Lumileds was "driven by the display business, and technology investments." However, Philips' overall LED-based sales increased in the first half of 2011 by 24% over the same period last year.

Aixtron revises 2011 guidance

Meanwhile, Aixtron SE, the Aachen, Germany-based maker of MOCVD equipment for LED fabrication, issued a new 2011 revenue estimate of EUR 600-650 million, down significantly from the previous estimate of EUR 800-900 million. The company said it has received requests from several customers, particularly in Asia, to defer system deliveries into 2012. Aixtron's customers have revealed an increasing concern about the short-term fragility of the economic recovery. These concerns, coupled with the rapidly dropping end-market prices for LEDs, have caused purchase-order placement delays and deferred deliveries. Aixtron's Nasdaq stock price closed at $16.61 on Sept 16, down from its 52-week high of $45 reached in February.

In reaction to the Aixtron announcement, analysts also cut their ratings on Veeco Instruments (Nasdaq: VECO), Aixtron's main MOCVD competitor. As a result, shares in Plainview, NY-based Veeco fell to $30.51 on Sept 16, down 47% from a recent high of $57.67 in May.

As one example of an LED maker showing a more cautious attitude to expansion, Taiwan-based Epistar recently started operations at its LED joint venture, Epicrystal Corporation, in Changzhou, China. The new facility has the capacity to house 60 MOCVD reactors, but will initially be configured with only 10 reactors by the end of 2011 due to weak market conditions and a lack of demand growth. ◂

MORE: www.ledsmagazine.com/news/8/9/21

RETAIL LIGHTING

Nualight acquires retail accent-lighting company Lumoluce

Nualight, the Cork, Ireland-based provider of LED lighting for retail food displays, has acquired Lumoluce, a provider of accent retail lighting based in Amsterdam, the Netherlands. The deal, valued at just under EUR11 million ($15 million), will bring Nualight's revenue to over EUR25 million ($34 million) for 2011.

LED accent lighting, in the form of spotlights used to accentuate high-margin fresh-food displays such as fruit and meat, can save up to 40% in energy costs when compared with incumbent, equivalent HID lighting. Nualight estimates that its combined target market for primary and accent food-retail lighting could reach EUR1 billion ($1.36 billion) annually by 2016. Lumoluce also offers Nualight growth opportunities in the areas of high-end retail, infrastructure, commercial lighting and LED drivers.

Liam Kelly, CEO of Nualight, said that food

retailers today are very focused on deploying new technologies to make their business models as sustainable as possible. "In terms of price and performance, LED technology is fast approaching the tipping point for accent lighting in food retail," he said. "Nualight has acquired a portfolio of products and excellent technology expertise that allows us to move very quickly into accent lighting for food retail, and doubles the speed at which we can bring new products to market." ◂

MORE: www.ledsmagazine.com/news/8/9/13

HEALTH

Outdoor-lighting research suggests strong LED impact in suppressing melatonin

Not for the first time, the impact of white solid-state lighting (SSL) on human health has been questioned. A new research project says that LEDs, for the same photopic flux output, increase "pollution in the...melatonin-suppression bands" by five times relative to high-pressure-sodium (HPS) sources. The publication recommends regulatory limits for future SSL products.

The research entitled "Limiting the impact of light pollution on human health, environment, and stellar visibility," was published in the *Journal of Environmental Management*. The authors are Fabio Falchi of Italy's Light Pollution Science and Technology Institute (ISTIL), Christopher Elvidge of the National Geophysical Data Center in » page 14

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TEST AND MEASURMENT

Cree launches TEMPO luminaire testing program

One recurring obstacle to broad deployment of solid-state lighting (SSL) is the complexity of developing reliable LED-based lighting systems, and Cree plans to help its LED component customers with its new TEMPO (Thermal Electrical Mechanical Photmetric Optical) luminaire testing and evaluation program. Luminaire designers can utilize Cree services to validate a design before joining what's become a queue at LM-79 testing labs.

TEMPO is essentially a sequence of services that Cree LED customers can access throughout the design cycle of integral lamps or luminaires. For example, Cree will help with optical and thermal simulations early in the design process. Later in the process Cree offers what it calls SPOT (Single Point Of Test) testing on a light engine. And then the TEMPO-21 test, covering 21 test points, will be performed on complete luminaire or lamp designs.

At the conclusion of the TEMPO-21 tests Cree will deliver a sizeable document to the customer who can then share that data with its customers, providing a third-party validation of performance. The Table below is taken from the Executive Summary of a sample TEMPO-21 test that Cree performed on one of its reference designs. That table is focused primarily on optical and photometric properties and power consumption, but the full document addresses the other design elements as well.

According to Mark McClear, global director of applications engineering at Cree, the TEMPO concept evolved from bad design practices in the field that often lead to luminaire makers blaming the component supplier. McClear used an example where a customer chose improper glue that created gases as temperature increased inside the luminaire, damaging the LEDs.

McClear said that luminaire makers have no-one to turn to for help and often approach LM-79 and Energy Star testing not knowing if their design will pass. There are specialty firms that might evaluate a thermal design for a substantial fee. LM-79 testing cost $1000 or more, and manufacturers often must wait for a test slot.

Some of the other tests that TEMPO-21 includes in the electrical area are driver efficiency, transient analysis, dimmer compatibility, power analysis, and Hi-pot testing for dielectric breakdown. In the thermal and mechanical area, the tests include validation of a proper solder point for junction-temperature monitoring, thermal imaging with an infrared camera, and a chemical compatibility analysis. The test also includes a TM-21-based estimate of product lifetime that accounts for the thermal design of the fixture, and a review against Energy Star criteria.

Ultimately TEMPO-21 is both a superset and subset of LM-79 which McClear says covers only about half of the evaluation points that are critical to judge a design. But Cree can't perform the complete LM-79 test suite right now. Expect that to change, however, as the company is planning to install a moving-mirror Type C goniophotometer that is required for some LM-79 tests.

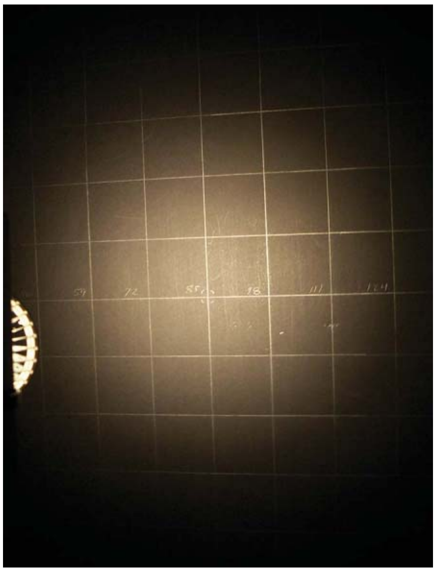
That leads to the question of whether Cree will seek official recognition as a Certification Body so that it could handle LM-79 and Energy Star testing for its customers. However, McClear said the company has no such plans for now.

Cree believes it can offer the TEMPO services with turnaround times in days rather than weeks and help customers accelerate time to market. SPOT tests will cost only $300 and a full TEMPO-21 test will cost $1200. The company is clearly not looking to profit directly from the services at those price levels, but rather TEMPO is simply another way to achieve Cree's stated mission of accelerating the adoption of LED lighting.

Although TEMPO was formally introduced in late September, the company has already performed a number of TEMPO-21 tests for customers. When asked if he knew of any similar program at other LED vendors, McClear said, "I think this is something the other component vendors should consider doing." ◂

Results for an MR16 lamp reference design

Criteria	Result	See Page
Total luminous flux	275	7
Power (W)	4.76	12
Tsp/Tj (°C)	67.1/76.8	20
Power factor	n/a	
Lumens per Watt (lm/W)	57.6	12
Optical Efficiency (%)	93.4	15
Driver Efficiency (%)	81.1	16
CCT (K)	2990	8
CRI (Ra)	82	8
Chromaticity (x-coord.)	0.435	8
Chromaticity (y-coord.)	0.399	8
LED lumen maintenance	Projected L70(6k): n/a	
LED lumen maintenance	Reported L70(6k): n/a	
Center beam candle power (cd)	620	35
Energy Star	OK	28
Cree partner criteria	Pass	



Illuminance measurements for Cree's TEMPO program are made on a 2-in grid.

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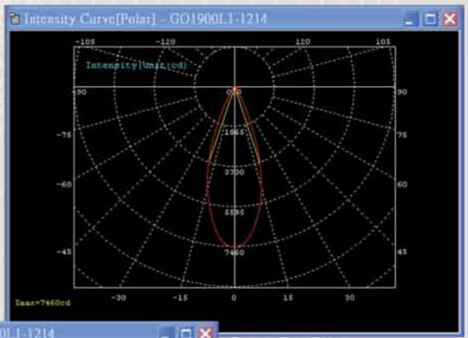

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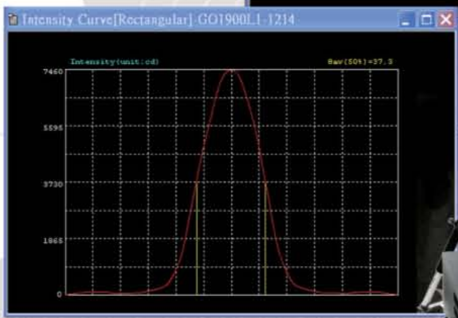

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Health from page 10

Boulder, CO, David Keith of Marshall Design in Boulder, and Abraham Haim of Israel's University of Haifa.

The research studied LED and metal-halide (MH) sources relative to reference HPS sources. Both the LED and MH sources produce white light that includes more blue content at shorter wavelengths than do HPS sources, which produce orange- to yellow-tinted light. Like much similar research, the new study apparently didn't test actual subjects, but rather relied on prior research on melatonin-suppression levels relative to spectral content. The researchers came to the conclusion that MH lights suppress melatonin at a rate 3 times greater than HPS lights, and LEDs suppress melatonin at 5 times the HPS rate.

Not surprisingly, the original news item on our website attracted a large number of comments. ◂

MORE: www.ledsmagazine.com/news/8/9/12

INTERVIEW

GE Lighting's Irick says reliable, system-level SSL solutions will prevail

In a recent press conference at the company headquarters at Nela Park in Cleveland, Ohio, Jaime Irick, president and CEO of GE Lighting Solutions, outlined a future of lighting that is dominated by solid-state solutions, making all other technologies obsolete, eventually.

Jaime Irick, CEO and of GE Lighting Solutions (left) and David Schuellerman, PR manager (right).

GE has made a strong investment in its LED sector recently, increasing its R&D personnel by 2.5× in the last three years. In Cleveland, the company has 30 LED technologists researching next-generation optics, thermal components and electronics, while 90 LED engineers investigate performance and reliability. This group developed GE's 40W-equivalent, 450-lm LED lamp on which its subsequent 60W-, 75W- and 100W-equivalent LED lamps will be based.

In the medium term, customers in the US will have a choice of high-efficiency halogen bulbs, CFLs or LED lamps that meet the energy-efficiency requirements of the Energy Independence and Security Act of 2007. "It's all about choice for our customers, but they were looking for more energy-efficient alternatives, even before the legislation was enacted," said Irick.

Asked when LEDs are likely to dominate the general indoor-lighting market, Irick said he expects that to still be 10 years in the future. However, LED costs are coming down at approximately 20% per year, and the introduction rate for LED lamps has accelerated. "We have 70 Energy Star LED products now and will have 120 by the end of the year," said Irick.

Customers are dictating the form that lighting will take, says Irick. "While other companies may have product expertise, GE's will offer the best system-integration platform, bringing together the LED module, thermals, optics and drivers to provide the most efficient lighting platform for the application," said Irick. One example is GE's LED edge-lighting fixtures, which are based on backlighting technology, and use LEDs around the perimeter of the panel and Rambus MicroLens technology to distribute the light uniformly across the panel.

Irick indicated that the industry is in a period of transition. He said that GE is supporting the efforts of the FTC with the new Lighting Facts label. "The DOE has found that nearly 30% of the products tested in its Caliper studies do not meet manufacturer's performance claims. In fact, we have already seen some products being pulled from retail shelves," he said. "[The new labels] will help level the playing field."

GE is already seeing a shake-out of manufacturers. John Strainic, global product general manager at GE Lighting, claimed this is similar to the consolidation seen with CFLs when they began to replace incandescent bulbs, which took 5-7 years to complete.

Product reliability is a cornerstone of GE's operations. While the company does not manufacture LEDs, its reliability laboratory performs incoming qualification and accelerated lifetime testing on LEDs and LED modules. "Not all lighting manufacturers test their LEDs, but we have rigorous testing requirements and over ten years of field test data," said Cherian Jacob, systems manger of GE Lighting Solutions. ◂

COMPETITIONS

Lighting for Tomorrow announces 2011 winners

In a ceremony held at the American Lighting Association (ALA) Annual Conference in Palm Beach, Florida on September 13, the winners of the ninth-annual Lighting for Tomorrow competition were recognized for designing the best energy-efficient lighting products

Designers Fountain's Aero track

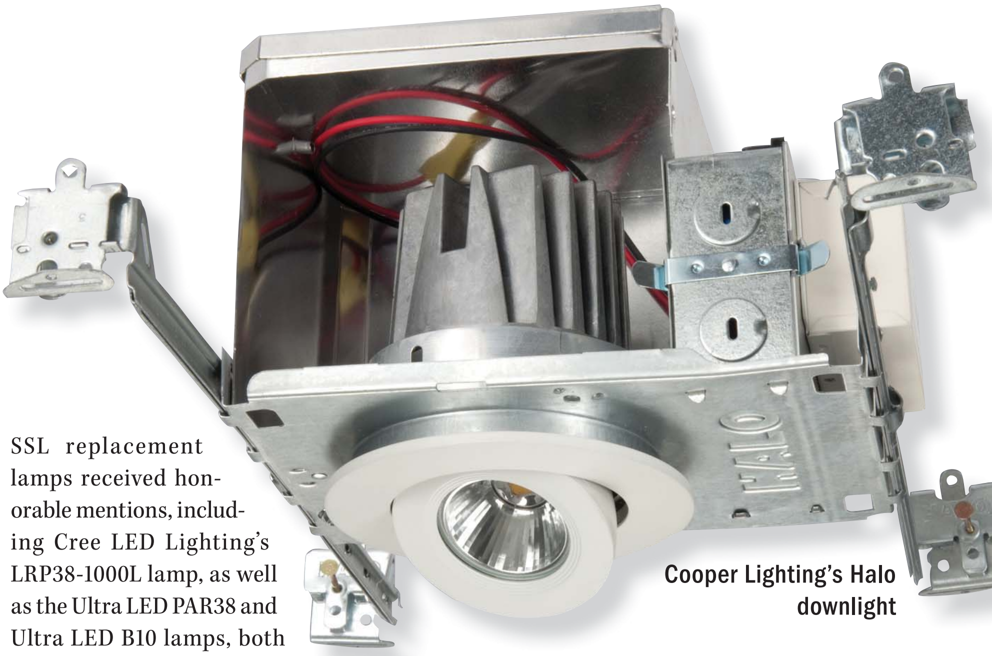
news+views

for the residential market. The judging panel recognized eight winners and six honorable mentions, including solid-state lighting (SSL) fixtures and replacement lamps, and lighting controls.

The SSL products were judged based on color appearance, color rendering, amount and distribution of light, overall aesthetic appearance, and application efficiency. Winners in the SSL fixture competition were:

- The Aero 4-head fixed track from Designers Fountain
- The Berne Chairside reading lamp from Holtkötter International
- Cooper Lighting's Halo 4-inch adjustable round and square downlight
- Osram Sylvania's Ultra RT4 LED recessed downlight kit
- The CR4 downlight from Cree LED Lighting
- Lithonia Lighting's outdoor LED versatile area/wall light

The SSL replacement lamp winner was the Osram Sylvania Ultra A-line lamp. Several SSL replacement lamps received honorable mentions, including Cree LED Lighting's LRP38-1000L lamp, as well as the Ultra LED PAR38 and Ultra LED B10 lamps, both from Osram Sylvania.



Cooper Lighting's Halo downlight

The winners of the lighting controls competition were selected on the basis of functionality, value, ease of installation, ease of use, innovation, ability to interface with other LED or CFL lighting systems, and adaptability to existing luminaires. The lighting controls winner was Lutron Electronics for its Diva CL dimmer.

The Lighting for Tomorrow program, organized by the ALA, the non-profit Consortium for Energy Efficiency (CEE) and Underwriters Laboratories (UL), has the financial support of 21 energy-efficiency-program administrators across the US and Canada. ◂

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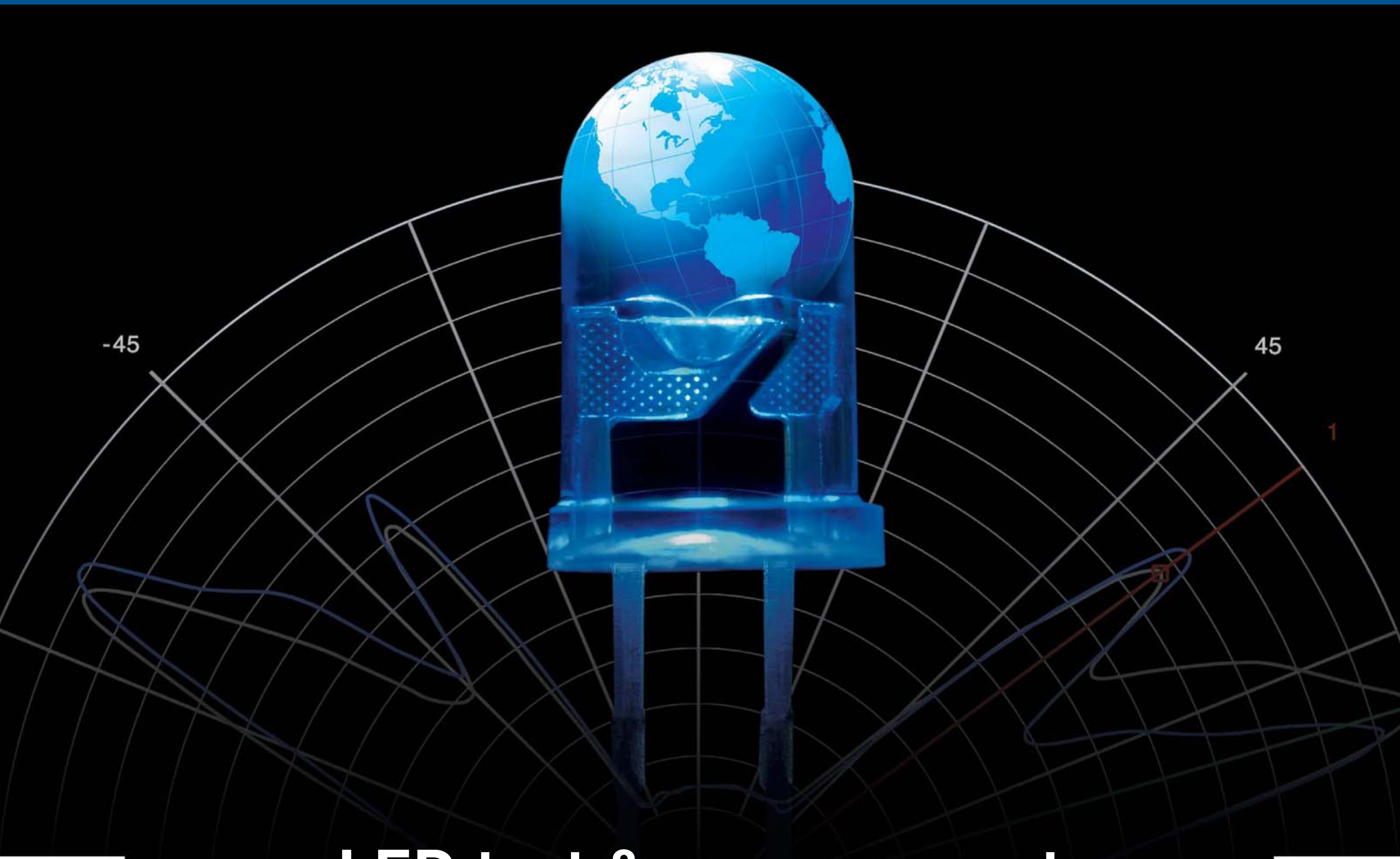

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Zeta LED uses UK funding to develop unique LED lamp

Zeta LED, a UK-based technology company, has unveiled the LifeBulb, a lamp that it developed after winning a funding competition from the UK Technology Strategy Board (TSB). The lamp is currently undergoing extensive testing by the TSB, and Zeta is seeking a manufacturing partner for production. The 8W lamp, which the company describes as the "world's first true replacement for the 60W incandescent bulb," uses a unique approach to thermal management. Its LED arrays are mounted on the exterior of an aluminum cage. In the photos here, the cage is beneath the lamp cover, which contains a number of holes. Air flows through the lamp's body and around the cage, providing passive cooling and removing the need for a large heat sink that is often seen around the base of many LED replacement-lamp designs.

The LifeBulb had to meet TSB's stringent design criteria. "The lamp had to fit in the exact same envelope as a conventional lamp," said Phil Shadbolt, Managing Director of Zeta Controls. The lamp provides omnidirectional illumination via 10 LED arrays, 5 each in the upper and lower hemispheres. The chip-on-board LEDs are coated in phosphor but have no other optics.

The lamp has an overall efficiency of 76%, a power factor of 0.9, a CRI in excess of 80 and a color temperature of 3200K. The lamp may be dimmed to 1% with most conventional wall dimmers, says Zeta. The light output is 720 lm, short of the level of 806 lm required to claim equivalence to a 60W incandescent lamp. The efficacy is 90 lm/W, and the expected lifespan is 25 years when operated 4 hours per day or 36,500 hours.

The LifeBulb project is the result of a development contract that Zeta won in 2010 for GBP450,000 (around $700,000) from the UK Department for Environment, Food and Rural Affairs (Defra) and the TSB to develop an ultra-efficient lighting prototype for domestic use. The GBP450,000 was to be used toward the development of prototypes and production of 50 fully-functional, tested demonstration units.

Zeta has produced 100 LifeBulbs and expects to produce 1000 by year end. "Our target is for the price to be below GBP10 in volume production," said Shadbolt, meaning a volume in excess of half a million units annually. Zeta is looking for potential investors or manufacturing partners. ◄

MORE: www.ledsmagazine.com/news/8/9/19

Europe says goodbye to 60W lamps

As of September 1, the 60W incandescent lamp can no longer be manufactured in Europe or imported into the region. The new regulation comes into force as a result of the Ecodesign Directive (2009/125/EC), which has already outlawed 100W and 75W incandescent lamps (in September 2009 and September 2010, respectively).

Specifically, the regulation says that clear (transparent) lamps with a wattage level of 60W or above need to have

an energy-label class of C or above (A is the highest, G is the lowest). This effectively eliminates ordinary incandescent lamps from the market.

In addition, since September 2009 there has been a requirement that all non-clear (also known as pearl, or frosted) lamps must be class A, which in practice means that non-clear lamps have to be CFLs.

In its current form, the Directive only applies to non-directional lamps, while further legislation will cover directional lamps.

The European Commission (EC) has a useful website on "energy-saving light bulbs" at: http://ec.europa.eu/energy/lumen/index_en.htm. The EC has also implemented new packaging regulations that require the inclusion of data such as light output (lm), lifetime (hr), the number of switching cycles the lamp is designed for, the color temperature, the warm-up time, the size of the lamp and whether the lamp can be dimmed or not. ◄

MORE: www.ledsmagazine.com/news/8/9/1

funding+programs

DOE Gateway reports shows superior quality of LED lamps when illuminating artwork

The US Department of Energy (DOE) has recently published two Gateway reports that evaluate LED replacements for track lights used to illuminate artwork. The installations are in the lobby of the Bonneville Power Administration (BPA) headquarters building in Portland, Oregon, and in a gallery at the Jordan Schnitzer Museum of Art (JSMA) in Eugene, Oregon.

In the Portland demonstration, Cree 12W PAR38 LED-based lamps were installed in place of 15W and 23W reflectorized CFLs, which had been installed in 2001. The study also compared CFL performance and cost to the original 90W halogen PAR38 reflector lamps. The project results showed superior lighting quality and more-efficient energy use with LED lamps, yet with an 8-year payback period.

In the Eugene demonstration, fifty-four 90W halogen PAR38 narrow-flood lamps were replaced with 12W LED PAR38 lamps, resulting in an energy saving of over $500 per year and a payback period of 9 years. The 54-lamp LED system uses 14% of the energy and offers a ten times longer lifetime than the halogen lamps.

In both cases, the low electricity rate (0.0695/kWhr) and the high cost of LED lamps ($108 each) led to longer payback times and lower energy savings than might have been otherwise expected.

Quality of light reflecting artwork

The Portland project involved the illumination of historical black-and-white photos and printed color posters from the 1930s and 1940s. The PAR38 LED replacement lamps provide a narrower light distribution, concentrating the lumens on the artwork and minimizing the amount of light wasted on the wall above the art, which occurred with both the 15W and 23W CFLs.

LED lamps illuminate art in Eugene, Oregon. Courtesy of Jordan Schnitzer Museum of Art (JSMA).

Color quality improved with the LED lamping, from a CRI of 82 for the CFL to a CRI of 93 for the LED. The LED lamps showed improved rendering of red tones in architectural finishes and artwork compared to the CFL products.

In Eugene, the museum staff staged a comparison between the standard halogen lamps and three LED PAR38 replacement lamps from three different manufacturers. Using clusters of similar art mounted on a gray wall, including an oil painting, a black-and-white photographic print, and a color-checker card, each cluster was illuminated by one of the four lamps.

Artists, museum staff and visitors were asked to rank the smoothness of light pattern, the warmth/coolness and suitability of light for the art, as well as color rendering and visual clarity.

The artists and museum staff preferred a different LED lamp than the visitors, but neither party preferred illumination by the halogen lamp. Observers said they appreciated how the LED lamps improved the ability to see blue colors. ◄

MORE: www.ledsmagazine.com/news/8/9/24 and www.ledsmagazine.com/news/8/9/7

India identifies LED lighting as key technology to control energy demand

The Indian government has developed policies to stimulate the adoption of LED lighting in the country, and is funding a number of pilot LED street-lighting projects, explains **PHILIP JESSUP**.

Until recently, the high-brightness LED revolution had bypassed India. This is surprising because the lighting market in India, according to industry reports, is valued at $1.4 billion and has been growing at the robust rate of 18% annually. Meanwhile, western lighting companies like Philips have been manufacturing in India for 75 years, with thousands of employees, alongside well-known Indian brands such as Crompton Greaves and Bajaj Electricals.

In 2009, the rapidly-growing influx of inexpensive Chinese-manufactured LED products caught the notice of policymakers. By that year, the LED lighting market in India had grown to $49 million. India's National Manufacturing Competitive Council, a national agency with Cabinet ranking, convened a Core Committee chaired by the Ministry of Power to look into the appropriate policy measures for accelerating the adoption of LED lighting in India. After extensive consultation with the lighting industry, LED manufacturers, Indian states and cities, and other stakeholders, the Committee submitted its report, entitled "The Economic Case to Stimulate LED Lighting in India," in May 2010.

A key driver of Indian government LED policy is the need to significantly enhance energy efficiency across all sectors of the economy, in order to decouple growth in energy demand from economic growth. Otherwise, a very expensive three- or four-fold increase in primary energy production will be required by 2031-32 to sustain economic growth of 8-9% annually. India wants to sustain this rate of growth in order to eradicate poverty and improve living standards.

PHILIP JESSUP *is a Senior Advisor to The Climate Group (www.theclimategroup.com) and to its global LightSavers initiative.*

FIG. 1. Philips Lumec LED lights outside Kolkata City Hall, India. Photos courtesy of Prodyut Mukheree, The Climate Group.

LED lighting report

The Core Committee's report, which was drafted largely the Ministry's Bureau of Energy Efficiency (BEE), highlighted the potential for LEDs to reduce electricity demand for lighting, which consumes 22-25% of the national load. Peak demand is a particular worry, as its rapid growth tends to increase the need for more power plants to supply the necessary headroom load.

The report singled out residential electricity demand as a significant potential market for LED A-lamps. There are 400 million lamps in Indian households, mostly incandescent bulbs, consuming 70 million MWh annually. The penetration of LEDs in this sector could reduce household electricity use by 30%. Street-lighting applications and commercial buildings are other areas where LEDs also need to be promoted.

The Committee's report identified the key barriers to the market penetration of LEDs in India, as follows:

- Limited product availability in India;
- High initial cost, even with carbon finance assisting;
- Absence of national technical standards for LEDs, leading to the importation of sub-standard LED devices;
- Lack of testing protocols and laboratories;
- Lack of incentives such as demand or fiscal measures to attract major LED firms to manufacture in India.

In order to address these barriers, the Committee focused in particular on a new aggregate-demand policy, modeled after the Government of India's Bachat Lamp Yojana program. This innovative market transformation increased compact fluorescent lamp (CFL) sales from 20 million annually in 2003-04 to 250 million in 2009-10. It did this by creating an aggregate-demand mechanism in which electricity-distribution companies pooled product purchases with funds from private investors, who in turn received emissions-reduction certificates through the Clean Development Mechanism.

The aim of the new LED aggregate-demand policy will be to attract leading LED manufacturers to India and to rapidly reduce product costs. The government has established the Central Institutional Mechanism (CIM) with representation of all the key ministries and regulatory bodies to implement the new aggregate-demand policy and other measures recommended by the Core Committee's report. Details are being work out.

Pilot trials of LED street lights

Meanwhile, since 2009 the BEE has been providing grants to Indian municipalities to undertake pilot trials of LED street lamps. Public lighting in India requires approximately 4400 MW of connected load, so targeting street lighting makes sense, if 50-70% energy reduction can be achieved through installation of LEDs. To date, 13 LED projects have been completed in cities in Arunachal Pradesh, Assam, Maharashtra and Nagaland. Anecdotal evidence suggests that results of these pilots have been mixed, largely because of lack of knowledge about how to go about procuring quality LED products at the municipal level. Reportedly, there have been some product failures.

In this context, The Climate Group has been working closely with the BEE to promote LED street-lighting in two municipalities: Kolkata in the state of West Bengal, and Thane, a suburb of Mumbai in the state of Maharashtra. The BEE has provided grants of $100,000 each to Kolkata and Thane for one-year trials, to be matched with local funds. Additionally, The Climate Group is working with Haldia Development Authority (HDA), in West Bengal, in an LED street-lighting project in the port city of Haldia, investment for which is being borne wholly by HDA.

The Kolkata trial has advanced the furthest. Installation of the first group of 273 Philips Lumec luminaires took place in October 2010, with 180W and 150W LED models replacing the existing 440W and 250W high-pressure sodium (HPS) lamps, respectively (www.ledsmagazine.com/news/7/11/20). Monitoring began in January 2011.

Results to date have been encouraging. Only one luminaire has failed to date, due to a faulty driver. The LED luminaires are meeting India's IS 1944 Group A1 roadway-lighting standard, which mandates an average illuminance of 30 lux. The LED luminaires are also providing more illuminance than the baseline HPS luminaires, while

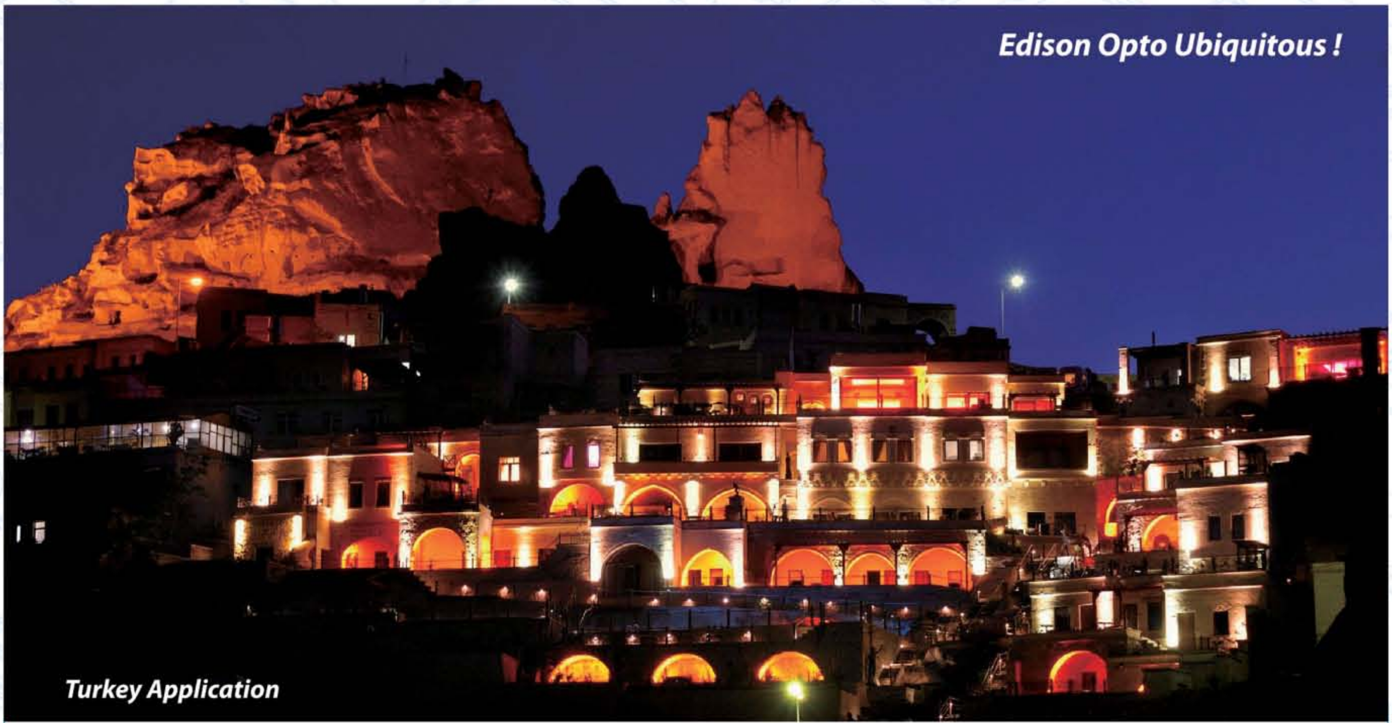
achieving nominal savings ranging from 40% to 59% for replacement of the two HPS wattage types. A full year of monthly data is needed to assess lumen maintenance.

Meanwhile, consumer feedback has been extremely positive. A professional public survey conducted in July 2011 interviewed 85 drivers, pedestrians, shopkeepers and park visitors. More than 90% of the driver respondents said the LEDs improved visibility on the road, and more than 70% of the pedestrians interviewed had the same view. In terms of road safety, 70% of drivers felt safer, while 40% of pedestrians felt safer (40% of respondents felt there was no change). A majority of respondents favored an LED rollout across Kolkata's busy streets, the positive responses ranging from 75% of shopkeepers to 90% of drivers.

FIG. 2. Images of an Indian 1000-rupee note, illuminated at left by high-pressure sodium lights, and at right by Philips Lumec luminaires at the KMC trial in Kolkata.

The positive trial results and consumer feedback have convinced Kolkata Municipal Corporation (KMC) officials to scale up. KMC now plans to install 15,000 LED streetlights through the next phase of the Kolkata Environment Improvement Project (KEIP). This project, funded by the Asian Development Bank, plans to go to tender in January 2012.

As central-government LED policies evolve, municipal trials like the one in Kolkata are lending practical experience to national policymakers as they decide what new technical resources, standards, and institutions are needed to enable India to join Japan, China, Taiwan, and Korea at the forefront of the high-brightness LED revolution in Asia.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Planting virtual trees: the challenge of meeting LEED requirements for light-pollution reduction

Reducing the amount of obtrusive light in an outdoor-lighting scenario while also minimizing the carbon footprint of the lighting system presents a difficult challenge, writes **MICHAEL SMOLYANSKY**.

Computer simulations are widely used in many aspects of our daily life. In the practice of engineering, it is critically important to verify the computer model before attempting real-world implementation. Similarly, we would expect some degree of precision to be found in computer simulations of the light distribution produced by luminaires. Sometimes, however, that is not actually the case.

Consider the key parameter regarding the thermal management of an LED device, the junction temperature, which can be simulated by using a computer model. Direct measurement of the junction temperature is often impractical. However, the junction temperature can be accurately calculated, based on a known case or board temperature and the materials' thermal resistance.

In the practice of engineering, it is common to have information about parameters that can't be directly measured; such information is based on other parameters which have a strong correlation to the parameter in question. Unfortunately, these engineering principles don't seem to apply to LEED (Leadership in Energy & Environmental Design) Light Pollution Reduction requirements. In reality, we are trying to measure the immeasurable.

MICHAEL SMOLYANSKY *is a Senior Applications Engineer with Cooper Lighting Canada.*

LEED requirements

During a recent meeting of our local IES chapter, we discussed various approaches to prevent and/or reduce outdoor light pollution. One discussion addressed LEED requirements, especially Sustainable Sites credit 8 (SSc.8): Light Pollution Reduction. Some useful strategies mentioned included the use of full-cutoff optics, spill-light shields, and the reduction of both pole height and luminaire wattage.

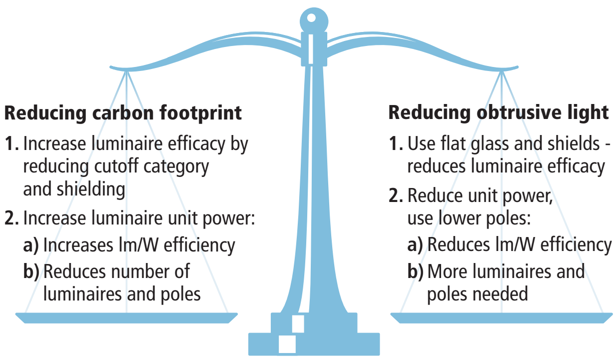

FIG. 1. The strategies proposed for how outdoor-lighting systems can get closer to achieving LEED Light Pollution Reduction requirements serve only to highlight the contradiction between the two objectives of reducing carbon footprint and reducing obtrusive light.

However, even while incorporating all of these measures, compliance with LEED requirements remains very challenging. "There is not really a problem to meet strict LEED requirements," said one lighting designer who participated in the discussion. "Just plant as many trees and bushes along the property line as you need to reduce light pollution to the required level in your computer model".

While this "virtual trees" suggestion was offered tongue-in-cheek, even that approach would not translate to real-world results because of the effect of moonlight, which ranges from 0 fc to 0.04 fc, depending on the phase and the sky conditions. Even using an average of 0.01 fc for moonlight's contribution, it becomes impossible to ensure that the light pollution doesn't exceed the 0.01 fc LEED requirement.

The "virtual trees" suggestion highlights the schism between achieving results in the real world versus the virtual model. The LEED Reference Guide shows strategies to achieving Credit 8 requirements based on a layout where the property line is located 25-30 feet from the lighted area (courtesy of Clanton & Associates). Who are the property owners that would keep this expansive buffer zone just to achieve one credit towards LEED certification?

In reality, a property line is generally located very close to the parking lot or other public area. Even utilizing the best shielded optics in the industry, it is extremely difficult, if not impossible, to meet LEED requirements without at the same time compromising recommended illuminance targets for exterior applications.

Carbon footprint

LEED was developed to reduce human impact on ecological systems, reduce carbon

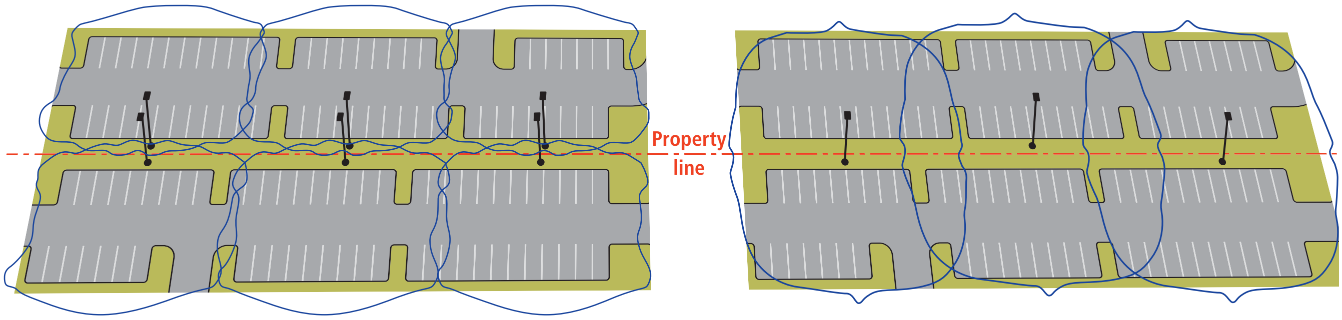

FIG. 2. **Two neighboring parking lots are separated by a property line, and belong to the same lighting zone. At left, luminaires have optics that eliminate back-spill for both properties. The plan includes six poles and six 150W luminaires, for a total load power of 1170W. With spill-lighting requirements removed (right), this plan utilizes three poles and three 250W luminaires with symmetrical optics, for a total load power of 930W. Both lighting systems provide similar illuminance and uniformity.**

footprints and other industrial pollutants, and to reduce global warming. Some parts of the document provide guidelines for reducing human impact on our planet through saving energy, water, land, and materials. Other sections describe how to improve the quality of living and working environments without increasing our carbon footprint. Credit SSc.8 Light Pollution Reduction provides guidelines for reducing obtrusive light, but without respect to carbon footprint.

According to the recently-approved Model Lighting Ordinance (www.ledsmagazine.com/features/8/7/17): "The environmental impacts of outdoor lighting fall into two categories: carbon footprint (energy used in the life of a lighting product) and obtrusive light."

However, these two concepts, summarized in Table 1, are challenging to achieve simultaneously because they contradict one another. The strategies that have been proposed for how outdoor-lighting systems can get closer to achieving LEED Light Pollution Reduction requirements serve only to highlight the contradiction between the two objectives i.e. reducing carbon footprint and reduced obtrusive light (Fig. 1):

– Use shielded optical systems. These are inherently less efficient than unshielded systems, and therefore require more energy, more raw materials, and proportionally more greenhouse gas emission.

– Utilize more luminaries with lower wattage and lower mounting heights. From our design experience, the average LEED project requires 1.5-2 times more luminaires and poles than non-LEED projects. That means essentially more raw materials and energy must be used for manufacturing the fixtures and poles, as well as more energy consumption throughout the site.

All this is contrary to the basic tenets and goals of sustainability. The reduction of light pollution is a good idea only if its implementation doesn't increase carbon footprint. The carbon footprint of a compliant LEED SSc.8 lighting system should not exceed the baseline performance of a non-LEED compliant lighting system. Otherwise we are simply trading one set of problems for another.

Table 1. Environmental impacts of outdoor lighting

Carbon footprint	Obtrusive light
Cost & impact of mining the materials used	Impact on humans
Energy used in production	Impact on the environment
Energy used during product life	
Disposal/recycling costs	

Setting boundaries

LEED requirements for boundary-line spill light are reasonable only if the bordered property has a lower zone classification. For example, if the designed property is an LZ3 zone and this property borders two other LZ3 properties and one LZ2, then it is reasonable only to do a boundary calculation where you border the LZ2 property. The request for spill-light limitation for two neighboring properties belonging to the same lighting zone is similar to establishing border customs between neighboring US states.

Fig. 2 illustrates two neighboring parking lots separated by a property line, and belonging to the same lighting zone. The plan on the left utilizes luminaires with optics that eliminate back-spill for both properties. The plan includes six poles and six 150W luminaires, which consume a total of 1170W. The plan on the right utilizes three poles and three 250W luminaires, which consume a total of 930W. Both lighting systems provide similar illuminance and uniformity. Simply removing the spill requirements in this case could essentially reduce the carbon footprint of the lighting system.

In situations where the real illuminance on – and beyond – the boundary cannot be measured, where the computer model is the only avenue, the door is open for incorrect results, either purposely or in error. One common scenario is for the arm in the computer model to be too short, causing the pole to essentially shield the backlight.

We have to find another realistic and measurable approach to the LEED Light Pollution Reduction problem that allows a reduction in light pollution without additional luminaires, poles and increased energy, when compared to non-LEED projects.

Let's stop planting virtual trees, and instead save the real ones.

LED-based products must meet photobiological safety standards: part 1

The reappraisal of the place of LEDs in safety standards has had a significant impact on the process of bringing to market not only LED-based products, but any product containing non-laser sources of optical radiation, writes **LESLIE LYONS**.

A consideration of the potential hazards to the human body posed by exposure to optical radiation has, in the past, been limited to lasers and sources of UV, with a minimalist approach being adopted for LEDs. This latter treatment may have been acceptable in the past, where LED performance had not reached current levels. However, a brief glimpse of many of the LEDs of today attests to the significantly-improved optical performance, and that a consideration of the photobiological safety of LEDs within an appropriate framework is now very much required.

This article is the first in a three-part series that takes a wide-ranging view of the place of LEDs in photobiological safety standards, from the underlying photobiological concerns to the implementation of current product-safety standards.

Overview of photobiology

Photobiology is the study of the interaction of optical radiation with living organisms. Optical radiation is defined as electromagnetic radiation having wavelengths between 100 nm in the deep ultraviolet (UV) to 1 mm in the far infrared (IR). However, this range is often restricted for practical purposes to 200-3000 nm due to atmospheric absorption below 200 nm, and the negligible effect of low-energy photons in the far IR.

LESLIE LYONS *is the Technical Support Manager with Bentham Instruments Ltd (www.bentham.co.uk), Reading, UK. He is a member of BSI and IEC committees including TC76, Optical Radiation Safety and Laser Equipment.*

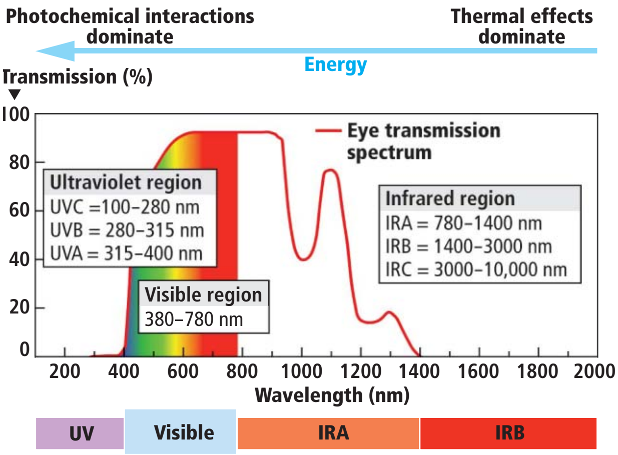

FIG. 1. Different spectral regions of the optical-radiation spectrum, together with a curve showing the transmission spectrum of the human eye.

Since optical radiation is strongly absorbed in tissue, with penetration depths of a few microns for UV to millimeters for IR, it follows that it is the skin and eyes of the human body that are most at risk of exposure. The biological response to exposure results from a variety of energy-transformation processes, broadly categorized as either photochemical or thermal interactions. While photochemical interactions dominate in the short-wavelength range, where photon energies are greatest, thermal effects tend to dominate at the long-wavelength end of the spectrum.

In a photochemical interaction, light of a specific wavelength (and therefore energy) excites electrons in cellular molecules, leading to the breaking or reorganization of chemical bonds therein. This may have direct consequences to DNA, whereby base pairs are bound together, creating a disruption in the DNA strand. Indirectly, an excess of highly-reactive free radicals may be produced. These can interact with DNA to cause structural reorganization, and with other cells such as retinal photoreceptors to cause deterioration of cellular function and cell death. Importantly, damage to DNA, if not repaired, has the potential to give rise to cancer.

The mechanisms underpinning thermal interactions are related to the absorption of light giving rise to an increase in temperature at the exposure site, leading to protein denaturation and thermally-induced cellular damage.

While thermal interactions pose the same hazard over all wavelengths, the strong wavelength dependence of photochemical interactions is characterized by hazard-weighting functions (Fig. 2). Such functions are the reciprocal of dose (or energy) required at each wavelength to elicit a given level of response and normalized to unity: a low response requires a high dose, and vice versa.

Furthermore, while the effects of low-level thermal exposure may be mitigated by thermal conduction from the exposure site, photochemical interactions generally follow the Bunson-Roscoe law of reciprocity. This states that photochemical processes are dose dependant, meaning that low-level, long-term exposure gives rise to the same damage as high-level, short-term exposure.

Photobiological hazards posed to skin and eye

In consideration of the hazards posed to skin and eye, three exposure scenarios should be taken into account: exposure of the skin, of the front surface of the eye (cornea, conjunctiva and lens), and of the retina.

On exposure of skin, a proportion of incident light is reflected, the remainder being transmitted through the epidermis and dermis. The principle concern for the skin resides in UV exposure, which presents a photochemical hazard due to direct damage of DNA, giving rise to the familiar inflammatory response producing erythema (sunburn). Another hazard is the production of reactive free-radicals which may attack DNA and other skin cells, such as collagen. This structural protein gives skin its elasticity, and collagen damage gives rise to elastosis, resulting in wrinkles and aged skin. The risk of thermal burn is also present, yet is of less concern since exposure is generally limited due to the associated feeling of pain. Skin may develop a protection mechanism upon repeated exposure to UV: this results in the thickening of the upper skin layers to reduce UV transmission and the production of UV-absorbing melanin, the pigmentation of tanned skin.

Exposure of the superficial structures of the eye demonstrates a response analogous to that of skin. The dominant concern is in the UV region, where photokeratitis (arc eye/snow blindness) may result: this is an inflammatory photochemical response, akin to sunburn, that occurs in the cornea and conjunctiva. Another possible result is a UV cataract (clouding) of the lens. In the IR, a thermal response to chronic high-level exposure may cause an infrared cataract.

Due to the transmission characteristics of the lens, exposure of the retina needs only to be considered over the wavelength range 300-1400 nm. The exception is in the specific case of the aphakic eye, in which the lens has either not yet developed or is removed during surgery. The dominant damage mechanism for exposure times greater than 10s is a photochemical blue-light hazard (photoretinitis), resulting in the production of free radicals which damage both photoreceptors and the retinal pigmented epithelium (RPE - a layer of cells on the outer surface of the retina, which supports the photoreceptors' function). For shorter times, a thermal hazard dominates which causes the denaturation of proteins and key biological components of the retina.

The eye is afforded a number of protection mechanisms in response to visual stimuli (380-780 nm) only. These include an aversion response (blinking, head movement and constriction of the pupil to limit the amount of light reaching the retina) and continuous eye movement (saccades), ensuring that the same area of the retina is not continuously exposed.

Table 1 summarizes the six photobiological hazards to the skin and eye.

Hazard	Wavelength Range (nm)	Principle Bio-effects	
		Skin	Eye
Actinic UV skin and eye†	200-400	Erythema (sunburn) Elastosis (ageing, wrinkles)	Photokeratitis Cataractogenesis
UVA eye	315-400	-	Cataractogenesis
Retinal blue-light†	300-700	-	Photoretinitis
Retinal thermal†	380-1400	-	Retinal burn
Infrared radiation eye	780-3000	-	Corneal burn Cataractogenesis
Thermal skin	380-3000	Skin burn	-

TABLE 1. Six photobiological hazards posed to the skin and eyes († denotes the use of a hazard weighting function).

Evolution of safety standards for LEDs

In consideration of these photobiological concerns, the International Commission on Non-Ionising Radiation Protection (ICNIRP) publishes exposure-limit (EL) values for each hazard considered. These values are based on thresholds for damage obtained through reported effects of optical radiation and experiments on animal tissue. Whilst a safety factor is provided, account is not taken of abnormal photosensitivity or the presence of photosensitisers in the body or on the skin (including certain pharmaceutical compounds, cosmetics and plants).

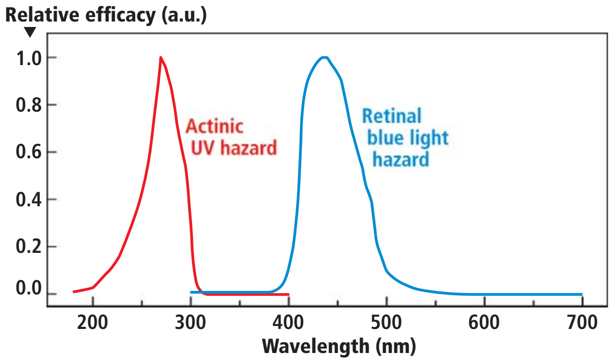

FIG. 2. Hazard weighting functions demonstrating the strong spectral dependence of photochemical interactions.

In 1993, the year in which Nichia introduced commercially-viable blue GaN LEDs, the photobiological safety of LEDs was for the first time considered, as the International Electrotechnical Commission (IEC) took the decision to include LEDs within the scope of the existing laser standard, IEC60825. The rationale behind this decision was twofold; firstly that LEDs may be considered as a technology intermediate between lasers and conventional lamps, due their narrow spectral bandwidth, small source size and the potentially strongly-directional spatial distribution of the emitted light. The second reason was due to the use of IR-LEDs in optical-fiber communication systems for which laser diodes were also employed.

In 1996 and 2001, attempts were made to

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better accommodate LEDs within the laser standard, mainly through a revised safety philosophy, which had consequences for all lasers. However, difficulties were still encountered in that the hazards tended to be over-estimated, largely due to not taking into account the divergent nature of LED emission.

In parallel to the development of IEC60825, in 1996 the Illuminating Engineering Society of North America (IESNA) published ANSI/IESNA RP27.1, "Recommended Practice for Photobiological Safety for Lamps and Lamps Systems: General Requirements." This heralded a series of standards concerned with non-laser sources. In 2002, the International Commission on Illumination (CIE) adopted the main body of ANSI/IESNA RP27.1 to publish the CIE Standard S009/E-2002, "Photobiological Safety of Lamps and Lamp Systems," thereby disseminating this standard to the world.

Given that the application of laser limits to LEDs was considered by experts as being overly conservative, and given advances in LED performance and the attendant increase in application areas, the IEC took the decision to remove LEDs from consideration by the laser standard, updating IEC 60825 in 2007. The exception was for fiber-coupled and free-space-communications applications. This change required the provision of an alternative context in which to consider LEDs.

The introduction of IEC62471-2006

In 2006, the IEC adopted the existing CIE S009/E-2002 guidelines, to publish IEC62471:2006 "Photobiological Safety of Lamps and Lamp Systems" as a dual-logo standard with the CIE. The scope of this standard is to provide guidance for the evaluation of the photobiological safety of lamps and lamp systems, excluding lasers, emitting light in the spectral region 200-3000 nm.

A measurement methodology and exposure limit values (based on ICNIRP data) are given in the consideration of the six hazards (Table 1) to the skin and eye for an exposure duration of up to eight hours, taken as a working day. No consideration is taken of the potential effects of long-term exposure.

Risk Group	Philosophical Basis
Exempt	No photobiological hazard
RG1	No photobiological hazard under normal behavioral limitation
RG2	Does not pose a hazard due to aversion response to bright light or thermal discomfort
RG3	Hazardous even for momentary exposure

TABLE 2. **The IEC62471:2006 standard contains a four-tier classification structure for lamps and lamp systems, excluding lasers, emitting in the 200-3000 nm spectral region.**

A four-tier classification structure, based on permissible exposure time before exceeding the EL of each hazard, is defined, ranging from "Exempt" to "Risk Group (RG) 3" (Table 2). In the case of retinal hazards, the aversion-response time of the eye is taken into account. It should be noted that this classification system is different from the class system used for lasers.

The evaluation consists of a complex series of measurements of spectral irradiance (200-3000 nm) in consideration of hazards to the skin and front surfaces of the eye, and spectral radiance (300-1400 nm) in consideration of hazards to the retina. Measurements are performed in specific geometrical conditions which replicate biophysical phenomenon, such as the effect of eye movements on retinal irradiation, and at a measurement distance dependant on the application of the source in consideration i.e. general lighting service (GLS) or non-GLS.

In the next part of this article, we shall adopt a more practical approach, considering the finer details of source measurement and the implementation of the standard in Europe and the rest of the world.

Look for part 2 in our series on Optical Safety in our next issue.

LED FABRICATION

LED wafer and automation standards are on the fast track, ready for more industry feedback

Thanks to SEMI's HB-LED manufacturing standards program, the industry is taking the first steps towards agreement on basic issues such as wafer dimensions and equipment interfaces to enable low-cost automated production, explains **PAULA DOE**.

Big growth projections are often made for the general solid-state lighting market, but these depend on major cost reductions – perhaps as much as 20× improvement in $/klm at the packaged LED level (Fig. 1). That's only going to be possible by scaling to automated high-volume production with tightly-controlled processes for high yields. Luckily, some of the sector's manufacturing technology experts have been working together on the nitty-gritty details to help speed this transition.

Wafer and automation standards

Less than a year after the formation of the first committee for HB-LED manufacturing standards, industry experts have identified the critical issues for common wafer characteristics and common equipment hardware and software interfaces, to enable the industry to move to automated production.

"These kinds of standards are a long way from creating commodity production," notes Bill Quinn, Chief Technologist of Veeco Instrument's MOCVD business, and co-chair of the SEMI HB-LED standards committee. "They're just the basics for a volume industry."

The emerging consensus on the basic dimensions and marking for 6-inch wafers, the modeling of a wafer carrier for automated transfer between tools, and the software protocols for communication between equipment and the manufacturing execution system (MES) are now ready for wider industry review before drafting these first basic manufacturing standards.

"For some years, people were not interested in standards, they thought LEDs were different, but all of a sudden we've all realized that LEDs are more similar to other micro manufacturing industries than we thought, and we're going to need semiconductor-style production control," argues Rainer Beccard, Aixtron VP of marketing.

Though automation hasn't been particularly important to increase throughput in LED fabs, as faster handoffs between machines are less important when the key MOCVD process takes 6 hours, it is becoming vital to control yields. "Big producers running 6-inch production won't accept any manual wafer handling," notes Beccard. "They won't run without automation, period, to assure reproducibility without having to depend on the availability of enough highly-skilled operators."

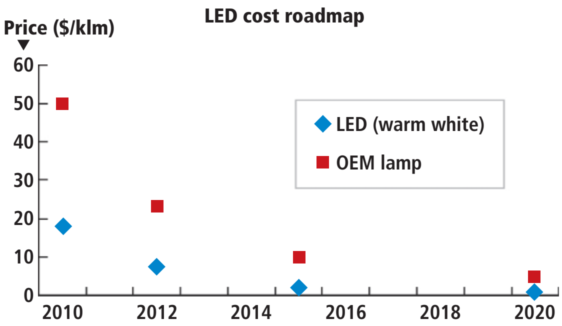

FIG. 1. The aggressive roadmap target of nearly 20× improvement in LED cost per kilolumen – to $2.20/klm by 2015 and $1.00/klm by 2020 – will require high-volume production on larger wafers with tight control of yields. Source: US Department of Energy (DOE) Manufacturing Roadmap 2011.

Feedback requested

Much of the initial heavy lifting on the standards committees has as usual been done by the supplier community, whose expert technologists know the production issues, have a good window into what's going on at LED makers across the industry, and need to look ahead to develop what their customers will need next.

"Most users don't know, and don't want to know, about some of these inner details," notes Chris Moore, CEO of Semilab and another co-chair of the SEMI HB-LED standards committee, along with Quinn and Iain Black, VP worldwide manufacturing engineering, technology & innovation at Philips Lumileds. "But now at the end, when they can see how it impacts them, it's time for them to give their input."

"These standards are based on what works, decided by the people who know," notes Quinn. "Now that we're coming to understand the process better, users will be able to start with wafers that work with the process and can concentrate on optimizing their recipes, instead of having to also tweak the wafer to

PAULA DOE supports SEMI's micro-manufacturing trade group and HB-LED programs. SEMI is a global industry association serving the manufacturing supply chain for the micro- and nano-electronics industries.

get it to work with the process."

But, says Quinn, "even the biggest players who already are ordering high volumes of wafers with their own established specifications will benefit, because standards will drive tighter tolerances at suppliers." Focusing production on higher volumes of fewer product variations will help suppliers achieve better control of key parameters and drive down costs. As a consequence, both manufacturers and suppliers will have more time and resources to focus on the key aspects of their business that genuinely add value to their products.

"The LED sector must transition from a research- and technology-driven industry to a manufacturing-engineering model with focus on equipment productivity to drive down unit costs and prepare for high volume," says Daniel Babbs, Brooks Automation senior director of engineering, strategic technology development, and co-chair of the HB-LED automation interface standards task force.

Babbs notes further how the semiconductor industry has benefited from industry groups like Sematech and the ITRS, who help establish a vision of the future factory and drive the supply chain in the direction major end-users will need. He also notes how the LED industry would benefit from having a similar solution to prepare its suppliers now for their automation needs into the next five, ten and twenty years.

The manufacturing experts on the wafer- and automation-standards task forces have done a tremendous amount of work to identify and specify almost 20 wafer parameters, including experimental tests of wafer-edge marks and the thermal impact of 3-μm markings, and to identify the key issues for hardware- and software-automation interfaces. They are now collecting wider user feedback on their proposals, and will soon start to share draft standards with industry stakeholders in a series of meetings in Asia for comment and input.

How to get involved

Manufacturers and other stakeholders can participate in the decision-making process by registering with SEMI standards at no cost, and can attend meetings in person or by teleconference call-in. For details see www.semi.org/en/Standards or email info@semi.org. ◄

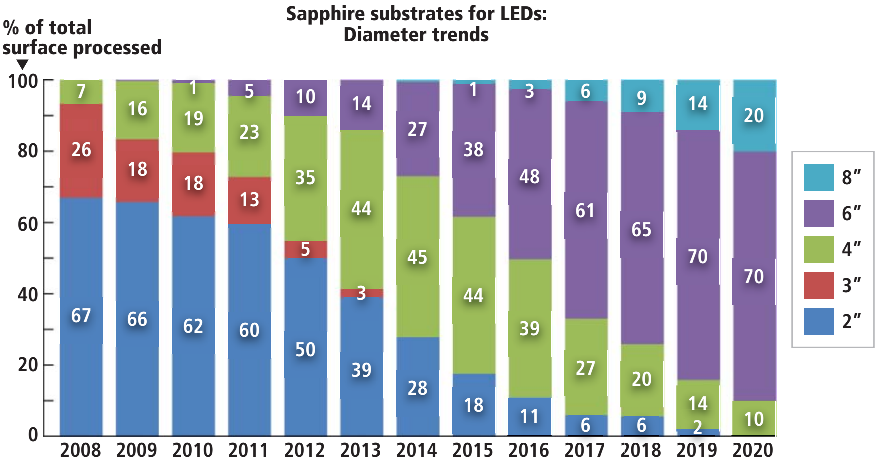

FIG. 2. Moving to larger substrates is one key to reducing LED manufacturing costs. The start of the transition to 6-inch wafers makes this the ideal time to set basic specifications to control tolerances and enable automation. Source: Yole Développement.

Wafer handling

Automated lines are clearly needed to scale to high-volume, low-cost production and improve yields, and that requires clear communication and smooth handling from cassettes to handlers to tools and back. The first basic requirement is a common carrier to move the wafers from tool to tool, so equipment from any manufacturer can be easily plugged into the production line, and automatic handlers and software can be designed to locate individual wafers in these boxes to move them in and out of each tool.

However, the thicker sapphire wafers, bowed from epitaxial layer growth, won't fit into the slots in the standard 25-wafer carriers used by the semiconductor industry.

The experienced manufacturing technologists on the SEMI HB-LED equipment automation task force have concluded that the most cost-efficient solution would be to keep the external dimensions of the semiconductor 25-wafer carriers to continue to use much of the existing semiconductor industry automation infrastructure, but to put the pockets at double pitch, to enable the existing IC automation software to pick every other pocket. That means dividing the wafers from one 25-wafer shipping cassette into two 13-pocket handling cassettes, and lowering the first slot to make room for 13 wafers and still provide enough clearance to pull out the first wafer.

A 12-pocket approach would also be an option, but the additional 13th slot allows higher throughput, and allows the 25-wafer lot to all be handled with two cassettes. More pockets would mean having to change the cassette box size and/or the robotic software.

Cassette maker Entegris is currently working on modeling the 13-slot concept to get feedback from a wider range of LED makers to make sure it won't cause any serious throughput issues, and that the slots will be large enough to allow the maximum amount of bow. "The more industry involvement we have, the better the standards will be," notes automation task force co-chair Jeff Felipe, Entegris' regional product specialist lead. "The more a company participates, the more it will benefit."

Communication software

Also key is the software that enables the tools to communicate with the MES system. Can the LED industry use the SEMI Equipment Communications Standard/Generic Equipment Model (SECS/GEM) standard protocols, used by semiconductor and solar manufacturing equipment, to interface with the host factory-automation systems? Or will it need to use the more sophisticated Interface A for at least the MOCVD tools for greater bandwidth and control flexibility? This would enable handling of the more-complex recipes and enable feeding data from in-situ metrology on the process tool to the host and making adjustments on the fly.

Another question is which data should be handled at the tool level and which in the central system? Semiconductor equipment for some of the more-complex new IC processes is starting to use Interface A for more-flexible control, but it requires more development resources from the tool makers.

"We need the guys who know about this to all discuss it in a group and decide what's needed, instead of all trying to figure out their own systems," argues Quinn, "so users can just buy the software on the tool or in the MES system and not worry about it. Although automation is important for high-volume production, automation interfaces are not core value-add."

Wafer sizes

LED industry participants routinely refer to 6-inch wafers, but the actual diameter of such wafers is 150 mm. In this article, and throughout the industry, "6 inch" and "150 mm" are used interchangeably when referring to LED wafer sizes. ◄

"These committees are the only forum where the competing tool makers are talking together," notes Moore. "Suppliers want standardized load ports and software interfaces because it saves them – and their customers – money. Custom features have to be custom made – and custom supported. It may not actually [cost] that much more initially for the custom equipment, but my cost – and the customer's cost – to support these orphans or snowflakes is much higher, especially for custom parts repair and replacement."

Basic characteristics of 6-inch wafers

Though most large producers have qualified 6-inch production, few have yet to invest in


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new lines to ramp production, as some concern remains with substrate availability and cost. So the timing is right to think about how to specify the wafers from the start to improve yields and reduce costs.

"LG Innotek is the most advanced LED maker in term of volumes regarding the transition to 6-inch," says Eric Virey, LED analyst at Yole Développement. "Philips Lumileds is following closely but many other companies have started rolling out some 6-inch manufacturing capacity, including Osram, Lextar, and Sharp."

Much of the current capacity in China is on 2-inch wafers, keeping the 2-inch share of the market higher than initially expected. Most makers in Taiwan started converting from 2-inch to 4-inch in the second half of 2011. But within five years, nearly half of all production will likely be on 6-inch wafers, according to estimates from Yole Développement (Fig. 2).

Improving yields will require marking wafers to allow defect tracking and root-cause analysis. If the industry can agree on common content and placement for its wafer ID marks, automation and metrology equipment makers will be able to identify and track the wafers from tool to tool without extra expense.

Standard fiducials for orientation will help MOCVD tool makers better tune their processes to account for that common wafer cutout. Draft standards will specify size and placement for both a notch and a flat, but ultimately the industry will likely go to notches since they take up less wafer area and interfere less with wafer spin. The committee is also testing, but has not yet validated, edge marking.

The sector seems to be settling on thicknesses of 1000 μm and 1300 μm for 150-mm-diameter wafers. Tolerances are of course a more complex cost/performance tradeoff, but some experts suggest that reasonably-achievable targets are to control diameter within 0.1 mm or 0.2 mm (trading off MOCVD impact of gas-flow effects around the pocket vs. edge chipping), thickness within 25 μm, edge exclusion of 2 mm, impurities <1ppm (though those who remove the sapphire can perhaps tolerate more), and edge chipping <5 mm cumulative length and defined maximum radial penetration.

As the industry and its equipment matures and producers generally get more control over their processes, it's getting to the point where, for many producers, the cost and consistency advantages of buying wafers with some common basic properties outweigh the competitive advantage of production on custom specs. Users could order a wafer with the standard specs off the shelf from multiple suppliers, but could of course also order custom wafers with particular desired characteristics.

"We're trying to bring our machines to the point where there are no calibration runs, and all machines perform the same, but it only works if the wafers are the same too," notes Beccard. "If we could tune to a type of wafer with fixed mechanical specs it would save a lot of time and money."

Ongoing discussions

Wafer task-force members are presenting proposals for discussion at Semicon events in Taiwan and Germany this fall, and at the October SEMI standards meetings in San Jose, aiming for a first-draft standard on some of these basic wafer characteristics by November.

While plenty of industry expertise has gone into these initial working drafts, manufacturing technology experts at other HB-LED makers who take the time to give their input on these basic future automation and materials issues – such as the number of wafer slots in a cassette, the degree of sophistication needed in future automation software interfaces, or where to mark the wafer – can help direct the supply-chain's investment towards the solutions they need.

LINKS

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E11
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focus on Entertainment

PLASA, the annual tradeshow for event, installation and entertainment technology, took place on September 11-14, 2011 at Earls Court in London, UK (www.plasashow.com). As has always been the case in recent years, LED lighting products were very much in evidence. Many traditional types of entertainment-lighting fixtures are now being replaced by LED-based alternatives, thanks in part to the development of compact, high-power LEDs and light engines. TIM WHITAKER reports.

One novel feature at this year's PLASA was the LED Shootout hosted by the Society of Television Lighting and Design (STLD, www.stld.org.uk), which attempted to answer the question: "Can you light a TV set entirely with LED fixtures?" Twenty-three manufacturers submitted 83 different LED products, which were assessed and compared in various scenarios. LED fixtures were used to illuminate an 8-meter-wide cyclorama (pictured), where they were compared with traditional 1250W tungsten-halogen lights. In the center of STLD's stand was a mini TV studio, where attendees could get hands-on experience of lighting the studio set-up, and view the results on HD broadcast cameras. A number of case studies were also presented, notably the ITV Daybreak studio (see below).

LED Shootout

STLD's event organizer Paul Middleton said the Shootout demonstrated "huge advances" in LED technology. "The 120W LED engines being used by a number of manufacturers are on a par with a typical 1000W Fresnel," he said. "Manufacturers are beginning to listen to the unique requirements of TV production, and are building fixtures that not only allow considerable savings in lamp power consumption, but also give reduced need for air conditioning."

However, said Middleton, manufacturers need to work on bringing down the cost of products, so power-reduction savings are not outweighed by the cost of purchase or hire. "They also need to fully reproduce all the features of controllability of beam shape and color enjoyed by current fixtures," he said. "The ideal solution for many existing studios might be to unplug an existing tungsten bulb and plug in a new LED unit. Some manufacturers are taking that type of approach by either using an existing housing and converting it to take an LED engine, or else developing new back-ends to fit onto existing industry-standard lens assemblies. Others are producing brand new types of fixtures that don't easily fit into traditional categories."

As part of the STLD LED Shootout, lighting designer Matt Carter described the revamp of a TV studio in London, UK, for a new breakfast-time show, Daybreak. "The set is lit almost entirely with LEDs," said Carter. "LEDs have been used for sets before now, but not for faces." This "quite

Daybreak studio

radical" approach was not taken from a desire to use LEDs, but because the studio's unique situation made LEDs the only choice, said Carter.

The studio presenters sit in front of large windows with a view of St. Paul's Cathedral in the background. However, the windows face east, and the sun rises as the show progresses. The first task was to control ambient lighting, and this was done using SPD SmartGlass, which can be automatically altered from clear to almost opaque, controlling glare and solar heat gain.

Around 70 LED-based Selador Lustr and Vivid fixtures from ETC comprise about 95% of the studio's lighting. The fixtures are built using the x7 Color System, which utilizes arrays of 7 different colors of LEDs, and provides a huge range of control, as Carter explains: "The Seladors allow me to mix the incoming natural light with the studio lighting perfectly, and because of the range of colors the fixtures output, we know that the white balance will always be perfect. These were the only lights that we're aware of that have such impressive brightness and saturation." Carter seemed convinced that seven colors would be needed for adequate control, rather than five or less. "The red, green and blue LEDs have the largest effect, and the other four colors are very subtle," he said.


Beamlight from i-Pix Ltd

Carter described a bright sunlit day when the windows were fully blue (almost opaque). When blue was dialed out of the camera picture, this returned the windows to a neutral color, but made the whole studio appear orange. Using the LED lights, Carter was able to make everything look normal on camera by reducing the red and orange content of the LED illumination and boosting the blue and cyan.

As well as providing the necessary lighting control, the LED installation has other advantages. In the old studio, the lighting rig used 120A per phase, or 360A continuously throughout the three-hour show. "Now we use just 67A for the entire rig," said Carter. "Of course, the added effect of this is less heat and less weight." One consequence is that the air conditioning can be run at much lower levels.

UK manufacturer i-Pix Ltd added to its range of entertainment lighting products with the distinctive Beamlight. Chris Ewington, CEO of i-Pix, said, "For six years we have wanted to displace the ubiquitous ACL beamlight, a regular fixture for concert touring and


Philips Selecon PL3 focusing luminaire

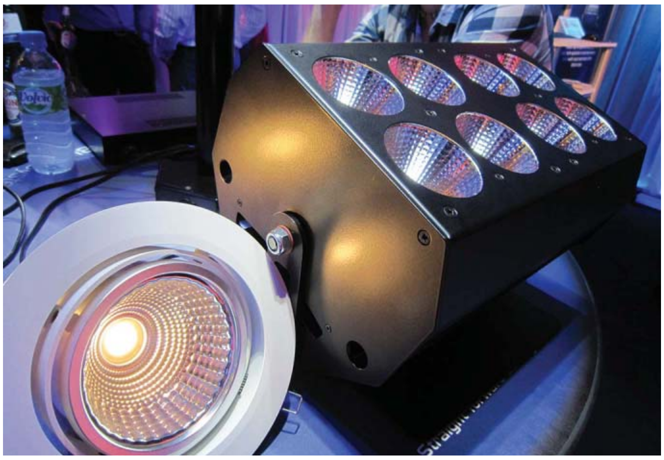
TV production, which typically consumes 240W, and with only a 15-hour lamp life." LED Engin's 12-die, 40W RGBW LZC enabled i-Pix to develop an LED-based replacement. Ewington said that i-Pix has produced "a new homogenized beamlight with the added benefit of being a focused device, weatherproof and capable of meeting arduous touring environments too."

The Beamlight contains a custom-designed parabolic reflector mounted onto a focusing system which enables a range of beam angles from +/-35 degrees down to a tight 5-degree beam (www.ledsmagazine.com/products/32569).


MAC Aura luminaire

The Philips Selecon PL3 LED luminaire, shown above, and its PL1 counterpart, are built around the Philips Vari-Lite VLX LED light engine (www.ledsmagazine.com/features/6/10/8). This delivers full control of beam-color composition irrespective of intensity, says Philips. The PL1 and PL3 focusing luminaires feature an adjustable beam spread of 15-55 degrees, smooth color mixing and stepless fades. Meanwhile, the Philips VariLite VLX3 Wash contains replaceable 120W RGBW

ARCSystem from GDS

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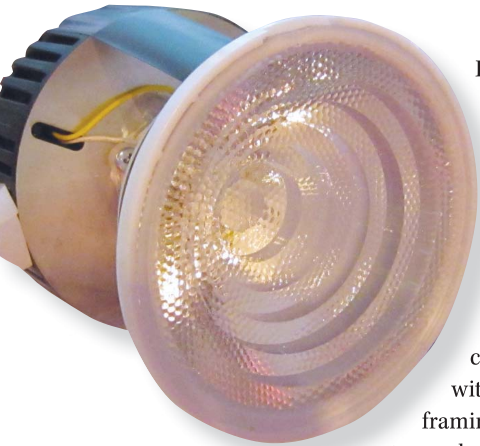
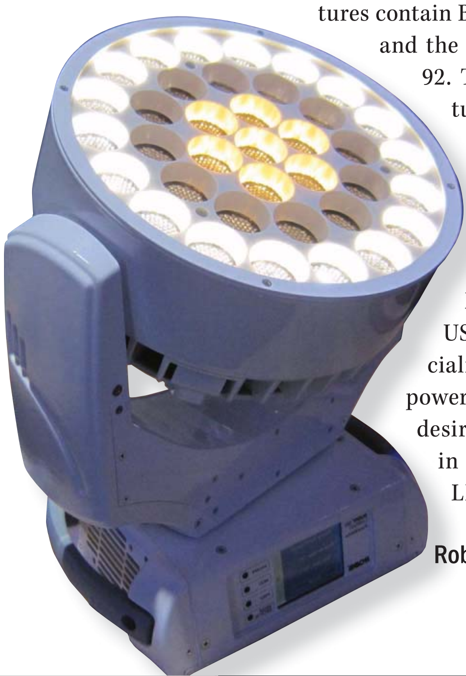

LED Engin lens

LED chipsets that are three times the efficacy of comparable tungsten sources.

According to Peter Rogers, Senior Director of Entertainment Marketing with Philips Lighting, most types of entertainment-lighting fixtures can now be readily produced with LEDs. One exception is the framing spotlight. "A few manufacturers have produced the first LED-based versions of the framing spotlight, but none of them have achieved the performance of the traditional luminaires they would need to replace. Considerable research is going on from all major manufacturers, and we anticipate more progress early next year."

Among the eight winners of the PLASA Awards for Innovation was Martin Professional's new MAC Aura luminaire, a compact LED moving-head wash light with zoom that provides, in the judges' words, "eye candy - we've never see it before." The optical system combines multicolor beam LEDs and a backlight LED lens array to produce a visual palette that takes the synthetic look out of LED wash lights for unique lighting-design possibilities, says Martin (www.ledsmagazine.com/products/32463).

UK-based GDS won PLASA awards (www.ledsmagazine.com/press/32512) for its ArcSystem of LED auditorium-lighting fixtures. The judges felt the system "will have a significant impact on the carbon footprint of the buildings it is utilized in, and provides an elegant replacement house-light system." The photo shows 1-cell and 8-cell ArcSystem fixtures, which are available in 19-, 24- and 37-degree beam angles and with a range of color temperatures (2700K, 3000K, 4100K). The fixtures contain Bridgelux LED arrays, and the CRI is listed as over 92. The 150W 8-cell fixture has a light output of 10,000 lm.


Robe's Robin 600 PureWhite

Many PLASA exhibitors are lighting-fixture manufacturers, and the only LED maker in evidence was US-based LED Engin, a specialist in making compact and powerful LED arrays of the type desired for many fixture types in this market. At the show, LED Engin announced two proprietary lenses; an 8-degree narrow spot lens and a 15-degree spot lens, designed for use with the company's compact, high-flux-density LZC (12-die) and LZP (24-die) LuxiGen emitters, respectively.


Aledin 330LF LED Wash (left) Aledin 630 Profile (right)

LED Engin was also able to showcase a number of design wins with companies exhibiting at PLASA. For example, 4-die LuxiGen RGBW LEDs are used in the P5 wash-light from SGM, which comprises an array of 44 LEDs with Khatod optics. Also, Martin has used the 4-die (10W) flat-top CW/WW LED in its MAC 401CT white-light moving-head wash fixture. Each package contains two warm-white and two daylight-white LEDs in a 7.0x7.0x1.1-mm footprint.


Highlite's Phantom LED25 Wash contains LED Engin's 12-die RGBW emitter.

The Aledin 330LF LED Wash from Robert Juliat complements the Aledin 630 Profile, which was introduced last year, and both are based on the same 85W LED light source. Robert Juliat's sales director Lionel Garraud said: "The feedback we are receiving is that customers find the Aledin wash a very powerful LED product which is easy to daisy chain and produces a clean, even beam. The dimming is very smooth with no stepping, its strobe feature is useful for concert lighting and the choice of color temperature [3500K and 5800K] lends itself well to exhibition work."

Among the many LED-based products introduced by Robe (www.ledsmagazine.com/press/32366) was the Robin 600 PureWhite, containing 37 Cree MC-E multi-chip LEDs. The Smart White (SW) version (left) has variable color temperature from 2800–6300K. Robe also introduced the Robin 1200 LEDWash containing 61 multichip RGBW LEDs in 4 concentric rings.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LED STANDARDS APPROVED

Understanding the difference between LED rated life and lumen-maintenance life

The rated life of an LED light source is different from the lumen-maintenance life, and is an essential reliability value that is required by luminaire makers and end users, as **JIANZHONG JIAO** explains.

With the completion of the IES test method TM-21-11 (see page 9), the SSL industry now has a standard method of obtaining long-term lumen-maintenance information for LED light sources. The method is made up of two steps. First, the LED light sources must be tested per LM-80. The new TM-21 method is then applied to the collected measurement data to make lumen-maintenance projections, including in-situ temperature calculations.

However, there is still one measure that is missing: the rated life for LED light sources. Rated life is an essential reliability property for LED integrators that design LED luminaires, providing luminaire users with warranty and usage information.

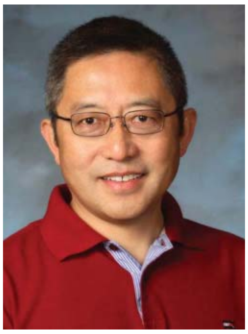
Rated life

The rated life of a lamp or light source is defined, per ANSI/IES RP-16, as "the life value assigned to a particular type lamp. This is commonly a statistically-determined estimate of median operational life." The rated life in hours of an LED lamp or light source, specified by the manufacturer, applies under certain operational conditions and for defined failure criteria. The statistical measure for the rated life is designated B_p and is measured in hours, where p is a percentage.

For example, a B_{50} rated life of 1,000 hours means that 50% of the tested products have lasted 1,000 hours without failure. B_{50} is also known as the products' rated average life.

If a product has a B_{10} rated life of 1,000 hours, this means that only 10% of tested products failed within 1,000 hours, so the product should last much longer than a product with a B_{50} rated life of 1,000 hours.

Lumen-maintenance life



For LED light sources, LM-80 defines lumen-maintenance life as "the elapsed operating time at which the specified percentage of the lumen depreciation or lumen maintenance is reached, expressed in hours." Different from rated life, the rated lumen-maintenance life is defined as "the elapsed operating time over which an LED light source will maintain the percentage (p) of its initial light output."

Rated lumen-maintenance life is measured in hours with associated percentage of light output, noted as L_p. In other words, L_{70} of 30,000 hours means that the tested LEDs produce 70% of the initial light output at 30,000 hours. If an LED has L_{50} of 30,000 hours, its lumen output decays faster than one with L_{70} of 30,000 hours.

While B_p life is a statistical measure, L_p life is a defined durability measure. When testing for B_p life, a large statistically-meaningful sample size is required. When testing L_p life, there is no sample size requirement. However, when LM-80 test data is utilized to make lumen-maintenance projections (per TM-21), the sample size will affect the uncertainty of the projection. As a consequence, a smaller sample size will lead to shorter projected life in order to increase the statistical certainty.

Failure

For LED light sources, one can define failure as when the LED can no longer produce a certain percentage of the initial light-output value. For example, failure might be defined as when the light output of an LED reaches 70% or lower of the initial light output (including if the LED's light output is zero). In other words, for a given period of time, if an LED produces insufficient light or no light, the LED is considered at failure.

Using this definition of failure criteria, the statistical measure can be combined with the defined durability measure. The combination of lumen-maintenance life (L_p) with statistically-measured failures (B_p) is the LED light source's rated life, or B_pL_p value. For example, if an LED light source is claimed to have $B_{50}L_{70}$ of 30,000 hours, then 50% of tested samples should have a lumen-maintenance life of 30,000 hours.

Ideally, to obtain the rated life for LEDs, the statistical failure measurement can be integrated with lumen-maintenance mea-

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surements during the life test. One can use a large LED sample size, large enough to be statistically meaningful as when measuring traditional lamps, and then track and record the sample behaviors including light-output change and failures during the life test. When 50% of the tested samples reach a light output equal to 70% of initial lumens, including the samples that failed to produce light, then $B_{50}L_{70}$ (in hours) is obtained.

Obviously, as is the case with lumen maintenance, it is not practical to conduct real-life tests to get $B_{50}L_{70}$ values when such a value can be as long as 30,000 hours, or nearly three and a half years. The challenge is how to make a projection using the data obtained in a shorter testing period.

Projections

LED manufacturers have been conducting studies and establishing practices for reliable approaches to project the rated life for LEDs; in general, there are two approaches.

The first approach is to conduct LM-80 testing with a large sample size. The test data are collected for both light-output changes and failures. The data is then fitted into a mathematical model with a statistical-certainty band. In addition to the lumen-maintenance projection curve, the associated sample distribution bandwidth is also plotted. By analyzing the curve and bandwidth, an estimated $B_{50}L_{70}$ life is projected.

The second approach is to conduct the lumen-maintenance (LM-80) test separately from the accelerated-failure-modes test. Using TM-21, the lumen-maintenance projection can be established. The data collected in the accelerated-failure-modes test are modeled with a different mathematical expression. The rated life is then projected by mathematically combining both models.

There are some discussions in standardization organizations regarding development of a document or recommendation to address LEDs' rated life. To help the LED lighting industry to properly use LED light-source information, it is necessary to clarify that rated life is not lumen-maintenance life.

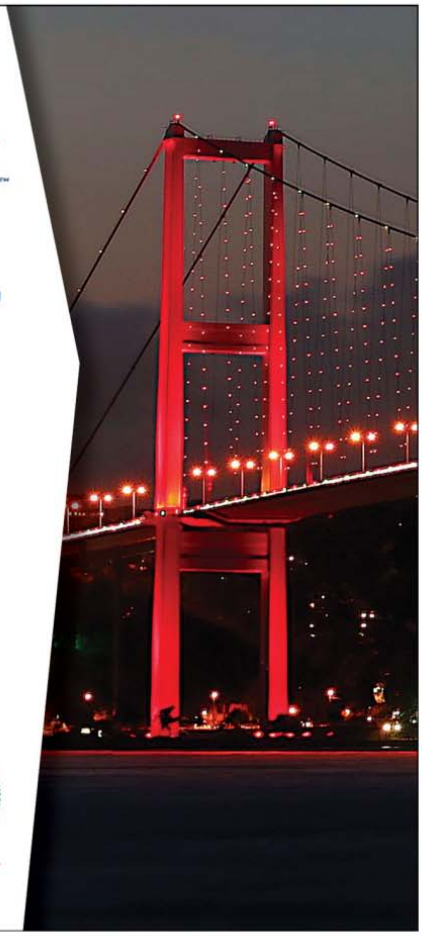
Before the industry establishes a recommendation for a standard practice, LED integrators may need to request more testing and modeling information from the manufacturers in regards to the statistical failures of LED light sources.

LINKS

ANSI evaluates revisions to SSL chromaticity standard
LEDs Magazine Jul/Aug 2011, p31; www.ledsmagazine.com/features/8/7/5

TM-21 seeks methods for lumen-maintenance prediction
LEDs Magazine Feb 2011, p37; www.ledsmagazine.com/features/8/2/10

TM-21-11: Projecting Long Term Lumen Maintenance of LED Light Sources
http://bit.ly/pwRSvK



Unique desk lamp designs combine LEDs with heat pipes, and OLEDs with carbon fiber

Two desk lamps make the best of LED and OLED technology, respectively, although their price range is probably out of the reach of most consumers, writes **TIM WHITAKER.**

LED desk lamps and reading lights are easy to find in many retail outlets, but few are built with quality and longevity in mind. Even fewer contain heat-pipe technology to cool the LEDs, and in this respect the CSYS desk lamp (Fig. 1) from UK-based Jake Dyson Products is probably unique. Meanwhile, Germany-based OLED manufacturer Novaled is targeting the luxury market with the Victory desk lamp (Fig. 2), which incorporates four OLED panels in a carbon-fiber frame.

LEDs and heat pipes

Design company Jake Dyson Products has engineered an LED-based desk light – the CSYS – that uses heat-pipe technology to maintain an LED junction temperature of just 30°C above ambient. The LEDs are mounted at the end of a thin, horizontal arm, with the heat-pipe positioned inside the arm to draw heat away from the LEDs themselves, maintaining the low junction temperature. The heat sink is therefore incorporated as a structural element, and its entire surface area is used to dissipate heat.

"There is a discernible lack of reliability and innovation in existing LED desk lights," said designer Jake Dyson. "Current issues in this area include: poor heat management; weak light distribution; light color erosion; and a lack of comfortable, warm-white color." Dyson believe that such issues are making consumers and industry alike cautious about committing to LED technology in lighting. However, he says: "We have managed to address all of these problems and believe that the CSYS will truly change people's minds about LED lighting."

FIG. 1. Jake Dyson Products' CSYS LED-based desk lamp.

The heat pipe comprises a sealed copper pipe, which is evacuated. A small amount of water is placed inside, and when one end of the tube is heated, the water evaporates and moves to the cooler end of the tube. The water condenses and moves back to the hotter end by a capillary process, setting up a continuous cycle which (in this case) moves heat away from the LEDs.

Because of the focus on thermal management, which involved 18 months of R&D to optimize the heat-pipe technology for this application, the company is claiming a lifetime for the product in excess of 37 years. This is based on 12 hours of use per day, and a projected L_{70}/B_{50} lifetime (see page 51) of

LINKS

Jake Dyson Products www.jakedyson.com
Liternity www.liternity.com
Novaled AG www.novaled.com

160,000 hours at a junction temperature of 60°C. Jake Dyson Products says that the lifetime data is provided by the LED maker.

The LED power is 8.8W and the efficacy is quoted as 56 lm/W, which equates to a light output of 493 lm. The warm-white color temperature is 2700K and the CRI is 82.

The desk lamp also has a unique positioning mechanism to orientate the light through three axes. A CSYS is the system of coordinates that defines an object's position in x, y and z axes. The spread and the intensity of light can be controlled onto the working area, and its optical design minimizes glare, says the manufacturer, because the LEDs are set back into the head of the horizontal arm. Another feature of the luminaire is touch-sensitive dimming. Of course, this all comes at a high price, namely GBP 550 ($860) retail.

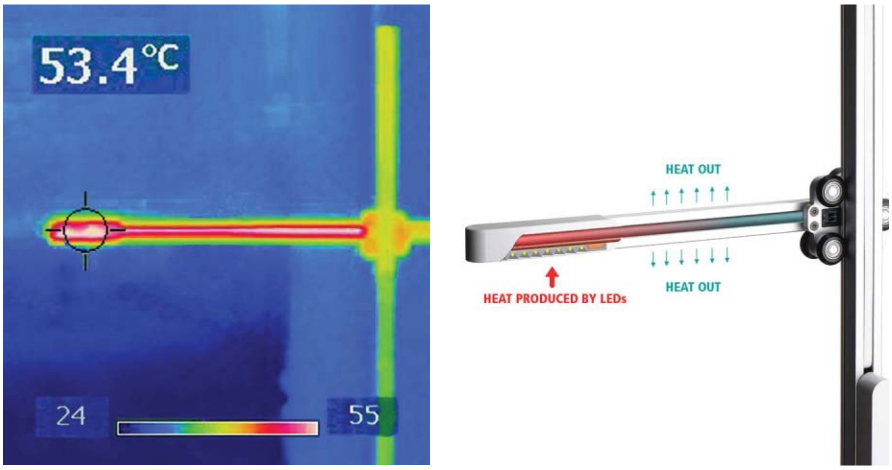


FIG. 3. Thermal management is a key feature of the CSYS desk lamp. (left) Thermal image of the LEDs (circled) and the horizontal heat-pipe structure. (right) Cross-section of the lamp showing how heat is transferred away from the LEDs.

Noting that the UK government is promoting CFLs as an energy-efficient lamp technology, Jake Dyson Products lists four advantages of LEDs versus CFL alternatives. These include the cost saving associated with the lack of need to replace the LED light source; the absence of mercury; the directionality of illumination and good color rendering; and the slim and compact design of the LED lamp, which is difficult to achieve with CFLs.

OLEDs and carbon fiber

Although the Jake Dyson product is highly engineered, the Victory desk lamp from Liternity is in a different class, with a price tag to match of $7500. Liternity is the brand name for a new range of luxury, limited-edition OLED luminaires launched recently by Novaled AG, the Germany-based OLED manufacturer. The Victory desk lamp is described as "the world's first luminaire to showcase OLED lighting in an ultra-thin, ultra-strong, carbon-fiber base." The Victory desk lamp is 35 cm high and 40 cm deep, and its "V for victory" design includes two arms with embedded ultra-flat OLEDs that provide "pleasant, diffuse light over the entire surface," says the company.

FIG. 2. The OLED-based Victory desk lamp.

The lamp contains four OLED panels, each with an active area of 41 cm^2. The color temperature is 3200K and the lifetime is quoted as 10,0000 hr. The power consumption for the whole luminaire is 16W. The operating brightness is 3000 cd/m^2 and the illuminance at the desk level is 400 lux. Gerd Guenther, chief marketing officer at Novaled, said, "OLEDs redefine our understanding of light, due to their extraordinary characteristics. They enable imaginative designs and applications that simply could not have been created with existing lighting to date, and even offer the potential for transparent and bendable light sources in the future. [The] Liternity brand [is] providing outstanding warm-white light that equals the quality of daylight, in a form factor as unique as a human fingerprint."

LEDs headline at SALC, speakers predict significant efficiency gains

SSL technology dominated both the sessions and exhibits at the annual Street & Area Lighting Conference, reports **MAURY WRIGHT**, and LED-based lighting that is already succeeding based on efficacy will soon deliver significant additional power savings.

The annual IES (Illuminating Engineering Society) Street & Area Lighting Conference (SALC) took place Sept 19-21 in New Orleans, LA and the first speaker, Entergy Services business systems manager Bob Olsonoski, said "We're not against LEDs. We just don't know what to do with them. We don't know how to price them yet." Olsonoski likely felt like the Lone Ranger through the remainder of the event because LEDs were central to virtually every other presentation, and dominated the exhibit hall. Despite higher upfront costs, LED-based solid-state lighting (SSL) is winning in outdoor applications based on energy efficiency and the inherent controllability of the technology. The prevailing theme of the conference was that energy savings will escalate significantly through more efficient LEDs, better lighting that can be operated at lower levels, and standards and technologies that minimize over-lighting.

The IES limits the exhibit area to 50 booths and around ten companies took dual booths so there were even fewer companies displaying products. One booth included induction street lights and one had high-pressure sodium (HPS) street lights. More than 20 featured LED street and area lights. Even exhibitors such as Philips Lighting, Osram Sylvania, Acuity, and Cooper that sell legacy lighting products only exhibited SSL.

Why the focus on SSL? Edward Smalley, the director of the US Department of Energy (DOE) Municipal Solid-State Street Lighting Consortium (MSSLC) and the manager of street light engineering at Seattle City Light, pinpointed the reason. Smalley showed a graph from the DOE's latest SSL Multi-Year Program Plan (MYPP) (www.ledsmagazine.com/press/31338) that charts luminous efficacy against time for various light sources (Fig. 1). While efficacy is slowly increasing for HID and fluorescent sources and has been for 70 years, SSL (both LED and OLED) is on a steep ramp.

Exhibit hall at SALC (courtesy of the Illuminating Engineering Society of North America; Bob Horner, photographer).

Today HPS and low-pressure sodium (LPS) sources are still more efficient than SSL. But that advantage won't last long. Moreover, adaptive controls and dimming can deliver energy savings for SSL relative to HPS and LPS sources. And as we'll discuss shortly, broad-spectrum LED light is simply a better match for the physiology of the eye than are HPS and LPS sources. These were all prevailing themes at SALC.

Of course SSL still has to overcome steep upfront cost, although that premium is certainly dropping rapidly. John Curran, president of LED Transformations, presented a graphic that precisely describes the LED value proposition (Fig. 2). It's the combination of long life and energy efficiency that provides the LED value proposition.

Improving LED sources

Mark McClear, global director of applications engineering at Cree, discussed the state-of-the-art in LED components and the near-term outlook for improvements.

MAURY WRIGHT *is a Senior Technical Editor with LEDs Magazine.*

Cool-white LEDs at 6000K CCT (correlated color temperature) are readily available with an efficacy of 160 lm/W. McClear said that a luminaire design typically suffers a 10% loss due to thermal issues, a 10% loss due to optics such as lenses, and a 15% loss due to driver efficiency. So cool-white luminaire system efficacy is a bit over 100 lm/W.

At the other end of the LED CCT spectrum, 2700K warm-white LED efficacy is 115 lm/W, resulting in a system efficacy of around 75 lm/W. McClear said, "I really like the 4300K and 4100K LEDs." At 4100K system efficacy is 93 lm/W and that CCT is preferable for many people relative to the 6000K LEDs that have more blue energy in the spectral distribution. McClear said the cooler temperatures work better from an economic perspective because you can use fewer LEDs in a luminaire design.

McClear and others including the DOE expect a continued increase in efficacy. McClear pointed out that the first DOE MYPP projected an efficacy plateau at around 150 lm/W. That plateau has been moved to 250 lm/W in the latest MYPP update issued earlier this year.

McClear said that LED luminaire efficacy has improved from 50 to 90 lm/W, at maximum drive current, over the last six years (Fig. 3). He projected system efficacy for sources in the 4100K CCT range to hit 120 lm/W within the next two to three years. He added, "LEDs will be the most efficient light source available."

It's also noteworthy to mention that prices are dropping at the same time that LED components are improving and volumes are increasing – a recurring trend in the semiconductor industry. McClear said, "The semiconductor industry has always been a massive solution looking for a problem." The message is that the same juggernaut that delivered cheap PCs and cell phones will drive lighting going forward, and the escalation in LED manufacturing has begun. McClear said that more MOCVD (metal-organic chemical vapor deposition) reactors, used for epitaxial growth in LED manufacturing, have been installed in the past two years than existed previously.

The fact is that LED cost has already diminished significantly in terms of the bill-of-materials (BOM) cost in luminaires. According to McClear, LED cost accounted for around 70% of the BOM in 2008 and has dropped typically to around 25%. The driver is now the biggest part of the BOM, but McClear said, "The driver community is now just as engaged [in SSL] as the LED community." And the drivers are largely comprised of semiconductors so prices should drop as efficiencies increase.

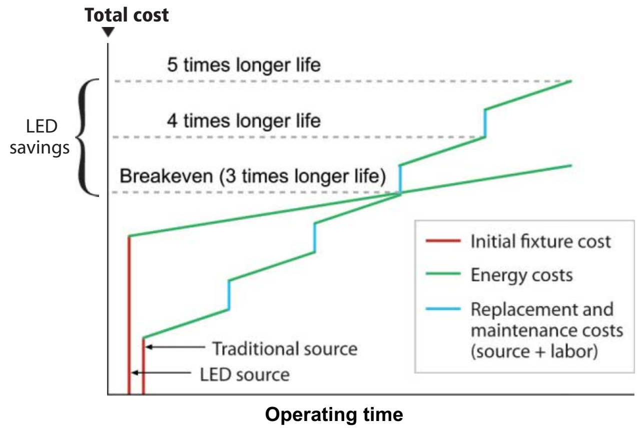


FIG. 2. Long life and energy savings justify SSL deployments (courtesy of LED Transformations).

CCT and broad-spectrum light

While McClear had noted the economic advantages of cooler CCTs, other speakers described the benefits of white light with a broad spectral distribution – typical of today's LED sources. Ron Gibbons of the Virginia Tech Transportation Institute, said, "White broad-spectrum light may provide equivalent task performance at lower illuminances than a less-broad source." Gibbons presented a graph that depicted the luminosity function of the human eye both for bright photopic and dark scotopic conditions. And he showed the energy peak of a LPS light that falls almost completely outside the spectrum of scotopic response by the eye at night.

Across CCTs that range from 3500K to 5000K Gibbons showed that LED sources have significant spectral content in both the photopic and scotopic bands. Gibbons said, "The physiology of the eye lends itself to broad-spectrum sources."

The ultimate goal of Gibbons' research is to determine whether white light sources can be operated at lower levels than have been conventionally required, and still provide driver and pedestrian safety. Indeed many people believe the world is significantly over-lit and reducing light levels would provide direct energy savings.

Of course there are both scientific and emotional challenges to white-light in general and a move to lower levels. Many peo-

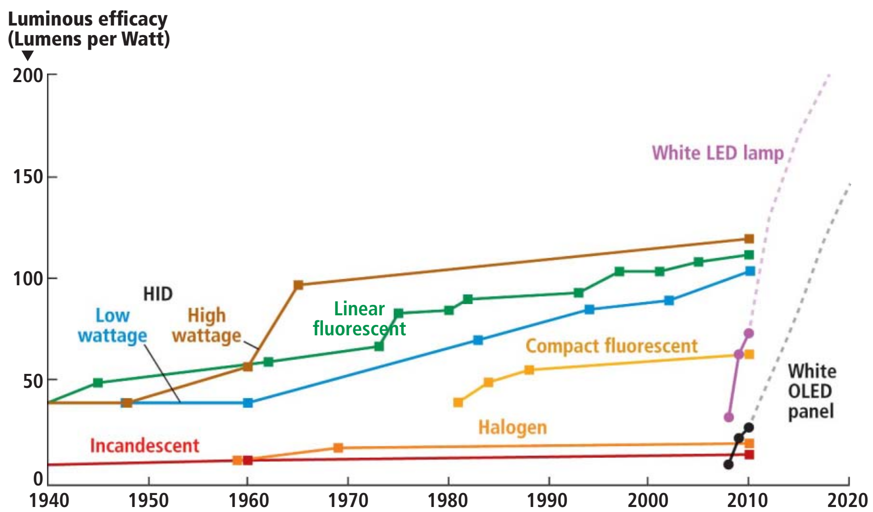


FIG. 1. LED system efficacy is on a steep ramp (courtesy of US DOE).

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ple including several questioners in the SALC audience insist that driving under yellow- and orange-tinted HPS and LPS lights is more relaxing than driving under white lights. Gibbons, however, insisted that every study conducted finds that "people like white light better" although they may not realize it until going through a controlled experiment.

Gibbons also said that white lights render colors better. And color contrast is important in enabling the eye to detect objects, especially in the peripheral vision, he said.

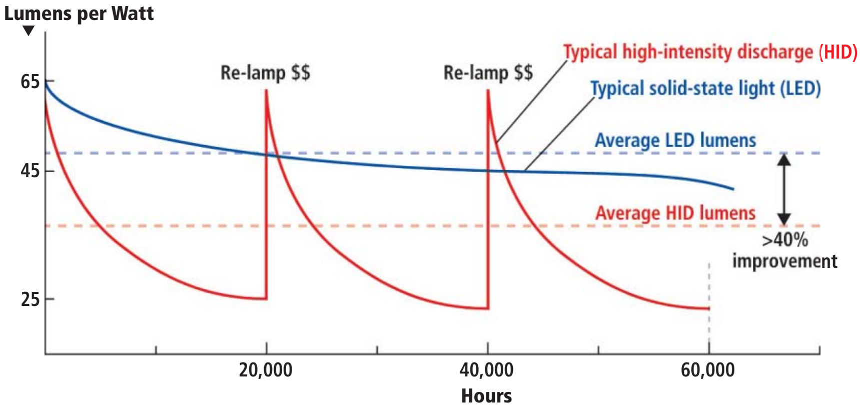


FIG. 4. LEDs offer superior lumen maintenance (courtesy of Kauffman Consulting).

Leveraging light research

Gibbons and Rick Kauffman, of Kauffman Consulting and the chairman of the IES committee working on the latest update to the ANSI RP-8 standard for roadway lighting, both discussed how the research on lower light levels will be applied in the near term. The RP-8 update due imminently will allow for lower light levels in some cases in mesopic conditions (relatively low light levels where the eye combines photopic and scotopic response).

The new standard will specify calculations called Effective Luminance Factor (ELF) and Effective Luminance Multiplier (ELM) that rely on photopic and scotopic luminance values: these are presented in a table relative to various light sources. The math is beyond our scope here, but Kauffman presented a relatively simple example in a case where a light source has a scotopic to photopic ratio of 2 and photopic luminance of 0.3 cd/m^2. In such a case the required minimum light level could be reduced by 16.6%.

There is a caveat to the change to RP-8. For now the standard prescribes that the lower light levels can only be used on streets where the speed limit is 25 mph or less. At such speeds, drivers don't even need street lights according to Gibbons because the headlights illuminate a distance greater than the stopping distance of the car. Street lights in such cases are primarily intended for pedestrian safety. Gibbons has begun another research project that will determine if lower light levels are also safe at higher speeds.

Minimizing over-lighting

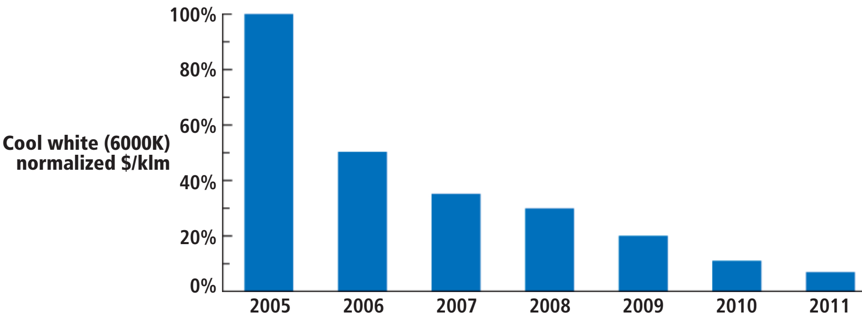
In addition to discussing the ability to reduce light levels, Kauffman addressed the larger issue of over-lighting and wasting energy. We routinely install lights that operate at higher light levels than necessary to compensate for light loss. Lighting specifiers typically calculate a light-loss factor (LLF) when planning a project. The calculation can be quite complicated, said Kauffman, and includes accounting for thermal issues, driver or ballast issues, and even ambient temperature at an installation. But primary factors are lumen depreciation and luminaire depreciation caused by dirt.

The RP-8 standard includes a graph for dirt depreciation factors. For very clean environments the factor can be as high as 0.9 over 8 years. In very dirty areas the factor can be in the 0.8 to 0.9 range for one year but as low as 0.3 over 8 years. Kauffman described DOE tests that have measured dirt depreciation of 3.7% to 5.3% per year but said more testing is needed.

Lumen depreciation is a well-known phenomenon and has been documented for a number of light sources. Ironically many have questioned LED performance over time, but LEDs actually provide superior lumen maintenance to most other sources with only HPS matching SSL. The graph in Fig. 4 depicts the typical advantage LEDs offer in terms of uniformity over time.

The specifier will often utilize a lumen depreciation factor of 0.7 for LEDs essentially tied to the widely-accepted definition of the L70 LED lifetime that describes how long a light will maintain 70% of the initial lumen output. Multiply lumen depreciation of 0.7 by dirt depreciation of 0.9 and you get 0.63 as the LLF. This is used to de-rate lumen output. A 100-lm source would be used in an application requiring 63 lm.

LEDs, however, offer our best chance yet of minimizing over-lighting. Some companies are designing luminaires that slowly increase drive current over time in a way



	2005	2006	2007	2008	2009	2010	2011
$/klm change (y-o-y)		-50%	-30%	-14%	-33%	-45%	-36%
Efficacy at maximum drive current	50 lm/W	50 lm/W	60 lm/W	73 lm/W	78 lm/W	81 lm/W	90 lm/W
lm/W change		0%	20%	46%	56%	62%	80%

FIG. 3. LED luminaires drop in price while efficacy improves (courtesy of Cree).

that matches the projected lumen depreciation curve. And it turns out that L70 may not be the right lumen-depreciation factor with LEDs getting better and the new IES TM-21 standard available to project LED life.

Constant light output

David Baum, director of sales and marketing at Philips Roadway Lighting, addressed constant light output relative to the company's Fortimo linear LED module. Baum compared the Fortimo light with a legacy source and a typical LED source (Fig. 5). The legacy light provides significantly too much light each time it is relamped over time. The legacy LED source provides too much light initially and gradually degrades over time.

The Fortimo design gradually increases drive current over time thereby maintaining the target lumen output – although that also means the power consumption gradually increases as well. Baum showed an example where luminaire system power increased from 26W to 31W over 50,000 hours. But he said a conventional source with comparable light output would require 38W.

In the case of TM-21, meanwhile, a solution to reduce over-lighting may be an unintended consequence. TM-21 was in the works for a long time as we covered in a feature earlier this year (www.ledsmagazine.com/features/8/2/10). The idea behind the standard was development of a mathematical model that allows accurate projection of LED lifetime. LEDs rarely fail over time but rather degrade to the point of being ineffective. That led to concepts such as L70 life. TM-21 provides a way to take the reams of data that are produced in LM-80 LED component testing and produce projections across a range of scenarios.

The details of TM-21 are beyond our scope here, but let's examine the basics. TM-21 utilizes data from a 5000-hour window of LM-80 testing. If a particular LED model has been tested for the requisite 6000-hour minimum required by LM-80, then TM-21 uses data collected from the 1000-hour mark forward. If an LED has been tested for 10,000 hours, then TM-21 data uses data collected from the 5000-hour mark forward.

Rick Kauffman of Kauffman Consulting (courtesy of Illuminating Engineering Society of North America; Bob Horner, photographer).

TM-21 and over-lighting

TM-21 results are reported in hours alongside a descriptor in the form Lxx(Yk) where Lxx is the level of lumen maintenance and Y is the number of hours tested. A rating described by L70(10k) would infer that the LED would maintain 70% of its initial light output and was based on 10,000 hours of LM-80 testing. The TM-21 methodology delivers two results, one called calculated and one called reported. The former is the calculated output of the TM-21 math. The latter is limited to the lesser of the calculated life or 6 times the number of LM-80 test hours. An LED tested for the 6,000 hour minimum can have no greater reported life spec than 36,000 hours.

You can calculate TM-21 results for any lumen maintenance value you desire. For example, Cree's McClear showed an actual example where an L70(10k) test included a calculated life of 290,000 hours. And while TM-21 will be broadly used to project life, here's how it comes into play in reducing over-lighting. The example McClear showed also included a L80(10k) calculated life of 186,000 hours and a L90(10k) calculated life of 94,200 hours. McClear's point is that maybe we should use 0.9 as a lumen-depreciation, life-loss factor rather than 0.7. McClear said "LEDs are unshackled from L70" and the result can be additional energy savings.

Of course the LEDs are only one part of the SSL system-life puzzle. For example, McClear mentioned things like gaskets and paint that may not last 100,000 hours and of course the driver is an issue. Philips' Baum said quality drivers have a maximum life of 100,000 hours. But he said that driver life declines rapidly when case temperatures exceed 65°C.

Adaptive controls and dimming

Not surprisingly, adaptive controls and dimming was a popular topic at SALC since dimming lights during periods of low activity can compound energy savings. And LEDs are dimmable to a fine level of granularity with commensurate energy savings whereas other light sources lack that attribute. The talks included the need for standards, ongoing field trials, and activity on controls within the DOE MSSLC.

Let's start with the MSSLC, which launched a control task force about one year ago. Tod Rosinbum from the city of Portland is a member of the task force and described a wish list that is being molded into a model specification that municipalities and communities can utilize in specifying control systems. The document will be very similar in concept to the Model Luminaires Specification that the MSSLC released in draft form earlier this year (www.ledsmagazine.com/news/8/4/5) and that is due for final release imminently.

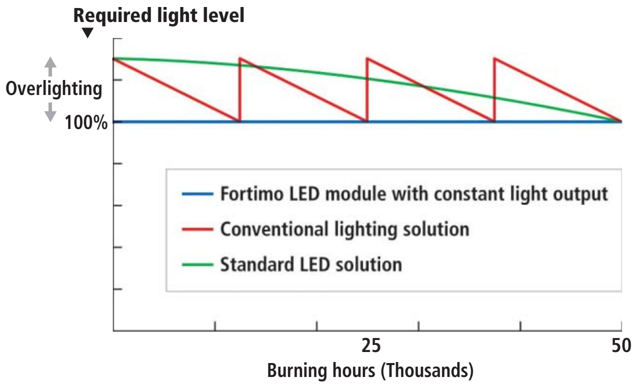


FIG. 5. Constant light output eliminates over-lighting (courtesy of Philips Roadway Lighting).

The controls specification will be released in beta form later this year for review and a final version is due next year.

Rosinbum said on/off, dimming, and scheduled-based control are widely desired by consortium members. The members also want diagnostic capabilities, energy measurement for billing purposes, and automation of the work-order process for repairs. He also said that the membership is universal in wanting to own and control the data in-house. The most complete controls solution on the market today, by contrast, is the Acuity Roam system in which fees for maintaining the system and managing the data are part of the Acuity business model (www.ledsmagazine.com/features/8/2/8).

Michael Poplawski, another controls task-force member from the Pacific Northwest National Laboratory (PNNL), addressed some obstacles and lamented the lack of network standards that can be used in a wireless network. He noted that Zigbee is a possibility but as we covered last year, Zigbee doesn't include the definition of a complete protocol stack or a layer specific to the lighting application (www.ledsmagazine.com/features/7/11/13). Poplawski also noted that work needs to be done to

The combination of controls and baseline LED efficiency appear to be the right match for broad deployment of SSL.

ensure that different luminaires operate similarly when dimmed. He showed a graph of the performance of three luminaires that revealed noticeable differences in light level and power consumption when set to the same level by a 0-10V controller. But he said that operation could be normalized with standardization.

Roadway reclassification

Laura Stuchinsky heads the controls task force and is also managing a pilot controls project in San Jose, CA where she serves as the sustainability officer in the city's Department of Transportation. San Jose has been a leader in trialing control technology and dimming. Indeed the city's work has been seminal in pushing the concept of reclassifying roads at night so that light levels can be reduced. Table 1 shows an example where light-level is reduced by as much as half later at night when there is little pedestrian activity.

Ron Gibbons of Virginia Tech Transportation Institute (courtesy of Illuminating Engineering Society of North America; Bob Horner, photographer).

San Jose had previously worked with Pacific Gas & Electric (PG&E) to negotiate a lower fixed tariff for LED lighting. The city subsequently asked for even lower rates based on operating the lights at reduced levels during portions of the night. PG&E didn't offer to lower the rate now but agreed to participate in a 3-year pilot program.

The utility mandated that the luminaires include a power meter with 2% accuracy. Moreover PG&E has insisted that the metering include the power consumption of the control electronics – not just street-light power. San Jose must also monitor the power used by the wireless gateway that connects to a group of lights. San Jose's work is being used as a guideline in the development of the MSSLC controls specification.

The combination of controls and baseline LED efficiency appear to be the right match for broad deployment of SSL. And there are more savings coming through better LEDs. There is also more potential for savings in system design. Earlier this year, Tom Geist of the Electric Power Research Institute (EPRI) contributed an article to our publication on LED street-light field trials, and at SALC presented some additional data. Geist said EPRI has documented energy savings in the range of 25-70% in different trial installations. But he added that there is other low-hanging fruit in terms of savings. He said driver-efficiency improvements, temperature compensation in fixtures, and better quality control by fixture manufacturers could deliver more than 10% in additional savings.

Street classification		Avg. lumin. (cd/m²)
Street	**Pedestrian area classification**	
Major	High	1.2
	Medium	0.9
	Low	0.6
Collector	High	0.8
	Medium	0.6
	Low	0.4
Local	High	0.6
	Medium	0.5
	Low	0.3

TABLE 1. Light levels are allowed to drop by half as pedestrian activity wanes at night.

Also it's important to realize that LEDs are being held to a higher standard. A couple of times during Q&A sessions at SALC audience members asked why there is no standard such as LM-79 with which legacy lighting must comply. Smalley of the MSSLC said, "We are asking more out of LEDs than we ever have of HID."

Quantum dots unleash high-color-gamut performance in LED-backlit displays

Quantum-dot technology can be used in LCD BLUs to create an optimized spectrum that enables brighter, more-efficient displays with vibrant colors, writes **JASON HARTLOVE**.

LCD technology has made great progress in the past few years, with innovations such as high resolution and 3D, yet color performance continues to lag. Displays on popular tablets can only express about 20% of the color a human eye can see; for HDTVs this is still only 35%. Surprisingly, color performance in displays has actually gone backwards since the days of CRTs.

Still, LED-backlit LCDs have become the standard for the mobile-device and TV industries, due to their high resolution, low cost and thin form-factors.

While new technologies with better color capabilities have emerged in recent years, such as discrete RGB LED, YAG with red phosphor, and OLED, they face critical hurdles to mass adoption – primarily cost, scale and brightness. Until now, consumers have chosen cheaper, thinner and more efficient displays over a truly cinema-quality experience- but could they have it all?

What's wrong with my current display?

To better understand the limitations faced by current TV and display makers, let's take a look inside an LCD. For those who are not familiar, a typical LCD is made up of essentially two major parts: a light source, called the backlight unit (BLU) and a liquid-crystal module (LCM).

Usually, when a display is operating, the BLU is on, providing a uniform, white sheet of light behind the LCM. The LCM contains millions of pixels, each of which is split into sub-pixels, typically with two green sub-pixels, one red and one blue. By controlling the amount of time each sub-pixel is open – i.e. allowing light to pass through it – and making use of the human eye's persistence of vision, any color that can be rendered from a combination of red, green and blue can be displayed at each pixel location. Since the quality or fidelity of those colors is a direct function of the sub-pixel color quality, how good is the quality of red, green and blue light coming from each sub-pixel?

The color of each sub-pixel is a function of two things; the quality of the light in the BLU, and the color filter at the sub-pixel. The color filter will separate its component color from the white light of the BLU, for example, the red color filter on the red sub-pixels will cut off the green and blue light. However, to make a high quality color of red, either the filter function needs to be very narrow, which results in substantial attenuation and loss of brightness, or the red spectrum in the BLU white light should be narrow and well matched to the desired peak red color. The same is true for the green and blue sub-pixels as well.

Since making perfect color filters is not practical from either a cost or brightness perspective, why not make a better white light?

The problem is, the LED light source at the heart of the BLU is starving those filters of the colors that they really need to shine. Today, white LEDs are very good at producing some of the spectrum of light that we see as white – but not all. While there are a variety of approaches for making white light from LEDs, the conventional approaches all suffer drawbacks for LCD displays.

A YAG-based white LED (i.e. an yttrium-aluminum-garnet phosphor pumped by a GaN blue source) produces a spectrum rich in blue wavelengths and with a broad yellow component. This light has very weak green and red content, and the spectrum is widely distributed from aqua-marine through green, yellow, orange and red (Fig. 1). When this light is filtered into the component RGB colors by the sub-pixels, the result is not accurate enough to produce the quality of color we see when we look at the natural world as illuminated by daylight.

So, an ideal light source for an LED-based LCD BLU would therefore be something in between daylight and two-color white. For vibrant colors, it would need to generate lots of energy across all of the red, green and blue wavelengths used by the filters. But, for efficiency's sake, it should also not spend energy producing light between R, G and B because

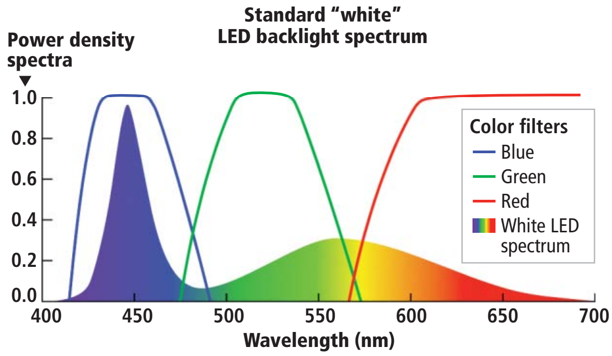


FIG. 1. Spectrum of a conventional white LED (GaN + YAG) backlight, which does not provide a good match with red, green and blue color filters in the liquid-crystal module (LCM).

JASON HARTLOVE *is the CEO of Nanosys (www.nanosysinc.com), a company based in Palo Alto, California that provides architected materials for LED backlighting and energy storage.*

we just won't see that light after it's passed through the filters.

Why quantum dots?

To solve the problems described above, what we need is a new class of material, not found naturally occurring anywhere on Earth, that can be tuned to emit light at just the right wavelengths for our displays and do so very efficiently. Fortunately, nanotechnology researchers have been working on designing just such a material for decades, building it literally one atom at a time, quantum-dot technology consists of tiny, nanocrystal phosphors that are a bit bigger than a water molecule but smaller than a virus in size.

Unlike conventional phosphor technologies such as YAG that emit with a fixed spectrum, quantum dots can be fabricated to convert light to nearly any color in the visible spectrum. Pumped with a blue source, such as the GaN LED, they can be made to emit at any wavelength longer than the pump source wavelength with very high efficiency (over 90% quantum yield) and with very narrow spectral distribution of only 30-40 nm full width at half maximum (FWHM).

The real magic of quantum dots is in the ability to tune (at the fabrication stage) the color output of the dots, by carefully controlling the size of the crystals as they are synthesized so that their spectral peak output can be controlled within 2 nm to nearly any visible wavelength.

This capability makes quantum dots stand out against emerging iterations of YAG phosphor technology such as red-phosphor-doped YAG, which adds some red-emitting phosphor to the green-yellow-emitting YAG to boost color performance. This idea is similar to quantum-dot technology in that it attempts to engineer a spectrum of white light by combining materials with different emission spectra. However, these crystalline phosphor materials are still fundamentally limited by their atomic structure and therefore cannot be precisely tuned to match either existing color filters or manufacturers' desired specifications. This leaves display manufacturers with a system that still results in light and efficiency losses due to the relatively-wide FWHM output of the phosphors and poor conversion efficiencies and stabilities of red phosphors.

With quantum-dot technology, display designers will have the ability to tune and match the backlight spectrum to the color filters (Fig. 2). This means displays that are brighter, more efficient, and that produce truly vibrant colors.

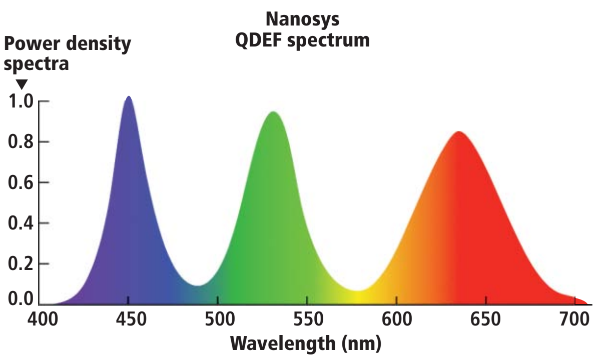


FIG. 2. Spectrum from a Nanosys quantum-dot enhancement film (QDEF). The film contains yellow- and red-emitting phosphors and is stimulated by a blue GaN LED.

How does it all come together?

Engineering the quantum dots to precise display-industry specifications isn't enough on its own to revolutionize the way LCDs are experienced. The dots need to be easily integrated into current manufacturing operations with minimal impact on display-system design if they are to be widely adopted. To do this, Nanosys spent a lot of time working with major display manufacturers to get the packaging just right so that it would be a simple, drop-in product that did not require any line retooling or process changes. The end result is the quantum-dot enhancement film (QDEF) – see Fig. 3.

Designed as a replacement for an existing film in LCD backlights called the diffuser, QDEF combines red- and green-emitting quantum dots in a thin, optically-clear sheet that emits white light when stimulated by blue light. (Of course, some of that blue is allowed to pass through to make the B in RGB at the LCM). So manufacturers who've invested billions in plant and equipment for LCD production can simply slip this sheet into their process, change their white LEDs to blue (the same LEDs but without the phosphor) and start producing LCD panels with the colors and efficiencies of the best OLEDs, at a fraction of the cost.

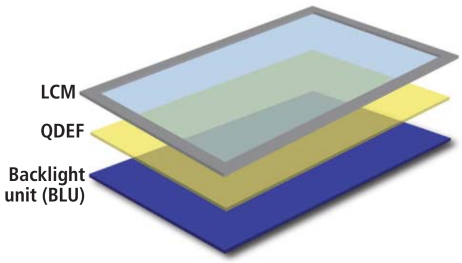


FIG. 3. The quantum-dot enhancement film (QDEF) from Nanosys is designed to replace the diffuser in an LCD backlight unit (BLU) and is placed between the BLU and the liquid-crystal module (LCM). The QDEF contains red- and yellow-emitting quantum dots and is illuminated by blue LEDs in the BLU.

Nanosys is currently shipping production samples to display manufacturers and is on track to begin producing at commercial volumes by the end of 2011.

What does it look like?

A QDEF-enabled display can express over 60% of the spectrum a human eye can detect, compared with 20% for today's LED-backlit LCDs. This means that browsing through photos on your tablet will be more like holding a stack of high-quality, professional prints in your hand and watching a movie on the big screen in your living room is more akin to attending a private screening at a Hollywood studio.

LED-backlit LCD TVs have established market dominance, and sales of tablet computers – which predominantly use LCDs–are expected to eclipse 100 million units over the next few years. Color is likely to be the next big differentiator in what is an increasingly cutthroat consumer-display market as more players enter the market and alternative technologies are further developed.

Displays with better color performance will allow developers and content creators to generate a stunning new visual experience for consumers. Display makers who can bring user experience closer to reality without sacrificing efficiency or cost will be able to establish a dominant market share.

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Indoor Lighting

In the world of LEDs, we see many outdoor lighting applications. But the conditions that LEDs experience indoors are not necessarily as predictable as one might expect. For instance, LED fixtures inside an indoor sports arena face different design criteria than LED luminaires that will illuminate a poultry farm. And other considerations come into play inside a hospital ward or a high-school auditorium. Here we look at how these applications differ and what they share in common. LAURA PETERS reports.

Hospital wards

Manchester, UK-based lighting company MHA Lighting Ltd. has worked with National Health Service (NHS) Trusts in the UK to combat hospital-acquired infection rates by utilizing sealed LED lighting units. MHA Lighting's patented LED technology has been designed as a fully-sealed unit to stop dust, bacteria and deadly superbugs from gathering around warm light fittings. The long LED lifespan, estimated at 60,000 hr, eradicates the needs for routine lamp replacement, which stops harmful bacteria from being distributed into the air.

MHA managing director Tom Harrison said, "Not only is the NHS saving money on operational costs for routine light maintenance, but our LEDs burn 20% of the energy of traditional fluorescents. The Carbon Reduction Commitment on large organizations such as the NHS means for every tonne of carbon saved, hospitals receive GBP12 ($19.50). This money can be directly ploughed back into front-line patient services."

MHA recently completed an installation in North Devon District Hospital in Barnstaple, which is part of the North Devon Healthcare Trust (NDHT). MHA replaced traditional 72W fluorescent lamps with 4000K Tilite 20W and 30W LED units in wards, corridors and reception areas.

Harrison said that MHA uses a reflector system where the LED light is shone sideways and reflected out of the fixture in a uniformly-distributed manner. In this way, he said, the photometric performance of traditional lamps can be achieved while providing the energy and maintenance savings of LED technology.

MHA Lighting also developed a custom dimming solution for NDHT to allow lights to be dimmed down to 5%. It was fundamental for the Trust to create a more pleasant and healing environment where patients and staff are in control of ward lighting levels during sleeping hours, for example.

The Trust reduced its energy usage from 127,910 kWh/yr to 33,044 kWh/yr. With the integration of dimmers, overall carbon-emission reductions have exceeded 75%.

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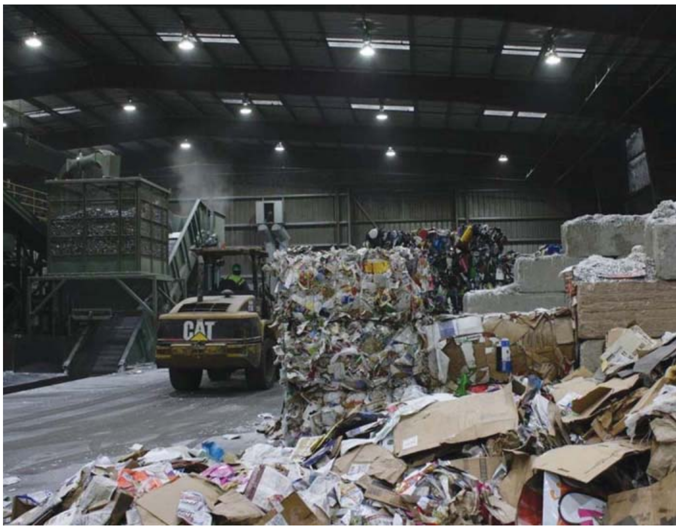
Waste-collection facilities

Waste Connections has installed Xeralux high-bay luminaires in a San Luis Obispo, California waste-collection facility, reducing energy costs by two thirds. Based on Cree XP-G LEDs, the luminaires replaced more than eighty 400W metal-halide (MH) lamps in the company's Cold Canyon



Material Recovery Facility. The company is realizing savings of 260-285 kWh per day via the 148W SSL luminaires – equating to a saving of more than $13,000 per year.

Waste Connections noted the energy savings, maintenance savings, and light quality as benefits of the retrofit. "Our previous lighting technology didn't deliver the high-quality light our facility needed," said John Ryan, Facilities Manager at Cold Canyon. "Now, not only do we seem to have more light, but we also have a brighter, whiter light that is very pleasing."

The 50,000-hour rated life of the SSL products equates to virtually no maintenance costs. Counting maintenance and energy savings, Waste Connections expects to achieve payback in less than three years.

"High-bay lighting has always been a challenge for industrial and commercial property owners, due to its high energy consumption and the high lumen-output requirements," said Jay Shuler, Xeralux VP of marketing.

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Sports facilities

Swedish companies LEDpower and Deltalux AB have developed an LED luminaire for indoor arenas, which has been installed at the tennis facility at Swan Pond in Uppsala, Sweden. LED lighting is used on the tennis court as well as in parts of the offices, corridors and locker rooms. Electricity consumption is estimated at 40-50% of original levels. Sports arenas traditionally use fluorescent lighting, and when lit for 10 hours per day these have a lifespan of 1-2 years, depending on the brand. The LED stadium lights have a lifespan of more than 10 years. "The luminaire design is based on proven LED technology combined with new optical design in a unique chassis as sports facilities need, with the right lighting for dynamic activities," said Michael Niklasson, CEO, LEDpower.

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Poultry farms

Poultry farming places specific demands on lighting systems; for example, the lamps should be waterproof, dimmable from maximum to zero, and capable of operating with high levels of dust and in a temperature range from 25-35°C. The Russian company Reserv

Ltd. has supplied LED lighting systems and controllers that satisfy these strict requirements to tens of poultry houses in Russia.

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High schools

St. Catherine's High School (SCHS), in Racine, Wisconsin, recently replaced 500-watt T4 quartz luminaires with 15 Essentia LED downlights from BetaLED (Racine, WI) in the school's auditorium. According to Mike Kost, director of maintenance for the school, it was inconvenient to access the crawl space to replace burned-out lamps; and the school waited until a number of lamps would burn

out before they went through the replacement effort, sacrificing aesthetics and illumination performance. With the LED luminaires, the school expects 15 years of near maintenance-free operation. In addition, the high school anticipates an 84% energy saving while optimizing the illumination performance and uniformity of the lighting. Richard Hagopian, drama department head, is delighted with the uniform, bright, clean white light. "When the previous lights got too hot they automatically shut off, which would become a problem during an assembly," said Hagopian. "The new LED luminaires produce far less heat [and] provide a significant improvement in reliability and sustainable illumination performance."

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Industrial use

Focus LLC has provided its Kolokol hanging LED light fixtures to SGMK, a Siberia, Russia-based mining, iron and steel company. The LED luminaires, which are used in industrial areas with medium to high ceilings, are manufactured using Nichia 119 series LEDs to provide an output of 7000 lm at 80W power consumption. The luminaire features a minimalistic design and aluminium-alloy casing for suitability in an industrial environment. The IP65 rating guarantees protection of the lamp from damage, and resistance to dust. The installation height is 6 to 20 meters, and built-in drivers allow a high level of electrical protection. The luminaire uses a PG13 plug type for cable diameters of 8-12 mm. The color temperature is 5500K.

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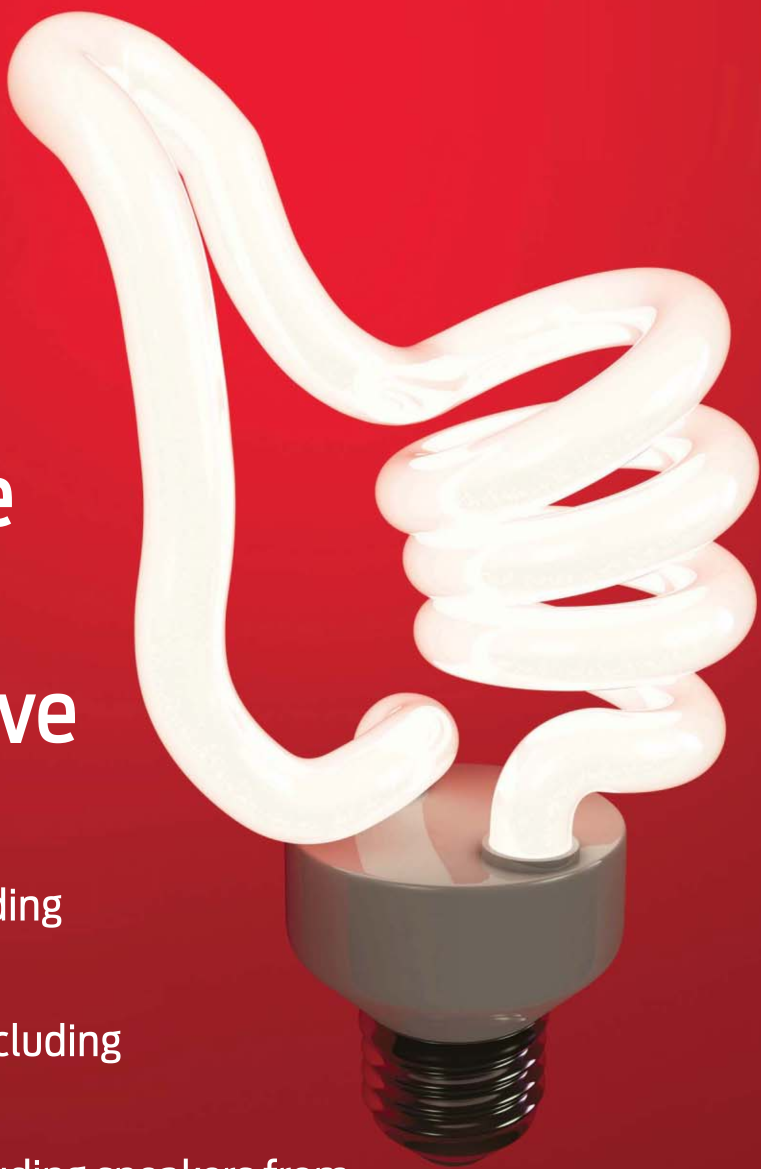

Tunable lenses offer compact solution to combine floodlights and spotlights in one product

A luminaire's beam angle can be flexibly adjusted using a tunable-lens technology in which the shape of the lens can be adjusted, as **JOERG WERTLI** and **MICHAEL BUEELER** explain.

When designing an LED spotlight, components are available that enable many different beam angles. However, because each component usually provides a fixed beam angle, the customer has to decide in the design phase which beam angle (or angles) to use for an installation.

Sometimes it's possible to exchange optics to produce different beam angles. However, this is time consuming and cumbersome, especially as lamps are often hard to access after the installation is completed.

Other solutions are available that enable a variation in the beam angle without exchanging components, but they are inefficient and can be complex. In some cases it's possible to shift the lens away from the LED to focus the beam (up to a certain point). However, rings and shadows typically appear in the spot, and a lot of light is lost as the distance from the LED increases.

On the other hand, large show-lights or even some museum lights are equipped with a zoom lens for spot-size adjustment. As well as requiring lots of space and being inefficient, such zoom lenses are expensive in development and manufacturing, making them unsuitable for mass lighting applications.

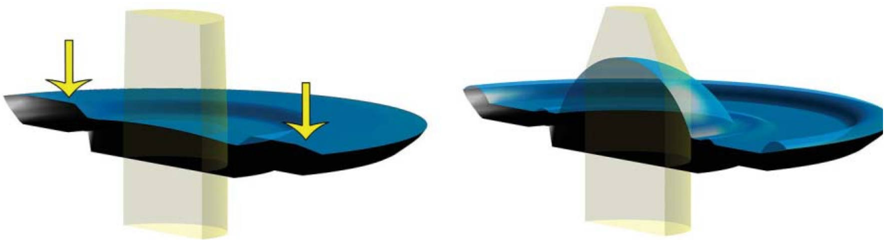

FIG. 1. Working principle of the tunable lens. Twisting the lens-shaper ring (left) applies pressure to the liquid-filled central container, causing a spherical lens to form (right), which reduces the beam angle.

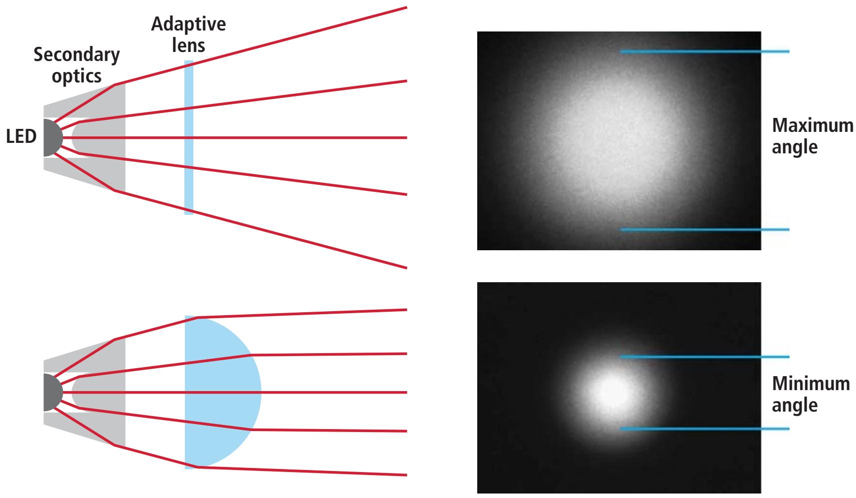

FIG. 2. Optical design using a tunable lens. (top) The maximum tuning angle corresponds to the beam-angle from the secondary lens. (bottom) The minimum beam angle/spot size results when the adaptive lens is fully tuned.

Tunable lenses

The tunable-lens technology developed by Optotune allows the beam angle to be set on site and to be adjusted whenever necessary. There is even the possibility of motorizing the tuning process for remote-controlled adjustments.

As well as reducing complexity costs by having just one product that can produce a range of outputs, from flood to spot, the tunable lens also offers new opportunities to change the beam angle for different settings, for example in a museum with chang-

JOERG WERTLI *is the Sales Manager and* MICHAEL BUEELER *is the Chief Engineer, Optics & Applications, with Optotune (www.optotune.com), a startup company based in Dietikon near Zurich, Switzerland.*

FIG. 3. ML-25-50 Lumilens tunable lens from Optotune, which has an aperture of 25 mm and an overall outer diameter of 50 mm.

ing exhibitions.

The principle of the tunable-lens technology is outlined in Fig. 1. A ring, or so-called lens shaper, is pressed into a polycarbonate container filled with an optical liquid and sealed with a thin polymer membrane. This causes a spherical lens to form. The focal length of the lens changes in proportion to the liquid pressure. The clear aperture remains constant throughout the whole tuning range.

While being very efficient and compact, this technology allows a flexible adjustment of the beam angle when implemented in a spotlight. Turning a ring controls the movement of the lens shaper into the liquid-filled container and therefore the shape of the lens. A cogwheel in the housing offers the possibility of motorizing this process, enabling remote control of the beam angle.

Optical design

Fig. 3 shows a spotlight design using Optotune's ML-25-50 Lumilens, illustrating the compact design possibilities for a spotlight. The optical design of a spotlight with a tunable lens is outlined in Fig. 2. The LED and the secondary optics define the maximum beam angle. It's important to use secondary optics with an even light distribution for a good tuning result. The tunable lens is then used to focus the beam from the wide flood angle to a narrow spot beam. For the spotlight design presented here, the beam-angle range goes from 40° down to 10°, but this range varies according to the design and optical components used.

Although a very new technology, tunable lenses have been extensively tested in various environments. Based on these results, the expected lifetime of the tunable lens is over 10 years within the operating temperature range of -20°C to 85°C. The lenses are built in a dust-free environment (clean room) and have a protective housing to keep them clean. However, the current products do not have waterproof housings, and are only suitable for indoor use.

The lens in Fig. 3 is one of Optotune's standard products, which has a clear aperture of 25 mm with an outer diameter of 50 mm. The largest lens currently available has a clear aperture of 55 mm, designed for large LED spotlights with lighting power of 2000-4000 lm. Prices for these standard lenses start at around EUR 20-30 depending on the volume and lens size. Technologically, it would be possible to build even larger lenses, or lenses as small as a 2-mm aperture.


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LED DESIGN FORUM

Driving alternate banks of LEDs improves efficacy

A power-management technique that alternately lights one bank of LEDs at a time can deliver greater efficacy for displays and lighting, as **EZANA HAILE** describes.

When a set of LEDs is controlled for a lighting application, LED luminous output versus electrical power is a key specification in determining the quality of visible light. In low-power applications, illuminating an entire set of LEDs simultaneously to achieve the maximum luminous level may not be possible, due to limitations in current source. The control electronics must efficiently manage the power dissipation per LED to produce optimum luminous output from the low-power source. This requires a power-management technique where, in a set of LEDs, only one bank of LEDs is powered for a given time. The design must manage this time interval to achieve the required luminous intensity.

The drive circuit discussed here depends on the fact that the human visual system will discern constant light when an LED is switched on and off above a certain frequency. Generally, a system that lights the LEDs at least 60 times per second (60 Hz) will not exhibit flicker.

In order to determine the number of LEDs in a system, and the number in a bank that must be lit for each given time interval, the circuit designer must first consider the available power and the luminous intensity required for the application. The circuit designer must carefully review the LED datasheet for luminous intensity versus forward-current characteristics, to select LEDs that meet the required intensity level. Once the number of LEDs needed to achieve the required level of luminous output from the application is determined, then the number of LEDs that can be powered at a given time interval is determined by taking the ratio of the total current required for the LEDs and available current, as follows:

Number of LEDs in a bank = total required current for LEDs / total available source current

As discussed above, the circuit designer must consider the frequency at which the bank of LEDs is turned on and off and the specific on- and off-time characteristics. The on time must, at a minimum, be long enough for full illumination of a bank. The off time is limited by the time it takes before the bank of LEDs start to visibly dim. Essentially, the off time limits the number of banks that can be controlled via time-interval management because excessive off times would create flicker.

Flip-flop-based driver

A low-cost implementation of this technique requires a clock source, digital flip-flops to control banks of LEDs, and an OR gate to detect a start condition with a simple on/off switch. Fig. 1 shows a block diagram of a D flip-flop configuration that can control four banks of LEDs.

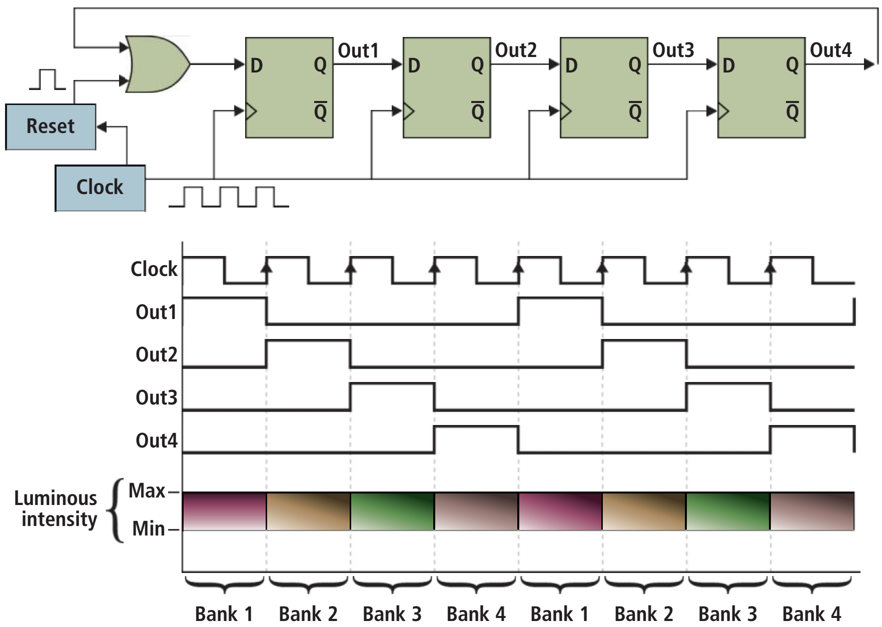

FIG. 1. LED lighting time-interval driven by a flip-flop circuit.

Initially, the flip-flop is in a no-change state and requires a start pulse. The duration of the start pulse must be at least one clock cycle, so that it can be detected by the first flip-flop at the rising edge of the clock. Also, the duration of the start signal must be momentary. It cannot be longer than one clock cycle, otherwise the first two flip-flop outputs will be set at the same time; and, since the source current is limited, the lighting application will not function properly.

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Therefore, with this configuration at the rising edge of every clock, one bank of LEDs is fully illuminated. However, to the human eye it appears as though all LEDs are fully turned on, simultaneously.

The limitation of this implementation is that it is monotonic, and does not provide design flexibility. It only has an on or off state. For some applications, such as LCD backlights, this circuit may be adequate. However, if dimming or pattern generation is needed, a microcontroller (MCU)-based circuit provides the greatest flexibility with minimum impact to the total cost of the solution. The circuit is also simpler to build, with fewer components. The MCU controls each bank of LEDs, and it can also detect user inputs for dimming control and pattern selection.

One example of a cost-effective implementation is to use a low-cost and low-pin-count, 8-bit MCU, such as Microchip's PIC10F or PIC12F family, with an I/O-port expander such as Microchip's MCP23018. I/O expanders can also be useful for driving LEDs, when the lighting circuit is remotely located with respect to the MCU.

MCU and I/O expansion

I/O-port expanders are devices that are used to expand the number of I/O signals to which an MCU has access. In this application, the MCU controls the I/O-expander ports via the I²C protocol, to drive the LEDs on or off. And the MCU's integrated I/O pins can be used to detect user inputs via a push-button switch, or by utilizing the built-in A/D converter (analog-to-digital converter) to detect a potentiometer level for dimming control.

I/O expanders are available with open-drain- or push-pull-output configurations. With today's MCUs operating at 3.3V or lower, an open-drain-output I/O expander lends itself well to this application. The advantage of using an open-drain-output design is that it permits the LEDs to operate at 5V or higher while the MCU and the I/O expander are powered at a lower voltage. Fig. 2 shows a circuit diagram for an open-drain-output I/O expander pulled up to 5V.

In this case, when the I/O port is set as a logical low or zero, then the voltage at the I/O-expander port is 0V and current flows, which forward biases and turns on the LED. The LED-biasing resistor, which also functions as a pull-up resistor for the open-drain output, limits the current to the LED for the required luminous intensity.

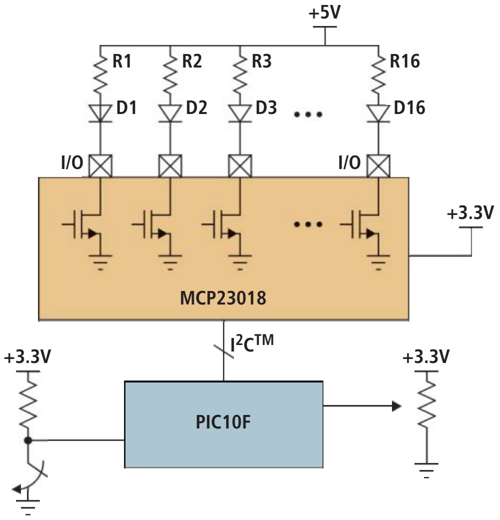

FIG. 2. Low-cost, microcontroller-based lighting solution using an I/O-port expander.

When the I/O-expander output port is set as logical high or 1, the open-drain output is off or high impedance and the voltage at the I/O-expander port is pulled up to 5V by the pull-up resistor. This is an off state for the LED, because current will not flow.

slightly longer duration than the circuit-design calculations would indicate because the next bank of LEDs will turn on prior to the former bank extinguishing. You don't realize that benefit with a push-pull output.

Sharing current

The MCP23018's 16 I/O ports can drive up to 16 LEDs. The I/O expander's output drive capability also limits the amount of current that can be sunk into the I/O port when the LED is fully turned on. The I/O port's low-level voltage is specified for 0.6V maximum at 8.5 mA of current. If the current is higher than 8.5 mA, then the low-level voltage will increase slightly although the impact is negligible so long as maximum current is kept to the specified limit of 25 mA.

Let's consider an example where the total source current is limited to 50 mA at 5V. If you budget approximately 2 mA for the microcontroller, the I/O expander and the resistors for user-input detection, then the rest of the available current can be dedicated for LED lighting. If the luminous intensity

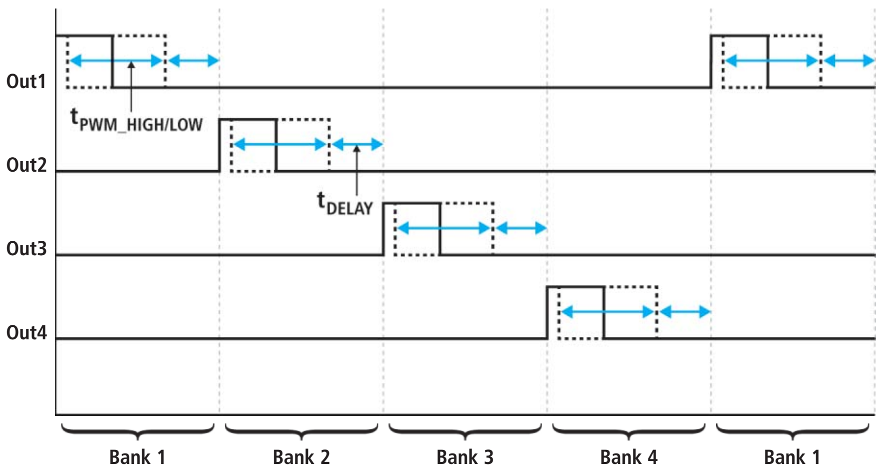

FIG. 3. Timing diagram for PWM control of intensity.

The open-drain-output configuration offers another advantage when the port is configured as high impedance or in the LED off state. The LED does not turn off immediately due to parasitic capacitance. Therefore the effective on time for each bank is extended for a

of the LEDs at approximately 10 mA is adequate, then 4 LEDs can be controlled per bank. And, the current-limiting resistor value will be approximately 440Ω.

The timing shown in Fig. 1 can be replicated using a relatively short MCU program.

An addendum to this article presented on the *LEDs Magazine* website (www.ledsmagazine.com/features/8/10/1) provides details of such an implementation with pseudo C Code that would be used to control the MCU. We will present a simpler description here.

The main segment of the program would consist of an infinite loop. A timer integrated on the MCU generates a periodic interrupt based on the required timing that has been determined in the hardware design stage. Each interrupt would result in the next bank of LEDs being refreshed. With such an implementation, the circuit outputs the required luminous intensity, and to a person it appears that all LEDs are turned on simultaneously from the available power source.

Patterns and dimming

You can easily extend the MCU-based design to add support for light patterns or dimming. The web addendum includes sample code for these concepts as well.

Patterns simply require that the program define a pattern of 1s and 0s for each of the 16 LEDs and that pattern would typically be stored in two bytes of memory. You could easily control a changing pattern by having the MCU monitor a push-button connected to one of the MCU input signals. The example code changes the pattern each time the button is depressed. A predefined look-up table contains various patterns of 1s and 0s for each bank.

Dimming control requires the addition of pulse width modulation (PWM) to control the duration for the on-time interval of each bank. Fig. 3 shows a timing diagram for such an application. The width of the tPWM_High pulse determines the intensity of the LEDs in each bank. The online example uses a thumb-wheel potentiometer with the center tab connected to the MCU's A/D-converter input. At one end of the potentiometer range, the LEDs are set to the lowest dim level and by adjusting the potentiometer the brightness can be increased over 16 steps.

You can further extend the concept and methodology described here to generate chasing and other complex patterns where a single, or small group, of on or off LEDs is varied in a dynamic pattern. Such a design might require a more capable MCU such as Microchip's PIC16F family that has sufficient on-chip memory to handle the program required for sophisticated lighting patterns, such as chasing lights.

While there are many methods to efficiently drive the banks of LEDs used in LCD backlights or lighting-pattern applications, designers are always looking for novel ways to cut costs without compromising performance. In low-power applications, LEDs can be controlled by managing the time interval for each bank of LEDs, for efficient illumination. In addition, low-pin-count MCUs and I/O-port expanders provide a low-cost alternative for lighting solutions with great design flexibility.

LED modules sit at the confluence of numerous technologies

Synergistic electronic, optical and lighting technologies are revolutionizing LED luminaires, says **DAN MCGOWAN**, an Engineering Manager with **MOLEX INC.**

Today's advanced LED lighting technologies can deliver the sustainability, scalability, and design flexibility that OEMs need to help them engineer competitive solutions for residential, commercial and industrial markets for solid-state lighting (SSL). However, despite many advantages, there are challenges intrinsic to LED technologies. For example, while LEDs run significantly cooler than incandescent lamps, without proper thermal management their effective service life can be shortened considerably due to heat build-up within the LED junction. Conversely, with proper thermal management in place, LED fixtures can last an impressive 50,000 hours at 70 percent lumen maintenance under normal usage.

LED emitters typically have been soldered to PCBs and assembled into integrated fixtures, without a mechanism to replace a failed LED or update the LED. This assembly approach poses several challenges to the fixture manufacturer, being closer to an electronics assembly than a typical lighting fixture. Even well-established fixture manufacturers can struggle with light sources that are actually electronic components requiring a secure connection to an electronic circuit. Successfully soldered designs still leave solder joints vulnerable to stress during handling. A cold solder joint can result in scrapping a high-cost LED array.

In effect, the LED lighting industry converged into the electronic-component space, requiring different expertise that did not yet exist. As a result, LED product development was initially slow, because the industry was rightly cautious about investing heavily in fixtures that could not be easily assembled, repaired or upgraded. Fixture manufacturers accustomed to traditional lighting have consistently demanded LED modules that more closely emulate traditional lighting.

To address these practical design issues and needs, some manufacturers have combined their electrical, thermal and optical expertise with in-house design and manufacturing capabilities. The resultant modular LED-lighting solutions introduced onto the market follow a familiar model long used by distributors, who are now able to broaden their portfolios beyond traditional light sources to include LED sources. Advances in electronic technologies are for the first time making LED luminaires practical and affordable for mass production.

One LED-lighting modular assembly that was recently introduced to the market uses a two-piece design that emulates a traditional lighting socket, to deliver an easy and familiar installation experience. The assembly consists of a socket or lamp holder that is permanently fastened into the luminaire. The light module inserts into the socket with a push to make the electrical connections, followed by an intuitive quarter-turn to lock the module in place.

This type of modular assembly allows for different flood-beam patterns that enable precision effects for a wide variety of lighting applications, and users can readily alter the beam angle, temperature or light output without removing or replacing the luminaire. Simply switching out the module (with an easy turn) can lend an entirely new look and feel to a lighting installation design.

With such simple LED-lighting modular designs, interior- and exterior-luminaire manufacturers can achieve LED-based products that require effortless installation, interchangeability and upgradeability. The simple plug-and-play modular solution allows manufacturers to adopt SSL into their luminaires, with a flexible path forward at a low price point. Luminaire designers can also use these types of modular designs to develop products in which the LED source can be easily replaced and upgraded, and do so at price points that offer short payback periods for SSL installations.

Potential applications can include down lights, task or accent lights, spot and track lights, troffers and interior-area lighting, retail and display lighting, hospitality lighting, architectural lighting, decorative lighting, and even museum lighting. Support for the industry standardization of module interconnect technology will help to ensure long-term design opportunities, while protecting the development investment of fixture OEMs and their customers.

As LED adoption progresses, the integration of lighting control systems with network devices will likely play an integral role in energy-cost reduction, allowing end-users greater flexibility and control over their environment. Intelligent lighting controls are already making jobs easier, while lowering the carbon footprint. New commercial, industrial and residential buildings are incorporating local-area networks directly into lighting systems to monitor maintenance requirements, determine occupancy, and offer daylight controls and light dimming systems – yet a few more simple and effective ways for OEMs to harness electronic technology to drive down LED power consumption.

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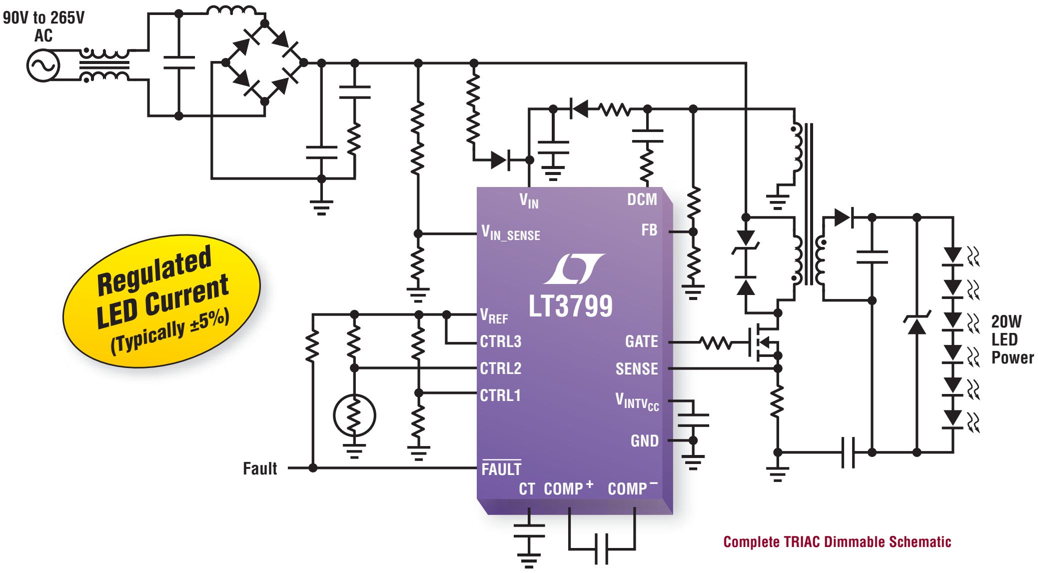
Isolated LED Current Control with Active PFC

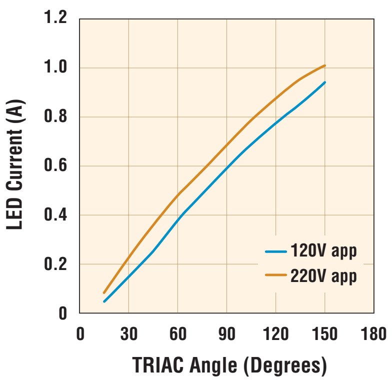


Complete TRIAC Dimmable Schematic

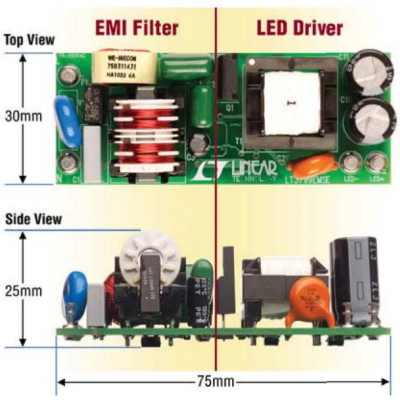
TRIAC Dimmable LED Driver Needs No Opto-coupler

Our LT®3799 isolated LED controller with active power factor correction (PFC) is specifically designed for driving LEDs over a wide input range of 24V to 480V+. It is ideal for LED applications requiring 4W to over 100W of LED power and is compatible with standard TRIAC in-wall dimmers. The LT3799's unique current sensing scheme delivers a well regulated current to the secondary side with no opto-coupler, enabling it to provide ±5% LED current accuracy. It also offers low harmonic distortion while delivering efficiencies as high as 90%. Open and short LED protection ensures long term reliability and a simple, compact solution footprint addresses a wide range of applications.

LED Current vs TRIAC Angle



LT3799 Demo Board (25W)



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