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Cover Story

The new generation of architectural SSL delivers effective illumination with beautiful light quality alongside aesthetic effects (see p. 36; courtesy of Philips Lighting).

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Smart lighting and IoT: Hoax or mandate for lighting manufacturers?

Look on our website every week or in every issue and you will see articles on smart lighting and the Internet of Things (IoT) trend. Most major LED lighting manufacturers have some luminaires in their portfolio with integrated networks and controls, although many still rely on simple schemes such as 0–10V controls. And it's tough to discern who is really serious about smart lighting — as we covered in our report from LightFair International this year, the IoT is winning headlines but quality of light and color rendering are still winning the day in solid-state lighting (SSL) with lighting designers.

So where do lighting manufacturers stand on the issue of networked smart lighting? In an article covering a presentation made by Mike Bradshaw of the IBM Watson IoT team, we described his warning that lighting manufacturers ignoring the IoT trend would suffer the same fate as taxi drivers in the Uber age (http://bit.ly/2dhnekm). The automobile, or the luminaire in the lighting industry, just won't matter anymore.

Still, smart lighting adds cost and the additive energy savings can be called into question. Shonika Vohra, an analyst with the Strategies Unlimited team, poses a number of questions about smart lighting in a column (p. 35).

Yet the IoT allure is clear. As this issue went to press, Philips Lighting announced an extension of its smart-city work with the city of Los Angeles, CA. With the help of Northeastern University, Philips and Los Angeles will trial the addition of microphones on connected street-light poles. The microphones will enable the capture of sound; digital signal processor algorithms will analyze the capture and discern events such as automobile accidents — almost immediately.

Perhaps the indoor space has applications that are a bit less exotic. But when someone such as IBM's Bradshaw discusses what can be accomplished with more sensors, it's hard to argue the value proposition. Or from the lighting manufacturer perspective, is it simply IT attempting to invade their turf?

Bradshaw did describe another interesting example of what might be accomplished in a connected outdoor lighting scenario. Automobiles are also part of the IoT movement. Ultimately, a smart street light might not need an occupancy sensor to detect the presence of a car. A GPS-enabled wireless transmission could inform the street lights as to the auto location. And the street light network may need to communicate with traffic signals to optimize traffic flow.

Lighting products are going to have to communicate with disparate systems. We will have more on that topic in an upcoming issue as the lighting and HVAC industries vie for the smart building reins.

The questions will be: Do lighting manufactures buy the vision, and can they solve the technical challenges of interoperability between systems? Bradshaw advised the lighting industry to find an experienced IoT partner that could deliver scale in terms of connected nodes. Of course, he was ultimately promoting IBM and its Watson platform.

I am far from clarity in my crystal ball viewing. But if I were running a lighting company, the IoT would have a significant portion of my attention — even if it doesn't pay off for several years.

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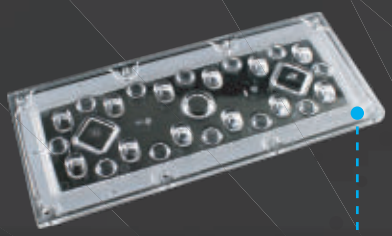

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LL56OS-CEZ55135L51
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Edison Federal 5050 color
Osram Ostar RGBW

Commercial lighting

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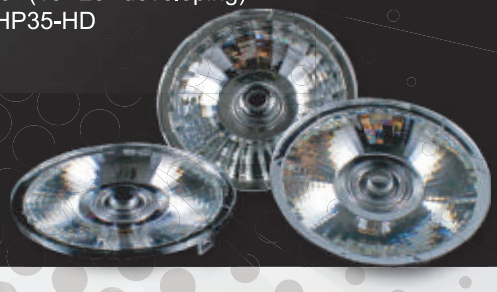

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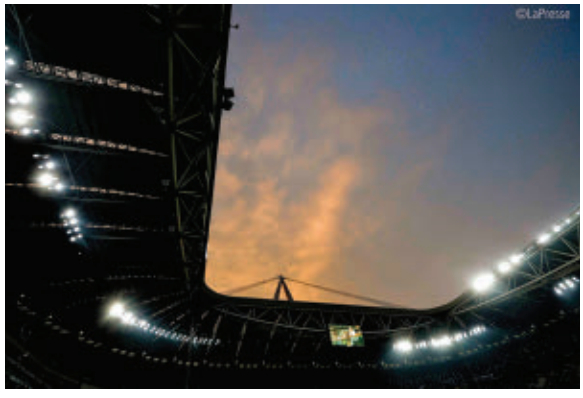
SPORTS LIGHTING

Italian soccer champs Juventus switch to LED stadium lighting



Reigning Italian soccer champions Juventus opened their new season under LED stadium lighting, in a move that supplier Philips Lighting said will support ultrahigh-definition (UHD) television broadcasts. The Turin club installed 396 Philips ArenaVision LED fixtures, replacing high-intensity discharge (HID) luminaires for field lighting.

"The Philips ArenaVision pitch lighting system meets the needs of TV broadcasters and football federations which need high-quality lighting to meet the needs of ultra-high-definition television and superslow-motion action replays," Philips said.

UHD television is a format defined by the International Telecommunications Union that calls for either 4096×2160 pixels (4K) or 8192×4230 pixels (8K). Both mark a big leap from conventional high-definition television. But UHD cameras require high-quality lighting. Philips implied in its announcement that HID does not support UHD.

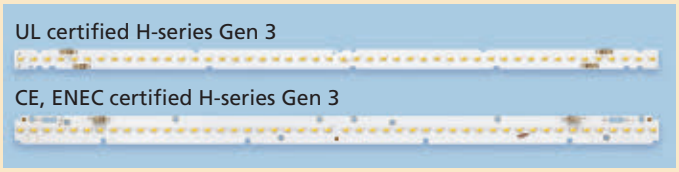
In order to make the ArenaVision LED stadium lighting work with UHD, Philips uses drivers that minimize flickering. Although flicker is undetectable to the human eye, it can nullify the benefit of the high-frame-rate cameras used for UHD. Conventional HID stadium lights generally have too much flicker to support slow-motion UHD, unless they are modified, according to a Philips video (http://bit.ly/2cAi3r8). (Flicker also occurs in general household and office LEDs).

With ArenaVision's flicker avoidance, "The » page 10

LIGHT ENGINES

Samsung ramps performance in level 2 linear LED light engines

The transition by many lighting manufacturers to rely on LED makers to deliver light engines or modules or so-called level 2 products as opposed to LED components is increasingly clear. Targeting that trend, Samsung has announced a third-generation (Gen 3) set of its



H-Series linear modules that luminaire makers can use in products such as integral-LED-based troffers intended to replace traditional linear fluorescent products. The new solid-state lighting (SSL) modules deliver 187-lm/W efficacy in a 4000K CCT; that level of performance means that fixture-level efficacy can hit the 140-lm/W range.

Level 2 products first began to emerge in large volumes about four years ago. Initially, the target customers for such products were second-tier and lower lighting manufacturers that lacked the » page 12

VISIBLE LIGHT COMMUNICATION

New phosphor blend for LEDs could crank up Li-Fi speed

LED-based data speeds could operate 40 times faster than they do today if manufacturers alter the design of the phosphors that convert light from blue LEDs into the white light of LED lamps and luminaires, researchers have concluded.

A team of scientists at King Abdullah University of Science and Technology in Saudi Arabia found that a color converter made from a combination of a red phosphor and perovskite nanocrystals supports visible light communication (VLC) modulation rates of nearly 500 MHz, which they said is 40 times faster than what conventional phosphor material allows.

VLC uses the invisible modulations in LED lightwaves to transmit data via the lightwaves. It is the technology behind Li-Fi, the light-based alternative to radio-based Wi-Fi, for wireless Internet » page 10

Juventus from page 9

camera can capture the smallest gestures and emotion of players for ultrahigh definition," a Philips spokesperson told *LEDs Magazine*. "This allows broadcast also to send ultraslow-motion shots."

In another benefit, the LEDs do not have to warm up before rising to their full brightness, as was required with the HIDs, Philips said.

The ArenaVision lights will also provide an average of 30% energy savings, it noted, although Philips did not emphasize energy savings as a reason for lighting a stadium with LEDs. Rather, it focused on broadcast quality.

Juventus also overhauled the lighting in hospitality and VIP areas to give more control over light settings and atmosphere. The Turin team has won Italy's top league, called Serie A, five years in a row. It switched on the new lights for its first game of the season on Aug. 20, when it beat Fiorentina 2–1.

Juventus is the latest major sports team to switch to LED stadium lighting. Other examples include American football teams the Dallas Cowboys and Arizona Cardinals and US hockey team the Nashville Predators (http://bit.ly/1snNWLk); the Seattle Mariners baseball team (http://bit.ly/1C-MAHW6); and a host of other baseball and soccer team venues. ◄

Phosphor from page 9

transmission. It is also one of several technologies that can be used in lighting-based indoor positioning systems which help track people, products, and assets around factories, stores, workplaces, and other environments (http://bit.ly/2caw0LK).

The red phosphor and perovskite material modulates faster than conventional yttrium aluminum garnet (YAG) phosphor because it has shorter "excited-state lifetimes," the researchers stated.

"The conventional lighting phosphors that are typically integrated with LEDs have limited modulation bandwidth and thus cannot provide the bandwidth required to realize the potential of VLC," the team said in the journal *ACS Photonics* (http://bit.ly/2cLdcZp). "In this work, we present a promising light converter for VLC by designing solution-processed $CsPbBr_3$ perovskite nanocrystals (NCs) with a conventional red phosphor. The fabricated $CsPbBr_3$ NC phosphor-based white light converter exhibits an unprecedented modulation bandwidth of 491 MHz, which is about 40 times greater than that of conventional phosphors."

The perovskite material supports data transmission rates of up to 2 Gbit/sec, the team said. The paper did not state whether that is also up to 40 times faster than the transmission rates of VLC using today's phosphors. But according to Phys.org, 2 Gbit/sec is significantly faster than Wi-Fi, which "can reach speeds of only a few tens of Mbits/second" (http://bit.ly/2d2osQ7).

Supporters of Li-Fi and its underlying VLC technology say that it will add enormous capacity to wireless communications, because the visible light spectrum is 10,000 times larger than the radio frequency spectrum that Wi-Fi uses. They also say that it has a much higher data density than Wi-Fi, and that it is less prone to electromagnetic interference. It does, however, have a shorter range than Wi-Fi.

Li-Fi could become an important artery in the Internet of Things (IoT). Last spring, Germany's Fraunhofer Institute of Telecommunications, Heinrich Hertz Institute (HHI) demonstrated how Li-Fi could help visually inspect cars on the factory floor at an automobile plant (http://bit.ly/1Oe8XMX).

Perovskite is a mineral with potential to improve performance across a range of products including LEDs, solar cells, and photodetectors. ◄

INTERNET OF THINGS

Osram launches business incubator to develop IoT technologies

Hoping to strengthen its fledgling push into digitally connected smart buildings and cities, Osram has opened a business incubator to fund the development of technologies that tie into lighting systems. The new Fluxunit GmbH, which Osram described as a "business accelerator," will invest and collaborate with initiatives both inside and outside the company, including startups.

"Osram has set up a flexible company unit outside its established structures that will promote new and disruptive business ideas," the company said. "At the same time, Fluxunit will serve as the central point of contact for external and internal startups."

Fluxunit is based in Munich near Osram corporate headquarters but on separate premises so that it can "think and act on its own," Osram said. It noted that the new group "will promote the development and implementation of innovative ideas that extend beyond the traditional business of the lighting company."

The new incubator states on its website that "we search for startups worldwide, but are equally interested in teams from the Osram environment." It says it is focused on three areas: smart cities, smart buildings, and industrial applications.

Like other large lighting companies swept up in the "beyond illumination" movement, Osram hopes to reinvent itself as a company that sells Internet-connected lighting services and lighting-based information technology systems, all as part of the IoT.

Traditional companies like Osram, Philips, and GE are positioning LED luminaires and light sources as nodes in networks that, when combined with sensors, will collect information and data that will help run other systems. In buildings, for instance, smart lighting systems can help adjust heating and cooling, can trigger security alerts, and can feed occupancy data to facilities managers to help them optimize room and property usage. In outdoor settings, smart street lighting could help monitor and improve traffic, parking, crime, air and noise pollution, shopping footfall, and much more.

Source: Mark Halper.

Osram's transition away from lamps and toward IT and services has included the

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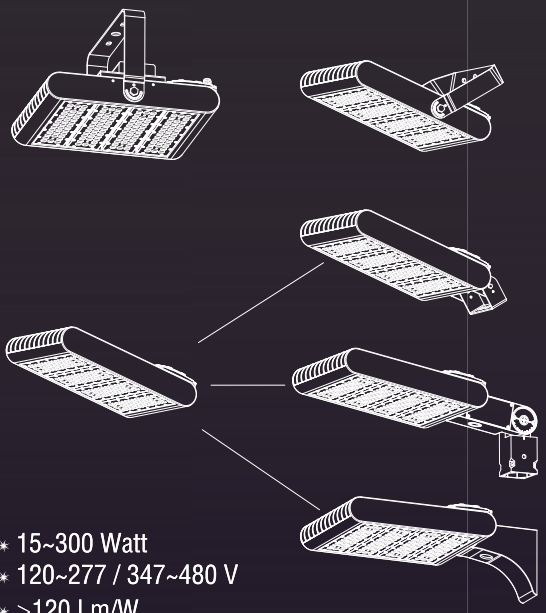

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recent sell-off of its bulb operations, now called LEDvance, to a trio of Chinese companies (http://bit.ly/2cgIqoW).

In one ongoing smart lighting initiative, Osram is developing a lighting-based indoor navigation system. The technology, called Einstone, embeds Bluetooth beacons inside ceiling luminaires and sends signals to smartphones (http://bit.ly/1R5Y3tY). It has many potential uses. Retailers could guide in-store shoppers to discounts, for instance.

Osram also recently showed a rudimentary energy monitoring prototype intended to help take real-time measurements of all electricity-consuming systems in a building, be they lighting, information systems, heating and cooling, or others (http://bit.ly/21qrzAd).

Fluxunit will work closely with Osram's innovation and strategy department, Osram said. That presumably includes an Osram group called Innoventures, which has been developing Einstone.

For all of the general industry talk about IoT lighting and moving beyond illumination, it is still early days. Osram itself suffered a setback in July when a security researcher revealed vulnerabilities that potentially allowed hackers to take control of Osram's Lightify smart bulbs for the home and office, as our sister publication *Lux Review* reported (http://bit.ly/2cpDoUs).

Recent industry-wide developments have indicated that more "traditional" LED advantages, such as energy savings and design continue to drive the market. Mass-market retailer Target has also pointed out that IoT devices (such as LED lights) must do a better job of communicating with each other if the IoT market is to take off (see below). ◄

Target's IoT reality check: "It's less than awesome"

The IoT represents a radical new future in both work and lifestyles, but general adoption of billions of digitized objects — including Internet-connected lamps — won't happen until they all speak a common language.

So warned a top innovation executive at Target, the mass-market retailer poised to sell many of the net-linked LEDs and myriad other objects into the consumer market.

"While we strongly believe that one day the IoT industry will change everything about how we live (even inside our bodies) — it's still early," noted Gene Han, Target's vice president of consumer Internet of Things, and the head of its San Francisco innovation office. "Mass adoption is not happening yet. And, speaking candidly, we're seeing first-hand that a lot about IoT is simply less than awesome."

Among the reasons why consumers aren't flocking to the concept: While the universe of things that can link together is as wide as the imagination, the things don't all necessarily talk well to each other.

Han did not single out lighting. But with the LED industry positioning the IoT and all of its smart lighting potential as a primary driver of revenue in a world where bulbs will last decades and thus rob the industry of continual replacement sales, his cautionary words should remind the lighting industry of the importance of compatibility with other devices and systems (http://bit.ly/1LhU23u). A set of smart LED bulbs that are intended to trigger action in, say, a home heating system or a home security alarm won't serve their purposes if the systems fail to communicate.

"Everyone in IoT knows interoperability — that is, all these gizmos actually connecting to each other — is the sticking point," said Han, whose San Francisco group tests IoT devices and systems and evaluates their readiness for the market. Han runs Target's Open House in the city, which offers consumers hands-on testing experience with connected living.

"Across the thousands of startup products we're seeing, many are trying to become a platform unto themselves," Han said. "And we can't blame them — platforms create incredibly defensible positions. But we need to get more creative about how we think about platforms. Proprietary communication protocols that make it difficult for other devices to connect to each other? These don't help the consumer. We don't have to all hold hands and sing Kumbaya, but we do have to proactively adopt standards that will help the consumer."

As *LEDs Magazine* has written, this digital Tower of Babel has given rise to a number of companies such as Mivune (http://bit.ly/1Uz8ICp) and Mozaiq (http://bit.ly/21qrzAd) that are one way or another trying to smooth the communications between IoT-connected LED light sources and other devices and systems.

Han pointed out that other factors holding

Modules from page 12

financial resources to build out automated assembly lines that could work with surface-mount devices (SMD) such as mid-power packaged LEDs. Lumileds, for example, was an early mover in the level 2 space and had mentioned the technology as a necessary vehicle for the transition to mid-power LEDs and eventually to LEDs in a chip-scale package (CSP; http://bit.ly/1foX4lz).

Today, however, many tier 1 lighting manufacturers build some parts of their portfolio around level 2 modules. The lighting manufacturers gain in the time-to-market race and the LED manufacturers deliver top-quality modules in popular form factors.

Samsung first announced its H-Series modules back in 2013 (http://bit.ly/2czg2yI). The products were then promoted as being Zhaga compliant — an element not mentioned in the latest news release. The original H-Series products topped out at 145 lm/W at a 5000K CCT.

Samsung offers several module series that are each optimized for a specific target such as low-cost products or commodity segments. The H-Series is the high-performance module offering from Samsung and targets the most demanding applications.

The H-Series of modules uses the Samsung LM561C mid-power LED — itself a third-generation product — that was announced early this year (http://bit.ly/1PK7qUJ). That LED enabled Samsung to deliver 18–26% improvements in efficacy over earlier level 2 products.

Samsung offers the H-Series in three sizes — 1, 2, and 4 ft. There are two sets of products for different regions of the world. Products for the North American market have UL certifications while products for the European market have CE and ENEC certifications. ◄

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back the IoT at this early stage include: It's expensive; it's not always easy to set up out of the box; and it does not always have a clear relevance to the consumer.

Meanwhile, the immaturity of the IoT has not stopped Target itself from trialing lighting-based indoor location systems in about 100 stores. As *Lux Review* has reported, Target is sending signals from LED ceiling luminaires to shoppers' smartphones to help guide the customers to promotions that might be of particular interest to that shopper, based on personalized information Target has collected through the customer's loyalty scheme (http://bit.ly/1JgkvCs). It's one manifestation of the IoT in which Target and other retailers see tremendous potential for customer engagement. ◄

GE outfits Walmart, Sainsbury's with LEDs, but where's the IoT?

Although the LED lighting industry likes to portray itself these days as moving beyond illumination into the bold new connected world of the IoT, a raft of announcements from GE's new energy and lighting group shows that some of the conventional messaging of LED's benefits — namely, energy savings — still apply.

The fledgling GE division — called Current, powered by GE — announced no fewer than five large indoor LED lighting installations in August with retailers including mass merchandise titan Walmart, supermarket giant Sainsbury's, and chains The Fresh Market, WaWa, and Brookshire Brothers.

All five extolled the benefits of energy savings — the classic justification for LEDs that is now yesterdays' news. Some also described the aesthetic and illumination improvements that LED light sources provided.

Yet none of them contained a single word about any of the newfangled ideas that Current and other LED vendors are promoting. None mentioned anything about the IoT, or about how the lights will become key cogs in data collection and consumer-engagement schemes.

Lighting networks equipped with VLC and/or other technologies such as Bluetooth are expected to make this happen, especially when they're tied into the cloud and into consumer loyalty schemes, where they can quickly analyze an individual's shopping history, needs, and habits and ping people with relevant messages as soon as they walk through the doors. Current calls it indoor positioning.

If any of the five ballyhooed new retail customers are deploying such schemes, Current is keeping it quiet. We inquired about one of them — the new 40,000-ft² Sainsbury's supermarket and general merchandise store in Leek, England, which is lit entirely by LEDs including GE's Lumination line of suspended and recessed ceiling luminaires, and its Infusion line for accent lighting. A GE spokesperson told us that the new store does not use lighting-based indoor positioning.

"Sainsbury's has partnered with GE to install the latest LED energy-efficient lighting solutions," GE said on the Current website, which claimed that the LED lighting will cut energy usage by 59% compared to conventional lighting and save 180 tonnes of CO_2. It also extolled the uniform light quality from the new lights.

It made similar claims for its other new all-LED retail lighting deployments. GE Lumination lighting, refrigeration lighting, and parking lot lighting will help the Walmart Supercenter in South Euclid, OH reduce energy in line with Walmart's overall goal of 20% reduction in kWh per square foot by 2020. The Lumination series will cut indoor lighting by 80,000 kWh per year in one instance and by 100,000 kWh in another compared to fluorescents; the GE Immersion RV40 refrigeration lighting will save 59,000 kWh annually compared to fluorescents; and the outdoor GE Evolve LED lighting will cut energy consumption by 50% compared to metal halides. GE will roll out the Lumination IS Series to over 200 Walmart stores, saving $34,000 per year in each store.

North Carolina-based upmarket food chain The Fresh Market is in the middle of replacing 64W halogen lamps in over 130 locations around the country with 17W GE PAR38 LED retail lamps, a process that will pay back in two years by saving on average 80,000 kWh per year per store. The more efficient LED lamps are also cutting the cooling bill because they emit less heat than the halogens. The LEDs also last longer, and provide superior color rendering and have less glare, GE and The Fresh Market said.

Mid-Atlantic convenience store and gas station chain WaWa is saving $1.2 million annually across some 600 stores after

installing GE LED refrigerator lighting in its display cases. And Texas-based regional supermarket chain Brookshire Brothers has reduced annual operating costs more than $235,000 in total across some 72 stores in Texas and Louisiana through a mix of new LED and fluorescent lights both indoors and outdoors, including general lighting and refrigerator cases. "The relamping has eliminated more than 3.8 million pounds of CO_2 emissions, which is equivalent to planting 490 acres of new trees and taking 350 cars off the road," GE said.

Those are all impressive numbers. They are also the sort of claims that we have become accustomed to with LEDs. As a marketing message they're not exactly anachronistic. The energy savings aspect of LEDs should never be forgotten. But the more modern concepts of IoT or indoor positioning are conspicuous by their absence.

GE has been rolling out many of the installations over the last several years,

going back as far as 2011, so it's not a surprise that lighting-based indoor positioning doesn't feature in some of them. As early days as the technology is now, it would have been even earlier five years ago.

Still, at locations like Walmart and Sainsbury's with huge customer followings and loyalty schemes, you'd expect some amount of indoor positioning in the lights, especially from a supplier like Current, which touts the concept.

"By unlocking and collecting data from sensors, LED light fixtures make possible an entirely new level of customer service and insight," Current said recently on its website. "GE is creating a family of indoor positioning technology and products that could enhance the shopping experience, increase traffic in stores, drive greater guest conversion from shopping to buying, increase operational efficiency and more."

In another recent post, Current noted, "Intelligent data-gathering technologies that can be integrated into the store's infrastructure have created a host of new channels for customer communication — capitalizing on a growing willingness from customers to interact with brands in-store through their smart devices" (http://bit.ly/2cpOJnC). Those channels include light-to-smartphone communication, it noted.

GE has said in the past that it is trialing lighting-based indoor positioning at a few locations in Europe and in North America. But it has yet to publicly name any installations (one reason could be that retailers might balk at outwardly associating themselves with what some observers dub "spy lights"). Its trials have involved technology from VLC specialist ByteLight, although GE rival Acuity Brands acquired ByteLight in April 2015, so it's not clear to what extent GE still works with them (http://bit.ly/1ED2oP6).

Meanwhile, as previously mentioned, Target has embarked on lighting-based indoor positioning at about 100 stores. A Carrefour store in Lille, France was sampling the technology with Philips, as is Dubai-based retail chain aswaaq (http://bit.ly/1SVVDTt). Other retailers are also kicking the tires. It is not yet generally known if these pilots have been successful.

We hope to hear more from Current soon. Until then, the more things change, the more they remain the same — a tad ironic from a company like Current, which prides itself on the new IoT and energy ethos of connecting things, extracting and exchanging data between them, and thereby improving operations. ◄

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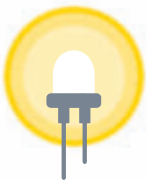

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INDOOR LIGHTING

New Philips LED luminaires show that style still counts

The future of LED lighting might well be in smart, Internet-linked illumination, but certain tried-and-true principles also continue to drive vendors. The latest example: Philips unveiled two new lines of stylish but "dumb" LED table and pendant luminaires lines, showing that design still matters (see our feature on p. 36 for more on indoor lighting).

The New Vintage task lamp series invokes classic and retro looks using metallic materials, while the Smart Volume luminaire family features modern design that plays with light and shade. "Smart" in this case is not the all-seeing, all-knowing smart bulb of the digital lighting movement. Rather, it's smart in the fashion sense of how the luminaire looks.

"We appreciate that it's not just the quality of light that is important, but also the way light is experienced and the choices we make about materials and form," said

Philips Lighting head of design Pierre-Yves Panis. "We have designed each range with a distinctive personality and light effect, so you can choose the one which speaks to your imagination."

Panis could just as easily have made those remarks decades ago in the heyday of incandescent bulbs, and not in today's IoT era of LED lighting. In announcing the two lines, neither Panis nor Philips mentioned a single word about connecting to the Internet or doing any of the digital things that have come to define the industry's future, such as tying lamps in to home security and heating systems, controlling them via smartphones, altering their brightness and color temperature via an app, turning them on and off from around the world, and collecting reams of data in the process.

In fact, the new LED lines do none of that. They have a low IQ by today's lighting standards. For all of the talk about lighting's IoT future, the new luminaires mark the latest in a swirl of recent LED industry developments indicating that vendors are still also empha-

sizing conventional selling points, such as design, and such as the more recent traditional hallmark of LED energy savings.

As previously reported, when Current, powered by GE trumpeted several recent LED installations at retail stores, it focused squarely on energy savings and said nothing about the IoT. Likewise, when the European Union banned certain halogen lamps recently, LED companies took the opportunity to herald the low-energy advantages of their wares (p. 30).

Philips' New Vintage Lamp line includes the Philips Beauvais table lamp, inspired by an iconic 1957 design from Louis Kalff, a Dutch architect who joined Philips in 1925 with the mission of transforming the company's look and branding from an old-fashioned one into a more vibrant image. The line also includes a metallic black- and copper-colored pendant called the Surrey. The contemporary-looking Smart Volume line of pendants (pictured on p. 17) includes a collection of sculpted shapes that together throw light and shade for an aesthetic effect. Philips did not state their material — it appears to be synthetic.

There is one modern LED twist to the new line: Some of the products deploy integrated LEDs, which generally means that the light source is built into the luminaire and thus deprives the user of simply replacing a bulb should the light source fail. The Beauvais desk lamp, for instance, uses an integrated LED. But Philips said the products should last at least 15 years, although it did not state how long the warranty lasts. ◄

CSP LEDS

Seoul Semiconductor expands CSP LED offering and moves to volume production

Seoul Semiconductor has announced an expansion of its CSP LED family that it calls WICOP (wafer-level integrated chip on PCB) and also said that the WICOP LED series that specifically targets general lighting applications is in volume production. The newest product, the 2.21×2.21-mm Z8Y22, delivers efficacy of 210 lm/W at a drive current of 350 mA and produces as much as 358 lm at 700 mA.

Seoul first introduced the WICOP products for general lighting one year ago (http://bit.ly/24d6GvE). But even at that time, the company said it had produced CSP LEDs in volume for markets such as display backlighting and automotive lighting. Product marketing manager Raj Swamy said the company has now supplied the WICOP LEDs into lighting applications including street lights, and that customers are buying both the LED components and so-called level 2 modular light engines that integrate the CSP LEDs (http://bit.ly/2cQGfXa). Indeed, most LED manufacturers have begun to supply level 2 modules as we covered recently and some lighting companies are simply not prepared or equipped to assemble PCBs that use surface-mount devices such as CSP LEDs.

There are now four LED series in the overall WICOP product line. The Z8Y19 products measure 1.81×1.81 mm, the Z8Y15 measure 1.41×1.41 mm, and the Z8Y11 measure 1.14×1.14 mm. Those three products are characterized at 350 mA drive current much like the bulk of high-power LEDs are characterized industrywide. At that drive current, the CSP LEDs deliver 175 lm, 160 lm, and 152 lm respectively. Seoul calls the newer Z8Y22 product a super-high-

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Seoul continues to attempt to differentiate its offering from other LEDs and thus the usage of the WICOP label. As we covered in a feature article, there is no precise definition of a CSP LED, but generally the LED die are not assembled on a lead frame and there are no wire bonds or substrate (http://bit.ly/1QvMEnx). The Seoul WICOP LEDs don't even have the growth substrate attached in the final form. That substrate is removed after the epitaxial process is complete. The finished LED consists of the die, phosphor coating on the top and sides, and two contacts that are constructed on the bottom of the device during manufacturing.

The company says the newest products offer superior performance to other CSP LEDs and other high-power LEDs in general. Of course, the WICOP devices do not include a primary optic and emit light on five sides. But that is typical of CSP LEDs and suits applications such as linear lighting and troffers just fine. Moreover, in applications such as street lights the LEDs are typically placed under a total internal reflection (TIR) secondary optic to form the appropriate beam pattern, so the primary optic is not needed.

Seoul clearly believes that CSP technology is going capture a dominant part of the LED market for lighting going forward. "The WICOP products which have been independently developed by Seoul Semiconductor would render the currently increasing investment in the packaging industry unnecessary, and will become the standard for next-generation LEDs as it is an innovative product that reflects a new wind of change in the LED market," said CTO Ki-bum Nam.

Clearly the barriers to wider usage of CSP technology are dropping. As Seoul's Swamy pointed out, the company has completed LM-80 testing on the three older WICOP series and testing is underway on the newest product. That data suggests that the LEDs are equally reliable, if not more reliable, than mainstream high-power LEDs. And ultimately, CSP LEDs could lead to a resurgence of the high-power sector in general lighting applications where mid-power LEDs have taken over in many applications over the past several years. For more on those LED sectors and markets, see our coverage of Strategies in Light presentations made by the analyst team at Strategies Unlimited (http://bit.ly/23pdqDC). ◄

INDOOR POSITIONING

Philips offers IoT location technologies to other luminaire vendors

Philips has begun licensing its lighting-based indoor positioning technology for other luminaire makers to embed in fixtures, and announced that a French company specializing in the retail and service industries is the first licensee.

Lille-based Trato-TLV Group demonstrated Philips-enabled luminaires in Paris at the Equipmag fair in early September, a bi-annual trade show for the retail industry. Philips, which also exhibited at the Paris gathering, will continue to sell its own indoor positioning systems.

Amsterdam-based Philips uses a form of indoor positioning technology known as VLC, and is targeting the retail environment, among other sectors as we mentioned in an earlier story. VLC guides shop-

pers to in-store discounts by sending information from LED ceiling lights to smartphones via modulating lightwaves that help the customer navigate around the store. The system tailors information to individuals based on their shopping history.

Philips is providing LED drivers that will be available by the end of the year to turn LED luminaires into such smart way-finders, in an OEM initiative called YellowDot. The drivers are the same size as other Philips LED drivers.

"With the YellowDot program, Philips Lighting and its customers are set to capitalize on the fast-emerging market for commercial lighting systems that use indoor positioning," said Simon den Uijl, manager of indoor positioning partnerships with Philips Lighting. "Venue owners such as retailers and malls will have more choice in LED luminaires, which they can combine with the most accurate and scalable indoor positioning system in the market."

The approach echoes the OEM strategy of smart lighting startups such as Gooee and Organic Response (http://bit.ly/2d2JcYi).

The OEM tack marks an extension of Philips' efforts to establish its own VLC luminaires in the retail trade, which on the surface is not yet racking up business. The company announced a trial with a single Carrefour store in Lille nearly a year and a half ago (http://bit.ly/1GJqnTc). But in recent months it declined several times to provide updates on it to *LEDs Magazine*, other than to tersely describe the trials as successful. Philips told *LEDs Magazine* that Carrefour users have reported the system is easy to use and accurate, and that Carrefour has said shoppers are now better informed about promotion availability.

Philips has declined to say whether Carrefour is rolling out VLC to other stores. The Lille trial is located in Trato-TLV's hometown, prompting speculation that Trato might be involved at Carrefour, which is one of the world's largest supermarket chains.

The Dutch lighting giant has officially announced only one other VLC trial, with the aforementioned aswaaq chain in Dubai. It disclosed that project in March and is not providing updates.

In a sign that deployments could start to pick up pace, Philips is helping to outfit the giant CapitalLand Mall in Singapore with VLC, as revealed in a story from *Lux Review* (http://bit.ly/2cydrDR). When *LEDs Magazine* followed up and asked Philips about the report, a spokesperson said that "such VLC implementation in a Singapore mall is in progress, representing a first-time deployment in a mall setting." The installation uses Philips luminaires.

If progress has been slow on lighting-based indoor positioning — a form of the IoT — Philips has not been the only vendor finding it so. Like Philips, GE has for some time been vocal about the great possibilities for indoor positioning. Yet it has never publicly identified a single customer or trial user.

And when LED and indoor positioning specialist Acuity last summer announced a major deal to provide smart lighting and controls to US retail giant Target, it omitted any reference to indoor positioning. "I am unable to comment beyond the Acuity public announcement," Acuity senior vice president and general manager of IoT solutions deployment Steve Lydecker told *LEDs Magazine*. The press release highlighted smart lighting's advantages in controls and dimming that would lower energy consumption and improve operational effectiveness.

Lydecker's reticence was particularly notable because as previously mentioned, Target has been trialing lighting-based indoor positioning at about 100 stores, so it would seem that a new smart lighting scheme would include location-based services. But a Target spokesperson was equally mum, telling us, "We don't have updates to share, nor any additional comments."

Yet Philips insists that the market for indoor positioning in commercial lighting is "fast emerging." The Philips spokesperson added that there is "growing market interest in VLC-based indoor positioning in France."

It could be that vendors and retailers are intentionally keeping indoor-positioning projects quiet. The technology can be

controversial, because it raises questions about shoppers' privacy and data protection. Typical indoor-positioning systems not only follow customers around stores and tap into their smartphones, but can also peer into their shopping history and patterns via databases in the cloud.

Retailers might also be reluctant to publicly reveal technology systems that they believe give them a competitive advantage. In indoor positioning's early days, vendors and stores are trying to establish which technologies to use. Deployments could pick up once the tire-kicking settles down.

While Philips prefers VLC, other vendors prefer to embed Bluetooth beacons in luminaires. VLC offers more accurate location services than Bluetooth does. But as Osram has noted, VLC requires a direct line of sight between a light and a phone, whereas Bluetooth does not (http://bit.ly/1R5Y3tY). Bluetooth also requires fewer luminaires than does VLC, according to Osram, which is developing a Bluetooth version of indoor positioning. The systems share the same goal of guiding people around stores or other venues in a manner tailored to individual needs.

The lighting industry also must compete against other industries. Bluetooth beacons, for instance, do not have to reside in luminaires, and could come from an information technology provider rather than from a lighting company. There have also been hints of intellectual property disputes within the lighting industry over technologies such as VLC. Other questions that might be holding back the technology include whether it works, and whether end users even want it. ◄

RETROFIT LAMPS

Cree relaunches its entire LED retrofit lamp family, targets customer experience

Cree has announced a broad new selection of LED-based replacement lamps with the new products supplanting its existing product line in A-lamps, directional lamps (PAR), floodlights (BR), and even downlight retrofit kits. Moreover, the company has entered the candelabra lamp market for the first time and offers a dim-to-warm lamp in the small, decorative-bulb category. Generally, the company said the new SSL portfolio offers a better customer experience through a better warranty and longer lifetime, and simply by delivering more pleasing light.

It's tough to find the differences in the new versus old retrofit lamps on the spec sheets. The bulk of the new products feature 85 CRI, although there are select models with 90 CRI or better including in the new candelabra family. The new products are rated for 25,000 hours of use and come with a ten-year warranty. Cree was the first company to offer a ten-year warranty on commercial SSL products back in 2012, and has covered some of its lamp products similarly in recent years (http://bit.ly/2cKWpSM). Evidently, that coverage extends to the entire replacement lamp portfolio now.

It appears that Cree has again started from the ground up in its A-lamp architecture. The new products bear no resemblance to the 4Flow Filament Design that was announced initially in 2014 and refreshed in 2015 with a five-year warranty (http://bit.ly/1WLz4PV). We haven't yet had a detailed look at the internal architecture of the new models. The CRI of the latest products offers a modest bump from 83 CRI in the 4Flow lamps.

Cree also said the new retrofit lamps will offer consumers a better price, although we'd expect modest changes there as well. A look at the Home Depot website shows the new and old 60W-equivalent lamps selling in the $5.00 range. Speaking of Home Depot, that retailer will as usual be the first source of the new residentially-targeted Cree lamps.

The most significant element of the new portfolio is probably the candelabra family, given that Cree is new to that space. There are 25W and 40W replacement products in the family, all in 2700K CCT that Cree calls Soft White. All of the products offer 90 CRI or better. And in both power grades, Cree offers what it calls Candlelight Dimming, going from 2700K at full output to 1800K at minimum dim. Moreover, Cree appears to have used some sort of optical

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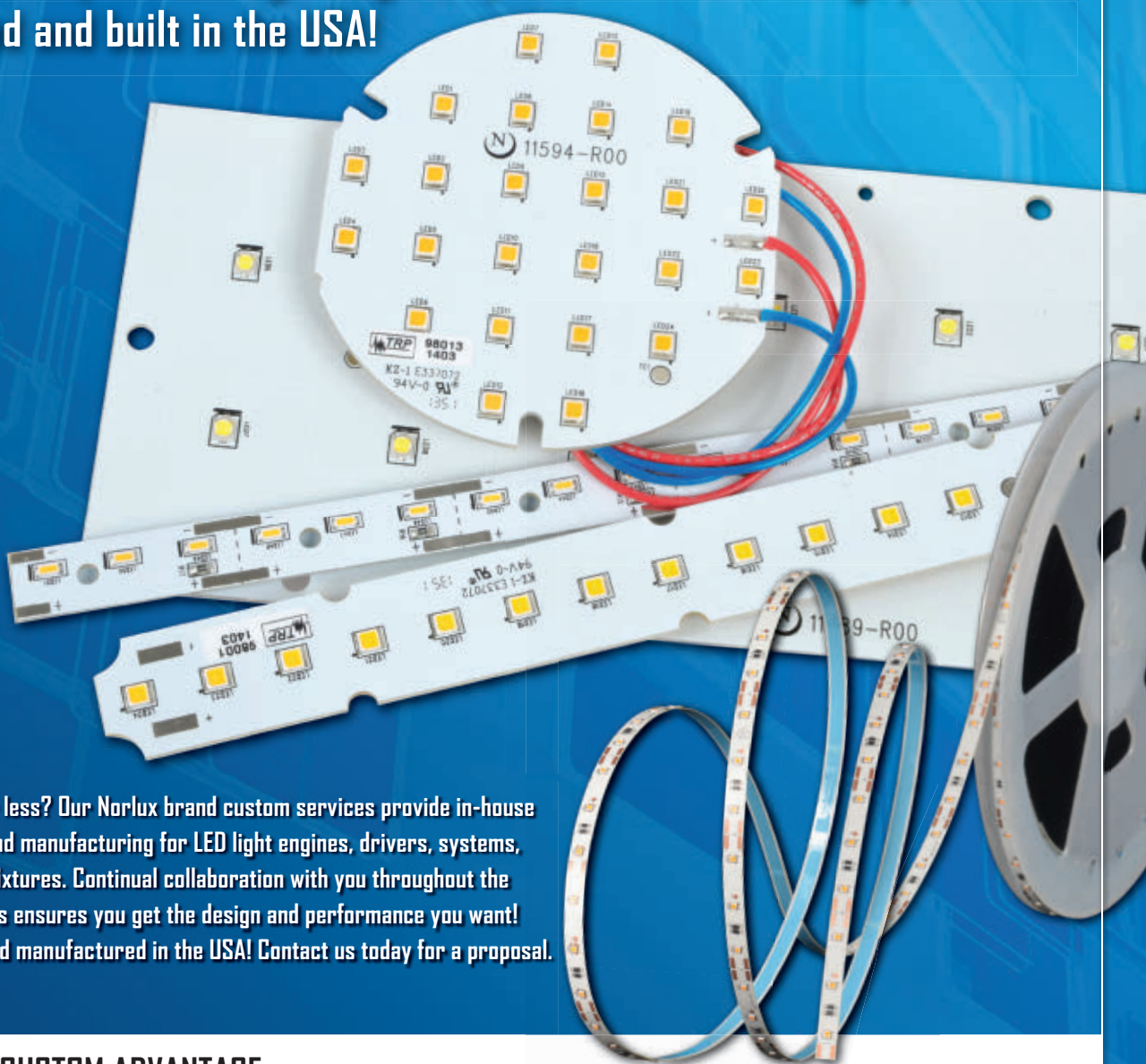

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light guide in the products to make the light source appear more reminiscent of a candle.

All of the new products in the broad announcement appear to meet Energy Star requirements. As you would expect, energy savings are substantial relative to legacy sources. For instance, in the candelabra family, a 40W-equivalent lamp uses just 5W in the Candlelight Dimming or standard version. ◄

Philips Lighting adds sensor and tunable-white LED lamps to Hue portfolio

Philips Lighting has used the consumer-electronics-centric IFA trade fair in Berlin, Germany as a venue to announce a number of additions to the Hue portfolio of LED-based smart lighting technology. New products include an expanded selection of tunable-white SSL retrofit lamps and an improved version of a dynamic-color A-lamp. Moreover, Philips has also added a wireless ZigBee-based occupancy and ambient light

or daylight sensor that can enable Hue systems to react autonomously to people or natural light from windows.

Surprisingly in terms of timeframe and the concept of the IoT, we first covered the Hue technology all the way back in the fall of 2012 when Philips announced the Hue color-tunable A-lamp (http://bit.ly/1DkNMFH). There have been many subsequent Hue announcements including the battery-powered bowl-shaped luminaire launched last year (http://bit.ly/1IJ68Fb). But

perhaps the best indication of where Philips was heading with the Hue portfolio came when the company launched a dedicated ZigBee-based wireless dimmer control (http://bit.ly/1Fd1uyW).

Now the Hue smart LED lighting family includes products ranging from RGB (red, green, blue) strip lights to color-tunable-lamps to tunable-white-point lamps. The latest Hue White Ambiance product line was launched earlier this year and now Philips is adding a GU10 (an AC-line-powered MR16 lamp) to the portfolio. Moreover, the latest wireless dimmer switch can allow consumers to easily set the lamps to a selection of Relax, Read, Concentrate, and Energize modes, all in the ranges of 2200K–6500K CCT.

"The Philips Hue white ambiance lamps enable our customers to experience the benefits of controllable white light — to help feel energized, wind down at night, or simply to set the perfect ambiance to suit their mood," explains Sridhar Kumaraswamy, business leader of Home Systems at Philips Lighting. "With Philips Hue white ambiance built-in, they deliver the high-quality light you need, when you need it, as you go through your daily routines in your home."

Still, the newest element in the IFA announcement is the ZigBee-based sensor. The battery-powered product runs on a set of two AAA batteries for two to three years. The sensor can trigger preset lighting scenarios based on occupancy or natural light. Consumers can simply place the sensors on shelves, adhere them to solid surfaces, or attach them via magnets. The company said a Hue light could respond to occupancy in a space in less than a half a second.

The sensor product will initially be available in Europe by the end of this month. It will sell in the $40 range. And North American availability will come soon after European availability. New color- and white-tunable lamps will be launched in both Europe and North America in the same timeframe. ◄

SMART CITIES

Verizon acquires Sensity Systems in a smart city push that will rely on LED lighting

Verizon Communications has announced its acquisition of Sensity Systems — a company that has focused on networking cities relying on an infrastructure built around LED-based street lights. The companies did not reveal the terms of the deal. The deal will impact the SSL sector with a leader in mobile wireless networks and services gaining access to a proven smart-city and IoT technology suite.

The Verizon acquisition of Sensity Systems marks yet another instance of a large technology/communication-industry player broadening its vision to encompass the lighting industry. For example, we have covered the clear interest of networking stalwart Cisco in the SSL sector (http://bit.ly/1QgdAui). Verizon may even be a better fit in the outdoor SSL sector because its wireless networks are

already being used in some smart-city applications and the company had organically been developing an IoT platform called ThingSpace. Access to the Sensity technology portfolio will enable Verizon to fast-track its IoT effort.

"Sensity is a leading provider of IoT solutions for smart communities with a strong ecosystem of partners, and this transaction will accelerate the deployment of large-scale implementations that will drive the digital transformation of cities, universities, and venues," said Mike Lanman, senior vice president of enterprise products and IoT at Verizon. "Verizon is uniquely positioned through its infrastructure investments at the network, platform, and application levels to provide holistic solutions that empower communities to address their most pervasive challenges."

The Verizon announcement didn't focus specifically on lighting and indeed Sensity has had a much broader focus on the full set of services envisioned for smart cities including emergency services, traffic management, and environmental monitoring. Still, much of Sensity's business has been dependent on LED street lights used as a network infrastructure. And the company has partnered with LED-centric lighting manufacturers such as Acuity Brands (http://bit.ly/20cTCDA).

The acquisition announcement did note that Sensity has capitalized on LED lighting retrofits and that the company has participated in 42 smart-city installations around the globe. And Verizon also said it has already offered lighting-centric services.

In many ways, the mobile wireless infrastructure is a perfect answer to the issue of network choice in outdoor SSL, although obstacles exist. The Strategies Unlimited analyst team contemplated the issues in a recent column (http://bit.ly/2cjM7qv). Moreover, the issue of networking SSL using cellular systems was covered in our feature article on presentations made at Strategies in Light 2016 (http://bit.ly/1Y8jcbe). Some of the potential success will depend on yet-to-emerge upgrades to the mobile wireless networking suite that will carve out lower-speed services for the IoT at lower tariffs relative to what mobile data users pay. Still, the largest rollout of connected SSL technology globally is happening in Los Angeles, CA based on a mobile wireless network (http://bit.ly/1L1tSl4).

Together, Sensity and Verizon believe they can accelerate the smart-city movement. "With Verizon, we look forward to delivering IoT connected systems on a massive scale to change how cities and communities operate around the world," said Sensity chairman and CEO Hugh Martin. "Rapid urbanization is putting a huge strain on city services globally, coupled with inefficiencies caused by an aging infrastructure that currently supports critical functions, such as fire and emergency services, public transportation, lighting, sewer, and sanitation systems. Sensity realized early on that IoT could be the key to breaking out of this dilemma. We have become the leader in the space by creating a visionary smart-city IoT platform and forming a powerful ecosystem of technology partners." ◄

SMART LIGHTING

IBM addresses smart LED lighting, IoT, and Watson at LPS

The LED Professional Symposium (LPS) kicked off in Bregenz, Austria in September, with smart lighting and the IoT at center stage. Mike Bradshaw, IBM sales leader for Watson Internet of Things, shared an IoT vision and the benefits that SSL manufacturers may realize with a solid smart-lighting strategy.

IBM appears to be the latest IT-industry stalwart to identify networked lighting as a prime target as a match for its systems and services. Cisco, for example, has looked at lighting as a key market that will ultimately allow the networking giant to sell more Ethernet switches and possibly services (http://bit.ly/1QgdAui).

In IBM's case, the company that arguably founded the IT sector is looking to expand the reach of its supercomputer architecture called Watson and the cloud-networking platform that is implemented around that computational platform. Watson is capable of what IBM's calling the Cognitive IoT.

This is not the first time Watson has been mentioned in relation to networked SSL. Late last year, IBM and PhotonStar, a UK-based LED-lighting manufacturer, partnered on a smart-lighting installation in the Munich, Germany-area Watson IoT headquarters building (http://bit.ly/1QgdAui). Moreover, that article reported that IBM had committed to spend $3 billion over four years on the IoT division.

At the LPS, Bradshaw cautioned lighting manufacturers to not sit on the sidelines and think that they had no play in the IoT space. To lighting manufacturers about their industry, he said, "If we don't disrupt it ourselves, some young startup is going to come do it for us."

Part of the IoT justification is the projection of the number of devices that will be connected to the Internet. Bradshaw said it is a moving target but some latest estimates peg it at 29 billion connected devices by 2020, up from 13 billion today. And the key to the Cognitive IoT in IBM's vision is the proliferation of sensors that allow gathering of massive amounts of data. Current, powered by GE targets its Predix analytics platform at such applications while acquiring companies and establishing partnerships (http://bit.ly/1SNYFoW).

Bradshaw said supporting data gathering and new applications will enable lighting manufacturers to convert their offerings from a capital expense (capex) to an operations expense (opex), enabling the end customer to pay as they use the service.

Bradshaw gave an interesting example of needing more sensors — say, beyond a simple occupancy sensor in a space. He said occupancy sensors tend to work well when someone enters a space but may later turn off the lighting as a person sits still and works. But a cognitive system that was also connected to a CO_2 sensor in the space would always know that a person is still present.

IBM has selected six specific areas in which its IoT offering could add value, especially in the context of smart lighting. Energy & Costs and Consciousness are easy to understand. And several others will ring true for anyone following the smart lighting movement. They include Health & Wellbeing, Safety & Security, Entertainment, and Convenience. ◄

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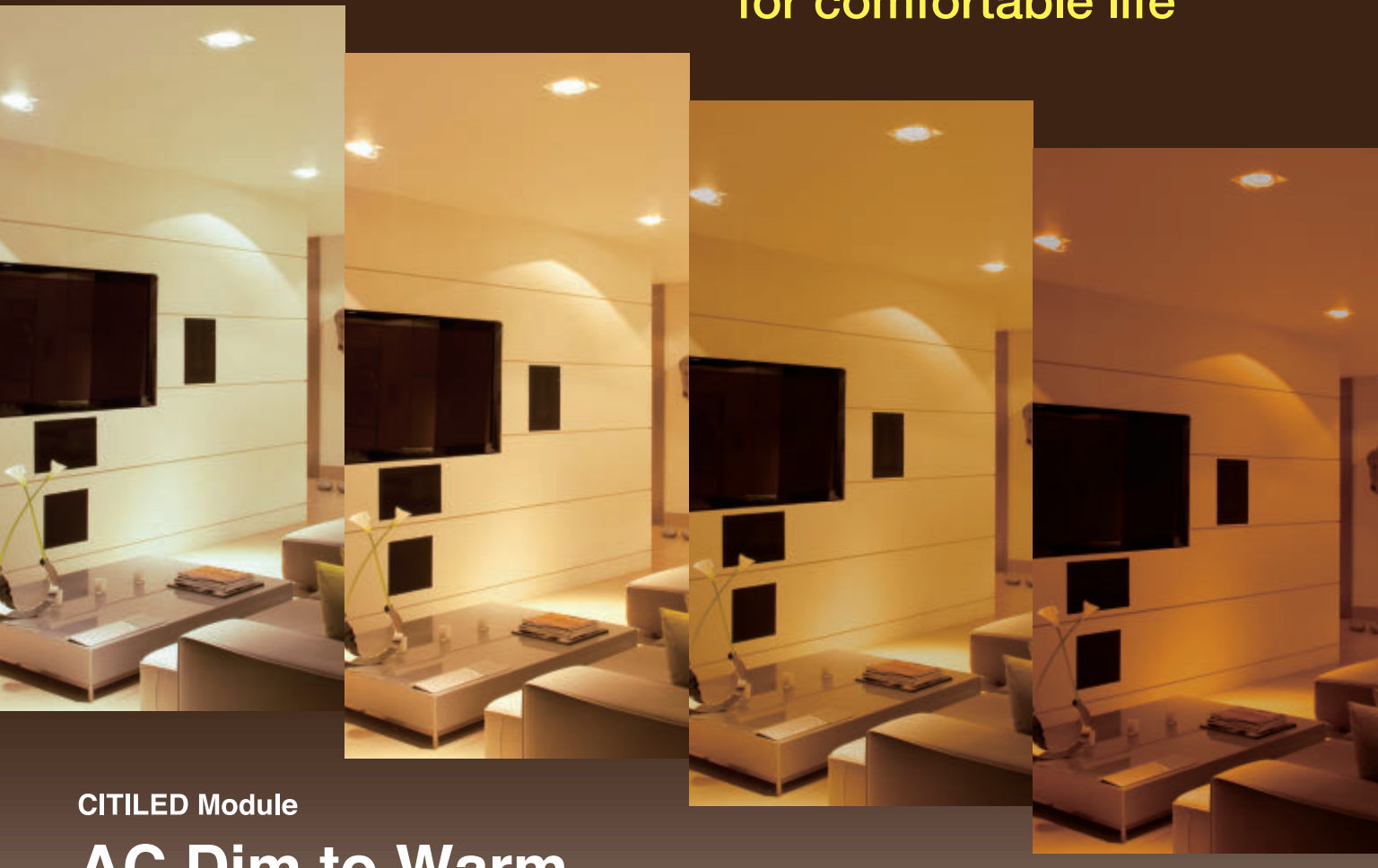

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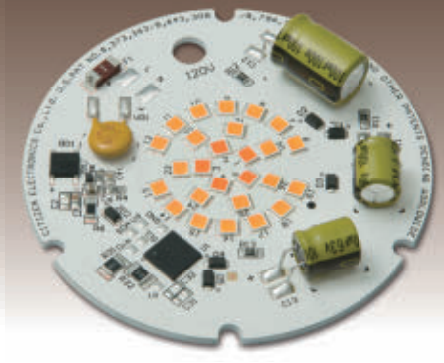

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DOE releases results in Gateway project testing tunable lighting for care facility

The US Department of Energy (DOE) has published another in its Gateway series of research reports that cover solid-state lighting (SSL) installations in challenging indoor and outdoor lighting settings. The "Tuning the light in senior care: Evaluating a trial LED lighting system at the ACC Care Center in Sacramento, CA" document details a programmatic, tunable LED-lighting system in resident rooms and corridors at a senior living facility. The researchers installed additional SSL products including occupancy-controlled night lights.

The idea of using tunable LED lighting in a variety of applications, and generally referred to as human-centric lighting (HCL), is not a new one. But some researchers believe we need to know more about the impact of tunable spectrum before trying to use lighting as almost a therapy (http://bit.ly/1l9Xc2d). Generally, Europe has been more proactive in the HCL area (http://bit.ly/295mEWt). We recently covered the use of tunable lighting in a dementia center in Germany (http://bit.ly/291WWyb), and you can read more about HCL theory and applications on p. 49.

It was very encouraging to see the DOE involved in an actual HCL trial in the US, even if the Gateway report only refers to tunable lighting and not to the HCL moniker. The project was conceived and led by the Sacramento Municipal Utility District (SMUD) working with the ACC Care Center. SMUD invited the DOE to participate and the agency's Pacific Northwest National Laboratory (PNNL) worked with SMUD in evaluating the photometric properties of the lighting and also evaluating the health and behavioral response of the residents.

The tunable elements of the project were installed in two places. SMUD installed tunable ambient lighting in one single-resident room and one double-resident room. That installation used Philips Color Kinetics iW Cove MX Powercore cove luminaires. In the corridors, nurses' station, a common area, and office, SMUD installed the Beetle tunable troffer » page 32

Scotland streamlines LED street light projects via vetted contractors

The Scotland Excel program has announced a new street light framework initiative in which 13 companies, eight of which are Scottish, have been vetted as capable of undertaking municipal LED street light installations. The so-called framework is intended to last four years and is projected to drive investment of £5 million ($6.6 million) per year in outdoor SSL projects in the 32 councils across the country. The program gives the councils immediate access to experienced contractors that can accelerate the LED conversion program and deliver energy savings.

The Excel program initially established a street-light-centric program some two years back, at the time identifying a supply chain for luminaires and other materials. The program is not dissimilar from the US DOE Municipal Solid-State Street Lighting Consortium (MSSLC) that sought to knock down barriers to the installation or more efficient LED lighting (http://bit.ly/1t8IWmb).

According to the latest news release on what was casually called a man power framework, Excel said that in the past two years Scotland has gone from having 10,000 LED street lights installed to today having 131,000 LED street lights — 15% of the country's total inventory. That scale of progress was equated to a GBP 32.7 million ($43.1 million) investment. Some of that funding came from the UK-based Green Investment Bank (GIB) as was covered in a story by our sister publication *Lux Review* (http://bit.ly/2cCedAm). Generally, the GIB funds such projects with the municipality paying back the initial investment over time through savings in electrical costs.

Now the man power framework will complement the earlier materials program. "Together the existing materials framework and our new » page 33

As Europe bans halogen spots, LED vendors pounce

As the European Union's ban of certain halogen bulbs took hold in early September, lighting vendors seized the opportunity to promote their LED offerings as an energy-efficient way for consumers to fill the void.

The EU outlawed halogen spot lamps, also known as GU10 and directional bulbs, effective Sept. 1. Halogens, as most *LEDs Magazine* readers will know, are a form of incandescent bulb that is slightly more efficient than conventional incandescents — somewhere between 5% and 25% — because they are treated with a halogen gas. They are much less efficient than LED lamps or CFLs.

The halogen spot lamp is thus the latest in the EU's ongoing staged phase-out of energy guzzlers that has included various wattages of conventional incandescents, and that will include other forms of halogens in September 2018. Halogen spots have also been a popular source of downlight in European homes. So Philips Lighting did not miss a beat in trying to usher its LED GU10 lamp form factor into the void.

"Focus now turns to LEDs, such as the Philips LED spot classic WarmGlow, as a high-quality alternative that looks, feels, and behaves like a halogen, but is up to 90% more energy efficient," the company said. It also warned that the ban will take Europeans by surprise, as a Philips survey showed that 75% of Europeans were not aware of it.

Feilo Sylvania also pounced. "Goodbye, inefficient halogen directional lamps — hello Sylvania LED," it said in a press release.

The rallying cry of energy savings marked the second recent reminder that energy savings is still a driving force of LED sales, even as it starts to take a marketing backseat to the ballyhooed possibilities of smart lighting connected to the Internet of Things (IoT). As we have reported, Current, powered by GE is heralding LED installations in retail stores for electricity and carbon reductions, rather than for any IoT deployments (p. 15).

Both Sylvania and Philips invoked another classic LED benefit, noting that LEDs outlive halogens by a long shot. "One Feilo Sylvania LED could last up to 25 times longer than your existing halogen," Feilo Sylvania said.

Furthermore, both companies claimed that their LED replacements will provide the same quality light as halogen, which, as incandescents, are generally regarded as giving off the sort of warm light that many consumers prefer at home in the evening. LEDs have long trailed incandescents in warmth ratings, but they have been gaining.

Philips was particularly emphatic, noting that its WarmGlow technique, which it also uses in other LED form factors, is the equal of halogen. "The WarmGlow technology we use in our new LED spotlight mimics the warm color you get when you dim a halogen," said Mahesh Iyer, leader of the Philips Lighting LED business group. "This technology is unique." Philips further claimed in a press release that the WarmGlow spot "looks the same and shines with the same color and intensity as halogen spotlights."

Feilo noted that its own LED spots "have a high luminous efficacy, great light output, and are available in a wide range of color temperatures, allowing customers to enjoy the light level and comfort they are used to."

Ironically, the LED industry via trade association LightingEurope had in recent years pushed for a delay in the halogen ban, saying that the big LED makers (such as Philips and Feilo Sylvania, previously called Havells Sylvania prior to an ownership change) would not be ready with halogen-equal products (http://bit.ly/1U4FtEw). That was a big reason why in April 2015 the EU delayed the ban of other halogen types — such as general pear-shaped non-directional bulbs and candle-shaped bulbs — until 2018 (http://bit.ly/1FIVh8e).

But vendors including Philips and Feilo Sylvania now say that at least their GU10s are up to the warm task of halogens. What the consumer sees and perceives can often be different from what the labeling on packages claims. Light that is purportedly warm by the numbers can still look cold to the human eye.

Then again, consumers won't have much choice in the matter, because halogen spots in principle will now disappear from the shelves. Except for one thing: As the *Telegraph* newspaper reported, UK retailers have been stocking up on halogens and will have plenty to sell to consumers for the foreseeable future (the ban prevents resellers, not consumers, from buying more; http://bit.ly/2cy3DZ7).

"Britain's biggest retailers are defying an EU crackdown on halogen spotlights by stockpiling up to five years' worth of the popular light bulbs," the *Telegraph* claimed. "Sources said supermarkets and major hardware stores had stockpiled tens of millions of bulbs to please customers, ensuring they would be able to buy the old-style bulbs for years to come. Stores which typically sell 2 million halogen bulbs a year had bought 10 million over the past few weeks, lighting experts said."

SIL Europe follows industry shift

As LED sources continue to be adopted into general illumination applications, the lighting industry has seen a shift in business strategy and the application of new technologies. At Strategies in Light (SIL) Europe, the program will follow these shifts with tracks designed around disruptions in the lighting market and the future of lighting technology. Speakers will address the roadmap for technology as well as business. To learn more about the direction of this year's conference, check out Philip Smallwood's conference preview from our September issue at http://bit.ly/2dbgR36. Register for SIL Europe at sileurope.com.

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Tunable lighting from page 29

from Samjin. But only the corridor lighting and the resident-room lighting was placed under programmatic control.

Scripts controlled the lighting in both spaces. In the corridors there were CCT and intensity changes. The standard script was:

- 7 AM–2 PM: 6500K at 66% output
- 2 PM–6 PM: 4000K at 66% output
- 6 PM–7 AM: 2700K at 20% output

The resident rooms only varied CCT, although the lights might be turned off at any time whereas the corridor had to remain lit. The script was:

- 7 AM–2 PM: 6000K
- 2 PM–6 PM: 4100K
- 6 PM–8 PM: 2700K

In both systems, there were controls that allowed for manual overrides. If an override happened, the script would resume at the next scheduled change.

There were other LED-based lighting products that were key to the project, because things such as bathroom lighting and lighting for exams in the resident rooms had to be at a warm CCT to avoid an impact on the installation of the tunable system. But those additional luminaires delivered primarily energy savings over what had been a system comprising linear fluorescent lighting with some compact fluorescent lighting (CFL).

The one exception in terms of impact of other LED fixtures was the motion-activated lighting installed for nighttime safety. That lighting was generally amber in color or 2400K CCT. The team found that night lights needed to be away from the floor to deliver the requisite safety. And the installation even included some handrail lighting, all focused on safety at night.

As mentioned earlier, the results of the project are generally positive, although privacy regulations prevent anything more than aggregate data from being published. But the report said target behaviors such as yelling, agitation, and crying were reduced by 41% for the three months of the study relative to the three months prior to the tunable LED lighting being installed. There was also a reduction of falls in the corridors.

The DOE said overall the SSL installation delivered 68% energy savings. Perhaps more significantly, illuminance levels met or exceeded current IES (Illuminating Engineering Society) levels whereas the fluores-

Lighting and its effect on human biology

During Strategies in Light Europe, the program will feature a session on the response of the human body to light, with speakers from Osram, Humanscale Corp, and Philips Research delivering details on what constitutes human-centric lighting and how to design it, as well as what the right light at the right time can do for the commercial workspace. View the full program at http://bit.ly/2cKPuNK.

Tunable lighting from page 32

cent lighting had not. The tunable features were determined to be positively impactful in controlling melatonin suppression or production to match circadian cycles. And the ambient lighting was deemed important to safety without impacting circadian cycles.

The project also taught some tough logistic lessons. The report said installing new tunable fixtures in a retrofit fashion can be challenging. The Color Kinetics products were difficult to install and wire without disturbing the walls in the space. The team found that commissioning remains difficult and it is hard to find contractors who have any experience with tunable lighting.

The tunable LED lighting research is just one topic among many you can find in the DOE Gateway series. In an indoor setting, we most recently covered an OLED project in an office building (http://bit.ly/29Rzdix). For more details on the senior living project, you can access the full report on the DOE website (http://bit.ly/2chOFWh). ◄

Scotland from page 29

installation framework give councils the tools to form contracts with suppliers for the materials and man power they need to deliver major LED upgrades," said Councillor Mike Holmes, who also serves as Convener of Scotland Excel. "This is a key focus of local authorities because it will deliver significant cost savings and carbon reductions."

The suppliers identified in the new Scotland program include Alan Mearns Electrical Ltd (Aberdeen); Gordon Electrical Limited (Dunblane); J Plant Hire (Lochgilphead); Lightways Contractors Limited (Falkirk); Neil Campbell Electrical Contractors Ltd (Western Isles); Power1 Electrical Contractors Limited (Paisley); Spie Limited (Rutherglen); T&N Gilmartin Ltd (Tayside); Centregreat Ltd (Wales); Amey LG Limited (England); BAM Nuttal Limited (England); Jones Lighting Ltd (England); and SSE Contracting Limited (England).

The announcement noted that nine of the contractors are considered small to medium enterprises and that could be critical to creating jobs through the program. Holmes added, "And because this framework is for installation only, as opposed to supply and fit, it's opened up opportunities to smaller companies that don't source and provide the materials as part of their service.

Back to the Green Investment Bank and its work funding SSL projects, the initiative has had notable successes. For example, we have covered a major UK program focused on 500 car parks (http://bit.ly/2chPfTW). The future of the GIB, however, may look far different. Rumors persist that the GIB may begin accepting private equity partners to support its green project investments and expand its green vision beyond the shores of the United Kingdom. ◄

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Are there smart lighting factors we shouldn't ignore?

Strategies Unlimited analyst **SHONIKA VOHRA** examines the smart lighting market for areas of concern and recommends focusing on the appropriate application of the technology.

"Smart lighting" is all the buzz right now, and most of my past writings have revolved around this topic. One of the reasons is that there is always something new in this emerging market. In this article, I would like to talk about some uncomfortable situations that could be associated with or caused by smart lighting. We always talk about the benefits of smart lighting, but this new business has been fairly disruptive to the traditional world of lighting and that also deserves attention. As a note of caution, some of my perspective in this column may be based on particular situations and may not apply to all of the situations in which smart lighting may be utilized.

Understand the benefits beyond energy

There are many benefits attributed to smart lighting these days. One of the biggest claims has been that it will further amplify your energy savings if you couple lighting controls with LED lighting. So why is it that the probability of end users adding smart lighting controls and networking is fairly low when they have already installed an LED lighting system? The truth is that the energy-saving benefit of smart lighting is only realized when it is coupled with LED lighting in the first stage of installation as a replacement for incumbent technologies such as high-intensity discharge lamps (HIDs). So, if an end user recently changed over to LED lighting in an indoor or outdoor project, the likelihood of them later adding smart controls to their lighting system decreases. Analyzing the energy savings from the smart lighting system in a vacuum doesn't always make the best business case for installing these products.

In terms of penetration, smart lighting has had high traction in outdoor street-light applications. However, cities usually tell us that energy savings is not always the biggest draw to install smart lighting, since the energy bills for street lights are still based on fixed tariff rates rather than the actual energy consumption. It is the ancillary benefits such as lowering maintenance costs, simplifying asset management, and future energy savings that fuel their decisions to install connected/smart LED street light systems. But there are applications in which smart lighting systems have been able to claim actual energy savings such as with high bays when the incumbent technology has been HID based.

Gathering all the data

Another disruption smart lighting may cause could be in the field of evaluation, measurement, and verification (EMV). Programs such as these have been used to justify the rebates and subsidies given by governments, utilities, and cities to support effective energy-saving technologies with taxpayer funds. To calculate the energy savings, the analyst or engineer has to note the features of the new and incumbent technologies and then, depending on the project, model the building or facility that went through the upgrade. With the integration of smart lighting into the overall building, all the lighting systems, HVAC units, and other building equipment could be monitored directly and evaluated. Instead of a one-time evaluation of the newly installed system, the continuous flow of data can make real-time system changes possible to ensure that the facility is being run in the most efficient way. Integration of smart lighting with the overall building is still a few years away because there are still interoperability issues that the industry has to deal with. But many smart lighting systems now will be able to easily detect the light source, its energy consumption, and projected lifetime, possibly rendering energy- and building-simulation models obsolete.

The outlook

Some traditional lighting companies do not have the in-house talent or resources to compete in the fast-evolving world of smart lighting. And some of them don't think that connected lighting or smart lighting will catch on. So they might get a rude awakening in a couple of years when they have to play catch-up with other competitors who have already built a strong smart lighting business.

Smart lighting is here to stay, and it is something that cannot be ignored. When we consider lighting programs such DOE's Solid-State Lighting Consortium, DesignLights Consortium, and Energy Star, we can see that smart lighting is very much part of our future lighting mandates and so needs to be applied judiciously.

SHONIKA VOHRA *is the analyst for the LED, lighting, and smart lighting market at Strategies Unlimited (strategies-u.com).*

LED luminaires advance in light quality and style

Lighting designers and specifiers working on architectural lighting projects have an ever-increasing selection of LED- and OLED-based luminaires to choose from, enabling a layered approach to lighting with pleasing ambience and impactful task lighting where needed. The latest solid-state lighting (SSL) products bring even more to indoor projects, however, with LED and OLED sources enabling luminaire designs in all new form factors. Meanwhile, the constant improvement in LED sources means that the latest luminaires deliver outstanding light quality and color rendering, and often even the ability to support tunable white point. In this article, MAURY WRIGHT covers some of the latest SSL products ranging from designs that integrate into the architecture to products with unprecedented optical and directional control.

Acuity Brands Olessence with Duet SSL Technology

Linear pendants are a mainstay of indoor commercial lighting projects, yet such workhorse products have not necessarily been considered stylish in many cases. But SSL sources are changing the dynamics of the pendant space these days, and stylish and sleek are some of the latest products. The Acuity Olessence certainly fits that description with its 0.5-in. thin and sleek form factor that's enabled by what Acuity calls Duet SSL Technology — implying the use of a mix of LED and OLED sources. The LEDs deliver ambient indirect uplight, while the

OLED panels deliver soft direct light to the task plane. Acuity offers the product in a choice of 3000K, 35000K, and 4000K CCTs, and at 80 or 90 CRI. The LED and OLED sources can be independently controlled using Acuity's nLight platform, allowing users of a space to precisely set the desired ambient and task light levels. Specifiers can choose from 4-, 6, or 8-ft sections that can also be cascaded, and Acuity offers white, black, and painted aluminum finish options. The driver is located remotely from the Olessence luminaire and Acuity supplies its eldoLED drivers with the product that support smooth dimming to dark functionality.

acuitybrands.com

Cree LN Series with WaveMax Technology

There are, of course, many ways to achieve planar lighting systems with the advent of SSL sources. OLEDs are inherently planar, although the technology is limited in terms of panel size and remains more expensive and less efficient than LED approaches as we have previously covered in feature articles (http://bit.ly/Ou1Zvv). LED-based edge-lit technologies that use optical light guides, such as Cree's WaveMax, can enable much larger panels, and Cree rates the LN Series luminaires as high as 115 lm/W while also delivering excellent color rendering at 90+ CRI. The LEDs in the LN Series are concealed in a small center frame running linearly through the luminaire while the planar panels deliver an extremely elegant look. The panels are transparent and even daylighting can pass through the luminaire while powered off. When powered on, the WaveMax optics design delivers

60% of the light upward and 40% downward. Emission is uniform from both surfaces of the panels, and users of a space lit by the product experience a soft diffuse light when looking directly at the luminaire. The LN Series integrates support for 0–10V dimming. Moreover, the luminaires can be ordered with Cree's SmartCast wireless network platform installed (http://bit.ly/1IN0JtA). You can cascade the LN Series luminaires for runs as long as 136 ft with a single power feed and a simple two-screw connection between each fixture.
cree.com

Current Lumination IS Series with TriGain

Current, powered by GE also has a planar light-guide-based technology called Intrinsx that it has used in a number of Lumination-branded linear pendant products, but the Lumination IS Series uses a different type of light engine that emits upward into twin reflectors to create an indirect light distribution. The IS Series was

actually brought to market more than two years ago (http://bit.ly/2cLk3lS), but we mention it here because of some updates that Current made in the Gen 2 (second generation) version of the product. Specifically, the product uses the Reveal TriGain technology developed by GE. Reveal is a brand that GE Lighting long used to indicate a premium level of performance in terms of light quality, even in retrofit lamps that deliver 90 CRI (http://bit.ly/2czFP7t). TriGain is a narrow-bandwidth, red-phosphor technology (http://bit.ly/1Am3AcU) that can enable high-CRI lighting, including high R9 performance with saturated reds, while also maintaining high efficacy. Indeed, the IS Gen 2 products can deliver 90 CRI and efficacy as high as 136 lm/W.
gelighting.com

Philips Lighting Luminous Patterns

Since the advent of LED-based lighting in general illumination, we have been hearing about the potential of light sources to be integrated directly into building materials, enabled in part by the fact that LEDs generate little heat and can be driven safely with low-voltage DC power. The industry is certainly progressing on closer integration of lighting and architecture and we covered one new

product, enabling such a trend, called Goldeneye that was demonstrated at LightFair International earlier this year (http://bit.ly/1U4Zrh1). Philips Lighting has been at the forefront of technologies that can enable architectural integration, and has launched the Luminous Patterns product family that is intended to add decorative LED lighting in settings such as hotels, office lobbies, restaurants, and retail. The panels are installed on walls and feature customized textures and light patterns. Philips is offering a choice of 3D Graphics, 2D Graphics, Round Sparkle, and Linear Sparkle light effects. A customized kit approach enables simple installation in a project. Moreover, while the technology doesn't produce functional light, a typical installation uses about the same amount of power as a 60W incandescent lamp. The impact for a business can be huge, however, because the products use a digital control system that makes each LED independently controllable and businesses that install Luminous Patterns can expose visiting customers to dynamic effects.
lighting.philips.com

Cerno Tersus

A wall sconce is perhaps the legacy luminaire form factor that comes the closest to integrating lighting into a building's architecture. And LEDs are enabling new sconce designs with the absence of heat from a legacy lamp, and the freedom of a low-profile source. Consider just material finish options for a moment. Cerno in its Tersus line offers the options of walnut, dark stained walnut, and maple finishes along with a variety of metal options including brushed rose gold. The minimalist design extends less than 3. in from the wall while delivering

functional light up and down. Indeed, Cerno delivers 90-CRI color quality in the sconce family despite the fact that such performance may not always be a requisite in a sconce. The standard CCT is a warm 2700K, and the products deliver 1130 lm from 13W. Cerno's principals believe the long-reach light combined with the options in finishes will make Tersus a good fit for many high-end residential applications and for commercial settings such as hospitality.

cernogroup.com

Eaton D2W for Portfolio and Halo

Tunable LED-based lighting is one of the most significant lighting-industry trends, as we mentioned in our feature coverage of LightFair earlier this year (http://bit.ly/2cfn7U2). And one usage for which tunable technology has shown up most often is the so-called dim-to-warm implementations that seek to mimic the performance of legacy halogen and incandescent lamps that produce a warmer CCT as they are dimmed. Eaton's lighting business unit (formerly Cooper Lighting) has branded its implementation of the tunable technology D2W, and has recently made it an option on the Portfolio and

Halo Series of recessed downlights. Typically, dim-to-warm luminaires or lamps rely on two channels of LEDs with CCTs at either end of the desired tuning range. In the Eaton D2W case, the company has focused on the 1850K- to 3000K-CCT range where architectural design, in commercial applications such as restaurants and high-end residential projects, would likely target operation. Eaton said the 1850K setting mimics the look of candlelight with an even warmer CCT than a legacy incandescent or halogen product would afford. Eaton offers the D2W downlights over a range of 900- to 2000-lm packages with a variety of trims and styles. The products deliver efficacy in the 70-lm/W range with a CRI of 90.

cooperindustries.com

Lumenpulse Fluxwerx Fold, Notch, and Inbox

Some of the newest LED-based lighting products almost defy definition or characterization in familiar terms, and that statement certainly holds true for the Fold, Notch, and Inbox luminaires developed by Fluxwerx — a company that was acquired by Lumenpulse early this year. The Fluxwerx products use optical light-guide principles

that are commonly used in LED-based planar lighting, but the resulting products don't at all resemble planar lighting. The Notch products pictured, for instance, are intended to be installed in linear runs recessed in a ceiling. An implementation could use a luminaire or panel on each side of a notch for a symmetrical pattern, or on one side for an asymmetrical distribution. The Fold products are intended for pendant mounting and feature a folded or almost tunnel shape. Those products can deliver both indirect uplight and direct light from the side surfaces on the inside of the fold. The Inbox products can be recessed in almost a troffer-like manner although the light-emitting surfaces are quite different from a typical troffer. The company refers to the planar optics as having anidolic optical structures that mix and diffuse the light. Traditional lighting metrics such as efficacy are meaningless with the products, although the company's website does a very good job of presenting application scenarios with accurate ratings of power used relative to square footage of a space.

fluxwerx.com

Soraa Barrel and Gable

Soraa is a newcomer to the LED luminaire sector, although the company has always staked its reputation on quality of light so we'd expect the same result out of the Barrel and Gable troffer-style products. The company came to life first as an LED manufacturer with a

still-to-this-day unique approach of building gallium-nitride (GaN) LEDs on GaN substrates whereas the bulk of the LED industry uses sapphire or silicon carbide substrates. The homogeneous substrate has meant that Soraa LEDs could operate at relatively higher power densities and Soraa leveraged that advantage from the start in its retrofit lamp products. Moreover, the company used what it calls VP_3 (violet emission 3-phosphor) technology in its LEDs to deliver inherently high CRI and high R9 performance. The tradeoff has been

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slightly lower efficacy in Soraa's lighting products, but the company points out that the Barrel and Gable products deliver 85 lm/W and meet the qualification requirements of the DesignLights Consortium (DLC). The Barrel only requires 3 in. of plenum space and comes in versions with 2500–3200-lm output. The Gable is in more of a standard troffer form and offers similar performance. Both products are packaged with drivers that implement 0–10V controls.

soraa.com

Hubbell Lighting Columbia Contemporary Wall Wash

Wall washers are certainly specialty products yet also important in any layered lighting approach to design in architectural spaces. Still, Hubbell Lighting made some bold claims about their price/performance play when introducing the CWW (Contemporary Wall Wash) fixture from the Columbia Lighting brand. The company said the CWW delivers architectural-grade performance at a commercial-

grade price point. Addressing performance, Hubbell said the luminaire meets uniformity of 5:1 on vertical surfaces from ceiling to floor, along with efficacy as high as 116 lm/W. The standard CWW configuration delivers 80-CRI performance but you can optionally specify a 90-CRI version. There are a range of lumen-output options topping out at 1300 lm/ft. Most of the CWW models also include the option to add a battery pack that will allow the fixtures to serve as emergency lighting.

hubbelllighting.com

Intense Lighting MX next generation

Tunable-white lighting products seem to be coalescing around two distinct product categories — the dim-to-warm category we discussed earlier and products that can be tuned to a CCT over a specified range and maintain CCT when dimmed. Intense Lighting (now a Leviton Company) calls the former Dynamic Dimming and the latter Tunable White. At LightFair earlier this year, the company added both capabilities to the MX family of luminaires that includes recessed downlights, track heads, and so-called recessed multiples that combine multiple track heads in a recessed housing. Intense is relying primarily on Bluetooth Low Energy (BLE) wireless

connectivity to enable control of the tunable features, although the company does offer optional DMX and DALI (digital addressable lighting interface) support. The Tunable White products can be set between 2100K and 4300K CCT, and at 3000K offer CRI of 90. Intense said the color points track just below the black body locus. The Dynamic Dimming products dim over the range of 3000K CCT down to 1800K.

intenselighting.com

Tech Lighting Element

Sticking in the recessed downlight and recessed multiple area, Tech Lighting has announced a number of new luminaire types within the Element family. One unique and interesting quality about Element is the Tech Lighting decision to base the products on modular LED

light engines. Indeed, you can specify among Citizen, Xicato, and Lumenetix modules. The modular approach allows for customization of the beam pattern, tunable features such as warm dimming, and color quality. For example, the optional Xicato Artist modules (http://bit.ly/2cjxLtP) support CRI of 98 and a score of 95 or better across the entire CRI sample set including the red R9 sample. That module targets high-end retail. Back to the fixture design, the

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Element 3" Flangeless Wood Ceiling option pictured offers a unique approach to the typically difficult installation in thicker materials including wood and stone. Some of the recessed multiples are also very interesting. For example, you can get a four-head linear recessed fixture with spotlights on the outside and diffused lighting through lenses in the middle. The options include square multiple models as well.
techlighting.com

Visa Lighting Limit OLED

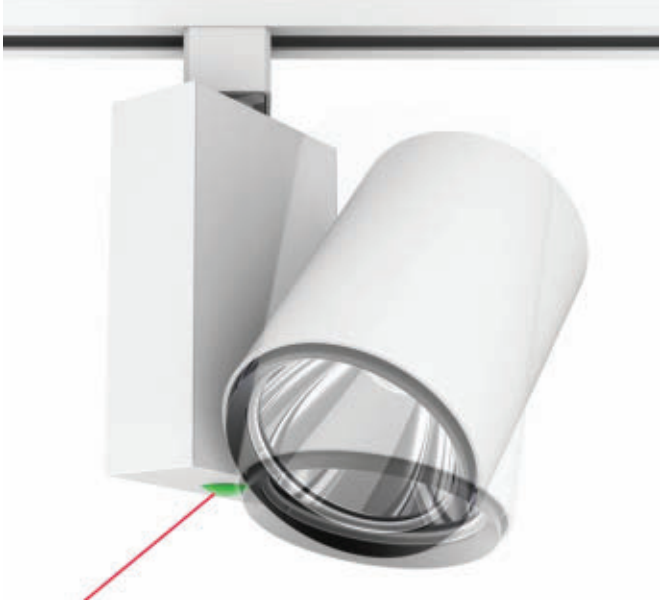
Pure-play OLED fixtures remain almost more curiosity than mainstream tool for the lighting design community, although the inherently diffuse panels enable some extremely compelling concepts. Earlier this year, for example, we covered an interesting project that uses the geometrically-flexible Trilia fixtures from Acuity (http://bit.ly/29Rzdix). Here, let's have a look at an interesting product called Limit from Visa Lighting that targets hospitality or high-end residential settings in a chandelier-type form. The performance deficiency relative to LED-based products is immediately clear when you look at Limit's specs. The luminaire produces only 850 lm and tops out at 80 CRI. But as the nearby bar photo illustrates, the luminaire design makes a fashion statement. The product design does have other interesting elements at play as well. You can individually address each of the OLED panels via DMX or DALI. And to further the sense of style inherent in the product, Visa offers 16 powder-coat paint options.
visalighting.com

PureEdge Lighting TruLine .5A and Zip Suspension

Earlier in this article, we discussed integrating lighting into architecture, but what about extending that concept seamlessly and connecting in-material light sources with traditional luminaires? PureEdge Lighting has just such an offering in the TruLine .5A and Zip Suspension combined product families. Pure Lighting and Edge Lighting generally target different applications with quite different LED product portfolios, although they together form PureEdge Lighting. TruLine has been a key component in the Pure Lighting portfolio and the linear products are intended to be integrated directly into drywall seams. The .5A version of the product has a 0.5-in. aperture and lens that generates diffuse light. The product can be cascaded for long runs and even turn 90° corners both in one plane such as on a ceiling or in applications such as a ceiling to wall run. Edge Lighting, meanwhile, has a new Zip Suspension product line that has equally thin linear luminaires intended for pendant mounting. And now lighting designers can install the TruLine systems in a wall or ceiling and have the Zip Suspension products seamlessly bring that channel of light out into a space, for example with the Zip product providing task light and the TruLine product providing ambient light. The combination was first announced back in March of this year alongside what the company calls an In/Out Connector to link the systems electrically and mechanically (http://bit.ly/2cpwhjI). The combined or separate linear products are powered by a remote driver, typically one that outputs 24 VDC. There are options for both phase-controlled and 0–10V dimming. And even RGB LEDs are an option in the TruLine portfolio.
puredgelighting.com

Loto Lighting LaserDim and Zero luminaire

Lighting a display such as in a retail environment or an exhibit in a museum is among the most challenging tasks in the lighting sector. Loto Lighting has pointed out that many such projects involve very tall displays where the top areas of the display end up being more brightly lit than the bottom areas. Dimmable LED-lighting technologies abound, but having the ability to control every fixture independently in such a display application would require a very expensive network control system using the typical SSL control scenarios. So Loto has developed a technology called LaserDim and applied



it to the new Zero 100 series of track heads. A curator working on a display can use a simple remote control in the LaserDim system to fine-tune each luminaire individually for an optimum display, enabling a far more cost-effective option in many cases relative to a networked system. The Zero, meanwhile, delivers 3400 lm from 40W and offers 90 CRI for optimal colors. Loto also offers many of its directional lighting products with motorized control to allow for simple adjustment of fixtures mounted on a high ceiling. The motorized trend may be a growing one. We reported on a new fixture back at LightFair that had controls for direction and even for zoom (http://bit.ly/2cgFXYP).
lotolighting.com

Halco Lighting ProLED Square Downlights

We will close this article with a look at a more traditional approach to downlighting that still may offer lighting designers maximum flexibility in a cost-effective package. This past summer Halco Lighting Technologies announced the ProLED Square Downlights in 4- and 6-in. versions. The products are designed to support LED retrofit lamps with an E26 base or optionally GU24 lamps. Flexibility is indeed at the base of the value proposition because customers can equip the luminaires with the exact type of lighting required on a project including CCT, CRI, beam spread, and more. Moreover, Halco developed a rotating collar that allows easy alignment of installed products relative to features like walls or to the presence of other luminaires. The standard product includes a frosted lens for diffuse light. Halco can supply fixture and lamp combinations that meet Energy Star requirements, and the product typically yields 80% energy savings relative to the incandescent products it is intended to replace.
halcolighting.com

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Explore and control LED-based tunable-white lighting

Two-color sources can enable tunable-white light, explains **ISHITA GOSWAMI**, but more colors can provide a broader tunable range, better quality light, and granular intensity control.

Solid-state lighting (SSL), leveraging white LEDs, has disrupted markets for traditional lighting products for some time now. With the transition to this energy-saving lighting technology, vendors have been able to offer cool, neutral, and warm white shades that have been quickly understood and accepted by consumers and professional buyers. But LED sources also afford luminaire manufacturers the ability to offer intelligent products that can be tuned to a desired CCT at any time by the user of a space. Let's discuss why the time is right for tunable LED-based products and how such products can be designed for optimum tuning range, light quality, and intensity control; and subsequently how such a product would be controlled.

Indeed, warmer white lighting, at lower correlated color temperatures or CCTs, is known to help establish a comforting or relaxing environment, which many people welcome early in the morning or in an evening setting. Cool or neutral lighting at higher color temperatures, on the other hand, can have an invigorating effect and therefore is often preferred in contexts such as industrial workplaces, offices, or kitchens to help enhance concentration and maximize human productivity. But SSL can offer flexibility beyond choosing a CCT based on a specific application and accepted lighting practices.

With LEDs affording the opportunity to experiment with light in practical situations, human responses to varying light specifications are becoming more widely understood. Industry and academia are engaged in exploring, demonstrating, and validating the benefits of human-centric lighting (HCL) in applications such as hospitals, retail stores, schools, and offices. Consumers are ready for tunable white lighting, opening the way for groups such as architects, interior designers, lighting specifiers, and facility managers to use their knowledge of the effects of different white shades to influence human moods and behavior and so establish even better environments for working, living, healing, buying, and spending leisure time.

ISHITA GOSWAMI *is a product manager at LED Engin (ledengin.com).*

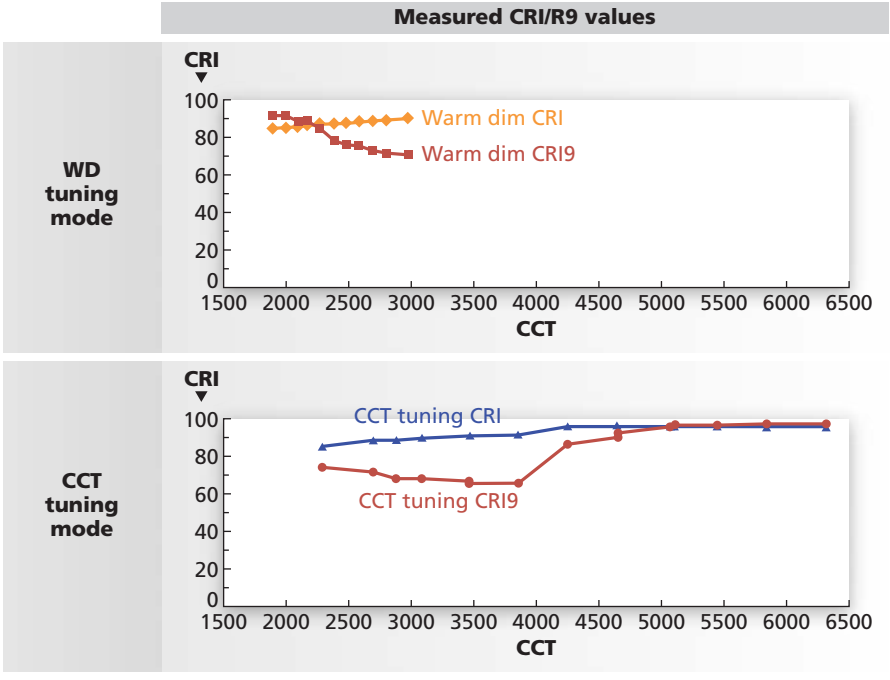

FIG. 1. The graph of CRI and R9 values across a broad range of CCTs is attributable to the three colors used in the LuxiTune white-light source.

Differences in tunable white sources

White LEDs are fabricated either by phosphor conversion of blue or near-ultraviolet emission, or by mixing light from multiple red, green, and blue (RGB) monochromatic emitters. A combination of these two methods is also sometimes used. Adjusting the phosphor-coating composition or color mixing causes the characteristic of the white light to vary. A tunable-white light source is characterized by how many colors or whites are used to achieve the final CCT. There are two, three, five, and even potentially seven color sources that can be mixed for tunable-white developments today, but the actual implementation depends on ease of use, quality, and cost.

The cool, neutral, and warm shades mentioned earlier are referred to as fixed or static CCT white lighting. Typical CCT ranges for warm, neutral, and cool white are 2700–3000K, 4000–5000K, and 5000–6500K, respectively. Together, these CCT ranges define a continuum of tunable-white CCTs that would be perceived as being white.

In a few tunable-white light sources using

three or more colors, these white CCTs lie along the daylight locus (DL) and black body locus (BBL) that traverse the long-established CIE (International Commission on Illumination) color space and those sources provide a higher-quality white as defined by CRI, the R9 CRI red sample, and the relatively new TM-30 color-fidelity metric published in 2015 by the Illuminating Engineering Society of America (IES; http://bit.ly/2bBubZM). Fig. 1, for example, charts the CRI and R9 values of a three-color LuxiTune source over a broad range of CCTs. Other tunable-white color sources using a two-color cool-white and warm-white averaging effect are limited in the range over which they can deliver high CRI and high color fidelity.

Importance of path

Each tunable-white solution has a predefined path or tuning profile. With three or more colors, it is possible to track the BBL as mentioned earlier and independently dim the intensity of the resulting white light. Two-color sources, on the other hand, follow a straight line over a limited tuning range, and the resulting flux also has limitations due to the averaging effect of cool white and

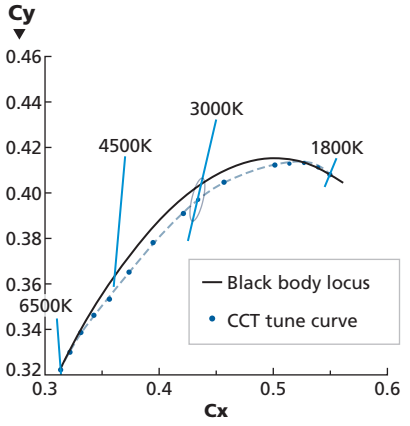

FIG. 2. More colors allow a tunable-white light source to deliver a tuning curve that can track the black body and daylight loci over a wide CCT range.

warm white needed to strike the right CCT, which has to be compensated with adding more LEDs in the tuning mix.

Both options are currently considered suitable for creating tunable-white LED light engines or modules. However, it is generally accepted that a high-quality white should have no more than a two standard deviation color matching (SDCM) variation along the tuning path. A two-color solution cannot meet this expectation over the entire range of 2700K–6500K CCTs. It is also recognized that true white may lie above, on, or below the BBL, depending on the observer. This flexibility of a tuning curve that is offset above or below the BBL by design is not possible with a two-color solution. Based on research and customer feedback, LED Engin has established a path for its own tunable-white LuxiTune products, which is within 2 SDCM below the BBL over the 2100K–4300K range and gradually transitions toward the daylight locus from 4300K–6500K. Fig. 2 illustrates this tuning range.

Flexibility in creating ambience

By adjusting in-source color mixing to follow a curve such as that shown in Fig. 2, it is possible to deliver tunable-white light sources that permit smooth adjustment between the limits of extremely cool (high CCT) to extremely warm (low CCT). Some sources also allow the intensity to be dimmed from 100% to as low as 0.5%, at each CCT over the tuning range. This is known as CCT tuning with deep dimming.

Moreover, natural human responses to phenomena such as sunrise and sunset have conditioned people to expect tones to be cooler when lighting is brightest and to become warmer as lighting is dimmed. Accordingly, retailers or owners of venues such as bars or restaurants often seek to attract customers by presenting a cool and invigorating environment during daytime hours, while using lighting to create a warm glow moving into the evening. This is another version of tunable white known as warm dimming.

Moving forward from the CCT tuning and dimming options that are possible today, one potential next step for tunable-white lighting is to introduce control over color saturation. This is known as Du´v´ tuning as represented in Fig. 3. Du´v´ tuning requires three control handles for CCT, intensity, and saturation. LED Engin has demonstrated Du´v´ tuning within the 7-MacAdam-ellipse rectangles of the ANSI white space along iso-CCT lines, using a DMX controller.

Control requirements and wireless options

The prospect of tunable-white lighting raises questions as to how users can apply settings

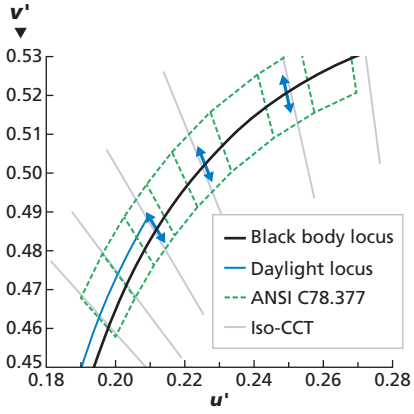

FIG. 3. Adjustment of color saturation along iso-CCT lines (blue arrows) allows for more tuning options.

or adjust the lighting to achieve the effects they desire. In fact, the adoption of tunable-white lighting is tightly linked to ease of use which is in turn determined by how intuitive the controls are. A color-aware user interface is required that allows the user to set flux levels and CCT directly without having to interpret what settings on the controller correspond to actual flux and CCT output.

A suitable control strategy needs to have two handles, capable of controlling CCT and intensity, independently and simultaneously. The basic LuxiTune light engine uses two 0–10V controls; 0–10V has been around in the lighting industry for a while. Although LED Engin has used DMX (both 512A and RDM) successfully for tunable white, DMX is not widely used outside professional or stage lighting markets. DALI (digital addressable lighting interface) is another alternative that is more popular in commercial markets, particularly in Europe. Currently, DALI protocols are available for managing one variable (Device Type 6, or DT6), or two (Device Type 8, or DT8), but DT8 devices cannot yet be certified by DALI.

The options for controlling tunable-white lighting continue to evolve and now include some important developments such as wireless connectivity. One opportunity may be to leverage the rapid pace of progress in the smart-building space. The ZigBee protocol has made some inroads in lighting. LED Engin has tested the tunable-white market with a ZigBee Home Automation (ZHA) enabled tunable-white solution. However, few if any ZHA controllers in the market today are suited for tunable-white applications as they lack the

two separate handles for independently controlling intensity and CCT.

Bluetooth Low Energy (BLE) mesh networking promises advantages for tunable-white lighting including an end-to-end solution. Not only is it possible to have two independent control handles for CCT and intensity, the BLE control interface is user friendly, and lights can be controlled by an app on a smart device with touchscreen operation. Secure networks with four levels of access can be set up to control multiple light nodes that extend over large distances without requiring hubs or gateways, and can be controlled from a single terminal with minimal restriction on communication range.

Because all devices on a BLE network can advertise their presence and status, the controlling app can be allowed to access all lighting fixtures and groups of fixtures. This feature would help in commissioning and managing a network of tunable light fixtures in a commercial environment spread across several floors. Moreover, autonomous coordination between nodes and the ability to incorporate input from sensors, would provide the opportunity to implement advanced features such as activating lights in sequence as a person walks along a corridor. LuxiTune with the BLE mesh option can incorporate all these advantages for luminaire developers.

FIG. 4. A modular platform enhances flexibility as the options for tunable control continue to evolve.

The market for tunable-white lighting may yet be too young for manufacturers to back one wireless option over another. One effective way to give luminaire product developers the flexibility to have multiple connectivity choices is a modular design. You can realize a flexible scenario by having a basic 0–10V driver that works with different modular control boards such as in the tunable-white light engine shown in Fig. 4. This allows a tunable-white solution to be assembled and commissioned with minimal effort by plugging the chosen control module into headers on the basic driver board.

Future of dynamic lighting

Lighting designers, luminaire manufacturers, and end users have become familiar with the effects that can be achieved by dynamic white lighting. The market is now ready to accept tunable-white lighting products capable of supporting even more varied effects. Some products have already been successfully realized. Other aspects need to come fully into place, such as the realization that dynamic lighting offers quantifiable benefits for applications in retail, healthcare, hospitality, commercial, and education. Control options for tunable white can be simplified with improvements such as BLE mesh, and intuitive controls are the key to enabling this exciting technology to deliver its full potential.

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Human-centric lighting set to drastically improve workplace and individual performance

The HCL concept is as old as humankind's place under the Sun. But putting it into practice via tunable LED lighting will be a challenge. Some people are already trying, as **MARK HALPER** discovers.

You might not have yet heard the phrase "human-centric lighting" (HCL). But it's one of the oldest concepts under the Sun. Ever since humankind first yawned and stretched at dawn, and lay down to sleep at night, a 24-hour pattern of natural light that changes throughout the day and gives way to darkness has paced and conditioned our movements. Some 2.5 million years of the genus *Homo*'s wakefulness under the blue-enriched wavelengths of daytime, and of tiredness in the reds and ambers of dusk, have conditioned the human circadian rhythm so that blues stimulate; reds, ambers, and darkness relax.

Yet in 120 or so years of artificial, electric lighting, manufacturers of lamps and luminaires have paid little attention to its color. The industry has existed for one main function: to illuminate. It has given little thought to how it might alter patterns of illumination and change wavelengths and colors to suit humans' daily cycle. While architects have paid homage (Fig. 1), the lighting industry has largely ignored it. But that is all beginning to change.

As we reported in our last issue (http://bit.ly/2cL4Fnn), scientific studies over the last 20 years have proven that light's spectral content and its intensity do indeed impact the human circadian rhythm. Blue-enriched white light, for instance, can play both a villainous and a virtuous role. Too much blue at night can undermine sleep, because blue frequencies suppress the sleep-inducing hormone melatonin.

Those same blue frequencies, however, play a stimulating role during the daytime — when we tend to need it — because they excite a pigment called melanopsin that resides in the eye's non-visual photoreceptors and send signals to the brain where they stir up the body's master clock, as discovered in the early 1990s by Oxford University neuroscientist Russell Foster and others. That clock controls a number of physiological clocks including the circadian one. The non-visual photoreceptors are called the intrinsically photosensitive retinal ganglion cells, or ipRGCs; the master clock is called the suprachiasmatic nucleus, or SCN.

This new knowledge comes along at a perfect technological juncture, as the modern emergence of LED lighting with its solid-state, digital nature opens the possibility of tuning light wavelengths and intensity to facilitate human performance — to induce alertness and restfulness when we need it, and even to correct the health hazards inherent in the blueish LED-lit gadgets, lamps, and streetlights that critics say can wreck our sleep and cause other bodily harm.

The potential to put LED lighting to use in such a manner is far greater than any other artificial light source has allowed.

Source: Mark Halper.

FIG. 1. Catalan architect Antoni Gaudí appreciated the relationship between the light spectrum and humans' daily cycles when he designed his still unfinished masterpiece, Barcelona's La Sagrada Família, beginning in 1883. The cathedral's east-facing windows emphasize the blues of daytime (top). The west-facing windows feature the ambers, reds, and oranges of sunset (bottom). The lighting industry is beginning to pay more attention to the same thing.

"The LED allows us to be a little bit more precise than incandescent because you can tune the spectrum," noted Mariana Figueiro, acting director of Rensselaer Polytechnic Institute's Lighting Research Center

MARK HALPER *is a contributing editor with LEDs Magazine (markhalper@aol.com).*

(LRC). "You can change the spectrum over the course of the day. You can achieve these things with other light sources. But obviously with LEDs it's easy because you can tune and change; you can pick what you want. So the flexibility of the LEDs is a must, there's no question about it."

Or as noted by Rensselaer's Bob Karlicek, the director of LRC's rival research group called the Center for Lighting Enabled Systems and Applications (LESA), "With LED lighting, we now have the ability to turn the full complement of knobs in intensity, in color, and in spectral power distribution."

But it's one thing to identify cause and effect in the scientific laboratory. It's another to engineer those findings into products and services that yield tangible results in real-world scenarios.

In our last *LEDs Magazine* feature, we noted that the healthcare industry is pioneering many of the applications of HCL, also known as circadian lighting. Hospitals such as the Aarhus University Hospital in Denmark; St. Augustinus Memory Center in Neuss, Germany; and St. Mary's Hospital in London are tuning white light to different levels of blues and reds and other colors to facilitate better rest and alertness and to thus aid the healing process among dementia sufferers, brain trauma patients, and others. Schools such as Miami-Dade County Public Schools in Florida (http://bit.ly/1RRSkwT) and Mobile County Public Schools in Alabama (http://bit.ly/2cgqWJM) are also beginning to work with circadian lighting.

But could the same principles apply in the workplace? Could specially tuned lighting that changes throughout the day and night make workers more alert, more engaged, happier? Could it improve their morale? Could the same principles apply at home? Could individuals tailor lighting schemes specifically tuned to their own idiosyncratic requirements?

More and more experts believe that the answer to those questions might indeed be a big, general *yes*.

Circadian office trials

In one broad, ongoing field test, Figueiro and the LRC have been working for about three years with the US Government's General Services Administration (GSA) to determine the effect of different lighting patterns on workers at five different GSA buildings across the country — two in Washington, DC, and one each in Seattle, WA (Fig. 2); Portland, OR; and Grand Junction, CO. They are also now adding two more GSA sites — another in DC and one in White River Junction, VT.

The LRC work at GSA focuses largely on "ways to deliver circadian light to people while they're at work during the day," said Figueiro. "It could be as simple now as your cubicle partition becomes an illuminated partition and it changes the lighting based on what you want. It could be a light table. It could be goggles (Fig. 3), a computer screen, a table lamp. There are different ways to deliver light that is not just your ceiling light. That's the beauty of LEDs — they allow you to think outside the box. You don't just think about ceiling lights anymore. You start thinking of very different ways of delivering the tunable light."

FIG. 2. It's difficult to tease out the exact effect of light in an office setting, but that's not stopping Rensselaer Polytechnic's Lighting Research Center (LRC) from trying. It's studying light in the workplace at several General Services Administration buildings, such as at this GSA facility in Seattle, designed by ZGF Architects.

The LRC has even developed a wearable device called a daysimeter that measures the amount of light a person receives during the day and, via a combination of apps, a hub, and connected smart lights, automatically rebalances the color temperature of room lights to maintain the person's circadian health, as our sister publication *Lux Review* wrote last year (Fig. 4; http://bit.ly/2ccZqfn).

While the LRC has yet to reach final conclusions on the human circadian effect of different light patterns at the GSA facilities, it has determined preliminary findings.

"One of the things we're learning is everybody's being exposed to very little light," said Figueiro. "We talk a lot about too much light at night, but the truth is we may be getting too little light during the day, and that may be the main issue of all the negative effects of the built environment on health and wellbeing. Part of what we're doing is we're establishing a minimum amount of circadian stimulus that people need to be exposed to in federal buildings."

Figueiro and her team are continuing to look into the consequences of too little light, and at the possible benefits of properly tuned and specific amounts of circadian lighting. Having already observed some 200

GSA office workers with more to come, they are investigating whether tunable lighting can indeed support circadian entrainment, which is a measure of how strongly the body clock is tuned to natural day/night patterns.

Early insights

"I'm still doing the data analysis, so I don't want to overstate any of these results, but we're seeing a relationship between how much light you get during the day and how well you sleep, how your mood is, how stressed you are," Figueiro noted. "The more light you get during the day, the more entrained a person is. We look at the relationship between light, dark, rest, and activity patterns. You tend to be both more awake and to sleep better when there's more circadian light. People are saying they're sleeping better when they have more light during the day in the built environment."

One reason that Figueiro is still deliberating over the causes and effects at the GSA facilities is that, as she allowed, "When you do these field studies, teasing out the effect of light is very hard."

Source: Lighting Research Center.

FIG. 3. One way to administer different light frequencies is through the use of goggles.

Whereas in hospitals — the setting for many of the early HCL implementations — patients are in controlled environments that typically already monitor many of their biometric functions and thus make it easier to infer the effect of light, workplaces are prone to many variables and other factors that impede reliable lighting studies. Those factors include all of the workplace's myriad physical and psychological elements, as well as the many individual factors in one's personal life and psyche that affect their mood, morale, performance, and the like.

"Moving into the workforce, it's really hard to do these studies," noted Karlicek at Rensselaer's LESA. "We're kind of in this interesting Catch-22 where we have enough anecdotal information from studies that have been done going back to the early 1900s on how artificial light impacts human beings. Light does have an impact on cognition, it does have an impact on alertness, it does have an impact on wellbeing — we don't have the expression 'mood lighting' for nothing — but we don't really have

what I would call a full evidenced-based understanding of how lighting's full spectral power distribution can really impact human performance. What we don't really have are very well-defined studies that allow us to have a prescriptive lighting recipe for light and human-centric lighting."

Call in the engineers

Karlicek and the engineering-oriented LESA are out to change that. LESA is developing eyewear, including a tiny pea-sized spectrometer, that measures the amount of different frequencies of lights that enter the eye. Wearers will link the spectacles wirelessly into a smartphone app that will then send data off to the cloud for analysis. The concept is similar to the daysimeter that the LRC first developed in 2005, but the design is different.

LESA hopes to leapfrog the LRC technology. With the spectrometer, it wants to measure light spectrum within 5–10-nm bands. It would also measure light that actually enters the eye, rather than the general surrounding light. LESA believes that such a device and system would represent a big breakthrough in accurately pinpointing and delineating the amount of different color and intensity of light an individual receives, although LRC says that it already provides those features.

"The one thing that's always been missing is the spectrally resolved light dose throughout the day," Karlicek said. "This is one of the things that's really needed to start taking a look at answering questions like 'How much light is really bad, what is the intensity, what light dose are you really getting, and what colors of light are you getting throughout the day? Are you staring at your monitor? Are you watching television in a dark room at night? Are you working in a brightly lit environment?' We want to take it to the next level and really involve spectrum, so that we can really answer questions like 'This was your blue light dose, versus your turquoise dose versus your cyan dose versus your yellow dose, and so on.'"

In addition to spectral distribution, the system will also take certain biometric readings including heart rate, facial temperature, and motion (actigraphy) that when combined and analyzed in the cloud will, according to Karlicek, ascertain a person's circadian state in a manner that today requires more tedious techniques such as blood or saliva samples.

"What we want to be able to do is take a look at how we process all of this noisy data including light dose data and heart rate data and actigraphy motion data, to try to extract an accurate circadian phase, using surrogates — obviously we're not going to be doing saliva testing, and we're not going to be drawing blood samples," said Karlicek. LESA has a patent pending on the signal analytics technology.

When *LEDs Magazine* spoke with Karlicek, he was awaiting delivery of the spectrometer from South Korea, and was hoping to have built trial units of the eyewear system by the end of this year.

The group's partners on the device include the Illuminating Engineering Society (IES), as well as George "Bud" Brainard, the director of the Light Research Program at Thomas Jefferson University in Philadelphia who is one of the developers of a circadian lighting system for astronauts on the International Space Station (http://bit.ly/2cL4Fnn).

Once LESA builds and debugs its prototypes, its hopes to then begin field trials through its corporate members such as Stoneham, MA-based Circadian, a technology and consulting company that specializes in helping to optimize round-the-clock operations.

Changing the clocks

The system could eventually help individuals understand their own circadian response to light — which varies for every individual. LESA's John Wen, a Rensselaer professor of electrical engineering, noted that it could then help individuals apply their own light treatment to help them rebalance their circadian rhythm in relation to, say, shift work or travel. Today, it takes an average human about 8 days to readjust after a 12-hour flip in their routine (for example, if they have traveled halfway around the world, or if their shift work changes from an 8 a.m. start to 8 p.m.).

FIG. 4. The LRC has developed a daysimeter that measures light levels that a person is exposed to, and rebalances color temperature for circadian health. It has used the daysimeter in many studies, and is currently working with the Swedish Energy Agency in home trials. LRC's internecine rival, the Center for Lighting Enabled Systems and Applications (LESA), is working on its own version.

A personalized treatment, based on the analysis of individual light intake and biometric effects, could expedite the adjustment — especially if combined with adjustments to other variables, such as room temperature and sleep homeostasis, which is a non-circadian sleep determinant that is essentially a measurement of one's inclination to fall asleep at any one moment. Sleep homeostasis is typically high at nighttime and low after awakening. Treatment could also help a person prepare in advance for an atypical 3 a.m. start.

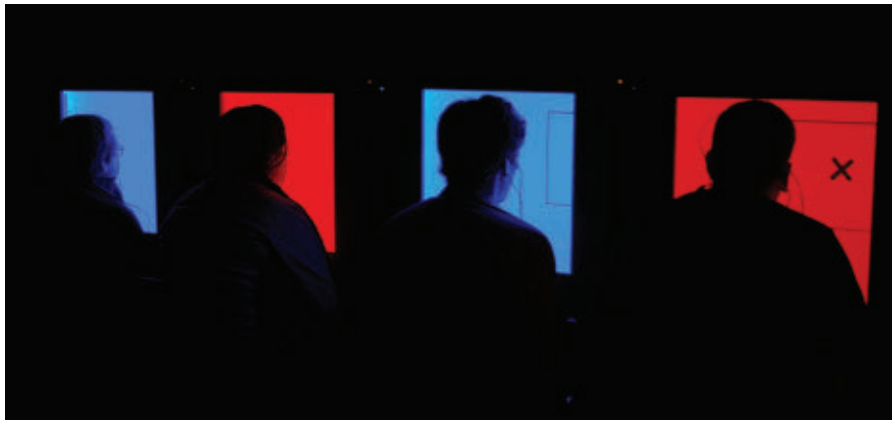
"I think in the future everything will be interconnected," said Wen. "The important thing is how do we get personalized data through this biometric sensor and tie it to your surroundings, which could include lighting, which could include a fan and a temperature setting, to keep you on a circadian schedule and to help you with your sleep and to eventually help with your alertness."

In fact, the device could help adjust other

physiological processes as well, because light has been shown to affect the release of other hormones, such as the stress-related hormone cortisol and the blood-sugar-controlling hormone insulin, all part of the endocrine system of glands. What's more, the master body clock (the SCN), which is stimulated by light via the retina's non-visual photoreceptors, controls other physiological clocks in addition to the circadian clock.

"There's this huge complex of other clocks that are all intertwined that's not well understood, but that's recognized to be exceedingly important," Wen said. "The master clock drives a lot of peripheral clocks, and regulates your metabolism and other physiological processes in your body. These couplings can be broken, and that can lead to things like diabetes. Your endocrine system can be disrupted. So it's an active area of research — how this interconnected network of clocks works."

Wen echoed the same caution as Figueiro, Karlicek, and others in emphasizing that light's precise cause-and-effect relationship with human physiology and alertness in environments as varied as the workplace and at home, and across the range of individual differences, is "all now still very much a research project."



Source: Lighting Research Center.

FIG. 5. Rensselaer's LRC thinks that red light can have an alerting effect, but for reasons that are different from the alerting nature of blue light. Red light's stimulation might relate to sleep homeostasis, or to humans' fight-or-flight responses. It might have nothing to do with suppressing the sleep hormone melatonin, as blue light does. That means red light could be used to stimulate night shift workers; melatonin suppression has been linked to higher cancer rates, which is another reason to avoid it at night.

Saving lives and money

But with certain fundamental connections already established, such as the link between blue light and the suppression of sleep-promoting melatonin, as well as light's stimulation of the body's master clock, lighting vendors are already promoting circadian lighting for the workplace.

UK-based PhotonStar, for instance, has installed its Halcyon circadian lighting systems in the offices of security consultants and investment trading banks to keep mission-critical personnel on the ball. "These are mathematicians or people who if they make a mistake it either costs a life or a lot of money," noted group marketing and business development director Fenella Frost.

Although the majority of PhotonStar's 200 circadian lighting installations are in the healthcare field, office installations now represent an increasing share, she said. Edinburgh-based Royal Bank of Scotland, for instance, will soon outfit one floor of its offices in Bristol, England with a Halcyon circadian system. IBM is also using Halcyon circadian lighting — PhotonStar and IBM are collaborating in the Internet of Things (http://bit.ly/2cd2FmM).

Obstacles

But office and workplace implementations in general have yet to take off in a big way. Perhaps one reason is the cost.

"Obviously, a circadian system is going to be more expensive — it does come at a premium," noted Frost. Offices that have already switched to energy-efficient lighting will thus typically not be able to justify the expense of a circadian system on LED energy-saving principles — a justification that some hospitals tend to use to get budgetary approval of circadian systems.

Peter Thorns, a member of the Light for Life working group at industry association LightingEurope and the head of strategic lighting applications for Thorn Lighting, estimated that the typical premium is 50% above the cost of a non-circadian LED system, a figure that some observers say is low and others say is high.

While LightingEurope has placed human-centric lighting squarely on its strategic roadmap, it has acknowledged that it could be a decade before HCL technologies are widely entrenched (http://bit.ly/295mEWt).

Thorns pointed out that a current dearth of industry standards is holding back progress. Along the same lines, PhotonStar's Frost called for regulations, noting that "At the end of the day, circadian lighting is a drug, and people are worried about what if they get it wrong."

Some HCL champions say that, given the early stage of field trials and clinical evidence, it would be premature to establish standards. The question of exactly how light affects workplace performance remains open-ended. Not only is it difficult to prove specific correlations, but experts also disagree over certain claims and assertions.

Red alert

For example, in one recent finding that has raised some eyebrows, Figueiro now believes that red-enriched light, as well as blue, can have a stimulating effect during the daytime. "We stumbled onto this when we were using red lighting as a placebo control in an experiment measuring EEG (brainwaves), cortisol, and performance," she said, recalling an experiment with US Navy submariners in which red light turned out to have a stimulating effect during the post-lunch dip.

Figueiro surmises that the red in this case is not related to the hormone melatonin, but that it might be connected to a human fight-or-flight response, which can assert itself particularly during the daytime when sleep-inducing melatonin does not contend

against it. She believes it is probably part of the sleep homeostasis system, as opposed to the circadian system.

To test her hypothesis, LRC is about one year into a four-year study of 90 nurses who work day and night shifts. If LRC proves that red light can indeed induce alertness, then that could potentially replace blue-enriched light at night. That, in turn, has a big potential health upside: It could reduce the risk of cancer in shift workers. Epidemiological studies have linked nurses who work day and night shifts to a higher incidence of breast cancer. One leading theory maintains that it is the suppression of melatonin at night that makes them more prone to the disease, because melatonin is known to have a preventative (oncological) effect on cancer. Red light as a stimulant would not suppress melatonin, and would thus not deprive them of melatonin's oncological benefit.

LRC is conducting the research in partnership with the US Government's National Institute for Occupational Safety and Health, which is part of the Centers for Disease Control and Prevention.

Don't use the 'P' word

For all the potential good that circadian and other forms of human-centric lighting could provide, many experts caution that it will be nearly impossible to prove that circadian lighting can improve workplace productivity per se. While workers could potentially benefit from circadian lighting in ways that should logically lead to advances in productivity, any commercial office or factory waiting for clinical proof before purchasing a circadian system might wait a long time.

Take Figueiro's red light study, for instance. "I can tell you that more red lighting during the day will actually make you more alert, like a cup of coffee," she noted. "Translating that to better performance or better productivity is a lot harder."

And the same goes for any light. "I'm very comfortable with saying if you keep people in dim light all day, they're going to feel sleepier, more tired, and less alert," she said. "But some people may be more resilient, and they can still perform even though they're tired. There are so many things that might affect productivity and performance. You might have perfect circadian entrainment, but maybe you had a fight with your spouse and you're in a bad mood, and you're not going to focus or get productive. I know everyone wants to link circadian lighting to productivity, but I'm telling you, it's a hard sell."

Thorns at LightingEurope agreed. "Productivity is such a difficult thing to define," he noted. "If a person has better sleep so that they are more alert, and they make fewer mistakes, the chances are the productivity will go up. I've got a problem saying outright that productivity will increase, but it's almost a side effect of making that person a healthier, happier person."

With side effects like that, bring on the drug. After all, thanks to the Sun, it has already enjoyed a field trial for millions of years. Perhaps it's time to bottle it.

Improving color consistency in LED-based general lighting

ALEXANDER WILM explains how the packaged LED industry could deliver improved color consistency in SSL products by changing the component binning methodology.

LEDs have become firmly established as relevant light sources for general illumination. Their costs are now at such a low level that they can be used in any application without any problems. In terms of efficiency they already outperform all previous light sources. There is still potential for improvement, however, in the quality of light produced by LEDs. One area ripe for improvement is color rendering and above all color consistency. One way to address color consistency would be to change the LED binning methodology to use the International Commission on Illumination (CIE) 2015 10° color space. The CIE recently developed the 10° binning to guarantee hitherto unprecedented color consistency for white LEDs.

Up to now, the standard international color space for general lighting and other applications has been CIE 1931 2°. It was published by the CIE way back in 1931 — as the name indicates. It's fair to say that the lighting industry has seen some changes since then. At the time, the incandescent lamp was the only electric light source, and that was joined later by the halogen lamp, the compact fluorescent lamp (CFL), and the high-intensity discharge (HID) lamp. Then came LEDs and LED retrofits — and finally the incandescent lamp was withdrawn for reasons of energy efficiency. Yet despite all these changes in the past 85 years, have there really been no adjustments in color metrics?

Well, yes, there have in fact been changes. In 1964 the CIE defined and published a new 10° Standard Observer color space. It has not been used in the lighting industry to this day. In 2015 the CIE made a fresh attempt and presented the CIE 2015 10° u′v′ color space — the second 10° color space after the 1964 one. So are the stars more favorably aligned for adoption by the lighting industry in this millennium than in the last? Osram Opto Semiconductors is convinced they are.

Image by Osram.

FIG. 1. White LEDs binned using existing industry practices can result in humans perceiving color discrepancy in general lighting applications.

Same color location, different color perception

What makes this 10° binning for LEDs in general lighting so interesting? In the usual CIE 1931 2° color space, two LEDs can exhibit noticeably different white tones despite the exact same color coordinates (Fig. 1). In white chip-on-board (COB) LEDs, which are used as single light sources in wallwashers, spotlights, and downlights, these differences in color can be particularly unpleasant. The rising demands placed on the quality of light produced by LEDs has led in recent years to more and more discussions regarding color consistency. To tackle this problem, Osram has adopted white-LED binning for some COB LEDs based on the CIE 2015 10° u′v′ color space.

The greatest benefit of the 10° color space is that it provides for the correct and more realistic rendering of color perception. The cause of a lack of color consistency among white LEDs is the discrepancy between the color location determined in the CIE 1931 2° color space and the actual color perception by the human visual system.

In the CIE 1931 2° color space it is assumed that the blue, green, and red cones that are responsible for color perception in our eyes are evenly distributed. That does not match reality, however, as the density of the pigments varies greatly across the field of view. For example, there is a small area in the center where there are no blue cones at all. At a dis-

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tance of 0.5m, the 2° color space only comprises a field of view with a diameter of 17 mm (Fig. 2). Most applications in general illumination are rated at a field of view of 10° (about a diameter of 90 mm at 0.5m distance) and larger. The different cone ratios at 2° and 10° therefore lead to distortions in color perception.

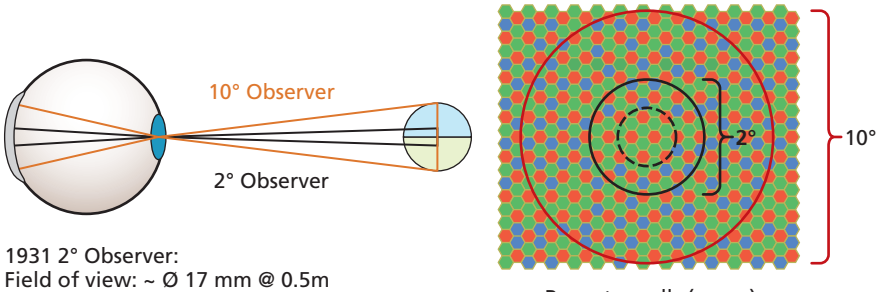

FIG. 2. A 2° field of view, such as is used in LED binning today, can result in varying color perception because there are no blue cones in the center of the eye, and a 10° field of view is much more representative of how humans perceive light in general illumination applications.

Spectral composition of light

But why are these distortions so pronounced with white LEDs? It has all to do with the spectral composition of the light — a problem that Bartenbach, the lighting design company, has recognized: The design firm did research that revealed some cases in which photometric evaluation of the light spectrum did not correspond to the actual visual appearance. Moreover, the difference was visible in some lighting design projects in which quality of light was highly valued. According to the effect known as metamerism, white light with different spectral compositions but with the same color location should actually be perceived as identical (*LEDs Magazine* published a four-part series of articles on color science covering metamerism and other concepts related to color perception — http://bit.ly/MqbtWY).

To understand this subject properly, we need first to take a step back and remember that the light from white LEDs is produced by conversion from a blue chip. The wavelength of this blue chip may vary, but this is compensated by adjusting the phosphor or converter mix to achieve exactly the same color location for different LEDs. Even so, the spectral composition of LEDs differs in the blue range — and it is precisely here that

the differences in color perception in the 2° field and the 10° field are particularly great. If an LED is optimized to exactly the same color location as part of extremely narrow 1-SDCM (standard deviation of color matching and often referred to as a MacAdam ellipse) binning for a 2° observer and if at the same time no differences are measured, then precisely these spectral differences can lead to perceivable color discrepancies in a typical general lighting application that corresponds more to a 10° observation field.

Matching human perception

Osram is convinced that white binning with a 10° viewing angle corresponds much more closely to human color perception in general-lighting applications. When it comes to 10° binning, major color differences can be avoided through different spectral shapes. The company combined the latest scientific findings on cones with fundamental knowledge about the chromaticity chart with its important axes in terms of physics and is applying the results to some LEDs used in general illumination.

The technology that Osram calls TEN° is available initially in a series of COB products, namely the third generation of the Soleriq S 13 (Fig. 3), which has been on the market since March 2016. The new binning methodology means that these LEDs will guarantee unprecedented color consistency. Meanwhile, the new Soleriq LEDs continue to be compliant with current industry standards, and continue to be compatible with existing white groupings. The 10° binning will by no means replace existing standards, but only add to them for now. This still enables customers to implement their specific products and applications without any problems.

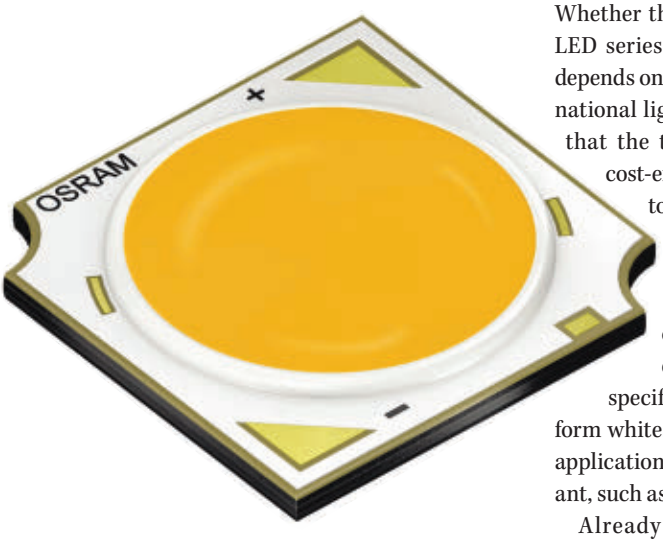

FIG. 3. The Osram Opto Semiconductors Soleriq S 13 is the first LED to be binned based on the CIE 2015 10° u'v' color space.

Future of binning

Whether the Soleriq S 13 remains the only LED series binned to the 10° color space depends on market acceptance by the international lighting industry. Osram believes that the technology delivers a reliable, cost-effective, and intelligent approach to resolve the problem in LED general lighting between high quality requirements on the one hand and cost pressures on the other. The binning scheme will enable lighting designers and specifiers to deliver projects with uniform whites in residential and commercial applications where light quality is important, such as in hospitality (Fig. 4).

Already some noted lighting practitioners share our opinion. "Osram's new white binning is the right way to improve the quality of an LED-based lighting system," was the comment from Bartenbach. And a representative of NEL Neontechnik Elektroanlagen Leipzig GmbH said, "I can only agree with what the Bartenbach Institute has said — it's the right step in the right direction. As a scientist I could possibly add that it's been a long time coming, and it's necessary. I just hope that the market will now do it justice."

FIG. 4. Hospitality applications are one of several project types in which uniform white perception is considered a critical element of lighting design.

COMING NEXT MONTH

Notable SSL projects, thermal management, tech toys, and more

As the close of 2016 draws near, we will turn our attention to a slew of sophisticated LED-based solid-state lighting (SSL) projects in the European region. Contributing editor Mark Halper will round up the latest in high-tech and novel lighting installations that embody the flexibility and form attributes of LEDs alongside architectural appeal in many cases. We'll also package up the techie presents you may be dreaming of in our tech toys feature, as well as addressing new information on thermal management in LED systems.

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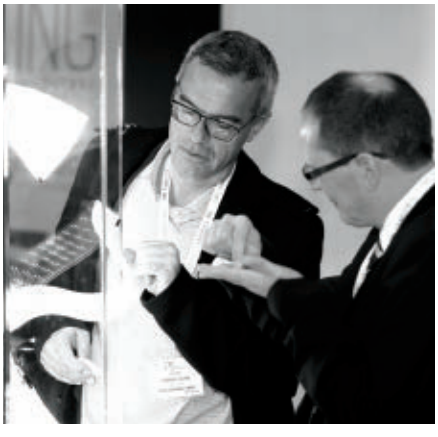

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Low-voltage scheme trivializes installation of LED lighting and supports controls

The first commercial installation of a new distributed low-voltage power platform for SSL delivers unprecedented ease of installation and excellent integration of controls, reports **MAURY WRIGHT**, and the scheme should also deliver added efficiency due to centralized power conversion.

Back at LightFair International (LFI) in April, Eaton (formerly Cooper Lighting) displayed a new distributed low-voltage power (DLVP) platform intended to simplify the installation and control of LED-based lighting and to further optimize the efficiency of solid-state lighting (SSL) through centralized AC-to-DC power conversion. Now Eaton has completed its first beta installation of a DLVP system in a small office building in Cincinnati, OH. The full impact of the DLVP platform remains to be determined in terms of energy efficiency. But the early indication is that the DLVP platform delivered superbly both in terms of the promised ease of installation and the inherent network and controls capability of the platform.

We have covered the concept of DC power grids on a recurring basis for several years, including in a feature article that explored the potential benefits of a move to DC power and the myriad options available to make such a transition in SSL systems (http://bit.ly/1lgXrSV). Back at the time of that feature article, it appeared that the DC grid promulgated by the EMerge Alliance would offer the most likely path to success in DC power. But times and technologies have surely changed.

Of late, we have most often covered Power-over-Ethernet (PoE) technology as the surging option — in terms of popularity — that provides a way to power and network LED lighting using standard Ethernet cables (http://bit.ly/1QgdAui). The fact that IT networking stalwart Cisco has put considerable marketing and technology dollars behind the PoE push has been a huge driver of the buzz around that technology. And of course PoE is an open, industry-standard platform, although sometimes that's an easy to forget fact with a behemoth such as Cisco involved.

Third option

Now it appears we have a third option from Eaton, and that option might just be the most in tune with the requirements of the SSL sector. It came as a bit of a surprise when Eaton rolled out the DLVP platform at LFI, because the company is a participant in other DC-grid technologies. Indeed, Eaton has been a member of the EMerge Alliance and offered luminaires compatible with that scheme — at least on a limited basis. There has been no high-volume commercialization of the EMerge platform, despite its many technical merits.

FIG. 1. The power distribution module (PDM) in a DLVP system includes connectors for DC power channels that can each drive multiple luminaires and separate connectors to implement sensors and controls.

Eaton is also a participant in Cisco's Digital Ceiling initiative that is centric to PoE technology. And the company has a number of luminaire products available in PoE flavors. Essentially, all it takes is a change in the modular driver in a luminaire to support a different power-distribution scheme.

Frankly, we may have dismissed the DLVP demonstration at LFI as simply a proprietary offering with limited potential, but Eaton made a sincere pledge that it would open the platform to use by other lighting manufacturers, as we covered in a video interview at LFI with Eaton executive Ken Walma (http://bcove.me/osf2dyne). Moreover, the platform seemed extremely well architected from a technology perspective.

DLVP platform

The heart of the DLVP platform is a power distribution module (PDM) that is roughly equivalent to the power supply in an EMerge Alliance system. The PDM unit (Fig. 1) includes multiple DC-voltage output channels that meet UL and NEC (National Electrical Code) Class 2 requirements for low-voltage wiring. The Class 2 designation means that the power cables can be free run like Ethernet cables and not through conduit to electrical junction boxes that are a necessary staple in AC power distribution.

Eaton did design a cable technology and connector scheme that the company feels is far more robust and reliable than the Cat-5/6 cable used to supply power in PoE systems. Fig. 2 depicts a sample cable. Still, the DLVP system does depend on Cat-5/6-type wiring to connect sensors and controls.

The controls aspect of the DLVP platform is inherent in the PDM, unlike the case with the EMerge Alliance technology where controls must be layered on any given installation. As a lighting designer/specifier, you could deploy a DLVP luminaire without control capability beyond on and off. But there is

inherent support for more such as autonomous dimming based on daylight and occupancy sensors.

Of course, the jury will be out on the DLVP platform for some time. Eaton's Walma, who heads the company's controls business, reported after LFI that several other lighting manufacturers had expressed sincere interest in using the DLVP technology (http://bit.ly/2cfn7U2). Meanwhile, Eaton is readying a commercial launch of luminaires, sensors, controls, cables, and more that will most likely happen before you read this article. And as we will discuss in the remainder of this article, the technology is off to an impressive debut.

FIG. 2. Custom cables developed by Eaton are used in a plug-and-play manner to link the PDM to luminaires.

Alpha and beta

When we interviewed Chris Andrews, product manager for low-voltage lighting and control systems at Eaton, for this article, we were a bit surprised at how long Eaton has been working on the DLVP platform. At LFI, the DLVP demo didn't appear to be something cooked up in an R&D lab in the week before the showing. But generally companies show such technology platforms a year or more before commercial deployment. But Andrews had been on the DLVP project for more than three years along with working on the other DC-grid schemes.

Eaton has had what it considers alpha installations of the DLVP technology in place for some time. These installations are within Eaton facilities. Over the summer, Eaton completed the first beta installation at an actual customer site. Andrews said the company looks for beta opportunities through its normal sales channels that are a good fit for the new technology in question, and that are in organizations amenable to perhaps some hand holding and growing pains as well as working with Eaton to deliver feedback on the project on an ongoing basis. The beta customer presumably gets a discount and access to new technology, just as beta programs have always worked in the broader electronics technology sector.

In the Cincinnati project, Eaton worked with USGreentech, a company focused on environmentally-friendly, artificial surfaces for athletic playing fields. The customer's green focus aligned well with the green aspects of both LED technology and the DLVP platform. The installation would simultaneously save energy and minimize the use of building materials.

The project

USGreentech was opening a new corporate office in the Cincinnati area that would total around 2000 ft^2. Ultimately, the DLVP platform will serve far larger spaces, but the project that comprised offices, meeting spaces, a lobby, and more was an appropriate proving ground for DVLP. Andrews said the project offered another compelling aspect. It would invariably need some AC-powered lighting, although 75% of the project would be DLVP products. But the mix afforded Eaton the chance to test how well the DLVP system could accommodate a mix of power grids with a unified controls platform based in the PDM.

The first test of the technology came in the installation, and that phase delivered what are the most concrete data in terms of DLVP benefits. Quentin Mecklenborg is the owner of a contracting firm called Brooks and Sons in the Cincinnati area that performed the installation on the project. Mecklenborg said a typical commercial office space in the 2000-ft^2 range would take a two-man crew a day and a half to two days to install and wire the lighting. He said he did the entire install in about five hours.

Mecklenborg's results were perhaps more impressive than you might first realize. He had never installed any LED lighting before, although he had done legacy lighting installations for years. Moreover, he knew nothing about the DLVP technology prior to the USGreentech project. Mecklenborg said subsequent installs would surely go faster.

Simplified installation

The ease of installation is due to a number of factors. Mecklenborg had considerable experience running low-voltage cables such as standard Ethernet cables. He said the DLVP cables were installed in exactly the same manner. The cables are fastened with cable ties or similar cable-bundling schemes and

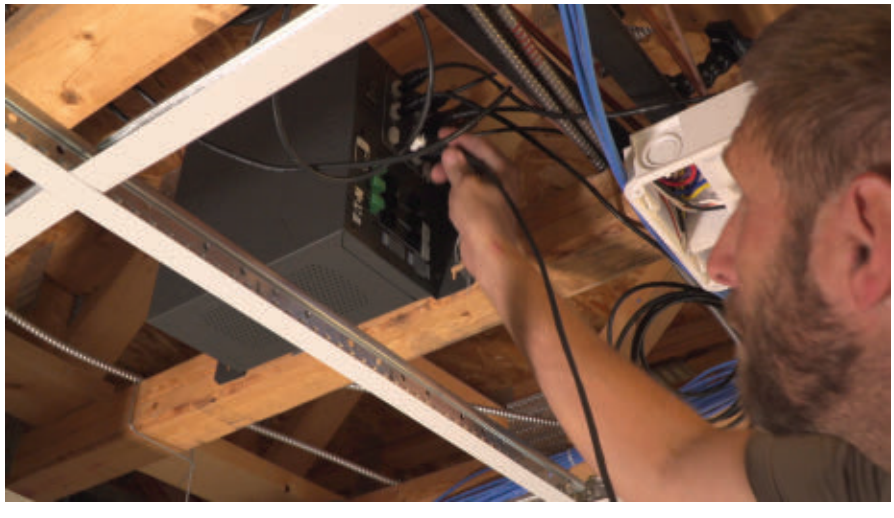

FIG. 3. Making the connection between the PDM and a luminaire is simple, and the cable is left exposed in the raised ceiling and secured with simple cable ties just like Ethernet cable.

again require no conduit or junction boxes. Fig. 3 shows a worker connecting a cable to one of the PDM units installed in the plenum space with simple connectors to both luminaires and controls, and the wiring is installed outside conduit just as you can see the blue Ethernet cables in the photo.

The benefits of the DLVP technology in terms of installation also extended to the controls. Mecklenborg said that with legacy lighting technology, most of the controls would be installed in junction boxes with AC wiring and conduit run to each box. The DLVP sensors and controls could be mounted to simple holes in ceilings and walls with no junction box and no conduit. Mecklenborg termed the installation a "plug-and-play system."

Mecklenborg did report some issues with the inspection process. The local inspectors had never seen a low-voltage, office-lighting system. But after reviewing the documentation, the inspectors cleared the technology with the exception of emergency lighting and egress or exit lighting. The inspectors insisted that the project team install AC-based luminaires in such roles, although Mecklenborg remains unclear as to why since either DVLP- or AC-powered luminaires will go dark in the case of an AC-power loss.

The emergency situation will surely change with maturity of the DLVP technology or any other DC-grid technology. The EMerge Alliance has long championed the fact that a DC battery could provide backup power in a DC-grid system. And Eaton will surely deliver DLVP-compatible luminaires with battery-backup capability.

FIG. 4. The low-voltage cable connects directly to the luminaires in a DLVP system and a single DC channel can be daisy chained to multiple luminaires.

DLVP architecture

We did also revisit the Cincinnati DLVP installation with Eaton's Andrews. He said the lighting includes Metalux 2×2-ft troffers, a selection of downlights, and other fixtures including under-cabinet lights. Eaton will launch an even broader array of products including seven Metalux luminaire families, probably by press time for this article. And the luminaire offering will be complemented with sensors, power receptacles that can control lamps or legacy sources, and various control panels.

Andrews said generally a 600W PDM could serve to power a 2000-ft² office. In the Cincinnati project, however, Eaton supplied two 600W PDMs and a 300W PDM to test the distributed capability of the system and the ability to mix and match low-voltage DC and mains-voltage AC products.

The PDMs include multiple 100W channels. A typical channel can be daisy chained to at least four fixtures to share the current. Each fixture must do a DC-DC power conversion to utilize the power.

We initially assumed that the broad range

of fixtures that Eaton would quickly offer for DLVP systems was due to the fact that the company could use the same DC-DC-power converter that was in EMerge-Alliance-compatible and PoE fixtures. But in fact, according to Andrews, Eaton has developed converters in-house for each of the different systems.

All of the aforementioned DC grids rely on Class 2 power, but each are different. The EMerge Alliance systems utilize a 24V power bus and PoE uses a 48V bus. Andrews said Eaton stretched the Class 2 limit to near 60V to minimize current on the distributed system. And designing an optimally-efficient converter for each platform required different architectures, but Eaton believes the 60V system will prove most efficient.

Mixing systems

Most of our discussion about the Cincinnati project with Andrews was during the installation phase of the project. But we had the chance to speak with Mecklenborg the week after the client moved into the space. He was on site and saw the system put through its paces. We asked Mecklenborg about the commissioning process because that is the stumbling block for many SSL installations with networked or adaptive controls. But Mecklenborg reported that the commissioning was relatively straightforward. He said the early documentation was ambiguous in some cases, but Eaton had improved instructions and most contractors should be able to install and commission the system.

Moreover, with USGreentech in the new space for a week, Mecklenborg said the occupancy and daylight sensors were working appropriately to dim or extinguish lights when appropriate. And he said the client was happy with the lighting.

In the end, the installation did use what Andrews had projected would be 75% DLVP-compatible lighting products. The client wanted some decorative pendants in the lobby that required exposed LED lamps and the need for a vintage look. Those LED lamps comprised part of the mains-voltage lighting along with the emergency and egress fixtures mentioned earlier.

But the DLVP concept has been intended from the start to support mains-powered lighting. Eaton has controls that can connect directly to the PDM and then deliver phase-controlled AC power to legacy lights for dimming. Moreover, the systems will ultimately bridge to 0–10V and other analog and digital control schemes, Mecklenborg said the integrated system was working seamlessly in the USGreentech facility. Fig. 4 shows a wide shot of a worker connecting a cable to one of the troffers installed in an open space.

Of course, Eaton is still riding multiple horses in the DC-grid space. Even while the Cincinnati project was in the planning and installation phase, Eaton announced a partnership with NuLEDs focused on PoE systems (http://bit.ly/2ctuWFS). It will be interesting to see if other lighting manufacturers sign on to support DLVP and how Eaton navigates the suddenly crowded space.

Understand how to measure luminous flux and radiant power

In this excerpt from an upcoming reference book entitled *Handbook of LED and SSL Metrology*, **GÜNTHER LESCHHORN** and **RICHARD YOUNG** explain the fundamentals behind luminous flux and radiant power measurements — a task critical in solid-state lighting (SSL) product development.

Typically luminous flux and radiant power are the most important optical parameters for LEDs although the spatial intensity distribution is sometimes also required. For smaller devices averaged LED intensity in condition B is still common. Partial LED flux is a quantity that is growing in acceptance but still not widely measured. For SSL sources, the photometric and colorimetric radiation characteristics are important.

The two principal methods for measuring total radiant power and luminous flux are using either an integrating sphere or a goniophotometer/goniospectroradiometer. The next two sections explain these two measuring methods with consideration of typical measurement challenges.

The integrating sphere method and measuring geometries

The luminous flux quantity is sometimes called total luminous flux to emphasize the fact that it is the total for all directions. It is also referred to as 4π flux since a complete sphere has 4π steradians of solid angle. To collect all light within the 4π steradians the source needs to be at the center of the sphere. This 4π geometry is the conventional configuration for measuring luminous flux (see Fig. 1a). The radiation emitted in all directions is captured and the total luminous flux is measured.

For light sources which have negligible or no radiation directed backwards, the total flux can be measured in the more convenient forward flux, or 2π geometry. Here, the light source is located at a port in the wall of the sphere. Only the light radiation emitted in the front hemisphere is recorded for the measurement (see Fig. 1b). This forward radiation is typical for most LED products. The integrating sphere must be calibrated absolutely based on the measuring geometry in conformity with the substitution principle. This principle states that the test light source should always be measured by comparison to a standard source having similar spatial and spectral distributions.

Guidelines for selecting the correct size

The test specimen should always be significantly smaller than the internal diameter of the sphere, in order to keep the interference factor caused by the sample itself as low as possible. However, the incident light intensity on the detector decreases as the sphere gets bigger. As a rule of thumb, the light throughput of an integrating sphere is a function of the inverse square of the sphere's radius. Selecting the correct relationship between the size of the test object and the size of the sphere is therefore crucial for an effective balance between high measuring quality and good throughput (see also Fig. 2).

There are guidelines for selecting the correct size of a sphere for a given size of the test sample. Using the 4π geometry, the total surface of the test sample should be smaller than 2% of the surface of the sphere. The length of a linear lamp should be less than 2/3 of the diameter of the sphere. Using the 2π geometry, the diameter of the measuring port and hence the maximum extension of the test specimen should not exceed 1/3 of the sphere diameter.

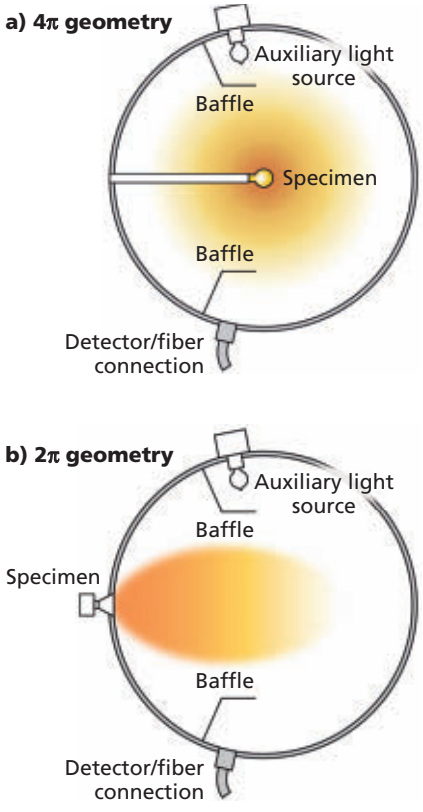

FIG. 1. CIE recommended sphere geometries for all sources (a) and for sources with no backward emission (b).

Self-absorption correction

The test object itself contributes to the absorption of light radiation in the integrating sphere. This form of interference known as self-absorption can result in a significant attenuation of light radiation and leads to

GÜNTHER LESCHHORN *is head of product management at Instrument Systems (instrumentsystems.com).* RICHARD YOUNG *recently retired from his role of chief scientist and is now working as a consultant for Instrument Systems.*

FIG. 2. A 1m-diameter sphere (left) is ideal for measuring most LEDs and modules in the 4π and 2π recommended geometries. A 2m sphere (right) is ideal for large luminaires and SSL products.

deviations in measurement. This attenuation becomes more pronounced as the test specimen becomes bigger and darker. Fig. 3 shows two typical examples of test specimen and the resulting transmission versus wavelength. Self-absorption can lead to a correction up to several ten percent.

A self-absorption correction with the assistance of a suitable auxiliary light source is therefore essential for precise measurements. A halogen lamp covering a wide spectral range is typically used for this purpose. The auxiliary light source must be positioned behind a baffle in order to avoid illuminating the sample directly and it should be operated by a stable power supply. This light source is used to determine the spectral absorption behavior of the device under test, the sample holder and the connecting cables, and then offset with the actual measurement. The effect of self-absorption increases as the reflectance of the coating rises and the ratio of the area of the sphere to the test specimen decreases.

Near-field absorption

Any object (such as a socket for example) that is in close proximity of the light source absorbs light significantly and may cause large errors. This so-called near-field absorption cannot be corrected by a self-absorption measurement. The cause of this effect should thus be avoided. The object should be placed as far away from the lamp as possible and the formation of cavities should be avoided. In addition, coating of the object surface with a high-reflectance material is recommended. As an example a good solution of a linear tube holder is shown in Fig. 4.

Burning position

As described in another chapter of the book, measurements of passively cooled SSL sources should be performed in the burning position defined by the manufacturer. This also applies to sphere photometry. When measuring in the 4π geometry, it is convenient to use an internal lamp post that can be mounted up-down or down-up, to realize the designed burning position of the light source. In the case of 2π geometry, a rotatable sphere is the method of choice (see for example Fig. 5). The complete sphere can be rotated within its mounting frame. The measuring port is therefore located at the side, top or bottom side.

Consideration of measurement errors

Contributions to measurement errors are manifold. An error analysis when using a spectroradiometer as detector can be found in another chapter of the book. The wide range of radiation characteristics shown by LEDs can introduce calibration errors in measuring luminous flux. A variation of 5% can be obtained for components with diffuse emission, but deviations of more than 10% are possible with narrow-angled LEDs.

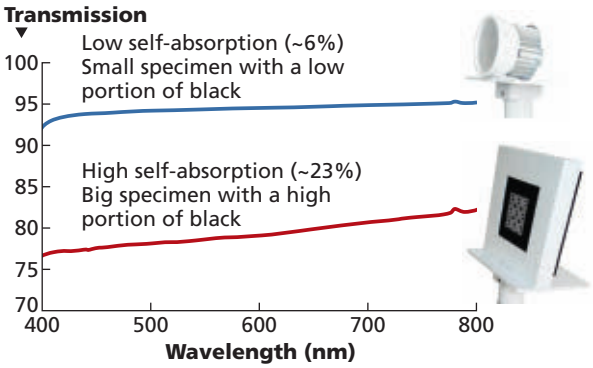

FIG. 3. Self-absorption spectra for two typical DUTs (devices under test).

As described above, selecting the right sphere size, performing a self-absorption correction, avoiding near-field absorption and measuring in the designed burning position of the light source is crucial for a high accuracy measurement.

Another big portion of error contributes when starting the measurement before the source is thermally stable. Furthermore, when testing according to CIE S 025 or EN

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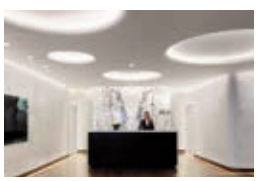
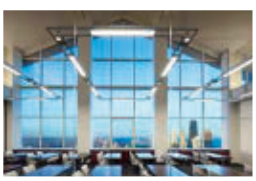
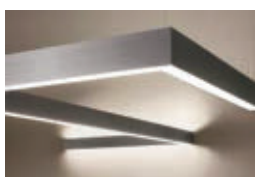

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FIG. 4. Example of avoiding near-field absorption effects. The holder of the linear tube is placed as far away as possible from the light source and coated with a high-reflectance material.

13032-4, an ambient temperature of 25°C is recommended. Putting a source which generates heat into an enclosure (the integrating sphere) the ambient temperature (temperature in the sphere) will rise and it will be different to the "normal" operating conditions. When measuring in the 4π configuration, it is therefore recommended to stabilize the source with the sphere hemispheres open. The sphere should be closed just before the measurement. This way, ambient conditions in normal operation can be simulated best. Care should be taken to close the sphere in a subtle manner in order to avoid air movement which might contribute in an undesired way to thermal management.

The goniophotometer method

Although measuring luminous flux or radiant power with a goniophotometer is more time-consuming compared to using integrating spheres, it is much more precise. This measuring procedure does not require luminous flux standard lamps as a reference value as it is the case in sphere photometry. It is the method of choice if lamps with different luminous intensity distributions have to be measured and it is the baseline for calibrating luminous flux standard lamps which provide the reference value for other test procedures. Another distinguishing feature of goniophotometry compared to sphere photometry is the capability to measure partial luminous flux and angle of half intensity. These values need to be determined when measuring characteristics relating to energy efficiency and conformity to Zhaga specifications.

The method can be best described by an imaginary sphere enclosing the LED. A cosine-corrected detector moves on the surface of the sphere along specific paths at distance r (the sphere radius). The detector is used to determine irradiance E arising as a result of the partial radiant flux $d\Phi$ incident on detector area dA as a function of θ and φ.

$$E(\Theta,\varphi) = \frac{d\Phi}{dA}$$

In order to determine total radiant power, the detector is moved incrementally in angle θ. Several measurements are taken for each angle θ with angle φ varying from 0° to 360°. Individual zones are scanned corresponding to a constant degree of latitude of the sphere. Total radiant power Φ is then

$$\Phi = r^2 \int_0^{2\pi} \int_0^{\pi} E(\Theta,\varphi)\sin(\Theta)d\Theta d\varphi$$

Alternatively, instead of moving the detector which might require considerable mechanical effort, a stationary detector can be used and the LED is scanned about its tip. However, for modules and luminaires that have convection cooling this may not apply and a correction for the luminaire position might be indicated.

Fig. 6 shows the setup for this kind of LED goniophotometer. The angle φ is adjusted by rotating the LED about its mechanical axis and angle θ by pivoting about its tip. The detector sits on an optical rail to permit

FIG. 5. A rotatable 1m sphere. Position-sensitive light sources can be measured in their designed operating position.

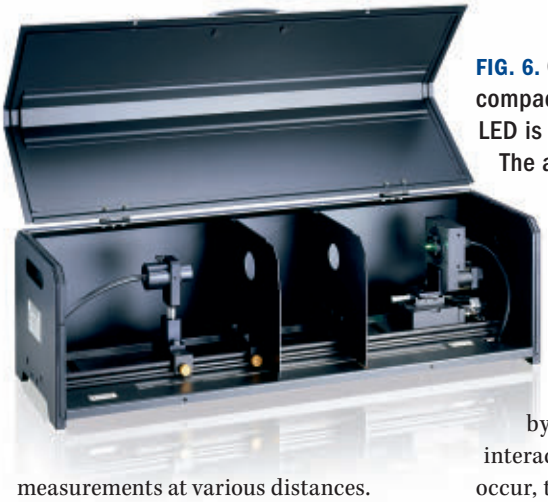


FIG. 6. Goniospectroradiometer with a compact light shielding enclosure. The LED is moved instead of the detector. The angle φ is adjusted by rotating the LED about its mechanical axis and angle θ by pivoting about its tip.

measurements at various distances.

Large distances are a requirement for luminous intensity distribution to meet the far-field condition. For measurements of total flux using a goniometer, the large distances are not required. Providing the detector has good cosine response the irradiance can be measured accurately at all angles. Irradiance is not a property of the lamp but is instead the light falling onto a surface. By measuring the irradiance at sufficient locations around a virtual sphere enclosing the lamp, the total flux can be derived by integration. Providing that no interactions between source and detector occur, the size of the source can be almost the size of the virtual sphere.

Efficiency and efficacy

If the total optical power emitted by a LED, module or luminaire is known then it can be combined with electrical power P [W or watts] supplied to the unit to give efficiency:

$$\mathcal{E}_e = \frac{\Phi_e\ [W]}{P\ [W]}$$

Efficiency is unit-less (the units in the numerator and denominator cancel) and specific to the conditions of measurement. Driver efficiency may be included or excluded and temperature de-rating to operational conditions may be required for practical applications.

Luminous efficacy is similarly calculated but using total luminous flux:

$$n_v = \frac{\Phi_v\ [lm]}{P\ [W]}$$

Luminous efficacy is expressed in units of lm/W. Like efficiency, luminous efficacy values are specific to measurement conditions and may include or exclude driver efficiencies and temperature effects.

ACKNOWLEDGMENT

This text is excerpted from *Handbook of LED and SSL Metrology*, to be published by Instrument Systems end of 2016. Figure references have been modified from the original for clarity.

The focus on efficacy is hurting the lighting industry

Market transformation programs like DLC and Energy Star were initiated to deliver energy-effiency requirements to the industry, but **JOHN BURNS** of Global Tech LED explains how the energy push can lead to a reduction in light quality.

The DesignLights Consortium (DLC) was formed within the Northeast Energy Efficiency Partnership in 2009. The goal of DLC was to lead the lighting industry toward high-quality, energy-efficient lighting. The organization started qualifying products and the first DLC QPL (Qualified Products List) was publicly released in 2010. Utility companies began to use this qualification as a requirement to award rebates to end users for upgrading to energy-efficient lighting. The US Environmental Protection Agency's (EPA) Energy Star program is the most popular qualification used in incentive programs, but DLC covers a far broader range of products.For example, Energy Star does not qualify LED-based T8 tubes but DLC does. Most LED product manufacturers seek DLC qualification. Though energy efficiency is obviously a good thing, this perpetually increasing focus is pushing end users in a direction that leaves them with a much lower quality of light.

DLC constantly updates and upgrades the requirements for having a product listed on its QPL. The organization released Technical Requirements Version 3.0 in June 2016. One of the most important features of Technical Requirements 3.0 is the introduction of a new classification of high-performing "Premium Products" that have a higher efficacy (lm/W) than the "Standard Products," which, with many utility companies, results in a larger rebate for choosing a product that is super energy efficient. Recently, the efficacy requirements have been raised even higher with the implementation of Technical Requirements 4.1, which goes into effect in 2017. The problem is that most premium-efficacy LED products must use many more LEDs on their circuit board and thus lose the ability to apply lensing to control the light distribution. This results in terrible implications in the quality of light delivered by these products.

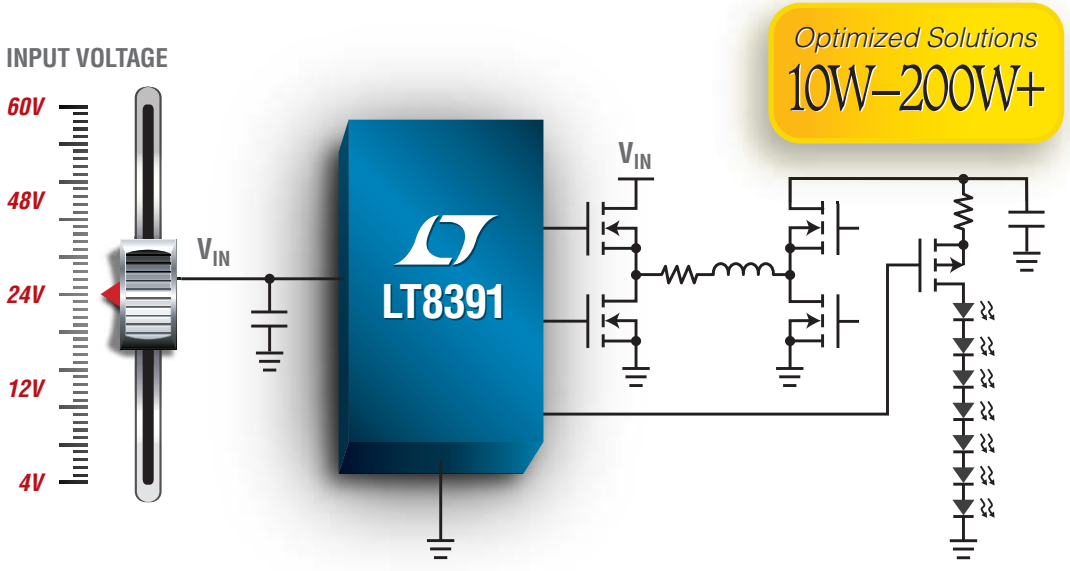
Two main issues arise from lack of customizable light distribution depending on the static distribution of premium-labeled products. If the static light distribution is too wide, more lumens are required to hit the desired light levels, because the uncontrolled light is spilling everywhere and unable to be focused effectively on the application. On the other hand, if the static light distribution is too tight, hotspots occur under the uncontrolled light sources, and more light sources are required to create an even distribution.

Using premium-efficacy products with no light distribution control can result in: 1) the need for increased lighting overall, which 2) increases site wattage, and 3) means a higher cost for the lighting end products. This leads to nearly the same overall energy usage on a site as employing the slightly lower-efficacy products that feature custom light-distribution control. The end user ends up paying more and getting a lower-quality light distribution. Compare an example of high-power (standard rebate, 200W, 95 lm/W) and mid-power (premium rebate, 200W, <110 lm/W) lighting products used in a parking lot. All variables, including wattage, are the same except for the light source being used. The conformity of the controlled high-power system with Type V optics will be far superior to the conformity of the mid-power system without optical control. The difference in average illumination on the ground is nominal — 3.61 fc for the high-power system and 3.85 fc for the mid-power system. The max/min fc for the high-power system in our example is 4.65 with smoother light distribution, versus max/min 66.71 for the mid-power system. The extra light from the higher-output, mid-power LED system spills and turns into light pollution due to the lack of optical control.

This situation does not only apply to outdoor lighting but also indoor lighting. In high-ceiling applications, secondary optical lensing allows you to focus the light more efficiently to the floor. With DLC incentives designed for lm/W, the consumer will choose a fixture that delivers less light to the floor than a luminaire with the optics in order to obtain the greater rebate.

In effect, the DLC is spreading the fallacious idea that efficacy is the best way to judge the performance of an LED luminaire with very little focus on control and conformity of the light distribution — which does not end up benefiting the end user. And it provides no incentive for lighting manufacturers to focus on delivering *quality* light distribution.

60V Synchronous Buck-Boost LED Driver



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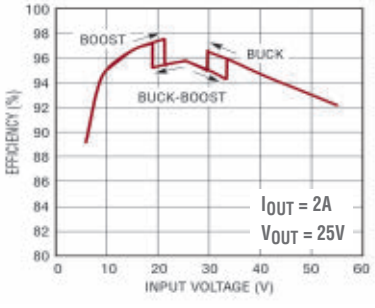
- Synchronous Switching: Up to 98% Efficiency
- ±3% LED Current Accuracy
- 2,000:1 External & 128:1 Internal PWM Dimming
- CISPR25, Class 5 EMI Requirements

Efficiency vs V_{IN}



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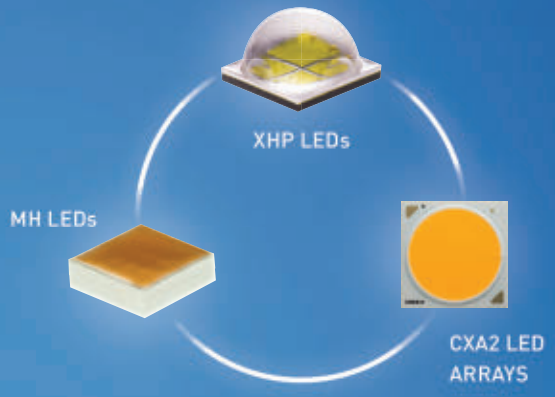

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